COOPERATIVE GROUND-WATER REPORT 3

Urbana, Illinois

1965

STATE WATER SURVEY

STATE GEOLOGICAL SURVEY

Preliminary Report on the GROUND-WATER RESOURCES OF THE HAVANA REGION IN WEST-CENTRAL ILLINOIS

William H. Walker
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STATE OF ILLINOIS DEPARTMENT OF REGISTRATION AND EDUCATION

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STATE OF ILLINOIS — OTTO KERNER, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION — JOHN C. WATSON, *Director*

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STATE WATER SURVEY
WILLIAM C. ACKERMANN, *Chief*

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JOHN C. FRYE, *Chief*

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PRELIMINARY REPORT ON GROUND-WATER RESOURCES OF THE HAVANA REGION IN WEST-CENTRAL ILLINOIS

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ABSTRACT

Pleistocene sand and gravel deposits underlying the Havana region of west-central Illinois constitute one of the largest underdeveloped aquifers in the state. The deposits are more than 100 feet thick in most places and were laid down in a wide lowland formed at the junction of several large valleys excavated in bedrock. Where they fill bedrock channels, the deposits locally exceed 150 feet thick.

The main aquifer consists of Sankoty Sand (Kansan) and overlying Wisconsinan sand and gravel outwash in much of the region. To the east, where Wisconsinan outwash terminates against Wisconsinan and Illinoian upland tills, the aquifer consists essentially of the Sankoty Sand.

Pennsylvanian and Mississippian rocks underlie the Pleistocene deposits and are not developed as a source of ground water where sand and gravel aquifers are present. Rocks below the Mississippian contain water too highly mineralized for most domestic purposes.

The average coefficient of permeability of the main sand and gravel aquifer ranges from about 2,000 to 15,000 gallons per day per square foot. Properly designed and developed wells should yield 1 million gallons per day with moderate drawdowns. Recharge from precipitation is received at the average rates of 490,000 gallons per day per square mile in areas where the granular deposits of the aquifer extend to the surface and 270,000 gallons per day per square mile in areas where layers of till overlie the aquifer. The quantity of water stored in the Pleistocene unconsolidated deposits is estimated to be about 7.2×10^{12} gallons.

Total ground-water pumpage in the Havana region was about 21 million gallons per day in 1960; 85 percent of this was pumped for industrial use in the extreme northern part of the region. Pumpage for supplemental irrigation was low in 1960 but is expected to increase at a rapid rate. In most of the region, pumpage has not appreciably affected the water table.

The water-yielding character of the sand and gravel deposits, recharge rates from precipitation, and possibilities for induced infiltration of surface water indicate that the potential yield of unconsolidated deposits in the Havana region may be about 350 million gallons per day.

INTRODUCTION

A large undeveloped ground-water reservoir underlies an area along the Illinois and Sangamon Rivers in west-central Illinois (fig. 1). The area is called the Havana region in this report. The reservoir consists of thick deposits of sand and gravel saturated with ground water that is of good quality and readily available to wells. The area is geographically situated near the population centers of Illinois and of the United States and is accessible to local and distant markets by river, rail, highway, and air. Mineral resources needed in many industrial processes are close at hand. Soils of the area yield bountiful field and truck-garden crops when supplemental irrigation practices are employed. Although increased demands for industrial and agricultural water in recent years have stimulated the development of available ground-water supplies, the ground-water reservoir has much greater potential.

Purpose and Scope

In anticipation of an increased rate of industrial, municipal, and agricultural development in the Havana region, the Illinois State Water Survey and the Illinois State Geological Survey began a detailed ground-water investigation of the area in 1957.

This report is based on data collected during the investigation and additional data on file at the Illinois State Water Survey and the Illinois State Geological Survey and in published reports. It presents geologic

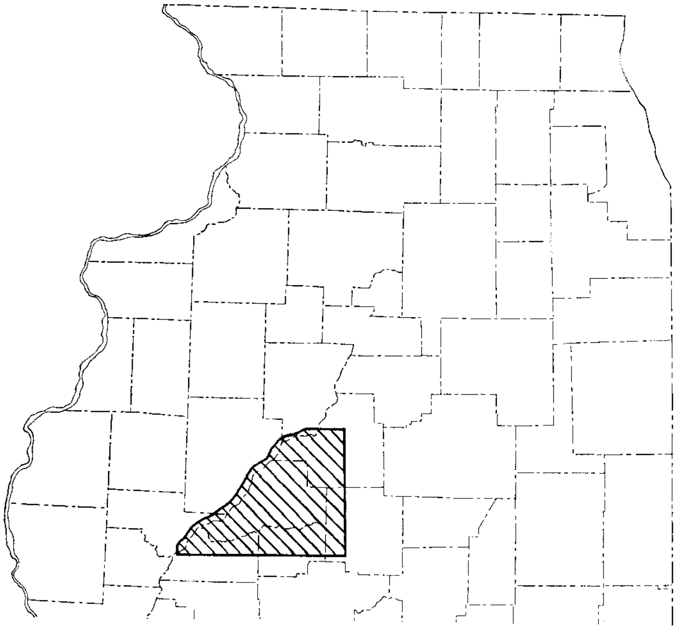


Fig. 1. Location of the area covered by this report and referred to as the Havana region.

and hydrologic information, the geologic history of the area, present hydrologic conditions, and effects of possible future development on the ground-water resources of the region. Special emphasis is placed on the extensive unconsolidated sand and gravel deposits, which are the principal aquifers in the region, and their potential yield is evaluated. The geology and hydrology of the bedrock formations are discussed only briefly as these formations contain limited quantities of ground water, and it is of relatively poor quality. Data on water levels, pumpage, well construction features, water temperature, mineral quality of water, well-production and aquifer tests, and other hydrologic information were collected by the State Water Survey. Well logs, drilling samples, geophysical logs, and other geologic information were collected by the State Geological Survey.

Although this report summarizes recent knowledge of ground-water conditions in the region, it is a preliminary report in the sense that it is part of a continuing study of the ground-water resources, and its conclusions and interpretations may be modified and expanded as more data are obtained.

Base maps of the area studied were drawn from U.S. Geological Survey topographic maps (fig. 2) and from Illinois State Division of Highways county highway maps. All elevations mentioned in this report were taken from these maps.

Previous Reports

Although this is the first detailed ground-water report of the Havana region, its large ground-water resources have been mentioned in geologic reports by Horberg (1950), and Wanless (1957). Ground-water conditions in the vicinity of Peoria and Pekin on the north edge of the study area were described by Udden (1908) and by Horberg, Suter, and Larson (1950). A description of municipal and industrial wells in use in the Pekin area was given in Illinois State Water Survey Bulletin 33 (1940, p. 81–114). A brief discussion of the occurrence of ground water in the area appeared in a report by Selkregg and Kempton (1958).

The major geologic reports that cover or contain references to the region, in addition to those cited above, are a study of the Peoria Quadrangle by Udden (1912) and stratigraphic investigations of the glacial deposits by Frye and Willman (1960), Leonard and Frye (1960), and Leighton and Brophy (1961). Root (1936) and Bredehoeft (1957) reported in detail on the areal geology and bedrock topography, and maps by H. A. Sellin (prepared in 1930 under the direction of George E. Ekblaw and kept on file at the State Geological Survey) show sand and gravel resources of Tazewell and Mason Counties.

Quadrangle topographic maps of the region have been prepared cooperatively by the United States Geological Survey and the Illinois State Geological Survey (fig. 2). Wanless (1957) published geologic maps of the Beardstown, Havana, and Glasford Quadrangles, and the Peoria Quadrangle was mapped by Udden (1912).

Well-Numbering System

The well-numbering system used in this report is based on the location of the well or test hole, which is identified by township, range, and land section.

The well number consists of five parts: county abbreviation, township, range, section, and coordinate within the section. Sections are divided into squares one-eighth of a mile long that correspond to a quarter of a quarter of a quarter section and contain 10 acres. A normal section of 1 square mile contains 8 rows of these squares;

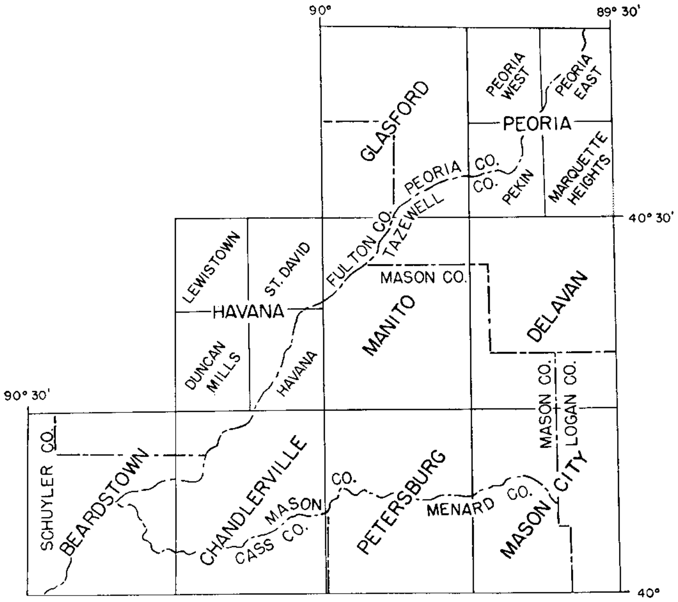
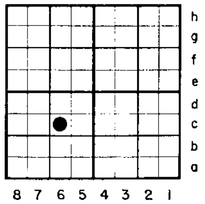


Fig. 2. Index of quadrangle topographic maps available for the Havana region.

an odd-sized section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as follows:



Sec. 27, T.24N. R.7W.
Tazewell County

The number of the well shown in section 27 above is TAZ 24N7W-27.6c. Where there is more than one well in a 10-acre square, wells are identified by arabic numbers after the lower case letter in the well number: TAZ 24N7W-27.6c2.

Abbreviations used for counties are:

CSS	Cass	MSN	Mason
FUL	Fulton	PEO	Peoria
LOG	Logan	SCH	Schuyler
MEN	Menard	TAZ	Tazewell

Acknowledgments

The authors appreciate the courteous and generous assistance of all who contributed information and aided in the collection of field data for this report. Much of the basic data was collected by R. R. Russell, A. R. Knodel, T. A. Prickett, and W. H. Baker of the Water Survey, and L. A. Reed and Bruce Adamson of the Geological Survey. J. D. Bredehoeft and L. D. McGinnis of the Geological Survey conducted seismic refraction studies in the area. Grover H. Emrich assisted in the preparation of some of the geologic sections and illustrations. Suggestions and criticisms were given by G. B. Maxey, T. E. Larson, George E. Ekblaw, H. F. Smith, and many others from both Surveys during the course of the investigation.

Velmar W. Davis, agricultural economist, U.S. Department of Agriculture, and Ray Lane, work unit conservationist, U.S. Soil Conservation Service, supplied much valuable information on agricultural practices, supplemental irrigation methods employed, and quantities of water used each year for agricultural purposes in the region.

This report would have been impossible without the generous cooperation of municipal officials, industries, engineers, and water well contractors who provided information on wells, water levels, and pumpage.

GEOGRAPHY

Location and Extent of Havana Region

The Havana region includes Mason, southwestern Tazewell, western Logan, northern Menard, and northern Cass Counties, and the strips of Peoria, Fulton, and Schuyler Counties adjacent to the Illinois River (fig. 1). It lies between parallels 40° 00' and 40° 35' N latitude and meridians 89° 30' and 90° 30' W longitude (fig. 2).

Detailed hydrologic studies were made within the Havana region in an area of approximately 720 square miles in Tazewell and Mason Counties. This area is bounded on the west by the Illinois River, on the south by the Sangamon River, and on the east by groundwater divides that trend roughly east-northeast in the vicinity of Kilbourne, Mason City, San Jose, and Delavan, and northwest and north near South Pekin (fig. 3).

The principal cities within the Havana region are Pekin, Delavan, Havana, Mason City, and Beardstown (fig. 3). Federal Highway 136 and State Highways 9, 10, 29, 78, 97, 121, and 122 pass through the region, as do the Illinois Waterway and the Chicago and Illinois Midland, Illinois Central, Gulf Mobile and Ohio, and Chicago and North Western railroads. In addition to these railroads serving the interior part of the region, the Atchison, Topeka and Sante Fe, New York Central, and Toledo, Peoria and Western railroads serve Pekin, and the Baltimore and Ohio and Chicago, Burlington and Quincy railroads serve Beardstown.

Topography

The Havana region is primarily a wide, low, rolling, roughly triangular sandy plain along the Illinois River, bordered on the east by glaciated uplands, on the south by the south bluff of the Sangamon River and Salt Creek, and on the west by the west bluff of the Illinois River. It includes three main physiographic areas (fig. 4): (1) the floodplains of the Illinois, Sangamon, and Mackinaw Rivers and Salt Creek; (2) the wide sand-ridged terraces east of the Illinois River; and (3) the loess-covered Illinoian drift upland in southeastern Mason County. Elevations in the region range from about 430 feet above mean sea level on the Illinois River floodplain near Beardstown to 736 feet in the uplands west of Mason City.

The Illinois River emerges from a narrow gorge north of Pekin into a floodplain 3 to 4 miles wide that has an average elevation of about 435 feet above sea level. It narrows downstream from Beardstown. The floodplain is marked by low natural levees, shallow lakes representing former river channels and meanders, alluvial fans of tributary streams, and river bars. The gradient of the river is slightly less than 2 inches per mile. In contrast to the tightly meandering natural courses of the Sangamon River and Salt Creek prior to artificial straightening, the course of the Illinois River in its floodplain is relatively straight to gently curving.

Bordering the Illinois River floodplain on the east is a terrace belt 3 to 17 miles wide. The terraces were formed during glacial stages when flow of the river was greater than it is today. The terraces are named, from lowest to highest, Beardstown, Bath, Havana, and Manito (Wanless, 1957). The Beardstown Terrace is about 445 feet above sea level at Beardstown, 10 feet higher than the floodplain, and is marked by large abandoned river meanders. The Bath Terrace slopes from an elevation of about 465 feet above sea level near Havana to about 445 feet east of Beardstown. Dunes or sand ridges on the Bath Terrace rise to about 500 feet above sea level. The Havana Terrace slopes from an elevation of about 485 feet near Pekin to about 465 feet south of Bath. It has an elevation of about 495 feet along Crane Creek and about 490 feet along Quiver Creek. Dunes or sand ridges are common on the part of the terrace near the Illinois River. The Manito Terrace is the most extensive terrace in the Havana region. From a 530-foot elevation west of Delavan it descends to 510 feet just west of Manito and to 490 feet at Kilbourne. Linear to arcuate sand ridges, which rise as high as 50 feet above the general level, occur in extensive tracts on the terrace.

Rising above the Manito Terrace, from San Jose southwestward to near the mouth of Crane Creek, is a hummocky tract of Illinoian sandy drift. Many hills and ridges between San Jose and Mason City stand from 50 to more than 100 feet above the surrounding level. The roughest topography is found in the narrow upland between the Sangamon River and the lower part of Crane Creek south of Easton where steep sand hills have elevations of more than 700 feet above mean sea level, or more than 200 feet above the Sangamon River floodplain. Southeast of Delavan the Illinoian sandy drift tract is bounded by the bold Wisconsinan morainal front.

Drainage

The Illinois River, with an average flow of 13,690 cubic feet per second (cfs) at Kingston Mines and 19,960 cfs at Meredosia, 15 miles south of Beardstown, receives all the drainage of the Havana region. Some of the

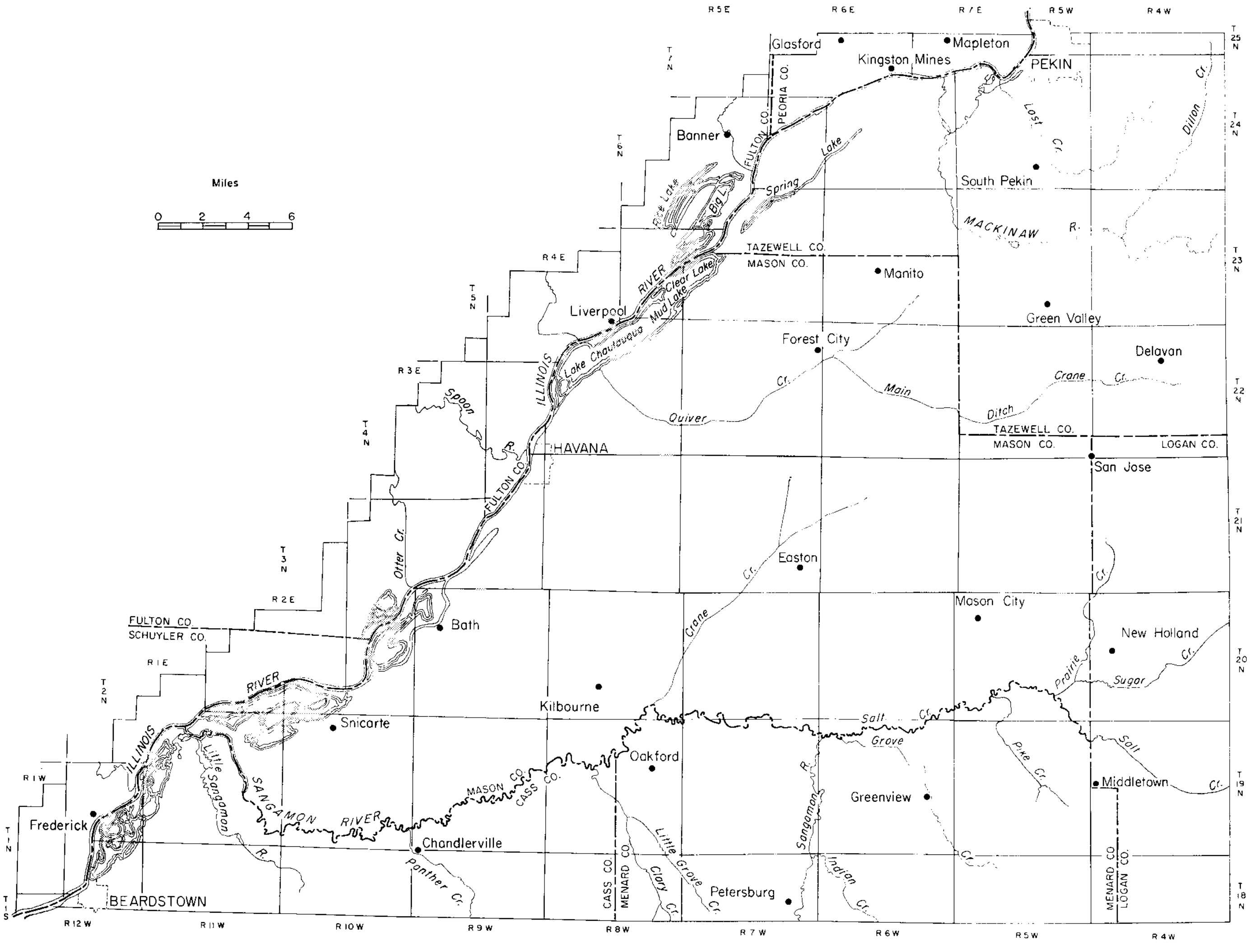


Fig. 3. Main geographic features and land divisions of the Havana region.

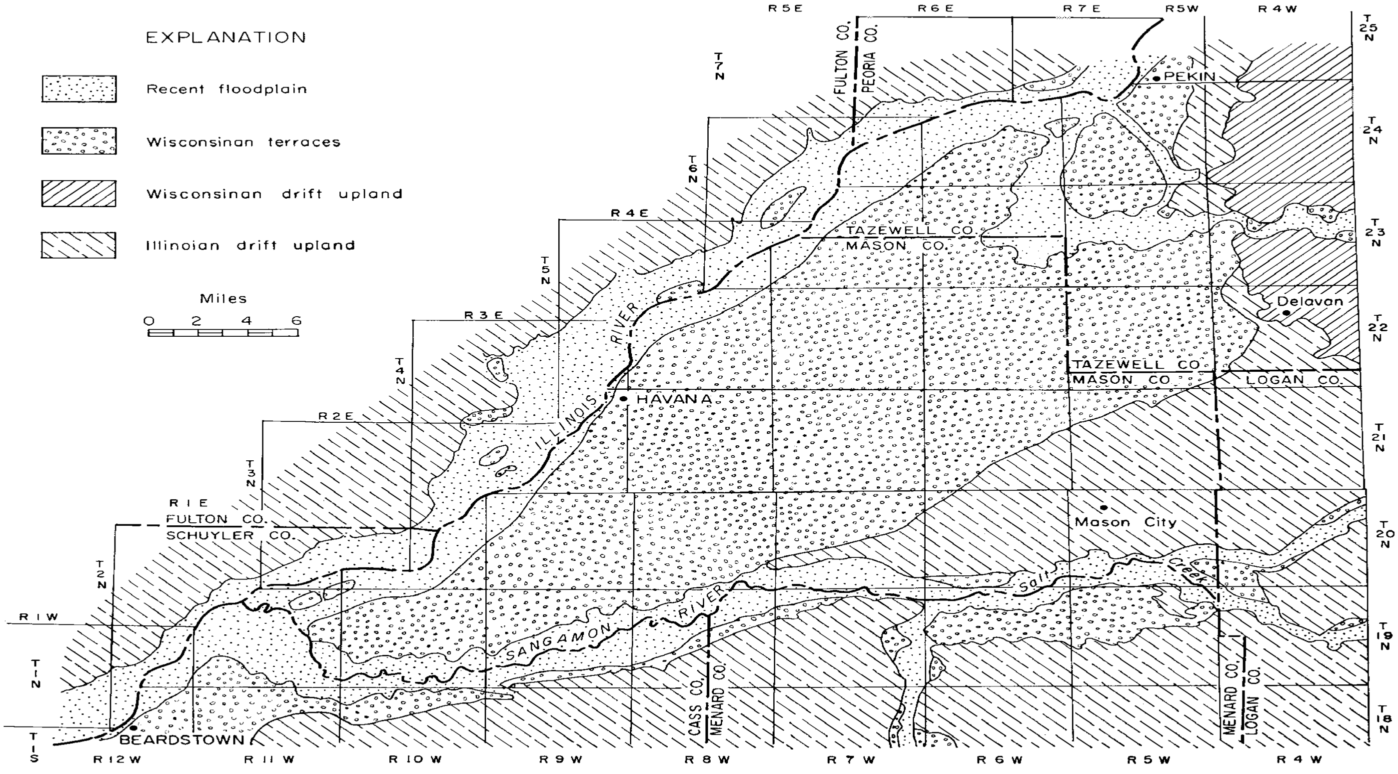


Fig. 4. Major physiographic areas of the Havana region.

drainage passes first into the Mackinaw or Sangamon Rivers or into Salt, Crane, or Quiver Creeks. Many streams emerge from the uplands west of the Illinois River, south of the Sangamon-Salt system, and north of the Mackinaw River, but within the valley bottoms and terraces in the main region studied there are few streams. The valley bottoms have extensive lakes and marshes. In the sandy terraces extensive ditches have been constructed along Crane and Quiver Creeks to improve drainage conditions on flat lands where the water table is shallow.

Climate

A summary of 1958 climatological data collected at the Greater Peoria Airport at Peoria, Illinois, just north of the Havana region is given below (U.S. Weather Bureau, 1959).

> The climate of this area is typically continental as shown by its variability and the wide range of temperature extremes.
>
> Monthly mean temperatures range from 25 degrees during January to 76 degrees during July with an annual average of 51 degrees. The average January has 28 days with freezing temperatures but only 4 days with readings as low as zero. Conversely the average July has 11 days with 90 degrees or higher but only 1 day with a reading as high as 100. Illustrating the extreme conditions that have occurred, the single year of 1936 had 17 days with temperatures 100 or higher in July while the early part of that same year had 26 zero days in a 31-day period. 1936 also had the absolute maximum record of 113 set on July 15 but the absolute minimum of –27° dates back to January of 1884. Autumn is considered the most pleasant time of the year, usually culminating in the "Indian Summer" period of warm and dry conditions in late October or early November.
>
> The average freeze-free period covers 189 days from April 15 to October 20. Past records indicate that general freezing conditions have occurred as late as May 9 in 1945 and as early as September 26 in 1928.
>
> The normal annual precipitation is 35.18 inches with individual years ranging from 23.18 inches in 1910 to 53.26 inches in 1858. May is normally the wettest month with 3.98 inches while the driest summer month is August. There are no wet or dry seasons but precipitation is heaviest during the growing

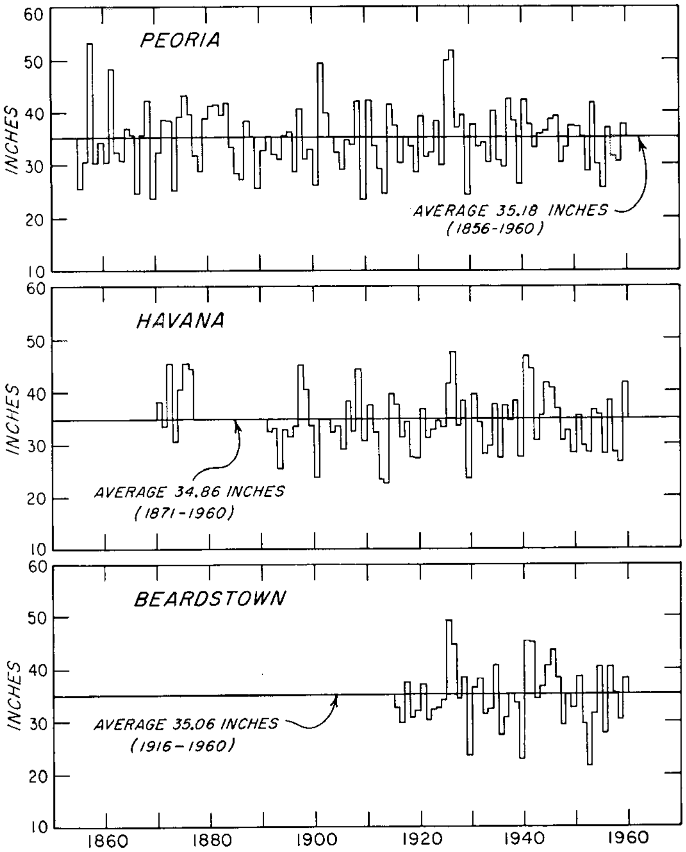


Fig. 5. Annual precipitation at Peoria, Havana, and Beardstown, 1856-1960.

season and at a minimum during mid-winter. The wettest month on record was September 1911 with 12.30 inches, but nearly half that much has fallen in a single 24-hour period (5.52 inches in 24 hours in May 1927). It is also interesting to note that the maximum 1-hour rainfall (2.60 inches) is almost half as great as the maximum in 24 hours.

Annual snowfall averages 21.6 inches and has ranged from 6.0 inches in 1928 to 45.7 inches in 1926. More than 70% of the annual snowfall occurs during the three months of December, January, and February. Snow has occurred as late as May 9 and as early as September 25 when one inch fell in 1942. The heaviest single storm of record brought 18 inches during the last two days of February in 1900.

Prevailing winds at Peoria are from the south during all months except February when they are from the northwest. This differs from the usual pattern in this general area where prevailing winds are from the south or southwest in summer and from the northwest during the four or five colder months. March is the month with the most wind while August has the least. Thunderstorms are reported on an average of 49 days per year with activity reaching a peak in June. The months of April through September average 5 or more thunderstorm days each while December is the month with fewest thunderstorms. Heavy fog is rare in this area with a peak occurrence of only 2 days per month during the winter season. Humidity varies considerably depending upon the direction of wind movement. The driest air moves in from the west or northwest while easterly and southerly winds bring more humid conditions. Relative humidity is lowest during the afternoons and is higher at and during precipitation. Sunshine is unevenly distributed during the year and is greatest during July when days are long and cloudiness is at a minimum. December is the darkest month and averages only 37% as much bright sunshine as does July.

Graphs of annual and normal monthly precipitation for the years of record at Peoria, Havana, and Beardstown (figs. 5 and 6) indicate that the mean annual precipitation in the Havana region is about 35 inches, with the Havana station during a normal year recording 0.20 inches less than Beardstown and 0.32 inches less than Peoria. Normal monthly precipitation at the three stations is similar, but slight differences are evident between the Peoria records and those for Havana and Beardstown. At Peoria the normal monthly precipitation increases from a low in January to a high in May, remains high during June and July, drops abruptly in August, and increases noticeably in September before decreasing during the remainder of the year. At the Havana and Beardstown stations, however, the yearly low and high values occur a month later, with the first abrupt decrease occurring a month earlier than at the Peoria station (fig. 6).

The annual maximum precipitation expected once in 5 years is 40 inches and the minimum is 29 inches. The maximum expected once in 50 years is 50 inches and the minimum 24 inches (Atlas of Illinois Resources, 1958).

Population

In 1960, approximately 79,000 people lived in the Havana region, about a third of them in Pekin in Tazewell County.

Mason County had a population in 1960 of 15,193 (table 1), nearly three-fourths of which was classified as rural. As in many other dominantly rural areas in Illinois, the population of Mason County has declined slightly in the past decade. In contrast, the population of most cities and dominantly urban counties in the region rose during the same period. For example, the

Table 1. Population of Counties and Selected Municipalities of the Havana Region, 1890- 1960

(From "U.S. Census of Population, 1960. Number of Inhabitants, Illinois.")

	1890	1920	1930	1950	1960
County					
Cass	15,963	17,896	16,934	15,097	14,539
Logan	25,489	29,562	28,863	30,671	33,656
Mason	16,067	16,634	15,115	15,326	15,193
Menard	13,120	11,694	10,675	9,639	9,256
Tazewell	31,338	38,540	46,082	76,165	99,789
Town					
Bath	384	408	346	423	398
Beardstown	4,226	7,111	6,344	6,080	6,294
Delavan	1,176	1,191	1,084	1,248	1,377
Easton	......	456	403	371	361
Forest City	......	314	269	278	249
Green Valley	......	446	454	503	552
Havana	2,525	3,614	3,451	4,379	4,363
Kilbourne	......	393	393	374	352
Manito	444	758	711	869	1,093
Mason City	1,869	1,880	1,941	2,004	2,160
New Holland	......	457	353	343	314
Pekin	6,347	12,086	16,129	21,858	28,146
San Jose	307	566	486	562	1,093
South Pekin	......	1,362	1,222	1,043	1,007

population of Tazewell County grew 30 percent between 1950 and 1960, and 69.9 percent of its 1960 population was urban.

Of the total population of 79,000, about 52,000 were served by municipal water systems and 27,000 by private systems. Nearly all water supplies in the area are obtained from sand and gravel aquifers.

Economy and Natural Resources

The economy of the Havana region is based primarily on agriculture, with support from manufacturing, mining, transportation, power generation, and recreation. Cash-grain farming is the principal enterprise in the region (Ross and Case, 1956, p. 45–48). As a group, the farms are among the largest in the state, averaging more than 200 acres, and use from 85 to 90 percent of the land area. In Mason County, there were 1157 farms in 1950, of which 849 were classified as cash-grain, 111 as livestock, and 83 as general. Thirty-five percent of the crop land was in corn, 17 percent in wheat, 10 percent in soybeans, and 9 percent in oats. The sandy soils of the area also favor the growth of melons, potatoes, and other truck crops, and conifers, all of which supplement the income received from grain.

Of the total land area within the region, about 50 percent is composed of terraces, 20 percent is floodplain, and 30 percent is upland (fig. 4). Light to dark sandy soils with coarse-textured, highly permeable subsoils predominate on the terraces; dark to light fine-grained soils with medium to fine-textured, poorly to moderately permeable subsoils occur in the valley bottoms; and dark soils with medium-textured, moderately permeable subsoils occur on the uplands. The upland soils, fairly high in organic matter from the former growth of prairie grasses, are moderately to highly productive. Dune sands, which occupy more than 20 percent of the land area in Mason County, are generally left in timber because they are very low in organic matter and are susceptible to wind erosion if cultivated intensively.

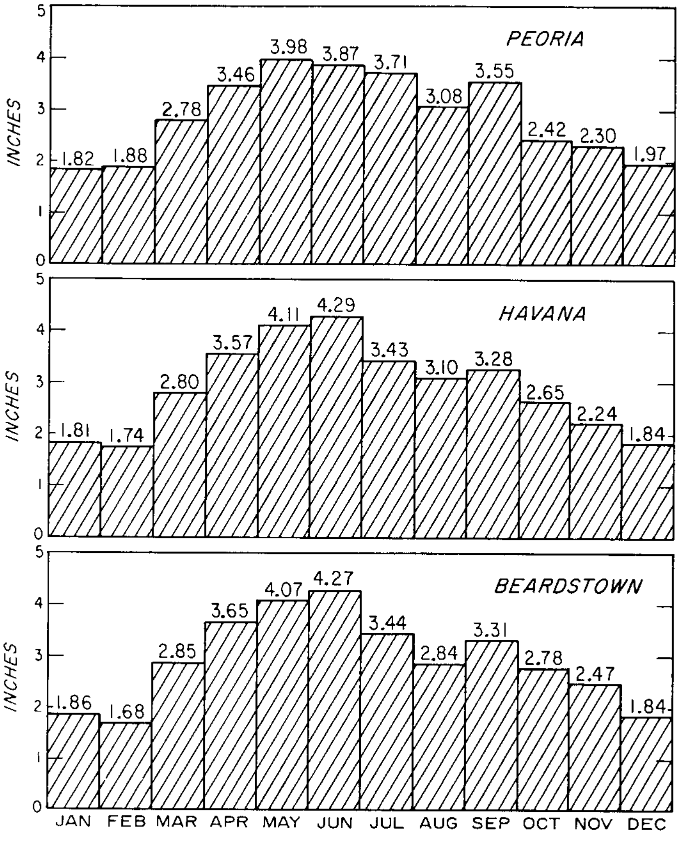


Fig. 6. Normal monthly precipitation in inches at Peoria, Havana, and Beardstown.

The sandy soils require frequent moisture replenishment during the growing season. The availability of large ground-water supplies has led to the increasing use of supplemental irrigation in Mason County, and it is likely that irrigation will continue to increase in the future.

Industry in the region is concentrated around Pekin. The bulk of the manufacturing is in the processing of food and kindred products, or in such related lines as packaging.

The Illinois River and the many lakes of the floodplain provide additional economic benefits to the region. More than 17 million tons of shipping passes up and down the Illinois Waterway annually, and storage facilities for grain, coal, sand and gravel, and petroleum products are found at Beardstown, Havana, Liverpool, Kingston Mines, and Pekin. Electric utility power plants along the river near Pekin and at Havana have a capacity of 550 thousand kilowatts and an annual electric power output of more than 1.5 billion kilowatt hours. Recreational areas, with facilities for hunting, fishing, boating, and swimming are plentiful along the river.

Coal mining is of sufficient magnitude in adjoining Fulton, Peoria, and Schulyer Counties to be of importance to the economy of the Havana region. In 1962 more than 6 million tons of coal was produced having a value greater than 26 million dollars (Busch, 1963, p. 16–23). More than 5 million tons was from Fulton County, presently the third largest coal-producing county in the state. At least five coals of minable thickness are present, including the Springfield (No. 5), Herrin (No. 6), and Colchester (No. 2). Mining is almost entirely by stripping, and vast reserves are known to be present. All the coals in the area belong to the high-volatile bituminous "C" rank. Analyses of coal samples were given by Cady (1935, 1948).

Most of the sand and gravel deposits worked commercially are Wisconsinan outwash, which rises as low terraces above the floodplains of the Illinois and Mackinaw Rivers. The outwash becomes finer downstream, ranging from clean, well sorted gravel near Pekin to fine, sandy gravel and gravelly sand south of Havana. At a few sites in the upland in the San Jose area, sand and gravel pits have been operated in Illinoian deposits.

Numerous unsuccessful oil and gas tests have been drilled in the region and the outlook for commercial production is unfavorable.

GEOLOGY

Deposits of sand and gravel in the unconsolidated sediments overlying the layered bedrock supply nearly all the ground water used in the Havana region. The unconsolidated sediments consist of glacial drift, windblown silts (loess) and sands, and recent stream deposits.

The drift is differentiated into that deposited directly from the melting ice (till) and that modified by the associated meltwater into glacial river (glaciofluvial) and glacial lake (glaciolacustrine) deposits. *Till* is a mixture of fragments of all sizes with rarely any stratification. It occurs in the form of ridges (end moraines) and intervening undulatory plains (ground moraines). The end moraines were deposited when the melting of the ice was equivalent to the advance of the glacier, so that the ice front was temporarily relatively stationary. The ground moraines were deposited when the melting of the ice front exceeded the forward advance of the glacier.

Glaciofluvial deposits were laid down by meltwater that was discharged along the front of the ice and through crevasses and channels extending back into the ice. Rock fragments picked up by the meltwater were transported and deposited downstream. Among the land forms created by meltwater in the Havana region are *valley trains, outwash plains, crevasse-fill ridges,* and roughly circular hills called *kames.*

UNCONSOLIDATED DEPOSITS

		STAGE	SUBSTAGE	VALLEY DEPOSITS			UPLAND DEPOSITS	
QUATERNARY SYSTEM	PLEISTOCENE SERIES	RECENT		Alluvium. colluvium up to 50' thick			Alluvium, colluvium	
		WISCONSINAN	VALDERAN	BEARDSTOWN TERRACE				
			TWOCREEKAN					
			WOODFORDIAN	BATH TERRACE HAVANA TERRACE MANITO TERRACE BLOOMINGTON OUTWASH TERRACE (UNMODIFIED)	Underlain by sand & gravel up to 100' thick	Dune sand	PEORIA LOESS	up to 90' thick RICHLAND LOESS Glacial till up to 125' thick MORTON LOESS
			FARMDALIAN	Not differentiated			FARMDALE SILT	
			ALTONIAN				ROXANA SILT	
		SANGAMONIAN					Weathered zone	
		ILLINOIAN	BUFFALO HART				Till, silt, sand, and gravel 40' to 200' thick	
			JACKSONVILLE					
			LIMAN					
		YARMOUTHIAN					Weathered zone	
		KANSAN		SANKOTY - MAHOMET SAND 0-175' thick			Till, silt, sand, and gravel up to 50' thick	
		AFTONIAN					Weathered zone	
		NEBRASKAN		Not differentiated			Till and sand 5' to 15' thiiiick	

BEDROCK

SYSTEM	SERIES	GROUP OR FORMATION	LITHOLOGY	THICKNESS (ft.)
PENNSYLVANIAN			Shale, sandstone, coal, limestone	0-700
MISSISSIPPIAN	VALMEYERAN	ST. LOUIS FORMATION	Cherty limestone	0-60
		SALEM FORMATION	Dolomite, sandstone, shale	0-50
		WARSAW FORMATION	Shale	0-90
		KEOKUK- BURLINGTON FMS.	Cherty limestone	200-250
	KINDERHOOKIAN		Shale	200-240
DEVONIAN			Limestone	0-50
SILURIAN			Dolomite	50 -250
ORDOVICIAN	CINCINNATIAN	MAQUOKETA GROUP	Shale, dolomite	170-200
	CHAMPLAINIAN	GALENA-PLATTEVILLE GPS.	Dolomite	290-340
		GLENWOOD-ST. PETER FMS.	Sandstone	170-250
OLDER ORDOVICIAN, CAMBRIAN, 8 PRECAMBRIAN ROCKS				

Fig. 7. Unconsolidated deposits and bedrock formations of the Havana region.

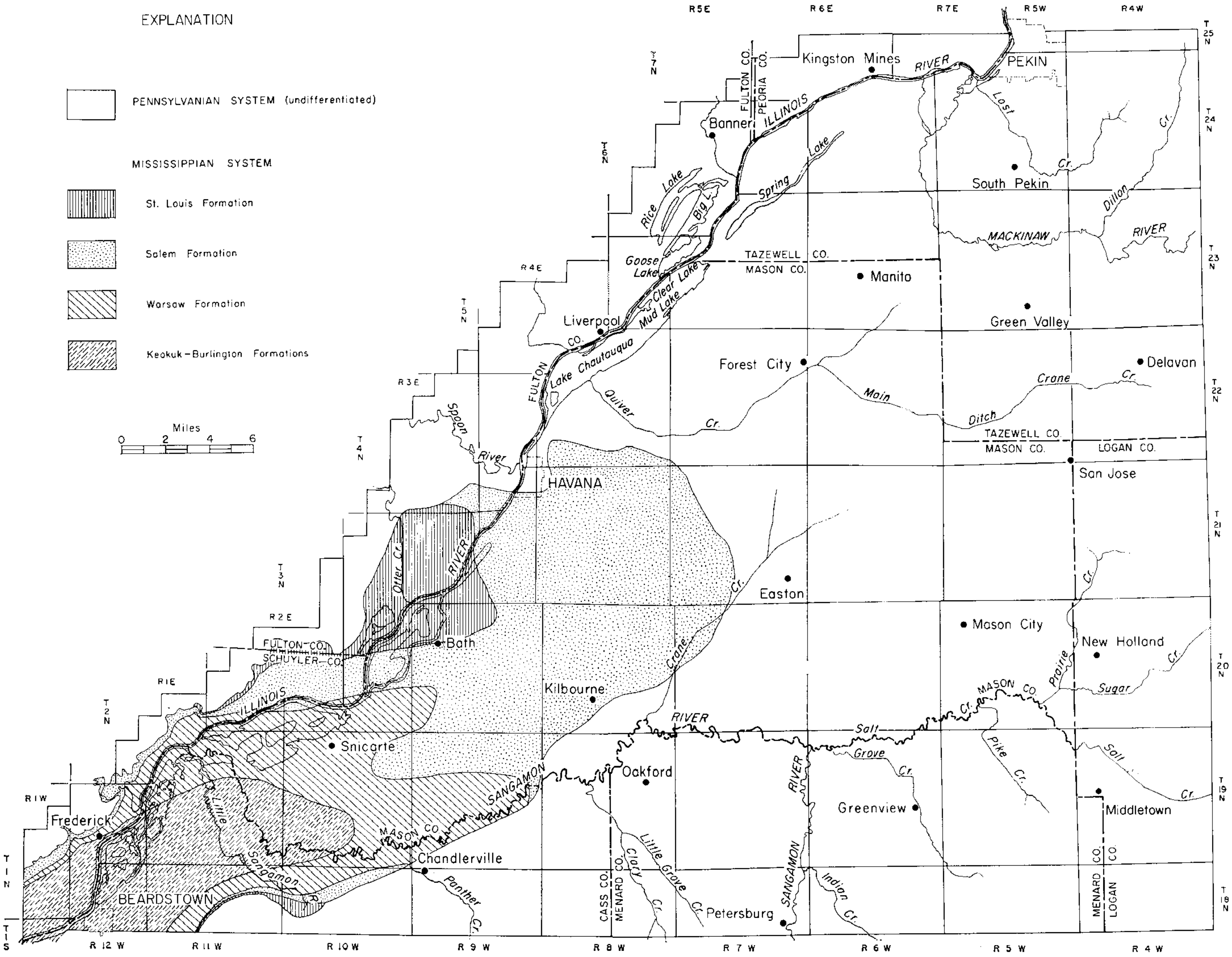


Fig. 8. Areal geology of the bedrock surface of the Havana region. (Partly after Wanless, 1957, pl. 5.)

More than 100 feet of unconsolidated deposits cover the bedrock in most of the Havana region; however, bedrock crops out in the steep bluffs west of the Illinois River and east of Pekin and in the bluff of the Sangamon River east of Beardstown. The sequence and descriptions of both the unconsolidated deposits and bedrock are shown in figure 7.

Nature and Water-Yielding Properties of the Bedrock

The bedrock formations dip generally to the southeast at an average rate of 15 to 20 feet per mile. Locally the rocks are warped into minor folds. Northwest of Manito, one such upfold has been explored for oil and, later, for storage of natural gas.

The youngest bedrock formations in the region are of Pennsylvanian age. They occur directly below the drift in Tazewell County and much of Mason County. Erosion of the Illinois River Valley south of Havana has reached, successively, the St. Louis, Salem, Warsaw, and Keokuk-Burlington Formations (fig. 8).

Pennsylvanian rocks crop out extensively in the west bluffs and tributaries of the Illinois River and are exposed in many strip mines in Fulton, Schuyler, and Peoria Counties. The exposures have been described in detail by Wanless (1957). They consist mainly of shale, but include at least five minable coals and several beds of sandstone and limestone. In general, the Pennsylvanian rocks are relatively unfavorable as a source of ground water, although fractured zones or beds of sandstone locally yield up to 10 gallons per minute (gpm) to wells.

The Mississippian formations are mainly limestone and shale, with some dolomite and sandstone. In recent test drilling for gas storage northwest of Manito, water-yielding zones were encountered throughout the interval of the Keokuk-Burlington Limestone between depths of about 400 and 600 feet. Udden (1908, p. 330–331) also reported water-yielding zones in this limestone in Peoria. The other Mississippian rocks rarely yield appreciable quantities of water. Wells tapping Mississippian rocks in this area seldom have yields exceeding 20 gpm.

Water-yielding crevices are fairly abundant in the Devonian and Silurian rocks, but water in these rocks is generally reported as salty or sulfurous. An analysis of water from Devonian and Silurian rocks at a depth of 1100 to 1136 feet in well MSN 21N5W-19.1h shows 7772 parts per million (ppm) total dissolved solids (tds) and 4260 ppm chlorides (Meents et al., 1952, p. 35). The high mineralization of ground water may be a result of poor circulation of fresher waters through the rocks, resulting from limited lateral openings, and containment by relatively impermeable shale formations below and above.

The Galena-Platteville Dolomite and Glenwood–St. Peter Sandstone of Ordovician age have yielded ground water to most deep wells in the region. Although water in the Galena-Platteville and Glenwood–St. Peter rocks is less highly mineralized than that in the Devonian and Silurian rocks because of better circulation of fresher water through the permeable sandstone, it is still too highly mineralized for most domestic uses. Water occurs in the Galena-Platteville Dolomite in solution openings along fractures and bedding planes. It occurs in the Glenwood–St. Peter Sandstone in the pore spaces between grains. The water is under artesian pressure, and flowing wells usually result where land surface is below an elevation of about 535 feet. In well MSN 22N6W-19.7e at elevation 495 feet, water began flowing at the surface when drilling reached a depth of 1295 feet, or 6 feet into the top of the Galena-Platteville Dolomite. An estimated flow of 5000 barrels a day (138 gpm) of water was reported for an oil test well (MSN 22N8W-31.8e, elevation 472 feet) that penetrated the Galena-Platteville Dolomite from 1140 to 1435 and the Glenwood–St. Peter Sandstone from 1435 to 1442 feet.

Most oil tests in the region have gone no deeper than the Glenwood–St. Peter Sandstone. Below the Glenwood–St. Peter lies some 3000 feet of older sedimentary rocks of Ordovician and Cambrian age. The water in these rocks probably is highly mineralized. The sedimentary rocks overlie still older Precambrian crystalline basement rocks, mainly granites.

Bedrock Topography

The Havana region is essentially that described by Horberg (1950, p. 25, 36) as the Havana Lowland, a subdivision of the buried Pennsylvanian Lowland. Following Horberg's interpretation, figure 9 shows that the broad Havana Lowland and its extensions upstream developed at the junction of several important drainage lines and just above the point where massive Mississippian limestones cross the valley at Beardstown. The combined discharge of large streams in the Mahomet and Mackinaw bedrock valleys and the narrow Peoria-Pekin channel accomplished much of the excavation of the wide bedrock lowland in the relatively weak Pennsylvanian rocks.

The configuration of the bedrock surface (fig. 10) and the nature of the overlying and underlying rocks are interpreted from logs of about 300 wells and borings, of which 117 are records based on studies of drill cuttings. Seventy-eight of the logs are from oil or coal tests which penetrated the bedrock to a considerable depth. At 58 stations, bedrock surface elevations were calculated from seismic data. (See Addendum, p. 54.)

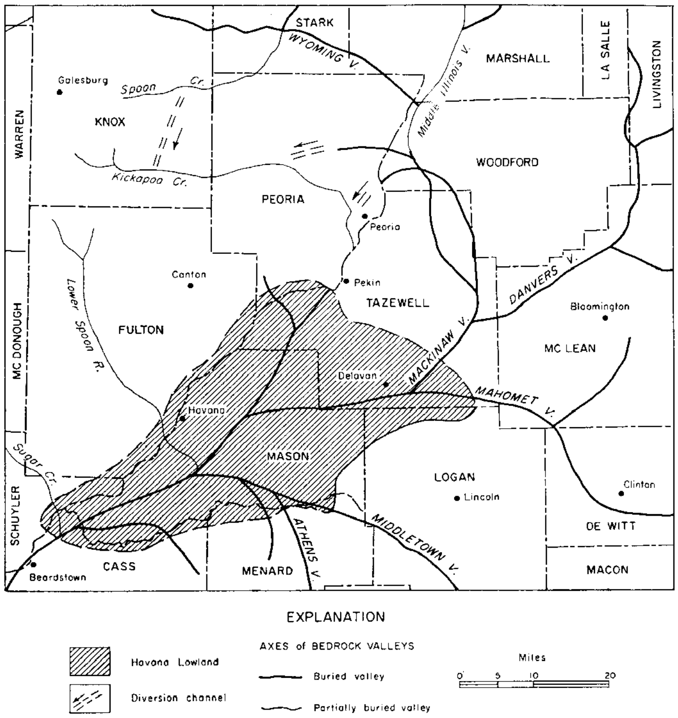


Fig. 9. Bedrock valleys of west-central Illinois and location of the Havana Lowland. (Modified from Horberg, 1950, pl. 2.)

The Havana Lowland (figs. 9, 10, and 11) consists of gently rolling to fairly flat bedrock benches notched by channels. The floor of the lowland is generally below an elevation of 400 feet, whereas the adjoining bedrock upland has some elevations above 500 feet (fig. 10). The southern and western boundaries of the lowland and the eastern boundary north of South Pekin are essentially steep walls, as shown by the proximity of the 400- and 500-foot elevation contours. The eastern boundary has slopes that rise gradually above the broad bedrock valley that passes beneath Delavan.

The flat to rolling benches are the most widespread erosion surfaces in the Havana Lowland. The benches have a gradual rise to the north, from an elevation of about 340 feet at Beardstown to slightly below 400 feet east of Manito. The benches also widen northward. At Beardstown a narrow bench is developed on the resistant Keokuk-Burlington rocks (fig. 11, A—A'), whereas to the north, benches developed on the softer rocks of Pennsylvanian age (fig.11, B—B') are wider. Horberg (1950, p. 96) considered the benches represented a widespread erosion level (Havana Strath) that was brought about by lateral cutting upstream from Beardstown where the river crossed the Keokuk-Burlington rocks.

Channels are cut from 50 to 80 feet below the level of the lowland benches. The main channel, carved by combined drainage of the Mahomet and Mackinaw bedrock valleys, passes southwestward beneath Delavan and Beardstown, with tributary channels that approximately underlie Middletown, Greenview, Petersburg, Chandlerville, Spoon River, Glasford, and Pekin. The floor of the main channel has an elevation below 320 feet and is excavated in Pennsylvanian rocks to a point between Havana and Easton and in Mississippian rocks southward (figs. 8 and 11). Horberg (1950, p. 96–99) referred the channels to a "deep valley" stage of erosion that occurred subsequent to the development of the Havana Strath.

In cross sections the channels appear to be narrow and V-shaped in some reaches and fairly broad in others (fig. 11, A—A' and B—B'). It is likely that the actual configurations would prove to be less anomalous and closely related to lithology and structure if abundant well control were available. Additional well control might also change the interpretation of the elevation of the floor of the main channel. Horberg's map of bedrock topography (1950, pl. I) showed a deep channel in the Havana region with elevation below 300 feet, whereas this study suggests that the main channel floor is somewhat higher (fig. 10). Our report also departs from Horberg's map in placing the main deep channel in a more northerly position and giving a more westerly lower course for the Middletown Valley.

The bedrock channels are important from the standpoint of ground water because they contain the thickest sand and gravel deposits (fig.11). They are commonly overlain by deposits 50 to 75 feet thicker than those on adjoining benches. The benches are overlain by substantial deposits of sand and gravel in some areas, but in others they are high enough to approach the level of present drainage (fig. 11, B—B').

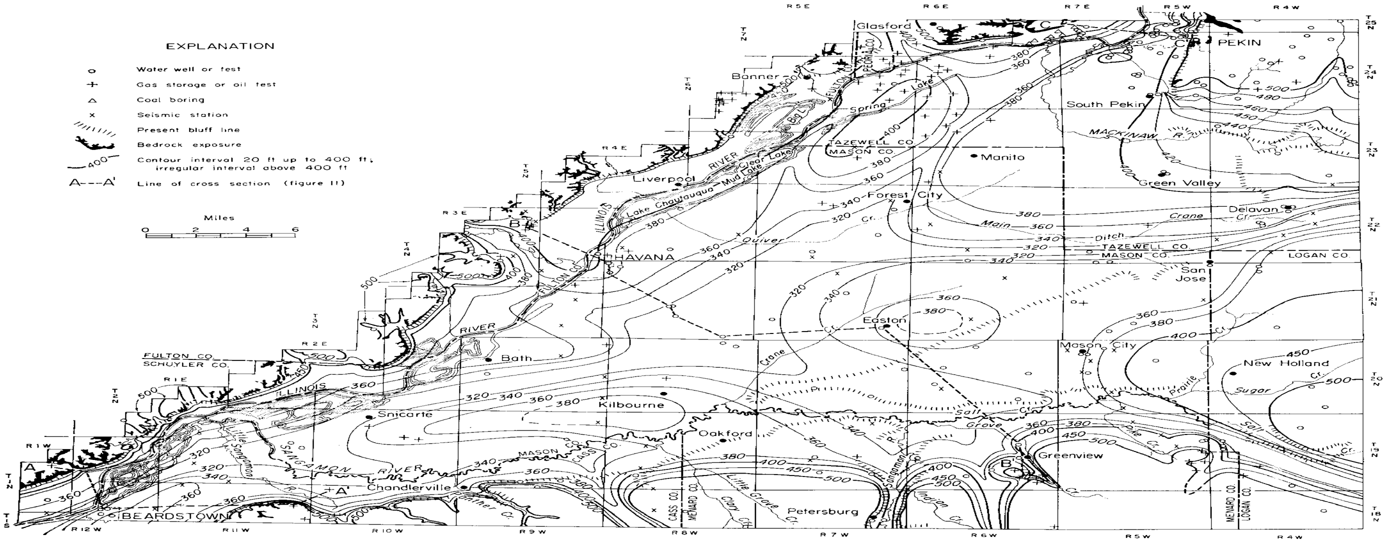


Fig. 10. Bedrock topography of the Havana region. Cross sections are shown in figure 11. (See Addendum, p. 54).

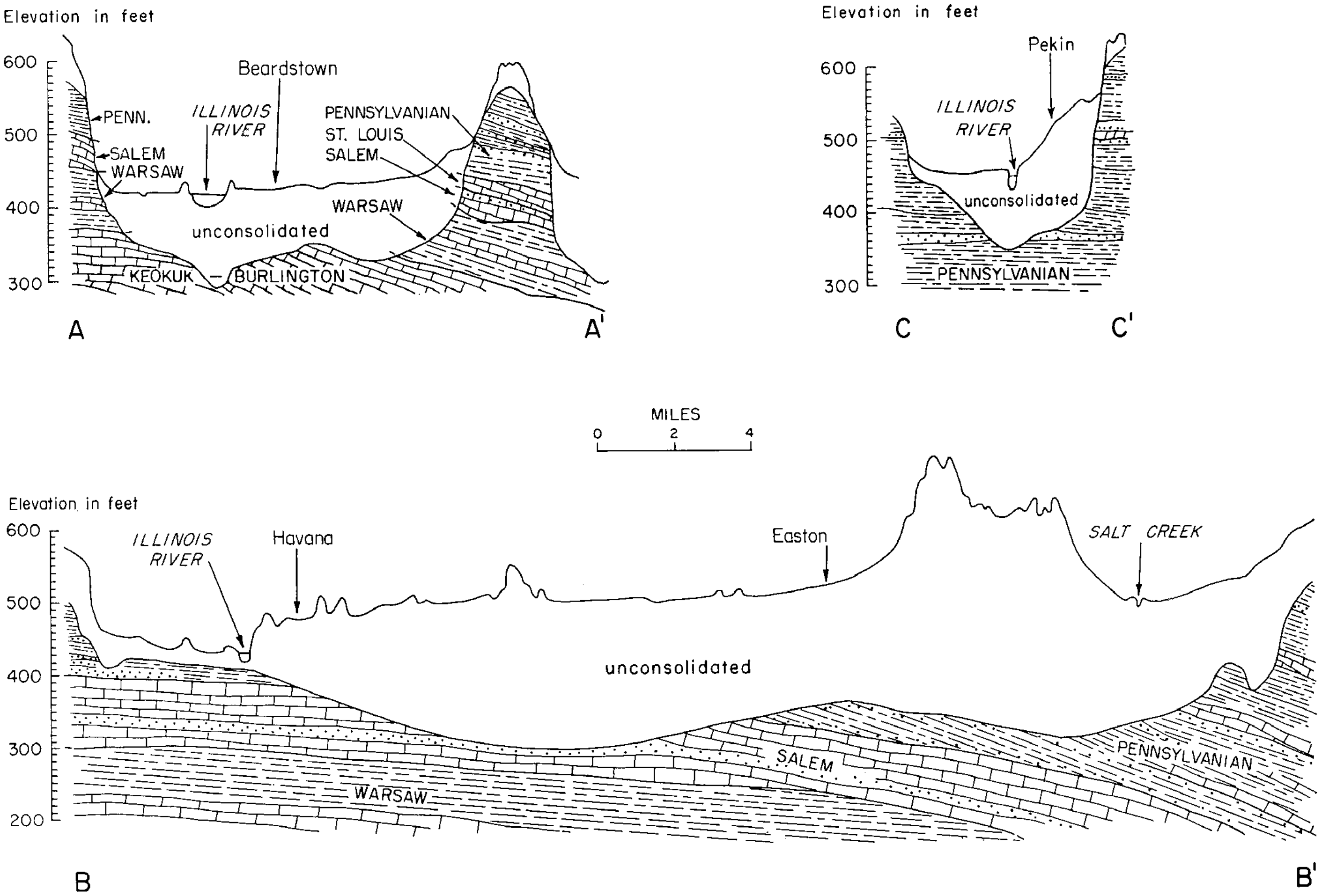


Fig. II.Cross sections of the bedrock in the Havana region. Lines of cross section are shown in figure 10.

Except in the narrow valley north of Pekin and the valley south of Beardstown, the Illinois River at present occupies a course along a bedrock bench and is well to the west of the deep bedrock channel. Consequently valley sediments are much thinner along the river than in most of the Havana region. Between Havana and Kingston Mines where the bedrock bench is above elevation 400 feet (fig. 11, B—B'), it is likely that in times of scour the Illinois River reaches bedrock. On the other hand, the bedrock surface is relatively deep beneath the lower courses of the Sangamon River and Salt Creek.

Unconsolidated Deposits

Distribution and thickness

Sand and gravel constitute the bulk of the unconsolidated deposits below the Wisconsinan terraces (figs. 12 and 13). However, below the Illinoian and Wisconsinan drift uplands, such as those at Mason City and Delavan (fig.13), the sands and gravels occur just above bedrock and are overlain by about 100 feet of finer grained, wind-blown, ice-laid, and mixed deposits.

The basal sand and gravel deposits are fairly distinct lithologically and have been named Sankoty Sand (Horberg, 1950, p. 51-52; Horberg, Suter, and Larson, 1950, p. 34-36). Beneath the upland the top of the Sankoty is between elevations of 450 and 500 feet; the average elevation is about 490 feet. The Sankoty thins and terminates east of Mason City and north of Delavan as the bedrock surface rises (fig. 13), but the deposits continue to the east up the Mackinaw-Mahomet bedrock valley beneath Delavan and westward beneath the terraces where they underlie Wisconsinan glacial sands and gravels. They also are present in the Peoria area where they overlie the bedrock in the deeper valleys and in turn are overlain by Illinoian and older drifts. Deposits in similar stratigraphic position in the Mahomet Valley were named the Mahomet Sand (Horberg, 1953, p. 18-20). The Mahomet Sand probably is present in the Havana Lowland, but because it is less distinctive than (and is no doubt mixed with) the Sankoty Sand it has not been differentiated.

The unconsolidated deposits of the Havana region range from a few feet to more than 400 feet thick (fig. 14). The thickest deposits occur west of Mason City where a tract of high kames and dune sand is underlain by the deep Middletown and Athens bedrock valleys (figs. 9, 10, and 13, B—C). Thin deposits (less than 50 feet) occur along and west of the Illinois River.

Throughout the broad tract of terraces from the river east to the Illinoian and Wisconsinan drift uplands (fig. 12), the sand and gravel deposits are from 100 to 200 feet thick. The deposits are commonly from 125 to 150 feet thick above the broad bedrock benches of the region, whereas they exceed 200 feet in some of the bedrock channels (fig. 13).

The lines showing the thickness of the unconsolidated deposits in figure 14 reflect both bedrock topography and present land surface features. For example, the finger-like contours west of San Jose, north of Forest City, and between Bath and Kilbourne show the thickening of the drift in deep bedrock channels. The crenulated or closed contours west of Mason City outline some of the high sand hills. The 200-foot thickness line running northeastward between Kilbourne and San Jose marks the rise of the Illinoian drift upland.

History

Planation of the broad Havana Lowland was complete prior to the advance of the Kansan glacier, as the presence of pre-Illinoian (probably Kansan) till in bedrock valleys to the east suggests, and may possibly have been complete before Pleistocene time (Horberg, 1950, p. 96-99; Wanless, 1957, p. 127-128). The deeper channels incised in the Havana Strath suggest that erosion proceeded in two stages.

Glacial ice advanced into the area adjacent to the Havana Lowland during both the Nebraskan and Kansan Stages (Wanless, 1957, p. 128-133; Horberg, 1953, p. 15-23). Within the lowland itself no ice-laid deposits assignable to these stages have been recognized, but the Sankoty and Mahomet Sands are now considered by the Illinois Geological Survey to be Kansan outwash deposits. The sands were deposited to an elevation of almost 500 feet, or about 200 feet above the bedrock floors. The Sankoty Sand was derived from sandstones and crystalline rocks in Wisconsin and Minnesota and was carried southward through the Middle Illinois and Mackinaw Valleys into the Havana Lowland. The Mahomet Sand appears to have been derived from glacial deposits (Manos, 1961). Later, melting of the Kansan ice left the Mackinaw Valley and much of the Mahomet

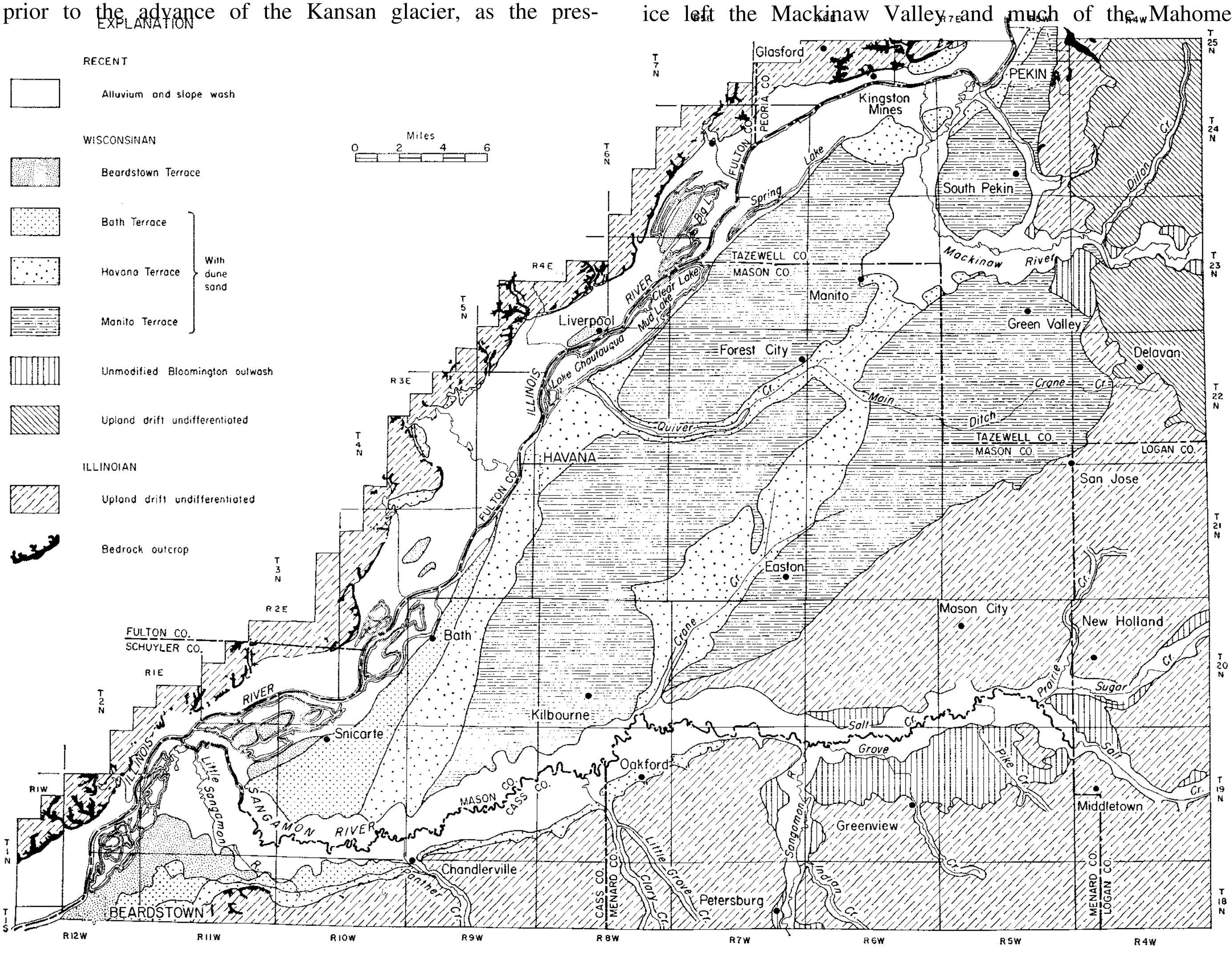


Fig. 12. Surficial geology of the Havana region. (Modified from Wanless, 1957, pls. 1-3, fig. 59.)

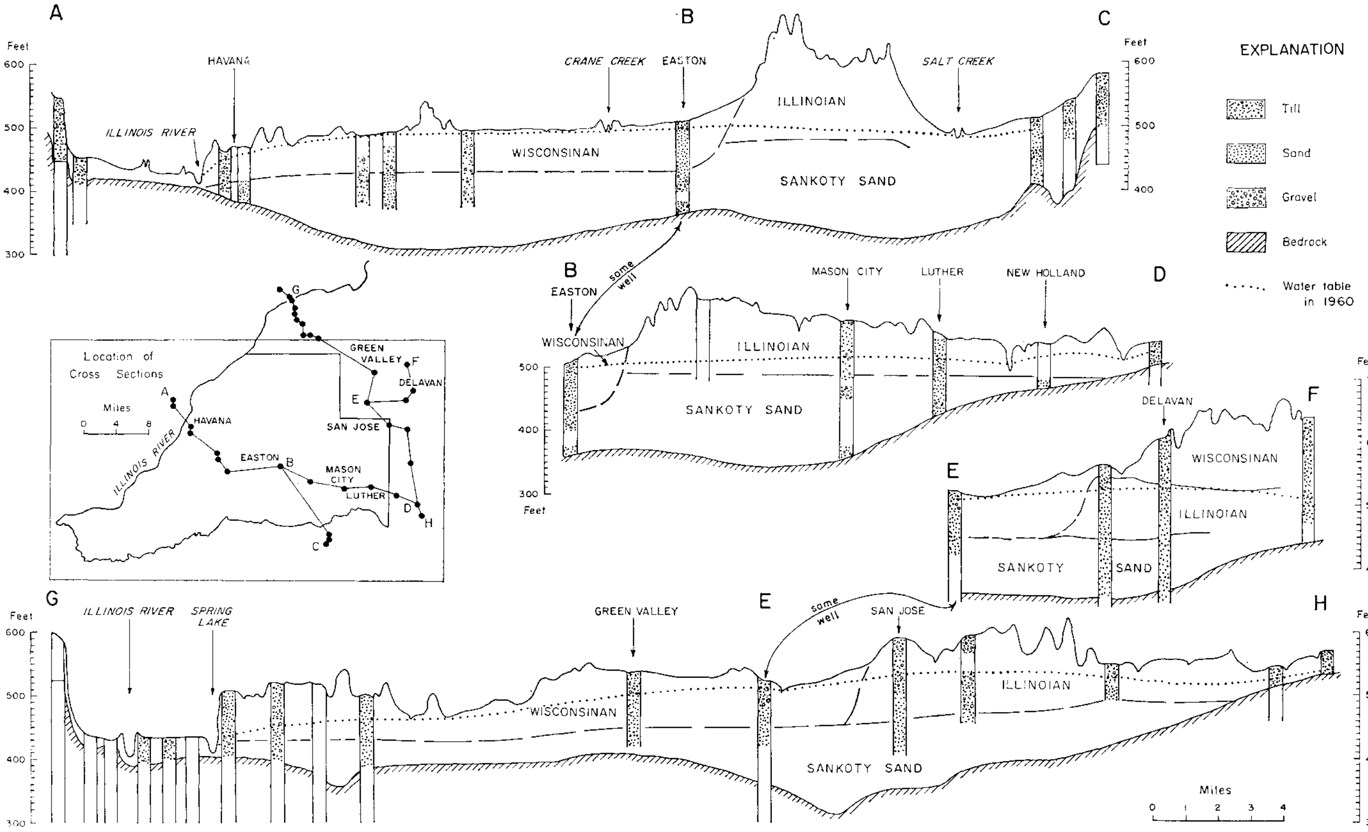


Fig. 13. Cross sections of the unconsolidated deposits of the Havana region, with profiles of the water table, 1960.

Valley filled with drift, and the Peoria-Pekin channel probably began carrying the main drainage from the north.

The Illinoian glacier advanced from the northeast approximately as far south as Harrisburg and Murphysboro in Illinois and as far west as southeastern Iowa. It built low, discontinuous moraines, one of which (Buffalo Hart) forms the hilly ridge in southeastern Mason County and continues south across the east end of Menard County. To the east and southeast in Logan and Sangamon Counties the Buffalo Hart Moraine is associated with a complex of sandy crevasse fillings and moulin kames. During Illinoian time abundant meltwater was channeled into the Havana region, resulting in the deposition of sandy drift. After the Illinoian glacier melted, the surficial drift was weathered and extensive erosion occurred along the Middle Illinois Valley and the Peoria-Pekin channel.

The beginning of Wisconsinan glaciation was marked by a spread of outwash down the Illinois River Valley. Winds blew silt from the outwash flats during dry periods and deposited it on the adjoining uplands as loess. Wisconsinan glaciers later advanced to the vicinity of Delavan, Pekin, and Peoria and built a series of end moraines that rise above the loess-blanketed Illinoian drift plain. During the building of one of these moraines, the Bloomington, meltwater from the ice built a thick valley train or outwash fan of sand and gravel down the Illinois Valley past Pekin to south of Beardstown. The surface of the outwash fan (unmodified Bloomington outwash, fig. 12) sloped from an elevation of about 640 feet near Peoria to about 485 feet near Beardstown (fig. 15; Wanless, 1957, p. 175). The base of the fan cut well into the much older Sankoty deposits. When the ice retreated from the Bloomington end moraine a lake was formed in the Illinois River Valley north of Peoria. It discharged through a narrow channel along the west valley wall, a course the river still follows.

Subsequently, when the Wisconsinan glacier was melting in northeastern Illinois, south-central Michigan, and northern Indiana, a great flood of meltwater (the Kankakee Flood) poured down the Illinois Valley eroding channels in the Bloomington outwash fan and building sand bars. As the volume of meltwater subsided it was confined within the Illinois, Mackinaw–Quiver Creek, and Crane Creek Valleys. The Manito and Havana Terraces (fig. 12) record levels of erosion of the original Bloomington outwash fan surface, which is preserved in a few protected places along tributary valleys. During low-water stages of the Kankakee Flood, the sands and silts exposed as bars were reworked by the wind into dune complexes.

Later, during the melting of the Wisconsinan ice, further erosion along the Illinois River developed the Bath Terrace. The Beardstown Terrace was formed, after a stage of deeper erosion, along the river by sand and gravel deposited when the flow of meltwater diminished.

Lithology and water-bearing properties

The unconsolidated deposits, which in general can be subdivided into those of the bedrock valley or lowland areas and those of the adjoining bedrock uplands, occur as units that have considerably different properties in relation to the occurrence and movement of ground water. Sands and gravels of the valley areas are the main aquifer of the region, whereas the finer grained upland deposits are significant chiefly for their control of the percolation of rainfall to the water table and to deeply buried sand and gravel deposits.

The individual units of unconsolidated deposits (fig. 7) are discussed in detail in the following sections.

Sankoty Sand

The Sankoty Sand is typically pinkish gray, medium- to coarse-grained sand. About 75 percent of the grains are composed of quartz, 10 to 15 percent of feldspar, and 10 to 20 percent of crystalline and sedimentary rocks. More than 75 percent of the quartz grains are clear and untinted, the majority subrounded to rounded. From 10 to 20 percent of the quartz grains are pink, and many have flecks of reddish stain in tiny pits. The abundance of pink-tinted quartz and potash feldspar grains gives the Sankoty the pink cast that helps distinguish it from overlying deposits.

Texturally, the Sankoty Sand ranges from fine to very coarse sand with granule gravel, although beds of clean, well sorted, medium to coarse sand are most common. Gravel beds are somewhat more abundant in the narrower parts of the bedrock valley north of Manito and in the area south of Beardstown than in the wide reach east of Havana. In general, however, the Sankoty Sand is finer than overlying Wisconsinan outwash. For example, sieve analyses (fig. 16) of samples from well MSN 21N8W-6.8g2 (Havana City Well 4) show coarser Wisconsinan deposits to a depth of 50 feet and finer, well sorted Sankoty Sand below.

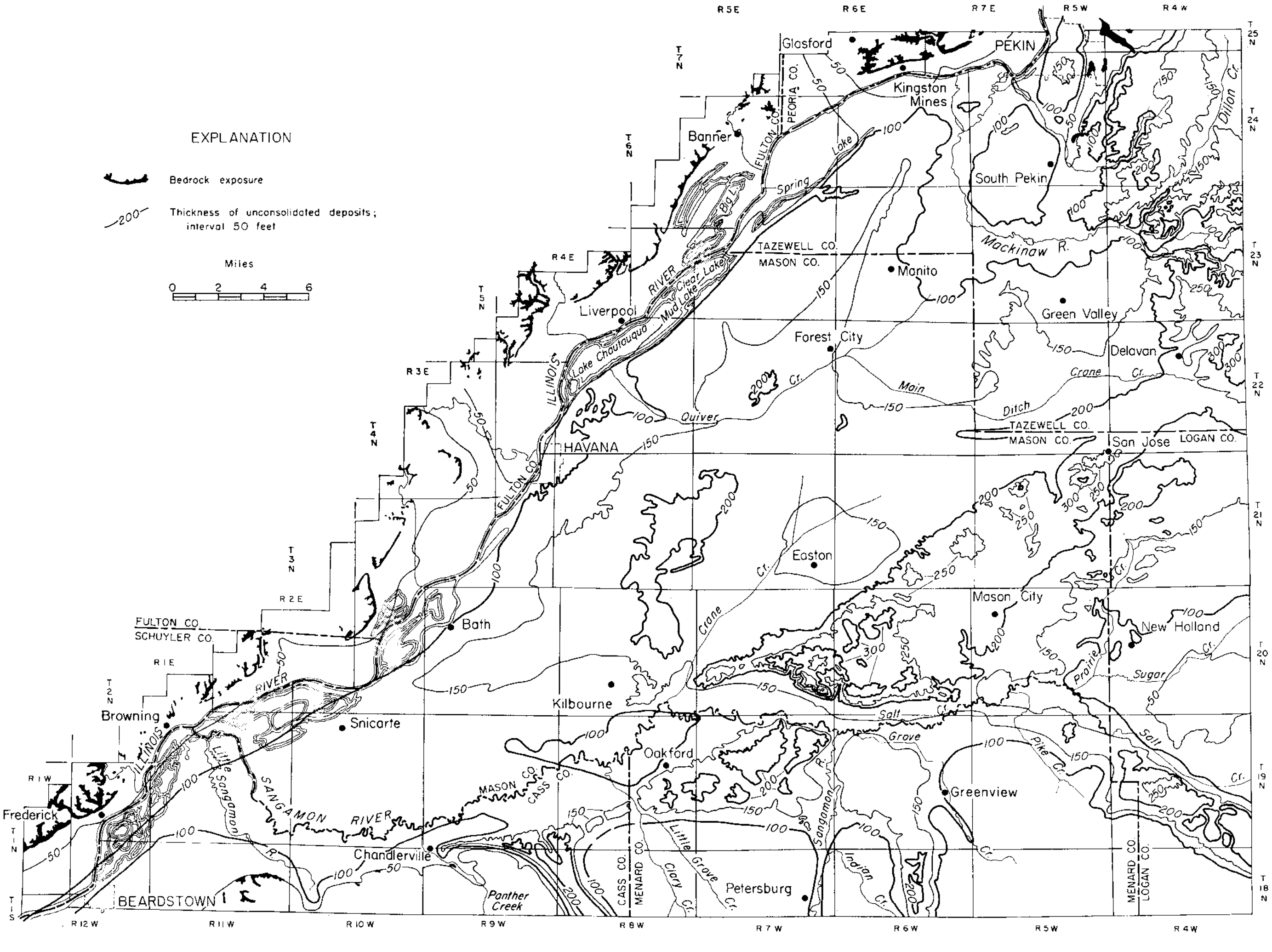


Fig. 14. Thickness of the unconsolidated deposits in the Havana region.

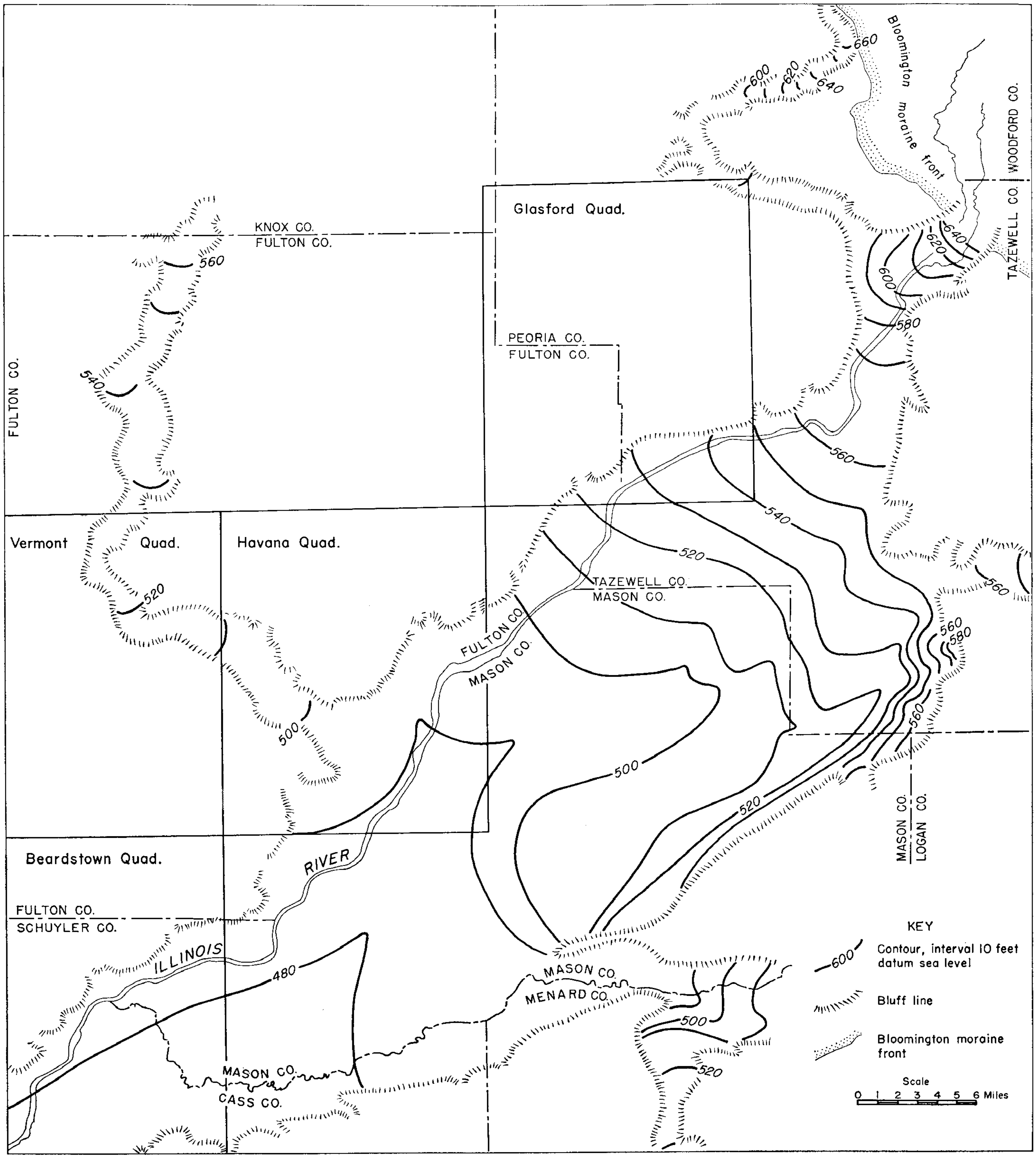


Fig. 15. Contour map showing the original form of the Bloomington valley train (Wanless, 1957, fig. 58).

The coarser fractions of the Sankoty Sand (coarser than 4 millimeters) are composed dominantly of dolomite (46 to 56 percent noted in random counts), chert (9 to 16 percent), limestone (8 to 13 percent) and fine-grained, dark, igneous rocks (3 to 13 percent). Dolomite pebbles are significantly more common than in the shallower Wisconsinan outwash.

The Sankoty Sand overlies the bedrock throughout much of the Havana region and can be identified in well cuttings, except in some localities where it is mixed with other deposits or has been eroded. Its thickness varies greatly because of the irregular surface on which it was deposited and because of erosion of its upper surface. It is probably missing beneath the present valley of the Illinois River (fig. 13). It may attain a maximum thickness of some 175 feet where the deep bedrock channel underlies the Illinoian and Wisconsinan upland, but generally it is less than 125 feet thick. The elevation of the top of the Sankoty Sand rises from Havana eastward toward Mason City and Delavan and northward toward Pekin, averaging about 425 feet at Havana, 445 at Forest City, 450 at Delavan, 490 at Mason City, and 440 at South Pekin.

Where the Sankoty Sand is recognizable below the Wisconsinan terraces, it appears to be overlain directly by Wisconsinan outwash. Illinoian deposits, if present, cannot be recognized. The sample study log of well MSN 21N6W-28.1g on the Manito Terrace between Havana and Kilbourne illustrates the sequence of Wisconsinan outwash above Sankoty deposits.

	Thickness *(ft)*	Depth to base *(ft)*
Pleistocene Series		
No samples	18	18
Wisconsinan Stage (Bloomington outwash)		
Sand, fine to medium; yellowish brown subangular grains; ferruginous staining; abundant yellowish quartz grains; some brown silt	8	26
Sand, medium, as above; some granule gravel	10	36
Silt, brown, calcareous	2	38
Sand, medium; yellowish brown subangular grains	4	42
Sand, medium to coarse with granule gravel, yellowish brown; granules of dolomite, quartz, and granite	12	54
Sand, fine to coarse, some very coarse, yellowish brown; abundant grains of yellowish quartz and feldspar	12	66
Kansan Stage		
Sankoty Sand		
Sand, medium to coarse, pinkish gray; subangular to rounded grains; abundant pink and pink-stained quartz grains; some granule gravel and fine sand beds	22	88

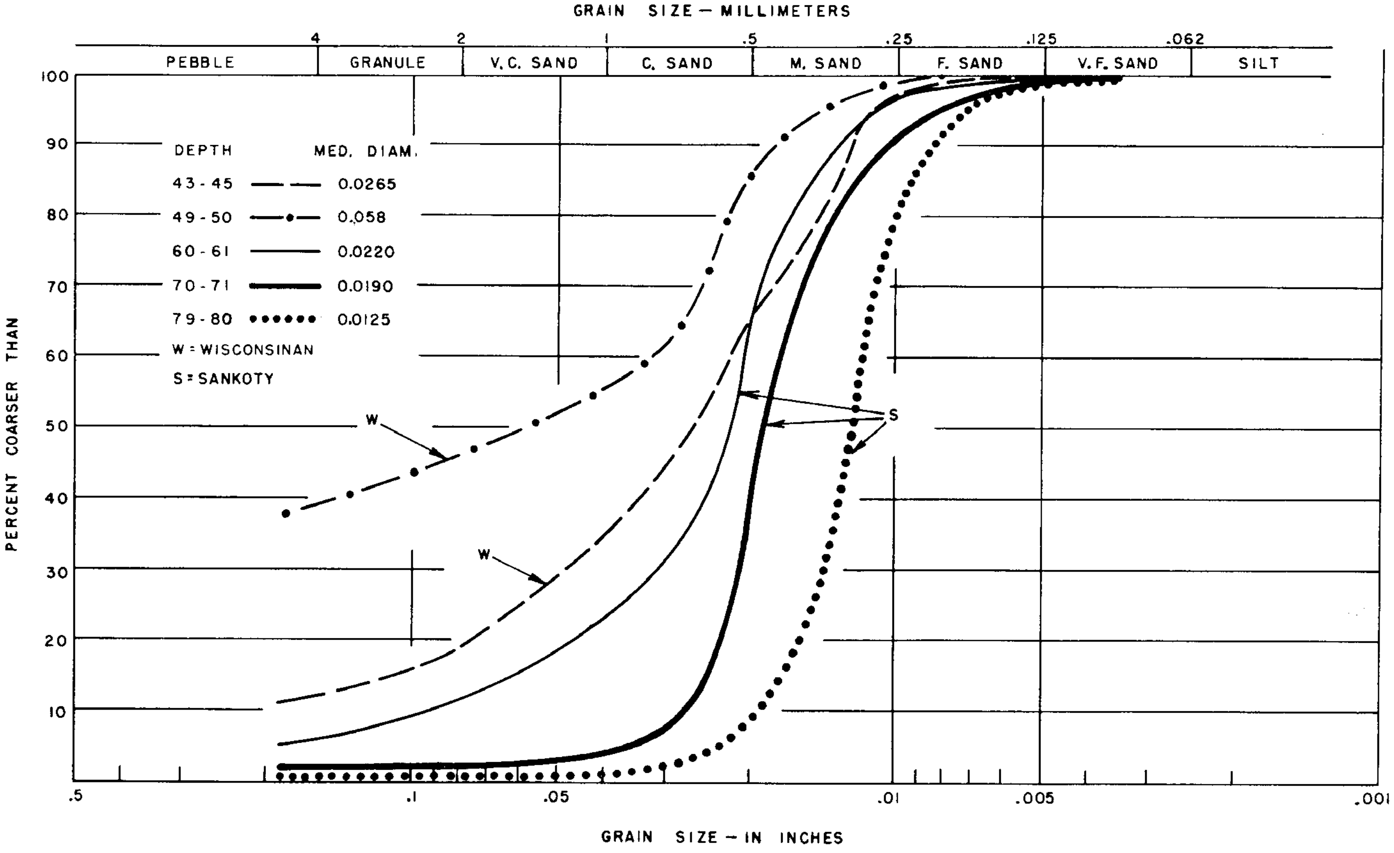


Fig. 16. Sieve analyses of samples from well MSN 21 N8W-6.8g2.

Sand, fine to very coarse, pinkish gray; abundant pink grains; some granules of dolomite, quartz, feldspar, and igneous rock	10	98
Sand, fine to medium, reddish brown, subangular; abundant pink grains; many grains with pink clay skins	8	106
Sand, medium to very coarse, pinkish gray; pink grains; granules of chert dolomite and dark igneous rock	12	118
Gravel, granule, with very coarse sand; granules of dolomite, granite, sandstone, felsite, and dark igneous rock	4	122 (total depth)

The Sankoty Sand and the overlying Wisconsinan outwash constitute the main aquifer of the Havana region. They form a fairly homogeneous unit that extends from near land surface to bedrock in the broad Wisconsinan terrace area. Most wells on the terraces that are 100 or more feet deep penetrate at least the upper part of the Sankoty Sand (fig. 13). The Sankoty Sand also extends eastward beneath the Illinoian upland, where it is overlain by heterogeneous Illinoian deposits. In the area of the broad bedrock valley east of Delavan, the Sankoty and the related Mahomet Sand are overlain by both Illinoian and Wisconsinan drift.

Composed of well sorted, generally clean sand and gravel, the Sankoty Sand is a highly permeable reservoir with considerable areal extent. Recharge to the Sankoty Sand is most rapid where it is overlain by the Wisconsinan outwash, because the outwash itself is permeable and in much of the area is covered by dune sands that lack integrated drainage lines, which facilitates infiltration of rainfall. Recharge conditions are less favorable beneath the Illinoian uplands because layers of till overlie the Sankoty. Recharge to the Sankoty is poorest beneath the Wisconsinan drift uplands where it is overlain by both Illinoian and Wisconsinan tills.

Other Pre-Illinoian Deposits

Occurrences of pre-Illinoian deposits west of the Illinois River were described by Wanless (1957, p. 128-133) and those east of the river by Horberg (1953, p. 20-25). They are primarily remnants of weathered tills found at low elevations in outcrops and indicated in wells. With the exception of the Sankoty Sand, pre-Illinoian deposits are not recognized in the Havana region and are not important from the standpoint of ground-water occurrence.

Illinoian Deposits

Illinoian drift in the upland around Mason City, south of San Jose, and north of New Holland (fig. 12) is mantled by loess and is well exposed in only a few places along the north bluff of Salt Creek and the Sangamon River, where it is dominantly sand and gravel and is locally associated with dense, dark brown to reddish brown, very sandy, pebbly till. A gravel pit in the north bluff of the Sangamon River in NE¼ SE¼ NE¼ sec. 36, T. 20 N., R. 7 W., Mason County, has the following section:

	Thickness *(ft)*
Pleistocene Series	
Wisconsinan Stage	
Peoria Loess	
Silt, reddish at base, becoming tan above, slightly calcareous	10
Illinoian Stage	
Till, orange to reddish brown, dense, sandy, noncalcareous; abundant pebbles	4 to 8
Sand and gravel, gray to tan; cobbles up to 8" in diameter; beds dip back into bluff to north (elevation of base of exposure, 595')	40 exposed

Essentially the same sequence of sand and gravel, dense till, and reddish and tan silts is repeated at several exposures in the bluff for the next 10 miles east. The silts are considered to be Wisconsinan deposits, whereas the till and associated sand and gravel deposits are believed to be Illinoian.

A complex array of reddish to pinkish coarse gravel with boulders, bedded sands, and silts is exposed in roadcuts across the narrow, rough upland east of Crane Creek and north of the Sangamon River. The lower coarse deposits are considered Illinoian, and the upper pink silts and sands are considered Wisconsinan.

A gravel pit a mile west of San Jose (NE¼ NE¼ NE¼ sec. 2, T. 21 N., R. 5 W., Mason County) shows 10 feet of well bedded sand and gravel dipping northward, with boulder beds in which some individual boulders are as much as 1½ feet in diameter. Brown laminated sand and silt overlie the sand and gravel and are in turn overlain by crudely layered, pebbly, clayey colluvium and additional sand and gravel. The deposits are all part of the Illinoian kame complex.

Well records showing subsurface details of the Illinoian deposits in the vicinity of Mason City and San Jose are scarce. Probably some Illinoian till and other fine-grained sediments are present in addition to sand and gravel.

A drillers log of well MSN 20N5W-17.8c, 2 miles north of Mason City, recorded the following sequence:

	Thickness *(ft)*	Depth to base *(ft)*
Soil	6	6
Yellow clay	33	39
Red sand	12	51
Blue sand	32	83
Quicksand	21	104
Coarse gravel	6	110

Samples from well MSN 20N5W-7g2 at Mason City show the following sequence:

	Thickness *(ft)*	Depth to base *(ft)*
Pleistocene Series		
Wisconsinan Stage		
Soil	5	5
Sand, fine (wind-blown), brown, noncalcareous	35	40
Silt, brown, noncalcareous	5	45
Illinoian Stage		
Till (?), brown, silty	5	50
Sand, medium to coarse	5	55
Sand, very coarse; granule gravel; very dirty (till?)	10	65
Till, yellowish brown, calcareous	20	85
Sand, fine to medium, calcareous	5	90
Kansan Stage		
No samples	105	195
Sankoty Sand		
Sand, very fine to fine, brown, abundant pink grains	4	199
Sand, medium to very coarse; granule gravel	21	220 (total depth)

These logs suggest that Illinoian till is present in the depth range of 50 to 85 feet, with loess and wind-blown sand above and mainly sand and gravel below. Scarcity of subsurface information prevents the projection of this sequence to the west with certainty. A few well records from northwestern Logan County southeast of San Jose indicate that the Illinoian deposits are composed of finer grained materials, logged as "clay," "hardpan," or "drift," rather than as "sand and gravel."

Illinoian drift in Tazewell County east of Pekin is dominantly compact dark gray till that contains somewhat more sand and silt than nearby or overlying Wisconsinan tills. The Sangamon weathered zone is commonly recognized on top of the Illinoian drift in outcrops and is indicated in drillers records by such terms as "old soil," "peat," "black muck," or "dark clay."

Illinoian deposits west of the Illinois River are assigned to the Liman, Jacksonville, and Buffalo Hart Substages. These Illinoian tills are lithologically similar (Wanless, 1957) and are differentiated on the basis of their position in and behind end moraines. The till averages 25 to 35 feet thick, is light gray where unweathered, locally contains large blocks (6 to 16 feet in diameter) of sedimentary and igneous rocks, has an abundance of dolomite pebbles derived from the Silurian rocks of the Lake Michigan region, and is associated with considerable sand and gravel. At several outcrops in Fulton and Peoria Counties, a zone of sand and gravel or laminated silt occurs within the Illinoian drift, separating an older till from the younger surficial till.

Illinoian drift south of the Sangamon River and Salt Creek is composed of till with considerable associated sand and gravel. From the hilly tract of Illinoian drift in southeastern Mason County a belt of crevasse ridges and kames extends southeastward across eastern Menard, western Logan, and northeastern Sangamon Counties. These ridges and kames contain sand deposits that are more or less restricted to the ridges and knobs themselves; subsurface records of borings in the intervening flats show mainly till and other fine-grained material.

Deposits in the Middletown and Athens bedrock valleys (figs. 9 and 10) and in the bedrock valleys at Petersburg and east of Chandlerville (fig. 10) are largely Illinoian and older till, with locally thick beds of sand and gravel.

Well MEN 19N5W-13.2h (Middletown Village Well 1) penetrated the following section as interpreted from drilling samples:

	Thickness *(ft)*	Depth to base *(ft)*
Pleistocene Series		
Wisconsinan Stage		
Silt, brown, noncalcareous	5	5
Illinoian Stage		
Till, yellow, very silty, noncalcareous	10	15
Till, yellow, noncalcareous	10	25
Sand, yellow, fine to medium, dirty, calcareous	5	30
Till, yellow, calcareous	25	55
Silt, brownish gray, calcareous	5	60
Till, yellow, brownish gray to brown, calcareous	15	75
Silt, gray-buff to yellow, calcareous	27	102
Sand, fine to medium, dirty, calcareous	13	115
Sand, gray, fine to coarse; gravel, granular, calcareous	35	150
Sand, gray, fine to coarse, calcareous	5	155 (total depth)

The well is located on the western flank of the Middletown bedrock valley. Farther east in the valley the drift probably attains a thickness of more than 250 feet.

The interbedding of deposits of differing permeabilities makes hydrologic conditions in the Illinoian upland east of Crane Creek more complex than those in the Wisconsinan terrace areas where the deposits are dominantly sand and gravel. Till or silt beds of low permeability limit recharge and also partially separate or confine water in aquifers. Because of the irregularity of the deposits, probably no given set of hydrologic conditions persists for wide areas. At some locations, beds of Illinoian sand and gravel yield ground water to relatively shallow drilled or dug wells, whereas at other locations it is necessary to drill several hundred feet to reach the Sankoty Sand in order to obtain adequate ground-water supplies. In some areas ground water is apparently "perched" above beds of low permeability that also confine the water in underlying sands and gravels.

There is some indication that the Sangamon weathered zone at the top of the Illinoian deposits affects the quality of ground water. Methane, or marsh gas, which may be related to the Sangamon zone, is reported at a

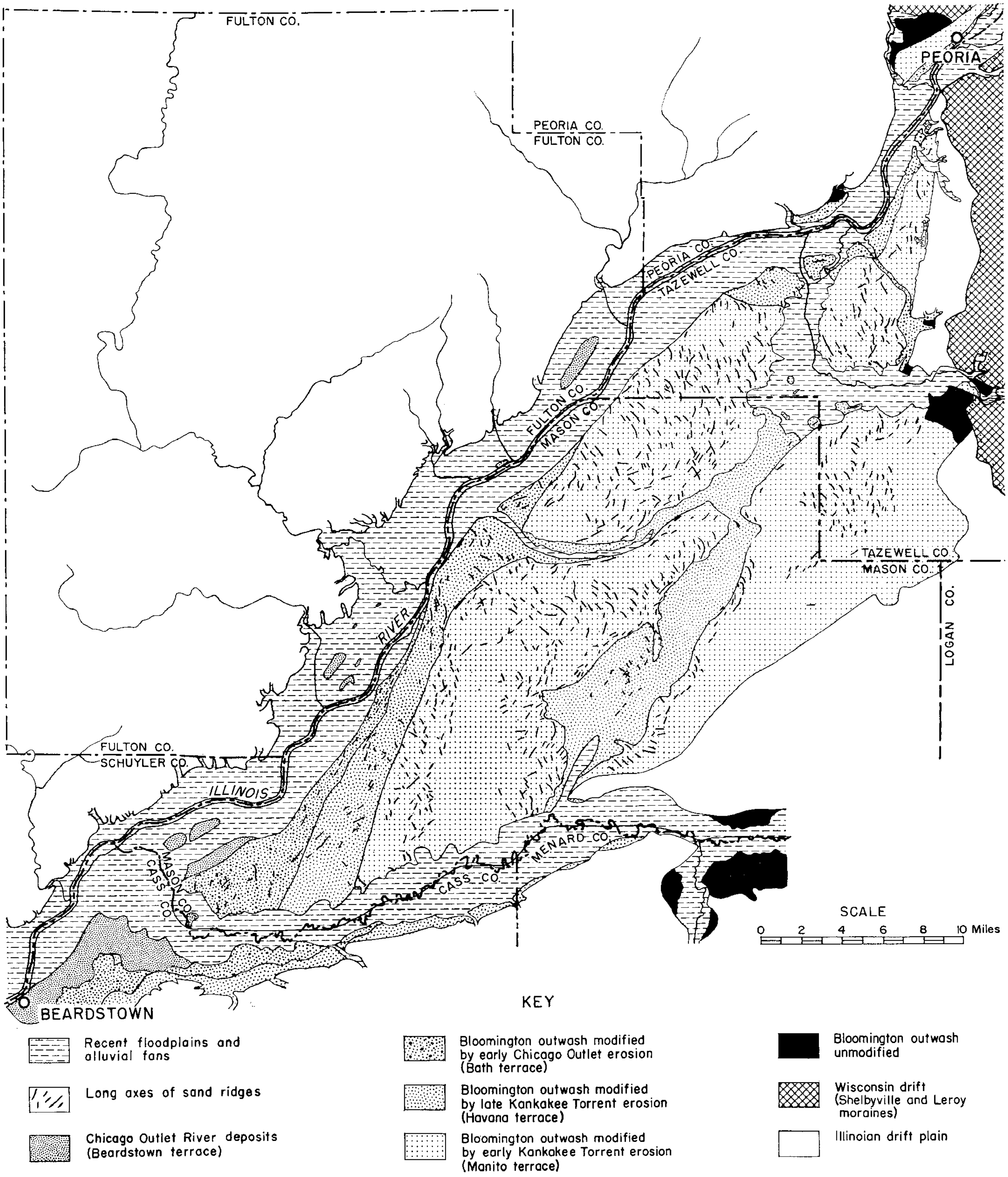


Fig. 17. Distribution of terraces and pattern of sand ridges in the Illinois Valley from Peoria to Beardstown (Wanless, 1957, fig. 59).

depth of about 60 feet in several wells between Easton and Mason City. In approximately the same area, the ground water has higher concentrations of nitrates, which perhaps are related to oxidation of ammonia in buried soil zones.

Wisconsinan Outwash

Wisconsinan (Bloomington) outwash deposits underlie the terraces (fig. 12) at shallow depths. They are extensively overlain by wind-blown sand and silt, and by silt and peat along some of the low swampy areas adjacent to streams. The outwash consists of sandy gravel with beds of pebbly sand at the northern edge of the terrace area near Pekin, and grades southward to sand with scattered pebbles and gravel lenses.

The grains of the sand outwash are 60 to 75 percent quartz, 10 to 20 percent feldspar, and 20 to 30 percent sedimentary and crystalline rocks and minerals. The sand is commonly light brown to yellowish brown and contains fairly abundant yellowish grains of quartz and feldspar, scattered fragments of pearly mollusk shells, tiny rod-like spicules (from fresh-water sponges?) and amber-colored spores.

The pebble-sized gravel (coarser than 4-mesh) is made up dominantly of dolomite (30 to 38 percent noted in random counts), limestone, and chert, and also has substantial numbers of igneous and metamorphic rock pebbles. An exposure of the gravel reported in a pit at Liverpool (Wanless, 1957, p. 143) shows 2½ feet of Recent silt and sand over 5 to 6 feet of flat-bedded sandy gravel, which in turn overlies 10 to 11 feet of cross-bedded gravel with foreset beds dipping west-southwest at angles of 20° to 25°. The cross-bedded gravel is Bloomington outwash, which retains the structure left by sediment-choked, braiding meltwater streams.

Since the Manito, Havana, and Bath Terraces represent various levels of erosion of the original Bloomington outwash fan, the Wisconsinan deposits are correspondingly thinner under each lower terrace. The maximum thickness of the Wisconsinan outwash beneath the Manito Terrace is probably about 100 feet, although the tops of the deposits are masked by thick dune sand or by alluvial silts.

A sample study log of well TAZ 23N5W-26.8a at Green Valley, on the Manito Terrace, shows the nature of the Wisconsinan and Sankoty deposits.

	Thickness *(ft)*	Depth to base *(ft)*
Pleistocene Series		
Wisconsinan Stage		
Silt, black, dark brown, carbonaceous	3	3
Silt, dark yellowish brown, noncalcareous	9	12
Sand, medium to coarse, with gravel, yellowish brown; abundant dolomite, limestone, and chert	10	22
Sand, medium to coarse, yellowish brown, very silty	5	27
Sand, medium to coarse, with granule gravel, yellowish brown, very silty	14	41
Sand, fine, pale brown; subrounded grains; abundant white and yellow limestone and dolomite grains; some wood and mollusk fragments	59	100
Kansan Stage		
Sankoty Sand		
Sand, fine to very coarse, pinkish gray; abundant pink grains of quartz and feldspar	15	115 (total depth)

Wisconsinan outwash deposits are the coarsest and most permeable sediments of the region. Along with the Sankoty Sand, which they apparently immediately overlie in much of the area, they are the main aquifer, nearly everywhere exceeding 100 feet thick (fig. 14). The coarseness and, presumably, the permeability of the outwash generally increase from south to north, though the width of the valley and the presence of bedrock "islands" have locally influenced depositional conditions and the resulting textures of the sand and gravel.

Recharge to the Wisconsinan outwash and underlying Sankoty Sand is facilitated by the broad, hummocky areas of sand dunes on the terraces. Only small areas of outwash are covered by fine-grained sediments that restrict the infiltration of rainfall.

Wisconsinan Dune Sand

Sand ridges cover about 375 square miles of terrace east of the Illinois River and also occur on the east bluffs and uplands east of the Illinois Valley in Mason and Cass Counties. The distribution and orientation of the ridges, which probably originated from wind modification of bars of sandy outwash, are shown in figure 17 (Wanless, 1957, p. 145). Most ridges are at an angle to the trend of the Illinois, Mackinaw-Quiver Creek, and Crane Creek Valleys, but the ones near the valleys generally curve to lie approximately parallel to the valleys. Wanless (1957, p. 176) attributed the orientation of the sand ridges to overflow currents that first diverged from the valleys and then, when the water level subsided, were confined to the valleys. The first modification of ridges by wind action was probably right after subsidence of the Kankakee Flood, before vegetation was well established. Further modification by wind has taken place at various times since then.

Many of the sand ridges are 40 to 50 feet high, and a few are as much as 80 feet high. The wind-blown sand mantles outwash bars and in some places forms ridges and knobs without cores of outwash. In extensive areas the dune sand is more than 20 feet thick. A sandy soil 1 or 2 feet thick is developed on the dunes, though the wind has excavated blowouts in some places where the natural vegetation has been removed.

Commonly, 30 to 70 percent of the grains in the dunes are in the medium sand range, the rest being finer. Cumulative frequency curves of representative dune sand samples are shown in figure 18. Excellent sorting is indicated by the steepness of the curves. Thirteen samples average 48 percent medium sand and .0107 inches median diameter. The sand is generally finer grained in dunes along the east edge of the terrace near Kilbourne and Easton. On the upland near Mason City, the sand is still finer grained, one sample just west of Mason City having a median diameter of .007 inches (fine sand) and containing only 10 percent medium sand.

The rough dune topography of ridges, knolls, and blowouts, with highly permeable soils and absence of integrated drainage, provides favorable conditions for the infiltration of rainfall. The dune sand itself is not a significant part of the aquifer, generally being above the water table.

Wisconsinan Loess and Silt

Uplands bordering the terraces east of the Illinois River are mantled by some of the thickest loess deposits in the state (fig. 7). The area of thickest loess, shown as exceeding 300 inches on uneroded topography in figure 19, includes part of the Illinoian upland south of the Sangamon River and Salt Creek in Cass and Menard Counties, and the triangular Illinoian upland in eastern Mason County and northwestern Logan County. Here the loess is generally more than 10 feet and often more than 30 feet thick. Loess thicknesses of 68 and 92 feet are reported at two localities on the bluffs near Chandlerville in Cass County (Smith, 1942, p. 157).

A traverse from Menard County southeastward (Smith, 1942) shows that the loess decreases rapidly in thickness and coarseness within 2 miles of the bluff, then thins and becomes finer textured at a gradual rate for the next 50 miles. Within 2 miles of the bluff, some 20 percent of the loess is sand, but farther away only 2 percent or less is sand. The mean diameter decreases to .024 millimeters (mm) at 3.8 miles, .024 mm at 9.3 miles, .022 mm at 14.7 miles, and .017 mm at 42 miles (Smith, 1942, p. 154-156).

Loess overlying the Wisconsinan upland east of Delavan and the Bloomington outwash (fig. 12) is generally only 5 to 10 feet thick, whereas the younger Wisconsinan terraces are relatively free of loess.

The Wisconsinan loess and silt are not important sources of ground water, though they provide small supplies to a few dug wells, especially on the Illinoian upland east of Crane Creek where they are thick and contain considerable sand. They are moderately permeable.

Wisconsinan Upland Drift

The Wisconsinan undifferentiated drift sheet forms a ridged upland plain that rises above the Illinoian

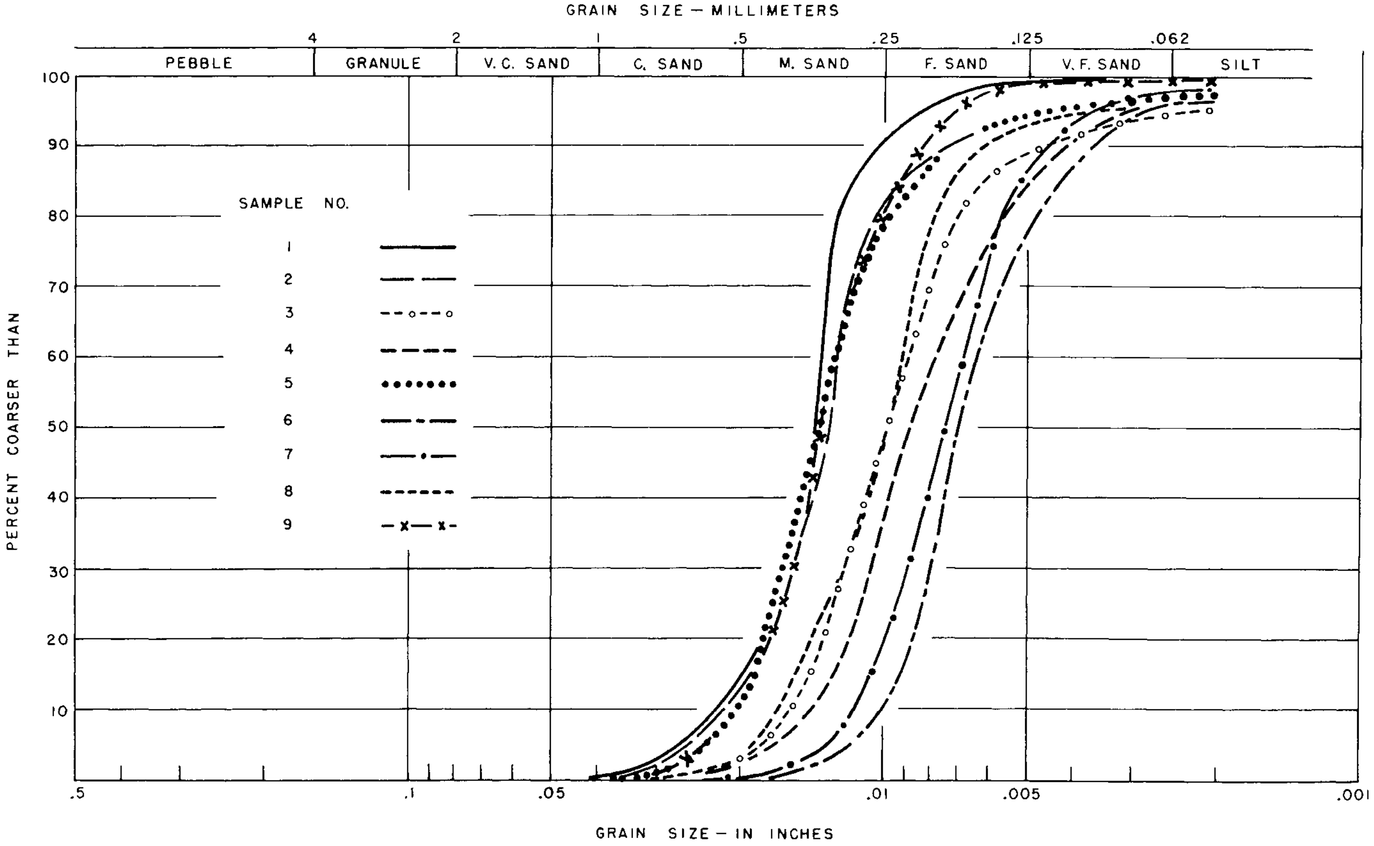


Fig. 18. Sieve analyses of dune sand. Location from which the samples were taken are (1) 21-23N-7W (depth 6 ft); (2) 21-23N-7W (depth 4½ ft); (3) 16-23N-7W; (4) 22-22N-7W; (5) 33-22N-8W; (6) 12-20N-6W; (7) 33-20N-8W; (8) 18-20N-9W; (9) 9-19N-10W.

plain and Wisconsinan terraces north and east of Delavan (figs. 12 and 13, E—F). It is mantled by 5 to 10 feet of loess. Delavan is situated on the lower frontal portion of the Shelbyville end moraine, which forms the outermost ridge of the Wisconsinan drift plain.

Wisconsinan till is brownish to pinkish gray or maroon - gray, somewhat more clayey, less sandy, and less compact than the underlying Illinoian till. A drillers log of well TAZ 22N4W-9.1d in Delavan records the following section:

	Thickness *(ft)*	Depth to base *(ft)*
Soil and clay	20	20
Blue clay	25	45
Drift	20	65
Clay	10	75
Hardpan	20	95
Sand and gravel	25	120
Gravel	27	147 (total depth)

The "soil and clay," "blue clay," and "drift" probably represent Wisconsinan loess and till, the "clay" from 65 to 75 feet is lower Wisconsinan loess, the "hardpan" is Illinoian till, and the sand and gravel are Illinoian and older deposits. The maximum thickness of the Wisconsinan deposits near Delavan is about 125 feet.

Since the Wisconsinan deposits of the upland are mainly clayey till with little associated sand and gravel, recharge conditions are less favorable than on the Wisconsinan terraces or on the Illinoian drift upland. It is generally necessary to drill through the Wisconsinan loess and till and into Illinoian and older sand and gravel to obtain ground-water supplies east and north of Delavan.

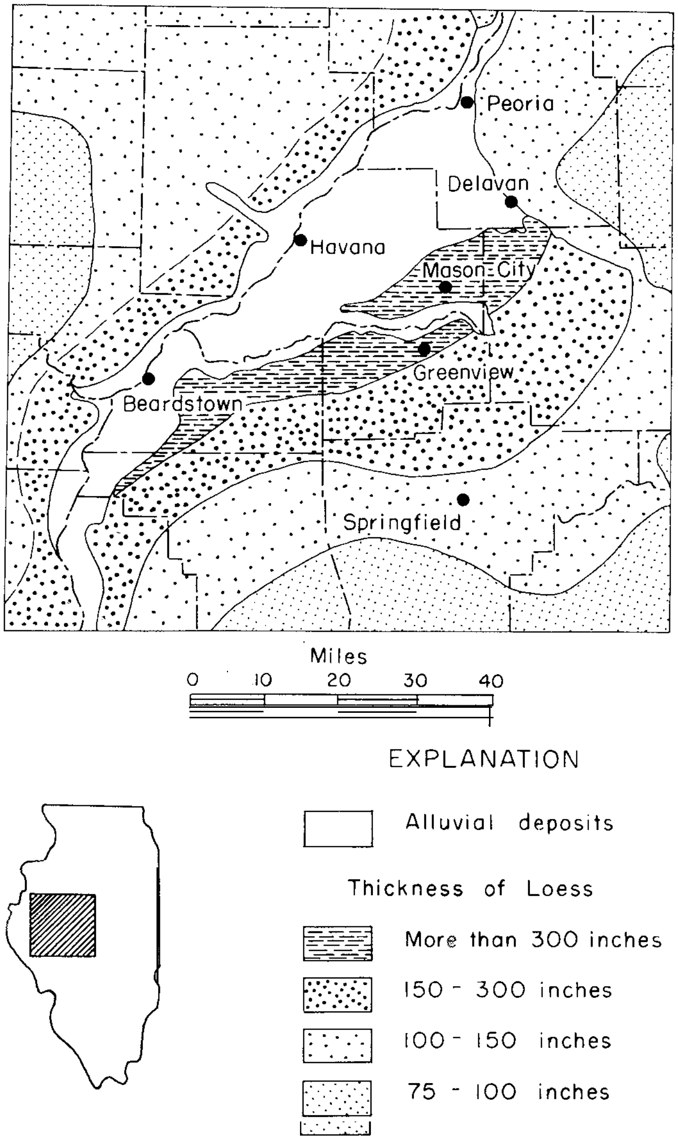


Fig. 19. Thickness of loess on uneroded topography. (After Smith, 1942, fig. 3.)

Recent Deposits

Recent deposits include those made under present-day conditions by running water, standing water, wind, and organisms. They occur mainly in the floodplains (fig. 12) and at the base of steep slopes. The floodplains are generally floored with clay, silt, and sand deposited by flood waters and by slope wash from the loess-covered uplands. In addition, the Illinois River floodplain contains a number of lakes in which silt and mud from floods, plant debris, and some shells have accumulated. Deposits coarser than those in the floodplains occur in stream channels. Although the rivers have low gradients and are sluggish streams under normal conditions, they flow rapidly during floods and deposit sand bars that are exposed at low-water stages.

In general, the thickness of the Recent alluvium along the Illinois River is a measure of the scouring effect of the river since the last glaciation. Deepest scouring occurs during the spring floods and in the winter when ice jams cause the river to deepen its channel to pass beneath the ice. The effect of scour, in combination with channel migration, has been to produce an upper blanket of Recent alluvium that coarsens with depth as a result of successive periods of scour and deposition, with the coarsest particles settling out first. The uppermost portion of the alluvium contains only fine-grained material; its thickness is increased at the surface by deposition of silt and clay from flood waters that cover the area after the river channel has migrated to a new position.

As suggested in figures 13 and 14, the floodplain of the Illinois River from Havana to Kingston Mines and from Frederick to north of Browning is underlain by less than 50 feet of unconsolidated deposits. The deposits beneath and west of the river in these stretches are mainly Recent alluvium. Between Browning and Havana the alluvium is underlain by glacial outwash.

GROUND WATER

Source, Movement, and Occurrence

The general principles underlying the source, movement, and occurrence of ground water have been presented in papers by Meinzer (1923, 1932, and 1942), and Wenzel (1942), among many others. The following discussion is a brief outline of those general principles that are essential to an understanding of ground-water conditions in the Havana region.

Ground water is derived from precipitation that falls mainly as rainfall and seeps into the ground. The water infiltrates through loose particles of the soil and percolates downward. Below a certain depth all openings in the earth materials are filled with water. *Ground water* is defined as water in the zone of saturation. The process of addition of water to the ground-water reservoir is called *recharge.*

Openings in which ground water is stored in the zone of saturation range in size from tiny pores between particles of clay and silt to large crevices in dolomite and limestone. The *porosity* of an earth material refers to its pore space and is expressed quantitatively as the percentage of its total volume.

Earth materials that have interconnected openings large enough to store and transmit water readily into a well or spring are called *aquifers.* The capacity of an earth material to transmit water under pressure is called its *permeability.*

The upper limit of the saturated zone is called the *water table.* The water immediately below the water table is unconfined and can rise or fall freely as water is added or withdrawn. In wells that penetrate the saturated zone under such conditions, the water level indicates the elevation of the water table; such wells are called *water-table wells.*

Under natural conditions, the water table roughly parallels the surface topography, rising under the uplands and intersecting the ground surface along perennial streams, lakes, and swamps into which ground water is discharged by gravity flow from adjacent areas where the water table is higher. The position and shape of the water table may be modified by the kind of rocks present or by other factors affecting permeability. The position of the water table and the discharge of ground water to streams fluctuate from season to season and year to year.

If a permeable water-bearing formation, or aquifer, is confined between nonpermeable beds and water is supplied to it from a higher elevation, the water is confined under hydraulic pressure. When such an aquifer is penetrated by a well, water will rise above the aquifer in the well to a height equal to the hydraulic head of the aquifer. Ground water that is confined under pressure in this manner is said to be under *artesian conditions.* Wells penetrating such aquifers are called *artesian wells.* If the hydraulic head is above land surface at the well, the well will flow.

To supply a producing well, ground water must move through the aquifers toward the well. Under water-table conditions, pumping lowers the water table in the vicinity of the well and induces the flow of ground water toward the well from adjacent areas. Under artesian conditions, pumping causes, in the vicinity of the well, a reduction of hydrostatic pressure that induces the flow of ground water toward the well. The aquifer under artesian conditions is not dewatered but remains full because the discharged water is derived by the compaction of the aquifer and associated beds, by the expansion of the confined water, and by flow from the recharge area. The compaction of the aquifer and associated beds and expansion of confined water constitute the storage factor of an artesian aquifer.

The depression of the water table, or the reduction of artesian pressure, that results from pumping takes the form of an inverted cone with the well at the center, and is called the *cone of depression.*

The measurement of the elevation of the water level or artesian pressure surface is made by determining the water levels in wells. Two types of water levels are recognized: nonpumping levels and pumping levels.

The *nonpumping level* is the level at which the water stands in a well not influenced by pumping in the immediate vicinity of the well. The level may change over long periods of time, and it also may be affected by regional pumpage and changes in barometric pressure. It is of great importance in evaluating the water resources of a region.

The *pumping level* is the level to which the water surface falls in a well during pumping. This level depends on rate and duration of pumping, permeability and thickness of the aquifer, and well characteristics.

The difference between the nonpumping level and the pumping level in a well is called *drawdown.* The drawdown is a temporary lowering of the water level due to pumpage in the well. When the pump is stopped, the water level rises. This rise in the water level is called *recovery.* The yield of a well in gallons per minute per foot of drawdown is the *specific capacity.*

A continued lowering of the nonpumping level of a region is called a water-level *decline.* Decline of water level is usually caused by excessive pumpage, diversion of recharge, or drought.

Water-Level Fluctuations

Water levels in wells are almost constantly fluctuating and decline or rise a fraction of an inch or many feet within a relatively short time. Water levels in wells in artesian aquifers generally fluctuate to a much greater extent than water levels in water-table aquifers and are sensitive to such factors as changes in atmospheric pressure, earthquakes, earth tides, and changes in surface loading. Artesian wells also are influenced by with-

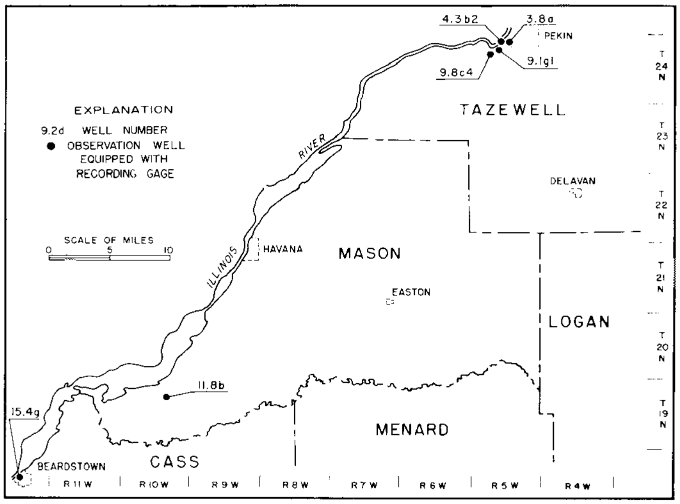


Fig. 20. Location of observation wells equipped with recording gages.

drawals from wells and springs and by recharge from precipitation, although the effects of recharge are sometimes not immediately noticeable.

Water levels in water-table aquifers are affected by direct recharge from precipitation, evapotranspiration, withdrawals from wells, discharge to streams, and changes in surface-water stage. Fluctuations in water levels indicate changes in the actual quantity of water stored in aquifers and movement of ground water. The amount of water taken from or added to storage per unit change in water levels is generally many times larger under water-table conditions than under artesian conditions.

The water table in the Havana region under natural conditions recedes in late spring, summer, and early fall, when discharge by evapotranspiration and by groundwater runoff to streams is greater than recharge from precipitation. Water levels begin to recover in wells late in the fall, when evapotranspiration losses are small and conditions are favorable for the infiltration of rainfall, first to replenish depleted soil moisture and later to percolate to the water table. The rise of water levels is especially pronounced in the wet spring months, when the ground-water reservoir receives most of its annual recharge. The high and low points of the annual cycle of water levels occur at different times from year to year, depending in large part upon the seasonal and areal distribution and intensity of rainfall.

Superimposed on the annual cycle are changes in water levels caused by pumping. Pumping lowers water levels in the vicinity of the well until (1) a hydraulic gradient is established from a source of recharge to the pumped well sufficient to bring from the recharge area the amount of water being pumped, (2) sufficient water is diverted from an area of discharge to balance pumpage, or (3) a combination of increased recharge and diverted discharge balances the pumpage.

To determine the character and magnitude of water-level fluctuations, recording gages were maintained for a number of years on two wells in the southern part of the Havana region and on four wells in the northern part (fig. 20). Descriptions of these wells are given in table 2. Monthly water levels in wells CSS 18N12W-15.4g and MSN 19N10W-11.8b in the southern part for 1957 through 1960 are shown in figure 21; daily water

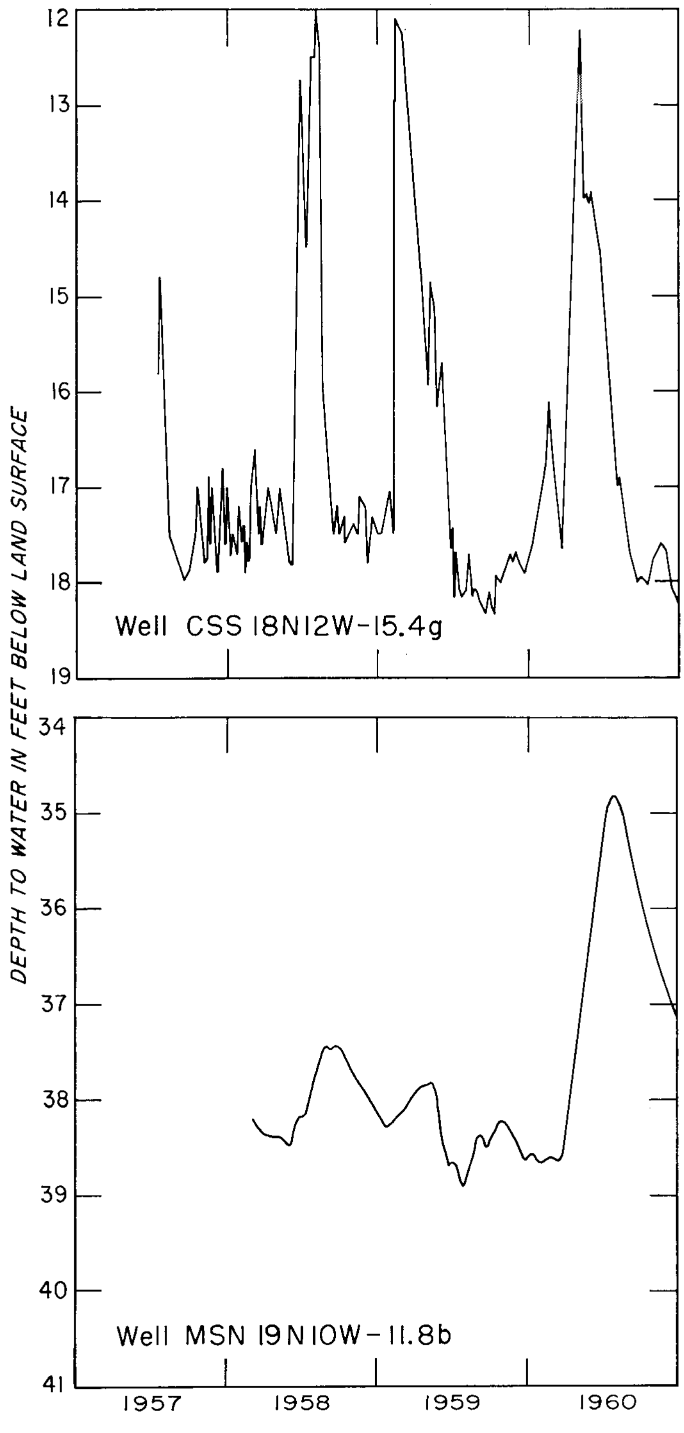


Fig. 21. Water levels in wells in the southern part of the region, 1957-1960.

levels for these wells and Illinois River stages at Beardstown during 1958, 1959, and 1960 are shown in figure 22. Monthly water levels in wells TAZ 24N5W-4.3b2, -3.8a, -9.1g1, and -9.8c4 in the northern part of the region for 1943 through 1961 are shown in figure 23; daily water levels in these four wells and Illinois River stages at Pekin during 1960 are shown in figure 24. The water levels shown are nonpumping water levels.

The close correlation between ground-water levels and Illinois River stages is apparent from the data for well CSS 18N12W-15.4g (fig. 22). The well is about 50 feet from the river's edge at the city of Beardstown. Except during periods of high river stage, water levels in the well are above the surface of the river and there is discharge of ground water into the river. Well MSN 19N10W-11.8b is much farther from the river (about 2 miles) and is little affected by changes in the river stage (fig. 22). Water levels in this well reflect, for the most part, seasonal variations in recharge directly from precipitation. During most years water levels in well MSN 19N10W-11.8b fluctuate less than 2 feet.

As shown by the hydrograph of well TAZ 24N5W-9.1g1 (fig. 24), water levels in the pumping center south of Pekin decline rapidly during each 5-day work week and recover during weekend industrial shut-downs. Superimposed on these weekly cycles are changes in water levels caused by daily purmpage cycles. In general, there is a close correlation between major river stage changes and water-level fluctuations in the heavily pumped area. Water levels in wells TAZ 24N5W-4.3b2 and TAZ 24N5W-9.1g1 are below the surface of the river at all times, whereas water levels in wells TAZ 24N5W-9.8c4 and TAZ 24N5W-3.8a are at times above the surface of the river. Hydrographs (fig. 24) and water-level

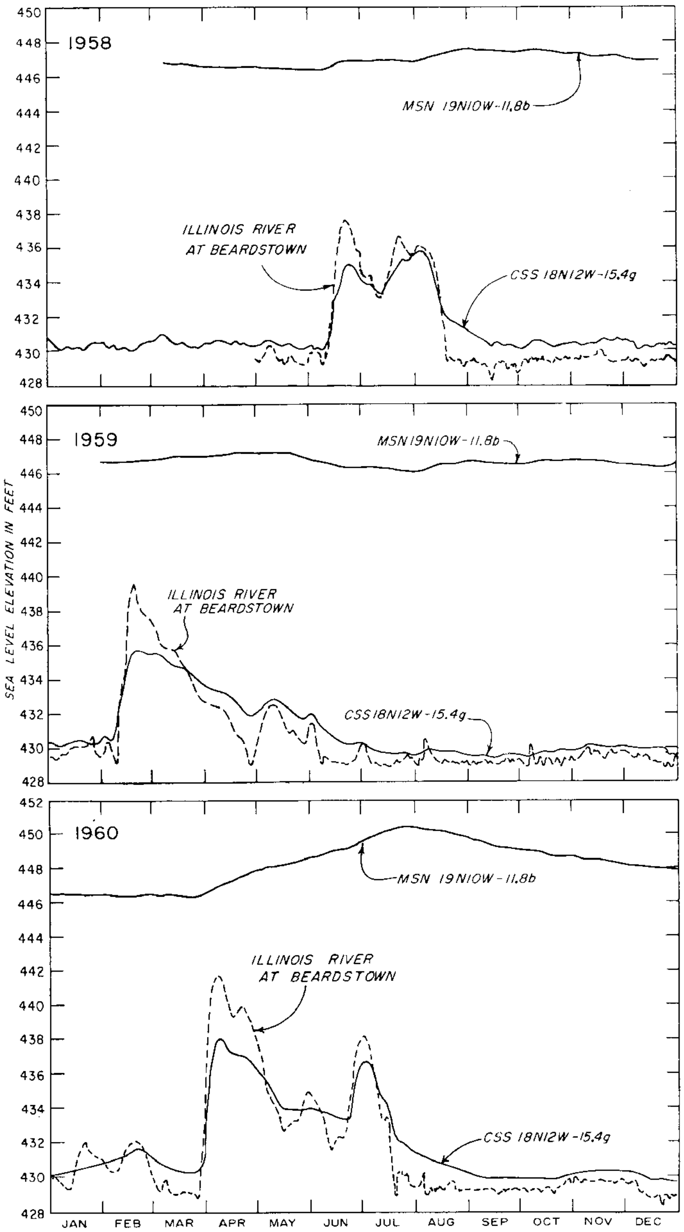
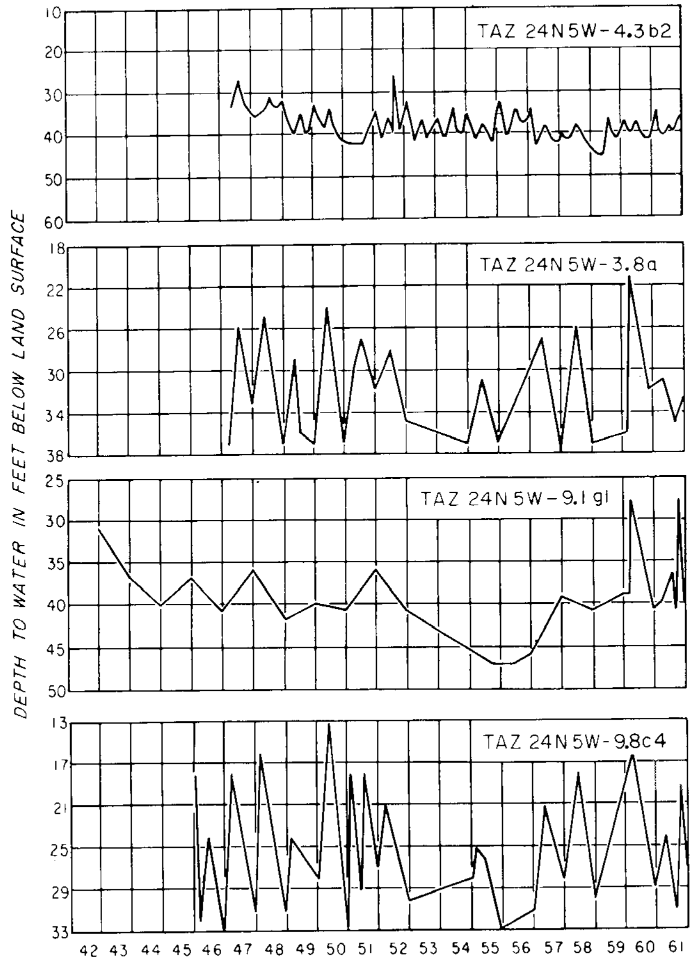


Fig. 22. Water levels in wells in the southern part of the region and Illinois River stages at Beardstown, 1958-1960.



Fig, 23. Water levels in wells in the northern part of the region, 1943-1961.

Table 2. Descriptions of Selected Observation Wells

Well number	Owner	Well		Screened interval
		Depth (ft)	Diameter (in)	(ft below land surface)
CSS 18N12W-15.4g	U.S. Corps of Engineers	74	12	64-74
MSN 19N10W-11.8b	Harold Banks	40	42	Open end
TAZ 24N5W-3.8a	Corn Products Refining Co.	83	26	63-83
TAZ 24N5W-4.3b2.	American Distilling Co.	85	24	65-85
TAZ 24N5W9.1g1	Standard Brands, Inc.	76	25	51-76
TAZ 24N5W-9.8c4	Commonwealth Edison Co.	65	24	25-65

contours (figs. 25 and 26) suggest that ground water withdrawn from the pumping center consists partly of water that under natural conditions would have discharged into the river and partly of water induced to flow from the river into the cone of depression. Water levels in the pumping center (figs. 23 and 24) fluctuate more than 15 feet during the year; however, there is no continuous long-term decline, suggesting that in the past recharge has balanced discharge.

Configuration of the Water Table

Figure 25, prepared from data (table A, appendix) collected in 103 observation wells, shows contours on the water table in the Havana region in 1960. Figure 13 shows geologic cross sections and profiles of the water table. The water-table contours indicate the configuration of the water table, areas of recharge and discharge of ground water to streams, and the direction of ground-water movement. A study of the location of pumping centers and figure 25 suggests that, with the exception of the area immediately south of Pekin, contours have not been distorted to any great degree by pumping. In most of the region, present pumpage has not appreciably affected the water table.

The water table conforms generally to the configuration of the land surface. Its slope is greatest in the vicinity of parts of the Illinois River where the glacial materials are thin and is least at places where the glacial materials are thick and very permeable. Ground water moves, in general, from uplands in the east towards the Illinois River. The water table slopes from an elevation of about 540 feet east of Delavan to about 440 feet along the Illinois River. The average slope is about 3.5 feet per mile.

Ground water locally moves in all directions toward small streams and drainage ditches and to the Mackinaw, Sangamon, and Illinois Rivers. Contours warp upstream, indicating discharge of ground water to these streams.

The contour maps in figure 26, prepared from data (table A, appendix) collected in 40 observation wells, show elevations of the water table in the pumping center south of Pekin in May and August, 1962. The illustration shows clearly the cones of depression in the water table that have developed as the result of heavy pumping. Pronounced cones are centered at the well fields of industries in the area. A ground-water mound appears in the vicinity of a recharge pit near the center of the area. The 440 and 435 water-table contours bend irregularly around intake and discharge canals and roughly parallel the river's edge.

Storage

The amount of water in storage in the aquifers in the Havana region is determined by the areal extent of the aquifers, their saturated thicknesses, and their porosity. A portion of the stored water is free to drain by gravity; the remainder is retained in the pores of the aquifers by

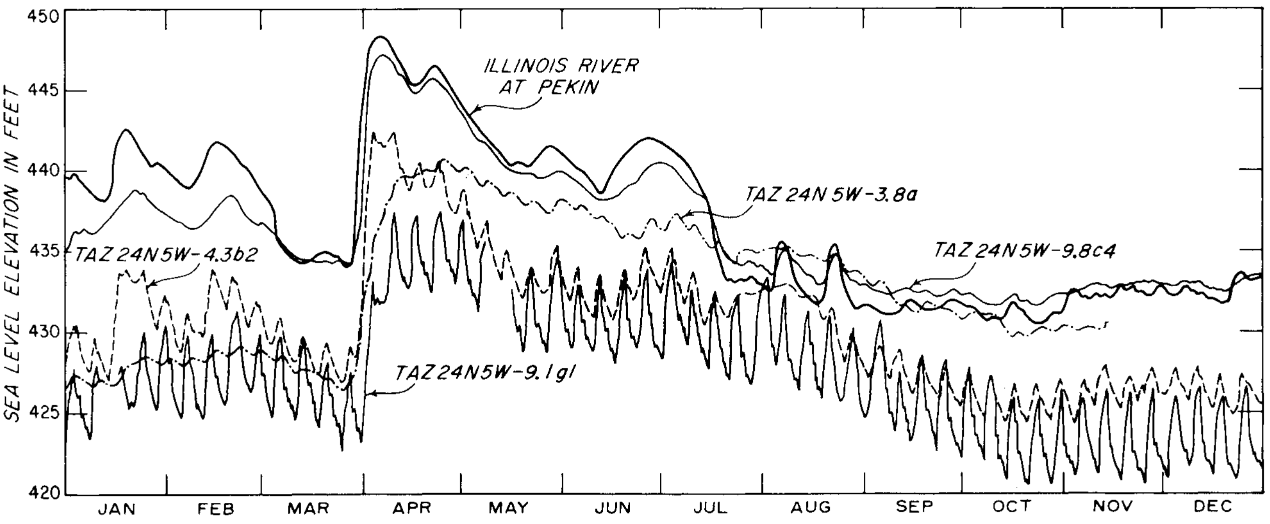


Fig. 24. Water levels in wells in the northern part of the region and Illinois River stages at Pekin in 1960.

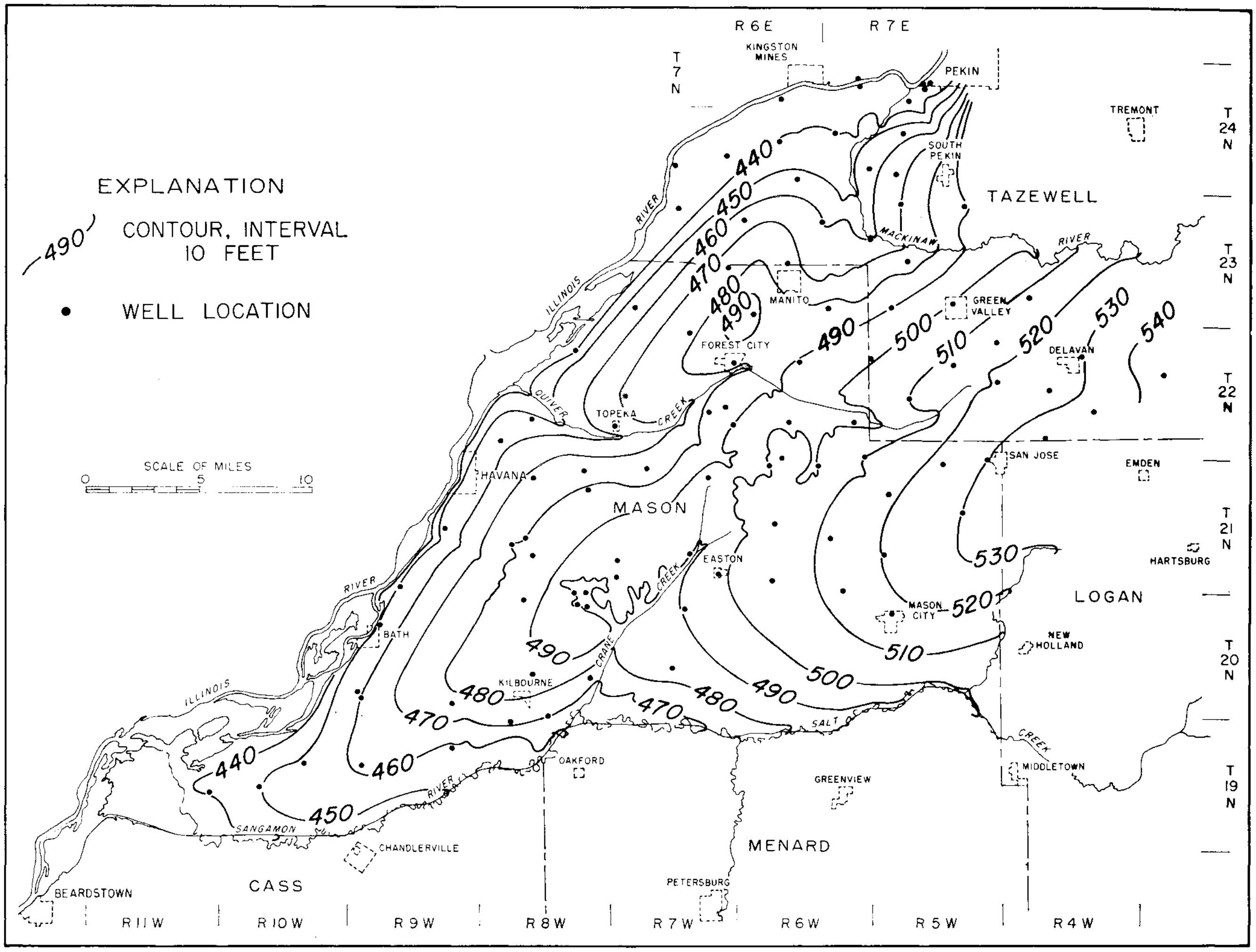


Fig. 25. Approximate elevation of the water table in the Havana region in 1960.

molecular attraction. However, not all the water that is free to drain by gravity can be practically withdrawn through wells.

A map (fig. 27) showing the saturated thickness of the unconsolidated deposits in 1960 was prepared from the water-table and bedrock-surface contour maps. The total volume of saturated unconsolidated deposits in the region was computed to be about 2.75 X 10^{12} cubic feet. The saturated thickness is greatest (170 feet or more) in the channel of the buried valley south of Delavan, north of Mason City, at Forest City, and east of Havana. It exceeds 100 feet in most of the region and is less than 60 feet at places in the vicinity of the Illinois River. The unconsolidated deposits are comparatively thin above bedrock terraces adjacent to valley walls.

The deposits underlying the Wisconsinan terraces (fig. 12) are essentially sand and gravel from surface to bedrock. Porosities of the cleaner portions probably range from 30 to 40 percent. The deposits underlying the Illinoian and Wisconsinan uplands, roughly east of Easton, Delavan, and Green Valley, consist of silts, tills, and sands and gravels, with about half of the section sand and gravel (fig. 13). Porosities of the finer sediments probably exceed those of the sands and gravels.

The average porosity of all unconsolidated deposits is estimated to be about 35 percent. The quantity of water in storage, therefore, is about 7.2 X 10^{12} gallons. From a study of the water-yielding properties of the aquifers in the region and of the values of specific yield determined for a comparable area of sand and gravel and associated sediments at Louisville, Kentucky (Stuart, 1944), the average specific yield of all unconsolidated deposits is estimated to be 20 percent. If the average specific yield of the aquifers is 20 percent, about 4.1 x 10^{12} gallons of water could be made available from storage in the region by completely dewatering the unconsolidated deposits. The complete dewatering of the aquifers is impractical, however, for the yields of wells fall off rapidly as the saturated thickness of the aquifer is greatly reduced.

Hydraulic Properties of Aquifers

The yields of wells, quantity of water moving through an aquifer, and the magnitude of water-level fluctuations due to recharge and discharge of ground water are largely dependent on the hydraulic properties of an aquifer. The principal hydraulic properties of an aquifer are the coefficients of transmissibility, T, or permeability, P, and storage, S.

The capacity of a formation to transmit ground water is expressed by the *coefficient of transmissibility,* 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 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,* 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 released from or taken into storage per unit surface area of the aquifer per unit change in the water level. Under water-table conditions, the coefficient of storage is equal to the specific yield, provided gravity drainage is complete.

The manner in which T and S are related to water-level decline and the yields of wells can best be illustrated by a discussion of the cone of depression. The shape of the cone is controlled in part by the permeability of the aquifer. With other factors remaining constant, the lower the permeability, the steeper will be the gradient of the cone of depression and the greater will be the drawdown in a well.

During the initial period of pumping, discharge is balanced by water taken from storage within the aquifer close to the well. As pumping continues, a larger percentage of water is taken from storage at greater distances from the well. The larger the coefficient of storage, the smaller the water-level decline required to obtain from storage the amount of water being pumped.

With continuous pumping, the cone of depression grows in size and depth at a diminishing rate until hydraulic gradients are established sufficient to capture enough recharge to balance the amount of water pumped. Provided the aquifer is infinite in areal extent, the dimensions of the cone of depression depend upon the hydraulic properties of the aquifer, the pumping rate, and the pumping period. Water-level decline is directly proportional to the pumping rate and diminishes in a logarithmic manner outward from the well. In a multiple-well system the cones of individual wells overlap and there is mutual interference between wells. The amount of interference depends in part on the hydraulic properties of the aquifer and is directly proportional to pumping rates and inversely proportional to the logarithm of the distances between wells.

Aquifer tests

The hydraulic properties of an aquifer 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 after pumping started, and/or of drawdown versus distance from the pumped well, are used to solve equations that express the relation between the coefficients of transmissibility and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well.

The nonequilibrium formula (Theis, 1935) is the equation most commonly used to determine hydraulic properties with aquifer-test data. The nonequilibrium formula is:

$$s = (114.6\, Q/T)\, W(u) \qquad (1)$$

where:

$$W(u) = \int_u^\infty e^{-u}/u \,\mathrm{du} = -0.5772 - \mathrm{In}\ u + u - (u^2/2.2!) + (u^3/3.3!) - (u^4/4.4!) \quad . \quad . \quad .$$

and

$$u = 2693 r^2 S/Tt \qquad (2)$$

s = drawdown, in feet (ft)

Q = discharge, in gallons per minute (gpm)

T = coefficient of transmissibility in gallons per day per foot (gpd/ft)

r = distance from pumped well to observation well, in ft

S = coefficient of storage, fraction

t = time after pumping started, in minutes (min)

Methods for solving the nonequilibrium formula were described by Cooper and Jacob (1946) and Ferris (1959).

The nonequilibrium formula is based on the following assumptions: (1) that the aquifer is homogeneous and isotropic; (2) that the aquifer is infinite in areal extent and is confined between impermeable beds; (3) that the coefficient of storage is constant; and (4) that water is released from storage instantaneously with a decline in water levels. Generally none of these conditions is completely fulfilled in nature, but in many areas they are substantially satisfied.

The existence of geohydrologic boundaries serves to limit the continuity of aquifers. Geohydrologic boundaries may be divided into two types, barrier and recharge. Barrier boundaries are lines across which there is no flow, and they may consist of folds, faults, or relatively impervious deposits such as shale or clay. Recharge boundaries are lines along which there is no drawdown, and they may consist of rivers and lakes hydraulically connected to aquifers. The influence of geohydrologic

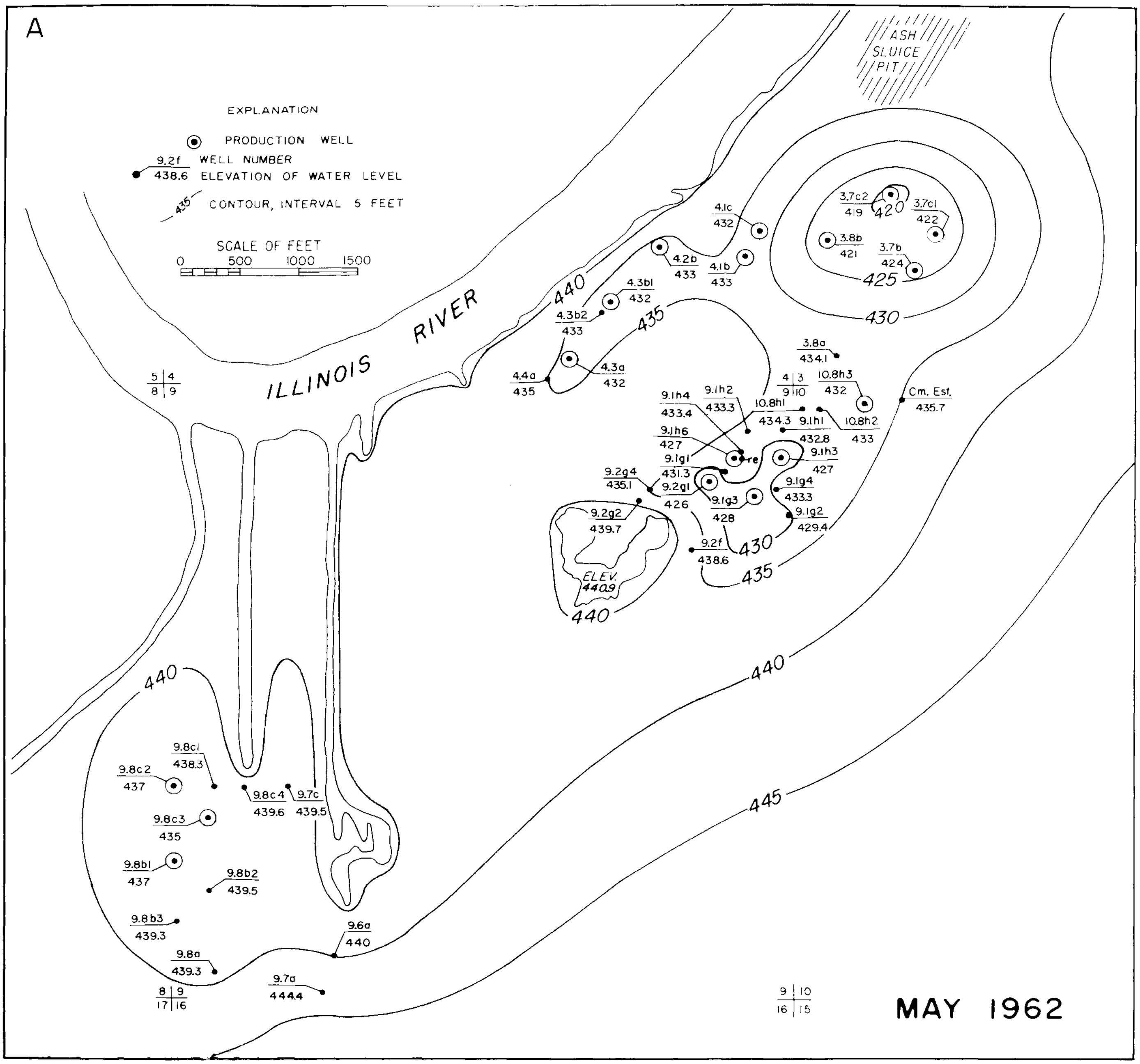


Fig. 26A. Approximate elevation of the water table in the northern part of the Havana region in May 1962.

boundaries on the response of an aquifer to pumping can be determined by means of the image well theory described by Ferris (1959).

During 1959 and 1960, six aquifer tests (fig. 28) were made by the State Water Survey in the Havana region to determine the hydraulic properties of the unconsolidated deposits. To illustrate methods of analysis, data for three aquifer tests are given in figures 29 through 32.

A summary of the coefficients of transmissibility and storage obtained from aquifer tests is given in table 3. These data indicate a considerable range in hydraulic properties from place to place within the region. In the northern part of the region, the coefficient of permeability ranges from 7500 to 15,000 gpd/sq ft and the coefficient of transmissibility ranges from 150,000 to 500,000 gpd/ft. In eastern parts of the region, the coefficient of permeability ranges from 2000 to 2500 gpd/sq ft and the coefficient of transmissibility ranges from 200,000 to 275,000 gpd/ft. In western parts of the region, the coefficient of permeability ranges from 4000

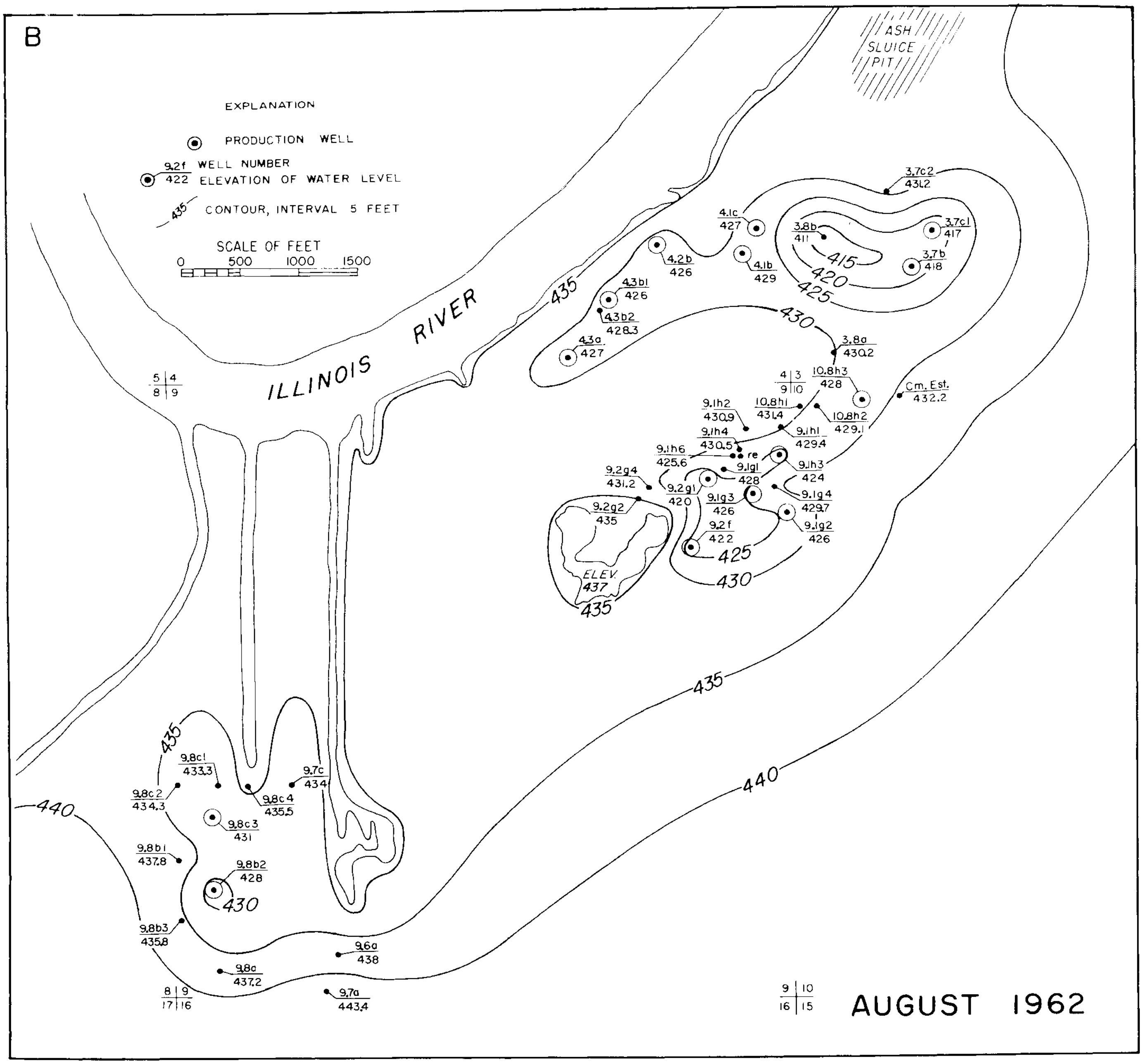


Fig. 26B. Approximate elevation of the water table in the northern part of the Havana region in August 1962.

to 8900 gpd/sq ft and the coefficient of transmissibility ranges from 560,000 to 1,250,000 gpd/ft. Most coefficients of storage are in the artesian or leaky artesian range. The coefficients of storage were computed from the results of relatively short-term tests. Longer pumping tests would give larger coefficients of storage as gravity drainage of interstices occurs. For periods of pumping involving several months or more, a coefficient of 0.10 is more realistic than the determined values and is used in this report.

Well-production tests

During the period 1930 to 1962, well-production tests were made by drillers, well owners, and the State Water Survey on 30 wells in the region. The well-production 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; rates of pumping were usually measured by means of a circular orifice at the end of the pump discharge pipe.

Table 3. Results of Aquifer and Well-Production Tests

Well number	Dept *(ft)*	Diameter *(in)*	Length of screen *(ft)*	Year of test	Length of test *(min)*	Pumping rate *(gpm)*	Draw-down *(ft)*	Method of analysis*	Observed specific capacity *(gpm/ft)*	Adjusted specific capacity *(gpm/ft)*	Saturated thickness of aquifer *(ft)*	Coefficient of transmissibility *(gpd/ft)*	Coefficient of permeability *(gpm/ft²)*	Coefficient of storage
CSS—														
18N12W-14.8h	89	36-16	20	1959	1-250	1000	....	T-D	....	....	80	600,000	7500	0.0003
					250	1000	16.7	SC	60	295	80	600,000	7500	....
18N12W-15.2f	86	48-16	25	1956	150	600	3.7	SC	162	305	84	600,000	7200	....
19N9W-31.7b2	32	36-16	16	1936	1440	154	7.9	SC	20	111	90	220,000	2500	....
MSN—														
21N6W-4.3g	102	36 16	20	1961	270	700	12.0	SC	58	410	160	820,000	5100	....
21N7W-5.7f	128	36-16	40	1962	270	1480	12.3	SC	120	470	170	950,000	5600	....
21N7W-15.7f	112	36-16	52	1962	360	650	3.7	SC	175	482	150	1,000,000	6700	....
21N7W-25.6a	150	6	10	1960	1-60	60	....	T-D	....	....	125	275,000	2200	0.0007
21N7W-25.7a	135	8	15	1960	424	60	1.97	SC	30.5	147	125	310,000	2500	....
21N8W-28.1g	122	36-16	56	1959	180	1000	4.3	SC	230	400	165	820,000	5000	....
21N8W-36.7b	106	36-16	40	1960	180	1150	10.0	SC	115	450	170	850,000	5000	....
22N6W-33.7b	105	36-16	28	1960	120	750	6.3	SC	118	630	165	1,250,000	7600	....
22N7W-23.2d	80	36-16	44	1959	180	1735	12.0	SC	144	307	140	560,000	4000	....
22N7W-24.4e	108	36-16	40	1960	180	150	10.0	SC	115	423	160	800,000	5000	....
22N7W-27.2c	125	36-16	40	1961	180	1200	12.2	SC	99	382	170	720,000	4200	....
22N7W-33.8h	136	6	10	1940	60	210	23.0	SC	9.1	344	155	640,000	4100	....
22N7W-34.6c	127	36-16	40	1961	240	1225	13.0	SC	95	367	170	700,000	4100	....
23N6W-21.3d	81	10	20	1937	60	120	2.0	SC	60	375	90	800,000	8900	....
TAZ—														
22N4W-16.8a	213	42-18	80	1960	1-360	2250	....	T-D	....	....	168	275,000	1640	0.0024
					540	2250	23.0	SC	98	157	150	310,000	2000	....
22N4W-16.8bl	212	6	15	1960	350	200	11.1	SC	18	152	166	360,000	2100	....
22N4W-16.8b2	209	46-16	80	1960	360	2250	25.0	SC	90	165	168	330,000	2000	....
23N5W-26.8al	115	8	8	1948	60	150	13.4	SC	11.2	104	95	200,000	2200	....
24N5W-9.8b2	99	38-26	20	1930	30	1000	6.7	SC	148	167	33	300,000	9000	....
24N5W-9.8b6	67	2	38	1930	1-60	1000	....	T-D	....	....	33	240,000	7300	0.01
24N5W-9.8bl	59	38-25	30	1944	60	2000	14.0	SC	143	163	31	330,000	10000	....
24N5W-9.1g2	88	48-30	20	1950	465	1016	9.0	SC	113	210	44	420,000	9500	....
PEO—														
7N7E-28.6el	67	8	15	1959	0	430	2.8	SC	150	270	33	500,000	15000	....
7N7E-28.6e2	64	1.25	3	1959	1-10	430	....	T-D	....	....	33	500,000	15000	0.0002
7N7E-28.6e2	64	1.25	3	1959	1100	430	....	D-D	....	....				....
7N7E-28.7e	64	1.25	3	1959	1100	430	....	D-D	....	....	33	500,000	15000	....
7N7E-28.8d	64	1.25	3	1959	1100	430	....	D-D	....	....				....
7N7E-29.2dl	73	16	20	1960	2	985	18.4	SC	53.5	95	20	150,000	7500	....
					1-500	985	....	T-D	....	....	20	180,000	9000	....
7N7E-29.2d2	73	6	6	1960	1	985	....	D-D	....	....	20	182,000	9100	0.0002
7N7E-29.2d3	72	6	6	1960	3990	985	....	D-D	....	....	20	180,000	9000	....
7N7E-29.1d	75	6	6	1960	....	....	....	....	....	....	....	....	....	....

* T-D = time-drawdown; SC == specific capacity; D-D = distance-drawdown.

Drawdown data were adjusted for the effects of partial penetration which methods described by Butler (1957), the values he gave (table 4), and the following equation:

$$s = C_{pp}\, s_{pp} \qquad (3)$$

where:

s = drawdown for fully penetrating conditions, in ft
C_{pp} = partial penetration constant from table 4
s_{pp} = observed drawdown under partial penetration conditions, in ft

Drawdown data were further adjusted for well loss, which is the head loss or drawdown in the pumped well due to the turbulent flow of water as it enters the well itself and flows upward through the bore hole. Well loss may be represented approximately by the following relationship (Jacob, 1946) :

$$s_w = CQ^2 \qquad (4)$$

where:

s_w = well loss, in ft
C = well-loss constant, in sec^2/ft^5
Q = rate of pumping in cubic feet per second (cfs)

In wells having appreciable well loss, the specific capacity decreases with an increase in the pumping rate. The value of C in equation 4 may be estimated from the

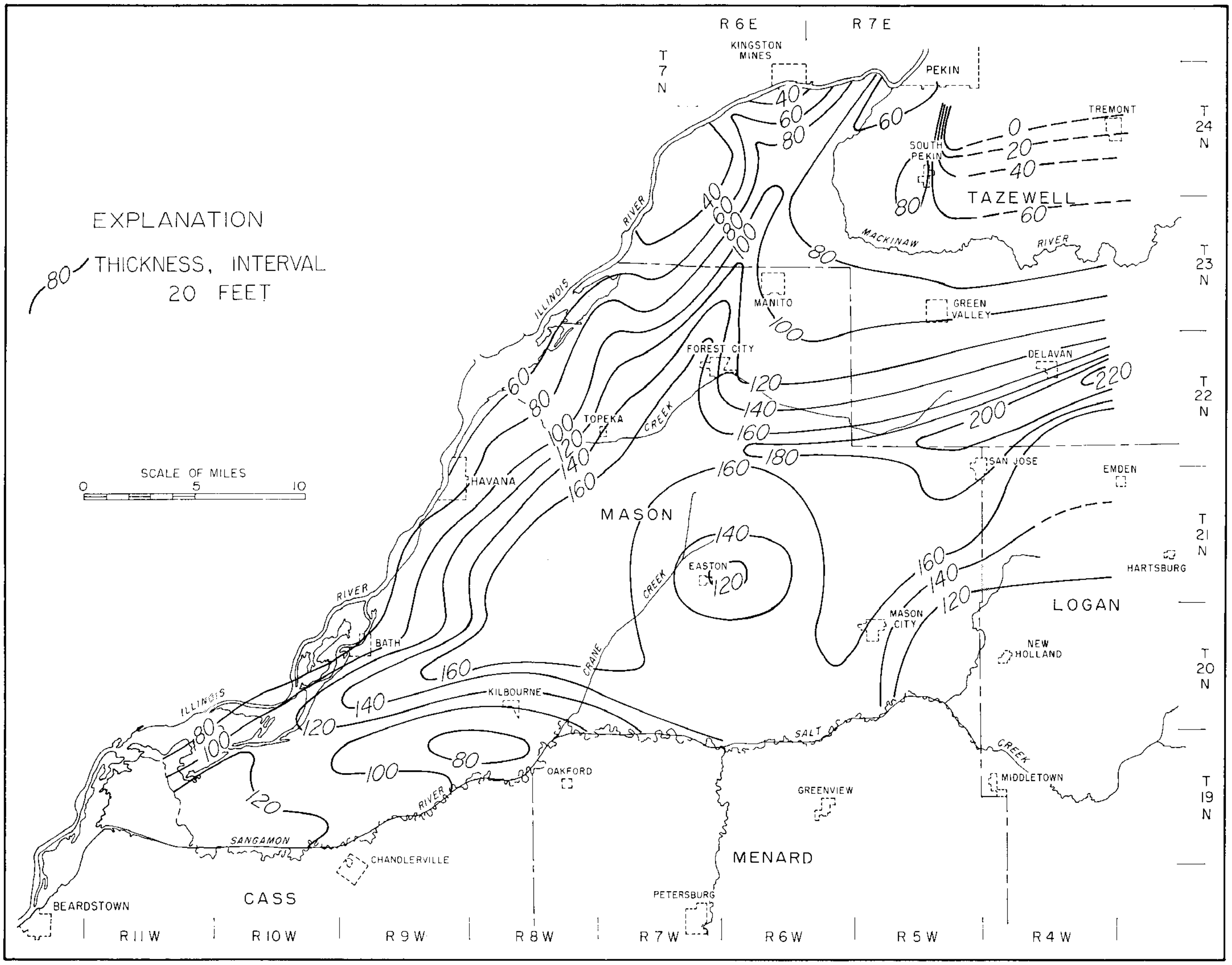


Fig. 27. Saturated thickness of unconsolidated deposits in 1960.

data collected during a "step-drawdown" test by using the equations given below (Jacob, 1946). During a step-drawdown test the well is operated during three successive periods of 1 hour at constant fractions of full capacity.

For steps 1 and 2

$$C = \frac{(\Delta s_2/\Delta Q_2) - (\Delta s_1/\Delta Q_1)}{\Delta Q_1 + \Delta Q_2} \qquad (5)$$

For steps 2 and 3

$$C = \frac{(\Delta s_3/\Delta Q_3) - (\Delta s_2/\Delta Q_2)}{\Delta Q_2 + \Delta Q_3} \qquad (6)$$

where:

The Δs terms represent increments of drawdown produced by each increase (ΔQ) in the rate of pumping. The commonly used dimensions of Δs and ΔQ are feet and cfs, respectively.

Step-drawdown tests were made on several wells in the region. Data collected during these tests were substituted into equations 5 and 6 to determine well-loss constants. Computed values of C are given in table 5.

Table 4. Values of Partial Penetration Constant for Pumped Well

	a*			
	0.2	0.3	0.5	0.7
$(rw/m)\sqrt{Pv/Ph}$ *	Values of Cpp			
0.0000	0.200	0.300	0.500	0.700
0.0001	0.221	0.324	0.525	0.719
0.0003	0.236	0.342	0.543	0.732
0.0010	0.266	0.376	0.578	0.759
0.002	0.294	0.408	0.611	0.783
0.003	0.315	0.432	0.636	0.803
0.006	0.363	0.487	0.692	0.846
0.010	0.410	0.541	0.748	0.888

* rw = nominal radius of well, in ft; m = saturated thickness of aquifer, in ft; a = fractional penetration, length of screen divided by saturated thickness of aquifer; Ph = horizontal permeability of aquifer, in gpd/sq ft; and Pv = vertical permeability of aquifer, in gpd/sq ft.

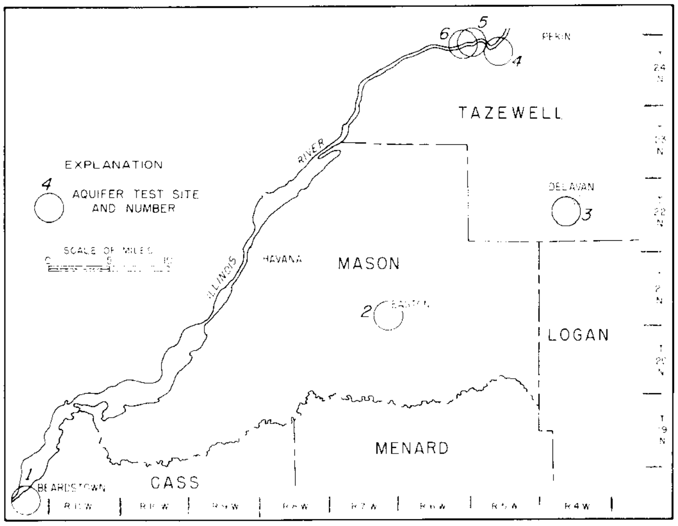


Fig. 28. Location of aquifer test sites.

Values of well loss were estimated, for all wells for which well-production data are available, on the basis of results of the step-drawdown tests, well-construction data, pumping-rate data, and equation 4.

The average coefficient of storage, 0.0004, computed from aquifer-test data and several values of pumping period, *t,* and radius of a well, r_w, were substituted into the following equation (Walton, 1962) to determine the theoretical relationship between specific capacity and the coefficient of transmissibility for various values of r_w^2/t.

$$Q/s = T/\,[264 \log\,(Tt/2693 r_w^2 S) - 65.5] \qquad (7)$$

where:

Q/s = specific capacity, yield of the well in gpm/ft
T = coefficient of transmissibility, in gpd/ft
S = coefficient of storage, fraction
r_w = nominal radius of well, in ft
t = time after pumping started, in min

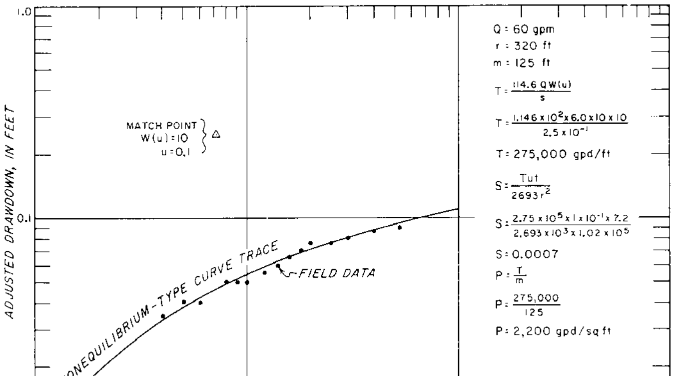


Fig. 29. Time-recovery for well MSN 21N7W-25.6a at Easton.

Table 5. Computed Well-Loss Constants

Well number	Average *C* (sec^2/ft^5)	Well number	Average *C* (sec^2/ft^5)
CSS 18N12W-14.8h	1.7	TAZ 22N4W-16.8b2	0.2
CSS 18N12W-15.2f	0.3	TAZ 23N5W-26.8a1	43.5
MSN 21N7W-25.7a	0.4	TAZ 24N5W-9.8b5	0.1
MSN 22N7W-33.8h	79.0	TAZ 24N5W-9.8b1	0.2
MSN 23N6W-21.3d	16.0	TAZ 24N5W-9.1g2	0.8
TAZ 22N4W-16.8a	0.2	PEO 7N7E-28.6e1	1.4
TAZ 22N4W-16.8b1	10.1	PEO 7N7E-29.2d1	1.6

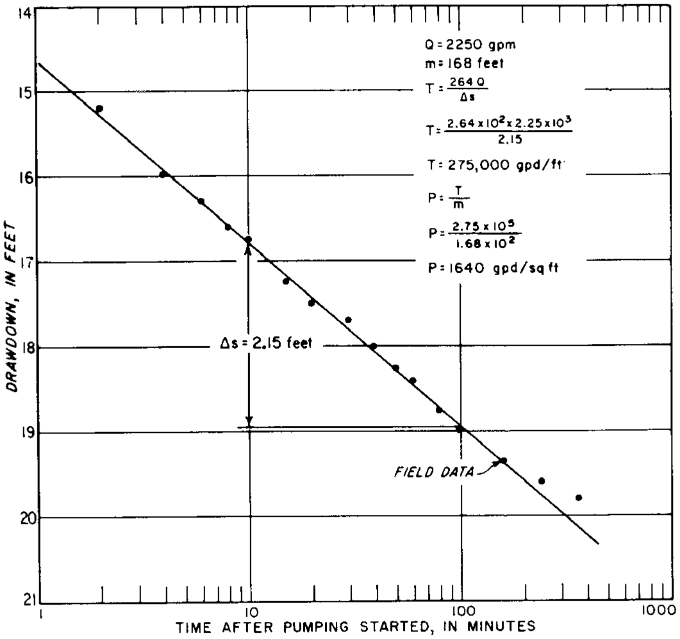


Fig. 30. Time-drawdown for well TAZ 22N4W-16.8a near Delavan.

Figure 33 shows the relationship between specific capacity and the coefficient of transmissibility for several values of r_w^2/t. This graph, specific capacities adjusted for the effects of partial penetration and well loss, and data concerning the lengths of tests and radii of wells were used to estimate coefficients of transmissibility. Coefficients of transmissibility estimated with well-production data are given in table 3.

The results of aquifer and well-production tests and available geohydrologic data were used to delineate areas of high (area 1) and relatively low (area 2) permeabilities (fig. 34). Area 1 is approximately the belt of coarse Wisconsinan outwash, underlain by thick Sankoty Sand, paralleling the river. Area 2 is a belt containing the margins of Wisconsinan outwash, Wisconsinan and Illinoian upland, and underlying Sankoty and Mahomet Sands. Within area 1 the average coefficient of permeability of the sand and gravel deposits ranges from 15,000 gpd/sq ft in the northern part of the region, where very coarse deposits were laid down in the narrow gorge, to about 4000 gpd/sq ft in the wide

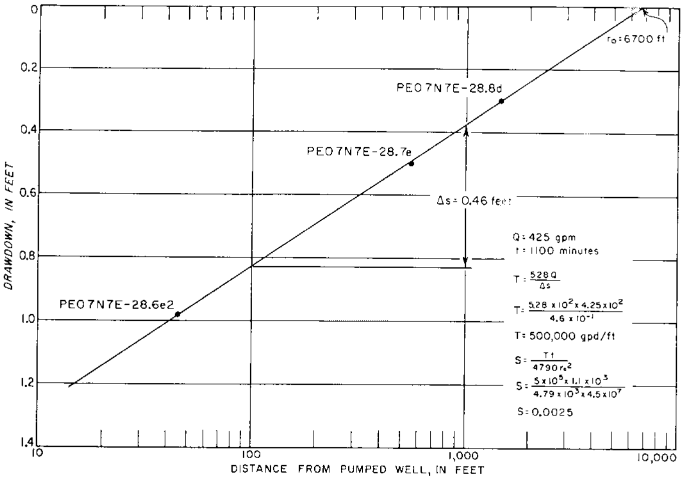


Fig. 31. Distance-drawdown for aquifer test made near Mapleton, October 1959.

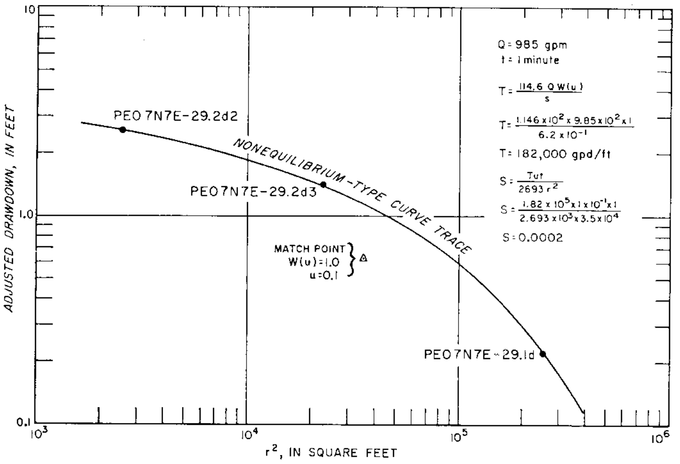


Fig. 32. Distance-drawdown for aquifer test made near Mapleton, October 1960.

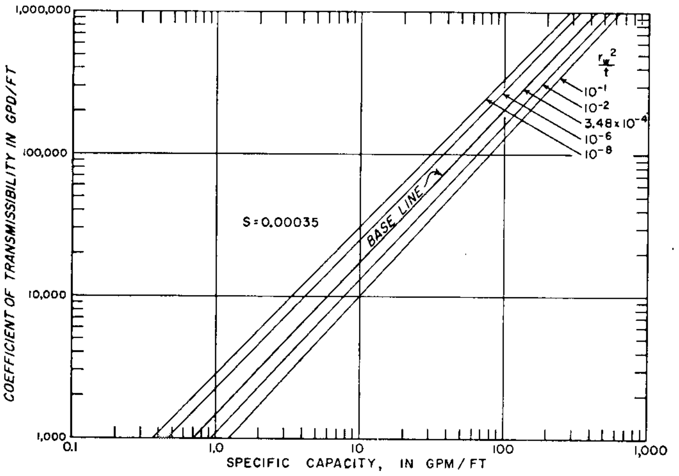


Fig. 33. Coefficient of transmissibility versus specific capacity for several values of well radius and pumping period.

central part. In area 2, the eastern part of the region, the average coefficient of permeability ranges from 2000 to 2500 gpd/sq ft. To estimate the probable coefficient of transmissibility at any site, the coefficient of permeability at the site (fig. 34) is multiplied by the saturated thickness of the aquifer at the site (fig. 27).

Theoretical Effects of Pumping

Pumping from wells in the sand and gravel deposits has a widespread effect on water levels. The nonequilibrium formula, hydraulic properties determined from the results of aquifer and well-production tests, and an estimated long-term storage coefficient were used to evaluate the magnitude of interference between wells and well fields and to compute the theoretical decline in the water table at any distance from a pumped well and after any pumping period.

Figure 35 shows the amounts of interference that will occur at distances of 100 feet to 10 miles from a well pumping continuously at 1000 gpm for periods of 90 days, 180 days, and 1 year in parts of the aquifer (areas 1 and 2 in fig. 34) with coefficients of transmissibility of 800,000 and 300,000 gpd/ft, respectively. The drawdowns given occur at equal distances from the pumped well in all directions. The values of coefficient of transmissibility used in preparing the graphs cover the general range of the hydraulic properties in the Havana region. The graphs assume that all the water pumped is withdrawn from storage and that the aquifer is infinite in areal extent.

The drawdown is appreciable several miles from the pumped well, indicating that even widely spaced wells in the sand and gravel deposits will interfere with one another. For example (fig. 35A), the drawdown at a distance of half a mile is about 0.80 feet for a pumping period of 1 year. The theoretical drawdown is directly proportional to the pumping rate. If the pumping rate is 2000 gpm instead of 1000 gpm the drawdown would be double that shown in figure 35.

Figure 36 shows the amounts of interference that will occur at any time from 0.1 to 100 years at a distance of 1000 feet from a well being pumped continuously at 1000 gpm in the parts of the aquifer (areas 1 and 2, fig. 34) with coefficients of transmissibility of 800,000 and 300,000 gpd/ft, respectively. Again an aquifer infinite in areal extent is assumed.

To show the factors governing the response of the aquifer to pumping, theoretical values of drawdown were computed for a hypothetical well system southeast of Havana.

For this example, it was assumed that two 12-inch radius wells, 180 feet deep and having 40 feet of screen, are developed on a line along State Route 97 and spaced 1000 feet apart about 1.5 miles southwest of Havana. It was assumed also that each well is pumped continuously at a rate of 1000 gpm for 1 year. The total drawdown in feet, st, at the end of the 1-year pumping period in well 1 is equal to the drawdown, s_1, due to pumping the well itself, plus the interference, s_2, due to pumping well 2, minus the buildup, s_3, due to the image wells associated with the Illinois River, or

$$s_t = s_1 + s_2 - s_3 \tag{8}$$

The drawdown, s_1, has three components: (1) the drawdown or head loss due to the laminar flow of water in the aquifer towards the well, s_a; (2) the drawdown or head loss (well loss), s_w, resulting from the turbulent flow of water in the aquifer in the immediate vicinity of the well, through the well screen, and in the well casing; and (3) the drawdown or head loss, s_p, resulting from the partial penetration of the pumped well.

The effect of the Illinois River on the drawdown in the well, s_3, is the same as though the aquifer were infinite and as if recharging wells were located across the real boundary, on a line at right angles thereto, and at the same distance from the Illinois River as the real pumping wells.

Equation 1 was used to compute s_a, s_1, and s_3. An effective radius equal to the nominal radius, 1 foot, was assumed in the computations, as were an average coefficient of transmissibility of 800,000 gpd/ft and a long-term coefficient of storage of 0.05. A reasonable estimate of the value of C for a properly constructed and developed well is 1.0. A C value of 1.0 and equation 4 were used to determine s_w. A (P_h/P_v) ratio of 2.5 was assumed in computing s_{pp} with equation 3. The difference between s_{pp} and s_a is equal to s_p.

The drawdown values for s_1, s_2, and s_3 are as follows: s_1 equals 11.39 feet (s_a of 3.06 plus s_w of 4.94 plus s_p of 3.39); s_2 equals 1.08 feet; and s_3 equals 0.06 feet.

The total drawdown, s_t, in well 1, as the result of pumping wells 1 and 2 at rates of 1000 gpm for 1 year, is about 12.4 feet. The nonpumping water level in the vicinity of the hypothetical well field is about 20 feet below land surface. The pumping level in well 1 at the end of the pumping period thus would be about 32 feet below the land surface.

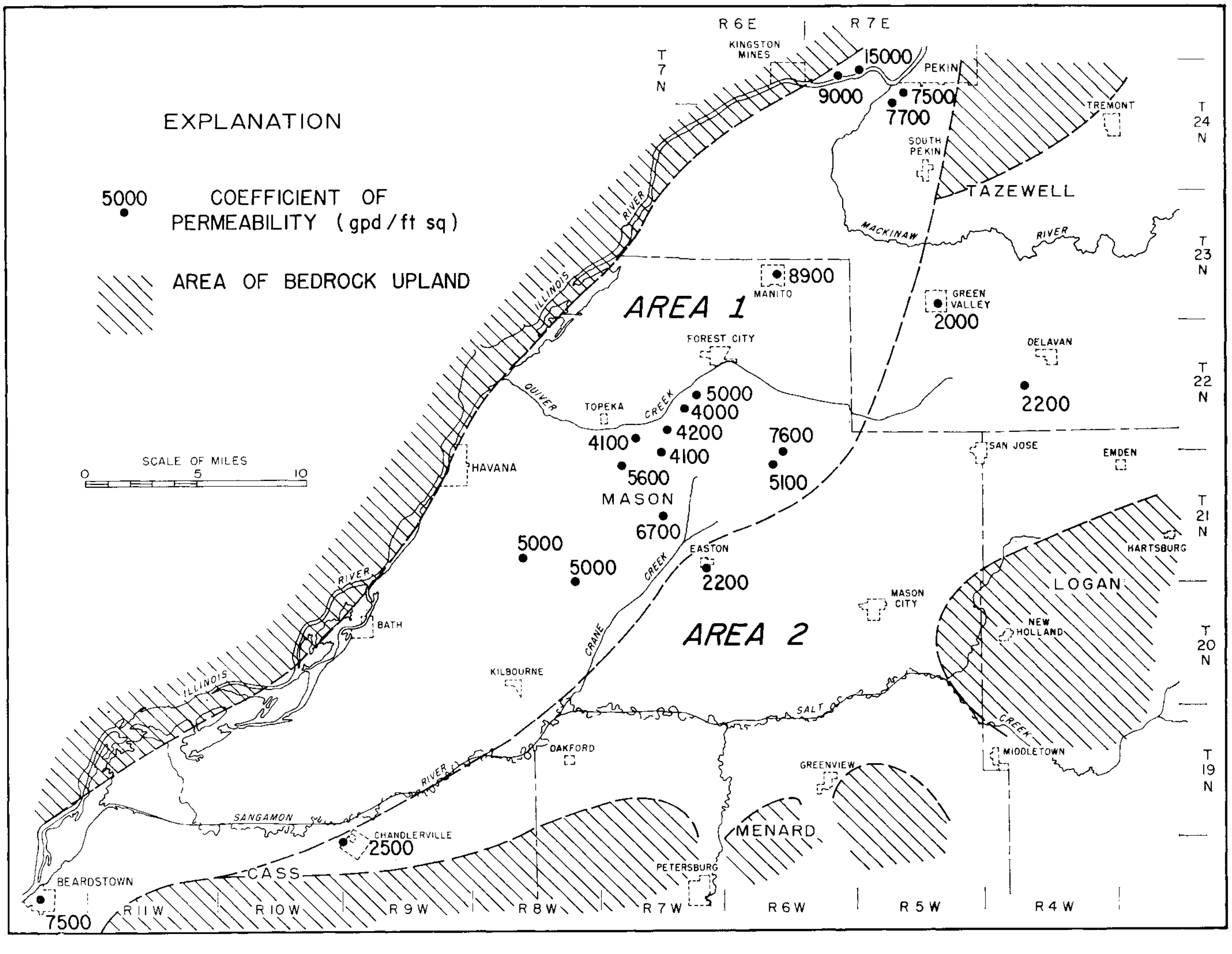


Fig. 34. Areas of high (area 1) and relatively low (area 2) permeabilities of unconsolidated deposits.

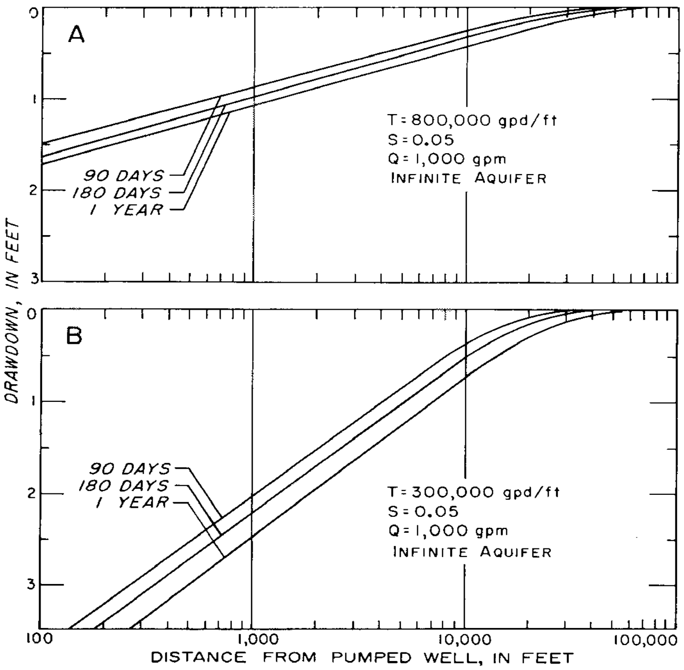


Fig. 35. Theoretical distance-drawdown for area 1 (A) and area 2 (B). Area boundaries are shown in figure 34.

The hydraulic properties of the aquifer in the vicinity of the hypothetical well field are not precisely known; therefore, the results of computations indicate only the order of magnitude of the effects of pumping wells southeast of Havana.

Recharge Directly from Precipitation

Flow lines were drawn at right angles to water-table contours (fig. 25) down-gradient from ground-water mounds and ridges to delineate the four flow channels shown in figure 37. The amounts of recharge directly from precipitation minus ground-water evapotranspiration losses to parts of the unconsolidated deposits within the flow channels are equal to the quantities of water moving through flow cross sections A—A', B—B', C—C', and D—D', The flow channels are in the areas where the water table is below plant feeding depth and ground-water evapotranspiration losses and storage changes are small; therefore, for practical purposes recharge is equal to the quantities of water moving through flow cross sections. Flow through cross sections A—A', B—B', C—C', and D—D' was computed to be about 1.7, 2.2, 3.2, and 2.0 mgd, respectively, with the following form of Darcy's law:

$$Q = TIL \qquad (9)$$

where:

Q = quantity of water percolating through a given flow cross section, in gpd
T = coefficient of transmissibility, in gpd/ft
I = hydraulic gradient of water table at flow cross section, in ft/mi
L = length of flow cross section, in mi

Recharge rates were estimated as the quotients of flow through cross sections and surface areas of flow channels. Areas of flow channels 1, 2, 3, and 4 are 6.6, 7.7, 6.4, and 4.2 square miles, respectively. Recharge rates average about 270,000 gpd/sq mi in flow channels 2 and 3 and about 490,000 gpd/sq mi in flow channels 1 and 4. Flow channels 2 and 3 lie in areas where layers of Illinoian till overlie the aquifer and retard the vertical movement of water. Flow channels 1 and 4 lie in areas where fairly coarse-grained sand and gravel deposits occur from the surface down to bedrock.

Pumpage

Pumpage-use data are classified in this report according to the four main categories used by the U.S. Bureau of the Census. These are (1) public, (2) industrial, (3) rural nonirrigation, and (4) irrigation. Most water-supply systems furnish water for several types of use. In all cases, the total pumpage may be known approximately, but the final use of the water cannot always be determined. Any water pumped by a municipality is called a public supply, regardless of the use of water; any water pumped by an industry is called an industrial supply, regardless of the use of the water. Rural nonirrigation supplies provide water for domestic and stock use on farms and individual residences and may include water for irrigating lawns and home gardens. Irriga-

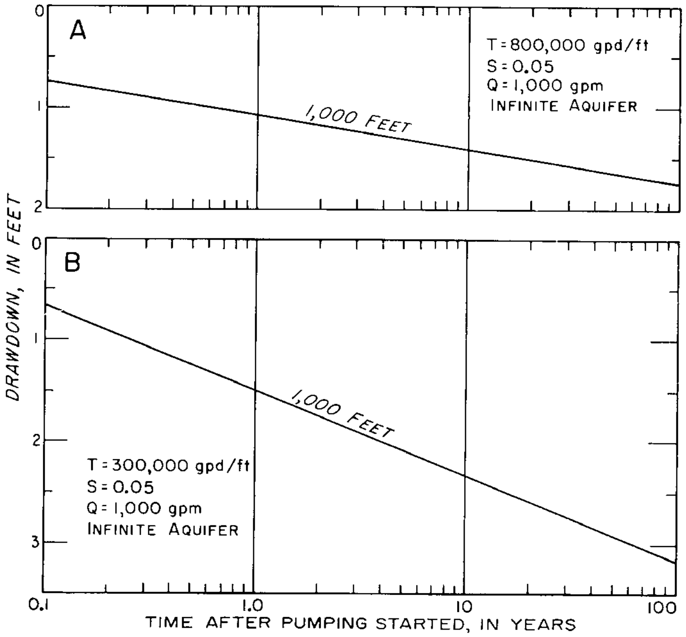


Fig. 36. Theoretical time-drawdown for area 1 (A) and area 2 (B). Area boundaries are shown in figure 34.

tion water is that which is applied to the land to supplement natural soil moisture for growing crops.

Public pumpage shows a gradual change with seasons, the average winter use being about three-fourths of the average summer use. Industrial wells generally have the most uniform pumpage during the year unless air-conditioning installations are used or the industry is seasonal. However, if a change in operation occurs, as during strikes or vacation shut-downs, the variation in pumpage is radical or sudden. Pumpage for irrigation is seasonal and varies considerably from year to year, depending on weather conditions.

The reliability of pumpage data varies greatly. Municipal pumpage is nearly always metered in cities, but many smaller villages operate without meters. Only a small part of the industrial supply is metered. Pumpage data from municipalities and the larger industrial establishments are systematically recorded. The pumpage from farm wells and from the many individual residential wells is estimated on the basis of detailed use surveys of a few selected sections considered typical. Irrigation wells nearly always operate without meters. For these reasons it is difficult to ascertain exact pumpage figures.

Total ground-water pumpage in the Havana region in 1960 was about 21 mgd. Of this amount, approximately 85 percent was pumped for industrial use in the extreme northern part of the region; the remaining 15 percent was withdrawn largely by municipalities (table 6). Graphs of estimated municipal and industrial

Table 6. Estimated Pumpage in the Havana Region in 1960, Subdivided by Use

Type of use		Total pumpage *(mgd)*
Industrial		18.32
Municipal		2.44
Rural nonirrigation		0.50
Irrigation		0.09
	Total	21.35

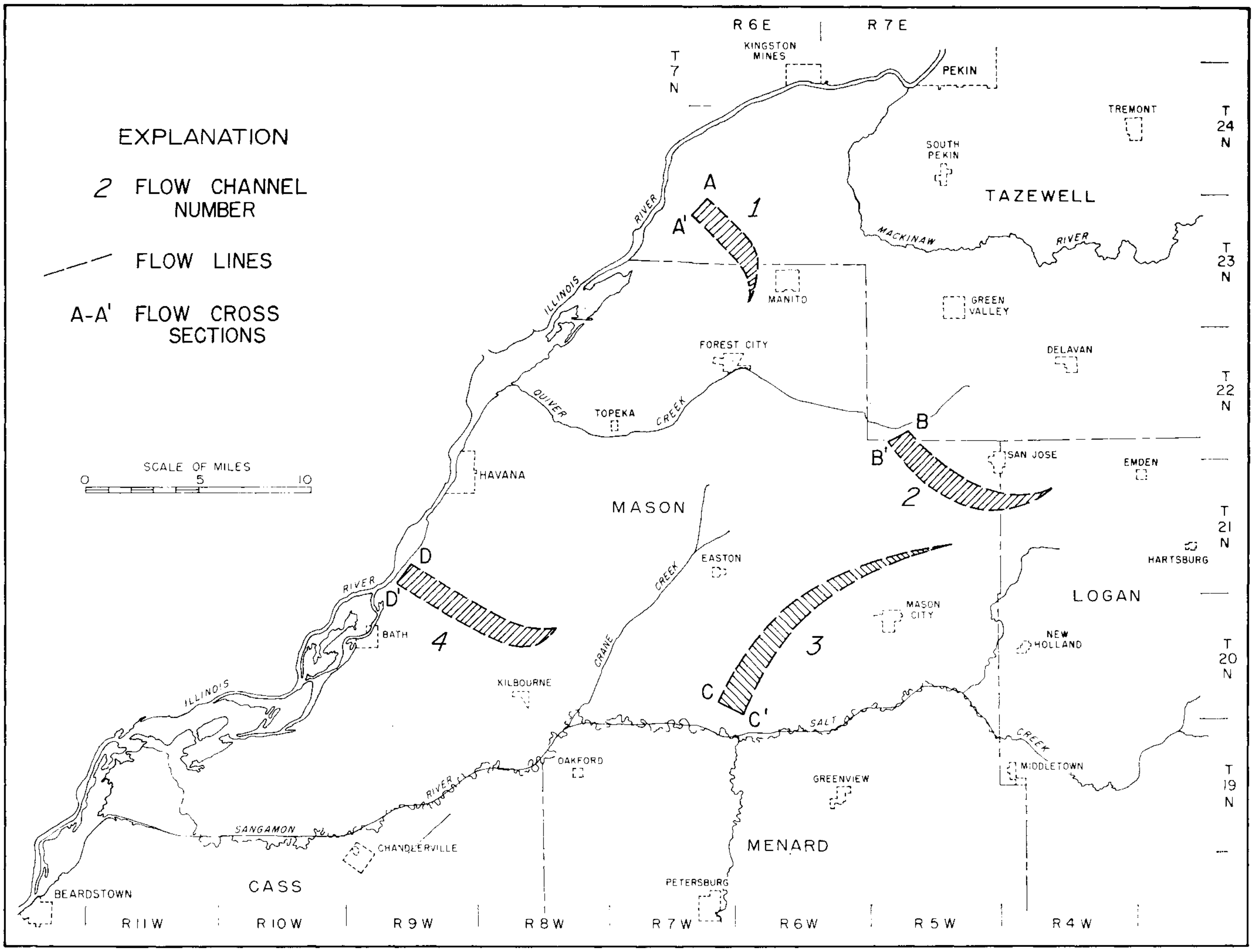


Fig. 37. Location of flow channels used to determine recharge rates.

pumpage for the period of record in the northern, central, and southern parts of the region are given in figure 38.

Municipal pumpage has gradually increased as per capita use has increased with the introduction of automatic washing machines, dishwashers, and garbage disposal units into the average home. Major fluctuations in pumpage are due to large changes in industrial pumpage. The increase in pumpage in the central part of the region in 1947 (fig. 38) reflects the increase in ground-water use by the Illinois Power Company plant at Havana, which was placed in operation during that year; the reduction in pumpage after 1952 was caused by a decrease in ground-water use by that plant. The pumpage graph for the northern part of the area reflects changes in pumpage within the industrial complex south of Pekin.

Rural nonirrigation pumpage was estimated on the basis of data in the 1950 and 1960 reports of the U.S. Bureau of the Census and on a per capita consumption value of 50 gpd. Total rural nonirrigation pumpage was about 500,000 gpd in 1960.

Surveys of the extent of supplemental irrigation development and the total yearly pumpage for supplemental irrigation were made in 1957 and 1959 by the Department of Agricultural Economics, University of Illinois, in cooperation with the Agricultural Research Service, U.S. Department of Agriculture (Davis, 1960; Davis and Jansen, 1960). Data on supplemental irrigation pumpage gathered during these surveys and additional data furnished by Ray Lane, Soil Conservation Service, U.S. Department of Agriculture, are used in this report.

In 1960 there were 14 known supplemental irrigation systems within the Havana region, all located in Mason County. Of this total, 11 systems used ground water, 2 used surface water, and 1 used a combination of ground and surface water as sources of supply.

Supplemental irrigation

Although annual rainfall generally is sufficient to support sustained production of crops and pasture in the region, short periods of drought are common, and supplemental irrigation is used to stabilize annual yields. The irrigated acreage has increased in recent years largely because of the availability of an adequate supply of good ground water for irrigation. Other factors that have encouraged supplemental irrigation are the occurrence of sandy textured soils that have little water-holding capacity; improvements in irrigation equipment, particularly portable, lightweight pipe and sprinklers; the desire for increased yields and crops of higher quality; and the proximity of city markets for truck crops. Only in recent years have farmers in general come to realize the full potentialities of supplemental irrigation. Information, including costs, is given in yearbooks of the U. S. Department of Agriculture (1955, 1957).

Data on supplemental irrigation from ground-water sources in the Havana region are summarized in table 7. The number of irrigation systems and total acres irrigated increased in 1960; however, total ground-water withdrawals for supplemental irrigation decreased because of an abundance of precipitation during the growing season of that year. The correlation between total

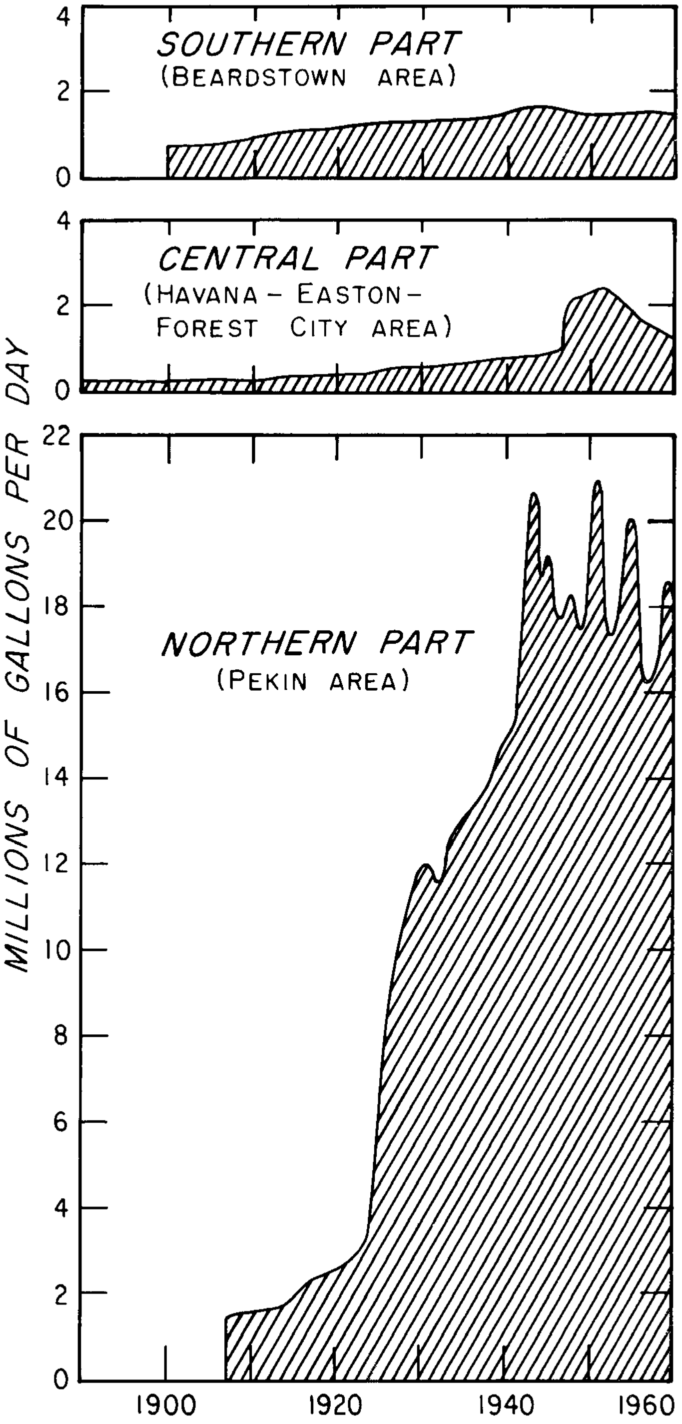


Fig. 38. Estimated municipal and industrial pumpage, 1890-1960, in the Havana region.

Table 7. Supplemental Irrigation from Ground-Water Sources in the Havana Region

Year	Number of irrigation systems	Acres irrigated	Annual pumpage *(mil gal)*	Precipitation during growing season *(in)*	
				Total	Departure from normal
1954	4	130	14.7	13.17	+2.32
1955	5	330	33.7	12.35	+1.50
1956	5	190	14.5	19.97	+2.12
1959	6	340	59.1	6.07	-4.75
1960	11	530	32.2	17.78	+6.96

pumpage and precipitation during the growing season is apparent. The large rate of increase in the number of irrigation systems between 1959 and 1960 was caused by drought conditions and unfavorable rainfall distribution during the summer of 1959, which had resulted in poor crop production and heavy losses in income. Currently, sprinkler irrigation systems are used almost exclusively for supplemental irrigation.

Farm crops most likely to receive supplemental irrigation in the Havana region are (1) alfalfa; (2) corn, wheat, and other grains; (3) pasture; and (4) potatoes and other vegetables. Approximate moisture requirements of these crops for moderate climatic conditions, such as are found in Illinois, were compiled by the U. S. Bureau of Reclamation (1951) and are given in table 8.

Table 8. Moisture Requirements of Selected Crops

Crop	Daily moisture demand per acre *(in)*	Irrigation capacity requirements	
		gpm/acre	*gpd/acre*
Alfalfa	0.20	5.4	7800
Grain	0.20	5.4	7800
Pasture	0.16	4.3	6200
Potatoes	0.12	3.3	4750

Also given is a tabulation of the water required per acre for these crops with an irrigation system operating at a field efficiency of 70 percent. Alfalfa and grain crops use approximately one-fifth of an inch of water per acre per day, whereas pasture and potatoes require slightly over one-sixth to one-eighth of an inch of water per acre per day, respectively. An irrigation system designed on the basis of a maximum crop demand of one-fifth of an inch per acre per day must be capable of producing 5.4 gpm per acre continuously during drought periods to satisfy the moisture requirements of the crop.

The primary factor controlling the rate of water application per acre is the infiltration capacity of the soil. The infiltration capacity of the various soil types commonly found in the region are assumed to be comparable to infiltration capacities determined by the U. S. Bureau of Reclamation (1951) for soils of the western states. These capacities are given in table 9.

Sand and sandy loam soils predominate in the region, and table 9 indicates that the infiltration capacities of these soils are about 2 and 1 inches per hour (54 and 27 gpm), respectively. On the basis of these values and pumping rates of 500 and 1000 gpm per irrigation well, the maximum number of acres that can be irrigated by one well ranges from 11 to 19 in sandy soil and from 22 to about 37 in sandy loam soil. The irrigation time required to meet daily peak moisture requirements of alfalfa and grain on these acreages would be about 3 and 1.5 hours for sand and sandy loam soils, respectively.

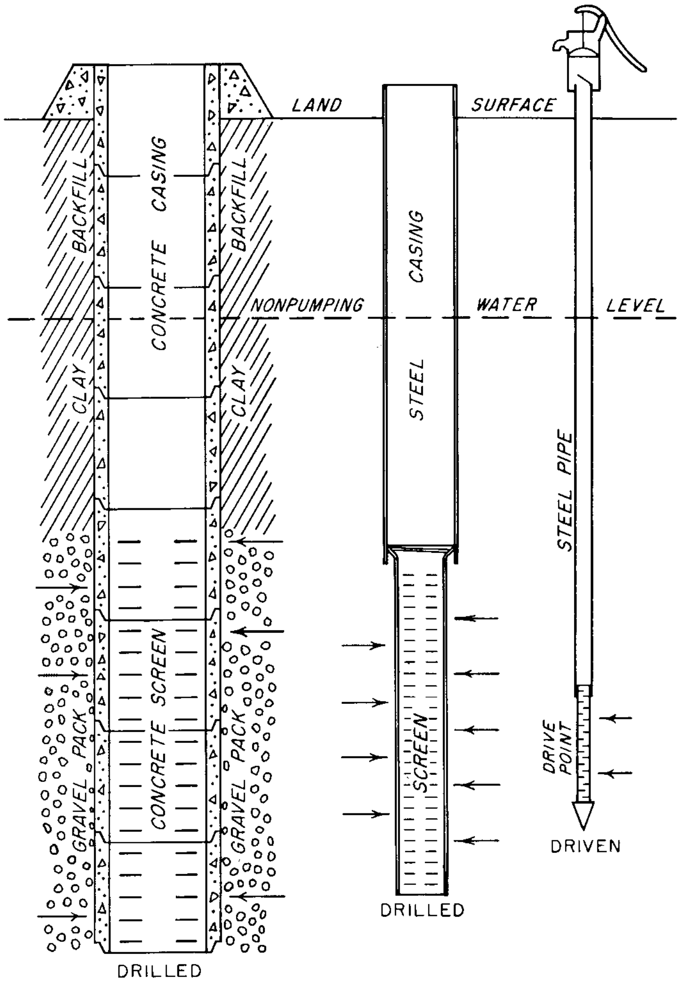


Fig. 39. Construction features of drilled and driven wells.

Construction Features of Wells

Wells may be classified according to the method of construction used in drilling the hole and inserting the screen; the two types commonly found in the Havana

Table 9. Infiltration Capacity of Soils

Soil type	Infiltration capacity *in/hr*	Infiltration capacity *gpm**
Sand	2	54
Sandy loam	1	27
Loam	0.5	18.5
Silt and clay loam	0.2	5.4

* 70 percent irrigation efficiency.

region are drilled and driven wells. A few dug and bored wells still exist, but these methods of well construction are rarely used today. The drilled wells may be further classified as to method of completion—natural pack or artificial pack. Natural coarse materials surrounding the well are developed in the natural pack well; materials having a coarser, more uniform grain size than the natural formation are added around the screen of the artificial pack well.

Drilled wells (fig. 39) in the Havana region may be cased with either concrete or steel casing. If concrete casing is used, the well screen is generally made of perforated sections of the same material; steel casing wells may be equipped with a section of slotted pipe, or a commercial well screen made of stainless steel, red brass, or other relatively noncorrosive metal. Driven wells (fig. 39) are generally cased with black or galvanized pipe 1 to 3 inches in diameter and equipped with 3 to 10 feet of commercial wellpoint screen.

The driven well is, by far, the most common type of well used for domestic and stock water purposes in most of the Havana region because the water table is near the surface and is overlain by materials easily penetrated by a drivepoint. Relatively high yields are obtained from small-diameter wells penetrating only the upper few feet of the aquifer, the method of construction is simple, and the cost is low. This type of well is not practical on uplands along the eastern edge of the region, however, because of the difficulty encountered in driving the well deep enough to intersect the aquifer, which lies more than 100 feet below the land surface. Where the depth to water is more than about 50 feet, drilled wells 4 to 6 inches in diameter are usually constructed to obtain water for domestic and agricultural use.

Drilled wells are commonly constructed to obtain large quantities of water for municipal, industrial, and irrigation purposes. Records of large-capacity wells in the region are given in table B in the appendix.

Case histories of many large-capacity wells revealed a rapid decline in well yield, often resulting in costly well repairs and even well abandonment, after only a few months of operation. This rapid deterioration in well yield can be directly traced to overpumping in many of the wells. Overpumping in this instance refers to pumping rates high enough to induce the migration of fine-grained material from the aquifer toward the well face, thereby lowering the permeability of the aquifer in the immediate vicinity of the well to the extent that well yields are greatly reduced. In some cases the entrance of fine sand through the well screen becomes excessive. It is important that wells be properly designed to prevent entrance of fine material into wells and that pumping rates be limited to those that will not cause rapid deterioration in yield. Well design criteria were given by Walton (1962).

The spacing of production wells is frequently a problem. The farther apart wells are spaced the less their mutual interference but the greater the cost of connecting pipeline and electrical equipment. The spacing of wells is often dictated by practical considerations such as property boundaries and existing distribution-pipe networks. This discussion is concerned only with the influence of aquifer characteristics and economics on the spacing of production wells.

Theis (1957) derived the following equation for determining the optimum well spacing in the simple case of two wells pumping at the same rate from a thick and areally extensive aquifer:

$$r_s = 2.4\times10^8 c_p Q^2/kT \qquad (10)$$

where:

r_s = optimum well spacing, in ft

c_P = cost to raise a gallon of water 1 foot, consisting largely of power charges but also properly including some additional charges on the equipment, in dollars (1 gal lifted 1 ft = 3.15×10^{-6} kwh)

k = capitalized cost for maintenance, depreciation, original cost of pipeline, etc., in dollars per year per foot of intervening distance

Q = pumping rate of each well, in gpm

T = coefficient of transmissibility, in gpd/ft

In aquifers 100 or less feet thick, it is generally advisable to separate production wells by a distance at least equal to twice the thickness of the aquifer, to minimize the effects of partial penetration. Experience has shown that in the case of a multiple well system consisting of more than two wells the proper spacing between wells is at least 250 feet.

Quality

Typical analyses of ground water are given in table 10. Ground water in the unconsolidated deposits varies in quality from place to place but is of much better quality than water in the Pennsylvanian and Mississippian rocks. Water in Devonian, Silurian, Ordovician (table 11), and older rocks is too highly mineralized for most purposes.

Temperature

Ground-water temperatures have been measured periodically for several years in production wells located in the pumping center south of Pekin. Additional temperature measurements have been made in production wells throughout the region at the time of collection of water samples for chemical analyses. Measured temperatures of well water are included in table 10 and in figure 40.

In the deeper parts of the aquifer away from the Illinois River, the ground-water temperature generally

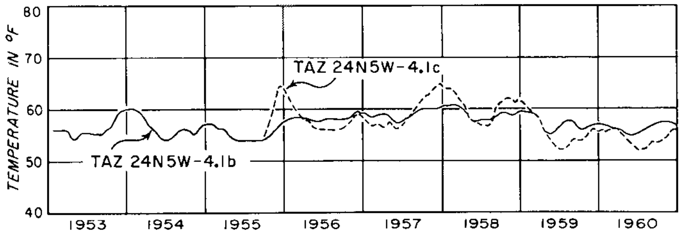


Fig. 40. Ground-water temperatures in selected wells near Pekin, 1953-1960.

ranges between 53° F and 57° F, with an average of 55° F. In the shallower parts of the aquifers near the Illinois River, however, ground-water temperature may vary during the year from a low of about 50° F to a high of about 68° F because of infiltration of warmer or colder surface water.

Surface water entering the aquifer ranges in temperature from 32° F to 85° F. Because of the heat exchange with the sand and gravel under the bed of the river, and a blending of surface water with cooler ground water recharged from rainfall, the range in ground-water temperatures is not so great as the range in surface-water temperatures. The changes in ground-water temperature in a well a few hundred feet from the river's edge may lag behind temperature changes in surface water by as much as 8 months because of the slow movement of water through the aquifer.

The primary factors that control the time lag and range in ground-water temperature are (1) temperature of the surface water, (2) distance of production wells from the river, (3) spacing of production wells, (4) pumping rates, and (5) amount and temperature of ground-water flow from the land side. In wells located at or near the river's edge, the water pumped from production wells often consists of a high percentage of surface water that enters the aquifer in the immediate vicinity of the pumped well; therefore, there is a wide range in the temperature of the ground water. Production wells located farther landward, however, receive a large percentage of ground water of nearly uniform temperature recharged by precipitation and a smaller percentage of surface water; therefore, the range in these ground-water temperatures is small.

Table 10. Chemical Analyses and Temperature of Water in Wells in Unconsolidated Deposits
(Chemical constituent in parts per million)

Well number	Owner*	Depth (*ft*)	Temperature (*°F*)	Iron (Fe)	Fluoride (F)	Boron (B)	Silica (SiO_2)	Chloride (Cl)	Sulfate (SO_4)	Nitrate (NO_3)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Alkalinity (bicarbonate) (as $CaCO_3$)	Hardness (as $CaCO_3$)	Total dissolved minerals
CSS—																
18N12W-14.8h	Beardstown (C)	89	.....	0.6	0.2	0.3	16.3	39.0	123.6	1.2	97.4	35.0	26.0	260.0	388.0	512.0
LOG—																
20N4W-18.1b	New Holland (V)	74	55	0.3	0.0	.....	30.2	33.0	135.8	66.0	129.4	59.6	14.2	360.0	569.0	708
21N4W-26.7h	Scully Estate	30	.....	1.5	.....	.....	15.0	1.0	2.1	2.2	99.2	39.9	7.6	436.0	412	433.8
MSN—																
19N11W-13.7b	Wild Wing Land Co.	93	.....	0.8	.....	.....	15.0	2.0	18.5	1.1	57.7	21.4	6.2	200.0	232.0	244.8
20N5W-8.8fl	Mason City (C)	198	.....	0.8	.....	.....	16.8	4.0	2.0	0.9	63.5	27.9	7.8	280.0	273	299.3
20N5W-12.2a	E. M. Douglas	90	.....	5.5	.....	.....	13.0	15.0	41.3	3.2	136.6	44.8	10.1	482	525.5	553.7
20N5W-22.2a	A. D. Black Estate	145	.....	0.3	.....	.....	14.0	2.0	9.7	13.3	71.4	37.0	6.7	322	331	347.6
20N8W-2.4e	Ted Kruse	130	55	2.6	.....	0.1	.....	1.0	30.4	2.4	59.2	17.5	1.6	188	220	261.0
20N9W-8.4d	L. F. Connolly	63	56	Tr	.....	0.0	.....	0.0	30.9	3.0	27.4	9.8	3.0	80.0	109	143
21N5W-1.1h1	San Jose (V)	101	.....	1.0	.....	.....	14.5	23.0	82.1	33.2	96.1	41.4	8.1	282	409.5	467.9
21N5W-8.1h	R. M. Ainsworth	105	.....	0.1	.....	.....	14.0	6.0	17.1	32.8	86.4	36.4	9.7	334	365.5	392.8
21N5W-32.1g	Howard Stone	100	.....	0.2	.....	.....	13.0	10.0	19.6	66.4	85.7	42.5	9.4	300	389	410
21N6W-16.1b	L. G. Keisling	54	.....	1.6	.....	.....	10.0	3.0	28.0	1.3	69.0	22.1	3.7	238.0	264.0	279.9
21N7W-5.8f	C. H. Zurburg	63	.....	0.1	.....	.....	6.0	0.0	26.9	1.5	29.0	8.2	3.0	84.0	107.0	124.9
21N7W-15.3f	Burnell Steinhauer	119	55	6.9	.....	0.0	.....	1.0	36.4	1.3	73.6	22.4	2.3	240	276	313
21N7W-25.7a	Easton (V)	135	55	2.1	0.2	0.1	18.0	1.0	24.1	1.0	63.1	28.2	3.0	252	274	284
21N7W-30.3f	E. C. Ringhouse	105	.....	0.2	.....	0.0		2.0	39.6	.....	.....	.....	.....	144	179	194
21N8W-7.7h	Camp Dreier, D-5	75	.....	0.3	.....	.....	12.0	0.0	17.7	4.0	36.5	14.3	6.9	124.0	150.5	169
21N9W-1.2f	Havana (C)	125	.....	0.4	0.1	.....	19.3	3.0	24.7	0.2	44.9	15.6	Tr	152.0	177	197
22N6W-2.6h	Nicholas Graff	43	.....	0.1	.....	.....	8.0	9.0	48.6	33.6	73.0	29.3	0.5	214.0	303	330
22N6W-29.4a	G. A. Barnes	40	.....	0.1	.....	.....	.....	2.0	38.7	.....	.....	.....	.....	134	153.8	185
22N7W-3.1h	Mason State Forest	31	54	Tr	.....	0.0	.....	1.0	26.7	2.1	40.9	14.0	3.0	136	160	180
22N7W-33.8h	Mason State Tree Nursery	136	.....	5.7	.....	.....	28.0	0.0	2.3	0.9	74.3	23.5	2.1	286	284.5	308
22N8W-10.8b	U. S. Dept. of Agr.	62	.....	0.16	.....	.....	13.5	1.0	21.2	18.6	47.6	18.3	1.8	160	194.5	218
23N6W-21.3d	Manito (V)	82	59	1.1	0.2	0.0	13.0	4.0	63.4	3.4	64.4	22.9	5.0	192	255	320
23N6W-24.8e	John Meeker	35	.....	2.5	.....	.....	9.0	6.0	103	1.7	98.8	29.5	8.3	270	368	419
TAZ—																
22N4W-10.7d1	Delavan (C)	160	54.5	2.0	0.2	.....	25.9	2.0	0.0	0.8	77.6	29.6	2.5	320	314	331
22N4W-16.8b2	Hiram Walker & Sons, Inc.	209	55	1.3	.....	0.0	.....	1.0	9.5	1.6	70.4	31.1	Tr	308	304	329
23N5W-26.8a1	Green Valley (V)	115	56	1.8	0.1	0.1	17.5	5.0	44.4	1.0	77.8	32.6	6.0	288	329	382
23N7W-1.5a	Star School	93	.....	10.0	.....	.....	14.0	7.0	40.7	9.7	45.2	16.0	5.1	130	179	216
23N7W-8.1a	Camp Isaac Walton	90	.....	0.0	.....	.....	14.0	0.0	33.6	8.0	39.8	12.0	7.4	130	167	190
24N5W-9.8c2	Commonwealth Edison Co	58	.....	0.1	.....	.....	8.0	8.0	45.1	10.6	65.2	26.3	11.7	216	271	307
24N5W-34.4h1	South Pekin (V)	90	.....	0.1	.....	.....	16.5	14.0	152.5	6.6	86.0	35.9	17.9	218	362	460
24N7W-13.5b	Lawrence Thomas	17	.....	3.6	.....	.....	13.0	12.0	94.1	4.0	90.3	41.3	2.5	284	396	425

* (C) = city owned; (V) = village owned.

Table 11. Chemical Analyses of Water Typical for the Glenwood-St. Peter Sandstone (Ordovician)

Sample of water collected April 26, 1961, from well MSN 22N8W-31 .8e, J. H. White-Hahn; near Havana, Mason County. Location: NW Cor. SW ¼ sec. 31, T.22N., R.8W. Depth: 1442 ft. Lowest formation penetrated: Glenwood-St. Peter Sandstone.

Laboratory No. 154713

	ppm	*epm*
Turbidity	26	
Color	0	
Odor	0	
Iron (Fe) (total)	6.8	
Fluoride (F)	3.6	
Chloride (Cl)	540	15.23
Sulfate (SO_4)	791	16.47
Alkalinity (as $CaCO_3$)	232	4.64
Hardness (as $CaCO_3$)	504	10.08
Total dissolved minerals	2277	

Sample of water collected April 26, 1961, from well MSN 23N6W-31.3c, Dr. Joseph P. Sparks; Manito, Mason County. Location: 350′N and 100′W of SE cor. NW ¼ SE ¼ sec. 31, T.23N., R.6W. Depth: 1806 ft. Lowest formation penetrated: Glenwood-St. Peter Sandstone.

Laboratory No. 154712

	ppm	*epm*
Turbidity	24	
Color	0	
Odor	0	
Iron (Fe) (total)	6.6	
Fluoride (F)	2.6	
Chloride (Cl)	410	11.56
Sulfate (SO_4)	1004	20.89
Alkalinity (as $CaCO_3$)	224	4.48
Hardness (as $CaCO_3$)	580	11.60
Total dissolved minerals	2361	

Chemical character

The chemical character of the ground water in the Havana region is shown by the analyses of samples from 34 wells (table 10). The constituents listed in the table are given in ionic form in parts per million; the major constituents, expressed in equivalents per million, are shown graphically in figure 41. Most waters from unconsolidated deposits contain less than 500 ppm of dissolved minerals. Dissolved minerals range from 125 to 708 ppm and average 297 ppm.

Waters from sand and gravel wells are essentially bicarbonate waters having an alkalinity greater than the hardness and almost equal to the total mineral content. More than half of these samples contained more than 0.3 ppm iron, with a median of 0.7 ppm and a maximum of 10 ppm. The hardness ranges from 107 to 569 ppm with a median of 274 ppm. The chloride content ranges from 0 to 39 ppm with a median of 3 ppm. The sulfate content ranges from 0 to 152 ppm and averages 48.8 ppm.

In heavily pumped areas adjacent to the Illinois River, where the water table has been lowered below stream level, the ground water is a blend of water recharged to the aquifer directly from precipitation and by the induced infiltration of surface water. Such water is generally of better quality than that from unconsolidated deposits in the proximity of the bedrock valley walls.

The chemical composition of the water from bedrock wells is very different from that of the water generally found in the sand and gravel. Table 11 gives analyses of water from two deep bedrock wells obtaining water from the Glenwood-St. Peter Sandstone. Water from the bedrock is much more highly mineralized than water from unconsolidated deposits.

According to classifications given by the U. S. Salinity Laboratory (1954), ground water in the study area is generally excellent to good for irrigation purposes. For all the water sampled, the highly permeable sandy soils of this region provide adequate leaching to prevent the accumulation of harmful salts derived from supplemental irrigation. No boron concentrations above 0.3 ppm were found, and the sodium absorption ratio was always well below a hazardous level.

Potential Yield of Unconsolidated Deposits

A study of the water-yielding characteristics, recharge from precipitation, and the relation between ground-water levels and the Illinois River indicates that the potential yield of unconsolidated deposits in the Havana region is large. The potential yield is here defined as the amount of ground water that can be continuously withdrawn from a reasonable number of wells without creating critically low water levels or exceeding the recharge rate.

The amount of recharge directly from precipitation was estimated to be about 300 mgd. The estimate was based on data from geologic maps and on recharge rates determined from flow-net analysis of the water-table map. If ground-water levels were lowered below the water surface of the Illinois River by pumping from wells adjacent to the stream, recharge by influent seepage of surface water would result. The amount of recharge by induced infiltration depends largely on the permeability of the stream bed and the underlying aquifer, the surface water temperature, the depth of water in the river, and the width of the stream bed. Potential recharge from induced infiltration of surface water cannot be estimated in the absence of specific data on the permeability of the bed of the Illinois River. However, based on studies made in the East St. Louis area (Schicht and Jones, 1962) it is not unreasonable to believe that as much as 50 mgd of surface water could be induced to flow into the unconsolidated deposits under heavy pumping conditions.

A study of the water-yielding character of the unconsolidated deposits (see Hydraulic Properties of Aquifers) indicates that on a gross basis these aquifers, if properly developed, are capable of yielding far more water to wells than will be recharged under heavy pumping conditions. Thus, the potential yield depends upon recharge rates rather than on the water-yielding character of the aquifer. Available data on the specific capacities of existing production wells and hydraulic properties of aquifers were used to determine the probable number of wells needed for full development of the potential yield. It is estimated that, on the average, one well must be in service for each 1 mgd of ground water withdrawn. This figure includes necessary standby wells. If the potential yield is 350 mgd, about 350 wells would be required to produce the amount of ground water available.

Probable consequences of development

Some insight into the probable consequences of developing large quantities of ground water in the Havana region can be gained by reference to ground-water conditions in the East St. Louis area. The East St. Louis area is in southwestern Illinois, encompasses the major cities of East St. Louis, Granite City, and Wood River, and extends along the valley lowlands of the Mississippi River from the city of Alton south to the village of Dupo. The area covers about 175 square miles and is approximately 30 miles long and 11 miles wide at the widest point.

As in the Havana region, the aquifer consists of sand and gravel deposits and is underlain by Mississippian and Pennsylvanian rocks. The unconsolidated deposits have an average thickness of 120 feet and range in thickness from a feather edge, near the bluff boundaries of the area, to more than 170 feet near the city of Wood River. The thickness of the sand and gravel deposits is generally greatest and exceeds 120 feet near the center of a buried bedrock valley that bisects the area.

The coefficient of transmissibility of the unconsolidated deposits commonly exceeds 150,000 gpd/ft and, in the Monsanto, East St. Louis, National City, and

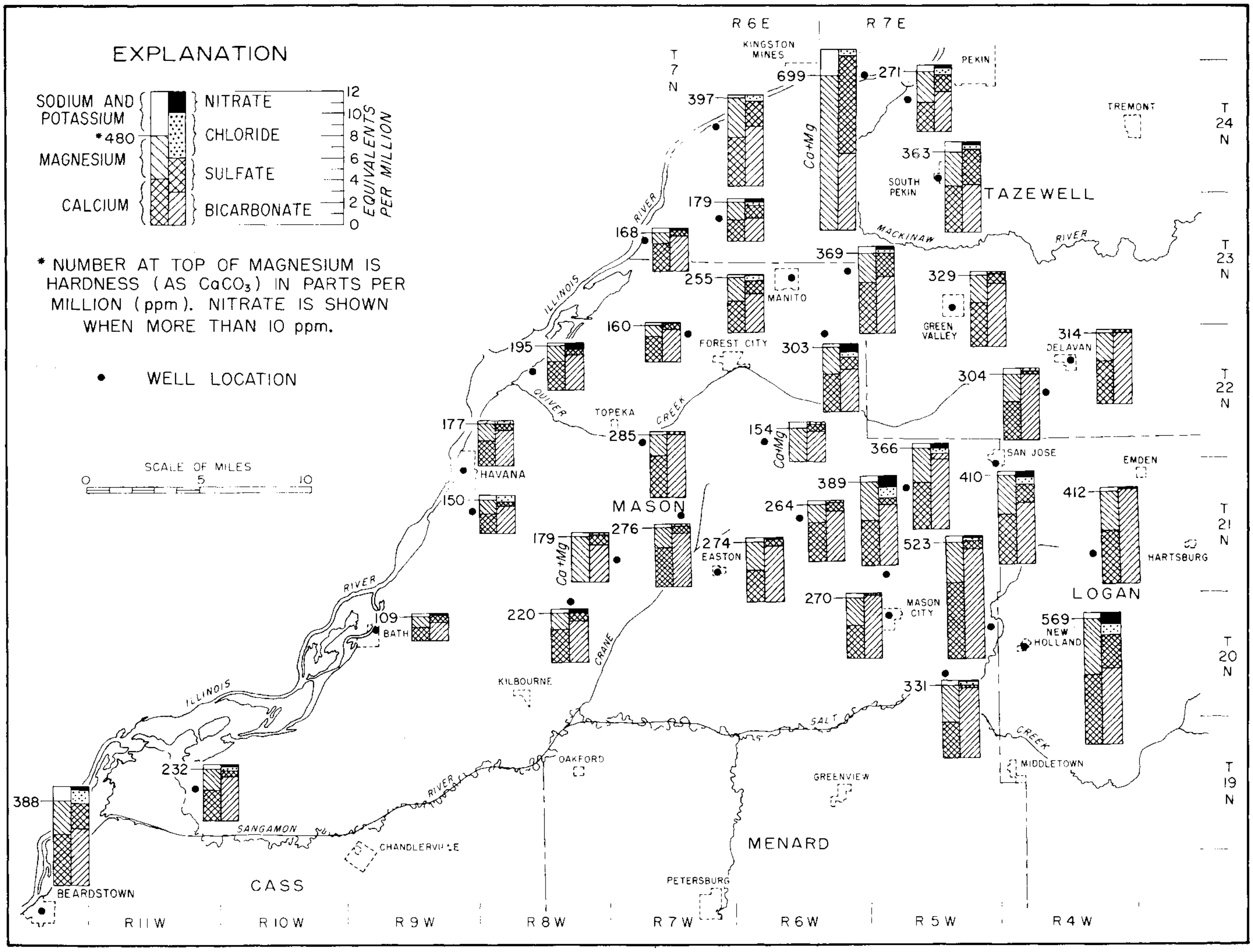


Fig.41. Chemical analyses of water from selected wells.

Granite City areas, exceeds 200,000 gpd/ft. Coefficients of permeability range from 3000 to 1000 gpd/sq ft. Recharge directly from precipitation averages about 340,000 gpd/sq mi.

Pumpage increased from 2.1 mgd in 1900 to 111.0 in 1956 and was 93.0 mgd in 1960; as a result of heavy pumping, water levels declined about 50 feet in the Monsanto area and more than 10 feet in other pumping centers (Schicht and Jones, 1962, figs. 5 and 34). A piezometric map for the East St. Louis area (Schicht and Jones, 1962, fig. 33) was prepared from water-level measurements made in 225 wells in 1961. The general pattern of flow of water in that year was slow movement from all directions towards cones of depression in pumping centers and streams in the area. Pumping of wells has considerably reduced ground-water discharge to the Mississippi River but has not at all places reversed the natural slope of the water table toward that stream. Ground-water levels have been lowered below the water surface of the river at places, and appreciable quantities of water were diverted from the river into the aquifer by the process of induced infiltration of surface water.

A comparison between aquifer conditions in the East St. Louis area and in the Havana region seems to indicate that heavy pumping similar to that in the East St. Louis area would result in less water-level decline per unit of pumpage in the Havana region. The aquifer in the Havana region has greater areal extent, thickness, permeability, and average recharge rate than does the aquifer in the East St. Louis area.

SURFACE WATER

Streamflow records are available for only one small drainage basin contained entirely within the Havana region. This basin is located near Easton in Mason County, and is drained by a tributary of Crane Creek. Topographic divides of this basin do not coincide with the ground-water divides; the surface water basin is 28.7 square miles in area and the ground-water basin is 24 square miles in area (fig. 42). Approximately one-third of the ground-water basin is underlain by Wisconsinan outwash deposits; the remainder is underlain by less permeable Illinoian drift.

Streamflow records prepared by the U. S. Geological Survey for the Crane Creek tributary basin are available for the 10-year period, 1950-1959. The average daily discharge for years of record is 13.2 cfs. The maximum discharge of 425 cfs occurred on February 10, 1959; the minimum of 0.4 cfs occurred on September 20, 1955.

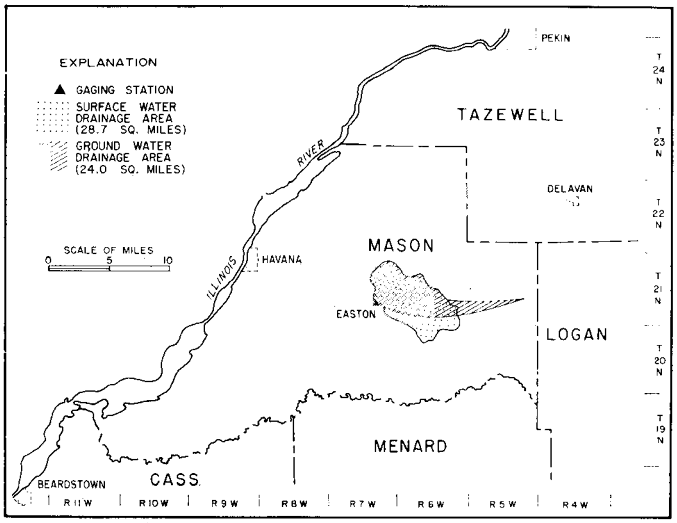


Fig. 42. Location of the drainage basin of Crane Creek tributary.

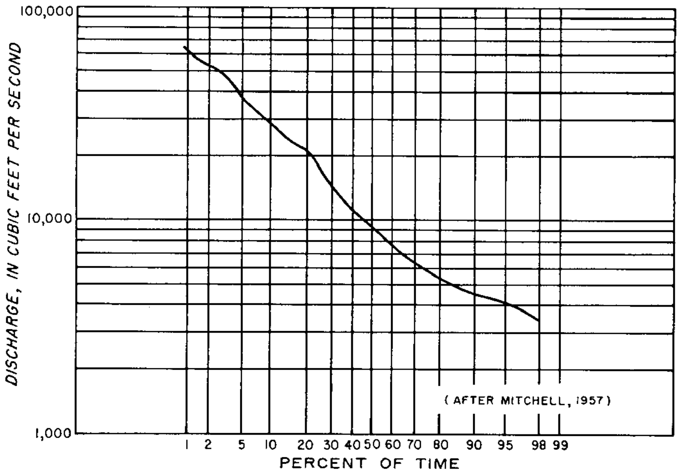


Fig. 43. Flow-duration curve for station at Kingston Mines on the Illinois River.

In general, streamflow is high in winter and spring and low in summer and fall. Streamflow hydrographs have sharp peaks coinciding with heavy rainfall or rapid thaws.

A flow-duration curve for the Illinois River at Kingston Mines is given in figure 43. Daily flows arranged in order of magnitude are plotted against percentage of the time discharges were equaled or exceeded. Thus, the probability of occurrence of specific discharges is indicated. The drainage area of the Illinois River above the gaging station located 2.3 miles downstream from the Mackinaw River in SE¼ SE¼, sec. 26, T. 7 N., R. 6 E., is 15,200 square miles. Since January 17, 1900, flow has included diversion from Lake Michigan through the Chicago Sanitary and Ship Canal. The average daily discharge for the period 1921 through 1945 is 16,800 cfs (10,000 cfs after adjustment for diversion and pumpage). The maximum discharge for the period 1939 through 1950 was 83,100 cfs and occurred on May 23, 1943; the minimum of 2300 cfs occurred on September 27, 1943.

The 32-year average discharge of the Sangamon River for the 5120-square-mile drainage area measured at the gage at Oakford in Menard County is 2989 cfs. The maximum discharge recorded at this gage was 123,000 cfs recorded May 20, 1943; the minimum was 68 cfs (30,600 gpm) recorded December 3, 1940.

The 35-year average discharge of the Mackinaw River for the 1100-square-mile drainage area measured at the gage near Green Valley in Tazewell County is 688 cfs. Maximum discharge through 1956 was 31,000 cfs on July 10, 1951; minimum was 17 cfs (7680 gpm) recorded October 26-27, 1940. Although no discharge measurements of Quiver Creek are available, the average flow in this stream appears to be less than in the Mackinaw River but considerably greater than in Crane Creek.

Ground-Water Runoff

Streamflow consists of surface runoff, R_s, and ground-water runoff, R_g. Surface runoff is precipitation that finds its way into the stream channel without seeping into the soil. Ground-water runoff is precipitation that seeps into the soil or to the water table and then percolates into the stream channel. Surface runoff reaches streams rapidly and is discharged from the basin within a few days. Ground water percolates slowly and reaches streams gradually. Two or three days after precipitation ceases, there is no surface runoff and streamflow is derived entirely from ground-water runoff.

Ground-water runoff depends in part upon the position of the water table because a particular mean ground-water stage is associated with a related hydraulic gradient and a consequent discharge of ground water into a stream. In summer months evapotranspiration reduces ground-water runoff. With the same ground-water levels, much less ground-water runoff occurs in August than in February.

Ground-water runoff generally is at a maximum during spring and early summer months and at a minimum in late summer and fall months. Ground-water runoff often increases in the fall even though the ground-water levels decline because of the rapid decrease in ground-water evapotranspiration during that period. Annual ground-water runoff depends upon antecedent soil moisture and ground-water level conditions as well as the amount and distribution of annual precipitation.

Ground-water runoff to the Crane Creek tributary during 1951, 1956, and 1958 was computed with streamflow data. Precipitation was above normal in 1951, below normal in 1956, and near normal in 1958. In the Crane Creek basin, streamflow consists entirely of ground-water runoff three days after rainfall ceases. During protracted rainless periods, actual streamflow is ground-water runoff. Ground-water runoff under flood hydrographs and during rainless periods was estimated by using streamflow hydrograph separation methods outlined by Linsley, Kohler, and Paulhus (1958).

Daily ground-water runoff was plotted beneath streamflow hydrographs, and lines were drawn connecting points to describe ground-water runoff hydrographs (fig. 44). The shaded areas between streamflow and ground-water runoff hydrographs represent surface runoff. Ground-water runoff was 9.3 inches during 1951 and 2.6 inches during 1956. In 1958 when precipitation was near normal, ground-water runoff was 4.7 inches. Ground-water runoff amounted to 24, 9, and 13 percent of streamflow in 1951, 1956, and 1958, respectively.

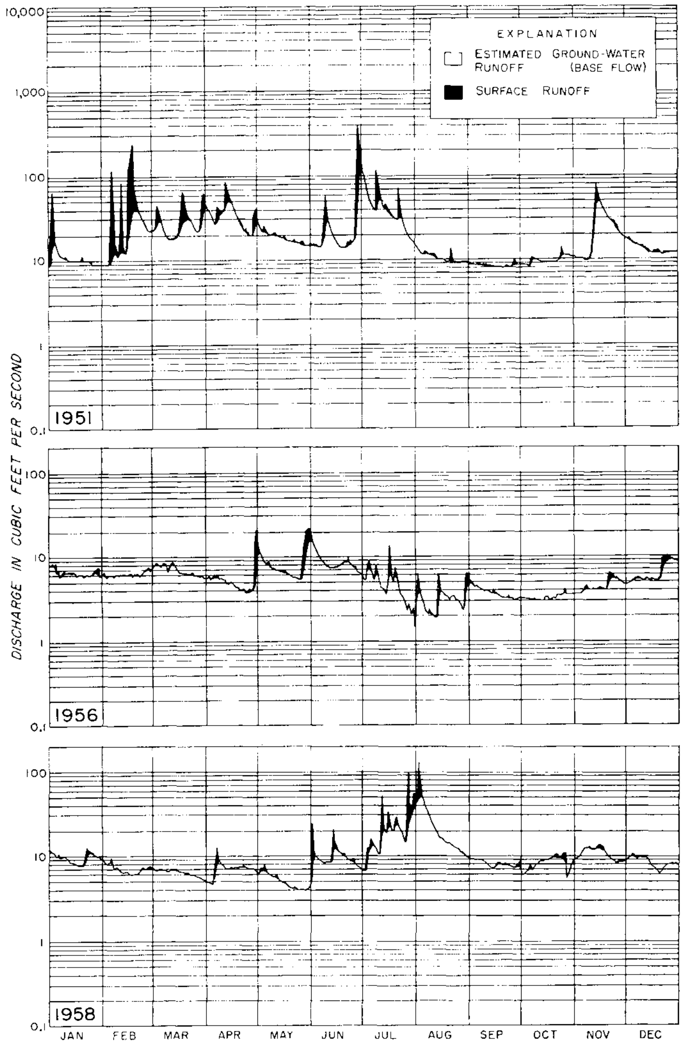


Fig. 44. Streamflow at gaging station, Crane Creek tributary basin, for 1951, 1956, and 1958. Location of gaging station is shown in figure 42.

CONCLUSIONS AND RECOMMENDATIONS

The Havana region has four important assets that could make it of significant economic importance to west-central Illinois.

1. *Water resources.* A large ground-water reservoir with a highly permeable aquifer and favorable conditions for recharge is available. It has not been extensively developed and offers enough water for substantial irrigation projects and for industrial use. The Illinois River and other streams, along with numerous floodplain lakes, provide opportunity for water-based recreation.
2. *Other natural resources.* Coal, sand and gravel, and manageable soils already provide economic benefits to the region, but the land has not been despoiled and has possibilities for much more intensive use.
3. *Location.* The region is close to several large population centers, yet, with the exception of Pekin, has a small population and much open space.
4. *Transportation.* Several railroads, the Illinois Waterway, and a number of major highways give access to the area.

Before the natural advantages of the Havana region can be used successfully, additional studies are needed on the water and mineral resources, agricultural management, industrial possibilities and requirements, population projections and urban needs, and alternative land uses.

In the field of ground-water resources, a highly accurate estimate of the potential yield of aquifers in the Havana region must await improved methods of analysis and more detailed geologic, hydrologic, meteorologic, and engineering data relating to both ground and surface waters. The following programs are recommended.

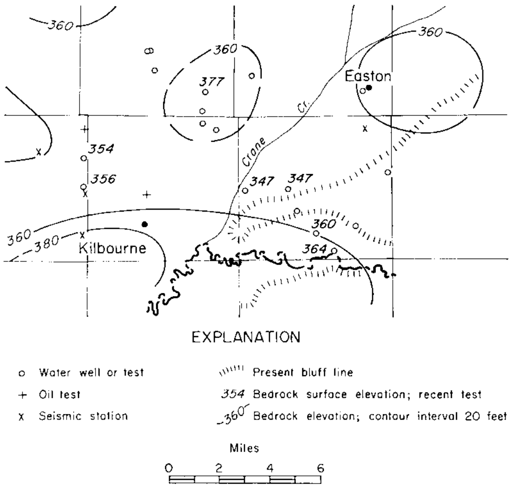
1. A collection of additional data on the physical characteristics of the unconsolidated sediments. Such data could be used in evaluating and extrapolating apparent variations in permeability, defining boundaries of aquifers, and determining recharge and other surficial conditions. Geologic data concerned with the nature of the deposits are especially needed for the Illinoian upland east of Easton and for the tributary valleys to the south.
2. Collection of additional data on depth of bedrock, which are needed for mapping the bedrock surface more accurately and determining the thickness of the unconsolidated deposits.
3. Continuation of the collection of data on water levels and pumpage in all pumpage centers so that ground-water development and its effects on water levels can be periodically evaluated.
4. Maintenance of recording gages on two wells in the southern part of the Havana region and on four wells in the northern part to provide continuous records of the character and magnitude of water-level fluctuations.
5. Further aquifer and well-production testing to provide additional information on the hydraulic properties of aquifers.
6. Measurement of water levels in as many wells as possible throughout the Havana region at least once every 10 years to provide data for the preparation of water-table contour maps.

ADDENDUM

Test drilling that took place in the area roughly between Easton and Kilbourne after this report was in press indicates that bedrock topography differs in some significant details from the interpretation given in figure 10.

The following test holes were drilled in 1964:

Well number	Owner	Surface elevation (ft)	Total depth (ft)	Thickness of drift (ft)	Bedrock surface elevation (ft)
MSN—					
20N7W-34.8b	Miller	482	119	118	364
20N7W-34.6h	Miller	482	122	122	360
20N7W-21.8h	Branson	507	160	160	347
20N7W-19.5g	Lynn	487	140	140	347
20N9W-24.3h	Leithoff	484	133	128	356
20N9W-12.2a	Kolves	488	134	134	354
21N8W-26.2a	Knuppel	497	124	120	377



The location of the test holes and revision of part of the bedrock topography map warranted by the new data are shown on the map on this page.

The map supersedes figure 10 for the area shown. Other modifications that should be made in figure 10 are as follows :

1. Deletion of 320-foot contour.
2. Deletion of 340-foot contour east of and north of Snicarte.

This does not mean that the bedrock surface in the Havana region is entirely above elevation 340 feet; rather, it means that the deep bedrock channel, if present, does not follow the course or have the width outlined by the 340 and 320 contours in figure 10. It is likely that a channel is present, for a few bedrock surface elevations below 320 feet have been discovered along the Mackinaw and Mahomet Valleys north and east of the Havana region. Location of the channel within the area outlined by the 360 contour in figure 10 must await the collection of further data.

Further implications of the recent drilling are that the total thickness (fig. 14) and saturated thickness (fig. 27) of the unconsolidated deposits between Easton and Kilbourne are less than those shown. Minor adjustments might be made in the estimates of volume of saturated sediments and water in storage. However, the new data do not change the over-all appraisal of ground-water conditions or potential of the region.

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APPENDIX

TABLE A. WATER-LEVEL DATA FOR WELLS IN THE HAVANA REGION

Well number	Owner*	Depth *(ft)*	Diameter *(in)*	Type of well †	Date of measure-ment	Depth to water below measuring point *(ft)*	Elevation *(ft above msl)*	
							Water level	Land surface
MSN—								
19N9W-7.2a	C. R. Bell	21	1.25	drv	7-7-60	13.81	462	474
19N9W-11.1h	W. H. Lane	33	1.25	drv	7-7-60	26.65	459	485
19N10W-11.8b	Harold Banks	40	42	dug	7-7-60	35.24	452	485
19N10W-16.8a	S. W. Lucas	29	1.25	drv	7-7-60	13.10	449	465
19N11W-24.4h	Albert Magnus	29	1.25	drv	7-7-60	15.75	443	458
20N5W-8.8f1	Mason City (C)	197	12	D	12-24-60	63.24	517	580
20N7W-3.3a	Myrtle Smith	65	1.25	drv	7-8-60	21.10	492	510
20N7W-22.6d	Howard Ermeling	175	3	D	8-7-60	159.42	483	642
20N8W-1.8c	Fred Kruse	114	18	D	1960	10	489	499
20N8W-2.4e	Ted Kruse	130	18	D	1960	14	490	504
20N8W-4.7e	Lenora Schmidt	17	1.25	drv	7-7-60	8.97	487	494
20N8W-21.4c	Victor Lane	26	1.25	drv	7-7-60	18.09	485	500
20N8W-24.7a	Blaine Close	23	1.25	drv	7-8-60	15.94	474	488
20N8W-32.4a	Glen Hughes	36	1.25	drv	7-7-60	17.32	473	490
20N8W-34.7c	Leonard Stout	38	1.25	drv	9-9-59	27.49	470	490
20N9W-4.8c1	L. F. Connolly	35	1.25	drv	7-7-60	18.34	452	467
20N9W-30.3b	Homer Lascelles	104	18	D	12-59	12	460	472
20N9W-30.4d	Homer Lascelles	26	1.25	drv	7-7-60	14.09	458	468
20N9W-35.1h	C. W. Friend	44	1.25	drv	7-7-60	25.54	476	498
21N5W-3.5h	North Western R.R.	66	5	D	7-26-60	7.97	522	529
21N5W-7.1e	J. F. Watkins	87	6	D	7-27-60	20.06	518	538
21N5W-14.7f	H. B. Smith	67	4	D	7-8-60	50.97	530	581
21N5W-30.2h	Elmer Pierce	99	4	D	7-8-60	78.60	521	600
21N6W-3.3h	Phillip Leinweber	20	1.25	drv	7-26-60	6.21	502	505
21N6W-5.4h	L. J. Pfeiffer	102	6	D	7-26-60	3.33	500	503
21N6W-17.2b	Willis Urish	49	1.25	drv	7-27-60	4.80	505	509
21N6W-23.5e	G. L. Martin	149	6	D	7-27-60	48.35	513	561
21N6W-32.2e	Old County Poor Farm	129	4	D	7-8-60	54.47	505	559
21N6W-35.1b	L. L. Fratzke	89	4	D	7-8-60	67.27	513	580
21N7W-2.1d	E. G. Knuzzel	57	1.25	drv	7-7-60	3.36	495	498
21N7W-4.7g	Frieda Wiemer	27	1.25	drv	7-7-60	19.70	475	494
21N7W-16.1d	H. R. Sinclair	14	1.25	drv	7-27-60	5.09	494	498
21N7W-25.6a	Easton (V)	150	6	D	7-8-60	13.48	498	510
21N7W-27.1h	Joseph Umbach	16	1.25	drv	7-8-60	12.46	491	500
21N7W-30.3f	E. C. Ringhouse	105	18	D	10-59	10	491	501
21N7W-31.3h	John Holstlaw	22.5	1.25	drv	7-8-60	8.73	491	497
21N8W-1.8e	Leslie Henninger	28	1.25	drv	1-6-60	20.90	478	499
21N8W-4.2d	A. N. Larson	21	1.25	drv	7-7-60	19.72	472	489
21N8W-12.7g	Jerry Stephens	48	1.25	drv	7-26-60	21.33	481	501
21N8W-20.1c	H. L. Leiding	32	1.25	drv	7-7-60	8.17	480	487
21N8W-21.4f	Louis Stelter	110	18	D	12-59	10	480	490
21N8W-28.1g	Julius Stelter	122	18	D	1959	13	484	497
21N8W-35.3b	Ted Kruse	122	18	D	12-59	8	489	497
21N8W-36.7b	Jesse Johnson	106	18	D	1-60	6	487	493
21N9W-14.1b	F. C. Speckman	26	1.25	drv	7-7-60	10.99	452	462
21N9W-33.3d	Joseph Sarff	18	1.25	drv	7-7-60	1.40	452	455
22N5W-36.5a	W. S. Palmer	71	5	D	7-26-60	53.90	530	584
22N6W-9.1e	Lewis Warner	46	4	D	8-10-60	13.31	492	505
22N6W-25.5h	Wilford Warner	60	4	D	8-10-60	17.57	497	515
22N6W-28.5h	Nelson Dosier	25	1.25	drv	8-10-60	13.08	497	510
22N6W-33.7b	Earl Pfeiffer	105	18	D	1-60	8	502	510
22N6W-36.1c	Ferd Imig	22	1.25	drv	7-26-60	7.12	510	515
22N7W-3.1h	State of Illinois	31	5	D	7-29-60	22.55	476	499
22N7W-12.1e	Forest City (V)	55	4	D	7-8-60	17.07	484	499
22N7W-17.8a	R. D. LeMasters	42	1.25	drv	7-8-60	38.11	472	506
22N7W-22.4g	Charles Thompson	42	1.25	drv	7-8-60	31.37	471	499
22N7W-23.2d	Theodore Kramer	80	18	D	12-59	13	483	496

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* (C) = city owned; (V) = village owned.

† drv = driven; D =drilled.

TABLE A (Continued)

Well number	Owner	Depth (*ft*)	Diameter (*in*)	Type of well †	Date of measurement	Depth to water below measuring point (*ft*)	Elevation (*ft above msl*)	
							Water level	Land surface
MSN— (*continued*)								
22N7W-24.4e	A. F. Pfeiffer	108	18	D	1-60	9	486	495
22N7W-25.1g	Olin Kennedy	28	1.25	drv	8-9-60	9.65	490	500
22N7W-30.4f	J. B. Martin	28	1.25	drv	7-8-60	13.49	463	474
22N8W-2.2b	S. C. Layman	66	6	D	7-28-60	34.88	440	475
22N8W-21.1b	E. E. Dierker	26	1.25	drv	7-8-60	10.88	451	463
22N8W-29.5a	Loveta Hahn	43	1.25	drv	7-8-60	28.81	457	483
23N6W-26.7a	Lloyd Meeker	24	1.25	drv	8-10-60	20.51	483	501
23N6W-31.1f	R. L. Mitchell	30	1.25	drv	8-9-60	23.30	495	515
23N7W-24.2h	Evert Palmer	59	5	D	7-29-60	50.47	475	523
23N7W-29.4a	F. I. Mitchell	46	1.25	drv	7-28-60	41.95	455	497
PEO—								
7N7E-29.2d1	Archer-Daniels-Midland	73	16	D	10-24-60	4.97	440	443
TAZ—								
22N3W-17.6h	Timothy Swain	270	4	D	8-25-60	164.97	545	710
22N4W-10.4g	H. R. Pieper	142	4	D	8-26-60	95.91	529	625
22N4W-16.8b1	Hiram Walker & Co.	212	6	D	4-20-60	24.5	526	551
22N4W-23.8b	May D. Cole	96	4	D	8-25-60	50.60	534	585
22N4W-29.1a	N. C. Yontz	113	6	D	8-25-60	44.23	536	580
22N5W-1.1d	Don Burns	104	4	D	8-25-60	22.60	517	540
22N5W-7.8f	Bruce Crosby	24	1.25	drv	8-10-60	16.83	498	515
22N5W-10.1d	Thomas Frazel	99	4	D	8-25-60	8.98	513	522
22N5W-13.1e	R. V. Grimmer	23	1.25	drv	8-25-60	7.95	523	531
22N5W-20.1h	Paschal Allan	28	1.25	drv	8-12-60	13.74	510	524
23N4W-29.6d	Ralph Allen	85	2.50	D	8-24-60	52.43	513	565
23N5W-2.5e	C. H. Calhico	60	4	D	8-22-60	15.01	488	503
23N5W-5.4f	Peter Fuelberth	47	60	dug	8-23-60	40.90	470	511
23N5W-7.7b	Johnanna Proehl	22	1.25	drv	8-23-60	9.93	460	468
23N5W-17.1a	Kenneth Everly	14	1.25	drv	8-24-60	8.84	474	480
23N5W-27.1b	Van Nattan	106	4	D	8-25-60	35.96	501	537
23N5W-29.7a	Cary Crawford	102	4	D	8-23-60	51.32	490	541
23N6W-6.4a	Henry Fornoff	64	4	D	8-23-60	56.69	465	522
23N6W-11.8h	Irma Terhune	20	1.25	drv	8-23-60	12.12	460	471
23N6W-16.5a	Glen Talbott	68	4	D	8-11-60	49.19	473	522
23N7W-3.4e	Frank Schachtrup	24	10	bored	8-22-60	5.90	430	436
24N5W-3.7b	Corn Products Co.	98	26	D	5-23-62	37.2	424.0	461.2
					8-1-62	42.2	418.0	
24N5W-3.7c1	Corn Products Co.	98	26	D	5-23-62	40.8	421.8	462.6
					8-1-62	45.9	416.7	
24N5W-3.7c2	Corn Products Co.	99	26	D	5-23-62	40.1	419.1	459.2
					8-1-62	28.0	431.2	
24N5W-3.8a	Corn Products Co.	83	26	D	7-15-60	25	435	460.0
					5-23-62	25.9	434.1	
					8-1-62	29.8	430.2	
24N5W-3.8b	Corn Products Co.	91	26	D	5-23-62	34.3	420.9	455.2
					8-1-62	44.0	411.2	
24N5W-4.1b	Corn Products Co.	90	26	D	5-23-62	25.7	433.0	458.7
					8-1-62	29.7	429.0	
24N5W-4.1c	Corn Products Co.	.....	26	D	5-23-62	26.7	432.0	458.7
					8-1-62	31.7	427.0	
24N5W-4.2b	American Distilling	104	26	D	5-23-62	26.7	433	459.7
					8-1-62	33.7	426	
24N5W-4.3a	American Distilling	85	26	D	5-23-62	32.2	432	464.2
					8-1-62	37.2	427	
24N5W-4.3b1	American Distilling	85	24	D	5-23-62	26.8	432	458.8
					8-1-62	32.4	426	
24N5W-4.3b2	American Distilling	85	24	D	7-10-60	27	433	459.0
					5-23-62	26.0	433	
					8-1-62	30.7	428	

TABLE A (Concluded)

Well number	Owner	Depth *(ft)*	Diameter *(in)*	Type of well †	Date of measure-ment	Depth to water below measuring point *(ft)*	Elevation *(ft above msl)*	
							Water level	Land surface
TAZ—*(continued)*								
24N5W-4.4a	American Distilling	80	20	D	5-23-62	28.3	435	463.3
					8-1-62	…..	…..	
24N5W-9.1g1	Standard Brands Inc.	76	25	D	7-10-60	27.5	433	460.0
					5-23-62	28.7	431.3	
					8-1-62	32.0	428.0	
24N5W-9.1g2	Standard Brands Inc.	88	30	D	5-23-62	47.0	429.4	476.4
					8-1-62	50.4	426.0	
24N5W-9.1g3	Standard Brands Inc.	99	26	D	5-23-62	54.4	428.0	482.4
					8-1-62	56.4	426.0	
24N5W-9.1g4	Standard Brands Inc.	87	8	D	5-23-62	45.0	433.3	478.3
					8-1-62	48.6	429.7	
24N5W-9.1h1	Quaker Oats Co.	51	17	D	5-21-62	11.4	432.8	444.2
					8-1-62	14.8	429.4	
24N5W-9.1h2	Quaker Oats Co.	78	25	D	5-21-62	28.9	433.3	462.1
					8-1-62	31.2	430.9	
24N5W-9.1h3	Standard Brands Inc.	95	26	D	5-23-62	45.8	427.0	472.8
					8-1-62	48.8	424.0	
24N5W-9.1h4	Standard Brands Inc.	75	8	D	5-23-62	25.6	433.4	459.0
					8-1-62	28.5	430.5	
24N5W-9.1h6	Standard Brands Inc.	73	30	D	5-23-62	37.1	427.0	464.1
					8-1-62	38.5	425.6	
24N5W-9.2f	Standard Brands Inc.	78	30	D	5-23-62	26.5	438.6	465.1
					8-1-62	43.5	421.6	
24N5W-9.2g1	Standard Brands Inc.	76	25	D	5-23-62	41.5	425.6	467.1
					8-1-62	47.0	420.1	
24N5W-9.2g2	Standard Brands Inc.	70	25	D	5-23-62	22.5	439.7	462.2
					8-1-62	27.2	435.0	
24N5W-9.2g4	Standard Brands Inc.	81	30	D	5-23-62	27.3	435.1	462.4
					8-1-62	31.2	431.2	
24N5W-9.6a	Commonwealth Edison	62	25	D	5-23-62	29.5	440.0	469.5
					8-1-62	31.5	438.0	
24N5W-9.7a	Commonwealth Edison	72	25	D	5-23-62	30.6	444.4	475.0
					8-1-62	31.6	443.4	
24N5W-9.7c	Commonwealth Edison	60	24	D	5-23-62	22.5	439.5	462.0
					8-1-62	28.0	434.0	
24N5W-9.8a	Commonwealth Edison	63	25	D	5-23-62	26.8	439.7	466.5
					8-1-62	29.3	437.2	
24N5W-9.8b1	Commonwealth Edison	59	25	D	5-23-62	23.7	436.8	460.5
					8-1-62	22.7	437.8	
24N5W-9.8b2	Commonwealth Edison	67	25	D	5-23-62	28.5	439.5	468.0
					8-1-62	40.0	428.0	
24N5W-9.8b3	Commonwealth Edison	64	25	D	5-23-62	29.2	439.3	468.5
					8-1-62	32.7	435.8	
24N5W-9.8c1	Commonwealth Edison	56	25	D	5-23-62	19.7	438.3	458.0
					8-1-62	24.7	433.3	
24N5W-9.8c2	Commonwealth Edison	60	25	D	5-21-62	25.2	436.8	462.0
					8-1-62	27.7	434.3	
24N5W-9.8c3	Commonwealth Edison	61	25	D	5-21-62	27.0	435.0	462.0
					8-1-62	31.0	431.0	
24N5W-9.8c4	Commonwealth Edison	65	24	D	7-10-60	22.5	437	460.0
					5-21-62	20.4	439.6	
					8-1-62	24.5	435.5	
24N5W-10.8h1	Quaker Oats Co.	79	17	D	5-21-62	30.3	434.3	464.6
					8-1-62	33.2	431.4	
24N5W-10.8h2	Quaker Oats Co.	87	18	D	5-21-62	32.1	433.0	465.1
					8-1-62	36.0	429.1	
24N5W-10.8h3	Quaker Oats Co.	90	18	D	5-21-62	37.4	432.0	469.4
					8-1-62	41.4	428.0	
24N5W-20.2h	Pete Bailey	90	4	D	8-22-60	60.25	455	514
24N5W-29.5a	Eidman School	58	4	D	8-23-60	44.28	466	510
24N5W-30.6c	Kenneth Lutz	23	1.25	drv	8-24-60	12.66	457	468
24N6W-1.1a	Archer-Daniels-Midland	68	6-1.25	drv	10-24-60	2.18	433	434
24N6W-9.6e	L. H. Vawter	12	10	bored	10-24-60	5.71	429	435
24N6W-21.7f	B. H. Wise	19	1.25	drv	10-24-60	14.04	441	455
24N6W-23.3h	W. E. Lowry	63	4	D	8-24-60	44.04	440	484
24N6W-33.1h	J. J. Waddell	59	4	D	8-23-60	47.52	453	501
24N7W-25.4h	Marilyn Pallor	36	4	D	8-22-60	7.03	429	436
24N7W-27.6e	Anna Helm	11	8	bored	8-22-60	5.08	430	435

TABLE B. PRODUCTION RECORDS OF LARGE-CAPACITY WELLS IN THE HAVANA REGION

Well number	Owner	Year drilled	Well		Screen			Non-pumping water level (*ft*)	Well-production test			Observed specific capacity (*gpm/ft*)	Remarks
			Depth (*ft*)	Diameter (*in*)	Length (*ft*)	Diameter (*in*)	Slot size (*in*)		Length of test (*min*)	Discharge rate (*gpm*)	Drawdown (*ft*)		
CSS—													
18N12W-14.8h	Beardstown (C)	1959	89	36–16	20	16	.080	19	10	400	6.0	67	Well 2; gravel pack
									10	620	9.3	67	
									10	800	12.6	63	
18N12W-15.2f	Beardstown (C)	1956	86	36–16	25	16	.110	16	60	600	3.7	161	Well 1; gravel pack
									60	800	5.2	154	
									60	1000	6.7	159	
19N9W-31.7b2	Chandlerville (V)	1936	32	36–16	26	16	4 x $^{3}/_{16}$	11.5	1440	154	7.9	20	Concrete casing and screen; gravel pack
LOG—													
20N4W-18.1b	New Holland (V)	1931	74	6	10	6	.014–.024	34	....	40	....	....	North well; natural pack
MSN—													
19N11W-24.8h	Albert Magnus	1956	65	6	10	6	.050	4	180	550	21	26	Natural pack
20N5W-8.8e	Chicago & Alton R.R.	1926	216	10	20	10	.025	53	270	55	5	11	Natural pack
20N5W-8.8f1	Mason City (C)	1916	197	12	12	12	.030	63	5	100±	8.5	10	South well; natural pack
20N5W-8.8f2	Mason City (C)	1928	222	12	12	12	.030	64	5	200±	18.2	10	North well; natural pack
20N8W-2.3h	Ted Kruse	1962	60	8	20	8	2 x $^{3}/_{8}$	4.5	180	60	1.7	35	No. 16-gage iron casing and slotted pipe screen; natural pack
20N8W-2.4e	Ted Kruse	1959	130	36–16	62	16	4 x $^{3}/_{16}$	14	....	....	10	....	Well 1; concrete casing and screen; gravel pack
20N9W-30.3b	Homer Lascelles	1959	104	36–16	54	16	4 x $^{3}/_{16}$	12	....	750	7.3	102	Concrete casing and screen; gravel pack
21N6W-4.3g	L. C. Pfeiffer	1961	102	36–16	20	16	4 x $^{3}/_{16}$	14	270	700	12	58	Concrete casing and screen; gravel pack
21N7W-5.7f	Ray Carpenter	1962	128	36–16	40	16	4 x $^{3}/_{16}$	16.0	270	1480	12.3	120	Concrete casing and screen; gravel pack
21N7W-15.3f	Burnell Steinhauer	1959	119	36–16	50	16	4 x $^{3}/_{16}$	7	....	1400	....	....	Concrete casing and screen; gravel pack
21N7W-15.7f	Burnell Steinhauer	1962	112	36–16	52	16	4 x $^{3}/_{16}$	6.7	360	650	3.7	175	Concrete casing and screen; gravel pack
21N7W-25.6a	Easton (V)	1955	150	6	10	6	.025	13.5	....	....	....	....	Fire protection well; natural pack
21N7W-25.7a	Easton (V)	1960	135	8	15	8	.025	15.5	150	110	3.5	32	Well 1; natural pack
21N7W-30.3f	E. C. Ringhouse	1959	105	36–16	40	16	4 x $^{3}/_{16}$	10	120	1310	20	66	Concrete casing and screen; gravel pack
21N8W-1.8c	Fred Kruse	1959	114	36–16	50	16	4 x $^{3}/_{16}$	10	....	....	....	....	Formerly Ted Kruse well 2 ; concrete casing and screen; gravel pack
21N8W-6.5d	Chicago & Ill. Midland R.R.	1949	92	6	4	6	.030	15	....	50	15	3.4	Natural pack
21N8W-16.1b	Mervin Roat	1962	108	36–16	24	16	4 x $^{3}/_{8}$	7.0	225	850	12.8	67	Concrete casing and screen; gravel pack
21N8W-21.4f	Louis Stelter	1959	110	36–16	60	16	4 x $^{3}/_{16}$	10	....	....	....	....	Well "B" ; concrete casing and screen; gravel pack
21N8W-28.1g	Julius Stelter	1959	122	36–16	56	16	4 x $^{3}/_{16}$	13	180	1000	4.3	230	Concrete casing and screen; gravel pack
21N8W-35.3b	Ted Kruse	1959	122	36–16	60	16	4 x $^{3}/_{16}$	8	....	....	....	....	Well 3 ; concrete casing and screen ; gravel pack
21N8W-36.7b	Jesse Johnson	1960	106	36–16	40	16	4 x $^{3}/_{16}$	6	180	1150	10	115	Concrete casing and screen; gravel pack
21N9W-1.1f1	Havana (C)	1942	85	12	15	12	.040	22	....	950	7	135	Well 2; natural pack
21N9W-1.1f2	Havana (C)	1960	78	12	20	12	.030	24	480	1000	26	38	Well 4; natural pack
21N9W-1.2f	Havana (C)	1952	125	12	35	12	.035	55	300	635	21.5	30	Well 3; natural pack
21N9W-11.2c1	Illinois Power Co.	1946	84	30–18	15	18	.080	29	....	....	....	....	Well 1; gravel pack
21N9W-11.2c2	Illinois Power Co.	1946	83	30–18	15	18	.080	17.6	480	410	10	41	Well 2; gravel pack
21N9W-11.2c3	Illinois Power Co.	1946	79	30–18	15	18	.080	26	480	430	....	....	Well 3; gravel pack
21N9W-11.2c4	Illinois Power Co.	1948	83	30–18	15	18	.080	30	480	500	10	50	Well 4; gravel pack
22N6W-33.7b	Earl Pfeiffer	1960	105	36–16	28	16	4 x $^{3}/_{16}$	8	120	750	6.3	118	Well on Louis Pfeiffer farm; concrete casing and screen; gravel pack
22N7W-23.2d	Theo. & Mabel Kramer	1959	80	36–16	44	16	4 x $^{3}/_{16}$	13	180	1735	12	144	Concrete casing and screen; gravel pack
22N7W-24.4e	Alvin Pfeiffer	1960	108	36–16	40	16	4 x $^{3}/_{16}$	9	180	1150	10	115	Concrete casing and screen; gravel pack
22N7W-24.5g	Alvin Pfeiffer	1962	113	36–16	40	16	4 x $^{3}/_{16}$	11.2	180	600	3.8	158	Concrete casing and screen; gravel pack
22N7W-24.7b	Alvin Busch	1962	105	36–16	40	16	4 x $^{3}/_{16}$	7.0	150	600	5.2	115	Concrete casing and screen; gravel pack
22N7W-25.7h	Mabel Kramer	1962	95	36–16	40	16	4 x $^{3}/_{16}$	5.1	270	1200	12.1	99	Concrete casing and screen; gravel pack
22N7W-27.2c	Glenn Strube	1961	125	36–16	40	16	4 x $^{3}/_{16}$	14.6	180	1200	12.2	99	Concrete casing and screen; gravel pack
22N7W-33.8h	Mason State Tree Nursery	1936	136	6	10	6	.060	28	60	210	23	9.1	Natural pack
									60	235	28	8.4	
22N7W-34.6c	Glenn Strube	1961	127	36–16	40	16	4 x $^{3}/_{16}$	13	240	1225	13	95	Concrete casing and screen; gravel pack

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*(C) = city owned; (V) = village owned.

TABLE B (Continued)

Well number	Owner*	Year drilled	Well		Screen			Non-pumping water level *(ft)*	Well-production test			Observed specific capacity *(gpm/ft)*	Remarks
			Depth *(ft)*	Diameter *(in)*	Length *(ft)*	Diameter *(in)*	Slot size *(in)*		Length of test *(min)*	Discharge rate *(gpm)*	Drawdown *(ft)*		
MSN—*(continued)*													
22N8W-9.2a	Chautauqua Wildfowl Refuge	1938	70	6	7	6	.030	6	90	50	7	7	Natural pack
23N6W-21.3d	Manito (V)	1937	81	10	20	10	.025	33	60	120	2	60	Well 1; natural pack
									60	255	7	36	
PEO—													
7N7E-28.6e1	Toledo, Peoria & Western R.R.	1959	67	8	15	6	.040	5.25	15	280	1.70	165	Test well 12-59; natural pack
									15	327	2.06	159	
									15	378	2.53	150	
									1132	430	3.31	130	
7N7E-28.6e2	Toledo, Peoria & Western R.R.	1959	64	1.25	3	.25	.010	2.86	….	….	….	….	Observation well 6-59; natural pack
7N7E-28.7e	Toledo, Peoria & Western R.R.	1959	64	1.25	3	1.25	.010	5.66	….	….	….	….	Observation well 4-59; natural pack
7N7E-28.8d	Toledo, Peoria & Western R.R.	1959	64	1.25	3	1.25	.010	4.30	….	….	….	….	Observation well 8-59; natural pack
7N7E-29.1d	Archer-Daniels-Midland	1960	75	6	6	5	….	11.22	….	….	….	….	Observation well 6-4-60; slotted pipe screen; natural pack
7N7E-29.2d1	Archer-Daniels-Midland	1960	73	16	20	16	.100	3.5	60	500	9	55.5	Test well 16-1-60; natural pack
									60	750	14	53.5	
									60	1000	20	50	
									3990	985	20.7	47.5	
7N7E-29.2d2	Archer-Daniels-Midland	1960	73	6	6	5	….	4.86	….	….	….	….	Observation well 6-1-60; slotted pipe screen; natural pack
7N7E-29.2d3	Archer-Daniels-Midland	1960	72	6	6	5	….	3.96	….	….	….	….	Observation well 6-3-60; slotted pipe screen; natural pack
TAZ—													
22N4W-16.8a	Hiram Walker & Sons	1960	213	42-18	80	18	.035	43	30	1350	13.2	102	Well 2; gravel pack
									30	1720	17	101	
									540	2250	23	98	
22N4W-16.8b1	Hiram Walker & Sons	1960	212	6	15	6	.014	34	15	112	6.09	18.4	Well 3; natural pack
									15	151	8.28	18.2	
									350	200	11.20	18	
22N4W-16 8b2	Hiram Walker & Sons	1960	209	46-16	80	16	.030	37	60	1525	16	95	Well 1; gravel pack
									60	2250	25	90	
									360	2250	25	90	
23N5W-26.8a1	Green Valley (V)	1948	115	8	8	8	.020	33	60	128	11.3	11.3	Well 1; natural pack
									60	149	13.3	11.2	
24N5W-3.7b	Corn Products Co.	1937	98	38-26	20	26	.080	22	480	1188	14	85	Well 2; gravel pack
24N5W-3.7c1	Corn Products Co.	1939	98	38-26	20	26	.080	31	480	1224	18	68	Well 3; gravel pack
24N5W-3.7c2	Corn Products Co.	1947	99	38-26	20	26	.080	26	480	915	15	61	Well 5; gravel pack
24N5W-3.8a	Corn Products Co.	1937	83	38-26	20	26	.080	19.5	480	1300	23	56	Well 1; gravel pack
24N5W-3.8b	Corn Products Co.	1942	91	38-26	13	26	.080	26	480	960	14	68	Well 4; gravel pack
24N5W-4.1b	Corn Products Co.	1951	90	38-26	20	26	.055	26	480	919	14	65	Well 6; gravel pack
24N5W-4.1c	Corn Products Co.	1955	….	38-26	20	26	….	26	600	900	8	112	Well 7; gravel pack
24N5W-4.2b	American Distilling	1943	104	38-26	18	26	.080	26	480	1500	14	107	Well 1; gravel pack
24N5W-4.3a	American Distilling	1957	85	48-26	20	26	.080	24	480	1400	16	88	Well 5; gravel pack
24N5W-4.3b1	American Distilling	1933	85	24	20	24	….	21	….	2000	….	….	Well 2; natural pack
24N5W-4.3b2	American Distilling	1933	85	24	20	24	….	21	….	1000	….	….	Well 3; natural pack
24N5W-4.4a	American Distilling	1936	80	20	30	20	….	….	360	3000	20.7	145	Well 4; natural pack
24N5W-9.1g1	Standard Brands, Inc.	1928	74	36-25	39	25	….	21	….	….	….	….	Well 3; concrete casing and screen; gravel pack
24N5W-9.1g2	Standard Brands, Inc.	1950	88	48-30	20	30	.105	44	60	1016	8	127	Well 8; gravel pack
									60	1460	14	104	
									465	1016	9	113	
24N5W-9.1g3	Standard Brands, Inc.	1940	99	26	20	26	….	….	….	850	21	40	Well 7; natural pack
24N5W-9.1g5	Standard Brands, Inc.	1926	76	36-25	38	25	….	20	….	450	3	150	Well 1; concrete casing and screen; gravel pack
24N5W-9.2g1	Standard Brands, Inc.	1926	76	36-25	38	25	….	20	….	450	3	150	Well 2; concrete casing and screen; gravel pack
24N5W-9.2g2	Standard Brands, Inc.	1931	70	36-25	43	25	….	25	….	1890	18.2	104	Well 4; concrete casing and screen; gravel pack
24N5W-9.2g3	Standard Brands, Inc.	1935	79	26	20	26	….	27	….	2475	….	….	Well 5; gravel pack
24N5W-9.2g4	Standard Brands, Inc.	1952	81	48-30	20	30	.105	38	540	1064	20	53	Well 9; gravel pack
24N5W-9.1h1	Quaker Oats Co.	1924	51	38-17	25	25	….	17	….	600	6	100	Well 1; concrete screen and casing; gravel pack
24N5W-9.1h2	Quaker Oats Co.	1929	78	42-25	34	25	….	18	….	600	5.5	109	Well 2; concrete casing and screen; gravel pack
24N5W-9.1h3	Standard Brands, Inc.	1940	95	38-26	15	26	.125	46	….	2426	37	66	Well 6; gravel pack
24N5W-9.1h6	Standard Brands, Inc.	1954	73	48-30	20	30	.105	46	540	1000	22	45	Well 10; gravel pack
24N5W-9.2f	Standard Brands, Inc.	1956	78	48-30	20	30	.105	43	450	1036	12.7	80	Well 11; gravel pack
24N5W-9.6a	Commonwealth Edison	1938	62	38-25	26	25	….	26	300	1000	20	50	Well 8A; concrete casing and screen; gravel pack
24N5W-9.7a	Commonwealth Edison	1948	72	38-25	24	25	….	30	330	1025	16.5	62	Well 11; concrete casing and screen; gravel pack
24N5W-9.7c	Commonwealth Edison	1927	60	24	40	24	….	24	….	1609	12.7	125	Well 1; slotted pipe screen; natural pack

TABLE B (Concluded)

			Well		Screen			Non-pumping water level	Well-production test			Observed specific capacity	
Well number	Owner*	Year drilled	Depth *(ft)*	Diameter *(in)*	Length *(ft)*	Diameter *(in)*	Slot size *(in)*	*(ft)*	Length of test *(min)*	Discharge rate *(gpm)*	Draw-down *(ft)*	*(gpm/ft)*	Remarks
TAZ—*(continued)*													
24N5W-9.7d	Commonwealth Edison	1927	64	24	40	24	......	24	......	1360	22.2	58	Well 2; slotted pipe screen; natural pack
24N5W-9.8a	Commonwealth Edison	1940	63	38-25	24	25	......	31	180	1050	15	70	Well 9 ; concrete casing and screen; gravel pack
24N5W-9.8b1	Commonwealth Edison	1944	59	38-25	30	25	......	28	30	1925	13.2	145	Well 6A; concrete casing and screen ; gravel pack
									30	2000	14	143	
									240	1875	15.5	121	
24N5W-9.8b2	Commonwealth Edison	1941	67	38-25	22	25	......	40	240	1300	20	65	Well 7A; concrete casing and screen ; gravel pack
24N5W-9.8b3	Commonwealth Edison	1940	64	38-25	23	25	......	27	180	900	17	53	Well 10 ; concrete casing and screen; gravel pack
24N5W-9.8b4	Commonwealth Edison	1930	57	24	40	24	......	21	360	1700	......	......	Well 6 ; slotted pipe screen; natural pack
24N5W-9.8b5	Commonwealth Edison	1930	67	38-25	38	25	......	34	30	550	3.5	156	Well 7; concrete casing and screen; gravel pack
									30	1000	6.7	148	
24N5W-9.8b6	Commonwealth Edison	1930	67	2	38	2	......	34	......	......	......	......	Driven
24N5W-9.8c1	Commonwealth Edison	1943	56	38-25	25	25	......	32	270	1720	......	......	Well 3A; concrete casing and screen; gravel pack
24N5W-9.8c2	Commonwealth Edison	1943	60	38-25	25	25	......	32	180	1990	......	......	Well 4A; concrete casing and screen; gravel pack
24N5W-9.8c3	Commonwealth Edison	1942	61	38-25	21	25	......	32	120	1730	17	102	Well 5 A; concrete casing and screen; gravel pack
24N5W-9.8c4	Commonwealth Edison	1928	65	24	40	24	......	27	......	1620	19.5	83	Well 3; slotted pipe screen; natural pack
24N5W-9.8c5	Commonwealth Edison	1930	58	24	40	24	......	21	480	1170	21	54	Well 4; slotted pipe screen; natural pack
24N5W-9.8c6	Commonwealth Edison	1930	58	24	40	24	......	25	330	1600	12.7	123	Well 5; slotted pipe screen; natural pack
24N5W-10.8h1	Quaker Oats Co.	1941	79	38-17	25	17	......	32	......	850	11	77	Well 3; gravel pack
24N5W-10.8h2	Quaker Oats Co.	1955	87	38-18	20	18	.080	40	......	869	10	87	Well 4; gravel pack
24N5W-10.8h3	Quaker Oats Co.	1958	90	38-18	20	18	.080	41	......	1056	13	81	Well 5; gravel pack
24N6W-1.1a	Archer-Daniels-Midland	1960	68	6- 1.25	3	1.25	.010	2.18	......	......	......	......	Observation well 6-6-60; located across Illinois River from well 16-1-60; driven

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