COOPERATIVE GROUNDWATER REPORT 6
ILLINOIS STATE WATER SURVEY
ILLINOIS STATE GEOLOGICAL SURVEY
Champaign, Illinois 61820

ASSESSMENT OF A REGIONAL AQUIFER IN CENTRAL ILLINOIS

Charles B. Burris, Walter J. Morse, and Thomas G. Naymik

Prepared in cooperation with
the Illinois Department of Transportation,
Division of Water Resources

STATE OF ILLINOIS
DEPARTMENT OF ENERGY AND NATURAL RESOURCES 1981

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STATE WATER SURVEY STATE GEOLOGICAL SURVEY

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CHAMPAIGN, ILLINOIS **1981**

STATE OF ILLINOIS
HON. JAMES R. THOMPSON, Governor

DEPARTMENT OF ENERGY AND NATURAL RESOURCES
FRANK H. BEAL, M.U.P., Director

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CONTENTS

(Concluded on next page)

CONTENTS *(Concluded)*

PAGE

Appendices

Assessment of a Regional Aquifer in Central Illinois

by *Charles B. Burris, Walter J. Morse, and Thomas G. Naymik*

ABSTRACT

This study of an important regional sand and gravel aquifer in central Illinois is part of an assessment of public groundwater supplies undertaken jointly by the Illinois State Geological Survey and State Water Survey with the support of the Division of Water Resources, Illinois Department of Transportation.

The aquifer has alleviated water problems for several communities in Macon, Christian, Montgomery, and Shelby Counties, which are located in a region with a long history of water shortages. Presently nine municipalities (Macon, Blue Mound, Assumption, Stonington, Taylorville, Palmer, Morrisonville, Harvel, and Raymond) and one industry (Hopper Paper Division, located in Taylorville) obtain all or part of their water supplies from this source. One additional village (Moweaqua) is planning to develop a supply from the aquifer soon.

This study was initiated to determine the adequacy of the aquifer both for present and anticipated future demands. The objectives were to identify the geologic and hydrologic characteristics of the aquifer and to develop a numerical model that would predict the response of the aquifer to future pumpage.

The results of the model indicate that the aquifer is capable of providing the present and future water needs of the communities presently tapping it, with the possible exception of Taylorville. If water levels at Taylorville decline as predicted, Hopper Paper Division and/or Taylorville may be required to reduce pumpage to avoid possible damage to their wells. Updating and expanding the surface water treatment at Taylorville may be a possible solution.

For the south part of the aquifer, the available data suggest that there has been no depletion of the resource due to pumpage. Historical data indicate that the most critical elements of water supply development in the south half of the aquifer are well design and maintenance. Well performance monitoring practices can determine deterioration trends and allow timely remedial actions to be taken.

INTRODUCTION

An assessment of public groundwater supplies, supported by the Division of Water Resources, Illinois Department of Transportation, was undertaken jointly by the State Geological Survey and State Water Survey Divisions, Illinois Institute of Natural Resources. Begun in 1977, it has focused on community water supplies which suffered water shortages during the 1976-1977 drought. This study of an important regional aquifer in central Illinois is part of the assessment.

The region of central Illinois comprising Macon, Christian, and Montgomery Counties has had a long history of water shortages. These counties are covered by thin glacial drift of Illinoian age containing few extensive deposits of water-yielding sand and gravel. The bedrock beneath the drift yields only small amounts of water to wells, and from depths below 250 feet this water may be too highly mineralized for use.

Because of the scarcity of water-yielding sand and gravel deposits and the poor quality and inadequate quantity of water from the bedrock, most large municipal and industrial supplies in central Illinois are obtained from surface water impoundments. In the past many of the smaller communities developed groundwater supplies from local sand and gravel aquifers. These aquifers were adequate when first developed, but after years of operation at increasing withdrawal rates their yields were exceeded. Water shortages resulted and many of the supplies routinely ran short of water each summer.

As a result, development was begun of a promising regional sand and gravel aquifer, which has alleviated water problems for several communities in these counties. This aquifer is a long narrow strip of shallow sand and gravel about 1/2- to 3/4-mile wide and 40 miles long, extending from near Macon, Macon County, to near Raymond, Montgomery County (see figure 1). The aquifer is bisected just south of Taylorville, Christian County, by the South Fork of the Sangamon River, which separates it hydraulically into two parts.

Nine municipalities and one industry presently obtain all or part of their water supply from this source, and one additional village is planning to develop a supply from the aquifer soon.

Purpose and Scope

The limited availability of groundwater in this region has led to concern that the regional aquifer may become overdeveloped as additional supplies are developed and pumpage from existing supplies increases. This study was initiated in an effort to determine the adequacy of the aquifer both for present and anticipated future demands. The objectives were to identify the geologic and hydrologic characteristics of the aquifer and to develop a numerical model that would predict the response of the aquifer to future pumpage.

As has been stated, the north part of the aquifer (from Taylorville to Macon) and the south part (from Taylorville to Raymond) can be considered separate hydrologic entities. Emphasis has been placed on the northern part of the aquifer, which is more productive and has undergone greater development. Information for the south half of the aquifer is limited and was not sufficient for development of a model.

Acknowledgments

This investigation was supported in part by funds provided through the University of Illinois by the Division of Water Resources, Illinois Department of Transportation, Frank Kudrna, Director. John K. Flowe was the contract project manager. General supervision was provided by Keros Cartwright, Head, Hydrogeology and Geophysics Section, Illinois State Geological Survey, and by

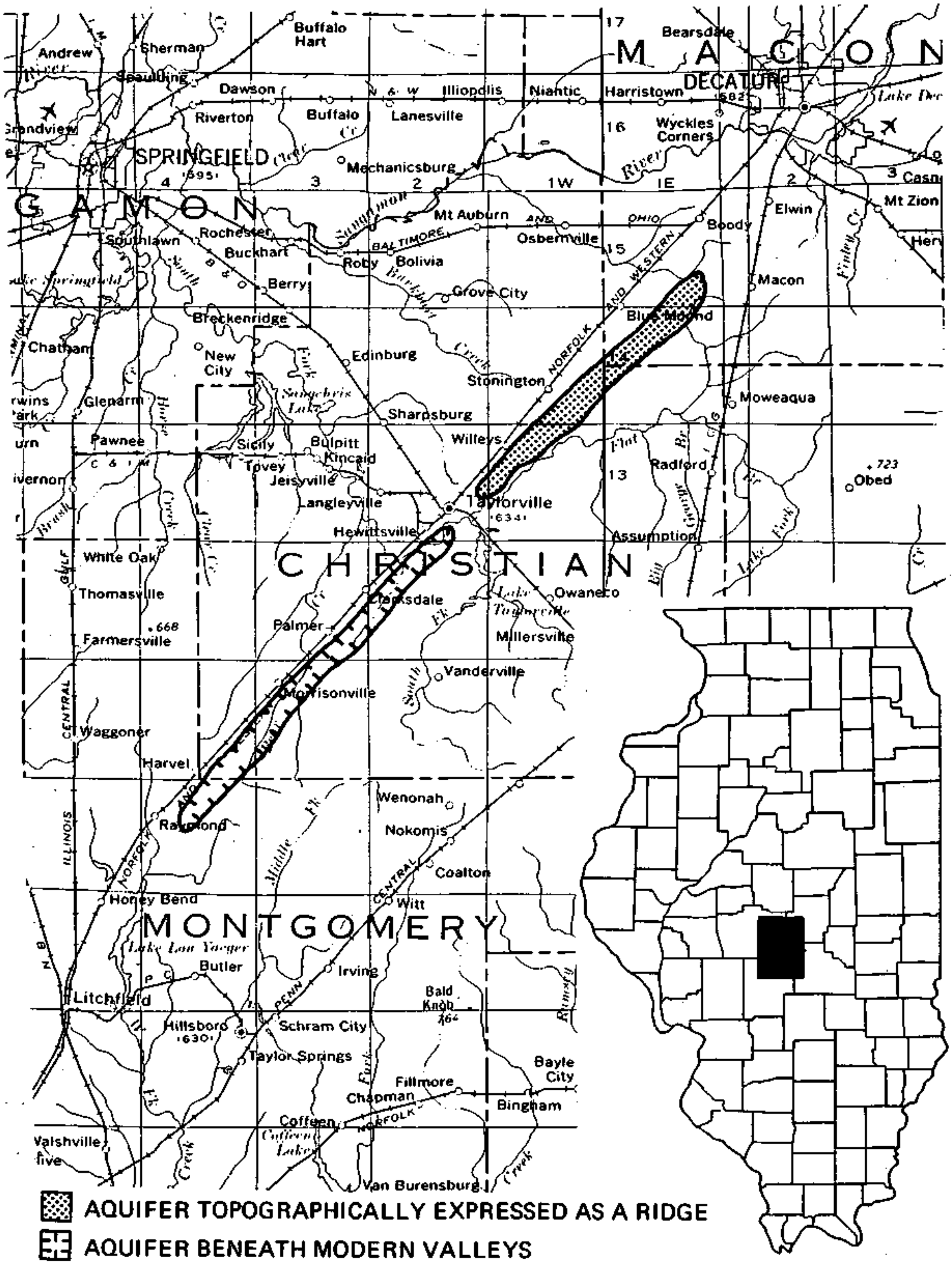


Figure 1. Location of study area

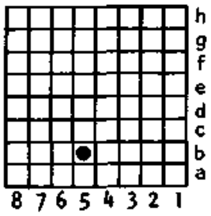
Richard Schicht, former Head, Hydrology Section, and James P. Gibb, Head, Groundwater Section, Illinois State Water Survey. Assistance during the hydrologic evaluation was provided by Adrian Visocky, State Water Survey. Paul Heigold of the State Geological Survey directed the geophysical field studies and helped interpret the results.

Illustrations were prepared by William Motherway, Jr., and Linda Riggin under the supervision of John W. Brother, Jr. Pamela Lovett typed the original manuscript and the camera copy, and Gail Taylor edited the manuscript .

This report would have been impossible without the cooperation of municipal officials, industries, water well contractors, and others who provided useful information, such as data on wells, water levels, and pumpage. Particular thanks go to the Village of Moweaqua for allowing the use of their Well No. 15 for a controlled pumping test. Appreciation is also extended to the landowners who allowed drilling and testing to be done on their property.

Well-Numbering System

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



The number of the well shown in section 25 above is as follows:

CHR 14N1W-25.5b

Where there is more than one well in a 10-acre square, the wells are identified by arabic numbers after the lower case letter in the well number.

The abbreviations for counties discussed in this report are:

Christian--CHR Macon--MCN
Montgomery--MTG

GEOGRAPHY

Area Studied

The general study area shown in figure 1 is a region of central Illinois consisting of portions of Christian, Macon, Montgomery, and Shelby Counties. The aquifer is generally shown in figure 1 as a long narrow strip extending from near Macon in Macon County southwest to Raymond in Montgomery County; it roughly parallels Route 48 and the Norfolk and Western Railroad. The north half of the aquifer is characterized by a low, narrow ridge, while the south half is generally beneath depressions coincident with drainage ways. Municipalities included in the study are Assumption, Stonington, Palmer, Morrisonville, and Taylorville in Christian County; Macon and Blue Mound in Macon County; Raymond and Harvel in Montgomery County; and Moweaqua in Shelby County. Locations of the communities and their well fields are shown in figure 2.

The economy of the study area is based primarily on agriculture. Grain farming is the principal land use;

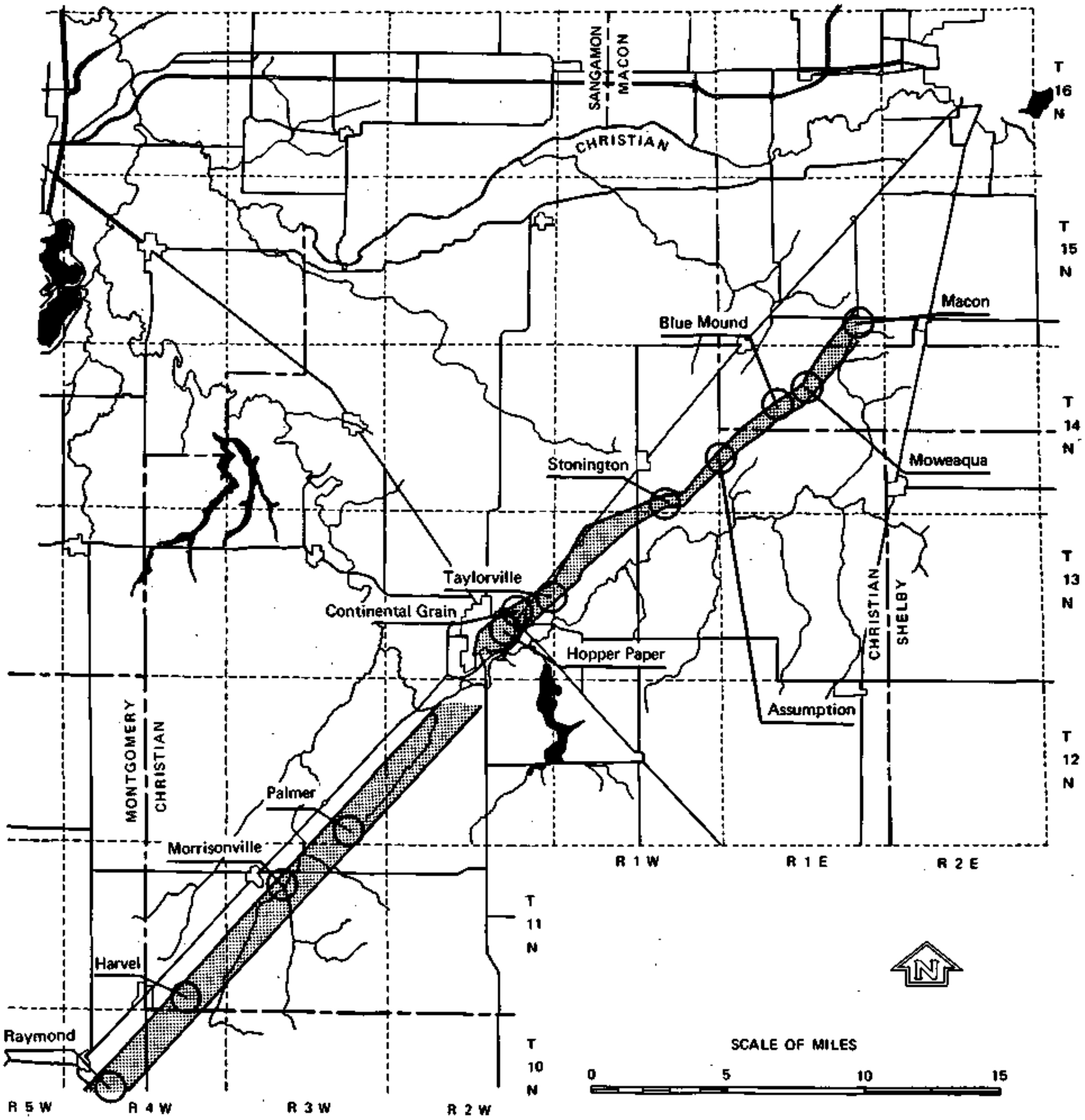


Figure 2. Municipality and well field locations

livestock production makes up a small portion of the farming market. Industry in the area is concentrated in Taylorville, with a few of the villages having small manufacturing plants. The coal, oil, and gas industry is not as important to the study area as it is to other nearby areas.

Climate

Graphs of annual and mean monthly precipitation for the study area are given in figure 3. These graphs were constructed from precipitation data collected by the U.S. Weather Bureau for Morrisonville (1906-1940), Taylorville (1941-1972), and Moweaqua (1972-1980). According to these records the mean annual precipitation is 36.95 inches. The months of greatest precipitation are April, May, June, and August. February is the month of least precipitation, having an average of just less than 2 inches.

A large part of central and southern Illinois, including the Taylorville area, experienced a severe drought beginning in the latter half of 1952 (Hudson and Roberts, 1955). For the period 1952 through 1956, cumulative deficiencies of precipitation at Taylorville were about 23 inches. Other dry periods included 1962-1964 and late 1975-1976. Records at Moweaqua for 1976 indicate a total rainfall of 24.13 inches, which is approximately equal to the lowest annual precipitation expected in 50 years (see below).

The annual maximum and minimum precipitation amounts expected to occur once in 5 and once in 50 years, based on data in Water for Illinois, A Plan for Action (1967), is given below:

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	30	41
Once in 50 years	24	54

The mean annual snowfall is 19 inches. On the average, about 24 days a year have 1 inch or more of ground snow cover, and about 2 days a year have 3 inches or more of ground snow cover.

Based on data collected by the U.S. Weather Bureau for Morrisonville and Decatur, the mean annual temperature is 53.5°F. June, July, and August are the hottest months, with mean temperatures of 73.1°F, 76.5°F, and 75.0°F, respectively, and January is the coldest month, with a mean temperature of 28.5°F. The mean length of the growing season is about 185 days.

Population

In 1980 approximately 22,000 people lived in communities that obtained their water supplies from the aquifer. As shown in figure 4, population for the region has grown from about 11,800 people in 1900 to 22,000 at present. This growth has been steady with the exception of the 1920s and 1950s. At the present time approximately 19,000 people, or 87 percent, live in the north half of the study area and 3,000, or 13 percent, live in the south half. The projected population of the area in the year 2000 is estimated by the Division of Water Resources, Illinois Department of Transportation, to be 27,600.

Tabulations of population for the individual municipalities are given in table 1.

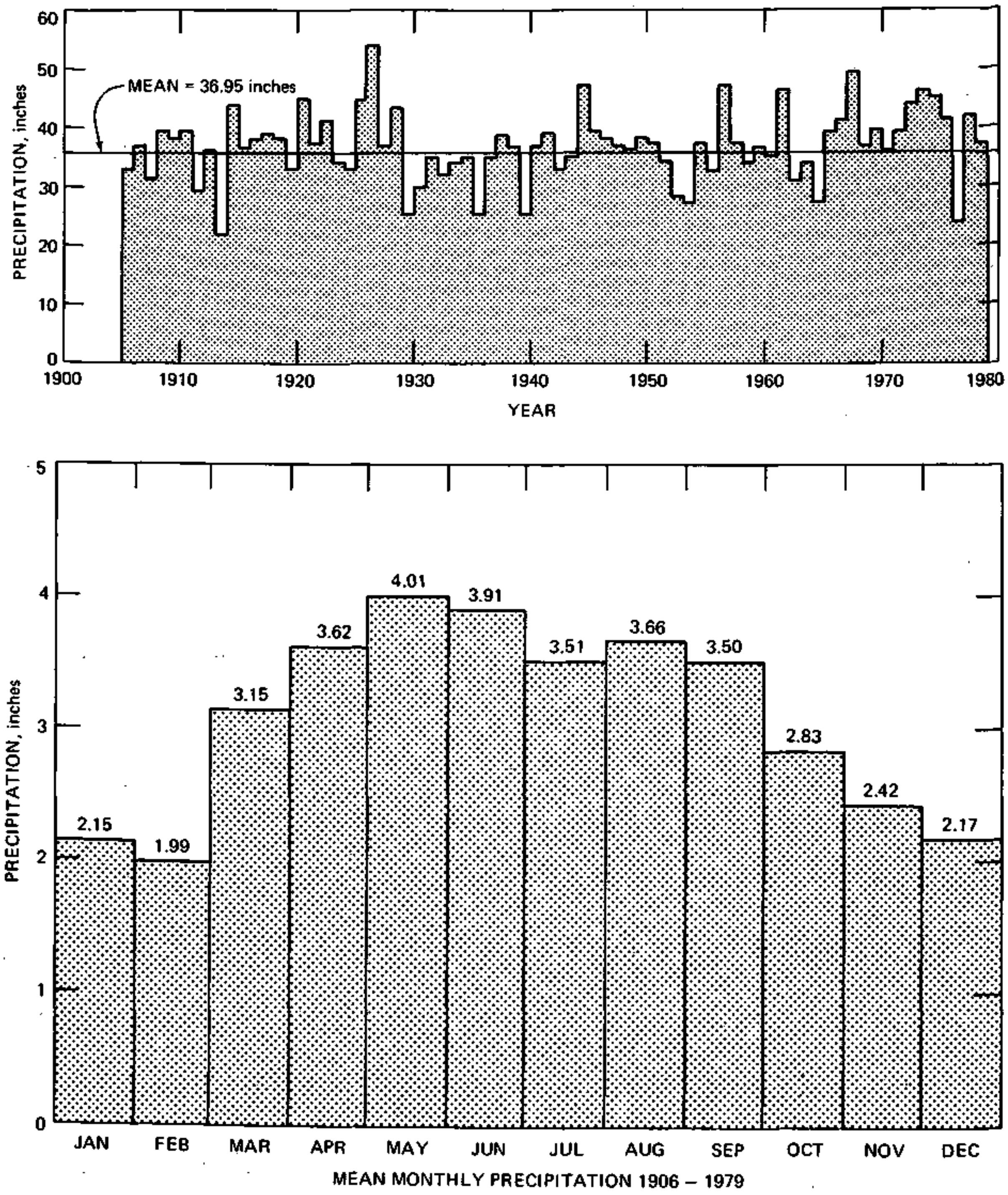


Figure 3. Annual and mean monthly precipitation

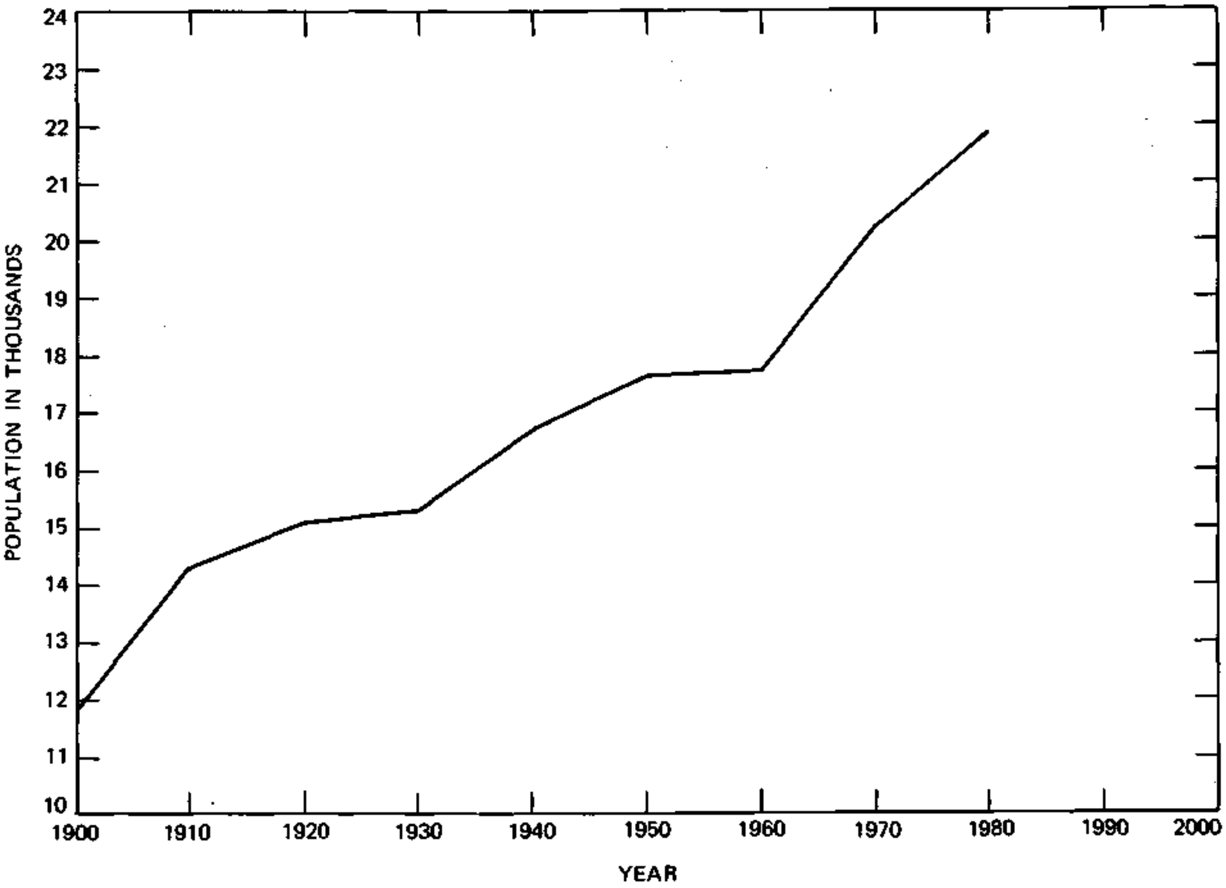


Figure 4. Regional population, 1900-1980

HYDROGEOLOGY

An aquifer is a body of earth materials from which a sufficient amount of water can be extracted for a specific purpose. Nearly all geologic materials will transmit water if saturated, but different materials transmit water at different rates. The amount of groundwater that will be available over a given period of time is dependent on both the potential rate of flow allowed by the hydraulic properties of the geologic material, and the rate at which water from precipitation can be added to that material. The replenishment of water to a geologic material is called recharge.

The availability of groundwater is also influenced by the hydraulic properties of the materials surrounding the aquifer. Thus, to determine the yield potential of an aquifer, it is important to know the nature and the geometry of the aquifer itself and to understand the nature and distribution of the surrounding materials.

The upper bedrock strata in central Illinois consist of a thick sequence of sedimentary rocks composed of layers of shale, siltstone, sandstone, limestone, and dolomite, with some relatively thin layers of coal. The upper bedrock units in central Illinois usually yield little water. Water obtained from deeper units is usually very mineralized and not suitable for most purposes.

After deposition of the youngest of these units, erosion of the bedrock

Table 1. Population of Municipalities Tapping the Strip Aquifer

	Population									
	1900	1910	1920	1930	1940	1950	1960	1970	1980	Est. 2000
Macon Co.										
Macon	705	683	788	800	875	942	1,229	1,249	1,211	2,021
Blue Mound	714	900	881	817	811	886	1,038	1,181	1,229	1,713
Christian Co.										
Assumption	1,702	1,918	1,852	1,554	1,561	1,466	1,439	1,487	1,619*	1,589
Stonington	438	1,118	1,466	1,057	1,103	1,120	1,076	1,096	1,195*	1,260
Palmer	299	404	312	281	326	335	265	244	253*	289
Morrisonville	934	1,126	1,178	968	1,206	1,182	1,129	1,178	1,267*	1,354
Taylorville	4,248	5,443	5,806	7,316	8,313	9,188	8,801	10,926	11,992*	15,256
Montgomery Co.										
Raymond	966	881	868	726	818	779	871	890	976*	1,278
Harvel	357	396	351	322	319	301	285	275	392*	322
Shelby Co.										
Moweaqua	1,478	1,513	1,591	1,478	1,366	1,475	1,614	1,687	N.A.	2,518
Totals	11,871	14,382	15,093	15,319	16,698	17,674	17,747	20,213	22,000E	27,600

* Figures obtained from West Central Regional Planning Commission, Carlinville, Illinois; all other figures from U.S. Census Bureau

N.A. = Not available

E = Estimated

Estimated Year 2000 pumpage from Illinois Division of Water Resources

surface left a well-developed system of valleys, which was subsequently buried during the Pleistocene ("Ice Ages"). Within the study area the bedrock surface contains small tributary valleys reflecting previous drainage toward a major valley just north of the mapped area (figure 5). The major bedrock feature within the study area is a north-trending valley in the center of the map. The bedrock surface topographic map in this report includes minor revisions of Horberg's map (1950).

The location and the configuration of the aquifer are independent of the underlying bedrock surface topography. However, the base of the aquifer is locally in direct contact with the bedrock surface, and there is some indication that bedrock topography may have had an influence on some minor bends in the otherwise straight feature.

Glacial deposits within the study area, which cover the bedrock surface, range in thickness from about 20 feet in the southeast to greater than 200 feet in the northeast. Although no bedrock exposures occur in the mapped area, there are a few bedrock outcrops along the South Fork of the Sangamon River immediately to the south and southwest.

Glacial deposits were left by several pulses of continental glaciers during the Pleistocene. Most of this material is a mixture of clay, silt, sand and gravel, called glacial till, which was deposited directly by the ice. Glacial till deposited by a specific glacier generally has similar physical and compositional properties, which are identifiable over a broad area. The stratigraphy of the glacial deposits was established by correlating till units utilizing these properties and/or by determining the relationship of a geologic unit to other identifiable units or maker horizons.

In addition to till, glacially-derived material includes outwash deposited by meltwater from glaciers.

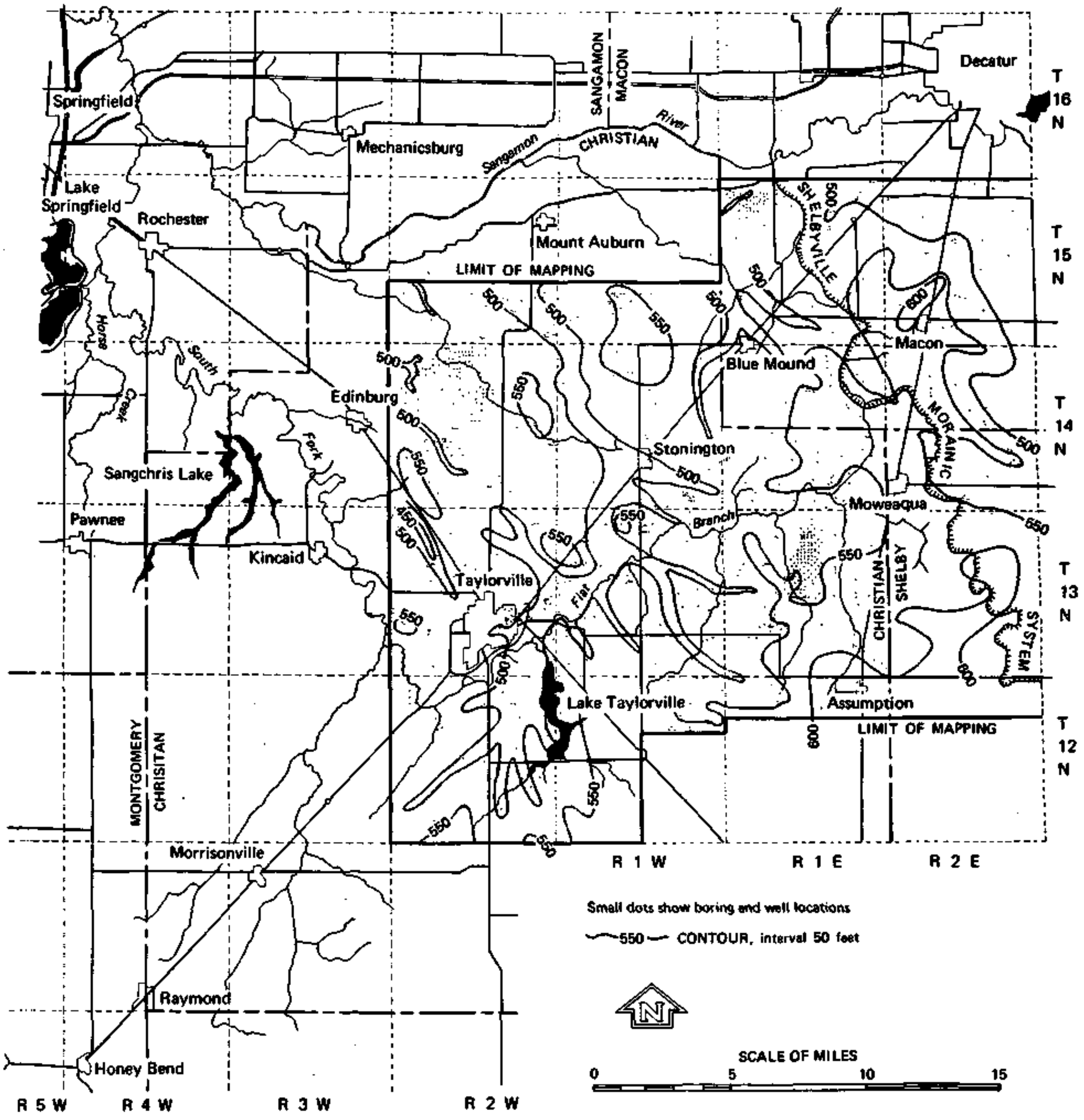


Figure 5. Bedrock topography

Outwash is deposited in direct association with the ice, as outwash plains along the ice margins or as valley train deposits from streams emanating from the glacier. Outwash deposits are frequently valuable aquifers, as is the aquifer described in this report.

A melting glacier develops a hummocky surface, with streams and ponds which leave water-laid deposits ranging from well-sorted to very poorly sorted. These frequently are intercalated with till or mudflow deposits. This type of material is called ice contact drift, ablation drift, or ablation till.

Methods of Geologic Study

The Illinois State Geological Survey and Water Survey files include water well driller's logs, engineering boring logs, driller's logs from oil, coal and gas exploration borings, outcrop descriptions made by Survey personnel, and electrical earth resistivity surveys. The Geological Survey also maintains an extensive samples library with water well drilling cuttings, cores from various types of borings, and outcrop samples. Pertinent samples were studied to add to the information base for the area.

The information was organized on base maps and was used to make preliminary evaluations and to determine where additional data were most needed.

Geophysics

Electrical earth resistivity surveying was employed to determine the dimensions and relative water-producing potential of the aquifer. All resistivity data gathered in this study were obtained from vertical electrical soundings (VES) using the Wenner electrode configuration.

The types of information most often desired from VES curves are the layering parameters, that is, the thickness and "true" resistivities of the strata immediately below the center stake of the VES profile. Several rather ingenious techniques offering a degree of objectivity in the determination of layering parameters from VES curves are available. One such technique, developed by Zohdy and Bisdorf (1975), was used in this study. It should be noted, however, that this technique, like most of the others, provides only one of a host of geoelectrically equivalent layering parameter solutions for a given VES curve. This shortcoming was greatly lessened by some prior knowledge of the geologic conditions in the study area.

The electrical earth resistivity data used in this study included data from the files of the Hydrogeology and Geophysics Section of the Illinois State Geological Survey and data specifically collected for this study. The former data consist of VES profiles gathered in a search for groundwater supplies for communities and industries located along the deposit. The latter data consist of a series of lines of VES profiles (close to 200 individual VES profiles) across the study area. The positions of several of these lines were chosen so that individual VES profiles were collocated with wells for which driller's logs, samples, and pump-test data are available. Wenner electrode configuration a-spacings in many of the VES profiles were as great as 200 feet. In all VES profiles the a-spacings were expanded to the extent that the associated VES curves adequately represented the sand and gravel aquifer where present.

Figure 6 shows a typical VES curve and one of its layering parameter solutions determined by the Zohdy and Bisdorf technique. This VES profile was centered very close to the Village of Assumption Well No. 11 (30 feet south and 1236 feet east of the northwest corner of Section 30, T. 14 N., R. 1 E., Christian County). Also shown is the driller's log from Assumption Well No. 11. Comparison of the layering parameters with the driller's log shows an uppermost layer with a "true" resistivity value of 138 ohm-feet corres-

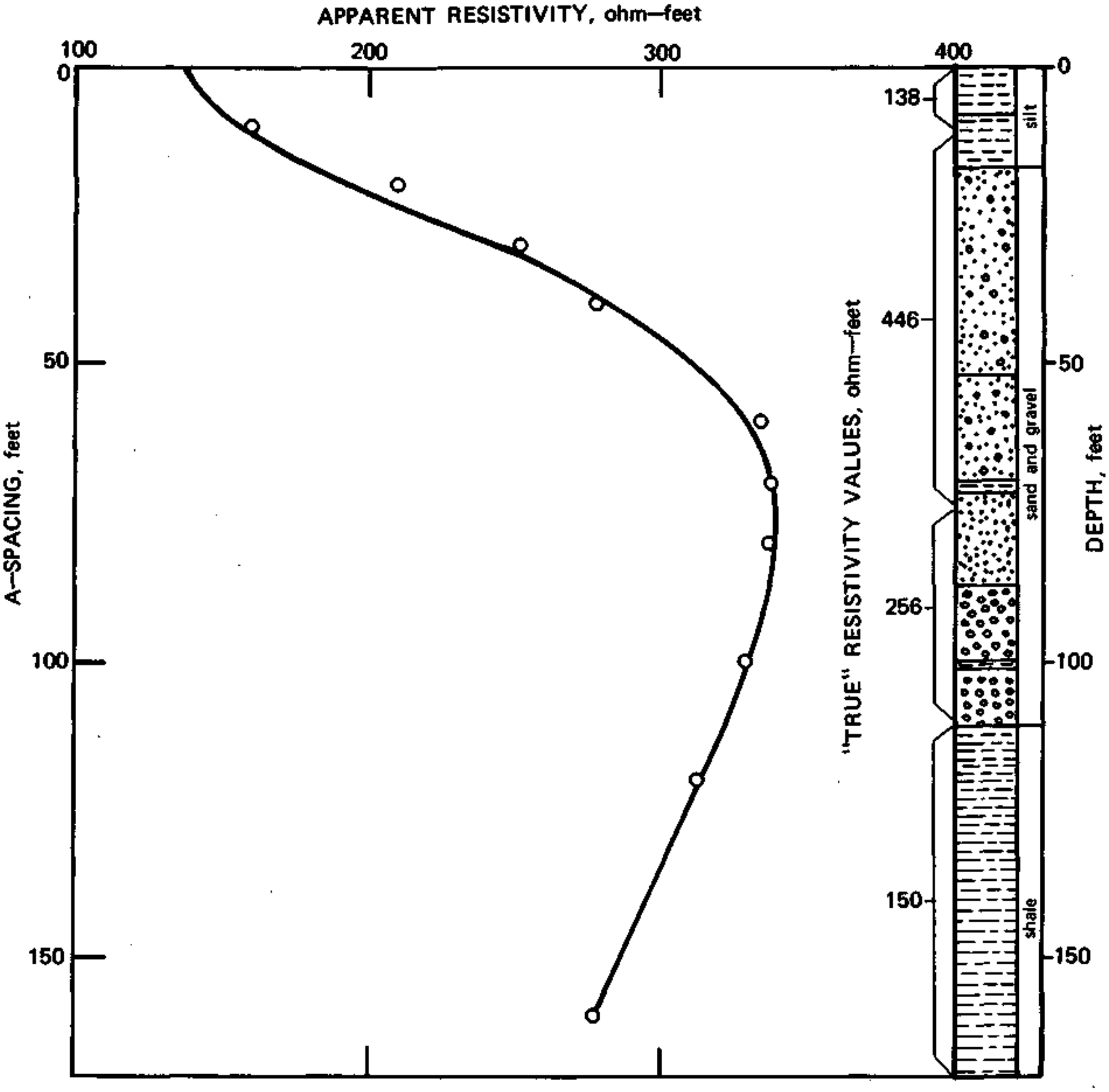


Figure 6. Vertical electrical sounding (VES) curve near Assumption's well field

ponding to the surficial fine-grained sediments. The intermediate layers of 446 and 256 ohm-feet correspond to a zone of sands and gravels. Finally, the lower layer with a "true" resistivity of 150 ohm-feet corresponds to shale bedrock.

The physical boundaries and the relative water-producing potential of the aquifer were defined rather well by the electrical earth resistivity methods. A second report dealing specifically with this aspect of the study will be forthcoming.

Drilling, Testing, and Mapping Procedures

Twenty borings were made to collect additional data for the study. The results of these borings, which are numbered TA-1 through TA-20, are included in appendix 1. Auger cuttings were collected from 0 to 8-1/2 feet.

Below 8-1/2 feet, the borings were advanced by rotary drilling, washing cuttings to the surface with water or, when necessary, with bentonite mud. Cuttings were collected at 5-foot intervals, and split-spoon samples were taken approximately every 10 feet. The sampler used is a standard 2-inch O.D. split-spoon which was driven 18 inches with a 140 pound hammer. Suitable samples were tested with a pocket penetrometer in the field.

After each boring was completed, a Logmaster downhole, geophysical logger was used to obtain self-potential, single-point resistivity and natural gamma ray logs of the boring walls. A generalized natural gamma configuration is included with each boring log in appendix 1.

After the drilling program had been completed, the samples were taken to the Geological Survey laboratories for more detailed study and testing. Selected samples of the aquifer were sieved to determine grain-size properties of the deposits. The results of these tests are reported in appendix 2. Grain-size analyses were run on selected fine-grained samples, both to characterize the nature of the materials confining the aquifer and to aid with the stratigraphic correlation of till units. The pipette method was used for this test. X-ray analyses of the clay fraction of selected samples were made as an additional tool for characterization and stratigraphic correlation of till units. The procedures used have been outlined by Killey (1980).

Carbon-14 analyses were made on two organic samples by the Geological Survey, using a benzene liquid scintillation technique.

Final maps, figures, and interpretations were made from the above types of information. Aquifer thickness and configuration were determined principally from TA borings, electrical resistivity surveys, water well logs and samples, and, to some extent, sieve data and geomorphic interpretations. Most of the bedrock topography interpretations were made from TA borings and oil and gas well logs, with significant contributions from samples and logs of water wells. The cross sections were drawn from TA borings and some water well logs and samples.

Geology

Bedrock Stratigraphy

The upper bedrock strata in the study area are Pennsylvanian in age. The uppermost bedrock formation in most of the area is the Bond Formation, which is generally less than 200 feet thick here. North of Macon, less than 100 feet of the Mattoon Formation overlies the Bond. Both of these formations are composed primarily of fine-grained materials and yield insignificant amounts of water either to wells or as recharge to other aquifers.

Pleistocene Stratigraphy

Central Illinois was crossed by continental ice sheets several times during the Pleistocene. A thick succession of Pleistocene units presently covers the bedrock in the study areas (figures 7 and 8). The oldest Pleistocene units encountered in the study area are referred to in this report as till units E and D (figure 7). These units are included in the Banner Formation and are deposits from pre-Illinoian age ice sheets.

Till unit E, the oldest and deepest unit, was encountered in borings 7, 9, 12, 13 and 15. It is a brownish-gray, silty till with a textural average for eight samples of 19 percent sand, 60 percent silt and 21 percent clay (disregarding one anomalously sandy sample in TA-7). The average clay mineral assemblage for nine samples is 18 percent expandables, 49 percent illite, and 33 percent chlorite plus kaolinite. Till unit E is usually slightly darker than the overlying till unit D. Unit E does not have the pink tinge which is frequently noticeable in D, but it does have variably colored, basal inclusions of underlying shale material. Till

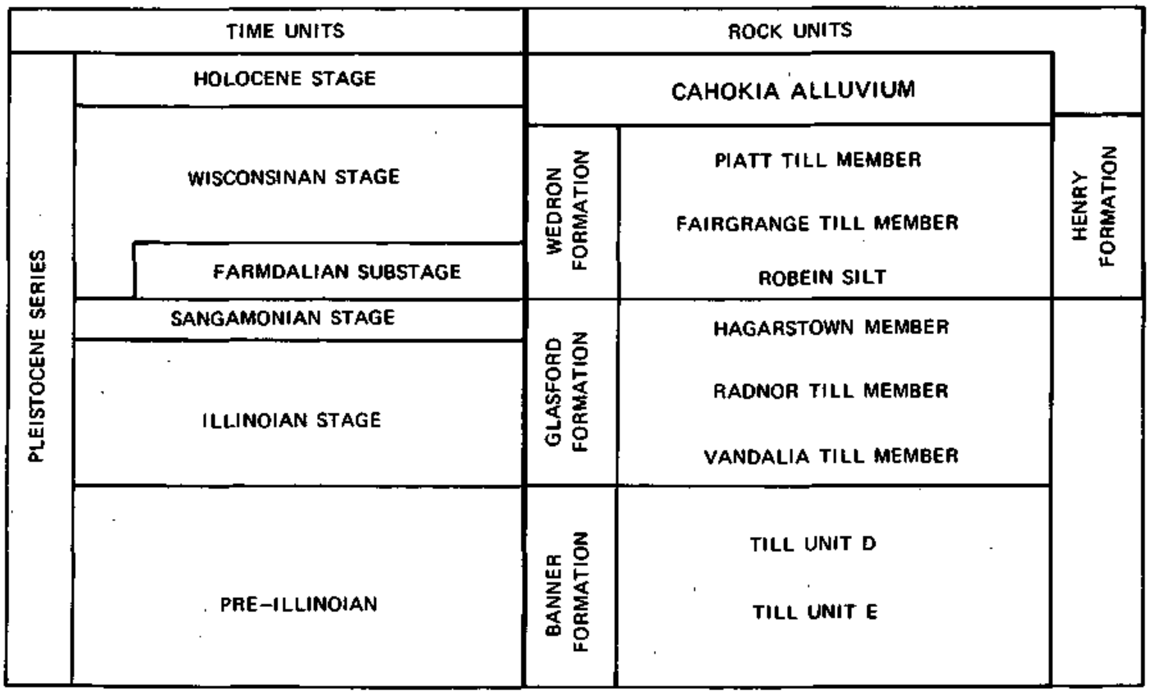


Figure 7. Pleistocene units in the study area

unit E is consistently lower in illite than till unit D, and on the average is higher in both of the other clay components. Texturally, till unit E is slightly less sandy than till unit D.

Correlation of till unit E with a named till outside the study areas is uncertain. There may be a relationship between till unit E and the Hegeler Till Member in east-central Illinois (Johnson et al., 1972; John P. Kempton, Illinois State Geological Survey, personal communication). However, long-distance correlation of these tills, which include basal incorporation of significant amounts of shale, may be questionable (H. D. Glass, Illinois State Geological Survey, personal communication). Stratigraphic control is inadequate in this case.

Till unit D, which was found in ten of the twenty borings, overlies till unit E and is beneath the Vandalia Till Member. In one boring, TA-14, till unit D was directly over bedrock and till unit E was absent. Frequently, a sand layer was found between the two tills. In TA-11, a thick sand occupied the entire interval between till unit D and the bedrock. In TA-10, a well-developed paleosol was sampled beneath till unit D. Unfortunately, samples between the buried soil and bedrock were too poor to allow determination of the geologic unit in this interval.

Till unit D is a pinkish, brownish-gray to grayish-brown, silty till. The pink tinge, although not always present, helps distinguish the unit from tills above and below. The average texture for seventeen samples was 29 percent sand, 53 percent silt, and 18 percent clay (two anomalous samples were deleted: one from TA-9 and one from TA-11). The average clay mineral percentages for ten unoxidized samples were 8 percent expandables, 66 percent illite, and 26 percent chlorite plus kaolinite. Till unit D has a much larger percentage of illite than till unit E. Till unit D is distinguished from the Vandalia Till Member above by a lower sand content and sometimes by a color change. Some samples are very high in calcite. Till unit D commonly contains silt and sand seams.

As with till unit E, correlation with other named till units surrounding

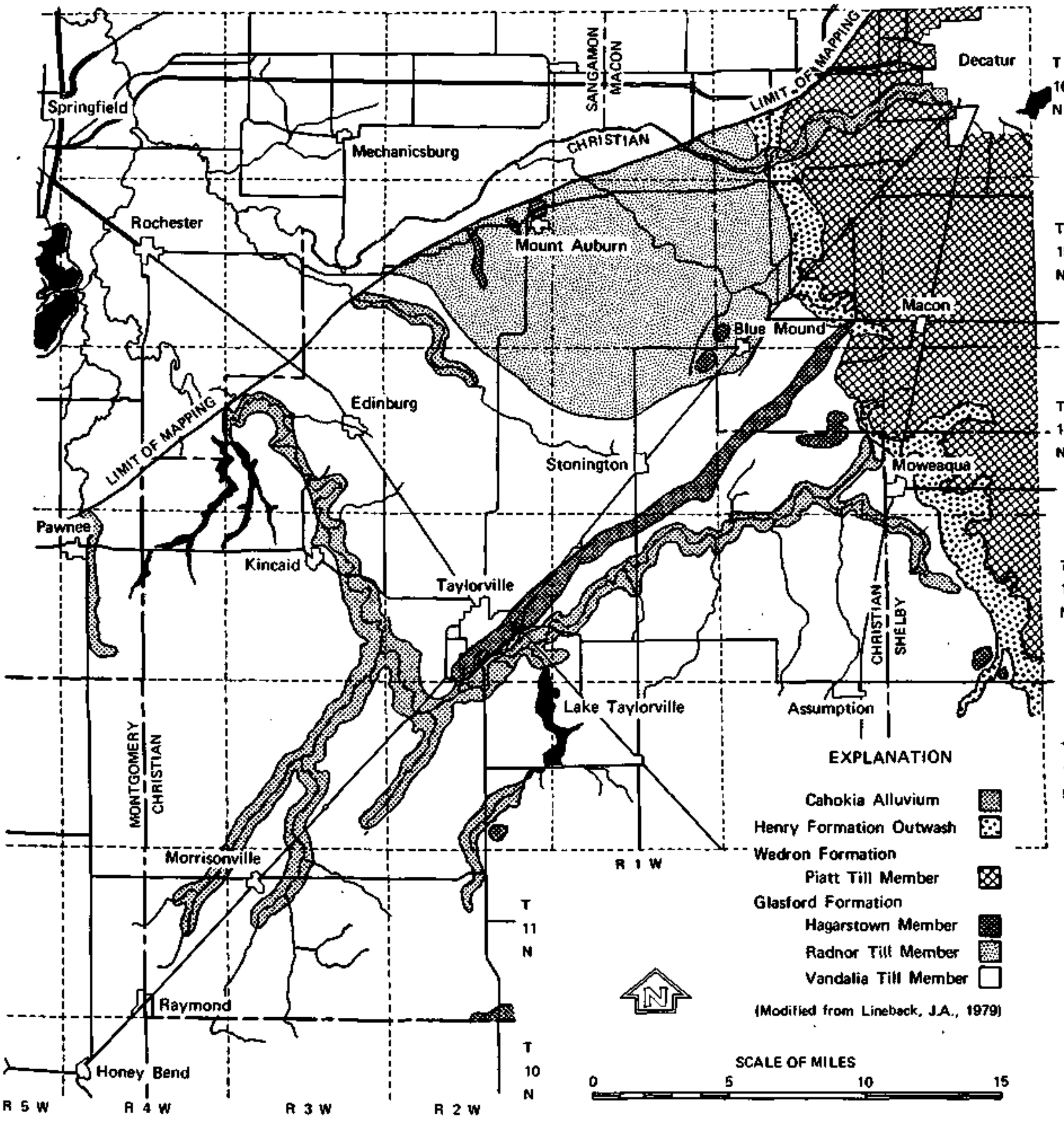


Figure 8. Pleistocene surficial deposits

the study area is uncertain. A possible relationship to the Hillery or Tilton Till Members in east-central Illinois is suggested (Johnson et al., 1971, 1972; John P. Kempton, Illinois State Geological Survey, personal communication) .

The uppermost till of the area is correlated with the Vandalia Till Member of the Glasford Formation (figure 7) and is Illinoian in age. The Vandalia Till lies directly beneath the loess in most of the mapped area. It overlies either till unit D or sand except in TA-5, where it lies directly on shallow bedrock.

The Vandalia Till is a brownish-gray, sandy till containing many thin sand seams, particularly in the upper part. The textural average of the samples is 42 percent sand, 44 percent silt, and 14 percent clay. The clay mineral averages are 11 percent expandables, 68 percent illite, and 21 percent chlorite plus kaolinite.

The Vandalia Till is distinguished from till unit D by its sandy texture, sometimes by color, and to some extent by a higher dolomite content. The natural gamma log configuration of the Vandalia Till usually indicates less radiation than from other tills. In fact, the existence of the Vandalia Till in TA-17 between split-spoon samples is inferred from the gamma log and from stratigraphic probability based on surrounding borings.

In the northern fringe of the mapped area, the Vandalia Till is beneath the Radnor Till Member of the Glasford Formation and/or the Piatt Till Member of the Wedron Formation (figures 7 and 8) of Wisconsinan age. The Vandalia Till is distinguished from the overlying Radnor by its sandier texture, lower illite content, higher expandable content, a change in the vermiculite index (see TA-6), and to some extent by a stronger brownish tint. There is frequently a sand layer between these two tills, as found in TA-6 and in previous studies (Kempton et al., in press).

The Vandalia Till is distinguished from the Piatt Till in the study area by a sandier texture, lower illite content, higher expandable content, and frequently by a paleosol between them.

The Vandalia Till is fairly thin in the study area and is missing in eleven borings where it has been removed by erosion and replaced by the sand and gravel of the aquifer.

The Radnor ice sheet advanced a short distance into the mapped area, depositing the Radnor Till Member of the Glasford Formation (figure 8). There is some evidence that the time interval between deposition of the Vandalia and Radnor Tills was short. In fact, the Radnor ice sheet may have overridden the Vandalia ice before the melting of that ice was complete.

The Radnor Till was encountered during this study only in TA-6. Three Radnor Till samples from this boring have an average texture of 33 percent sand, 47 percent silt, and 20 percent clay. Clay mineral averages are 3 percent expandables, 77 percent illite, and 20 percent chlorite plus kaolinite. The Radnor Till is less sandy than the Vandalia Till; mineralogically, it has a higher illite content and a lower percentage of expandables than either the underlying Vandalia Till or the overlying Piatt Till Member of the Wedron Formation. The vermiculite index of the Radnor Till is also distinct from the Vandalia and Piatt Tills. The Radnor Till is gray rather than the brownish-gray of the Vandalia Till.

The top of the Radnor Till and the base of the Piatt Till are separated in TA-6 by a well-developed paleosol, the Farmdale-Sangamon Soil. The same paleosol was found developed in the top of the Hagarstown Member, beneath the Piatt Till, in TA-3.

The Hagarstown Member, currently assigned to the Glasford Formation, consists of ice-contact deposits associated with Illinoian ice sheets. The Hagarstown is the uppermost member of the Glasford and has been generally restricted to hills and ridges on the Illinoian till plain, frequently referred to as "ridged-drift" (Jacobs and Lineback, 1969; Lineback, 1979). The composition of the Hagarstown varies from clean sand and gravel to till.

Many of the Hagarstown deposits trend in a northeast-southwest direction. The aquifer studied in this report is a Hagarstown deposit forming a nearly continuous ridge of sand and gravel with the characteristic northeast-southwest trend. The sand and gravel were deposited by a meltwater stream which was initially channeled upon or within the Vandalia ice sheet by a large linear ice crevasse. The stream cut a deep, narrow valley, reaching bedrock at some locations. The sand and gravel are probably in contact with the bedrock surface throughout most of the length of the deposit.

Between Taylorville and Macon, the top of the sand and gravel is up to 30 feet higher than the surrounding Illinoian till plain. South of Taylorville, the aquifer lies beneath modern stream valleys. The alignment of the north and south segments of the deposit suggests a common erosional history of the original valley now occupied by the aquifer. The differences in productivity and in geomorphic expression between the two halves suggest a difference in depositional history of the aquifer material. The Vandalia ice sheet must still have existed north of the South Fork of the Sangamon River during deposition, forming valley walls higher than the present land surface, while to the south the ice had probably melted or become very thin by the time deposition occurred. Whether the Radnor ice sheet reached its southern terminus during or after formation of the aquifer has not been established.

After deposition of the tills and associated outwash of the Glasford Formation, a warming trend evolved into a major interglacial stage, the Sangamonian. During this warm stage a well-developed paleosol formed, known as the Sangamon Soil.

As the Sangamonian Stage came to an end, continental ice sheets again pushed southward into Illinois. During the early Wisconsinan glaciation a thin deposit of loess covered the Sangamon Soil in the study area. Before any Wisconsinan ice reached the study area a major glacial retreat occurred, known as the Farmdalian Substage, that allowed further soil development on the land surface. In the study area the Farmdale Soil developed through the thin loess and into the Sangamon Soil. The organic-rich silt portion of the Farmdale Soil is known as the Robein Silt. Carbon-14 dates on the materials from the upper part of the Farmdale-Sangamon Soil found in TA-6 and TA-3 are, respectively, 21,250±170 and 20,870±130 years-before-present.

Late Wisconsinan ice reached the northeast corner of the mapped area, leaving the very prominent Shelbyville Morainic System to mark the approximate southernmost position of the ice front (figures 8 and 9). The till which composes the Shelbyville moraines in the study area is classified as part of the Wedron Formation and is correlated with the Piatt Till Member. The Fairgrange Till Member (figure 7) was not encountered in the study and may not be present. However, it has been mapped beneath the Piatt Till immediately north of the study area (Lineback, 1979) and is mentioned here because it may be present beneath the Piatt at the northern edge of the study area.

The Piatt Till was encountered in borings TA-3 and TA-6. The textural average of eleven samples, disregarding two anomalous samples, is 30 percent sand, 48 percent silt, and 22 percent clay. Clay mineral averages of twelve samples, with one oxidized sample in TA-6 deleted, are 7 percent expandables, 73 percent illite, and 20 percent chlorite plus kaolinite.

The Piatt Till is a gray till, distinguished from the underlying Radnor Till by a slightly lower illite content and a change in the vermiculite index. The paleosol at the base, found in TA-3 and TA-6, is frequently a good marker bed, as has been previously discussed.

The Henry Formation is outwash associated with Wedron ice sheets, and lies on top of or downslope from exposures

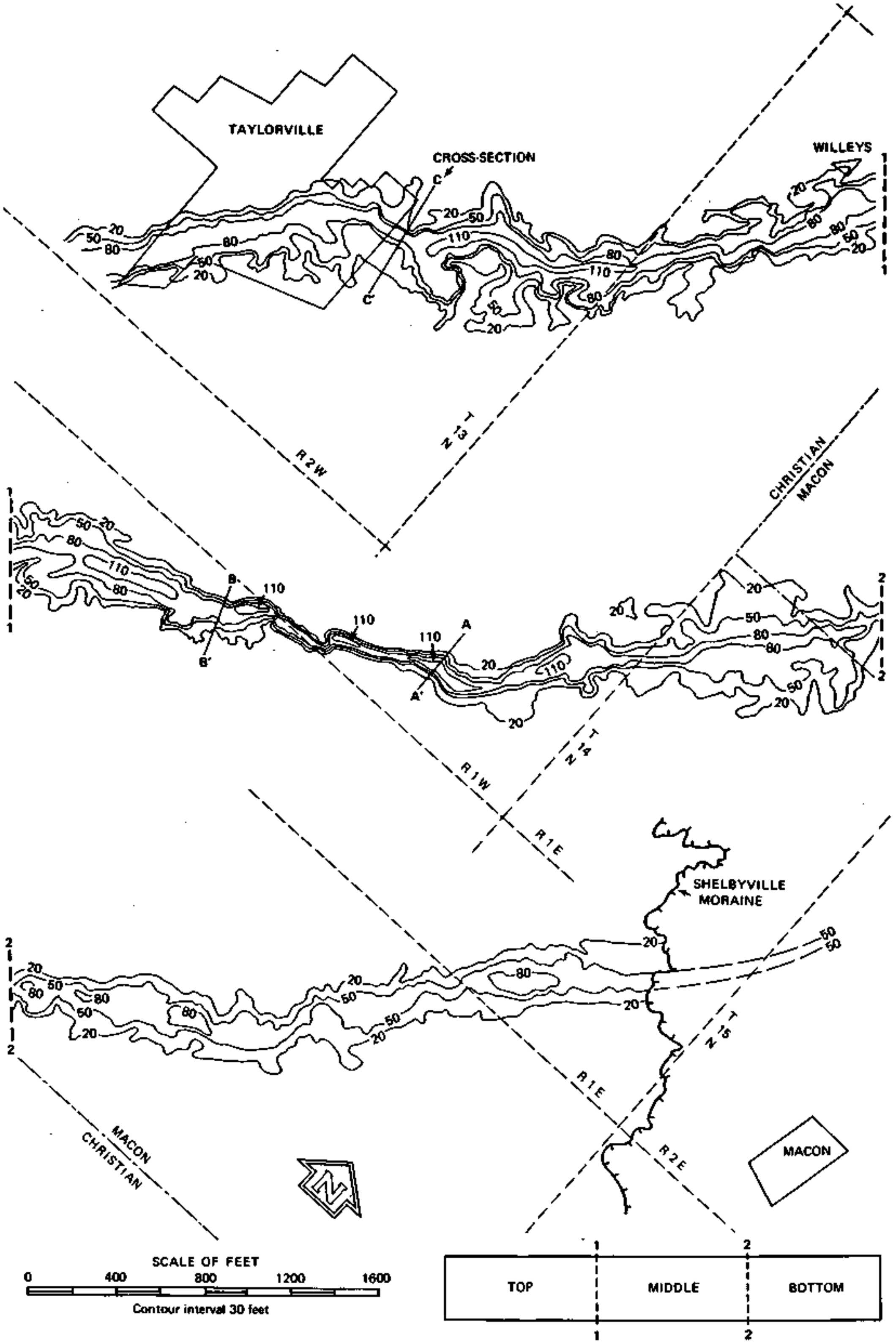


Figure 9. Aquifer thickness

of Wedron tills. In the study area, it occurs along the margin of the Shelbyville Morainic System (figure 8).

The Cahokia Alluvium includes all deposits from modern streams, and is found in several valleys in the study area (figure 8). Cahokia deposits were encountered in TA-20, along Brush Creek.

Aquifer Description

Where the Hagarstown deposit is less than 20 feet thick, the grain size usually is finer so that a hydrologic boundary exists. Therefore, the lateral boundaries of the aquifer for practical purposes are drawn to coincide approximately with the 20-foot thickness line (figure 9), even though the geologic unit is wider.

The southern part of the aquifer, which extends from the South Fork of the Sangamon River to Morrisonville, is generally thinner and less consistent in grain size than the northern part. It is topographically expressed as shallow valleys occupied by Brush Creek, Bear Creek, and a tributary of West Fork Shoal Creek. The till plain of the southern part of the study area is characterized by parallel and perpendicular valleys, commonly with right-angle bends. The pattern is suggestive of structural control from within the glacial ice. Surface drainage along the south part of the aquifer is into the overlying creeks which flow northeast to the South Fork of the Sangamon, except for some drainage into the West Fork of Shoal Creek, which flows southwest. Principal recharge is through the Cahokia Alluvium of the modern streams directly over the aquifer.

Data for the southern portion of the aquifer are much more limited than those for the northern portion. Information available is from electrical earth resistivity profiles, municipal water wells, and boring TA-20. The data are insufficient for detailed mapping of the southern part of the aquifer.

The northern part of the aquifer generally lies beneath a nearly continuous ridge extending from near the town of Macon to the South Fork of the Sangamon River at Taylorville. The ridge forms a local drainage divide on the Illinoian till plain. Southeast of the ridge, runoff is carried southwest in the Flat Branch valley. Drainage northwest of the ridge is to the north and west by small streams. Recharge to the aquifer is primarily through the thin loess cap directly over the aquifer.

The aquifer thickness map (figure 9) was made from data derived from borings made for this study, from records of previously drilled wells in and near the aquifer, and from the interpretation of numerous surface electrical resistivity profiles made specifically for this study and over the past 30 years by the Geological Survey. Even with this information, much extrapolation was necessary over areas of limited data. Where data are adequate, a strong relationship can be seen between the configuration of the aquifer and the land surface topography. Therefore, in areas where extrapolation of aquifer thickness was necessary, a strong reliance was placed on that relationship.

Prior to this study, there was no evidence that the aquifer extended north of the margin of the Shelbyville Morainic System near Macon. TA-3 was drilled where the projected continuation of the aquifer was expected if it existed beneath the Wedron Formation. When the aquifer was found at this site, the likelihood that the aquifer might be hydro geologically linked with the sands and gravels closer to Decatur was considered. TA-6 was drilled as a further test of this hypothesis, but the aquifer was not encountered. The probability of a continued northward extension of the aquifer is strong (see Kempton et al., in press), but the cover of thick Wedron Formation till will make it more difficult to trace. Surface resistivity work near TA-3 suggests that the aquifer may be much narrower at that point than it is just south of the moraine.

From the margin of the Shelbyville Morainic System to the Christian County line, the aquifer is a little less than 1/2-mile wide. The most noticeable directional change is in Sections 9 and 10 of T. 14 N., R. 1 E., in the vicinity of TA-1, 2, 4 and 5 (figure 9). The trend of the aquifer becomes more north-south in Section 9, then east-west in Section 10. After the short turn the more characteristic northeast-southwest trend is resumed. The jog corresponds to a bedrock high (figure 5) which may have influenced the direction of the eroding stream.

About one mile south of the county line the aquifer begins to narrow. The narrowing trend continues to Sections 34, T. 14 N., R. 1 W., just beyond the Stonington wells, southeast of town. The width of the aquifer is 1/8-mile at this point. A jog in the lineation of the aquifer at cross section A-A' (figure 9) by Old Stonington Cemetery, similar to the jog farther north, corresponds with crossings of first a small bedrock valley and then a bedrock high on an interfluve.

Another bend in the aquifer from the Stonington wells to cross section B-B' (figure 9) south of Stonington overlies a similar bedrock pattern but jogs in the opposite direction.

Between cross section B-B' and a point just east of Willeys, the aquifer progressively broadens to a maximum of seven-eighths of a mile. At Willeys, the aquifer curves, then narrows to about one-half mile in width. Again, this curve and the unusual width are quite likely related to a bedrock high. The bedrock configuration apparently diverted the stream to the south and caused a partial damming.

South of Willeys, the aquifer thickness map exhibits more small, detailed contortions, which may be caused partly by the availability of increased data points, and partly by erosion on the southeast side.

Three geologic cross sections were drawn to illustrate the configuration of the valley confining the aquifer (figures 10, 11, 12). Cross sections A-A' and B-B' were made with data from borings drilled for this study. C-C was drawn from driller's logs and sample studies of washed cuttings from water wells. All three cross sections reflect the steep walls of the valley and the narrow width of the aquifer. It can be seen that most of the laterally confining materials are glacial tills, which have very low water-yielding properties. Most of the recharge is through the overlying thin cap of loess which is very sandy at its base.

The asymmetrical shape of the valley in A-A' is a result of a curve in the eroding stream at that point (figure 9). The south wall on the outside of the curve is oversteepened. The asymmetry is not confined to the shape of the valley. Sieve analyses of aquifer samples from these borings show coarser sand on the outside of the curve (appendix 2).

The valley appears to be very symmetrical in cross section B-B'. As shown, the bottom of the valley does not reach bedrock, but it may in fact be in contact with the shale south of TA-12.

Also worthy of note in B-B' is 25 feet of clean, medium-grained sand encountered at a depth of 77 feet in TA-11. There are no other records of this sand, which is unrelated to the principal aquifer, but the landowner 1/2-mile north of TA-11 reports that his well is very good and is set at a depth that corresponds to this unit. If this is an older channel sand trending north-south, then it quite likely intersects the Hagarstown aquifer somewhere in this vicinity, and also probably extends farther north. This may be of local significance for water supplies in the future.

The unusual valley configuration interpretation indicated by cross section C-C is probably due in part to the lack of precision of well driller's logs in material description and/or location. However, the general trend of the aquifer can be easily discerned.

The driller reported the upper 38 feet as "drift" on a log at location CHR 13N2W-23.5a. It would not make sense for the top of the aquifer to be at that depth, so it has been assumed that part of the "drift" must be sand.

Geologic Controls of Groundwater Availability

Groundwater availability is dependent upon recharge to the aquifer, the hydraulic properties of the materials confining the aquifer, and the hydrologic properties of the aquifer material itself. This aquifer has a loess weathered drift cover of silt or clayey silt which is 10 to 20 feet thick. The lower 4 to 8 feet is usually very sandy. Most of the recharge comes through this cover, although some water may be replenished through the upper lateral boundaries of the aquifer. It is probable that very little water enters the aquifer through the compact tills of the valley walls or the bedrock shale beneath. The small sand lenses within and between the tills contribute little to the recharge of the aquifer.

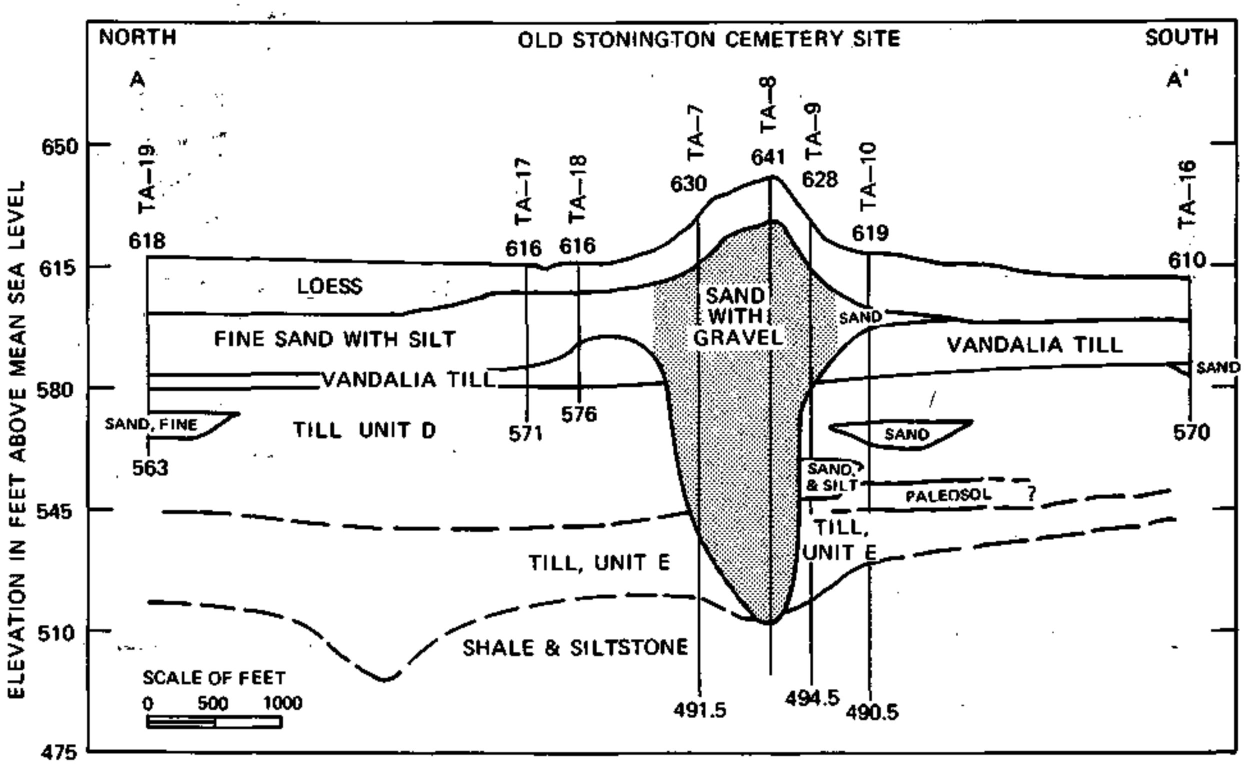


Figure 10. Cross section A-A' at Old Stonington Cemetery

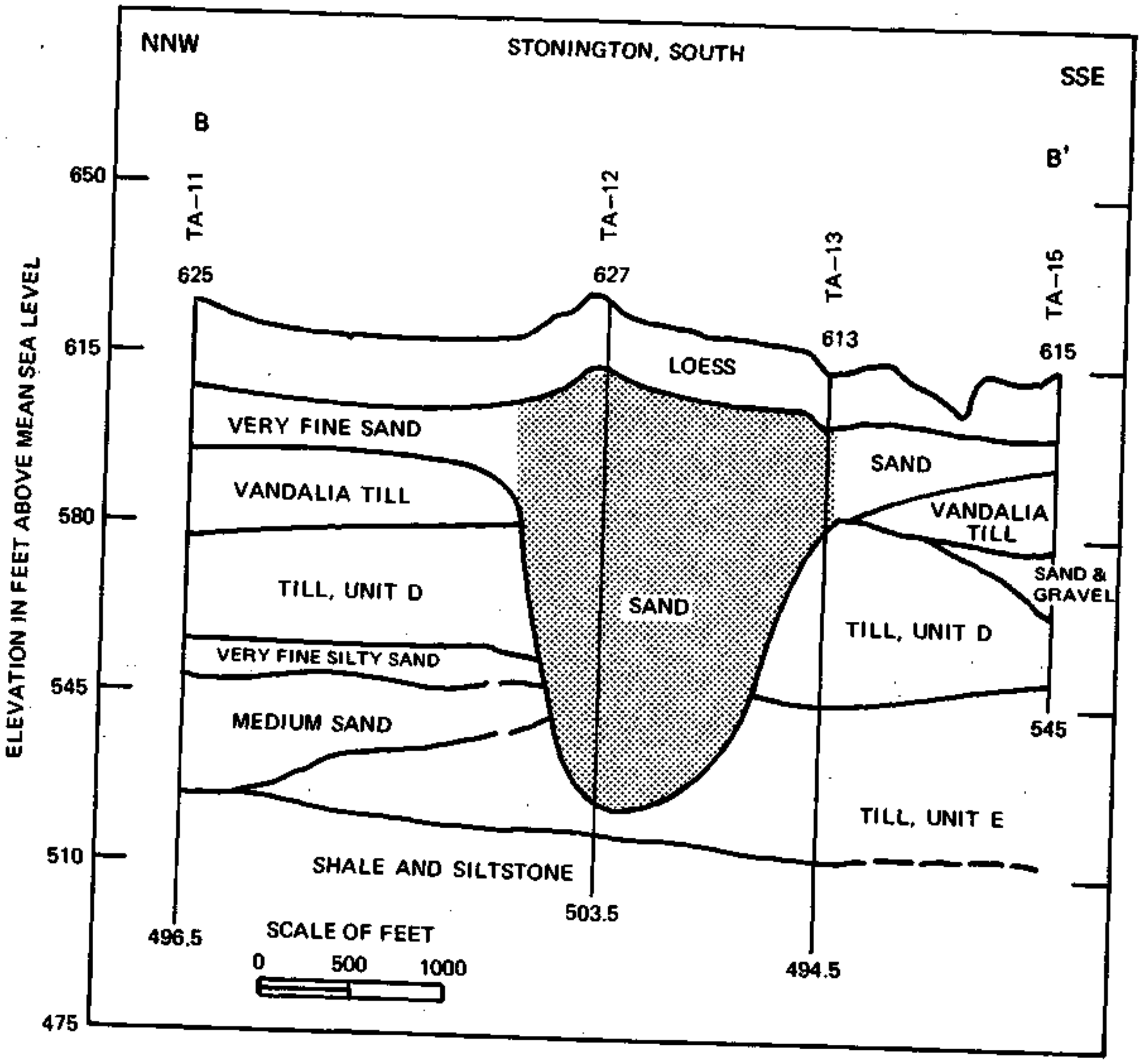


Figure 11. Cross section B-B' south of Stonington

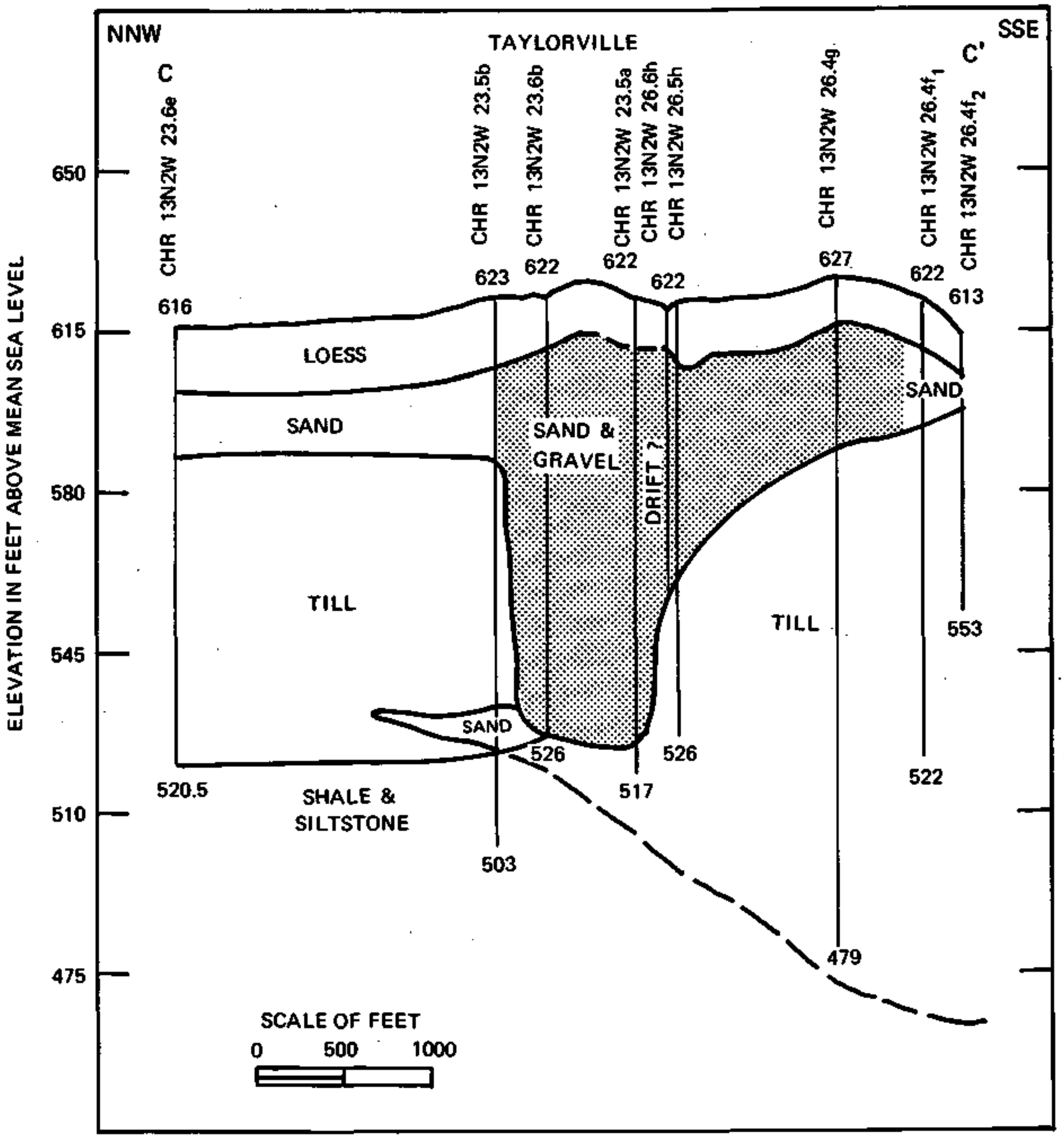


Figure 12. Cross section C-C at Taylorville

Historical Development of the Aquifer

The first municipal water supply from the aquifer was developed by Taylorville in 1888. The second municipal supply was not developed until 1933, when Raymond constructed a well. Nine municipalities currently receive all or a portion of their water from the aquifer, and a tenth (Moweaqua) is planning to develop a supply from the aquifer soon. These municipalities, which will be discussed in north to south order, include Macon, Moweaqua, Blue Mound, Assumption, Stonington, and Taylorville in the northern portion and Palmer, Morrisonville, Harvel, and Raymond in the south. Well logs are given in appendix 3.

Of historical interest is the fact that the Norfolk and Western Railroad, which parallels the aquifer approximately a mile to the west, carried out numerous drilling attempts during the early 1900s along their right-of-way to find a source of groundwater for their steam locomotives. Although the railroad paralleled the aquifer for nearly 40 miles, the strip aquifer was not found, and small ponds or hauled water were used to supply the water needs of the locomotives.

Macon

A public water supply for the city of Macon was installed in 1935. Until 1962 water was obtained from three wells on the northern edge of town. When that supply became inadequate, the city drilled the first of two wells in the regional aquifer and added a second in 1977.

Well No. 4 (MCN 15NlE-36.8h) is located about two miles west of town in the NW1/4, NW1/4, Section 35, T.15N., R.1E. Drilled to a depth of 62.5 feet and tapping 39.5 feet of saturated sand and gravel, the well is eight inches in diameter and cased to a depth of 48 feet, followed by 1.5 feet of 70-slot (0.070 inch), 3 feet of 40-slot (0.040 inch), 8 feet of 22-slot (0.022 inch), and 2 feet of 30-slot (0.030 inch) Johnson Everdur screen. Analysis of a production test following completion of Well No. 4 indicated that the long-term safe yield should be approximately 125 gpm. The well experienced a loss in specific capacity and was acidized in 1976 to restore some of its original yield.

In 1977, Well No. 5 (MCN 15N1E-36.8g), located some 840 feet north of Well No. 4, was completed at a depth of 88 feet in 70 feet of saturated sand and gravel. Eight-inch casing extends inside a 24-inch borehole to a depth of 73 feet, followed by 15 feet of 60-slot (0.060 inch) screen. A gravel pack was placed in the annulus between the screen and borehole. Upon testing, the yield of the well was estimated to be 200 gpm.

Currently, Wells 4 and 5 supply the total water demand at Macon, with the old well field being maintained on emergency standby. Pumpage averages 118,000 gpd (figure 13a).

Moweaqua

The Village of Moweaqua installed a public water supply in 1893. Water was originally obtained from a dug well located in the eastern part of the village. Later, two wells near an abandoned mine shaft near the southern limits of the village became the source of supply.

In 1905, the first development of a shallow sand and gravel aquifer, two miles north of town in Section 18, T.14N., R.2E., began. Well deterioration problems plagued its development, and at least 22 wells were eventually drilled in this aquifer, which proved to be of limited extent and yield. Controlled testing in 1968 indicated that a total yield of 115,000 gpd could

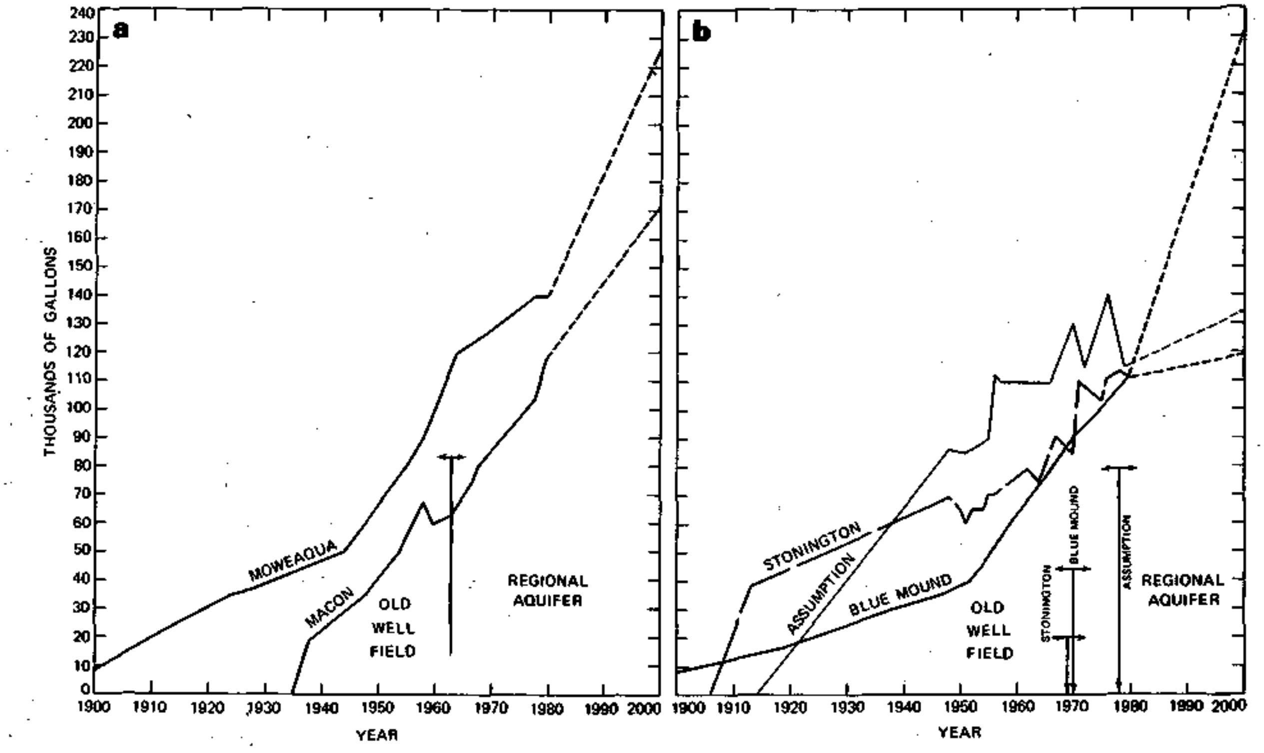


Figure 13. Distribution of pumpage, 1900-1980, and estimated pumpage to 2000 for north half communities except Taylorville

be expected from these deposits. Currently fourteen wells are still in use.

In anticipation of future growth in water demands the village has constructed a well in the aquifer about five miles northwest of town in Section 10, T.14N., R1E. Known as Well No. 15 (MCN 14N1E-10.8d), the well has not yet been placed into service. The construction features and estimated yield of the well are described later in the report as part of a discussion of a detailed 24-hour production test conducted on this well.

The average daily groundwater withdrawals at Moweaqua are presently 140,000 gpd (figure 13a).

Blue Mound

A public water supply was installed by the Village of Blue Mound about 1882, primarily for fire protection. The first well was a 16-foot-diameter well, 50 feet deep, which was later abandoned and filled. Two six-inch-diameter wells were drilled in 1917, and a third, known as Well No. 1, was added in 1935. Well No. 2 was drilled in 1944. All of these wells were located within the village and experienced a history of well deterioration and loss of capacity.

In 1970, Well No. 3 (MCN 14N1E-16.6h) was drilled in the regional aquifer, approximately 2-1/2 miles southeast of town, in the NW1/4 of Section 16, T.14N., R.1E. The well was completed at a depth of 88 feet in 63 feet of sand and gravel. Eight-inch-diameter casing extends to a depth of 72 feet, followed by 40-slot (0.040 inch) red brass screen to the bottom of the well. The long-term safe yield has been estimated at 200 gpm.

Well No. 3 is the primary source of water for the village. Current pumpage averages 112,000 gpd (figure 13b).

Assumption

The city of Assumption installed a public water supply in 1914. Attempts to locate a source of supply in or near the city were unsuccessful, and water was obtained from 6 drilled wells located about 3 miles southeast of the city in the valley of Spring Creek in the western part of Shelby County. Since 1914, 11 additional drilled wells and 16 dug wells have been constructed in the same area, Section 18, T.12N., R.2E., and Section 12, T.12N., R.1E., Shelby County.

These wells range in depth from 17 to 26 feet and tap a limited sand and gravel aquifer. Analysis of data collected from well tests conducted in 1960 and 1961 indicated that the aquifer has an estimated safe yield of about 55,000 gpd. Pumpage at that time was about 90, 000 gpd, and pumping water levels commonly dropped to the tops of the well screens. Water shortages were a continual problem, especially during dry periods when recharge was low.

Extensive test drilling conducted in and around Assumption indicated that no aquifers were present closer than the regional aquifer, approximately ten miles to the northwest.

During the dry period of 1976, pumping levels in the city wells were routinely at the tops of the screens, and it was decided to develop a well in the aquifer. This well, No. 10 (CHR 14N1E-30.8g), is located in the NW1/4, Section 30, T.14N., R.1E., Christian County. The well is 90 feet deep and taps sand and gravel from 16 to 90 feet. It is equipped with 10-inch-diameter casing and 60-slot (0.060 inch) screen set from 73 to 90 feet.

The following year Well No. 11 (CHR 14NlE-30.7h) was constructed to provide a standby source of water. This well, also located in the NW1/4, Section 30, is 105 feet deep and taps sand and gravel from 17 to 105 feet. The well is cased with 10-inch-diameter steel pipe. A 10-inch-diameter Johnson stainless steel (SS) screen, 25 feet long, with 40-slot (0.040 inch) openings is set from 80 to 105 feet.

Based on data obtained from well tests conducted on these two wells, the long-term safe yields were estimated to be 200 gpm each. Present average daily pumpage is estimated to be 115,000 gpd. Pumpage growth for Assumption is shown in figure 13b.

Stonington

The Village of Stonington installed a public water supply in 1906. The original source of water consisted of three drilled wells which by 1922 had all been abandoned. These were followed by a dug well and five drilled wells, all constructed in town between 1920 and 1951.

As water demands exceeded production capabilities, additional wells were drilled; by 1959 a total of nine wells had been placed into service. All of these wells were shallow, and production declined as pumping levels lowered.

In 1969, the first attempt by the village at tapping the regional aquifer was made when Well No. 10 (CHR 14N1W-34.1b1) was drilled about two miles southwest of town in the SE1/4 of Section 34, T.14N., R.1E. The well was finished at a depth of 124.5 feet and encountered sand from a depth of 12 feet to the bottom. An eight-inch-diameter casing was set in the well to a depth of 104.5 feet, followed by 10 feet of 10-slot (0.010 inch) and 10 feet of 30-slot (0.030 inch) Cook screen. The well was tested on completion, and the long term safe yield was estimated to be 150 gpm.

In 1974, a standby well was drilled 250 feet south of Well No. 10 (CHR 14NlW-34.1b2). This well, No. 11, was completed to a depth of 104 feet. A 24-inch-diameter hole was bored to 104 feet. Twenty-four-inch-diameter casing was installed to a depth of 10 feet, followed by 20-inch pipe from 10 feet to 86 feet. Eight-inch-diameter Layne shutter screen with No. 6 openings (0.080 inch) was installed from 86 to 104 feet. The annulus between the screen and borehole was packed with Meramec WB40 sand. Analysis of the data collected from a controlled production test indicated the well could safely produce 150 gpm.

Wells 10 and 11 currently provide the water supply for Stonington, and all other wells are either abandoned or in a state of disrepair. At present, pumpage is about 111,000 gpd (figure 13b).

Taylorville

The first municipal wells at Taylorville were constructed in 1888 at the old city water plant near Cherokee and Vine Streets or the NE1/4, NE1/4, Section 27, T.13N., R.2W. In 1900 about 28,000 gallons per day (gpd) were pumped from 8 drilled wells to satisfy the commercial and domestic water needs of the city. As shown in figure 14, water use has steadily increased since 1888 as the city has grown in population from 4,248 to 16,000 people. In 1980 approximately 2,000,000 gpd of groundwater and surface water were required to fulfill industrial, commercial, and domestic water demands. This represents an increase in total per capita consumption from 6.6 gpd per person in 1900 to nearly 125 gpd per person in 1980. In 1951, wells in the old city well field were abandoned, and the municipal water supply was obtained from wells in a new field northeast of the city limits in Sections 13 and 24, T.13N, R.2W., and Section 18, T.13N., R.1W. Water quality and well deterioration problems were responsible for the change in pumping centers.

During the 1950s increased withdrawal rates by Taylorville and two area industries (Hopper Paper Division and Continental Grain), coupled with below-normal precipitation from 1952 to 1956, caused water levels in the new well field to drop to alarming levels. This led to a search for an additional water source and to the construction of Lake Taylorville in 1961-1962. The reservoir went into service in March 1963, and for two years very little groundwater was pumped. However, the treatment plant did not treat the surface water satisfactorily, and the wells were again put into service. Since 1965 surface water and groundwater have been blended. Approximately 500,000 to 1, 000, 000 gpd of groundwater have been mixed with lake water to supply the total demand, which grew from about 1,750,000 gpd in 1965 to 2,600,000 gpd in 1976. In August 1976, Hopper Paper Division began using their wells again, which decreased Taylorville's average pumpage to 2,000,000 gpd in 1980.

The Hopper Paper Division of Georgia-Pacific Inc. (formerly Hopper Paper Company) began operations in 1908. As shown in figure 14, their water demand increased at a relatively uniform rate from 150,000 gpd in 1908 to 550,000 gpd in 1952. In 1926, the north wells at the plant were constructed, and they were in service until 1951. In 1951, the south wells were constructed and have provided the bulk of the groundwater since that time. All of the wells are located in the SW1/4, Section 23, T.13N., R.2W. In 1953 groundwater withdrawals increased to 1,320,000 gpd. This increased pumpage caused such a rapid decline in water levels that pumpage had to be reduced to 770,000 gpd in 1955, and to 650,000 gpd in 1958. A further reduction to 144,000 gpd was made in April 1958, and from that time to 1963 Hopper Paper Division purchased an average of 632,000 gpd from the city to supplement the amount pumped from their well field.

Hopper Paper was instrumental in helping the City of Taylorville obtain financing for construction of Lake Taylorville in 1961-1962. When the lake went into service in March 1963 the paper company put their wells on standby and purchased approximately 1,300,000 gpd until August 1976. Due to increases in municipal water rates, Hopper Paper began using their wells again in August 1976. Since then, they have pumped approximately 850,000 to 1,300,000 gpd from their wells and have

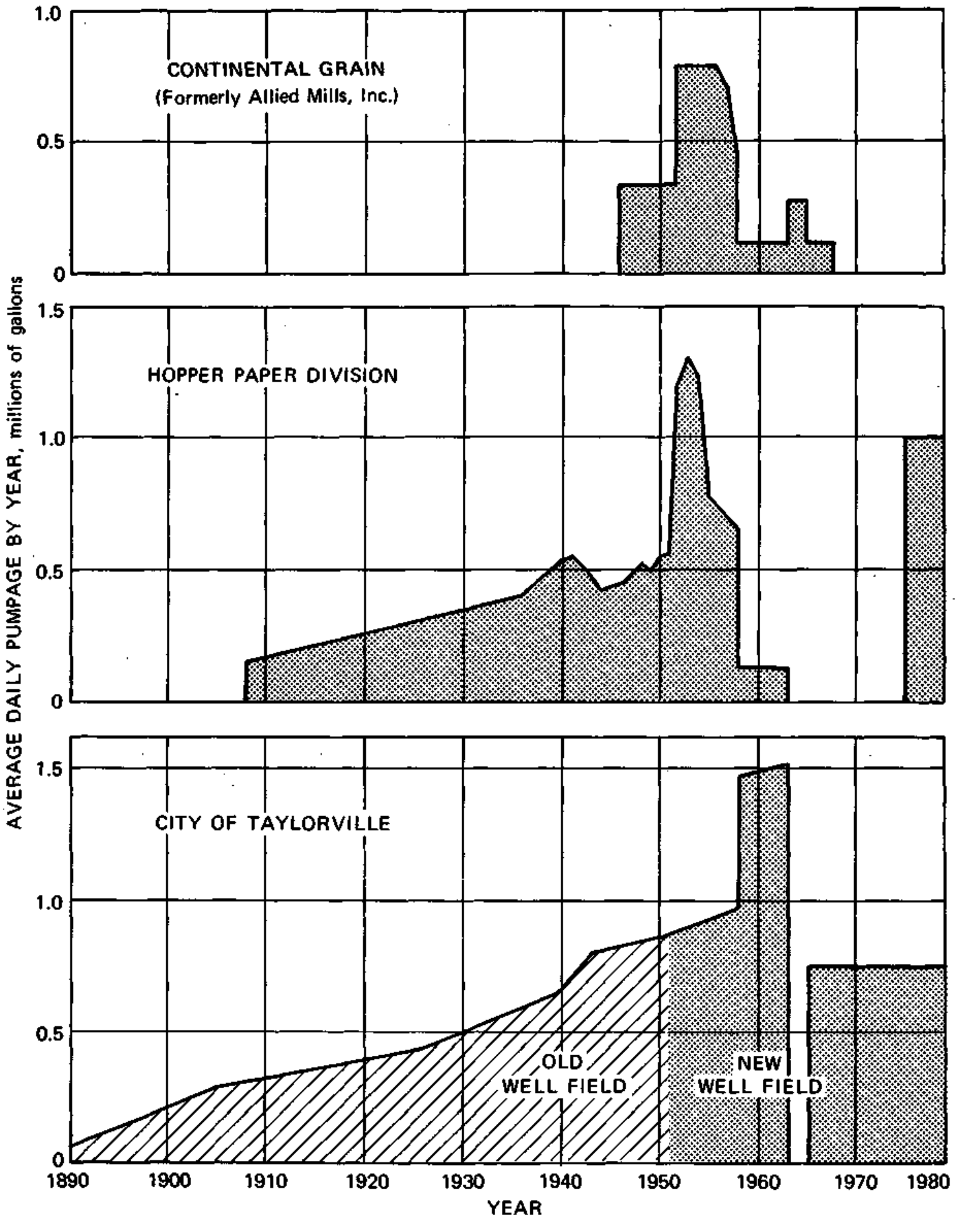


Figure 14. Distribution of groundwater pumpage at Taylorville, 1900-1980

supplemented this with 250,000 to 300,000 gpd from the city.

A soybean processing plant owned by Continental Grain Co. (formerly Allied Mills, Inc.) went into operation in 1946. Water was initially obtained from 2 wells located in the NE1/4, Section 23, T.13N., R.2W. As shown in figure 14, pumpage from 1946 to 1952 averaged about 350,000 gpd. Due to plant expansion in 1952, 3 new wells were constructed and pumpage increased to 800,000 gpd. Groundwater levels declined rapidly to critical stages, and in 1957 cooling towers were installed to conserve water. Conservation practices resulted in a reduction of about 675,000 gpd in groundwater withdrawals. From 1958 to 1961 pumpage was about 130,000 gpd. In 1962 and 1963 (when Lake Taylorville began serving Taylorville and Hopper Paper Division) pumpage was increased to 250,000 gpd. From 1964 through 1967 pumpage was lowered to about 100,000 gpd. In 1968 Continental Grain discontinued use of its wells and since that time has purchased an average of 100,000 gpd from Taylorville.

Palmer

Palmer established a public water supply in 1967. Previously, test holes drilled in the vicinity of the village had been unsuccessful. Based on the information available, electrical earth resistivity surveys were conducted, after which two test holes were drilled in 1965. They were located near the center of Section 35, T.12N., R.3W., Christian County, about one and one-half miles southeast of the village. Test hole results indicated that conditions were favorable for development, and in 1967, a permanent production well (No. 1) was constructed. This well (CHR 12N3W-35.5d2) is 76 feet deep and taps 17 feet of fine-to-medium sand overlain by 46 feet of fine sand. It is an 18-inch-diameter, gravel-packed well with a 6-inch-diameter casing extending from 2 feet above ground level to the top of the screen at 61 feet. The screen is a Layne-Western shutter screen consisting of 10 feet of 6-inch-diameter and 5 feet of 8-inch-diameter, with No. 6 (0.080 inch) openings. When completed, the well was test-pumped and the long-term safe yield was estimated to be 100 gpm.

Pumpage has increased from 8, 000 gpd in 1970 to about 17,000 gpd in 1980. The village plans to construct a standby well in the near future.

Morrisonville

A public water supply was installed by the village of Morrisonville in 1888. Water was originally obtained from two dug wells, 16 feet deep, located within the village. A test well, drilled to a depth of 100 feet, was unsuccessful and was abandoned. In 1928 the village purchased a well from the Southern Illinois Light and Power Company. This well is located about 1 mile northwest of the village.

By 1939 the three wells were unable to satisfy increasing water demands, and a serious shortage occurred. Due to the seriousness of the situation, an electrical earth resistivity survey was conducted by the State Geological Survey in February 1939 and five test holes were drilled within the village in 1940. However, suitable deposits of sand and gravel were not encountered.

Additional resistivity surveys were conducted in 1942 in the vicinity of the regional aquifer southeast of Morrisonville and five test holes were drilled. Well No. 4 (CHR HN3W-8.3a2) was built at the site of test hole 5, in the SW1/4, SE1/4, Section 8, T.11N., R.3W. The well is 44 feet deep, penetrates sand and gravel from 26 to 39 feet, and is cased with 35.6 feet of 8-inch-diameter steel pipe from 3.6 feet above ground level to 32 feet below ground level. A 7-1/2-inch-diameter Johnson Everdur screen with 60-slot openings (0.060 inch) was set with the bottom at a depth of 43.8 feet.

Between 1944 and 1948 the dug wells (Nos. 1 and 2) were abandoned. Well No. 3 was kept for emergency use, but was reported as being unserviceable in 1948. In 1952, Well No. 5 (CHR 11N3W-8.3a3), located 29 feet northwest of Well No. 4, was built. It was originally intended as a source of additional water, but its proximity to Well No. 4 precluded this, and the two wells were used alternately to provide the daily demand.

Well No. 5 is 41 feet deep and cased with 8-inch-diameter steel pipe to a depth of 32.5 feet. The screen consists of a 10-foot length of 8-inch-diameter Johnson Everdur screen with 60-slot openings (0.060 inch). The bottom of the screen is set at 41 feet, and there is an overlap of 1-1/2 feet of casing and screen.

Wells 4 and 5 have had well deterioration problems through their service lives. In 1956, both wells were out of service for two weeks, and Well No. 3 was hastily refurbished for use. The problems reportedly were caused by iron deposits on the well screens that reduced the yields of the wells significantly. The wells were acidized, resulting in some improvement in performance, and put back in service. However, the problem recurred, and both wells were re-acidized in 1964, 1969, and 1973.

In 1977 a new well, Well No. 6 (CHR HN3W-9.8c), was built in the aquifer in the SE1/4, SW1/4, Section 9, T.11N., R.3W., about 1/4 mile northeast of Wells 4 and 5. It was completed at a depth of 45 feet with 15 feet of 10-inch-diameter shutter screen with No. 6 (0.080 inch) openings placed from 30 to 45 feet. Ten-inch-diameter well casing extends to land surface and the annulus between the casing, screen, and bore hole is gravel-packed. Well No. 6 is presently the primary source of water, and Wells 4 and 5 are being used as standbys.

As shown in figure 15, pumpage at Morrisonville has increased from an average of 8,000 gpd in 1923 to 83,000 gpd in 1980.

Harvel

After several years of casual investigation, the Village of Harvel began seriously considering a public water supply in 1952. Up to that time water was obtained from individual shallow dug and bored wells which often provided only marginal household supplies. Large supplies were unavailable within the village, as demonstrated by numerous unsuccessful domestic drilling attempts.

Based on available information regarding the supplies at nearby Raymond and Morrisonville, electrical resistivity work was conducted in 1953 by the State Geological Survey to determine if the sand and gravel deposits tapped by these two villages were connected and present in the vicinity of Harvel. From this survey 2 test hole locations in Section 34, T.11N., R.4W., Christian County were recommended.

Three test holes were drilled in Section 34 in 1954. Well No. 1 (CHR HN4W-34.4e) was constructed to a depth of 38 feet at the site of test hole 3. The well was cased with 33 feet of 8-inch-diameter steel pipe and 6 feet of Cook wire-wound brass screen with 80-slot openings (0.080 inch).

Average daily pumpage at Harvel has increased from 16,000 gpd in 1956 to 45,000 gpd in 1980 (figure 15). Since about 1967 approximately 20,000 to 60,000 gpd have been provided to a local agricultural chemical company. Maximum daily pumpage has reached as high as 110,000 gpd for a few days each spring because of the chemical company's demands during that time of year.

Raymond

In 1933, the Village of Raymond began considering a public water supply. Based on the available information a test hole was drilled in the aquifer in Section 17, T.10N., R.4W., Montgomery County. Water-bearing sand was encountered from 15 to 29.5 feet. The test hole was completed as a test well, and,

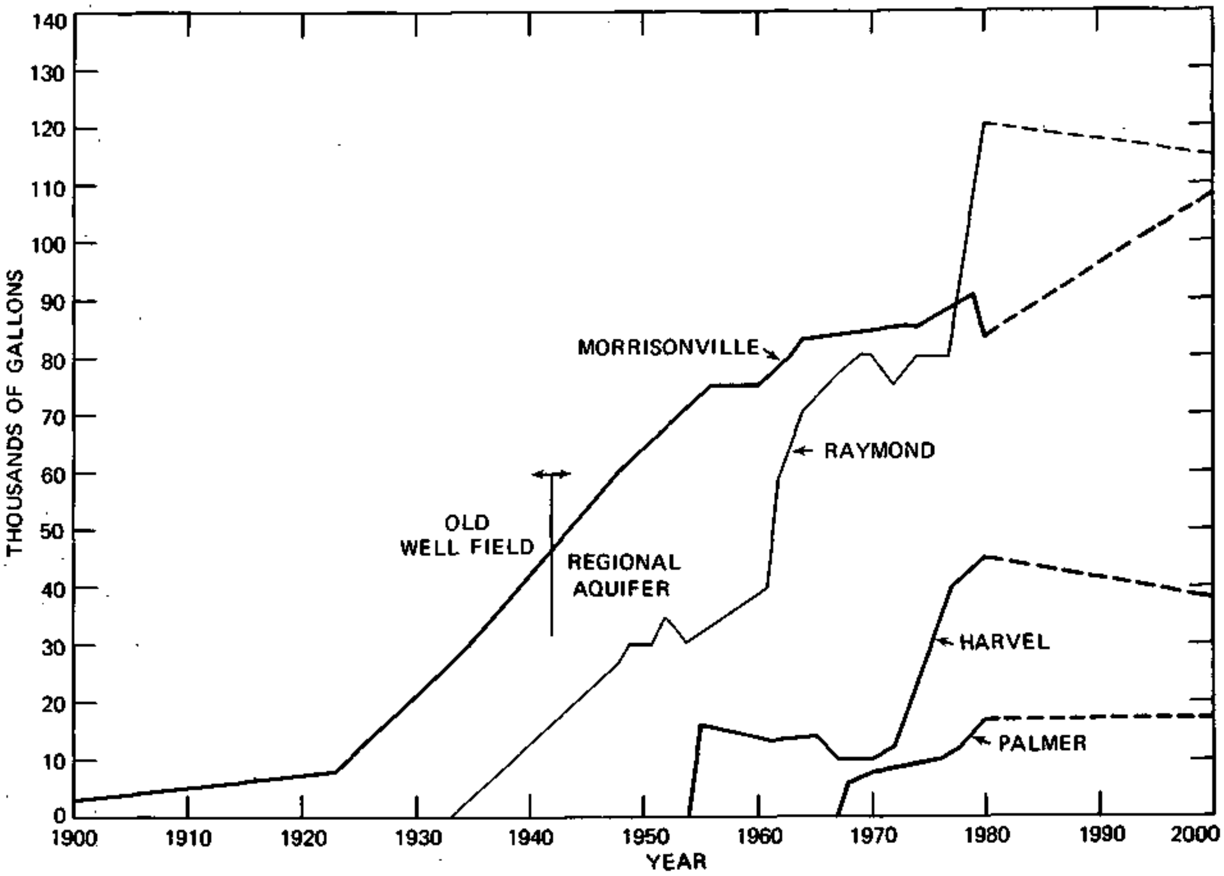


Figure 15. Distribution of pumpage, 1900-1980, and estimated pumpage to 2000 for south half communities

after successful testing, Well No. 1 (MTG 10N4W-17.3d) was drilled nearby. This well served the village as the sole source of water until 1946, when pump problems caused the well to be out of service for a period of days. Based on this experience a standby well (MTG 10N4W-17.2d) was built in 1952. Due to increased pumpage demands and large bulk water sales, Well No. 3 (MTG 10N4W-17.2a) was constructed in 1954. All three wells are located in SE1/4, Section 17. These wells have histories of deterioration problems and have been acidized several times. Due to sand pumpage Well No. 3 was reconstructed in 1962. In 1977, six test holes were drilled in Sections 8 and 16, T.10N., R.4W. A favorable site was found in the SE1/4, SE1/4, Section 5, and Well No. 4 (MTG 10N4W-8.1a6) was built. The well was drilled to a depth of 54 feet, cased with 8-inch-diameter steel pipe to a depth of 44 feet, and equipped with 10 feet of 8-inch-diameter Layne shutter screen with No. 6 openings (0.080 inch). The annulus between the casing and 24-inch-diameter borehole is gravel-packed. Well No. 4 is the primary water supply well, due to the deteriorated condition of the others.

Pumpage at Raymond has increased from 27,000 gpd in 1948 to 80,000 gpd in 1977. With the construction of Well No. 4, additional water was available for bulk sales, and average daily pumpage increased to 120,000 gpd in 1980. Because of the limited groundwater resources of much of the surrounding area, bulk sales to farmers make up a large portion of the total pumpage. Peak pumping days may double or triple the average amount of water pumped, especially during the spring and fall.

Well Construction Features

Municipal and industrial wells finished in the aquifer system have been drilled by cable tool and rotary methods. The production wells are cased through the fine overlying materials, and while a few have perforated casings most have commercial well screens opposite the more permeable zones in the aquifer. Two types of drilled wells are in the area: tubular and artificial gravel pack. Aquifer materials surrounding the well are in direct contact with the well screen for the tubular well; selected materials having a coarser and more uniform grain size than the natural formation are introduced between the borehole and screen for the artificial gravel pack wells. Available data indicate that about one-third of the municipal and industrial wells finished in the strip aquifer have been constructed with artificial gravel packs. However, this is somewhat misleading, as nearly all recent wells have been gravel-packed and it is expected that most of the future wells also will be gravel-packed.

For the naturally-developed wells, casing and screen diameters range from 6- to 12-inches. The gravel-packed wells usually have 15- to 30-inch diameter boreholes with 6- to 12-inch-diameter screens and casings. The annulus between the bore hole and screen is filled with a selected material designed to retain the natural formation. Casing diameters are determined by the physical dimensions of the pump to be installed. Criteria developed by Smith (1954), Ahrens (1957), and Walton (1962) have been used for designing many of the newer wells in the aquifer.

Generally, commercial screens used in this area are made of stainless steel, red brass, silicon bronze, or other relatively noncorrosive metals. Slot openings usually are measured in thousandths of an inch; for example, a 60-slot screen would have openings 0.060 inch wide. The slot size is selected that will retain a selected fraction of either aquifer formation material or the gravel pack. Typical construction features of a gravel-packed well are shown in figure 16.

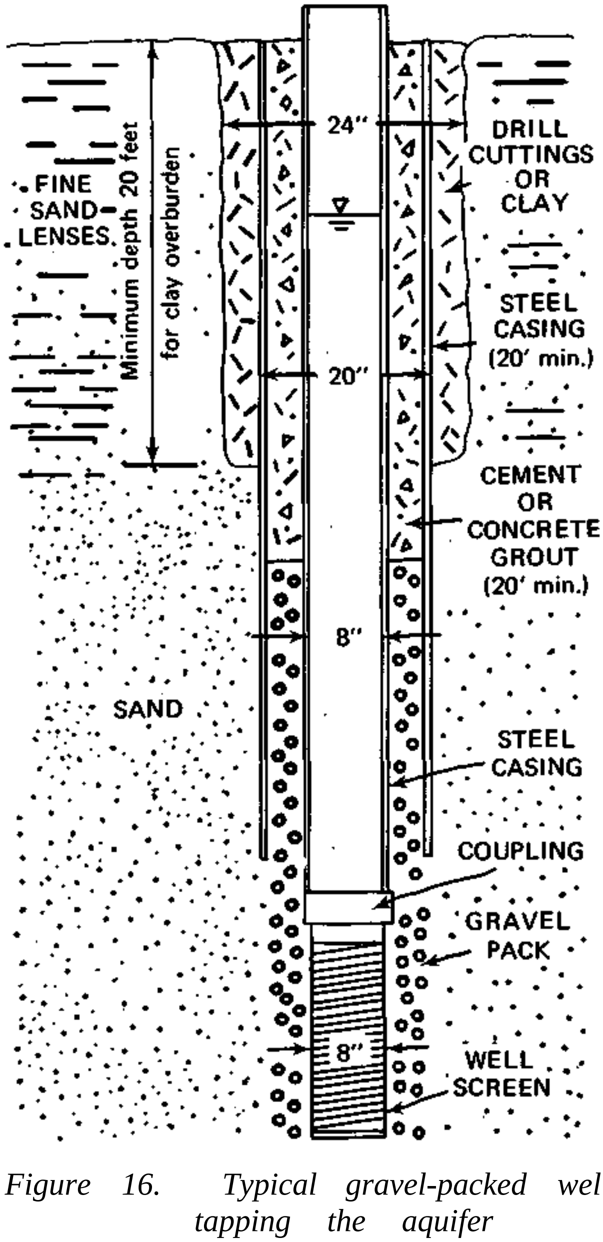


Figure 16. Typical gravel-packed well tapping the aquifer

Groundwater Withdrawals

The increased pumpage of groundwater from the north part of the aquifer is shown in figure 17. For the most part, this figure shows cumulative total pumpage for the three pumping centers in the Taylorville area, which were discussed previously. As is shown, withdrawals increased steadily from 28,000 gpd in 1900 to about 1,300,000 gpd in 1946. These withdrawals include the pumpage at Hopper Paper Division, which began in 1908. When the Continental Grain plant began operations in 1946, a pumpage increase of about 350,000 gpd occurred, for a total withdrawal of about 1,600,000 gpd. The shift of pumpage from the old Taylorville well field to the new field in 1951 coincided with sharp increases in pumpage by the two industries. It can be seen that by 1953 approximately 3,000,000 gpd were being withdrawn at Taylorville. The resultant decline in water levels brought about steady decreases in total pumpage from 1953 to 1960, until by 1960 estimated pumpage was 1,200,000 gpd.

The slight rise of pumpage seen for 1962 was primarily due to the development of the Macon well field in the extreme northern portion of the strip aquifer. This was the first supply in the north half to be developed away from the Taylorville pumping centers. Pumpage in 1962 for Macon was 62,000 gpd.

From 1963 (when Taylorville and Hopper Paper Division began using sur-

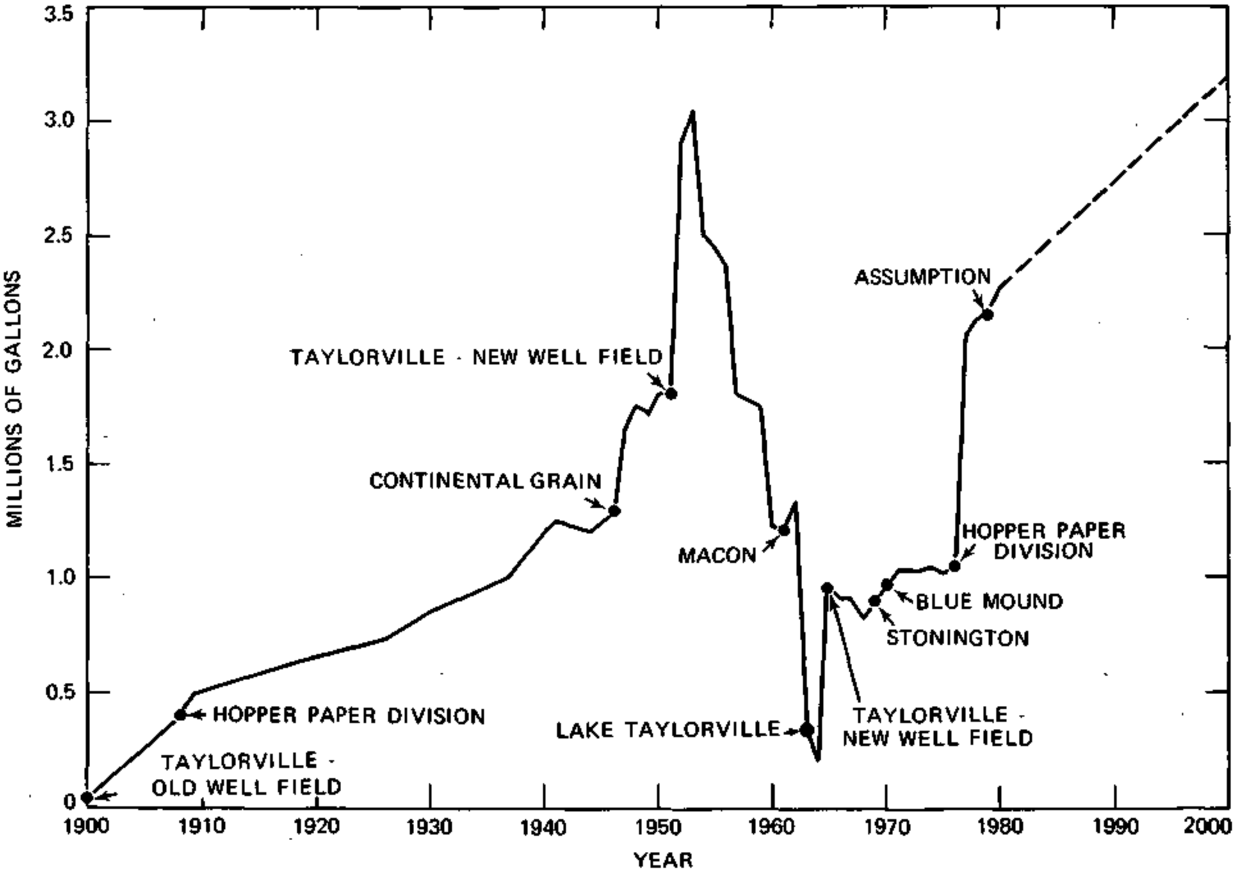


Figure 17. Combined average daily pumpage, 1900-1980, and estimated pumpage to 2000 for north half of aquifer

face water from Lake Taylorville and placed their wells on standby) until 1965, pumpage from the north part was limited to Macon and Continental Grain, which collectively withdrew about 200,000 gpd. Since 1965, when Taylorville resumed groundwater pumpage from the city wells, daily pumpage has ranged from 500,000 to 1,000,000 gpd. This is included in figure 17 as an average of 750,000 gpd.

In 1968, when Continental Grain discontinued use of their wells, a drop in pumpage of 130,000 gpd occurred. In 1969 Stonington developed water supplies in the aquifer, and Blue Mound did so in 1970. Total pumpage by these two villages was 176,000 gpd, only a slight increase compared to the overall aquifer pumpage.

Available records indicate that total withdrawals from 1971 to 1976 remained fairly constant at a little over 1,000,000 gpd. When Hopper Paper Division discontinued the use of purchased water in 1976, they refurbished their wells and since that time have pumped from 850,000 to 1,300,000 gpd.

Assumption developed their supply from the aquifer in 1978 (shown in figure 17 by an increase in pumpage of about 120,000 gpd). Pumpage from the north half of the aquifer currently totals about 2,250,000 gpd. Approximately 33 percent is withdrawn by Taylorville, and 44 percent by Hopper Paper Division. Thus about 77 percent of the pumpage is concentrated in the vicinity of Taylorville. The remaining 23 percent, or 500,000 gpd, is distributed uniformly among Stonington, Blue Mound, Assumption and Macon. Total projected pumpage for the north half of the aquifer for the year 2000 as estimated by the Division of Water Resources, Illinois Department of Transportation, is about 3,200,000 gpd.

Pumpage from the south half of the aquifer began in 1933, when the Village of Raymond developed a water supply. As shown in figure 18, increases in pumpage have been steady through the years. In 1942, 1954, and 1967 new supplies were developed by Morrisonville, Harvel, and Palmer, respectively. Each new development can be noted in the figure as a sharp increase in total pumpage. Current pumpage from the south half of the aquifer is about 270,000 gpd. Since no new supplies are anticipated, the projected rate of increase to the year 2000 is much lower than that of the past. Pumpage from the south part of the aquifer is estimated at 278,000 gpd for the year 2000.

A comparison of pumpage from the north and south halves of the aquifer indicates that withdrawals from the north half are significantly greater. Total pumpage from the aquifer in 1980 was about 2,520,000 gpd, of which 2,250,000 gpd, or about 89 percent, was from the north half and 270,000 gpd, or about 11 percent, was from the south half.

Water Level Fluctuations

Under natural conditions the aquifer is generally a water table aquifer. The nonpumping water level, or water table elevation, coincides with the depth at which the aquifer is saturated. The water table elevation fluctuates in response to precipitation and evapotranspiration. Water levels generally recede in late spring, summer, and early fall months when discharge by evapotranspiration and groundwater runoff is greater than recharge from precipitation. Water levels begin to recover late in the fall when evapotranspiration losses are small, soil moisture is replenished, and conditions are favorable for the infiltration of rainfall to the water table. The annual cycle of water levels reflects the seasonal variation in precipitation and other climatic factors. Although groundwater levels fluctuate from season to season and from year to year, the long-term effect is one of equilibrium between recharge and discharge.

At some locations the aquifer is overlain by a low permeability silt layer, and conditions will be artesian

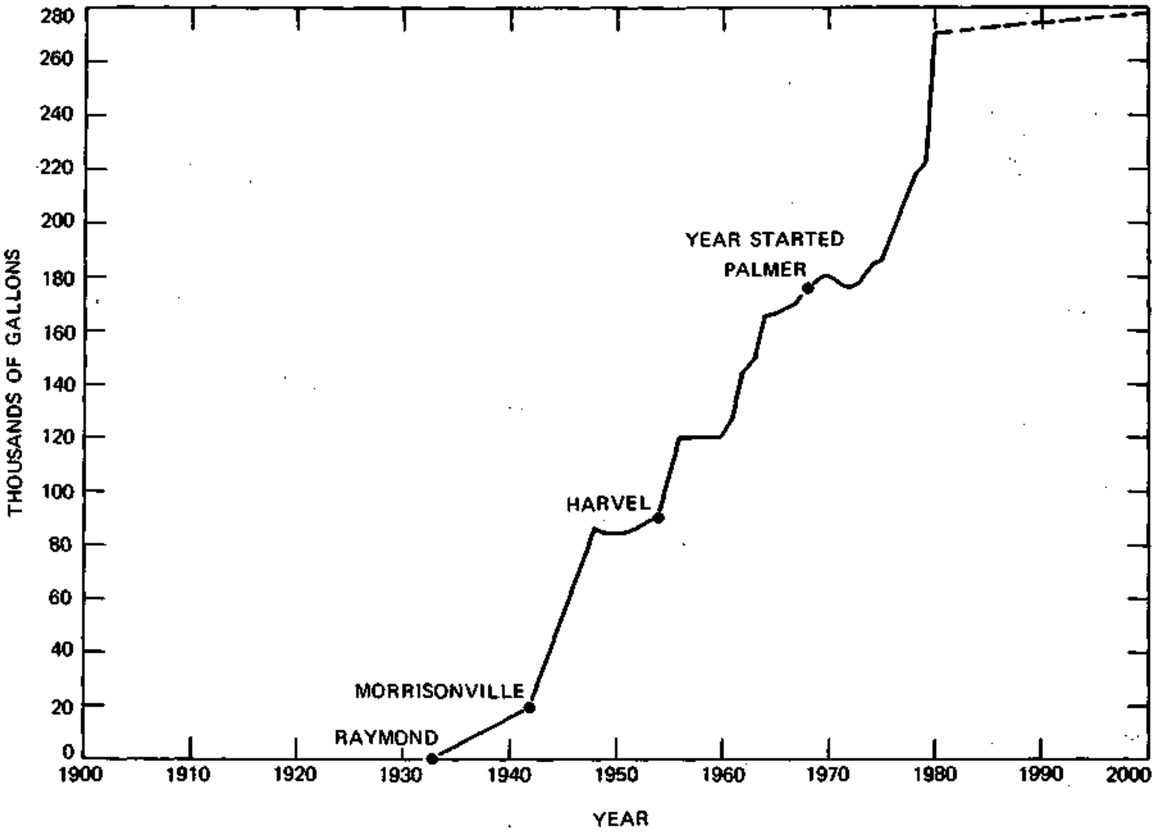


Figure 18. Combined average daily pumpage, 1900-1980, and estimated pumpage to 2000 for south half of aquifer

in the spring, when water levels are naturally high. However, as water levels recede later in the year the conditions again become water table.

In 1888 pumpage from the aquifer began at Taylorville, and water level fluctuations caused by pumping were superimposed on the natural cycle. If pumpage had remained constant, water levels would have declined at decreasing rates with time and eventually stabilized as recharge balanced pumpage. However, pumpage rates did not remain constant but increased almost without interruption. As a result, water levels never stabilized but declined continuously throughout the period of development.

Water level measurements were seldom made in the wells at Taylorville between 1913 and 1958, but beginning in 1950 periodic measurements were made in wells near the pumping centers. Water level hydrographs for well CHR 13N2W-27.2g3 in the old city well field, well CHR 13N1W-18.8a in the new city well field, weU CHR 13N2W-23.2f6 at Continental Grain Co., and well CHR 13N2W-23.6b6 at Hopper Paper Division are shown in figure 19. It should be emphasized that these are nonpumping water levels.

The average elevation of the water table at Taylorville in 1888 was probably about 615 feet. By 1951, in response to continual withdrawals of water, the water table had declined to an average elevation of 595 feet. Thus, over a period of 63 years, water levels declined 20 feet, or at a rate of about 0.3 foot per year. As a result of progressive increases in pumpage and drought conditions, water levels declined from an average elevation of 595 feet in 1951 to an average elevation of 575 feet in 1956. The

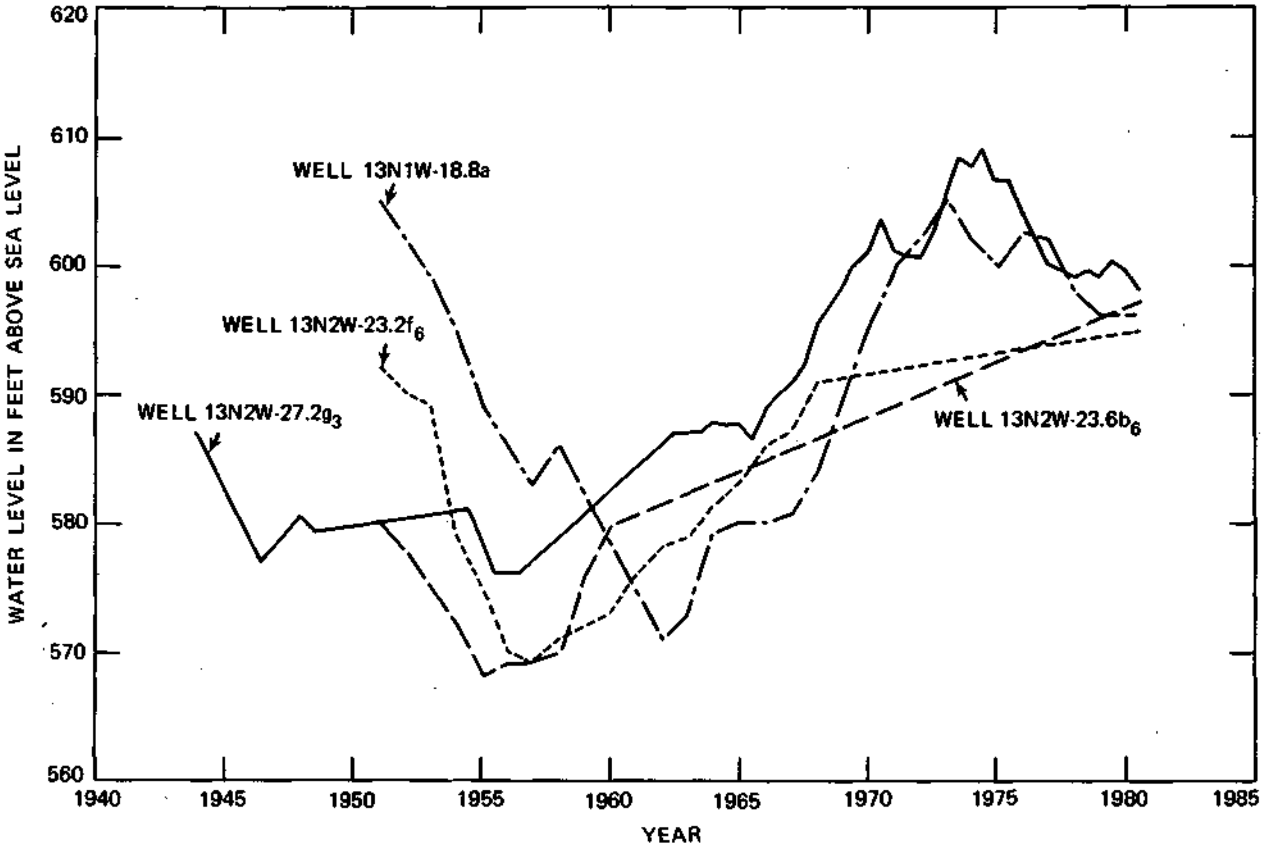


Figure 19. Nonpumping water levels in wells at Taylorville, 1944-1980

average of decline from 1951 through 1956 was about 3.3 feet per year. Between 1956 and 1958 water levels recovered slightly due to reduced pumping and above-normal precipitation. Recovery for the wells in the new city well field ended early in 1958, as shown by the data for well CHR 13N1W-18.8a. Water levels in those wells declined from 1958 until early 1963 when Lake Taylorville was put into service. During 1963 and 1964, little water was pumped from the wells and nonpumping water levels recovered from an elevation of 571 feet to an elevation of 579 feet. The rate of water level rise decreased in 1965 as pumpage restarted at a reduced rate of 0.5 to 1.0 mgd. In. response to pumpage, water levels then stabilized at about 580 feet until early 1968 when Continental Grain ceased pumpage altogether. Nonpumping water levels then rose from an average elevation of 580 feet in 1968 to 605 feet in 1973, a rate of increase of 3.6 feet per year. During this time precipitation was above normal and recharge exceeded withdrawals.

Increasing water demands at Taylorville eventually surpassed the capacity of the surface water plant and groundwater was withdrawn at a rate of about 1 mgd from 1973 to 1975. The below-normal precipitation in 1976 (only 24 inches instead of the normal of 36.95 inches), coupled with the resumption of pumpage from Hopper Paper Division in August, resulted once again in a decline in nonpumping water levels. The average water level elevation in the new well field dropped from 602 feet in 1976 to 596 feet in 1980.

The hydrographs for well CHR 13N2W-23.2f6, located between production wells at the Continental Grain plant, and for well CHR 13N2W-23.6b6 at the Hopper Paper Division plant correlate in general with the hydrographs for wells in the new city well field. The hydrographs for these wells are greatly affected by changes in pumping rates from the Continental Grain and Hopper Paper Division well fields. From January 1952 to September 1956, pumpage for Continental Grain was increased to 800,000 gpd, twice the original pumping rate, and water levels in the area declined 24 feet as a result of this increase in pumpage. Pumpage was reduced in 1956, and the water table recovered 7 feet by May 1959. The hydrograph for well CHR 13N2W-23.6b6 at Hopper Paper Division reflects the 632,000 gpd reduction in pumpage from the Hopper Paper well field in April 1958 (the water table rose 6 feet in less than a year).

The collection of water level data for Hopper Paper was discontinued in 1960, and pumpage ceased in 1963. It seems likely that the shape of the hydrograph for well CHR 13N2W-23.6b6 would be very nearly the same as for the Taylorville well (CHR 13N1W-18.8a) . The static water level elevation at Hopper Paper in August 1980 was 597 feet.

Continental Grain kept its wells in service at greatly reduced pumping rates until 1968, when the use of the wells was discontinued. Due to the reduction in pumpage, the nonpumping water level at well CHR 13N2W-23.2f6 rose from a low of 569 feet in 1957 to 591 feet by 1968. After 1968 no water level measurements were taken until July 1980, when the nonpumping water level elevation was 595 feet.

The average elevation of the water table in the vicinity of the old well field also was probably about 615 feet above mean sea level in 1888. By 1944 the water table had declined to an average of 587 feet in response to continued withdrawal of water (see the hydrograph for well CHR 13N2W-27.2g3 in figure 19). In 1951 the wells in the old field were abandoned. Occasional water level measurements taken between 1948 and 1962 indicate that water levels initially recovered following the termination of pumping in 1951. In 1955, when withdrawal rates at the other pumping centers were increasing, the levels at the old well field once again began to decline. Records of water levels from mid-1956 to 1962 are not available. It seems likely that the hydrograph for this period would be similar to others in figure 19, except that the recovery would be accelerated as no withdrawals were taking place from the old field. In 1962, monthly measurements were reinstated at well CHR 13N2W-27.2g3. These indicated that the water levels had recovered significantly. The old well field is far enough from the new well field that minor water level fluctuations correlate very closely with precipitation patterns. In 1976, when Hopper Paper Division once again began pumping, water levels began to drop. The 1976 nonpumping water level elevation reached 609 feet, still about 6 feet below the original assumed level of about 615 feet. From 1976 to August 1980 the average water level elevation dropped to 598 feet above mean sea level. Present nonpumping water levels near Taylorville are similar.

Nonpumping water levels for the rest of the well fields in the north half of the aquifer are not well documented. Scattered water level data are available for the Blue Mound and Stonington wells, and monthly water level data are available for the Macon wells from 1971 to the present. Since Assumption's and Moweaqua's supplies are relatively new, no long-term records are available for them.

The hydrograph for Macon's wells is shown in figure 20. In 1962 when its first well was built, the water table was at an elevation of 632 feet above mean sea level. Pumpage has since increased at a fairly uniform rate from 62,000 to 118,000 gpd. From 1971 to the present the nonpumping level primarily has reflected changes in precipitation patterns. Of significant note is 1976, when below-normal precipitation caused a seven foot drop in the

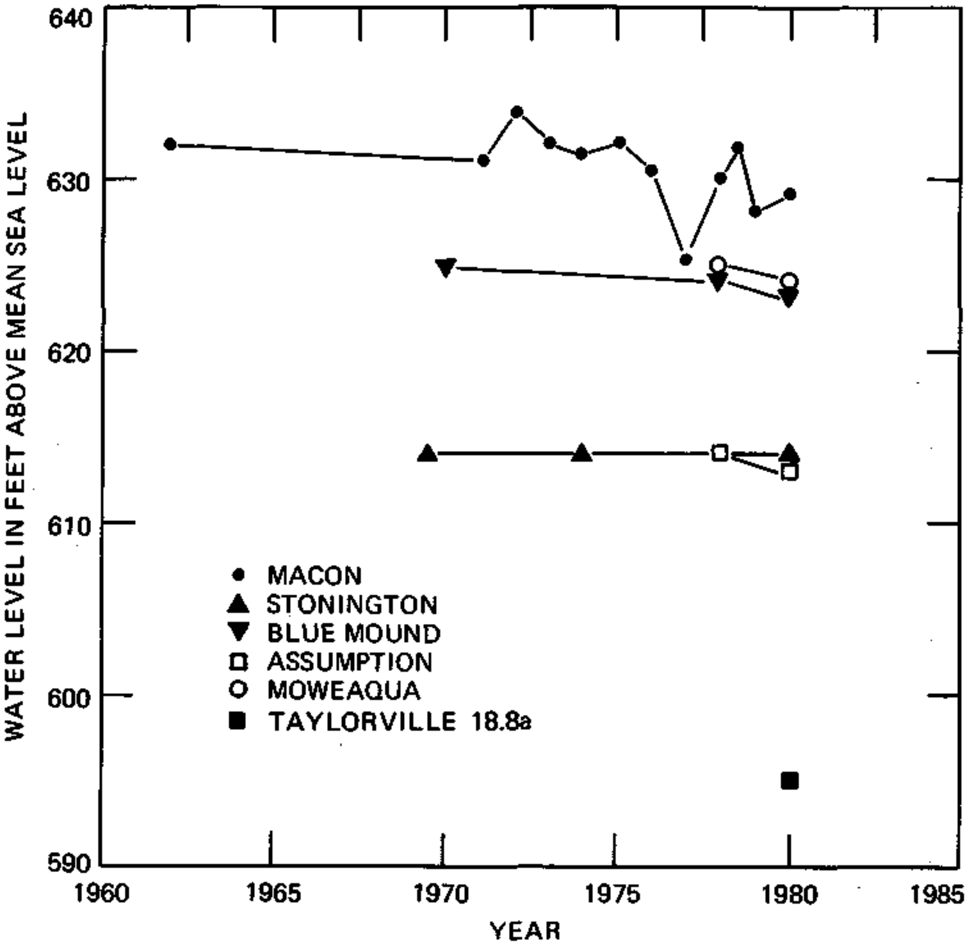


Figure 20. Nonpumping water levels in wells in north half of aquifer, 1962-1980

water table in a period of one year. Water levels rose again in response to normal precipitation.

At present, water levels in the Macon well field are at an elevation of about 629 feet above mean sea level or about 3 feet lower than when the aquifer was first tapped, indicating a decrease of about 0.17 foot per year. This could be a reflection of the effects of pumpage.

Data from the other pumping centers indicate no apparent declines. However, these centers are relatively new, and the period of record may be insufficient to show pumpage effects.

Figure 20 indicates that the static water levels in the north half of the aquifer dip from northeast to southwest. The average water level elevation at the north end of the aquifer near Macon's wells is about 630 feet, while at the Blue Mound and Moweaqua well fields the elevation is 624 feet. At Assumption's and Stonington's wells the average elevation is 614 feet, and at Taylorville the water table is about 596 feet. The slope from the Macon well field to the Stonington well field most likely reflects the land surface configuration. Nonpumping water levels are typically a uniform 10 to 15 feet below land surface except in the Taylorville area, where water levels have been depressed due to the effects of the comparatively high pumpage. Under normal conditions the general direction of groundwater movement would be from northeast to southwest, and natural groundwater discharge would be to the South Fork of the Sangamon River. However, the pumping centers at Taylorville effectively intercept groundwater flow toward the river.

Water levels in the south half of the aquifer are not well documented. Sporadic water level measurements taken at irregular intervals provide the best information available. The reported data are not complete (as to time of year collected, measuring point, length of airline, etc.), and it is impossible to interpret water level trends with confidence. However, nonpumping water levels measured by Water Survey staff during initial well production tests compare favorably to water levels measured during the summer of 1980. This would tend to indicate that there has been no regional decline in water levels due to pumpage.

Hydraulic Properties

The principle aquifer properties influencing well yields and water level declines within the aquifer are transmissivity, hydraulic conductivity and storage coefficient. The capacity of a formation to transmit groundwater is expressed by the transmissivity, T, 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 transmissivity is the product of the saturated thickness of the aquifer, m, and the coefficient of hydraulic conductivity, K, 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, S, defined as the volume of water released from storage per unit surface area of the aquifer per unit change in the water level. Under water table conditions, groundwater is derived from storage mainly by the gravity drainage of a portion of the aquifer and may be referred to as specific yield, S_y.

The manner in which T and S or S_y are related to water level decline and the yields of wells can best be illustrated by a discussion of the cone of depression. When a well is pumped, water levels decline and a funnel-shaped cone of depression is formed, with the deepest point at the pumped well. Water moves from surrounding areas down the gradient of the cone toward the pumped well. The shape of the cone is primarily controlled by the transmissivity of the aquifer. With other factors remaining constant, lower transmissivities result in steeper gradients for the cone of depression, and drawdown in a well will be greater.

During the initial period of pumping, discharge is balanced by water taken from storage within the aquifer close to the well. As pumping continues, an increasing percentage of water is taken from storage at greater distances from the well, the area of influence becomes greater, and the rate of water level decline slows. With larger coefficients of storage, smaller water level declines are required to obtain the amount of water pumped from storage.

With continuous pumping, the cone of depression grows in size and depth at a diminishing rate until hydraulic gradients are established that cause the amounts of water pumped to be brought from recharge or natural discharge areas. Provided the aquifer is infinite in areal extent, the dimensions of the cone of depression depend upon the hydraulic properties of an aquifer, the pumping rate, and the time after pumping started. Water level decline is directly proportional to the pumping rate and diminishes in a logarithmic manner outward from the well.

Under natural conditions, precipitation reaching the water table percolates toward streams to become groundwater runoff or is evapotranspired into the atmosphere. The cone of depression intercepts part of the water which otherwise would become groundwater runoff or groundwater evapotranspiration and diverts it into wells.

Thus far the cone of depression created by pumping a single well has been considered. In a multiple-well system the cones of individual wells overlap, and water levels lower more rapidly and to greater depths as the result of mutual interference between wells. The amount of interference 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 transmissivity and storage of an aquifer and the lowering of water levels in the vicinity of a pumped well. The following methods were used during this study.

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

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

where

$$W(u) = \int_u^\infty e^{-u}/u \; du = -0.5772 - \ln u + u - (u^2/2 \cdot 2!) + (u^3/3 \cdot 3!) - (u^4/4 \cdot 4!) \ldots \qquad (2)$$

and

$u = 2693\ r^2\ S/T\ t$
s = drawdown, in feet (ft)
Q = discharge, in gallons per minute (gpm)
T = transmissivity, in gallons per day per foot (gpd/ft)
r = distance from pumped well to observation well, in feet (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.

Under water table conditions the assumptions for the nonequilibrium formula are not satisfied. Water is derived largely from storage by gravity drainage of the interstices in the portion of the aquifer dewatered by pumping. Gravity drainage of water through stratified sediments is not immediate, and the nonsteady flow of water towards a well in an unconfined aquifer is characterized by slow drainage of interstices. Thus, the coefficient of storage, S, increases at a diminishing rate with the time of pumping. The important effects of gravity drainage are not considered in the nonequilibrium formula, and that formula does not completely describe the drawdown in wells. Methods of analysis for wells under water table conditions developed by Boulton (1963) and expanded by Prickett (1965) were used in cases where the length of the test was sufficiently long for gravity drainage effects to have essentially dissipated.

In instances where test data were insufficient for the above-mentioned methods or where results warranted verification, specific-capacity analysis was used. The equation for specific-capacity analysis from Walton (1962) was used for arriving at estimates of transmissivity.

$$Q/s = T/[264 \log (Tt/2693 r_w^2 S) - 66.2] \qquad (3)$$

where

Q/s = specific capacity, yield per foot of drawdown (gpm/ft)
T = transmissivity (gpd/ft)
S = coefficient of storage, fraction
r_w = nominal radius of well (ft)
t = time after pumping started (min)

Observed specific capacities were adjusted for the effects of well loss, partial penetration, and dewatering. Well loss is the head loss or drawdown in the pumped well due to the turbulent flow of water as it enters the well and flows upward through the bore hole. Well loss was estimated using the method of Jacob (1946). Drawdown data were adjusted for the effects of partial penetration with methods described by Butler (1957). Dewatering decreases the saturated thickness and therefore the transmissivity of an aquifer. The method of Jacob (1944) was used to adjust drawdown data for dewatering.

Values of adjusted specific capacity on the left side of equation 3 were then compared by trial and error to the right side where r_w and t were known, an appropriate value for S was assumed, and trial values for T were substituted. This process was facilitated by using a programmable hand calculator for solving the equation for various values of T.

Summary of Hydraulic Properties

The hydraulic properties of the aquifer are known from controlled well tests conducted by the Water Survey over the years. Most of these tests were conducted soon after completion of the well. The tests consisted of operating the well for a period of time at a known pumping rate and measuring the resultant water level declines in the pumped well and observation wells. The analytical methods previously discussed were applied to the collected data to determine values of transmissivity, hydraulic conductivity, and storage coefficient. Table 2 presents data from 25 well production tests in the north portion of the aquifer. Specific-capacity analyses were used to evaluate or check 18 of the tests. Time-drawdown analyses were made for nine tests, and observation wells were available for five tests, allowing distance-drawdown analyses to be made.

Hydraulic conductivity values range from 600 to 3,300 gpd/ft^2 and average 1490 gpd/ft . Higher values were generally noted in the Taylorville area than in the rest of the north half.

Transmissivity values are dependent upon the saturated thickness of the aquifer. Those wells located near the axis of the aquifer, where the deposits are thickest, had correspondingly higher transmissivities than wells located at the edges where the deposits are thinner. Values of transmissivity range from 34,000 to 195,000 gpd/ft. The average transmissivity is about 100,000 gpd/ft. Transmissivities in the north half of the aquifer are generally highest in the Taylorville area.

Storage coefficients have been estimated from five distance-drawdown plots. These tests were relatively short term, and gravity drainage was not complete at the ends of the tests. Longer pumping tests probably would have given larger coefficients of storage. The determined values (0.018 to 0.16) may, therefore, be low. For pumping periods involving months or years a coefficient of storage from 0.15 to 0.20 is more realistic for water table conditions.

The Water Survey has conducted 13 well tests in the south part of the aquifer. Eight tests were analyzed using specific capacity data. Data for five tests were adequate for time-drawdown analysis. Three tests were conducted using observation wells, allowing distance-drawdown analyses.

Table 2. Hydraulic Properties

North part

Well number	Owner	Owners No.	Depth (ft)	Date	Length of test (hr)	Non-pumping water level (ft)	Pumping rate (gpm)	Observed specific capacity (gpm/ft)	Draw-down (ft)	Aquifer trans-missivity (gpd/ft)	Hydraulic conduc-tivity (gpd/ft^2)	Land surface elevation	Type of analysis*	Storage coefficient
CHR														
11N3W														
18.8a	TaylorvUle	2	88	1951	7.5	-	820	-	-	66,000	1,100	636	Q/s	
18.8a	TaylorvUle	2	88	1951	7.5	-	851	-	-	98,000	1,600	636	D.D.	0.14
18.6d	Taylorville	4	96	1951	3.0	26.3	900	84.1	10.70	98,000	1,230	635	Q/s	
18.8a	TaylorvUle	2	88	1951	0.7	30.0	820	38.1	21.52	98,000	1,630	636	Q/s	
18.8c	Taylorville	3	88	1951	0.05	29.75	870	130	6.69	190,000	3,170	636	Q/s	
13N2W														
23.2f2	Continental Grain		90	1944	24.0	33	270	16.9	15.97	34,000	600	627	D.D.	0.16
23.6a	Taylorville	8	97	1930	4.0	32.2	315	81	3.89	91,000	1,110	628	Q/s	
23.8a1	TaylorvUle	9	100	1949	0.5	38.8	388	47.4	8.18	80,000	1,230	620	Q/s	
24.4f	TaylorvUle	T6	125	1930	2.0	23.7	190	51.1	3.72	100,000	1,100	629	Q/s	
24.4g	TaylorvUle	N1	118	1951	0.5	30.25	1,000	69.1	14.47	110,000	1,220	630	Q/s	
27.2hl	TaylorvUle	1	100	1923	-	35	775	22.1	35.07	92,000	1,640	625	Q/s	
27.2h3	TaylorvUle	3	100	-	-	-	800	21.0	38.09	95,000	1,700	624	Q/s	
27.2h4	TaylorvUle	4	115	1948	2.0	52.5	570	15.6	36.53	40,000	670	626	Q/s	
27.2h6	TaylorvUle	6	110	1940	0.5	40	900	64.2	14.01	170,000	2,300	624	Q/s	
27.2h7	TaylorvUle	7	128	-	-	52	650	65	10.0	145,000	1,810	630	Q/s	
27.2h8	TaylorvUle	8	130	1945	8.0	44	600	50	12.0	195,000	2,440	628	Q/s	
14N1E														
30.8g	Assumption	10	90	1978	3	14.0	200	13.67	14.63	100,000	1,351	628.0	T.D.,Q/s	
30.7h	Assumption	11	105	1978	3	11.1	280	3.80	73.71	90,000	1,050	633.5	T.D.,Q/s	
14N1W														
34. 1b1	Stonington	10	125	1969	3	15.52	153	39.4	3.88	130,000	1,300	630	T.D.	
34.1b2	Stonington	11	104	1974	3	7.65	150	19.0	7.89	132,000	1,400	620	T.D.,Q/s	
MCN														
14N1E														
10.8d	Moweaqua	15	79	1978	3	11.68	100	3.98	25.09	88,000	1,419	637	T.D.,D.D. Q/s	0.02
10.8d	Moweaqua	15	79	1980	24	13.14	100	4.54	22.02	89,760	1,360	637	T.D.,D.D.	0.018
16.6h	Blue Mound	3	88	1970	3	13.30	202	11.40	17.72	57,400	1,200	638	T.D..D.D.	0.003
15N1E														
36.8g	Macon	5	88	1977	3	21.58	201	30.36	6.62	100,000	1,550	651	T.D.	
36.8h	Macon	4	63	1962	0.95	9.45	235	44.76	5.25	100,000	3,300	642	T.D.	

Table 2. Concluded

South part

Well number	Owner	Owners No.	Depth (ft)	Date	Length of test (hr)	Non-pumping water level (ft)	Pumping rate (gpm)	Observed specific capacity (gpm/ft)	Drawdown (ft)	Aquifer transmissivity (gpd/ft)	Hydraulic conductivity (gpd/ft^2)	Land surface elevation	Type of analysis*	Storage coefficient
CHR														
11N3W														
4.1b	Morrisonville	T1	54	1942	7.0	10.5	36.5	6.6	5.53	25,000	833	610	Q/s	
8.3al	Morrisonville	T10	41	1942	5.0	2.83	25	12.5	2.0	27,000	1,170	600	Q/s	
8.3a2	Morrisonville	4	44	1944	7.0	5.56	185	16.9	10.93	30,800	1,106	600	T.D.	
8.3a3	Morrisonville	5	41	1952	6.0	5.40	200	24.7	8.1	31,000	1,352	600	D.D.,Q/s	0.1
9.6a	Morrisonville	6	45	1977	3	6.30	200	26.17	7.64	37,100	1,140	610	T.D.	
UN4W														
34.4e	Harvel	1	38	1954	7	10.75	90	52.9	1.7	40,300	2,015	634+	T.D.	
12N3W	Palmer	1	76	1967	4.5	5.46	100	12.6	7.93	20,000	322	625	T.D.,D.D.	0.2
MTU														
10N4W														
8.	Leroy Jones		31	1954	3	7.1	70	6.4	10.94	23,200	1,930	633	Q/s	
8.1a	Raymond	4	52	1977	3	11.16	90	22.73	3.96	46,600	1,165	624	T.D.,D.D.	0.15
L7.2al	Raymond	3	36	1954	1	16.7	108	20.5	5.2	21,300	1,180	614	Q/s	
17.3d	Raymond	2	39	1953	4	26.4	76	11.0	6.9	21,800	1,360	622	Q/s	
17.3dl	Raymond	T1	31	1936	3	13.25	76	16.7	4.5	15,800	1,090	615	Q/s	
17.3d2	Raymond	1	31	1936	1	15.3	75	18.3	4.1	17,500	1,210	615	Q/s	

*Q/s=specific capacity; T.D.=time drawdown; D.D.=distance drawdown

The sand and gravel deposits in the south half of the aquifer are thinner and slightly less permeable than those in the north half. Therefore, the hydraulic properties are lower. The hydraulic conductivities range from 322 to 2,015 gpd/ft^2, with an average of 1,130 gpd/ft^2. Transmissivities range from 17,500 to 46,000 gpd/ft, with an average of about 25,600 gpd/ft.

Based on data collected from observation wells, it appears that gravity drainage takes place more quickly in the south half of the aquifer and is more complete after short pumping periods than in the north half. Computed storage coefficients range from 0.1 to 0.2, which are close to those that would be expected.

Moweaqua Well Test

Hydraulic properties for the north part of the aquifer have been estimated from short tests, typically 3 hours. Observation wells were seldom available for measurement, and gravity drainage effects were still apparent. It was therefore desirable to conduct a longer test with several observation wells to confirm transmissivity and hydraulic conductivity values and to refine the estimates of storage coefficients.

With the permission of the Village, Moweaqua Well No. 15 was selected for testing. This well is located in Section 10, T.14N., R.1E., Macon County. The well was constructed in 1978, and has not yet been placed into operation.

The well is 79 feet deep and taps 62 feet of saturated sand and gravel from 17 to 79 feet. Eight-inch-diameter casing extends from 3.5 feet above land surface to a depth of 64 feet. A 15-foot length of 8-inch-diameter, 60-slot (0.060 inch) well screen is set from 64 to 79 feet. The annulus between the 16-inch bore hole and the 8-inch screen was filled with a selected gravel pack material.

For an earlier well test a 2-inch diameter observation well was installed 122 feet northeast of the pumped well. This well (Observation Well No. 2), located in a line parallel with the axis of the aquifer, is 84 feet deep and is cased with 2-inch plastic pipe to a depth of 84 feet. The last 10 feet of the casing are slotted.

Upon completion of Well No. 15 in 1978, a three-hour constant-rate test was conducted at a rate of 100 gpm. This was followed by 30 minutes of recovery and a step-test. Water level measurements were taken in both the pumped well and observation well during the constant rate and recovery tests.

Based on the collected data, the calculated values for transmissivity and hydraulic conductivity were 88,000 gpd/ft and 1,420 gpd/ft , respectively. The calculated storage coefficient was 0.003. It was obvious that gravity drainage was still taking place and that the storage value coefficient would be larger after a longer period of pumping.

To overcome gravity drainage effects during the early portions of pumping, a longer, 24-hour, test was planned and conducted in July 1980. Two additional observation wells (Observation Wells Nos. 1 and 3) were constructed in line with the pumped well and the first observation well. They were spaced 61 feet and 435 feet from the pumped well. Each of them was four inches in diameter and was equipped with plastic screens and casings. Observation Well No. 1, closest to the pumped well, was 85 feet deep. The casing extended to 80 feet, followed by 5 feet of 30-slot (0.030 inch) screen. The farthest observation well, No. 3, was completed at a depth of 95 feet, with casing to 90 feet, followed by a 5-foot length of 30-slot (0.030 inch) screen to 95 feet. The locations of the test wells are shown in figure 21, and a generalized cross section of the. test site and wells is shown in figure 22.

A contractor's pump and portable electric generator were used for the test. Approximately 600 feet of 4-inch-diameter plastic pipe was laid to transport water away from the test

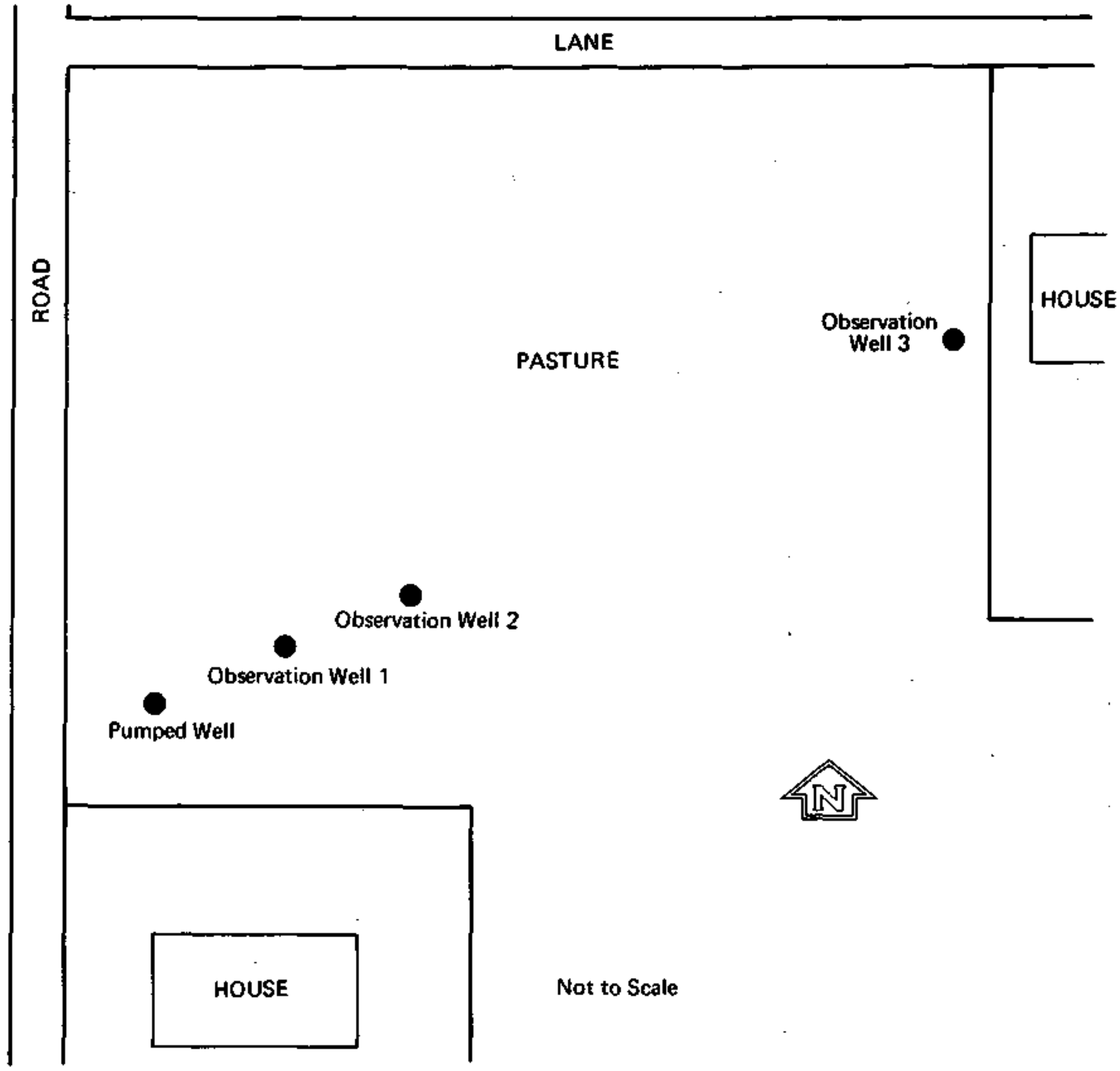


Figure 21. *Location of production well and observation wells for Moweaqua well test*

site. An orifice tube was attached to the end of the discharge line to measure the pumping rate.

Stevens Type-F recorders, modified for microtime measurements (Walton, 1963'), were installed on the two 4-inch-diameter observation wells. These facilitated accurate measurement of the early drawdowns before the effects of gravity drainage could take place. Water levels were measured in the pumped well with an electric dropline and in the 2-inch observation well with a steel tape.

To insure that everything was in working order, a one hour step-test was conducted the day prior to the constant-rate test. This helped to determine the rate at which the 24-hour test would be run.

After water levels recovered overnight, the 24-hour test was begun at 10 a.m., pumping at a rate of 100 gpm. Microtime measurements were taken at the observation wells for the first hour. Ater 296 minutes of pumping, the test was interrupted briefly by equipment difficulties. Observed drawdown

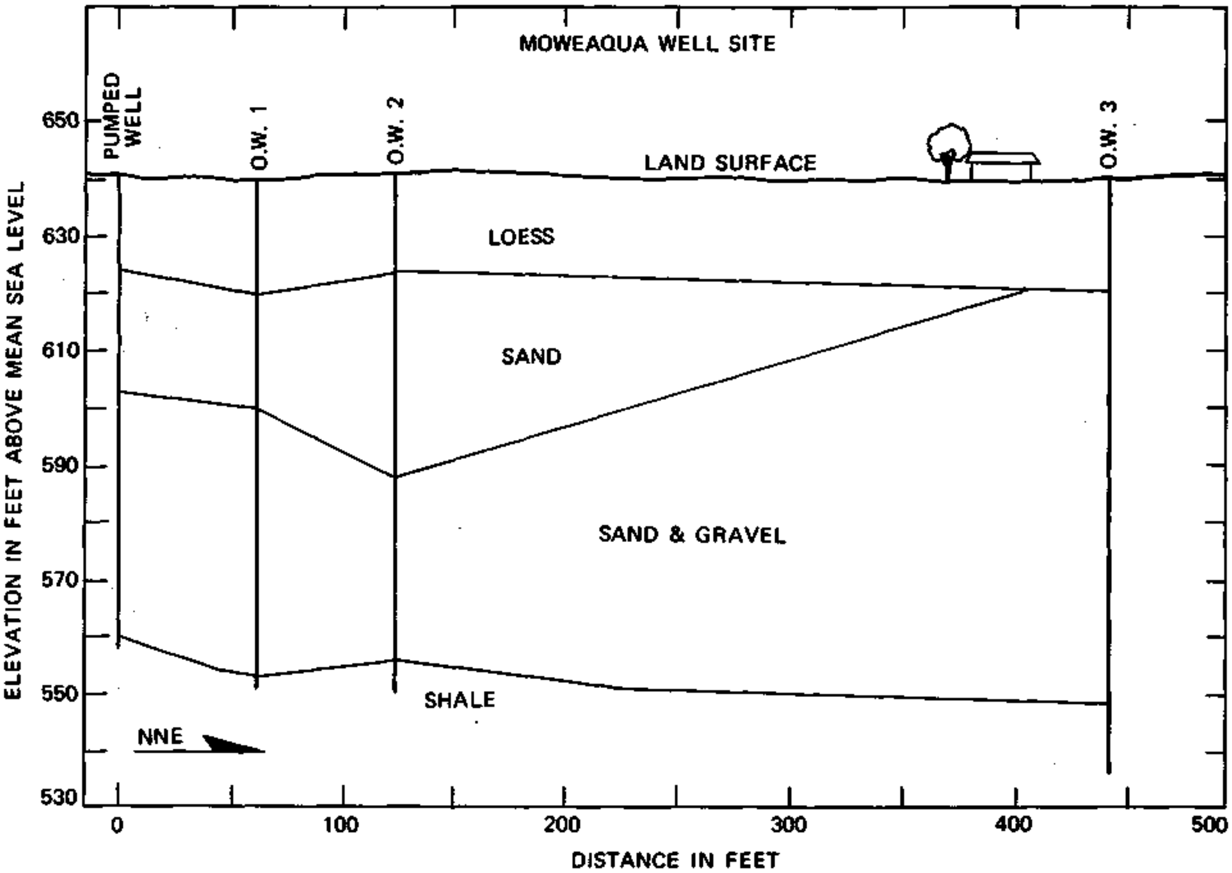


Figure 22. Moweaqua site cross section

in the pumped well after 24 hours was 21.80 feet below a nonpumping water level 13.04 feet below land surface. Observed drawdowns in Observation Wells Nos. 1, 2, and 3 were 1.08 feet, 0.91 feet, and 0.62 feet, respectively. Microtime measurements of recovery were taken for one hour after the pump was turned off. The recorders were left in place, measuring recovery, for the next 25 hours.

Analysis of the collected data yielded an average hydraulic conductivity of 1360 gpd/ft^2 (compared to 1420 for the previous test). Due to the differing thickness of the aquifer at each well location, a range of transmissivity from 89,760 to 118,320 gpd/ft was obtained. At the end of the test the effects of gravity drainage were still apparent, since the calculated storage coefficient was about 0.018.

Summary of Well Yields

Individual well yields are determined by the hydraulic properties at the location of interest, the amount of drawdown available, the degree of partial penetration, the efficiency of the well, and boundary effects.

In the north half of the aquifer the saturated thickness of the aquifer ranges from about 48 to 100 feet, and averages about 70 feet. From experience, it has been found that the wells are limited to yields of 100 to 300 gpm. Wells in the Taylorville area have been pumped at rates as high as 1, 000 gpm for extended periods of service. However, well deterioration problems are common at these rates.

The south half of the aquifer is shallower than the north half. This results in less available drawdown, which limits individual well yields to between 50 to 125 gpm. Well efficiency is especially important to the wells in the south part of the aquifer, as excessive well losses may result in a significant decrease in well yields.

Geohydrologic Boundaries

Geologic conditions limit the extent of the aquifer. The aquifer is bounded along the northwest and southeast by glacial tills which delimit the aquifer and act as barrier boundaries. A barrier boundary is defined as a boundary across which there is no flow of water. Its effect is to distort cones of depression and increase drawdown in wells. In the case of this aquifer the glacial tills along the edges of the aquifer have some water-transmitting capacity and thus do not form a completely impervious barrier. The aquifer is narrow and the cones of depression of wells are normally affected by both boundaries.

Based on data collected during controlled well production tests conducted throughout the aquifer, estimates of the distance to effective boundaries were made. The law of times described by Walton (1962) was the graphical method used to determine the distances. Analyses of data in which the effects of boundaries were seen indicated that boundary distances ranged from 870 to 2200 feet. Only one test, the Moweaqua 24-hour test, showed apparent multiple boundaries.

Since the available information indicates that these wells are located approximately along the axis of the aquifer, the effective boundary distances suggest that the aquifer width ranges from about 1740 feet to 4400 feet. This is in agreement with the geologic data.

Recharge

The source of recharge to the aquifer is precipitation; however, only a small fraction of the annual precipitation percolates downward to the water table. A large proportion of the precipitation runs overland to streams or reenters the atmosphere through evapotranspiration before it reaches the aquifer. The amount of precipitation that reaches the zone of saturation depends upon several factors. Among these are the character of the soil and other materials above the water table; the topography; vegetation cover; land use; soil moisture; the depth of the water table; the intensity, duration, and seasonal distribution of rainfall; the occurrence of precipitation as rain or snow; and the air temperature. Most recharge occurs during the spring months when evapotranspiration is small and soil moisture is maintained at or above field capacity by frequent rains. During the summer and fall months, evapotranspiration and soil moisture requirements place added demands on precipitation and are so great that little precipitation percolates to the water table except during periods of excess rainfall. Recharge is negligible during the winter months when the ground is frozen.

Figure 23, which shows precipitation and water levels for well CHR 13N1W-18.8a at Taylorville, illustrates the close correlation between precipitation patterns and nonpumping water level fluctuations and suggests that recharge to the aquifer takes place quickly.

Estimates of recharge in the Taylorville area were made by Walker and Walton (1961), using known withdrawals and changes in groundwater storage from 1951 to 1958. Recharge from precipitation was estimated at 1,400,000 gpd over a 6.3-square-mile area, or approximately 222,000 gpd/mi^2. Walton (1965) determined recharge rates for several basins in Illinois. Recharge rates for glacial sand and gravel aquifers range from 115,000 to 500,000 gpd/mi^2. In areas where sand and gravel deposits occur from near land surface to bedrock, recharge rates commonly exceed 300,000 gpd/mi^2. Since the period from 1951 to 1958 was one of below-normal rainfall, the estimate of 222,000 gpd/mi^2 may be conservative.

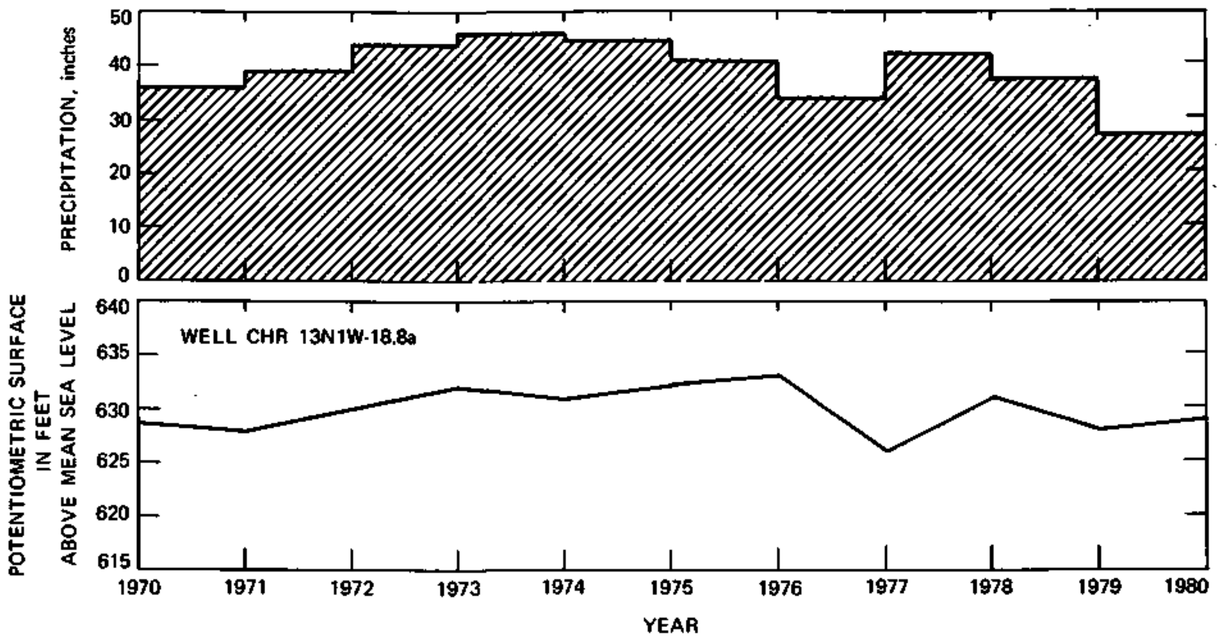


Figure 23. Relation between water levels and precipitation

Pumpage in the Taylorville area between 1951 and 1958 averaged 2,500,000 gpd. Water level hydrographs (figure 19) reflect the fact that this pumpage was in excess of recharge by about 1,100,000 gpd during this period. Elsewhere in the aquifer system, recharge appears to have matched withdrawals.

Water Quality

The ranges and mean values of certain constituents of groundwater from the aquifer are shown in table 3. More complete information on the chemical character of the groundwater is given in table 4. The quality of water from the north and south halves of the aquifer is generally the same. Water from the old Taylorville well field, CHR 13N2W-27.2h5 and 27.3f, is generally harder and more highly mineralized. The water quality and declining water levels in the old field were responsible for the development of the new Taylorville well field.

The chemical analyses tabulated in table 4 were made by the Analytical Chemistry Laboratory Unit of the State Water Survey.

Table 3. Ranges and Mean Values of Certain Chemical Constituents for Selected Well Water Samples

Constituent	Range	Mean
Iron (FE)	Tr.-4.2	1.2
Chloride (Cl)	2-47	11.4
Nitrate (NO_3)	0.0-18.9	3.4
Sulfate (SO)	18.3-336.1	83.6
Alkalinity (as $CaCO_3$)	176-364	260
Hardness (as $CaCO_3$)	177-678	303
Total dissolved minerals	221-858	377

Table 4. Chemical Analyses of Water from Selected Wells
(Milligrams per liter)

Well number	Owner	Depth (ft)	Date collected	Lab. number	Iron Fe	Manganese Mn	Ammonium NH_4	Sodium Na	Calcium Ca	Magnesium Mg	Fluoride F	Boron B	Nitrate NO_3	Chloride Cl	Sulfate SO_4	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Total Dis. Minerals	Temp. (°F)
CHR																			
14N1E																			
30.7h	Assumption(V)	105	4/27/78	208004	0.7	0.15	-	-	-	-	0.2	-	0.0	6	-	262	254	286	55
30.8g	Assumption(V)	90	5/16/78	208183	2.7	0.09	-	-	-	-	0.2	-	0.2	6	-	278	280	301	56
14 N 1 W																			
25.5c	Harold Garwood	70	3/9/79	210388	2.3	0.02	0.2	-	-	-	-	-	0.5	2	-	202	200	221	-
34. 1h1	Stonington(V)	124.5	2/26/69	177521	1.3	0.09	-	-	-	-	0.1	-	1.7	11	-	262	324	389	52
34.1h2	Stonington(V)	104	1/24/74	194689	0.2	0.11	-	-	-	-	0.2	-	0.4	5	-	220	226	250	54.1
13N1W																			
18.6d	Taylorville(C)	96	6/14/74	195911	0.2	0.01	0.0	10.7	63.2	22.5	0.2	0.1	18.9	9	54.5	196	250	337	-
18.8a	Taylorville(C)	88	2/19/51	124099	0.1	0.1	Tr.	15.9	45.7	15.2	0.2	-	1.8	5	18.3	184	177	237	54.2
18.8c	Taylorville(C)	88	6/14/74	195910	0.5	0.11	Tr.	14.2	91.2	30.8	0.2	0.1	12.2	7	99.6	270	354	463	-
13N2W																			
23.2b	Taylorville Country Club	80	10/17/47	112222	0.1	Tr.	-	-	-	-	-	-	-	4	71.0	184	243	285	55
23.2f3	Allied Mills	92	8/7/48	115493	1.6	0.1	0.2	15.4	72.8	20.3	0.2	-	0.6	7	46.9	240	266	300	55.5
24.4g	Taylorville(C)	118	1/26/51	124201	0.2	0.1	Tr.	12.7	55.5	18.1	0.2	-	10.4	9	34.6	184	214	270	54.5
27.2h5	Taylorville(C)	119	5/19/47	110316	2.8	-	-	-	-	-	-	-	-	35	-	328	656	798	-
27.3f	Capitol Theatre	100±	10/17/47	112221	0.3	0.4	-	-	-	-	-	-	-	47	336.1	348	678	858	55
12N3W																			
35.5d	Palmer(V)	76	5/1/67	171368	2.2	0.05	-	-	-	-	0.3	-	0.1	4	-	176	192	312	55
11N3W																			
8.3a3	Morrisonville(V)	41	12/10/74	197543	2.5	-	0.4	-	-	-	0.3	-	-	16	-	260	284	378	55
9.8c	Morrisonville(V)	45	5/16/77	208932	0.3	0.14	-	-	-	-	0.2	-	0.3	11	-	286	306	401	-
11N4W																			
34.2d	Harvel(V)	38	10/15/57	144805	4.2	0.2	Tr.	28.0	92.1	25.1	0.2	0.2	1.0	18	57.2	308	334	417	57
MCN																			
15N1E																			
36.8g	Macon(V)	88	10/4/77	206358	1.1	0.12	1.2	-	-	-	0.2	-	0.6	8	-	364	330	374	55
36.8h	Macon(V)	62.5	7/12/76	202493	2.2	0.06	1.5	-	-	-	0.2	-	0.4	10	-	330	344	385	-
14 N1E																			
10.8d	Moweaqua(V)	79	6/19/78	208490	1.5	0.05	-	-	-	-	0.2	-	0.5	9	-	312	294	338	56
16.6h	Blue Mound(V)	88	10/6/72	190038.	0.0	0.00	Tr.	-	-	-	0.2	-	17.2	3	-	192	196	239	55
MTU																			
10N4W																			
8.1a	Rayrnond(V)	52	12/5/77	208933	0.9	0.14	-	-	-	-	0.3	-	1.0	18	-	292	304	444	-
17.2a2	Raymond(V)	36	12/20/54	136532	0.7	-	-	-	-	-	0.1	-	1.0	12	-	280	292	382	55.7
17.3d	Raymond(V)	31.2	7/15/48	115294	Tr.	0.0	Tr.	28.1	76.1	23.5	0.1	-	0.4	11	34.6	296	287	374	54

NUMERICAL MODEL

Description

Geologic and hydrologic data obtained for the north part of the aquifer were used to develop a numerical model for the aquifer. Data for the south half are not sufficient to allow modeling with much confidence.

The computer program used in the study was the composite aquifer simulation program developed by Prickett and Lonnquist (1971). The governing equation solved by the program is:

$$\partial/\partial x(T\partial h/\partial x) + \partial/\partial y(T\partial h/\partial y) = S\partial h/\partial t + Q \qquad (4)$$

where

T = aquifer transmissivity
h = head
t = time
S = aquifer storage coefficient or specific yield, fraction
Q = net groundwater withdrawal rate per unit area
x, y = rectangular coordinates

The program was used to simultaneously simulate two-dimensional, non-steady-state flow in an aquifer under water table conditions, and nonleaky artesian conditions converting to water table. The governing equation is solved by using finite difference approximations.

The model of the aquifer contained 4,500 nodes, comprised of a grid 225 nodes long by 20 nodes wide. Spacing between nodes was a uniform 500 feet in both directions. The area represented by the model was 112,000 feet (21.2 mi) by 9,500 feet (1.8 mi), or a total area of 38.3 square miles. The grid was superposed over the aquifer, as will be seen later in figures 27 and 28. The dimensions of the aquifer were provided by the State Geological Survey, based on information from well logs and electrical earth resistivity surveys.

Nodes outside the aquifer were assigned uniform values for geologic and hydraulic parameters. The nodes inside the aquifer boundaries were handled with varied parameter input. The data for each node include:

1) Elevation of land surface
2) Elevation of the top of the aquifer
3) Elevation of the bottom of the aquifer
4) Elevation of hydraulic head
5) Elevation below which evapotranspiration ceases
6) The storage factor (SF1) for artesian conditions,

$$SF1_{i,j} = 7.48\ S\ \Delta x \Delta y$$

where

$SF1_{i,j}$ = storage factor (gallons per foot) for a node located at model coordinates i, j
S = the aquifer storage coefficient for artesian conditions
7.48 = number of gallons in a cubic foot of water
$\Delta x, \Delta y$ = finite difference grid intervals

7) The storage factor (SF2) for water table conditions, where SF2 was the same as SF1 except that the aquifer storage coefficient or specific yield for water table conditions was used
8) Constant withdrawal rate (in gallons per day)
9) The recharge factor (R),

$$R_{i,j} = Q_{ET(max)}/(RH_{i,j}-RD_{i,j})$$

where

$R_{i,j}$ = recharge factor (gpd/ft) for a node located at model coordinates i,j
$Q_{ET(max)}$ = maximum rate of evapotranspiration

$RH_{i,j}$ = elevation at land surface at model coordinates i, j
$RD_{i,j}$ = elevation below which evapotranspiration ceases at node coordinates i, j
$\Delta x, \Delta y$ = finite difference grid intervals

10) The aquifer transmissivity between i,j and i, j+1
11) The aquifer transmissivity between i,j and i+l,j
12) The hydraulic conductivity between i,j and i, j+1
13) The hydraulic conductivity between i,j and 1+1, j
14) The model column number
15) The model row number

Since the elevation of land surface, top and bottom of the aquifer, and nonpumping water levels were within fairly narrow ranges, constant elevations for each were assumed for the model. Land-surface elevations ranged from 620 to 650 feet and were modeled as an average of 630 feet. The elevation of the top of the aquifer ranged from approximately 600 feet near Taylorville to 630 feet at the Macon well field. A value of 610 feet was chosen as the most representative overall elevation. Similarly, an aquifer bottom elevation of 540 feet was selected. The initial saturated thickness of the model is 70 feet.

In most areas, the nonpumping water level coincided with the top of the aquifer; therefore, an elevation of 610 feet was used for initial conditions. Since a reasonable value of recharge was known from previous studies which incorporated the effects of leakage and evapotranspiration (Walker and Walton, 1961; Walton, 1965), the elevation at which evapotranspiration ceased was assumed to be land surface, 630 feet above mean sea level.

The storage factors for artesian and water table conditions were calculated by the method described by Prickett and Lonnquist (1971). For artesian conditions a storage coefficient of 0.001 was used. The specific yield for water table conditions was taken as 0.15. The storage factor at a given node changed as the conversion from artesian to water table conditions took place. High storage factors were set at the ends of the strip aquifer to simulate the extension of the aquifer beyond the model boundaries.

The rate at which recharge is put into the model is represented by the recharge factor. At a given node, recharge and evapotranspiration can be summed vectorially and entered into the model as a total. Through this method of superposition, the overall recharge factor was calculated.

Transmissivity values for the model were determined by multiplying the model saturated thickness of 70 feet by field-determined values of hydraulic conductivity. The hydraulic conductivities ranged from 1200 to 1500 gpd/ft^2, resulting in transmissivities from 84,000 to 105,000 gpd/ft. The transmissivities and hydraulic conductivities between i, j and i, j+1, and i, j and i+1,j were set equal for a given node, as the existence of directional properties was uncertain.

A transmissivity of 20,000 gpd/ft and a hydraulic conductivity of 286 gpd/ft^2 were assigned to the boundary nodes adjacent to the limits of the aquifer. Groundwater development within the modeled area has not significantly changed water levels along the boundary; therefore, the storage values outside the aquifer were set equal to those inside the aquifer.

Pumpage data, expressed as total annual withdrawals, were converted to a constant daily withdrawal rate for each supply. Nodes were located and identified that corresponded to the location of pumping centers. For these nodes, pumping schedules were entered which could be easily modified to analyze the effects of different pumping schemes.

Calibration

The model was calibrated for transient groundwater levels at Taylorville during the period 1950-1959. Data for this period provided the most detailed information on water levels and withdrawal rates. Water levels were continuously changing during this time in response to pumpage, and steady-state conditions were never reached. During the calibration, adjustments of hydraulic parameters were made in order to obtain satisfactory agreement between the observed and computer-generated water levels.

Nonpumping water levels observed in the Taylorville area during the 1950s were assumed to reflect regional trends. The water levels generated by the program were for pumping conditions; therefore the response at nodes away from pumping centers was selected for comparison to historical data. Water levels at these nodes were assumed to reflect regional response to the varying withdrawal rates.

The parameters that were varied during calibration were hydraulic conductivity, transmissivity, specific yield, and recharge. The calibration was found to be most sensitive to changes in recharge, as would be expected in a shallow water table aquifer. The calibrated model used 0.15 for specific yield and a recharge rate of 222,000 gpd/mi^2. Transmissivity and hydraulic conductivity were zoned as data blocks with values within the ranges discussed in the model description.

The model was calibrated using ten uniform time steps of 365 days. Total annual withdrawals were converted to average daily pumpages for input to the program. Transmissivities were recalculated for the time-steps as the saturated thickness in the aquifer decreased. There was good agreement between iteration and time-step recalculations of transmissivity. Historical nonpumping water levels for the three Taylorville pumping centers--Hopper Paper Division, Continental Grain, and the City of Taylorville--are shown in figure 24. Also shown are hydrographs generated by the computer program for representative nodes, (30,12) and (40, 12), midway between the pumping centers. These show a good fit for the Continental Grain and the Taylorville

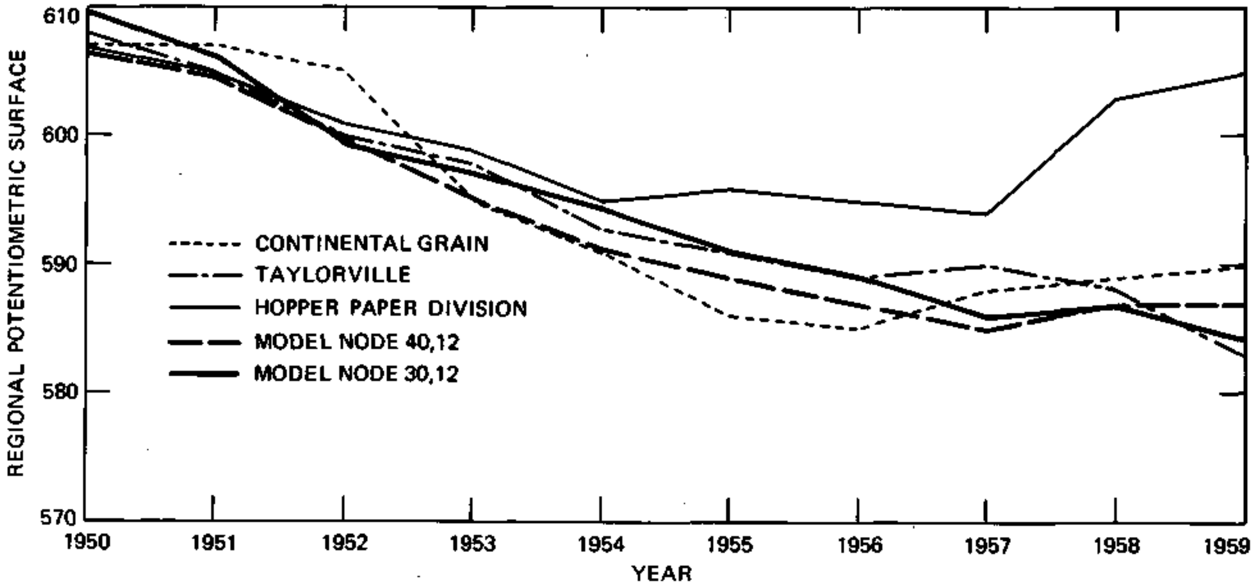


Figure 24. Comparison of historical and computer-generated water levels at Taylorville for 1950-1959

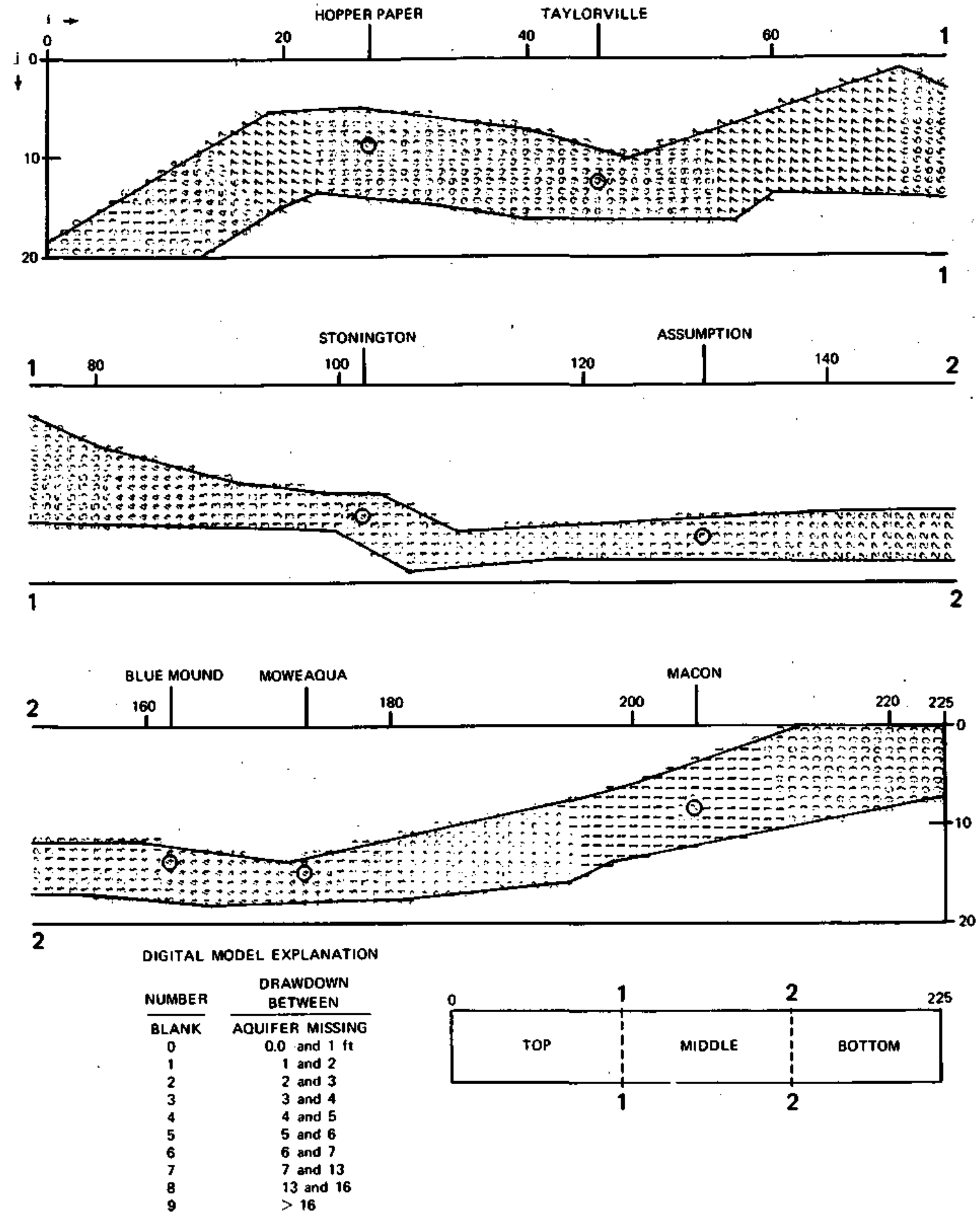


Figure 27. Dynamic water levels in the year 2000 resulting from continued present pumpage

Predicted Response to Projected Withdrawal Rates

The effects of future pumpage increases were examined, based on projected withdrawal rates as supplied by the Illinois Division of Water Resources. Table 5 shows the 1980 pumpage for each supply considered and the projected demand in the year 2000. Pumpage was assumed to grow linearly from 1980 to 2000. The projected increases for all the supplies were plotted against time, and the appropriate pumpage rates at two-year intervals were used as input to the program. Again Moweaqua was included.

The computer-generated water levels at pumping centers (in feet, elevation) are compared in figure 26 for present and projected pumpage. The most severe drawdown occurs in the vicinity of the Taylorville pumping center as water levels again reach the critical levels observed in the 1950s. The critical level is the top of the well screens at about 555 feet elevation. At Hopper Paper Division, the water level declines to an elevation of about 566 feet in the year 2000. For the remaining supplies, water-level elevations are predicted to range from 599 to 605 feet above mean sea level. The predicted drawdowns resulting from projected withdrawals are shown in figure 28.

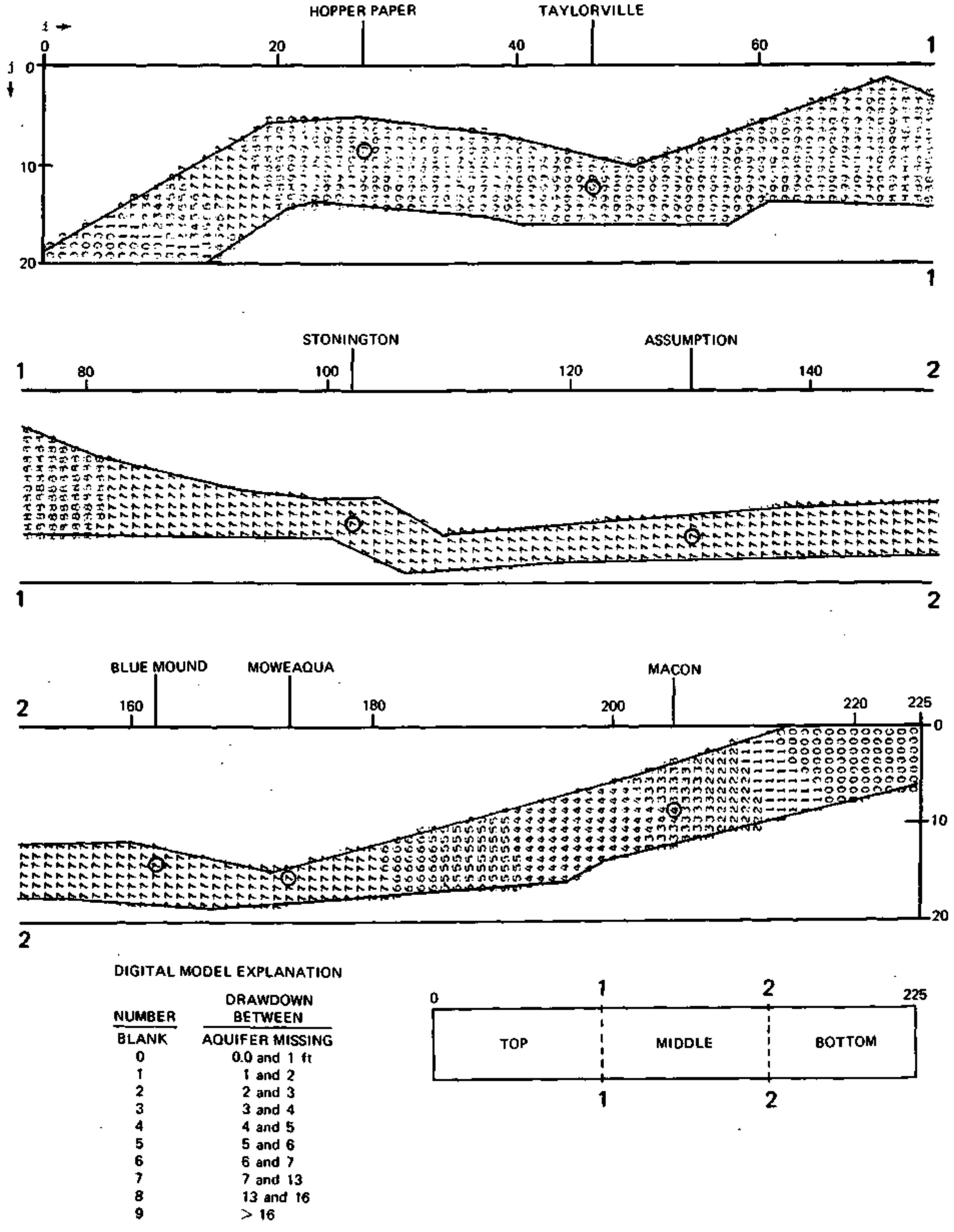
Table 5. Present and Projected Pumpage for the North Part of the Aquifer*

(Gallons per day)

North Part	1980	2000
Macon	118,000	171,000
Moweaqua	140,000**	226,000
Blue Mound	111,000	231,000
Assumption	115,000	135,000
Stonington	111,000	119,000
Taylorville	1,000,000	1,290,000
Hopper Paper Division	1,000,000	1,000,000

* From Illinois Division of Water Resources

** Assumed



NUMBER	DRAWDOWN BETWEEN
BLANK	AQUIFER MISSING
0	0.0 and 1 ft
1	1 and 2
2	2 and 3
3	3 and 4
4	4 and 5
5	5 and 6
6	6 and 7
7	7 and 13
8	13 and 16
9	> 16

Figure 28. Dynamic water levels in the year 2000 resulting from projected pumpage increases

SUMMARY AND CONCLUSIONS

The studied aquifer is part of the Hagarstown Member of the Glasford Formation. The sand and gravel of the aquifer were deposited in a valley formed by a melt water stream initially channeled by an ice crevasse upon or within the Vandalia ice sheet. The valleys of both portions of the aquifer were probably formed in similar environments. As the valleys were filled with sand and gravel, the ice walls were still present in the north, while the ice in the south had probably melted. This would explain the difference in present topography.

It was previously assumed that the sand and gravel deposit in the northern part of the aquifer system did not extend beneath the Wedron Formation units in the northeast corner of the study area. It is now known that the aquifer is beneath the Wedron units and probably can be found as far north as Decatur. A hydrogeologic connection probably exists between this aquifer and the sand and gravel deposits south and east of Decatur. The deposit is 1/2- to 3/4-mile wide and is as much as 125 feet thick. At the lateral boundaries near the ground surface, the deposit becomes thin and very fine grained. The hydrogeologic boundary as shown on cross sections A-A', B-B' and C-C' (figures 10, 11, and 12) reflects this decrease in grain size, as well as the thinning of the aquifer. Through most of its thickness, the aquifer is confined by steep valley walls of fine-grained glacial tills with a few discontinuous sand lenses. The base of the aquifer overlies fine-grained bedrock or, locally, glacial till. The deposit is covered by a blanket of loess 10 to 20 feet thick.

From 1888 to the present the aquifer has been providing water to the residents of the area at an ever-increasing rate. This important regional resource supplies approximately 22,000 people and provides water for hauling to the rural residents of the areas with inadequate well supplies. One large area industry is supplied directly from the aquifer, and many smaller industrial and commercial establishments are provided water indirectly through the public water supplies. As population increases and economic growth continues, the importance of an adequate regional supply cannot be understated.

From 1888 to 1962 the only water supplies developed in the north half of the aquifer were for Taylorville, Hopper Paper Division, and Continental Grain. All are concentrated in the immediate vicinity of Taylorville. Rapid pumpage growth from these 3 well fields and below normal precipitation in the early to mid-1950s resulted in a serious localized water level decline. This ultimately forced reductions in withdrawals in the latter part of the decade.

Water levels rose during the 1960s and first half of the 1970s as pumpage from the aquifer was significantly reduced by conservation practices of the industries, by the completion of Lake Taylorville, and by the occurrence of above-normal precipitation. The resumption of pumpage at Hopper Paper in 1976 and the steady increase of Taylorville municipal pumpage led once again to declining water levels in the Taylorville area.

Away from Taylorville other supplies were developed in the north half of the aquifer, the first being for Macon in 1962. Three additional supplies have been added, with one more to follow. Although the number of supplies has increased, the total amount of water withdrawn has not risen proportionately. The average daily pumpage outside the Taylorville area is about 455,000 gpd, or about 1/3 the total amount of water withdrawn from the northern half of the aquifer. As of 1980, there has been no discernible decline in water levels due to pumpage outside of the Taylorville pumping centers.

The model simulation illustrates the effects of continued pumpage at the current rates for the next 20 years.

Water levels in Taylorville will begin dropping at a slower rate than in the 1950s, but by the year 2000 pumping levels will again be at critical levels. The model results indicate, and experience has shown, that the water level effects from pumpage at Taylorville are fairly localized. This is due in part to the limited available drawdown in this shallow aquifer system. The pumping levels are at the tops of the well screens before the cones of depression have captured enough recharge to balance pumpage. The available data suggest that the Villages of Macon, Blue Mound, Assumption, and Stonington can continue pumping at their present rate, with no significant decline in nonpumping water levels. The Village of Moweaqua also can develop a supply from the aquifer at its present pumping rate, with a theoretical 7-foot drop in water levels after twenty years. Shown in figure 27 are regional water level declines in the year 2000 resulting from continued present pumpage.

Regional declines caused by increased projected pumpage demands to the year 2000 are shown in figure 28. Water level declines at the pumping nodes are 2 to 8 feet greater than those projected at present rates. Under the increased pumpage scheme dynamic water levels at Taylorville may be at the tops of the screens by 1995.

The results of the model indicate that the aquifer is capable of providing the present and future water needs of the communities presently tapping the aquifer, with the possible exception of Taylorville. Water level declines, except at Taylorville, are predicted to be within acceptable limits. If water levels decline as predicted, Hopper Paper and/or Taylorville may be required to reduce pumpage to avoid possible damage to their wells that would result from allowing pumping levels to drop below the tops of the screens. Updating and expanding the surface water treatment plant at Taylorville may be a possible solution.

For the south part of the aquifer, the available data suggest that there has been no depletion of the resource due to pumpage. Overall, the south part of the aquifer supplies approximately 3,000 people, or 13 percent of the population served. Pumpage from the south half is presently estimated at 270,000 gpd, or 11 percent of the total. Pumpage at Raymond and Harvel is expected to decrease slightly in the near future while withdrawals at Palmer will remain constant. The only supply where an increase in pumpage is predicted is Morrisonville. Pumpage for the south part of the aquifer is predicted to increase from the present 270,000 gpd to 278,000 gpd in the year 2000, an increase of about 3 percent. Assuming that the recharge from precipitation is of the same order as that estimated in the north half (222,000 gpd/mi^2), and that the recharge area is coincident with the boundaries of the aquifer, future pumpage for the south half of the aquifer should not cause any regional water level declines.

Historical data indicate that the most critical elements of water supply development in the south half of the aquifer are well design and maintenance. Deterioration problems have been commonplace, and with the limited available drawdown a reduction in the specific capacity of a well results in significant loss of yield. Proper well design, appropriate construction practices, and well spacing based on hydraulic characteristics at the particular site are essential to developing long-term satisfactory supplies. Well performance monitoring practices can determine deterioration trends and allow timely remedial actions to be taken.

The shallow nature of this sand and gravel aquifer, with only a thin loess cover and rapid infiltration rates, makes it susceptible to contamination. Care should be taken to insure that potential sources of contamination are not sited over the aquifer where present or future wells would be affected.

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Appendix 1. TA-Borings

Borings made for this study are numbered TA-1 through TA-20. Locations are given in two forms: the well-numbering system used by the State Water Survey, and the quartered-section system used by the State Geological Survey. All surface elevations are estimated from topographic maps.

Two logs of TA-borings are included here as a further illustration of the geologic framework and of the laboratory and field data that were used. Similar logs of all TA-borings are available on open file at the State Geological Survey. Samples from TA-1 and 2 are all washed cuttings collected at 5-foot intervals. The logs of the remainder of the borings show only the split-spoon samples, which were taken at approximately 10-foot intervals. Washed cuttings were also collected at 5-foot intervals. All test data for TA-borings apply to split-spoon samples.

Grain-size analyses of fine grained materials were made using the pipette method, assuming a clay/silt break of 2 microns and a silt/sand break of 62.5 microns. The results of sieve data of aquifer material are given in appendix 2.

An X-ray clay mineral analysis of the clay fraction (less than 2 microns) was made by H. D. Glass of the Geological Survey (Killey, 1980).

Natural gamma radiation as shown is greater to the right. Sand usually has lower gamma radation than more fine grained material.

N= Blow count in blows-per-foot: number of blows with a 140 pound hammer to drive the sampler from a depth of 6 inches to a depth of 18 inches; or number of blows for total depth if less than 18 inches

Q_P = Pocket penetrometer tests in tons-per-square foot

D_I = Illite ÷ (kaolinite + chlorite)

Exp = Expandable clay minerals

I = Illite

Chl+K= Chlorite + kaolinite

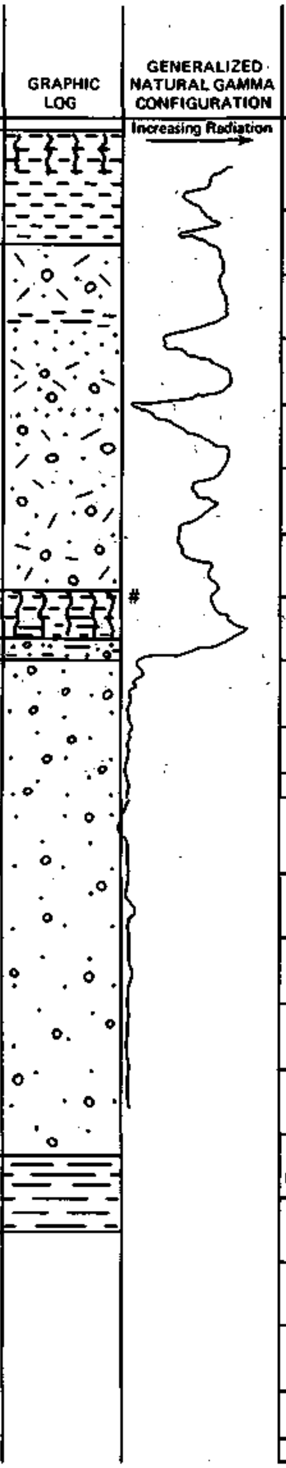
Cal = Calcite, in counts-per-second

Dolo = Dolomite, in counts-per-second

VI = Vermiculite index

C_{14} = Carbon-14 date, in years-before-present

Appendix 1. Continued

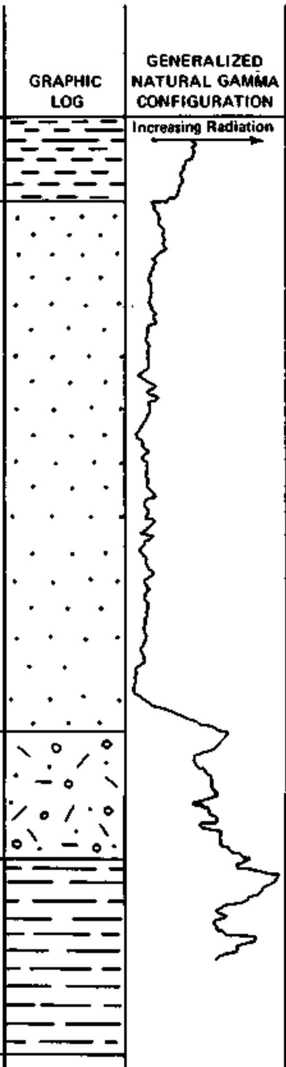


Spl No.	DEPTH OF SAMPLE	UNIT DESCRIPTION	N BPF	Qp TSF	GRAIN SIZE % total Gvl	GRAIN SIZE % <2mm Sd	Slt	Cly	X-RAY DATA D.I.	Exp.	I	Chl-K	Cal.	Dolo.
1	8½–10	LOESS, SILT, SOME CLAYEY ZONES	8	0.7										
2	18½–20	16' PIATT TILL GRAY, SILT AND SAND SEAMS	21	3.7	5	28	49	23	2.1	8	70	22	23	24
3	28½–30		36	3.0										
4	38½–40		17	2.5	5	29	49	22	2.4	8	72	20	26	26
5	48½–50		19	2.9	8	28	50	22		8	71	21	35	33
6	58½–60	ROBEIN SILT DARK BROWN, ORGANIC RICH	16	2.0	12	28	49	23	2.3	9	71	20	25	29
7	68½–70	69'	28	2.7										
8	78½–80	78' COLLUVIUM 80'	14	1.7*										
9	88½–90	HAGARSTOWN FINE TO COARSE SAND WITH GRAVEL	45											
10	98½–100		68											
11	108½–110		68											
12	118½–120		83											
13	128½–130		134*											
14	138½–140		89											
15	148½–150	153'	44											
16	155–156½	SHALE, DARK GRAY TO BLACK 165' END OF BORING	100 for 2"											

* Probably too high
#C_{14} date: 20,870±130 YBP

BORING: TA–3
LOCATION: MCN 15N2E-19.3c
1800' N, 1500' W of SE corner
Sec. 19, T15N, R2E
MACON COUNTY
SURFACE ELEVATION: 688 feet

Appendix 1. Continued



Spl No.	DEPTH OF SAMPLE	UNIT DESCRIPTION	N BPF	Qp TSF	GRAIN SIZE				X–RAY DATA					
						% <2mm								
					% total Gvl	Sd	Slt	Cly	D.I.	Exp.	I	Chl–K	Cal.	Dolo.
1	8½–10	LOESS, SANDY AT BASE	17	>4.5										
2	18½–20	13' HAGARS-TOWN FINE TO MEDIUM SAND	9											
3	28½–30		15											
4	38½–40		30											
5	48½–50		26											
6	58½–60		38											
7	68½–70		31											
8	78½–80		63											
9	88½–90		151											
10	98½–100	93' TILL UNIT E, BROWNISH GRAY	107	>4.5	5	45	41	14	1.3	22	51	27	12	17
11	108½–110		102		1	12	66	22	1.1	29	43	28	5	11
12	118½–120	109½' SHALE AND SILTSTONE	100 for 1"											
13	138½–140		100 for 2"											
		139' END OF BORING												

BORING: TA–7
LOCATION: CHR 14N1W-35.3f
Center of NE¼, SW¼, NE¼
Sec. 25, T14N, R1W
CHRISTIAN COUNTY
SURFACE ELEVATION: 630 feet

Appendix 1. Continued

Boring	Location	Surface elevation above sea level (feet)	Depth to top of aquifer (feet)	Depth to bottom of aquifer (feet)	Thickness of aquifer (feet)
TA-1	NW1/4,NW1/4,SW1/4 Sec. 10, T14N,R1E MCN 14N1E-10.8d1	640	16	87	71
TA-2	NW1/4,NW1/4,SW1/4 Sec. 10, T14N,1E MCN 14N1E-10.8d2	640	20	91	71
TA-3	1800'N,1500'W of SE corner of Sec. 19 T15N,R2E MCN 15N,2E-19.3c	688	80	153	73
TA-4	SE1/4,SE1/4,SE1/4,NE1/4 Sec. 9, T14N, R1E MCN 14N1E-9.1e	635	19	81	62
TA-5	SE1/4,SE1/4,NE1/4,SE1/4 Sec. 9, T14N,R1E MCN 14N1E-9.1c	641	20	55	35
TA-6	1320'S,1320'W of NE corner of Sec. 3 T15N,R2E MCN 15N2E-3.3i	712	Not present		
TA-7	center, NE1/4,SW1/4,NE1/4 Sec. 35, T14N,R1W CHR 14N1W-35.3f	630	13	93	80
TA-8	center, SE1/4,SW1/4,NE1/4 Sec. 35, T13N,R1W CHR 14N1W-35.3e	641	13	128	115
TA-9	SW1/4,SW1/4,SE1/4,NE1/4 Sec. 35, T14N,R1W CHR 14N1W-35.2e	628	15	48-1/2	33-1/2
TA-10	SW1/4,NW1/4,NE1/4,SE1/4 Sec. 35, T14N,R1W CHR 14N1W-35.2d	619	16	21	5
TA-11	SE1/4,NE1/4,SE1/4,SE1/4 Sec. 33, T14N,R1W CHR14N1W-33.1b	625	Not present		

Appendix 1. Concluded

Boring	Location	Surface elevation above sea level (feet)	Depth to top of aquifer (feet)	Depth to bottom of aquifer (feet)	Thickness of aquifer (feet)
TA-12	NW1/4,NW1/4,SW1/4,NW1/4 Sec. 3, T13N,R1W CHR 13N1W-3.8f	627	14	103	89
TA-13	NW1/4,NW1/4,SW1/4 Sec. 3, T13N,R1W CHR 13N1W-3.8d	613	10-1/2	32	21-1/2
TA-14	SE1/4,NW1/4,SE1/4,SE1/4 Sec. 7, T13N,R1W CHR 13N1W-7.2b	629	14	77	63
TA-15	SW1/4,SW1/4,NW1/4,SW1/4 Sec. 3, T13N,R1W CHR 13N1W-3.8c	615	14	20-1/2	6-1/2
TA-16	NW1/4,NW1/4,NE1/4,NE1/4 Sec. 2, T13N,R1W CHR 13N1W-2.2h	610	Not present		
TA-17	NW1/4,NW1/4,NE1/4,NE1/4 Sec. 35, T14N,R1W CHR14N1W-35.2h1	616	Not present		
TA-18	SW1/4,NW1/4,NE1/4,NE1/4 Sec. 35, T14N,R1W CHR14N1W-35.2h2	618	Not present		
TA-19	NW1/4,NW1/4,NE1/4,SE1/4 Sec. 26, T14N,R1W CHR 14N1W-26.2d	618	Not present		
TA-20	NW1/4,NW1/4,SW1/4,SE1/4 Sec. 8, T12N,R2W CHR 12N2W-8.4b	571	9-1/2	52	42-1/2

Appendix 2. Sieve Results

Well	Depth (ft)	Sample weight (g)	Medium & coarse gravel	Fine gravel	Very coarse sand	Coarse sand		Medium sand		Fine sand		Very fine sand	Very fine sand, silt & clay	Sorting coefficient	Median grain site
	Sieve Size (in.)		.185	.078	.039	.0276	.0195	.0138	.0097	.0069	.0049	.0035	<.0035		
	Tyler Mesh		4	9	16	24	32	42	60	80	115	170	Pan		
TA-3	88.5-90	179.14	3.6	7.5	13.6	21.3	34.1	53.2	70.8	82.5	90.0	93.8	100.0	1.673	.38
	118.5-120	225.87	27.8	43.4	55.7	62.6	74.5	85.0	90.8	92.7	94.1	95.0	100.0	3.364	1.41
	148.5-150	108.48	22.2	38.7	51.9	59.8	72.5	82.9	90.2	92.8	94.4	95.3	100.0	2.917	1.10
TA-4	28.5-30	182.00	0	trace	0.1	0.1	0.1	0.5	8.5	38.8	77.4	91.2	100.0	1.255	.165
	48.5-40	208.71	0	.0.1	0.3	1.0	5.2	23.0	61.3	80.9	90.5	94.0	100.0	1.306	.290
	58.5-60	180.12	0	0	trace	0.1	0.6	8.8	49.6	74.1	88.5	93.7	100.0	1.301	.250
TA-5	28.5-30	184.97	11.0	14.4	17.3	19.7	28.4	50.9	81.7	92.3	95.1	96.1	100.0	1.414	.354
	38.5-40	190.70	0	trace	0.1	0.4	3.7	21.4	66.4	85.0	92.3	94.8	100.0	1.233	.285
	48.5-50	187.86	1.1	2.5	6.4	14.8	38.3	61.6	81.9	89.8	93.4	95.0	100.0	1.474	.425
TA-7	28.5-30	183.93	0	trace	0.1	0.3	2.4	20.2	68.9	90.3	96.8	98.1	100.0	1.211	.290
	48.5-50	176.58	0.3	0.4	1.0	2.4	8.3	28.6	69.2	87.6	94.3	95.4	100.0.	1.254	.300
	68.5-70	194.99	8.0	24.2	47.4	56.4	65.8	73.6	83.8	88.8	91.4	93.0	100.0	2.593	.920
	88.5-90	194.79	0	trace	0.1	0.1	0.4	7.0	57.9	81.1	88.4	91.4	100.0	1.241	.270
TA-8	18.5-20	183.08	0	0.1	1.3	4.7	18.4	48.7	85.3	94.1	95.8	96.5	100.0	1.28	.350
	38.5-40	187.79	0	0	trace	trace	0.3	2.4	26.1	71.4	91.7	95.7	100.0	1.202	.210
	58.5-60	199.13	0.2	1.1	3.5	8.3	20.6	46.0	80.0	90.3	94.1	95.6	100.0	1.773	.265
	78.5-80	187.38	0	1.1	3.2	6.5	17.7	49.3	85.8	92.2	94.3	95.4	100.0	1.419	.354
	98.5-100	215.60	10.8	27.2	47.8	59.2	71.6	80.1	87.4	90.3	92.1	93.3	100.0	2.248	.95
	118.5-120	187.31	0.7	3.1	7.1	10.2	16.7	31.2	66.4	85.8	94.1	96.3	100.0	1.296	.295
TA-9	28.5-30	187.16	0	0.7	3.3	8.5	22.6	46.3	79.0	90.3	94.1	95.5	100.0	1.333	.340
	38.5-40	230.50	6.2	12.4	24.6	36.2	59.3	80.1	90.2	93.0	94.6	95.5	100.0	1.585	.535

Appendix 2. Continued

			Medium & coarse gravel	Fine gravel	Very coarse sand	Coarse sand		Medium sand		Fine sand		Very fine sand	Very fine sand, silt & clay		
Sieve Size (in.)			.185	.078	.039	.0276	.0195	.0138	.0097	.0069	.0049	.0035	<.0035		
Tyler Mesh			4	9	16	24	32	42	60	80	115	170	Pan		
Well	Depth (ft)	Sample weight (g)												Sorting coefficient	Median grain site
TA-10	18.5-20	172.17	0	0.1	0.3	0.9	9.0	47.7	85.3	92.8	95.0	96.0	100.0	1.163	.350
TA-11	18.5-20	93.11	0	0.1	0.3	0.4	0.7	1.7	6.1	16.4	33.8	54.9	100.0	1.218	.096
TA-12	28.5-30	187.26	0	0.1	0.2	0.3	1.9	12.5	54.1	80.3	52.8	96.1	100.0	1.285	.260
	58.5-60	187.89	0	0.2	3.3	10.1	28.4	55.5	83.1	90.8	93.6	95.0	100.0	1.351	.380
	88.5-90	197.34	1.7	5.6	16.5	30.0	51.7	69.9	82.7	87.0	89.4	90.8	100.0	1.581	.510
	98.5-100	191.11	0	0.1	0.4	1.0	6.4	34.1	76.4	87.3	91.7	93.5	100.0	1.240	.315
TA-13	18.5-20	170.86	0	0.1	0.2	0.3	0.5	1.0	2.3	9.1	34.0	57.0	100.0		.098
TA-14	28.5-30	175.87	1.5	8.6	19.2	25.8	36.6	54.7	75.4	86.1	91.8	93.8	100.0	1.732	.390
	48.5-50	203.60	0	0.2	1.4	3.8	14.2	44.9	75.8	85.3	90.2	92.3	100.0	1.319	.340
	68.5-70	202.95	0	0.1	0.8	2.4	11.1	43.3	78.7	87.8	91.6	93.3	100.0	1.258	.340
TA-15	18.5-20	107.95	5.0	11.0	16.4	21.3	34.9	62.4	87.2	91.1	92.6	93.7	100.0	1.541	.415
TA-18	18.5-20	182.16	0	0	trace	0.1	0.2	0.4	0.8	2.2	14.0	39.2	100.0		
TA-20	38.5-40	198.37	0	0	0.1	0.8	19.0	66.8	89.1	94.3	96.1	96.9	100.0	1.206	.400
MCN14N1E	65.0-80	220.10	0.6	14.7	50.5	66.0	77.8	89.3	96.2	98.5	99.1	99.3	100.0	1.732	1.01
10.8dl	80.0-84	296.10	-	8.4	45.8	64.9	78.6	89.8	96.3	98.4	99.0	99.2	100.0	1.627	.93
MCN14N1E 10.8d2	65.0-80	211.00	0.1	1.5	8.7	18.2	38.7	70.5	91.0	97.0	98.5	98.8	100.0	1.360	.45

Appendix 2. Concluded

Well	Depth (ft)	Sample weight (g)	Medium & coarse gravel	Fine gravel	Very coarse sand	Coarse sand		Medium sand		Fine sand		Very fine sand	Very fine sand, silt & clay	Sorting coeffi-cient	Median grain site
	Sieve Size (in.)		.185	.078	.039	.0276	.0195	.0138	.0097	.0069	.0049	.0035	<.0035		
	Tyler Mesh		4	9	16	24	. 32	42	60	80	115	170	Pan		
CHR14N1E	75.0-80	224.20	13.7	33.5	59.3	69.8	79.0	88.0	93.0	95.0	95.9	96.2	100.0	2.140	1.29
30.7hl	80.0-85	371.45	22.2	59.8	78.1	83.0	87.3	92.7	96.5	98.3	99.1	99.4	100.0	1.969	2.65
	85.0-90	288.95	33.7	64.0	80.0	84.4	88.9	93.8	97.0	98.3	99.0	99.2	100.0		3.00
	90.0-95	350.90	44.2	68.2	78.2	83.0	87.6	93.2	96.6	98.1	99.2	99.4	100.0		
	95.0-97	377.05	49.7	68.2	74.3	77.6	82.2	89.9	95.5	98.0	99.2	99.4	100.0		4.76
CHR14N1E	85.0-95	301.35	23.9	38.0	44.8	51.0.	63.3	79.8	90.3	95.0	97.7	98.6	100.0	3.396	.74
30.7h2	95.0-100	707.20	33.2	57.9	69.2	74.8	80.7	88.4	93.4	96.0	97.8	98.7	100.0		2.83
	100.0-105	303.20	25.4	38.5	51.8	60.5	68.0	78.2	86.4	91.7	95.8	97.5	100.0	3.516	1.10
	105.0-110	325.60	11.7	19.7	31.8	43.2	57.8	74.9	84.6	89.3	94.2	97.1	100.0	1.995	.600
	110.0-112	375.75	17.,3	35.0	48.9	56:3	65.9	77.3	87.8	93.2	96.4	97.9	100.0	2.966	.99
CHR14N1E	70.0-75	147.65	20.1	50.2	68.9	76.2	82.9	91.2	97.1	98.9	99.3	99.5	100.0	2.364	2.00
30.8g3	75.0-80	358.20	14.9	40.9	63.1	71.2	79.3	89.8	97.1	99.0	99.4	99.5	100.0	2.345	1.60
	80.0-85	304.30	25.5	55.4	71.9	76.9	81.7	90.3	97.0	99.0	99.5	99.7	100.0	2.439	2.40
	85.0-90	297.85	21.8	59.0	77.4	80.9	84.1	90.1	96.8	99.0	99.5	99.6	100.0	1.917	2.45

Note: Sieved samples from the TA borings are all from split-spoon samples. Samples from water wells are all washed cuttings. Sieve results from cutting are consistently coarser than results from split-spoon samples. The results are presented here as cumulative percent retained.

Appendix 3. Selected Logs of Wells and Test Holes

North half

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 13N2W				
23.2f2 [Continental Grain (1)]	driller's log	top soil	5	5
		clay	10	15
		clay, sandy	25	40
		sand	10	50
		sand, some gravel	20	70
		sand and gravel	20	90
		clay	--	92
23.5a	driller's log	drift	38	38
		sand	59	97
		clay and boulders	8	105
23.5b	abbreviated sample study	soil on loess	5	5
		gumbo sand, brown	5	10
		sand, clayey, gray, medium	6	16
		sand, yellow, medium, loose	9	25
		sand, grayish, yellow, coarse	11	36
		silt	9	45
		till, mostly dark gray	15	60
		clay, silty, light brown	5	65
		till, brown	20	85
		silt, gray	5	90
		gravel, fine	10	100
		shale & very fine argillaceous sandstone	20	120
23.6b	abbreviated sample study	silt, yellow to brown	5	5
		sand, clayey, silty, yellow-brown	5	10
		sand, silty, gravelly yellow-brown	3	13
		sand with gravel	42	55
		gravel	40	95
		silt, sandy, gray	1	96

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 13N2W				
23.6e	driller's log	black soil	1	1
		yellow clay	3	14
		yellow sand	14	28
		clay and sand	2	30
		gray sand	5	35
		blue clay gravelly, with thin streaks of sand	61'8"	96'8"
26.4fl	driller's log	yellow clay	12	12
		yellow fine sand	13	25
		gray sand & gravel	1	26
		gray clay & sand	14	40
		yellow clay	7	47
		gray sand & gravel	2	49
		gray sand	2	51
		sandy blue clay	9	60
		gray sand	2	62
		blue clay soft	38	100
26.4f2	driller's log	yellow clay	5	5
		yellow sandy clay	5	10
		yellow sand	5	15
		gray clay	15	30
		yellow clay	25	55
		gray clay	5	60
26.4g	driller's log	yellow clay	10	10
		dirty red sand	5	15
		yellow sand	23	38
		blue clay	29	67
		blue sand	4	71
		silt	4	75
		light blue clay	60	135
		blue clay	13	148
26.5h	abbreviated driller's log	clay, blue & yellow, sandy at base	15	15
		sand	5	20
		muck, sandy	5	25
		sand, white	5	30
		water sand, brown	3	33
		sand with drift	2	35
		sand, brown	10	45
		sand, red color, rusty	10	55
		sand	6	61
		blue clay	34	95

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 13N2W				
26.6h	sample study	till, yellow, silty	9	9
		sand, yellow, mostly fine, partly clean	21	30
		sand, yellow & buff, fine to coarse, partly dirty	30	60
		granule gravel, partly dirty	4	64
		"shale"	1	65
27.2h1 [Taylorville old (1)]	driller's log	clay	17	17
		sand, fine	43	60
		sand, coarse	5	65
		sand & gravel	34	99
		clay	–	100
27.2h2 [Taylorville old (2)]	driller's log	top soil & clay	18	18
		sand, fine	12	40
		sand, coarse	26	66
		gravel, coarse	31	97
		clay	--	97
27.2h6 [Taylorville old (6)]	correlated driller's log	<u>Pleistocene Series</u>		
		soil & clay	15	15
		sand, some clay	25	40
		sand & gravel	74	114
24.4g [Taylorville (1)]	driller's log	soil	2	2
		clay	14	16
		sand, fine	14	30
		sand, medium coarse	20	50
		sand, coarse	40	90
		sand, coarse & boulders	15	105
		sand & gravel, coarse	15	120
CHR 14N1E				
30.7h [Assumption (11)]	driller's log	yellow clay	8	8
		red clay	9	17
		yellow sand & gravel, few clay streaks	35	52
		sand & gravel, gray to white	18	70
		yellow clay	2	72
		sand & gravel	16	88

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 14N1E				
30.7h (cont'd)		very coarse gravel & small boulders	13	101
		clay streak	1	102
		coarse gravel & small boulders	10	112
		green hard shale	8	120
30.8g [Assumption (10)]	driller's log	top soil	2	2
		yellow clay	8	10
		red-yellow clay	6	16
		yellow sand & gravel	49	65
		yellow-gray sand & gravel	8	73
		blue-gray sand & gravel	17	90
		lime	--	90
CHR 14N1W				
34.1bl [Stonington (10)]	driller's log	black top soil	1	1
		yellow clay	11	12
		yellow sand & gravel	32	44
		sand, fine to medium	48	92
		sand, gray,fine to coarse-	9	101
		sand, gray, clean, fine to coarse	11	112
		sand, blue, fine to coarse gravel	12.5	124.5
34.1b2 [Stonington (11)]	driller's log	black top soil	1	1
		medium fat, yellow, silty, clay	10	11
		medium fat, yellow, with fine brown sand	3	14
		fine to coarse brown sand	76	90
		coarse gray sand with boulders	18	108
		shale	--	108
MCN 14N1E				
10.8d [Moweaqua (15)]	driller's log	top soil	1	
		yellow-brown clay	16	17
		silty, coarse to fine yellow sand	21	38

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
MCN 14N1E				
10.8d (cont'd)		fine to coarse yellow sand	15	53
		fine to coarse yellow sand with boulders	3	56
		coarse to medium gray sand with fine silty yellow sand	23	79
		boulder	2	81
		hardpan	3	84
		shale	--	84
16.6h	driller's log	top soil	5	5
[Blue Mound (3)]		yellow clay	10	15
		sandy yellow clay	10	25
		yellow sand	5	30
		hardpan-blue clay	5	35
		yellow sand	5	40
		gray sand--some gravel	15	55
		sand & gravel mix (blue)	5	60
		gravel 3/4-1 inch size; very little sand	18	88
		blue clay	--	88
MCN 15N1E				
36.8g	driller's log	yellow clay soil	20	20
[Macon (5)]		yellow sand	30	50
		blue sand,fine to medium	10	60
		blue sand, clean, coarse	31	91
36.8g	driller's log	top soil	3	3
[Macon (4)]		blue slightly gravelish clay	3	6
		yellow slightly gravelish clay	17	23
		compacted yellow sand, light gravel & clay	9	32
		fairly clean coarse sand with light gravel showing	9	41
		clean light gravel & coarse sand	21.5	62.5

Appendix 3. Continued

South half

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 11N3W				
4.1b [Morrisonville (T1)]	driller's log	soil	2	2
		clay, yellow	2	4
		clay, yellow sandy	6	10
		sand, yellow, fine	20	30
		sand, gray, fine water	14	44
		sand & gravel, gray water	4	48
		gravel & sand, yellow	2	50
		sand & gravel, yellow	7	57
		shale	--	57
8.2a [Morrisonville (T4)]	driller's log	soil	2	2
		clay, yellow	8	10
		clay, yellow, sandy	8	18
		sand, yellow	4	22
		sand & gravel, yellow	2	24
		sand, dirty	2	26
		sand, yellow	6	32
		sand & gravel	6	38
		coarse gravel, yellow	3	41
		shale	--	41
8.3a2 [Morrisonville (4)]	driller's log	silt	10	10
		sand, dirty	16	26
		sand & gravel	26	39
9.8c [Morrisonville (6)]	driller's log	clay	12	12
		fine sand	3	15
		sand & gravel, coarse	20	35
		sand & gravel, medium	12.5	47.5
		shale	--	47.5
17.4h [Morrisonville (T1-77)]	driller's log	clay, black organic slity	8	8
		clay, gray, silty	5	13
		sand, gray, with clay seams	3	16
		sand, gray	2	18
		sand, brown with trace of silt & clay & gravel	16.5	34.5
		shale, hard, gray	--	34.5

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 11N3W				
4.1b [Morrisonville (T2-77)]	driller's log	clay, brown, silty	9	9
		sand, fine, brown (dry)	6	15
		sand, fine, brown (wet)	40	55
		sand, fine, gray	8	63
		shale, hard, gray	8	63
CHR 11N4W				
34.4e [Harvel (1)]	correlated driller's log	Pleistocene Series		
		soil, yellow clay	3	3
		clay, yellow	12	15
		sand, yellow dirty	3	18
		sand & gravel, blue coarse, clean	20	38
		Pennsylvanian System		
		shale	3	41
33 [Harvel	driller's log (T1)]	clay, gray & soil	16	16
		clay, sandy	2	18
		hardpan	6	24
		sand & gravel, (dirty)	3	27
		shale (light, sandy)	9	36
33 [Harvel (T2)]	driller's log	soil	3	3
		clay, yellow	10.5	13.5
		hardpan, yellow	7.5	21
		shale	3	24
CHR 12N3W				
35.4e [Palmer (Tl)]	driller's log	soil	1	1
		sand, yellow	10	11
		sand, fine, blue	42	53
		clay	--	53
35.5d [Palmer (72)]	driller's log	soil	1	1
		clay, yellow	14	15
		sand, fine, blue	70	85
35.5d [Palmer (1)]	driller's log	top soil	1	1
		sand, fine, silty	2	3
		clay, brown	11	14
		sand, fine, few clay layers	46	60

Appendix 3. Continued

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
CHR 12N3W				
35.5d (cont'd)		sand, fine to medium	17	77
		shale and lime	3	80
MTG 10N4W				
8.1a	driller's log	soil & gray clay	5	5
[Raymond	(T1-77)]	clay, brown	5	10
		clay, sandy, yellow	5	15
		sand, yellow, coarse, clean	15	30
		sand & gravel, blue	22	52
		shale	--	52
8.1a	driller's log	clay, yellow	5	5
[Raymond	(T2-77)]	clay, brown	5	10
		sand, fine, blue	5	15
		sand, blue, fine to coarse	12	27
		shale	--	27
8.1a	driller's log	clay, brown	5	5
[Raymond (T3-77)]		clay, yellow	5	10
		sand, fine, blue	5	15
		sand, blue	10	25
		muck, blue	9	34
		shale	1	35
16.8h	driller's log	soil & black clay	5	5
[Raymond T4-77)]		clay, brown	5	10
		sand, fine, yellow, clean	5	15
		sand & gravel, yellow	10	25
		sand & gravel, blue	17	42
		shale	1	43
8.1a	driller's log	clay, yellow	5	5
[Raymond (T5-77)]		clay, dark brown	5	10
		sand, fine, yellow	5	15
		sand & gravel, medium to coarse	20	35
		sand, blue, fine to clean	--	57
		shale	--	57
8.1a	driller's log	clay, black	5	5
[Raymond (T6-77)]		clay, yellow	7	12
		sand, yellow, fine	3	15

Appendix 3. Concluded

Well number	Type of record	Material	Thickness (ft)	Depth (ft)
MTG 10N4W				
8.1a (cont'd)		sand, blue, coarse, clean	20	35
		sand, blue, fine, clean	10	45
		sand, blue, medium to coarse, slightly dirty	9	54
8.1a [Raymond (4)]	driller's log	clay, dark brown, silty	10	10
		sand, reddish brown, with clay	5	15
		sand, brown	10	25
		sand & gravel, coarse	30	55
		clay, gray	--	55
17.2a [Raymond (3)]	driller's log	clay	20	20
		sand, fine	8	28
		sand & gravel	8	36
17.2d [Raymond (2)]	driller's log	clay, yellow, very hard	18	18
		sand, gray, dirty	5	23
		sand, fine	2	25
		sand & gravel, clean, coarse	14	39
17.3d [Raymond (1)]	driller's log	soil, black	1	1
		clay, yellow	4	5
		clay, sandy, yellow	4	9
		clay & gravel, mixed	3	12
		sand, red	3	15
		sand & gravel, red	3	18
		sand & gravel, gray	11.5	29.5
		soapstone & yellow clay	1.5	31
		bedrock	--	31