Contract Report 630

Ground-Water Studies for Environmental Planning, McHenry County, Illinois

by
Scott C. Meyer
Office of Ground-Water Resources Evaluation

**Prepared for the
McHenry County Board of Health and
Illinois Department of Natural Resources**

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Illinois State Water Survey
Hydrology Division
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

GROUND-WATER STUDIES FOR ENVIRONMENTAL PLANNING, MCHENRY COUNTY, ILLINOIS

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Champaign, IL 61820-7495

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INTRODUCTION

Purpose and Scope

McHenry County's public water supplies are derived entirely from ground water, which makes ground water a resource of vital importance to the residents and economy of the county. As a consequence of the county's rapid population growth (Figure 1), however, ground-water withdrawals have increased, and the pace of development-related activities which could threaten shallow ground-water quality has increased. Clearly, the need to accommodate this growing population must be balanced with concerns over resource conservation, environmental protection, and public health.

This report provides planners and others in McHenry County with data and information to allow them to make informed decisions regarding activities that could have an impact on the county's ground-water resources. Specifically, this report provides (1) potentiometric surface maps of the five principal shallow aquifers in the county, (2) capture zone estimations for high-capacity public water supply wells in McHenry County, and (3) an assessment of nitrate contamination of shallow ground water in the county. The report has been prepared in conjunction with Illinois State Geological Survey Circular 559, *Geologic Mapping for Environmental Planning, McHenry County, Illinois* (Curry et al., 1998) and supplements that report.

Most of the effort of this study was directed toward preparing the five potentiometric surface maps. This mapping was a prerequisite to estimating the five-year capture zones and formed the basis for the report's discussion of influences on shallow ground-water flow. The potentiometric surface maps are valuable references for county and municipal agencies, engineering and geologic consultants, developers, well drillers, and county residents concerned with water levels and ground-water flow directions in the county, and they serve as a record of water levels in 1994. Comparison of the 1994 water levels with future measurements could allow forecasting of impacts such as alteration of wetland hydrology and reduced ground-water availability.

This report specifically considers the shallow aquifers of McHenry County. These include unconsolidated sand and gravel aquifers in the glacial drift as well as the uppermost bedrock immediately underlying the glacial drift. Bedrock units within the scope of the study include the Silurian dolomite and the Ordovician Maquoketa Formation, which underlies the Silurian dolomite. Bedrock units underlying the Maquoketa Formation, including the productive "deep sandstone" aquifer (principally the Glenwood-St. Peter and Ironton-Galesville sandstones), are not within the scope of this study.

The investigations of Johnson et al. (1985) and Keefer and Berg (1990) suggest that the ground-water resources in the complex glacial terrain underlying much of north-central Illinois, including McHenry County, are particularly vulnerable to contamination. Recognizing the region's rapidly growing population and the relatively high vulnerability of its ground-water resources to contamination, the Illinois Environmental Protection Agency (IEPA) and the Interagency Coordinating Committee on Groundwater in 1991 designated McHenry County together with Boone and Winnebago Counties as the Northern Illinois Groundwater Protection Planning Region. This

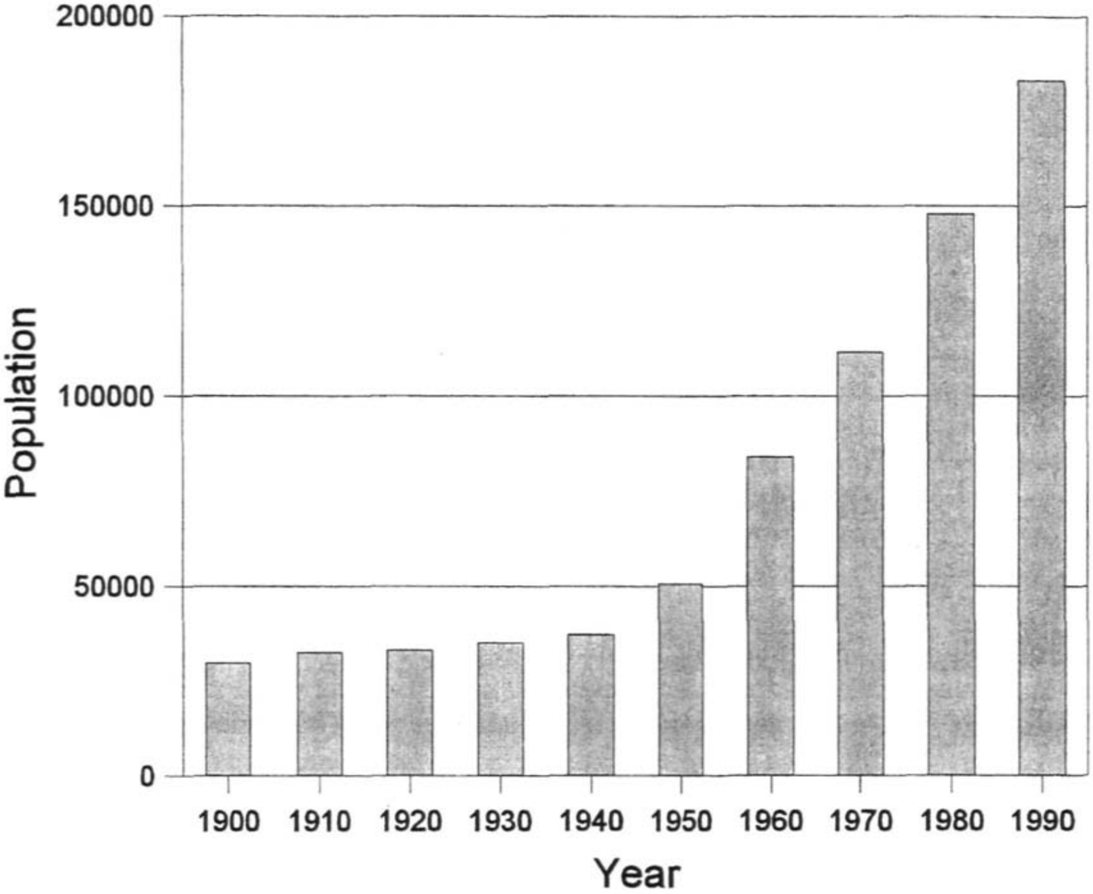

Figure 1. Growth of McHenry County population, 1900 to 1990
(source: U.S. Department of Commerce, 1962, 1971, 1982, and 1992).

designation provides a focus for ground-water protection funds allocated by the State of Illinois to be used for ground-water protection mapping and assessment by the Illinois State Geological Survey (ISGS) and the Illinois State Water Survey (ISWS).

Several incidents of well contamination have heightened public awareness of the vulnerability of McHenry County's ground-water resources and of the threat posed to these resources by development. Water samples collected in 1985 from 11 public water supply wells in the county were found to contain contaminants related to human activities. These include wells at Harvard, Union, Fox River Grove, Hebron, Woodstock, and Marengo. Details of these incidents are described by Lonsdorf (1993). In six of these cases, the contaminants were present in concentrations considered unsafe in drinking water. The incidents have resulted in expensive investigations, cleanups, and well relocations.

Description of Study Area McHenry County (Figure 2) is located in northeastern Illinois and is bounded on the north by the State of Wisconsin, on the west by Boone County, on the east by Lake County, and on the south by De Kalb, Kane, and Cook Counties. The largest city is Crystal Lake, in the southeastern part of the county, which had a population of 28,016 in 1990 (U.S. Department of Commerce, 1992). Principal drainage is provided by (1) the Fox River, which generally flows southward through eastern McHenry County and western Lake County and which drains the Chain-O'-Lakes lowland in northeastern McHenry County and northwestern Lake County; and (2) the Kishwaukee River, which flows westward across southwestern McHenry County. Figure 3 shows the lakes, rivers, and creeks of McHenry County mentioned in this report. A drainage divide, oriented northwest to southeast and passing through the city of Woodstock, in the center of McHenry County, separates the watersheds of the Fox River, in the eastern part of the county, and the Kishwaukee River, in the western part of the county. Marengo Ridge, a prominent moraine (a ridge composed principally of glacial drift), trends roughly north-south through the western part of the county from the Wisconsin border north of Harvard to the Kane County border. The Fox River and Chain O' Lakes occupy an area of lowlands that extends from the Fox River and western shores of the Chain O' Lakes eastward into Lake County.

The average elevation of McHenry County is about 885 feet (ft) above mean sea level (msl). Elevations range from a maximum of 1,189 ft msl north of Harvard to a minimum of 731 ft msl along the Fox River at Algonquin (Curry et al., 1998).

Previous Investigations

The geology and shallow ground-water resources of McHenry County have been described in many reports issued by the ISGS, the ISWS, and other entities. Curry et al. (1998) list several investigations by the ISGS that discuss the geology of McHenry County. These include reports and mapping projects that address limited aspects of the geology of the county as well as more comprehensive geology-for-planning investigations. Ground-water studies in McHenry County began with the work of Sasman (1957), who observed shallow ground-water levels in order to determine the cause of water level fluctuations of Crystal Lake, in southeastern McHenry County. Suter et al. (1959) discussed the ground-water resources of McHenry County as part of a summary of the ground-water resources of the Chicago region. Csallany and Walton (1963) conducted

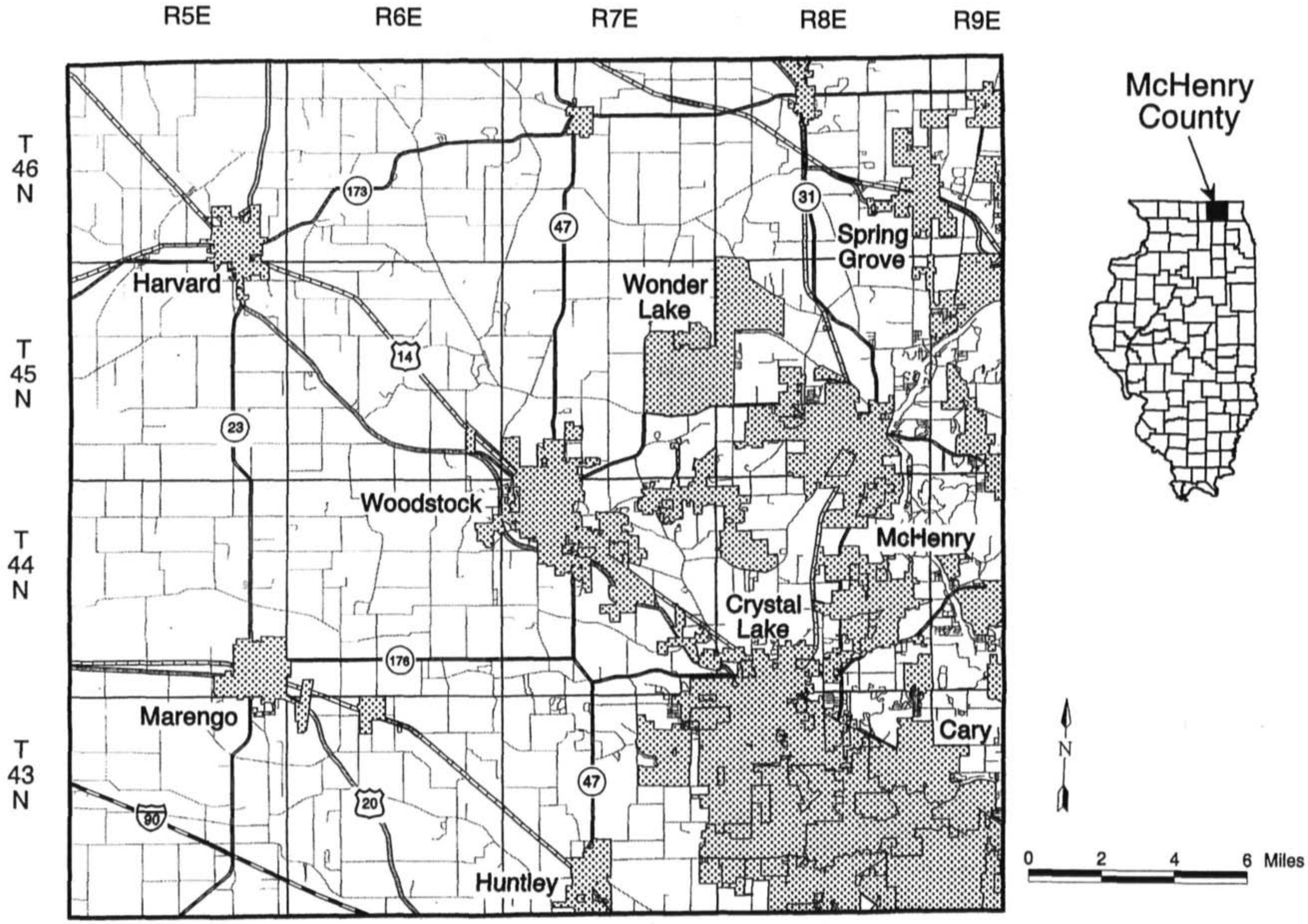

Figure 2. General location map of McHenry County.

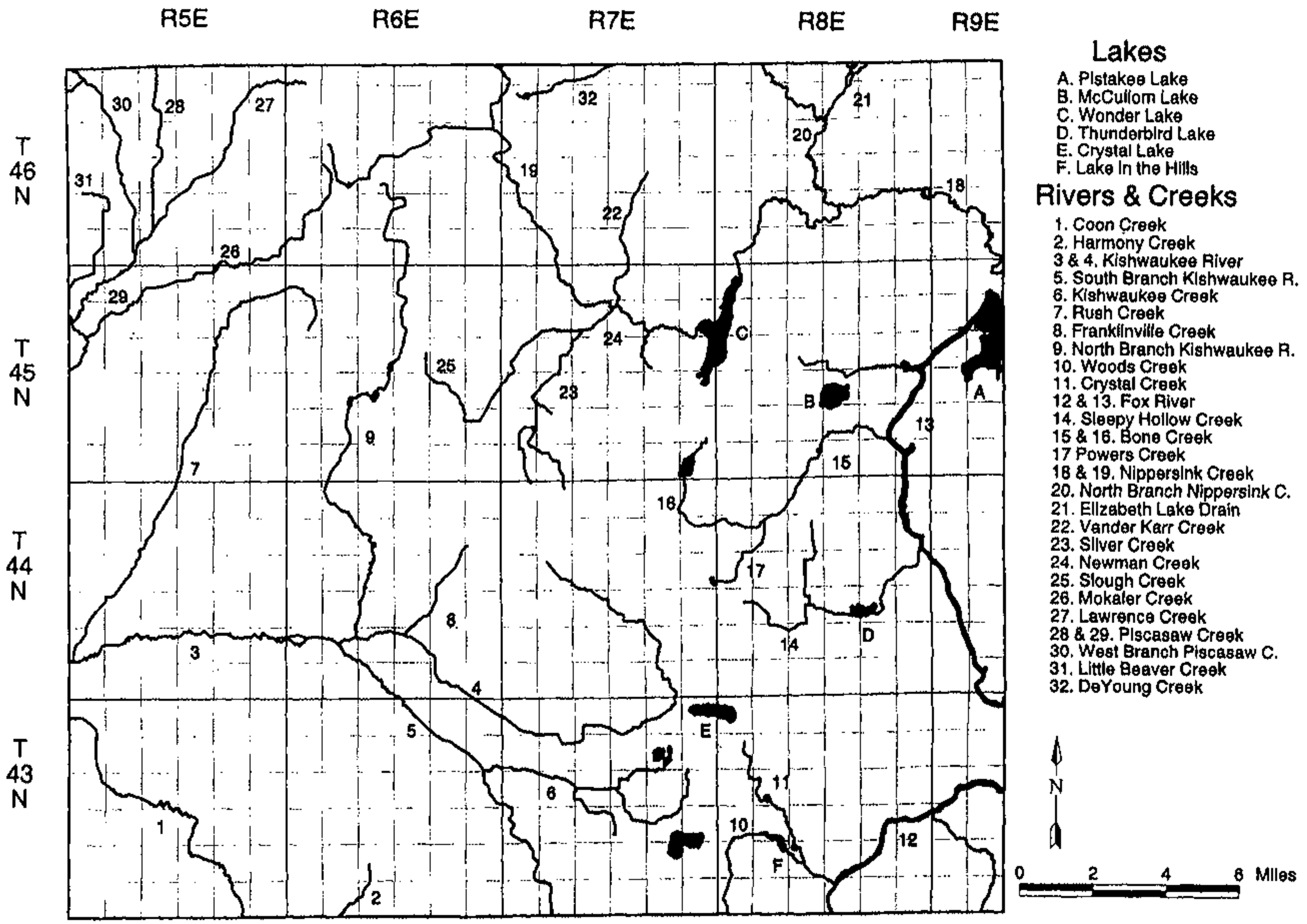

Figure 3. Hydrographic features mentioned in the report.

a statistical analysis of specific-capacity data derived from pumping tests of shallow bedrock wells in northern Illinois, including McHenry County, and estimated probable ranges in yields of these wells in a variety of geographic and hydrogeologic settings. Prickett et al. (1964) estimated the practical sustained yield of the existing municipal-well fields serving Woodstock, and Walton (1965), as part of a statewide assessment, estimated ground-water recharge in the Woodstock area. Woller and Sanderson (1976) described the public ground-water supplies in McHenry County. Schicht et al. (1976) summarized the availability, quality, and cost of water in northeastern Illinois and estimated areas of future ground-water shortfall.

Although Nicholas and Krohelski (1984) measured water levels in wells finished in the glacial drift in McHenry County, they did not use their data to develop potentiometric surface maps for specific drift aquifers; rather, they combined the data to create a single composite potentiometric surface map for all of the glacial drift aquifers. Their map would be of limited use for the purposes of this report.

Acknowledgments

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Special thanks also go to B. Brandon Curry, Richard C. Berg, and Robert C. Vaiden of the Illinois State Geological Survey, authors of the Geological Survey's report, which the present report supplements and builds upon.

Numerous individuals at the Illinois State Water Survey contributed to the project. Curt Benson, who is now retired, assisted greatly with obtaining permission from McHenry County well owners to use their wells in the project, as well as with surveying and water level measurement. Mark Sievers played a critical role in coordinating the mass measurement of water levels in 1994 and in processing the surveying data collected during this phase of the project. Mark Anliker, Steve Benton (of the Illinois State Geological Survey), Bryan Coulson, Randall Locke II, Robert Olson, and Ken Duwal assisted with surveying and water level measurement. George Roadcap provided technical input for the capture zone estimations. Technical review of the final report was provided by H. Allen Wehrmann.

Linda Hascall prepared figures and formatted the final report. Pamela Lovett assisted in processing the text, and Tom McGeary, of the Illinois State Geological Survey, edited the manuscript.

GENERAL BACKGROUND

Aquifers and Confining Beds

Although nearly all earth materials will transmit water, the rate of transmission varies widely and is chiefly dependent on the permeability of the material. Ground water moves relatively rapidly through highly-permeable materials and relatively slowly through those having lower permeability. An aquifer is a body of saturated earth materials that, by virtue of its comparatively high permeability, will yield useful quantities of water to a well or spring. Examples of materials that can function as aquifers include sand and gravel, fractured and jointed carbonate rocks (limestone and dolomite), and sandstone. A confining bed is a body of earth materials having a comparatively low permeability, which impedes the movement of water into and out of the adjacent aquifers. Materials that can function as confining beds include shale, silt, clay, and diamicton (a nonsorted sediment, typically of glacial origin, composed of sand-sized or larger particles dispersed through a fine-grained matrix of clay- and silt-sized particles). The term hydrostratigraphy refers to the study of the geometry and geometric relationships, both vertical and lateral, of aquifers and confining beds.

Aquifers are described as confined or unconfined. A confined, or artesian, aquifer has a confining bed both above and below it. The confining beds impede the vertical movement of ground water into and out of the aquifer and cause the water in the aquifer to be under greater than atmospheric pressure. As a result, the water level in a well that is screened or open to a confined aquifer will stand above the top of the aquifer. The confining beds bounding confined aquifers always "leak" to some degree; that is, they will transmit ground water at a comparatively low rate to the confined aquifer. If, however, there is a significant flow of ground water across one or both of the confining beds bounding the aquifer, a confined aquifer may be referred to as a semiconfined or leaky artesian aquifer. An unconfined aquifer has no overlying confining bed. The water table, or top of the saturated zone, marks the top of an unconfined aquifer, so the thickness of the aquifer varies as the water table rises and falls. Unconfined aquifers are frequently in direct hydraulic connection with rivers, lakes, streams, or other surface-water bodies. In such situations, the water level in the surface-water body closely approximates the water table marking the top of the adjacent unconfined aquifer. Similarly, the water level in a well finished in an unconfined aquifer closely approximates the water table.

Potentiometric Surface Maps The potentiometric surface map of an aquifer shows water levels, expressed as an elevation above some datum plane (usually mean sea level), in wells finished in that aquifer. The water level elevations are also referred to as heads. Heads are indicated on potentiometric surface maps by means of contours connecting points of equal head, which are called equipotentials. The principal application of potentiometric surface maps is to determine directions of ground-water flow. Ground water flows from high head to low head, and directions of ground-water flow are perpendicular to equipotentials.

The potentiometric surface of extremely shallow aquifers closely approximates land surface configuration, with even comparatively small surface features replicated in the potentiometric surface by "hills" and "valleys" of only slightly less relief than the land surface features. The degree of replication of surface topographic features decreases in the potentiometric surfaces of progressively more deeply buried aquifers, so that often only large-scale topographic features are replicated in the potentiometric surfaces of more deeply buried aquifers.

Heads rise and fall in response to ground-water pumpage, evaporation and transpiration, and, in the case of confined aquifers only, aquifer loading (Freeze and Cherry, 1979). Heads typically follow a seasonal cycle that is most noticeable at locations remote from large pumping centers, where pumping operations can overwhelm natural cycles and make them difficult to recognize. Natural declines in water levels usually begin in late spring and continue throughout the summer and early fall. Water levels begin to rise again late in the fall and peak during the spring, when ground-water recharge due to rainfall and snowmelt has its greatest effect (Visocky and Schicht, 1969).

Shallow Hydrostratigraphy of McHenry County Curry et al. (1998) describe the shallow hydrostratigraphy of McHenry County; this hydrostratigraphy is summarized in Figure 4. This report recognizes five shallow aquifers that are of primary importance to the residents of McHenry County, and potentiometric surface maps have been constructed for each of them. The following are descriptions of these aquifers and brief discussions of the relationships of these aquifer designations to the stratigraphic nomenclature and aquifer designations of Curry et al. (1998).

- *Aquifer 1* The principal water-yielding materials contained within Aquifer 1 are sand and gravel of the undifferentiated Henry Formation and the Beverly Tongue of the Henry Formation. Aquifer 1 also includes the Haeger Member of the Lemont Formation, which overlies the Beverly Tongue. The Haeger Member, although a diamicton, contains comparatively little clay (only about 15 percent) and, unlike other diamictons in McHenry County, does not appear to function as a confining unit. As described and used in this report, Aquifer 1 is equivalent to the surficial drift aquifer, or aquifer 1, of Curry et al. (1998). This is the shallowest aquifer of the five aquifers considered in this report. Curry et al. (1998) report that Aquifer 1 may be up to 200 ft thick in McHenry County. In many parts of McHenry County, the confining beds separating Aquifer 1 from Aquifers 2, 3, 4, and 5 pinch out; in these areas of aquifer connection, the materials composing the aquifers are hydraulically connected and function as a single aquifer. These areas of aquifer connection frequently correspond to prominent topographic valleys, such as the valley underlying Wonder Lake. In a few areas, no significant confining units are present, and sand and gravel extends virtually from land surface to the bedrock surface.

- *Aquifer 2* Aquifer 2 consists of sand and gravel that underlies diamicton of the Yorkville Member of the Lemont Formation and, less frequently, is contained within diamicton of the Yorkville Member. Where it occurs at the base of the Yorkville Member, Aquifer 2 is underlain by diamicton of the Tiskilwa Formation. As described and used in this report, Aquifer 2 is equivalent to the Yorkville aquifer, or aquifer 2, of Curry et al. (1998). In many parts of McHenry County, the confining beds separating Aquifer 2 from Aquifer 1 pinch out; and in these areas of aquifer connection, the materials composing the two aquifers are hydraulically connected and function as a single aquifer. Aquifer 2 is up to 20 ft thick (Curry et al., 1998) and occurs in a relatively limited portion of central and south-central McHenry County.

- *Aquifer 3* Aquifer 3 consists of sand and gravel lenses that (1) overlie the Tiskilwa Formation and underlie a tongue of the fine-grained, lacustrine Equality Formation or (2) are

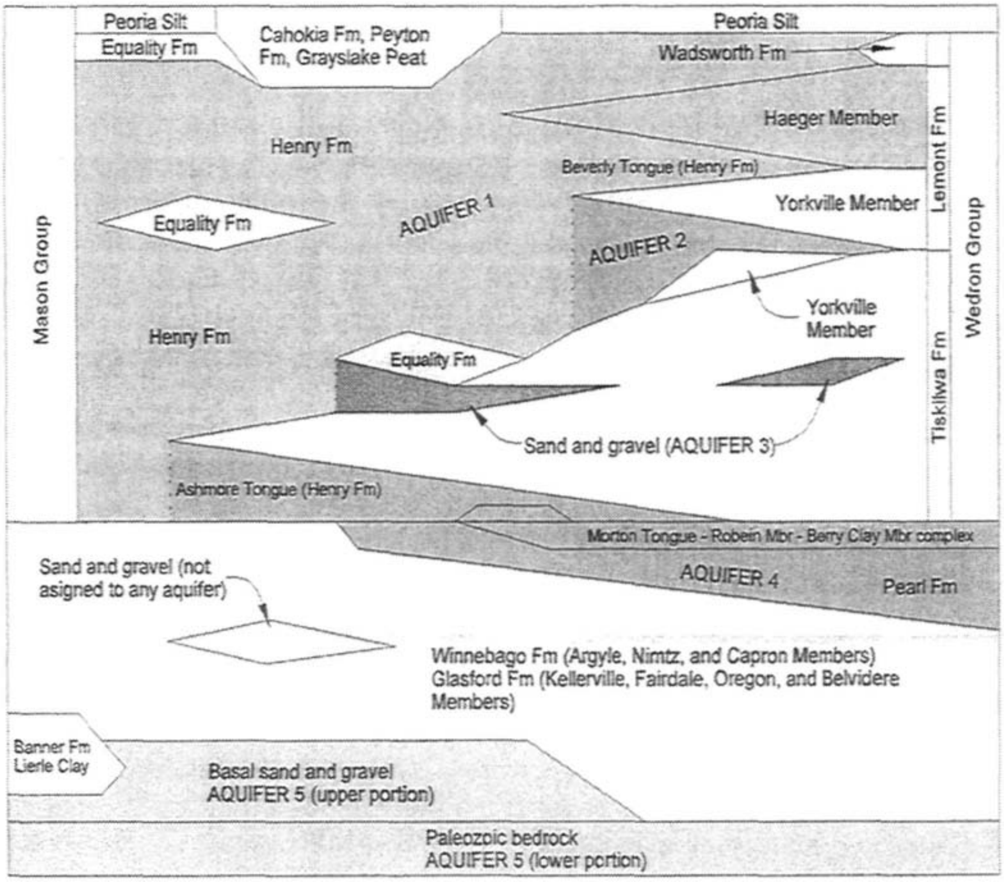

Figure 4. Stratigraphic and hydiostratigraphic relationships among shallow glacial and bedrock units in McHenry County (modified from Curry and others, 1998). Although not shown in this figure, Aquifers 1 and 4 may each rest directly on Aquifer 5.

contained entirely within diamicton of the Tiskilwa Formation. Although such lenses occur within and at the top of the Tiskilwa Formation throughout McHenry County, they have only been mapped as aquifers in northeastern and south-central McHenry County. In many parts of McHenry County, the confining beds that separate Aquifer 3 from Aquifer 1 pinch out, and in these areas of aquifer connection, the materials composing the two aquifers are hydraulically connected and function as a single aquifer. As described and used in this report, Aquifer 3 is equivalent to the Tiskilwa aquifer, or aquifer 3, of Curry et al. (1998).

- *Aquifer 4* The principal water-yielding materials contained within Aquifer 4 are sand and gravel of the Pearl Formation and the Ashmore Tongue of the Henry Formation. Also contained within Aquifer 4 are various thin, discontinuous, clayey and silty layers overlying the Pearl Formation and underlying the Ashmore Tongue. These units are combined by Curry et al. (1998) as the Morton Tongue-Robein Member-Berry Clay Member. The Pearl Formation is stratigraphically above the Winnebago and Glasford Formations and below the comparatively thin Morton Tongue-Robein Member-Berry Clay Member. Aquifer 4 is internally complex and contains materials deposited in a variety of settings during a comparatively long time period that included the retreat of glacial ice, an interval of relatively warm climate, and renewed encroachment of glaciers on the area. Despite this wide variety of depositional settings, Aquifer 4 forms a widespread sheet of water-yielding materials extending across much of eastern and central McHenry County, and it is widely used for domestic and public water supplies. Aquifer 4 is overlain by diamicton of the Tiskilwa Formation and underlain by the Winnebago and Glasford Formations. In many parts of McHenry County, the confining beds separating Aquifer 4 from Aquifer 1 pinch out, and in these areas of aquifer connection the materials composing the two aquifers are hydraulically connected and function as a single aquifer. Likewise, in many parts of the county, Aquifers 4 and 5 are hydraulically connected and function as a single aquifer. As described and used in this report, Aquifer 4 is equivalent to the Pearl/Ashmore aquifer, or aquifer 4, of Curry et al. (1998). In the present report, where the Glasford Formation and other, older drift units are absent, so that the Ashmore Tongue (otherwise included in Aquifer 4) rests directly on the bedrock surface, the Ashmore Tongue is included in Aquifer 5.

- *Aquifer 5* Aquifer 5 consists of both the sand and gravel occurring at the base of the glacial drift and the uppermost bedrock directly underlying it. These dissimilar materials are believed to be hydraulically connected and to function as a single aquifer (Gilkeson et al., 1987). The age of the sand and gravel at the base of the glacial drift varies across McHenry County. In most areas, this sand and gravel occurs at the base of the Glasford Formation. More rarely, this sand and gravel may occur at the base of the Banner Formation, which is older than the Glasford and appears to be sporadically present in McHenry County. In other areas, however, the Glasford and Banner Formations are absent, and the Ashmore Tongue of the Henry Formation rests on the bedrock surface. In these areas, as mentioned previously, the Ashmore Tongue (otherwise included in Aquifer 4) is included in Aquifer 5. As described and used in this report, Aquifer 5 is generally equivalent to the basal drift aquifer, or aquifer 6, of Curry et al. (1998).

The Glasford/Winnebago aquifer of Curry et al. (1998) (their aquifer 5) is included in Aquifer 5 of the present report. A potentiometric surface map of the Glasford/Winnebago aquifer was not constructed because domestic supply wells finished in the aquifer, necessary as data points for construction of such a map, are generally not present in McHenry County. Such wells may be absent because coarser-grained, thicker, more productive aquifers are present in the same areas as the Glasford/Winnebago aquifer or because less-expensive wells may be constructed by drilling only slightly deeper than the Glasford/Winnebago aquifer into the bedrock, where a screen is not necessary. The village of Harvard obtains water from this aquifer, and water levels measured in the Harvard wells for this project were used in construction of the Aquifer 5 potentiometric surface map. This use of the water level data is justified because the water levels in the Harvard wells are consistent with those finished in the uppermost bedrock in the vicinity of Harvard. Well logs suggest that the sand and gravel deposits supplying water to the Harvard wells are hydraulically connected with the basal outwash about 5,000 ft west of the wells. This connection may explain the consistency in water levels between these aquifers.

Hydraulic Properties of Aquifers and Confining Beds The ability of an aquifer to store and transmit water is generally a function of its (1) hydraulic conductivity, (2) transmissivity, and (3) storage coefficient.

(1) Hydraulic conductivity is the capacity of an earth material to transmit ground water. It is expressed as the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the directions of flow (Heath, 1983). Hydraulic gradient refers to the difference between heads measured in the direction of greatest (steepest) change. All other factors being equal, ground-water flow is directly proportional to the hydraulic gradient; that is, the steeper the hydraulic gradient, the greater the flow. In this report, hydraulic conductivities are expressed in units of feet per day (ft/d). Thus, 1 ft^2 of a material having a hydraulic conductivity of 100 ft/d could transmit 100 ft^3 of water during a 1 day period under a hydraulic gradient of 1 ft of head change per foot of horizontal distance (if the 1 ft^2 is perpendicular to the hydraulic gradient).

The hydraulic conductivity of a material varies with the density and viscosity of the water flowing through the material (which in turn are functions of temperature) and with the permeability of the material. For a given temperature, however, hydraulic conductivity is largely a function of permeability. Permeability, in turn, is a function of the size and degree of interconnection of pore spaces. In the unconsolidated sand and gravel aquifers of McHenry County, the porosity consists principally of the voids lying between the sand and gravel grains composing the aquifer framework. The hydraulic conductivity of these materials generally ranges from 1 to 10^4 ft/d (Heath, 1983). Hydraulic conductivity may range from less than 10^{-7} ft/d, in the case of shale and dense, unfractured rocks, to greater than 10^4 ft/d, in the case of coarse gravels and highly fractured and cavernous rocks (Heath, 1983).

(2) Transmissivity is the capacity of the entire thickness of an aquifer to transmit ground water. It is defined as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient (Heath, 1983), and it is equivalent to the product of the hydraulic conductivity and the aquifer thickness. In this report, transmissivity is expressed in units of square feet per day (ft^2/d). Whereas hydraulic conductivity may be thought of as an expression of the capacity of a block of aquifer material, 1 ft^2 in cross-sectional area, to transmit water under a unit hydraulic gradient, transmissivity may be thought of as an expression of the capacity of a slice of the

aquifer, 1 ft wide and having a height equal to the aquifer thickness, to transmit water under a unit hydraulic gradient.

(3) Storage coefficient is the volume of water that an aquifer releases from or takes into storage per unit surface area per unit change in head (Heath, 1983). The storage coefficient describes the capacity of an aquifer to store water as well as the source of water pumped from wells finished in the aquifer. The storage coefficient is unitless. For confined aquifers, the storage coefficient generally ranges from 10^{-5} to 10^{-3} (Heath, 1983). Thus, if the head in 1 ft^2 of a confined aquifer having a storage coefficient of 10^{-4} declines 1 ft, then 10^{-4} ft^3 of ground water will be released from the aquifer. This volume is derived from expansion of the water and compression of the aquifer. For unconfined aquifers, the storage coefficient ranges from 0.1 to 0.3 (Heath, 1983). Thus, if the head in 1 ft^2 of an unconfined aquifer having a storage coefficient of 0.2 declines 1 ft, then 0.2 ft^3 of ground water has been removed from storage. This volume is derived principally from simple drainage of the pore space in the aquifer.

The most significant hydraulic property of confining beds is the vertical hydraulic conductivity. Analogous to hydraulic conductivity, vertical hydraulic conductivity is the volume of water that will move vertically through a unit horizontal area of the confining bed under a unit vertical hydraulic gradient. The vertical hydraulic conductivity measures the ability of a confining layer to transmit water to an adjacent confined aquifer.

Ground-Water Recharge and Discharge

Ground-water recharge is the process by which water is added to the zone of saturation (the subsurface interval in which all pore spaces are filled with water and that underlies the unsaturated zone) to become ground water. The water table is the surface separating the saturated and unsaturated zones. Recharge occurs largely through the infiltration of precipitation. Although most precipitation runs off directly to streams or is diverted to the atmosphere through evaporation, some of it percolates downward through the soil and unsaturated zone. Some of this water, in turn, is taken up by plants and returned to the atmosphere by transpiration. The processes of evaporation and transpiration, which are sometimes difficult to quantify independently, are usually combined and referred to as evapotranspiration. Water that passes through the unsaturated zone and reaches the water table becomes part of the ground-water flow system. This process occurs most readily where the materials composing the unsaturated zone are comparatively permeable and where such factors as slope and land use practices discourage runoff and uptake of water by plants, and thereby facilitate the vertical movement of water.

Ground water eventually discharges to surface-water bodies, including springs, wetlands, streams, rivers, and lakes. Discharge processes sustain flow from springs, maintain saturated conditions at wetlands, and provide baseflow of streams and rivers. Discharge also occurs directly to the atmosphere through evapotranspiration. Such discharge occurs where the capillary fringe (the subsurface zone immediately overlying the water table) intersects the surface or the root zone of plants.

In McHenry County, as in the rest of the humid part of the United States (roughly the eastern half of the contiguous United States), recharge to the saturated zone occurs in all interstream areas. Discharge from the saturated zone occurs only in streams, lakes, and wetlands together with floodplains and other areas where the capillary fringe intersects land surface.

So far, this discussion has been general, dealing only with recharge to and discharge from the saturated zone, rather than to and from each aquifer in a sequence of largely confined aquifers, such as those in McHenry County. As mentioned earlier regarding ground-water flow within aquifers, ground water moves from high head to low head, and this principle applies as well to recharge to confined aquifers. Where downward vertical hydraulic gradients exist (that is, where heads decrease with depth within the saturated zone), ground water moves downward from the water table or from a surficial unconfined aquifer to recharge underlying confined aquifers. Where an upward vertical hydraulic gradient exists between a confined aquifer and the surface, ground water moves upward from the confined aquifer and discharges at the surface.

In general, the discharge areas of aquifers become separated by progressively greater distances as the depth of the aquifer increases. The shallowest ground water, which directly underlies the water table, discharges into even very small ditches and depressions. Recharge to the water table occurs only in the relatively small areas lying between these discharge features. The shallowest confined aquifers typically share both recharge and discharge areas with the water table. Upward hydraulic gradients are established beneath stream valleys and other discharge features at the surface, where the water table intersects land surface. The water table elevation surrounding relatively small-scale discharge features declines below heads in underlying shallow confined aquifers, and ground water moves upward from these aquifers toward the surface. The water table surrounding small-scale stream valleys and other discharge features will, however, remain at a higher elevation than the head in more deeply buried confined aquifers, and water within these aquifers will not move upward. The discharge areas for more deeply buried confined aquifers are comparatively large-scale rivers and lakes occupying major valleys and depressions, and the recharge areas for these aquifers include the comparatively spacious areas between these features.

Ground-water recharge occurs mainly during the spring, when rainfall is high and water losses to evapotranspiration are low. Before precipitation can pass through the unsaturated zone to recharge the underlying saturated zone, soil moisture must be replaced until it exceeds the maximum volume of water that the soil can hold, which is known as its field capacity. Recharge decreases during the summer and early fall when evapotranspiration diverts most precipitation and infiltrating water back into the atmosphere. Likewise, recharge is often negligible during the winter months when soil moisture is frozen, which diverts precipitation into surface-water bodies as runoff. Recharge can occur, however, during mild winters when soil moisture is not frozen (Larson et al., 1997).

Several factors affect the rate of ground-water recharge. Among these are the hydraulic characteristics of the materials both above and below the water table (which, in turn, are functions of the geologic characteristics of these materials); topography; land use; vegetation; soil moisture content; depth to the water table; the intensity, duration, areal extent, and seasonal distribution of precipitation; the type of precipitation (rain or snow); and air temperature (Walton, 1965). Hensel (1992) presents a detailed discussion of ground-water recharge processes in Illinois.

Recharge rate estimations for McHenry County are limited to those of Prickett et al. (1964) and Walton (1965). As part of a statewide study, Walton (1965) estimated recharge in the Kishwaukee River basin upstream of Belvidere, Illinois. This basin includes much of western McHenry County. He estimated recharge in the area for years of below-normal, normal, and above normal precipitation at 97,000, 194,000, and 401,000 gallons per day per square mile (gpd/mi^2), respectively. Prickett et al. (1964) and Walton (1965) estimated recharge rates of 125,000 and 127,000 gpd/mi^2, respectively, to Aquifer 5 in the Woodstock area.

Capture Zones

The withdrawal of ground water from a well causes a lowering of heads in the area around the well. This decline in head is called drawdown (Figure 5). In three dimensions, the head distribution surrounding a single pumping well resembles a cone with its apex pointed downward. The lowest head (and greatest drawdown) is present at the pumping well, and heads increase with distance from the well. The area of lowered heads surrounding a pumping well or well field is therefore called a cone of depression. In map view, the area enclosed by the cone of depression is referred to as the lateral area of influence (LAI). The lateral area of influence may be thought of as the area defined by the distance from the pumping well to the point at which drawdown is negligible.

As mentioned earlier, ground water flows from areas of relatively high head to areas of relatively low head. Thus, with the development of a cone of depression around a pumping well, hydraulic gradients are established such that ground water flows toward the well from all directions. The capture zone or zone of capture (ZOC) of a pumping well is that area of the source aquifer in which ground-water flow is toward the well. It is important to delineate capture zones because any dissolved contaminants within a capture zone will move toward the pumping well and can eventually contaminate the water supply. The capture zone and the lateral area of influence associated with a pumping well are not perfectly coincident because the lateral area of influence is defined by drawdown and the capture zone is defined by the head distribution in the source aquifer (Figure 5). For example, if heads in an area generally decrease from east to west, so that regional ground-water flow is from east to west, the capture zone of a pumping well in the area will extend farther up-gradient (east) than will the lateral area of influence (Figure 5). The capture zone generally extends up-gradient from the pumping well to the edge of the source aquifer or to a ground-water divide (a "ridge" on the potentiometric surface of the aquifer from which ground-water flow diverges). Thus, capture zones are generally asymmetrical.

Capture zones are usually defined in terms of time of travel. A time-related capture zone is that area of the source aquifer that contributes the ground water withdrawn by a well during a selected time period. For example, a five-year time-related capture zone, commonly referred to as a "five-year capture zone," is an estimation of the area of the aquifer that contributes water to a well within 5 years. In other words, ground water residing in the source aquifer and within the boundaries of the five-year capture zone will be withdrawn from the well within 5 years.

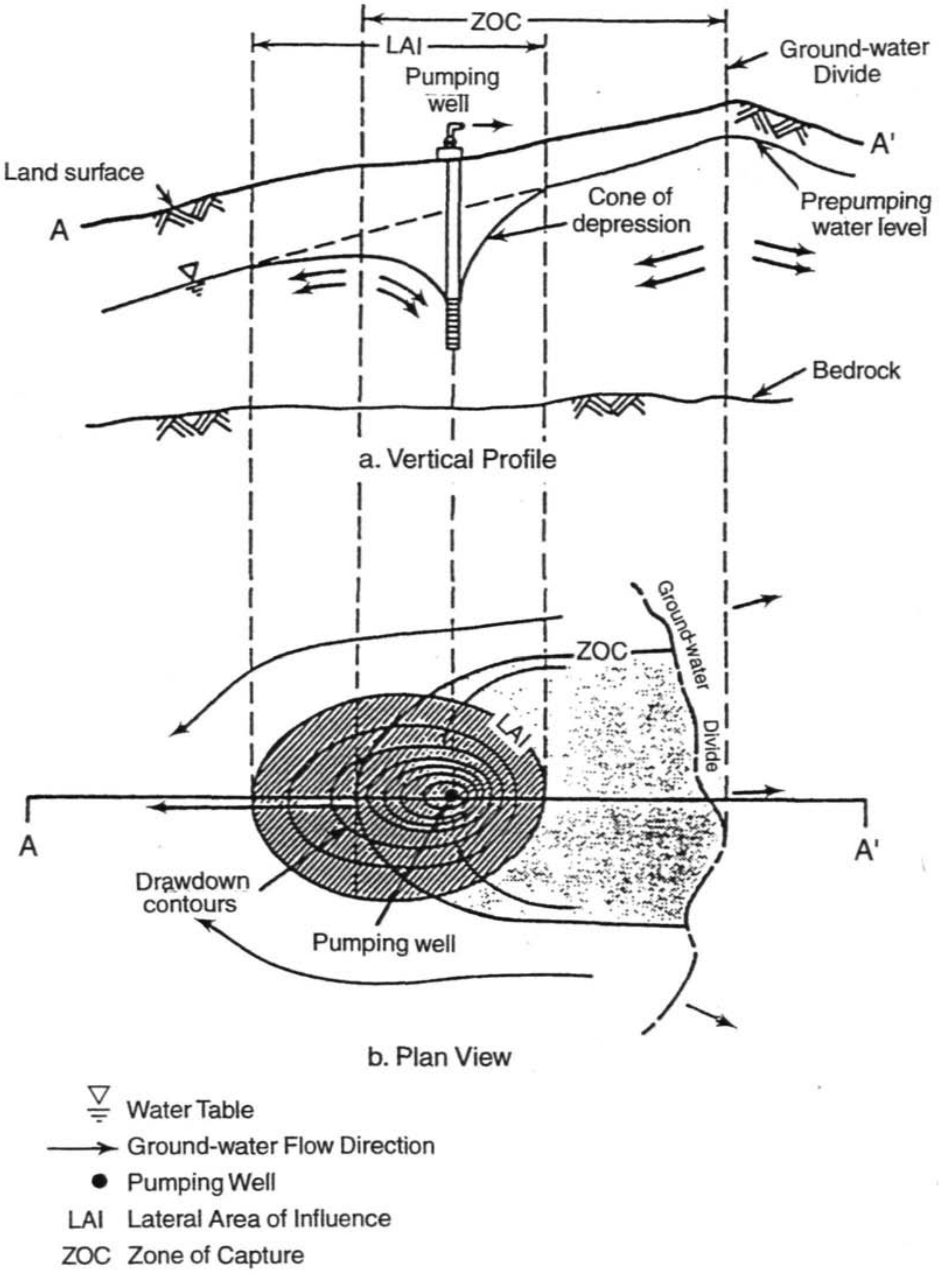

Figure 5. Illustrations of terms relating to impacts on water levels from pumping wells (source: Illinois Environmental Protection Agency, 1992).

Note that capture zones exist in three dimensions because ground water moves vertically, as well as laterally, toward the pumping well. The terms capture zone, zone of capture, and time-relatedcapture zone will, however, be used in this report to refer to the two-dimensional map views of these entities.

Nitrates in Ground Water

High levels of nitrate (NO_3^{-1}) in ground water can cause adverse health effects in both humans and animals. The U.S. Environmental Protection Agency (1977) established the drinking water standard for nitrate at 10 mg/L as nitrogen (NO_3^{-1}-N). Nitrate concentrations exceeding these standards may cause methemoglobinemia, or "blue baby syndrome," in infants up to about 6 months in age.

Nitrate is a natural component of shallow ground water. Natural nitrate concentrations in ground water are, however, relatively low, ranging only up to about 10 mg/L as nitrogen (NO_3^{-1}-N) in the United States (Davis and Dewiest, 1966). These concentrations, however, can be significantly increased by human activities. Identifying the source of excessive nitrate in ground water is often problematic. Sources include fertilizers, sewage treatment plants, industrial waste water, manure and urine from feedlots and pastures, septic tanks and associated leach fields, decaying vegetation and animals, leguminous crops, nitrate-bearing minerals, atmospheric deposition, urban drainage, refuse dumps and landfills, and surface runoff.

METHODS AND DATABASES

Development of Potentiometric Surface Maps

Potentiometric surface maps were constructed for each of the five aquifers described in the preceding section of this report. Construction of these maps relied heavily on water levels measured in wells. By subtracting the depth to water in a well from the elevation of the measuring point on the surface, the head is obtained. Head measurements from several wells open to an aquifer, plotted on a base map, can then be contoured in order to create a potentiometric surface map of the aquifer. Heads sometimes differ markedly between aquifers, so care must be taken that water level measurements employed in constructing a potentiometric surface map for a given aquifer are obtained from wells open only to that aquifer. Because heads constantly change in response to variations in precipitation, pumpage, and other factors, a potentiometric surface map for an area must be constructed from water level data collected over as brief a time period as possible. A potentiometric surface map, correctly constructed from data collected over a brief time period, offers a "snapshot" of heads in an aquifer at a specific time.

Field Procedure The potentiometric surface maps constructed for the five shallow aquifers considered in this study are based mainly on water level measurements obtained from 601 wells from October 17 through November 17, 1994. The wells used were domestic, farm, commercial, and public water supply wells. The "mass measurement" of water levels in fall 1994 was preceded by a period during which well owners were contacted and permission was sought from them to include their wells in the study; this period lasted from June 1993 through August 1994. For each aquifer, the goal of this effort was to develop a network of regularly spaced wells extending across the entire aquifer area in McHenry County. Prior to contacting well owners, candidate wells were identified by reviewing well completion reports submitted by drillers to state governmental authorities. These reports include location data, a driller's log of the geologic materials penetrated during drilling, and the construction details of the completed well; the driller's log allowed identification of the aquifer supplying water to the well.

The depth to water in farm, domestic, and commercial wells was measured with a disinfected steel measuring tape or, rarely, an electric dropline; the measuring point in most cases was the top of the casing after removing the cap from the well. In most public water supply wells, the depth to water was measured with a disinfected steel measuring tape; the tape was usually inserted through a vent tube or other access port in the casing or cap of the well. All water level measurements conducted with a steel measuring tape or electric dropline were made to the nearest 0.01 ft. In some cases, it was necessary to measure the depth to water in public water supply wells with an air line, which is an apparatus allowing the operator to measure the length of the submerged portion of a plastic or rubber tube attached to the column pipe of well. Measuring by the air line method is accomplished by displacing all the water in the tube by pumping air into it with a tire pump or compressed air source; the air pressure in the tube is then read from a gauge, and the height of an equivalent column of water is then calculated. The accuracy of air line measurements varies with the equipment, but most air line measurements are probably accurate to within 1 ft of the actual depth to water. Measurement with a steel tape was the preferred method of water level measurement, and was employed wherever possible, because this method affords greater accuracy than does measurement with an air line.

At the time water levels were measured, Water Survey staff used high accuracy global positioning system (GPS) equipment to survey the location and elevation of the measuring point at each well. The GPS equipment consisted of six Leica System 200 GPS units, which are designed to receive and log locational data broadcast by a satellite navigation system operated by the U.S. Department of Defense. At the same time the satellite data were logged at the water level measuring point, they were logged by a second staff member at a known reference point. National Geodetic Survey stations were used as reference points throughout the study area. Data collected at both the well and the reference point were later processed using Leica SKI (version 1.09) post-processing software (Leica AG, 1993a) to determine the location and elevation of each water level measuring point. The estimated accuracy of these determinations is ±2 centimeters (cm) horizontally and ±4 cm vertically (Leica AG, 1993b). The locations of the wells used to construct each of the five potentiometric surface maps are shown in Figures 6 through 10.

Considerations in Contouring the Head Data The process of contouring head data to construct a potentiometric surface map is essentially a process of estimating heads in all of the areas lying between irregularly scattered head measurements. Contouring may be carried out by hand or by using a computer program. The potentiometric surface maps constructed for this study (Plates 1 through 5) were constructed by hand-contouring the head data collected in fall 1994. Hand-contouring, while much slower than automated contouring, offers the advantage of being able to take into account several potential influences on the potentiometric surface configuration that automated contouring cannot easily consider.

One such influence is land surface topography. In general, the potentiometric surface of an aquifer is a subdued replica of land surface topography; that is, the pattern of "hills" and "valleys" on the potentiometric surface resembles that of the land surface, except that the relief (the difference between high and low elevations) is less and transitions between hills and valleys are much smoother. The degree of replication, however, decreases with depth, so that while relatively small variations of topography can be replicated in the potentiometric surface of a very shallow aquifer, only large topographic features would be reflected in that of a more deeply buried aquifer.

Another influence on potentiometric surface configuration not easily considered by automated contouring is large withdrawals of ground water through wells. Such withdrawals create cones of depression in the potentiometric surface of the source aquifer. Water levels in known high-capacity wells (which, for purposes of this report, are defined as wells pumping greater than 100,000 gpd) in McHenry County—all of which are public water supply wells—were therefore carefully considered in constructing the potentiometric surface maps. Pumping rates and historical water level data on file at the ISWS for these wells were consulted to evaluate whether the measured 1994 heads in the wells might indicate a significant decline from initial, prepumping heads. If so, a cone of depression was assumed to exist around the well. It is important to note that the geometry of these assumed cones of depression as shown on the potentiometric surface maps may not be accurate owing to the lack of closely spaced water level measurements in the vicinity of most high-capacity wells. Nevertheless, assuming a cone of depression around many of these wells is probably more

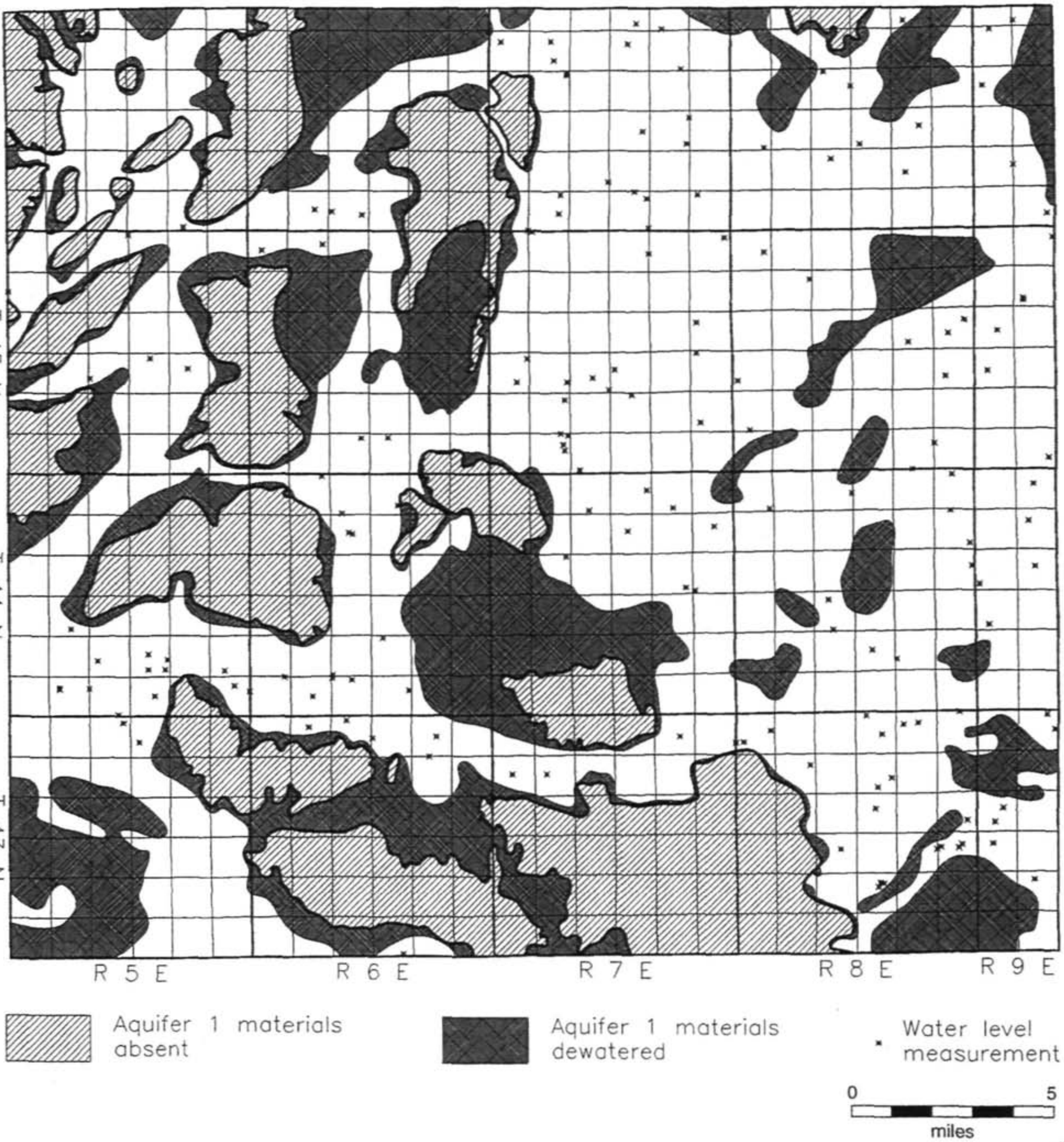

Figure 6. Locations of water level measurements used in construction of the potentiometric surface map of Aquifer 1 (Plate 1).

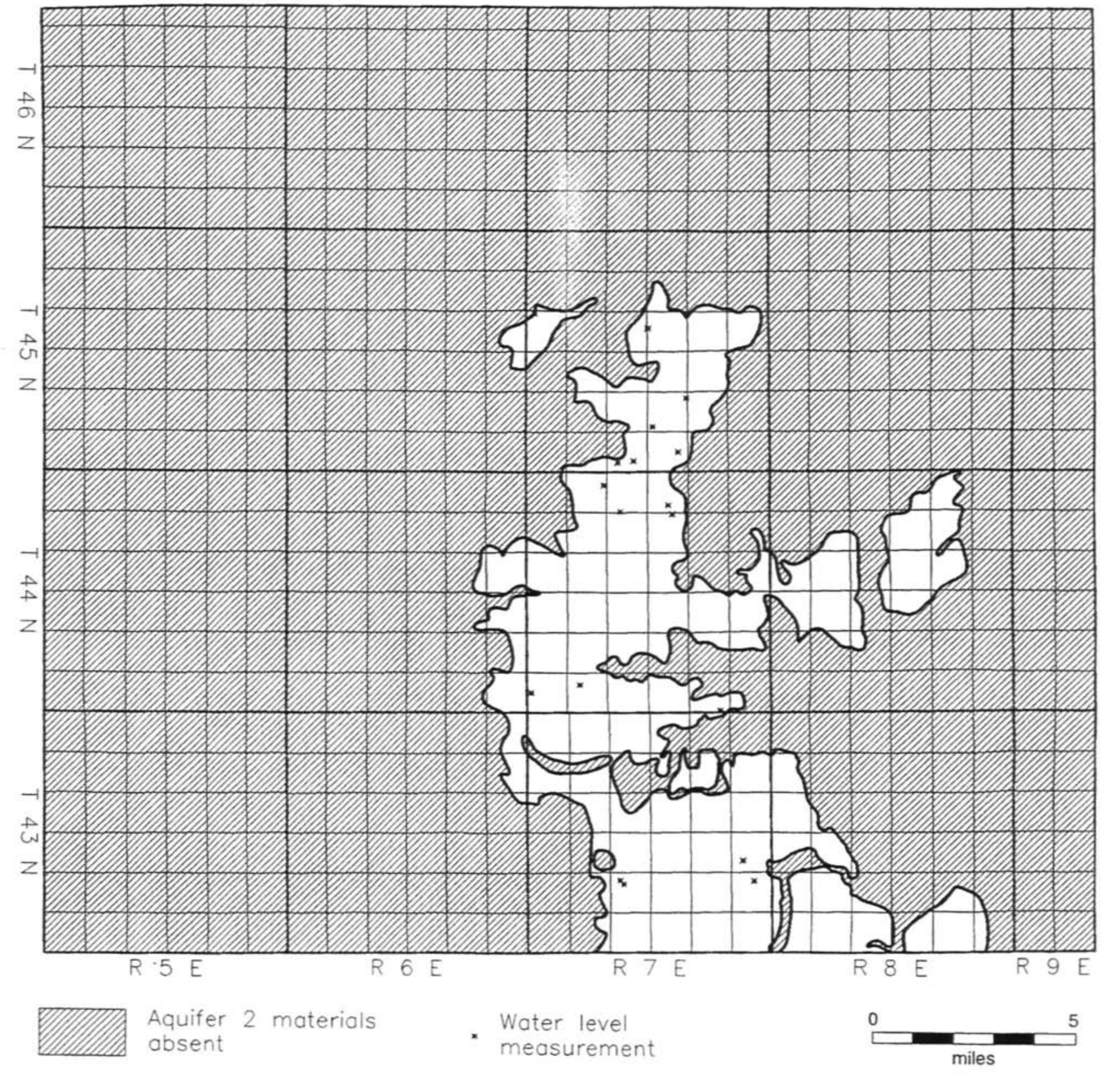

Figure 7. Locations of water level measurements used in construction of the potentiometric surface map of Aquifer 2 (Plate 2).

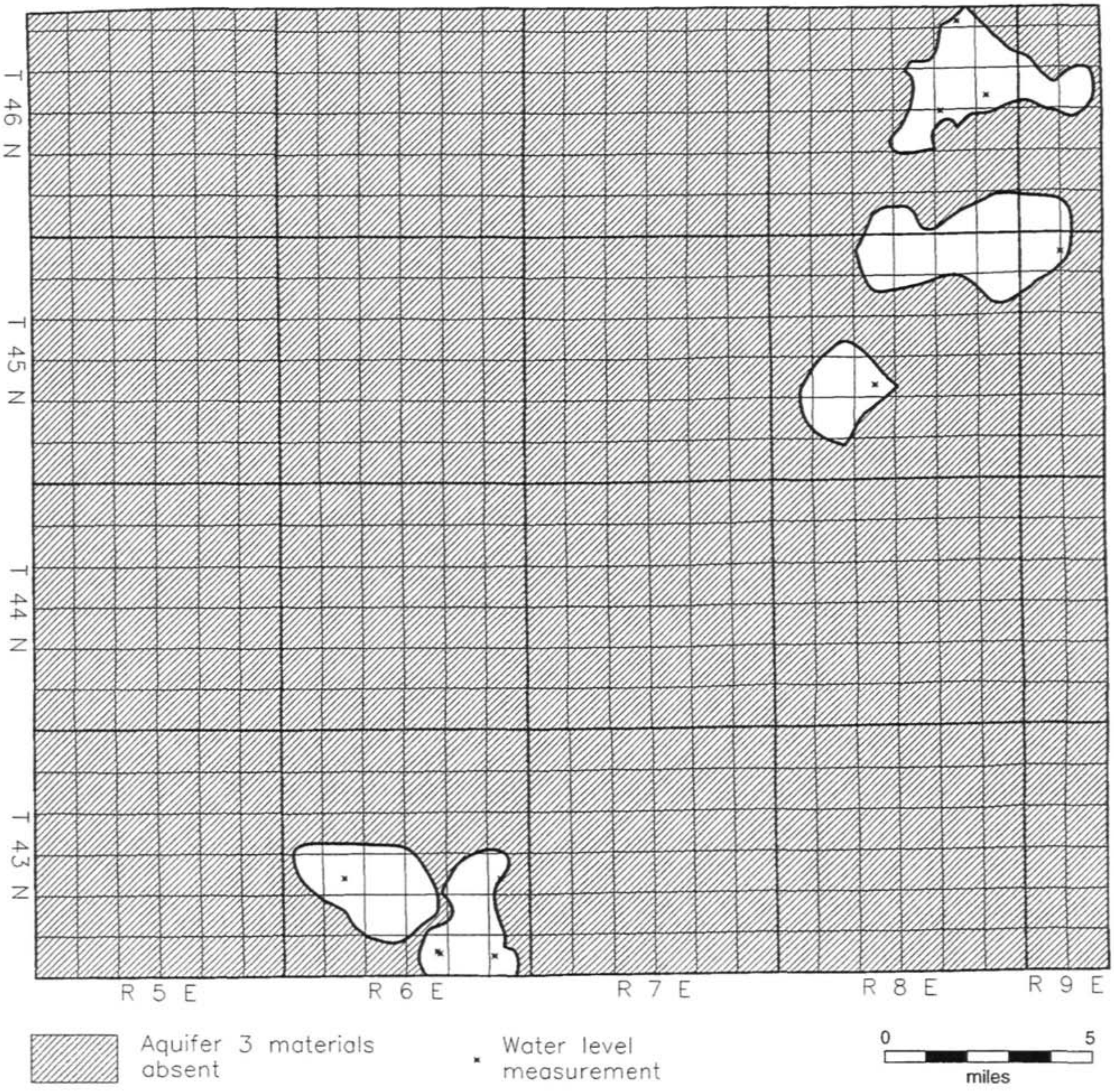

Figure 8. Locations of water level measurements used in construction of the potentiometric surface map of Aquifer 3 (Plate 3).

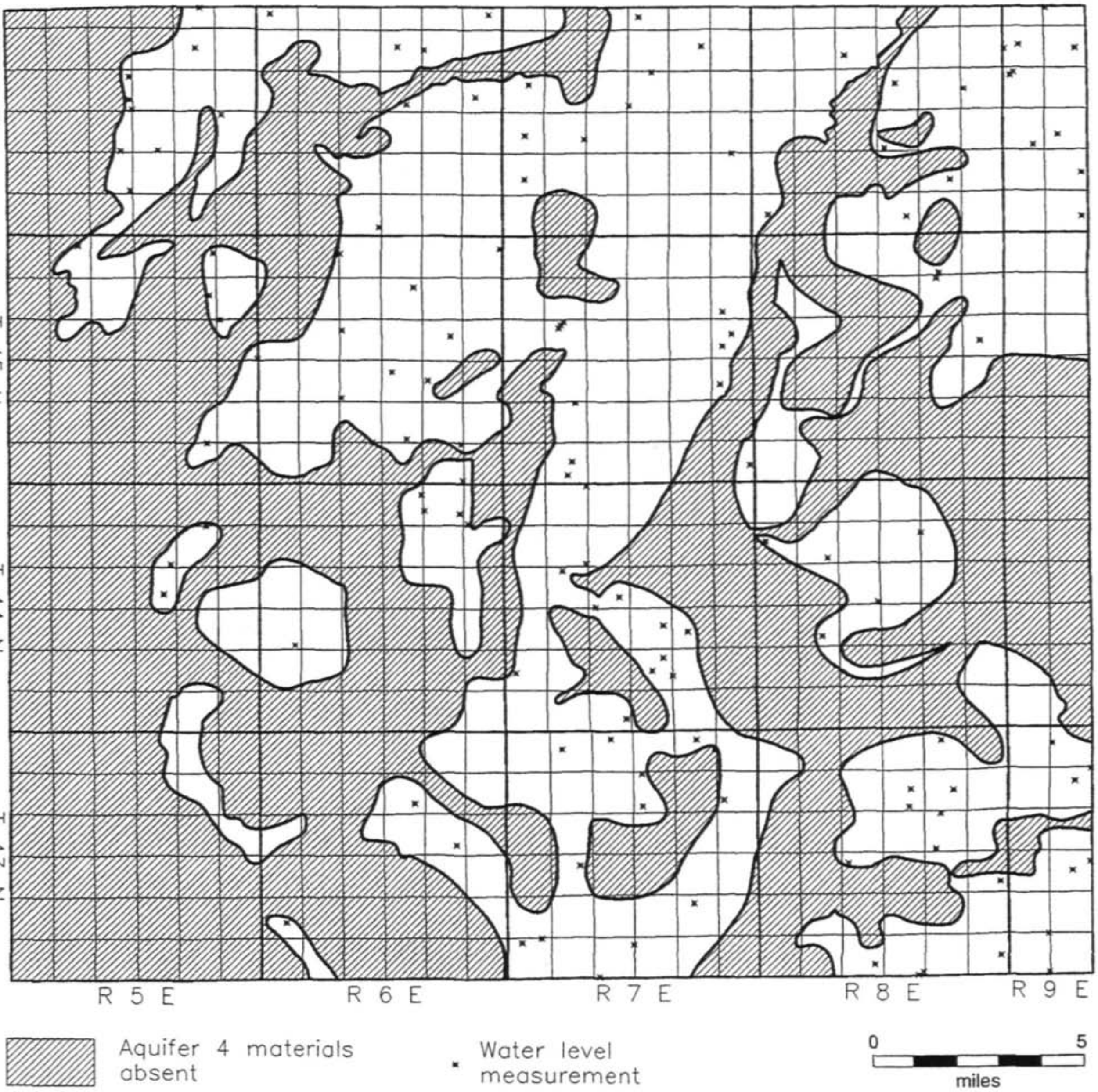

Figure 9. Locations of water level measurements used in construction of the potentiometric surface map of Aquifer 4 (Plate 4).

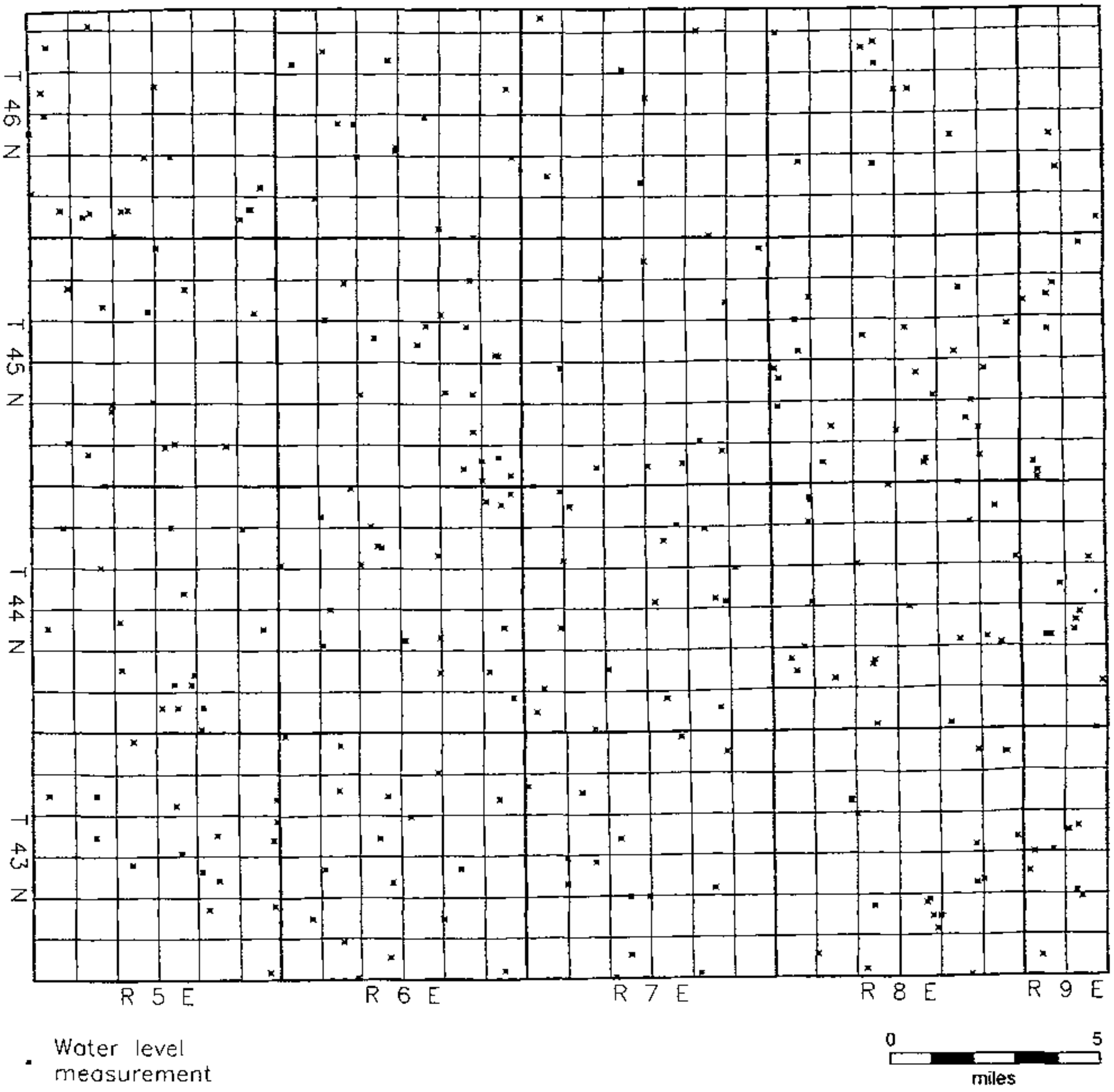

Figure 10. Locations of water level measurements used in construction of the potentiometric surface map of Aquifer 5 (Plate 5).

accurate than contouring the potentiometric surface as if the heads at the wells represented non-pumping conditions. In the absence of data suggesting the true configuration of a cone of depression, a roughly circular cone has been assumed. Actual cone configuration may not be circular because of lateral variations in aquifer hydraulic properties, aquifer thickness, and other factors. Anisotropy (having geologic properties that differ with direction) can be a factor governing cone configuration around wells open to the uppermost bedrock because fractures in the uppermost bedrock may be oriented in a preferred direction or directions. In a few cases, water level measurements were not obtained from high-capacity wells during the fall 1994 mass measurement. In these cases, water levels reported by public water supply operators annually to the ISWS through the Illinois Water Inventory Program (IWIP) were substituted. It should be noted that these measurements were not collected using the same methodology as those obtained during the fall 1994 mass measurement and that well elevations were inferred from topographic maps, a far less accurate method than the surveying employed during the mass measurement.

Hydrostratigraphy also influences the potentiometric surfaces of the aquifers in McHenry County. With the exception of Aquifer 5, all aquifers mapped for this study are laterally discontinuous (Curry et al., 1998). Theoretical considerations dictate that the equipotentials, or lines connecting points of equal head, must form a right angle with the aquifer boundaries. The potentiometric surfaces of aquifers in McHenry County are also influenced by the presence of connections between aquifers. A confining bed that separates two aquifers in one part of the county may not be present in other areas, and the aquifers may form a single hydrostratigraphic unit in the area where the confining bed is absent. As the confining bed thins in approaching this area of aquifer connection, heads in the separate, but converging, aquifers must themselves approach a single value. In map view, the location of pinchout of the confining bed (that is, where the confining bed thickness drops to zero) separating the aquifers appears as a line. The locations of known areas of aquifer connection are shown on Plates 1 through 5 using a set of symbols explained by the key on the right margin of each map. On one side of the line marking the confining bed pinchout, the aquifers are separated by a confining bed, while on the opposite side they form a single aquifer. The symbol marking the line of confining bed pinchout indicates the side of this line on which each of these conditions is true. The colors included in the symbol identify the aquifers involved in the connection. In the extreme case of aquifer connection, sand and gravel essentially extends from the surface to bedrock, and only a single shallow aquifer is present. Such areas are identified by a stippled pattern.

Construction of the potentiometric surface map of Aquifer 1 required that areas of aquifer dewatering (that is, where the aquifer materials contain no water) be identified. These areas were identified by two principal means. First, water levels in Aquifer 1 in areas where head measurements were obtained in 1994 were plotted on cross sections of McHenry County provided by the ISGS. In areas where heads fell below the bottom of Aquifer 1 as shown on the cross sections, the Aquifer 1 materials were presumed to be dewatered. Well completion reports on file at the ISWS were consulted to verify whether the Aquifer 1 materials were indeed dewatered in these areas. The absence of wells finished in Aquifer 1 or, more convincingly, driller's logs that reported the Aquifer 1 materials to be dry, were considered to be evidence corroborating this conclusion.

Development of Final Maps The hand-contoured maps were digitized and finalized using AutoCAD (Autodesk, Inc., 1992). Use of AutoCAD facilitated modification of the maps and development of final figures for this report, and it ensured perfect duplication of equipotentials in areas of aquifer connection on the potentiometric surface maps of each of the converging aquifers.

Uncertainties As is the case with many contour maps, the potentiometric surface maps constructed for this study are based on measured values, in this case heads, at relatively few locations. Heads in areas between these points are interpolated from the measured heads. No potentiometric surface map can be completely accurate, but the accuracy of the maps can be improved by skillful contouring of the measured head values. As has been discussed, the maps constructed for this study were contoured by hand, rather than by computer, because the hand-contouring process allows the effects of land surface topography, large ground-water withdrawals, and hydrostratigraphy to be considered during map construction. It must be recognized by users of the potentiometric surface maps, however, that actual heads will probably differ from those represented on the maps because heads in the large areas lacking data points remain unknown and, as such, are a matter of hypothesis.

Head distributions in the vicinity of high-capacity pumping wells (that is, the head distributions that define the cone of depression around these wells) are poorly understood owing to the lack of measurements in close proximity to the wells. Lacking such measurements, a roughly circular, and potentially inaccurate, plan view for the cones of depression has been assumed. The "depth" of a cone of depression (that is, the difference between the nonpumping water level and the water level measured in fall 1994 at the well at the center of the cone of depression) was estimated on the basis of comparison of the fall 1994 water level with historical water level data, if available, and/or comparison of the measured water level with a nonpumping water level assumed on the basis of trends in the potentiometric surface configuration in areas largely undisturbed by pumping. In some cases, high-capacity wells were not available for measurement in fall 1994. In these cases, fall 1994 water levels were estimated from annual reports submitted by water supply operators to the ISWS through the Illinois Water Inventory Program. It should be noted that there is uncertainty associated with these measurements because they were not necessarily conducted during the period of the fall 1994 mass measurement or in a manner consistent with the method used during the mass measurement.

Estimation of Time-Related Capture Zones

Five-year time-related capture zones for 33 selected public water supply wells in McHenry County were estimated using GWPATH (Shafer, 1990). GWPATH is an interactive software package that allows estimation of horizontal fluid pathlines and travel times in fully saturated ground-water flow domains. The theoretical background and development of GWPATH are discussed by Shafer (1987).

GWPATH permits delineation of two-dimensional capture zones, not three-dimensional capture zones as does MODPATH (Pollock, 1989) in combination with MODFLOW (McDonald and Harbaugh, 1988). The data necessary for three-dimensional capture zone delineation of a well (for example, effective porosity and hydraulic conductivity distributions for each aquifer and confining bed present in the vicinity of the well, detailed test drilling data in the vicinity of the well to establish the geometry of all aquifers and confining beds in the area, and ground-water recharge rates in the area) are not known in enough detail to warrant the significantly greater effort required to delineate a capture zone by this method. Given the lack of data, a two-dimensional approach probably offers a degree of accuracy comparable to that of a three-dimensional approach.

Each capture zone was estimated by "reverse tracking" (that is, tracking from low heads at the center of the cone of depression to higher heads in surrounding areas, the reverse of the normal ground-water movement) 100 or more particles arranged in a circle with a radius of 25 ft centered at the well location. The particles were reverse-tracked for a period of 1,826 days (5 years) using minimum and maximum time steps of 2 and 5 days, respectively, and two moves per cell. The endpoints of the pathlines of the reverse-tracked particles were used to estimate the outline of the five-year capture zone.

Capture zone estimation requires a great deal of information on well location, construction, and withdrawals. Well location data used in this report were obtained from information reported to the ISWS by drillers, consultants, and municipal water authorities, as well as from surveying data obtained by the ISWS during its mass water level measurement of McHenry County wells in fall 1994. Land surface elevations were estimated from topographic maps on the basis of reported well locations or from surveying data obtained during the 1994 mass water level measurement. Finished well depths, driller's logs, and well construction data were obtained from file information reported to the ISWS by drillers, consultants, and municipal water authorities. Source aquifers were identified by comparing driller's logs with regional geological data provided by the Illinois State Geological Survey and summarized in Curry et al. (1998). Ground-water withdrawal data were reported by water supply operators to the ISWS through the Illinois Water Inventory Program (IWIP).

In addition to location, construction, and withdrawal data, the following are required to estimate the capture zone of a well using GWPATH: (1) the potentiometric surface of the source aquifer in the vicinity of the well, (2) the hydraulic conductivity of the source aquifer in the vicinity of the well, and (3) the effective porosity of the source aquifer in the vicinity of the well. The potentiometric surface data appear in Plates 1 through 5. The rationale for the assumptions of hydraulic conductivity and effective porosity used in the capture zone estimations are summarized in Table 1.

Potentiometric Surface Data The sources of data used to construct the potentiometric surface maps employed in the capture zone estimations were discussed on pages 17-25. As already discussed, the maps were drawn using AutoCAD (Autodesk, Inc., 1992). GWPATH, however, requires that the potentiometric surface be represented by head values at equally spaced nodes on a grid covering the model domain rather than by equipotential lines such as are used to represent the head distributions on the potentiometric surface maps. Gridded head data, in the form of electronic data files of equally spaced head values, were created using SURFER® (Golden Software, Inc., 1995). To accomplish the reformatting of the AutoCAD-drawn equipotentials into a grid file representing the same potentiometric surface, equipotentials from a square or rectangular area expected to contain the capture zone were first exported from AutoCAD in DXF format (a format readable by SURFER®), and the resulting file was imported into SURFER® as a base map. The equipotentials included on the base map were then digitized in SURFER®, and the resulting data file was "gridded" in SURFER® over the area of the flow domain using a node spacing of 50 ft or, if the

Table 1. Rationale for Assumptions of Hydraulic Conductivity (K) and Effective Porosity (n) Used in Five-Year Capture Zone Estimations

Source aquifer	No. of capture zone estimations	K and n values used in capture zone estimations*	Rationale
1	3	K = 150 ft/d	No pumping test data are available for Aquifer 1 in McHenry County. The assumed value of 150 ft/d is the approximate midpoint of the distribution of hydraulic conductivities for sand and gravel, as given by Heath (1983); it is consistent with measured hydraulic conductivities of other sand and gravel aquifers in McHenry County.
		n = 0.225	Effective porosity measurements of sand and gravel aquifers in McHenry County are not available. The assumed value of 0.225 is the average of representative effective porosities for sand and gravel, as reported by Heath (1983), and the midpoint of the range of effective porosities for sand and gravel mixes, as reported by Driscoll(1986).
2	2	K = result of nearest available pumping test	The nearest available pumping test result is the most site-specific data available. Two pumping test data sets are available for Aquifer 2. Hydraulic conductivity values derived from analyses of the pumping test data range from 110 to 130 ft/d.
		n = 0.225	Effective porosity measurements of sand and gravel aquifers in McHenry County are not available. The assumed value of 0.225 is the average of representative effective porosities for sand and gravel, as reported by Heath (1983), and the midpoint of the range of effective porosities for sand and gravel mixes, as reported by Driscoll(1986).
3	0	Not applicable. No capture zones were estimated for wells screened in Aquifer 3.	
4	8	K = result of nearest available pumping test	The nearest available pumping test result is the most site-specific data available. Nine pumping test data sets are available for Aquifer 4. Hydraulic conductivity values derived from analyses of the pumping test data range from 70 to 1,800 ft/d.
		n = 0.225	Effective porosity measurements of sand and gravel aquifers in McHenry County are not available. The assumed value of 0.225 is the average of representative effective porosities for sand and gravel, as reported by Heath (1983), and the midpoint of the range of effective porosities for sand and gravel mixes, as reported by Driscoll(1986).
5**	20	*Upper consolidated layer*	
		K = result of nearest available pumping test of a well finished only in the upper consolidated layer	The nearest available pumping test result is the most site-specific data available. Pumping tests of wells both screened in the unconsolidated layer and open to the bedrock, although common, are not suitable because they do not provide results specifically applicable to the upper unconsolidated layer. Twenty-six pumping test data sets from wells finished only in the unconsolidated layer of Aquifer 5 are available. Hydraulic conductivity values derived from analyses of pumping test data range from ≤30 to 750 ft/d.

Table 1. Rationale for Assumptions—*continued*

Source aquifer	No. of capture zone estimations	K and n values used in capture zone estimations*	Rationale
5**	20	*Upper consolidated layer—continued*	
		n = 0.225	Effective porosity measurements of sand and gravel aquifers in McHenry County are not available. The assumed value of 0.225 is the average of representative effective porosities for sand and gravel, as reported by Heath (1983), and the midpoint of the range of effective porosities for sand and gravel mixes, as reported by Driscoll(1986).
		Lower carbonate layer	
		K = 40 ft/d	For the carbonate portion of Aquifer 5, pumping tests not influenced by the overlying unconsolidated layer are not available. The assumed value of 40 ft/d is based on analysis of specific capacity data summarized by Csallany and Walton (1963). Although not representative of the hydraulic conductivity that, in the Silurian dolomite and Maquoketa Formation as a whole, decreases downward, the value is probably representative of the upper portion of the bedrock.
		n = 0.04	Effective porosity measurements of the carbonate portion of Aquifer 5 are not available. The assumed value of 0.04 is the average seven measurements of effective porosities of fractured carbonate aquifers in Ohio, Pennsylvania, Australia, Hungary, and Belgium (Roadcap, 1990).

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* See Table 2 for hydraulic conductivity and porosity values used in specific capture zone estimations.

** Values of K and n employed in capture zone estimations for wells finished in Aquifer 5 are the values estimated for the Aquifer 5 layer having the highest ratio of K to n (K/n). The rationale for applying these values of K and n is that, all other conditions being equal, these values characterize the layer having higher ground-water velocities. For a selected time interval, flow lines will be longer in the layer having the higher ground-water velocities (hence, the higher value of K/n), and their endpoints will more accurately define the actual capture zone.

flow domain was large, 100 ft. The boundaries of the flow domain were selected so that the well was located at a grid node. During the gridding process, SURFER® calculates values at each of the regularly spaced nodes on the grid using the irregularly spaced data points provided to it during the digitizing process. The grid file thus developed was then contoured by SURFER®, and the resulting map was compared to the AutoCAD-drawn potentiometric surface map to check its accuracy. The grid file was then converted, using a utility included within SURFER®, to ASCII format, which is acceptable to GWPATH.

Hydraulic Conductivity and Effective Porosity Assumptions, Aquifers 1 through 4 For wells finished in Aquifers 2 and 4, the aquifer hydraulic conductivity assumed in each capture zone estimation was based on pumping test analyses from the nearest well completed in the source aquifer. A discussion of pumping tests and pumping test analyses is included in Appendix A, and Appendix C lists the results of analyses of 37 pumping tests of shallow aquifers in McHenry County. The locations of the pumped wells involved in each of these tests are shown in Figure 11.

No pumping test results were available for Aquifer 1. Lacking such information, a hydraulic conductivity of 150 ft/d was employed in all capture zone estimations for wells finished in this aquifer. This assumed value is the approximate midpoint of the distribution of hydraulic conductivities for sand and gravel given by Heath (1983) and is consistent with measured hydraulic conductivities of other sand and gravel aquifers in McHenry County. Determination of hydraulic conductivity values for use in capture zone estimations for wells open to Aquifer 5 presented special problems, which will be discussed later.

Data pertaining to the effective porosity of aquifer materials in McHenry County are not available, so assumed values of effective porosity are based on published values for comparable materials. The assumed effective porosity for Aquifers 1, 2, and 4 (0.225) is the average of representative porosities for sand and gravel reported by Heath (1983) and the midpoint of the range of effective porosities for sand and gravel mixes reported by Driscoll (1986).

Capture zones were not calculated for Aquifer 3 because no known public water supply wells obtain water from that aquifer in McHenry County.

Hydraulic Conductivity and Effective Porosity Assumptions, Aquifer 5 The difficulty in determining suitable values of hydraulic conductivity and effective porosity to employ in capture zone estimations for wells finished in Aquifer 5 is an outgrowth of the fact that in most areas the aquifer is a stratified unit consisting of an upper layer of coarse-grained unconsolidated materials and a lower layer of fractured carbonates or interbedded carbonates and shale. These differences in composition and texture are accompanied by differences in hydraulic conductivity and effective porosity. But because GWPATH is a two-dimensional ground-water flow modeling program that can not represent stratification, the hydraulic conductivity and effective porosity of Aquifer 5 could each be characterized only by a single value. The challenge to the modeler, then, is to select a single value for each of these variables that will yield the most accurate capture zone estimation possible given the limitations of GWPATH. This challenge is complicated by the observation that hydraulic conductivity and effective porosity decrease downward within the bedrock portion of the aquifer, rather than remaining uniform throughout this interval (Csallany and Walton, 1963; Bergeron, 1981).

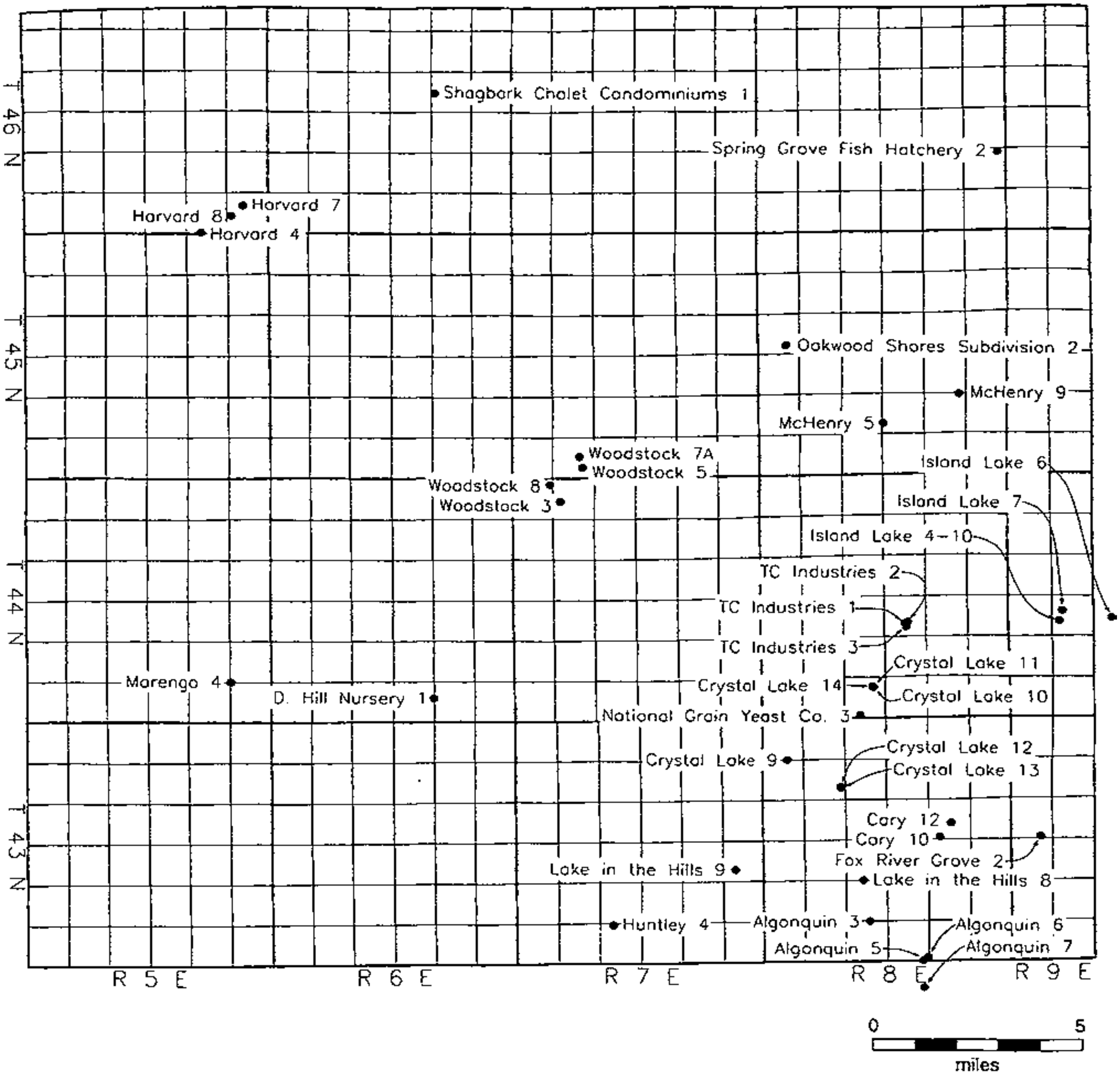

Figure 11. Locations of pumping tests of Aquifers 1 through 5 in and near McHenry County. Hydraulic properties estimated from data collected during these tests are listed in Appendix C.

This feature would be difficult to simulate in any modeling process, let alone the fairly simple approach applied in this study. Still another problem with assuming values of hydraulic conductivity to employ in capture zone estimations of wells finished in Aquifer 5 is that pumping test data collected in wells finished in Aquifer 5 do not necessarily provide an accurate indication of the actual hydraulic conductivity of either the sand and gravel composing the upper portion of the aquifer or the bedrock composing the lower portion of the aquifer. Unfortunately, data that might indicate actual values of effective porosity and hydraulic conductivity of the upper and lower layers of Aquifer 5 are ambiguous or nonexistent. This problem will be discussed later.

The problem of selecting hydraulic conductivity and effective porosity values to use in capture zone estimations for wells finished in Aquifer 5 was addressed by considering the effects on capture zone size of differing ground-water velocities in the two layers composing the aquifer. All other conditions being equal, ground-water velocity is proportional to the ratio of hydraulic conductivity to effective porosity (K/n). This effect is observable in three-dimensional ground-water modeling studies, which permit the definition of layers having different hydraulic properties (Figure 12). For this study, then, in which the technique of capture zone estimation permits the use of only a single value for hydraulic conductivity and for effective porosity, the time-related capture zone of a well finished in Aquifer 5 was estimated using the values for these variables from the layer having the higher ratio of hydraulic conductivity to effective porosity. The validity of the approach rests on the assumption that ground water entering a well finished in Aquifer 5 originates in both the upper portion of the aquifer, consisting of coarse-grained unconsolidated materials, and the lower portion of the aquifer, consisting of bedrock, regardless of whether the well itself was screened or open to only one of these layers. Lacking information to the contrary, this assumption was made in conducting all capture zone estimations of wells finished in Aquifer 5.

As mentioned earlier, effective porosity measurements of both unconsolidated and bedrock aquifers in McHenry County are not available. Published resources, however, suggest effective porosity values of 0.225 for the unconsolidated materials composing the upper portion of Aquifer 5 (Heath, 1983; Driscoll, 1986) and 0.04 for the carbonates composing the lower portion of the unit (Roadcap, 1990). It should be noted that the decrease in the degree to which dissolution has affected porosity within the carbonate bedrock suggests that the porosity of the bedrock may also decrease with depth. The effective porosity of the upper portion of the bedrock may in fact be greater than the figures reported by Roadcap (1990), which ranged from 0.01 to about 0.06, and the effective porosity of the lower portions of the upper bedrock may be less than this range. Nevertheless, in this study, in the absence of additional data, an effective porosity of 0.04 was assumed to be representative of the effective porosity of the bedrock portion of Aquifer 5.

Numerous pumping tests of wells finished in Aquifer 5 have been conducted in McHenry County, but determination of hydraulic conductivity from the test data is not straightforward. The difficulties in determining a hydraulic conductivity from pumping test data collected from a well finished in Aquifer 5 are related to the facts that (1) the aquifer is, in most areas, a unit containing two distinct layers, and (2) the thickness of the aquifer is not known. Pumping test data indicate the transmissivity of an aquifer, not the hydraulic conductivity. Hydraulic conductivity is determined by dividing the transmissivity by the aquifer thickness, which is usually determined from a well log. In the case of Aquifer 5, the transmissivity indicated by pumping test data would reflect contributions

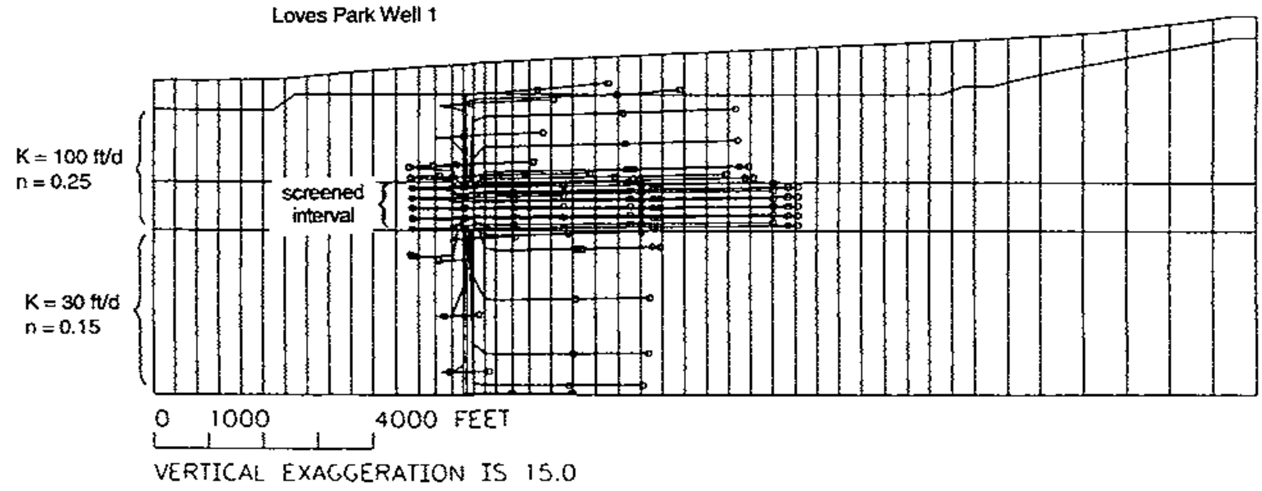

Figure 12. Cross section showing the effect of the differing ratios of hydraulic conductivity (K) to effective porosity (n) on the length of reverse particle pathlines calculated by three-dimensional modeling at Loves Park, Winnebago County, Illinois (modified from Wehrmann and others, 1996). The differing pathline lengths reflect the fact that, all other conditions being equal, ground-water velocity is proportional to K/n.

of water to the well by both the upper and lower portions of the aquifer (except in those comparatively rare areas where the upper portion of the aquifer is absent). Division of this value by the aquifer thickness (assuming that one can determine the thickness of Aquifer 5) would yield a hydraulic conductivity that would be a composite of the hydraulic conductivities of the two contributing intervals. To employ such a value in a capture zone estimation would require that a similar composite of aquifer effective porosity be used, and no such determinations are available. The second problem with determining a hydraulic conductivity of Aquifer 5 from pumping test data is that, despite the preceding discussion, the thickness of Aquifer 5 is not known because the bottom of Aquifer 5 is marked not by an easily recognizable lithologic interface, but by a decline in the hydraulic conductivity and effective porosity of the bedrock to a point at which it can no longer supply a significant quantity of water to a well. Even if one assumed an aquifer thickness (for example, based on the sum of the thickness of basal unconsolidated aquifer materials and the length of the uncased hole penetrating the bedrock), one could still calculate a composite hydraulic conductivity.

In the absence of other data, the hydraulic conductivity of the upper layer of Aquifer 5 (the basal unconsolidated materials) was assumed to be the hydraulic conductivity indicated by the nearest pumping test of a well screened in these materials without penetrating the underlying bedrock. This hydraulic conductivity was determined by dividing the transmissivity derived from analysis of the test data by the probable thickness of the basal unconsolidated materials only. Pumping test data from 26 wells in and near McHenry County and finished only in the upper, unconsolidated portion of Aquifer 5 indicate hydraulic conductivities of 30 to 750 ft/d for the interval. As discussed in the preceding paragraph, it is probable that, to some degree, these values are influenced by contributions of ground water from the underlying bedrock portion of the aquifer. Nevertheless, in the absence of other, better data on the hydraulic conductivity of the basal unconsolidated materials, these contributions were neglected, and the hydraulic conductivities suggested by the pumping tests discussed above were considered to be representative of the basal unconsolidated aquifer materials composing the upper portion of Aquifer 5. This approach is justified by the comparatively low hydraulic conductivity of the bedrock in relation to most unconsolidated sand and gravel, the evidence for which is discussed below.

The degree to which the bedrock contributes water to a well finished only in the basal unconsolidated materials is not ascertainable with existing data but probably varies with location. The influence of contributions from the dolomite on an individual tested well finished only in the basal unconsolidated materials is principally a reflection of the size, number, and degree of interconnection of fractures in the dolomite in the vicinity of the well bore. If one assumes, as has been done in the present study, that the thickness of Aquifer 5 at a well finished only in the basal unconsolidated materials is equivalent to the thickness of those materials, then contributions from the dolomite to the basal unconsolidated materials during a pumping test could result in overestimation of the hydraulic conductivity of the unconsolidated materials. It should be noted, however, that despite this potential for overestimation of the hydraulic conductivity of the basal unconsolidated materials, the underlying bedrock generally exhibited the higher ratio of hydraulic conductivity to effective porosity. Thus, the assumed hydraulic conductivity and effective porosity of the basal unconsolidated materials were employed much less often in capture zone estimations than were the assumed values for the underlying bedrock.

For two reasons, the hydraulic conductivity of the lower layer (the upper bedrock) of Aquifer 5 is not indicated satisfactorily by existing pumping test data. First, transmissivity values determined from these test data are probably more likely to be composite values influenced by the hydraulic conductivities of both the upper and lower layers of Aquifer 5 than are values determined from test data collected at wells only open to the upper layer of Aquifer 5. Transmissivity values are likely to be composites because, while penetration of the bedrock would permit contribution of ground water to the well from the bedrock, the presumed lower hydraulic conductivity of the bedrock as compared to the overlying outwash (the evidence for which is discussed below) would result in relatively greater head reduction in the vicinity of the well bore and, consequently, relatively greater vertical movement of ground water from the adjacent interval of Aquifer 5 than would be the case for a well finished only in the basal unconsolidated materials of Aquifer 5. A second reason that the hydraulic conductivity of the bedrock interval of Aquifer 5 is not satisfactorily indicated by pumping test data is that the thickness of the bedrock portion of the aquifer—a value which is essential to calculating hydraulic conductivity from transmissivity—is not clear because the base of the bedrock portion of Aquifer 5 is not a discrete surface; it is, rather, defined by a decrease in fracture porosity downward within the unit.

For the present study, the hydraulic conductivity of the uppermost bedrock has been estimated using a statistical summary of specific capacity data for wells open to the shallow dolomite aquifer (which includes the upper bedrock in McHenry County) compiled by Csallany and Walton (1963). Specific capacity is a measure of the productivity of a well and is calculated by dividing the pumping rate of the well by the drawdown incurred after pumping the well at that rate. Note that in cases wherein a well is pumped continuously, drawdown will increase with time; thus, specific capacity cannot be a perfectly accurate measure of the productivity of a well but is rather a function of the duration of pumping, among other factors. Nevertheless, since the rate of water level decline in a well typically declines dramatically with elapsed time after the start of pumping, specific capacity is often a viable and easily measured gauge of well productivity when the duration of pumping exceeds a few hours. In addition to being a function of the duration of pumping, note also that specific capacity is a function of aquifer transmissivity, aquifer storage coefficient, and well radius (see equation 21 in Appendix A). It may also be affected by partial penetration of the aquifer by the well, "well loss" (a component of drawdown brought about by mechanical inefficiencies in the well), aquifer boundaries, and other hydrogeologic phenomena.

Csallany and Walton (1963) analyzed specific capacity data from about 800 shallow dolomite wells in northeastern Illinois for the purpose of understanding the important influences on the yields of shallow dolomite wells in the region. They first estimated the drawdown caused by well loss in each of the 800 wells and subtracted this from the observed drawdown at the well; this permitted them to determine a specific capacity corrected for well loss. By assuming a storage coefficient and a rate of leakage into the aquifer identical to those calculated from pumping test data collected in Du Page County, they then adjusted the specific capacities (already corrected for well loss) to a common well radius and pumping duration. For each well, the observed and adjusted specific capacities were then divided by the total penetration of the well into the shallow dolomite to determine observed and adjusted specific capacities per foot of penetration. Frequency distribution plots of these data were prepared to show the response of the shallow dolomite to pumping in various geographic and hydrogeologic settings.

One of these plots illustrates the distributions of specific capacities per foot of penetration of wells in McHenry County finished in the shallow dolomite. The plot (Figure 18 in Csallany and Walton, 1963) shows adjusted specific capacities per foot of penetration for (1) wells penetrating only the upper 33 percent of Silurian rocks, (2) wells penetrating more than 33 percent of Silurian rocks, and (3) wells penetrating the entire thickness of Silurian rocks together with some portion of the underlying Maquoketa Formation. The average hydraulic conductivity of these three intervals can be estimated by applying the specific capacity relationship of Walton (1962) (equation 21 in Appendix A) to the fiftieth percentile of each distribution (that is, the most frequently occurring specific capacity) and solving by iteration. The values employed by Csallany and Walton (1963) in adjusting their data (that is, $S = 0.0003$, $r_w = 0.5$ ft, and $t = 720$ minutes) are substituted into the equation to obtain this estimate. For example, the fiftieth percentile of the distribution for wells finished in the upper 33 percent of Silurian rocks is 0.2 gpm/ft per foot of penetration. Solving by iteration the specific capacity relationship, an estimated transmissivity of about 40 ft/d is obtained. Since this number applies to a theoretical aquifer having a thickness of only 1 ft, it is identical to the hydraulic conductivity of the upper 33 percent of the Silurian rocks. Similarly, the specific capacity relationship yields a hydraulic conductivity of less than 10 ft/d for the Silurian as a whole and for the Silurian together with the Maquoketa Formation. These estimates of hydraulic conductivity of the Silurian are consistent with those of similar Silurian-aged fractured carbonates in Ohio discussed by Roadcap (1990) and Bair and Roadcap (1992), which ranged from 5 to 57 ft/d.

The estimated hydraulic conductivity of the upper 33 percent of the Silurian (40 ft/d) was considered to be representative of the bedrock portion of Aquifer 5 for purposes of comparing ratios of hydraulic conductivity to effective porosity (K/n) for the upper and lower portions of the aquifer, regardless of whether a well penetrated more than the upper 33 percent of the Silurian. If this ratio was greater for the bedrock portion of the aquifer than for the upper, unconsolidated portion, then the hydraulic conductivity of 40 ft/d was employed in the capture zone estimation, again regardless of whether a well penetrated deeper than this interval. It is likely, given the reported downward decrease in the degree to which dissolution has affected the bedrock, that both porosity and hydraulic conductivity decrease with depth; but as long as K/n remains constant through the Silurian dolomite and Maquoketa Formation, then the K/n estimated for the upper 33 percent of the Silurian would be representative of the entire bedrock portion of Aquifer 5.

It should be added that, in the absence of other data, the hydraulic conductivity of 40 ft/d was considered to be representative of the upper bedrock regardless of whether that bedrock was included within the Silurian dolomite or the underlying Maquoketa Formation. In many areas of McHenry County, the Silurian dolomite is absent, and the Maquoketa Formation is at the bedrock surface. This assumed hydraulic conductivity is probably reasonably accurate given that the Maquoketa Formation in McHenry County may contain thick beds of dolomite, such as the Silurian, and has therefore probably been affected similarly by fracturing and dissolution.

Scope of Capture Zone Estimations Five-year capture zones were estimated for all McHenry County public water supply wells that were (1) pumped at an average rate greater than 100,000 gallons per day (gpd) in 1994, (2) brought into service before January 1, 1994, and (3) finished in one of the five aquifers for which potentiometric surface maps (Plates 1 through 5) were constructed. These restrictions were necessary because the methodology used to estimate the capture zones is heavily dependent on the potentiometric surface maps developed for the study. The year 1994 is important because the maps were developed from data collected in fall 1994; the potentiometric surfaces shown on them are therefore a reflection of 1994 withdrawals. Only wells pumping more than 100,000 gpd during 1994 were considered for capture zone estimation because cones of depression around wells pumping less than this are generally not resolvable given the contour interval and density of data points employed in developing the potentiometric surface maps. In addition, historical water level data generally indicate that these wells have had a negligible impact on water levels in the source aquifers. To apply the methodology used in this report, it is essential that a recognizable cone of depression exist around the well. In addition to including only wells pumping more than 100,000 gpd in 1994, only wells active during the entire calendar year 1994 (as opposed to wells that were brought into service during 1994 or after) were considered for capture zone estimation. This restriction was necessary because the methodology employed for capture zone estimation in this report will only yield valid results if steady-state conditions have become established around the pumping well, which means that the diversion area surrounding the well has grown to the area necessary to intercept enough recharge to balance withdrawals. Assuming that recharge and withdrawals do not change, the geometry of the cone of depression will not change once steady-state conditions have become established, but establishment of steady-state conditions can take weeks to years.

Appendix D gives pumpage and location data for all shallow McHenry County public water supply wells active in 1994; wells that were on emergency or standby status are not included. Altogether, 37 of these wells were pumped at an average rate greater than 100,000 gpd in 1994. Four of these—Crystal Lake wells 10, 11, and 14 and McHenry well 9—were not considered for capture zone estimation because they were brought into service during 1994. Five-year capture zones were estimated for a total of 33 wells (Figure 13). Table 2 provides location and withdrawal data for these wells, as well as source aquifer identification and assumed values of hydraulic conductivity and effective porosity employed in the capture zone estimations. Special notes regarding the capture zone estimations are included in Appendix E.

Potential Inaccuracies in the Capture Zone Estimations The method of capture zone estimation employed in this study is a simple, two-dimensional approach that relies heavily on the potentiometric surface maps constructed for the study and on a single assumed value of hydraulic conductivity and porosity for each estimation. Three-dimensional modeling (see, for example, Wehrmann et al., 1996) is a much more sophisticated endeavor that permits lateral and vertical variation of hydraulic properties of aquifers and confining beds. Three-dimensional modeling approaches make use of potentiometric surface maps constructed from field data only as a check against model output. Although three-dimensional modeling may provide more accurate and reliable capture zone estimations than the two-dimensional method employed in this study, three-dimensional models require significantly greater data inputs, time, and expense than two-dimensional models. Shafer (1987) discusses several tacit assumptions and limitations associated with the two-dimensional method used in the present study. The following discussion covers potential inaccuracies in the capture zone estimations stemming from the assumptions made for data inputs.

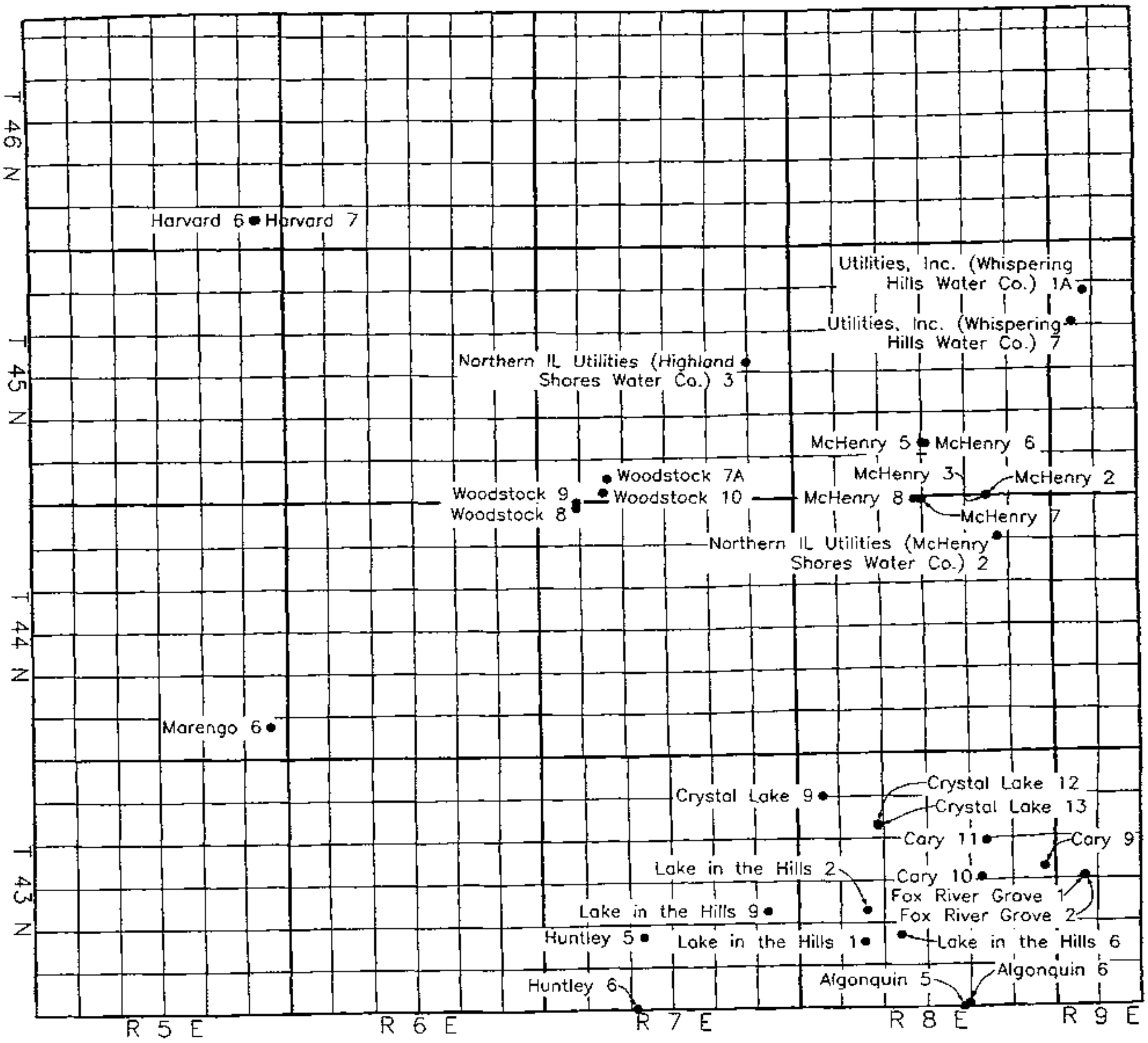

Figure 13. Locations of public water supply wells for which five-year capture zones were estimated for this report. Included are all public water supply wells finished in the five aquifers investigated for this report that were pumped at a rate greater than 100,000 gpd in 1994 and that were in operation before January 1, 1994.

Table 2. Shallow McHenry County Wells Pumping More Than 100,000 Gallons per Day in 1994

	Location						Values assumed in capture zone estimation		
Owner (well ID)	township-range	section	10-acreplot	Depth (ft)	Aquifer	Annual withdrawals gallons (year)*	K (ft/d)	n	Figure showing capture zone
Lake in the Hills (9)	43N-7E	24	6C	108	2	162,242,135 (1995)	130	0.225	28
Huntley (5)	43N-7E	28	6F	95	2	44,990,700 (1991)	130	0.225	25
Huntley (6)	43N-7E	33	7A	154	4	118,283,000 (1991)	1,000	0.225	26
Crystal Lake (9)	43N-8E	6	4A	205	5	145,635,000 (1994)	40	0.04	21
Crystal Lake (12)	43N-8E	8	1C	250	5	103,500,000 (1993)	40	0.04	21
Crystal Lake (13)	43N-8E	8	1C	250	5	132,972,000 (1993)	40	0.04	21
Cary (9)	43N-8E	13	2C	124	1	89,506,000 (1994)	150	0.225	19
Cary (11)	43N-8E	14	1G	127	4	164,209,000 (1994)	900	0.225	20
Lake in the Hills (2)	43N-8E	20	4C	347	5	47,550,010 (1995)	40	0.04	27
Cary (10)	43N-8E	23	6E	194	4	123,834,000 (1994)	190	0.225	20
Lake in the Hills (6)	43N-8E	28	5F	104	5	138,083,150 (1995)	40	0.04	27
Lake in the Hills (1)	43N-8E	29	4E	257	5	42,711,935 (1995)	40	0.04	27
Algonquin (6)	43N-8E	34	1A	152	4	204,491,000 (1994)	1,000	0.225	18
Algonquin (5)	43N-8E	34	2A	131	4	87,598,000 (1994)	1,000	0.225	18
Fox River Grove (1)	43N-9E	18	3A	140	5	110,503,000 (1994)	170	0.225	22
Fox River Grove (2)	43N-9E	18	3A	120	5	47,723,000 (1994)	170	0.225	22
Marengo (6)	44N-5E	36	4G	87	1	167,761,500 (1994)	150	0.225	29
Woodstock (8)	44N-7E	6	1G	166	5	259,684,200 (1994)	350	0.225	35
Woodstock (9)	44N-7E	6	1H	175	5	158,030,400 (1994)	350	0.225	35
Northern Illinois Utilities (2) (McHenry Shores Water Co.)	44N-8E	2	2A	135	5	37,896,500 (1994)	40	0.04	32

Table 2. Shallow Wells—*continued*

Owner (well ID)	Location township-range	section	10-acre plot	Depth (ft)	Aquifer	Annual withdrawals gallons (year)*	Values assumed in capture zone estimation K (ft/d)	n	Figure showing capture zone
McHenry (7)	44N-8E	4	1H	240	5	128,101,000 (1994)	40	0.04	31
McHenry (8)	44N-8E	4	2H	203	5	67,938,000 (1994)	40	0.04	31
Crystal Lake (10)	44N-8E	32	3F	258	5	50,319,000 (1994)	Zone not estimated		NA
Crystal Lake (14)	44N-8E	33	2G	243	5	42,890,000 (1994)	Zone not estimated		NA
Crystal Lake (11)	44N-8E	33	4F	237	5	58,793,000 (1994)	Zone not estimated		NA
Northern Illinois Utilities (3) (Highland Shores Water Co.)	45N-7E	14	1B.	167	4	44,956,100 (1994)	330	0.225	24
Woodstock (7A)	45N-7E	32	3E	114	4	277,211,000 (1994)	330	0.225	34
Woodstock (10)	45N-7E	32	4B	107	4	186,619,000 (1994)	330	0.225	34
McHenry (9)	45N-8E	26	2H	205	5	94,835,000 (1994)	Zone not estimated		NA
McHenry (5)	45N-8E	27	8C	95	5	113,492,000 (1994)	40	0.04	31
McHenry (6)	45N-8E	27	8C	131	5	102,450,000 (1994)	40	0.04	31
McHenry (2)	45N-8E	35	5A	60	1	117,570,000 (1994)	150	0.225	30
McHenry (3)	45N-8E	35	5A	185	5	57,418,000 (1994)	40	0.04	31
Utilities, Inc. (1A) (Whispering Hills Water Co.)	45N-9E	7	2G	303	5	49,069,000 (1994)	250	0.225	33
Utilities, Inc. (7) (Whispering Hills Water Co.)	45N-9E	7	4A	168	5	96,869,000 (1994)	250	0.225	33
Harvard (7)	46N-5E	36	5F	144	5	128,869,000 (1994)	200	0.225	23
Harvard (6)	46N-5E	36	6F	197	5	136,401,000 (1994)	200	0.225	23

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* Annual withdrawals are based on figures reported to the Illinois Water Inventory Program for 1994 or, when withdrawal totals were not reported for 1994, based on figures available for the most recent year preceding 1994. Withdrawals for Lake in the Hills wells 1, 2, 6, and 9 are based on totals reported for 1995 because withdrawal figures for the Lake in the Hills wells are not available for earlier years.

NA = not applicable

Each capture zone estimation relies heavily on the potentiometric surface map of the source aquifer of the well in question. Thus, the accuracy of the capture zone estimation for any high-capacity well is strongly related to the accuracy of the potentiometric surface map, in particular thearea of the map proximal to the well. Although discussed previously, some of the sources of inaccuracy in the potentiometric surface maps in the vicinity of high-capacity wells are reviewed here. First, in some cases, the wells for which capture zones were estimated were not available for measurement during the fall 1994 mass measurement on which the potentiometric surface maps are based. Thus, the head at the apex of the cone of depression surrounding these wells is not known with certainty. Heads at these wells were estimated from water level data reported annually to the ISWS through the Illinois Water Inventory Program (IWIP). It should be noted that these measurements were not necessarily obtained using the same methodology as those obtained during the fall 1994 mass measurement, and that measuring point elevations were inferred from topographic maps, a far less accurate method than the surveying employed during the mass measurement. Even in instances where the water level at the high-capacity well at the apex of a cone of depression was measured in fall 1994, the geometry of the cone of depression surrounding that well as shown on the potentiometric surface map of the source aquifer may be inaccurate. The inaccuracy arises because resources did not permit closely spaced water level measurements in areas proximal to these wells, where heads would be affected by pumping at the wells. These areas are generally served by public water systems, and most contain few, if any, domestic or other wells that would provide water level measurements to clarify cone geometries.

Uncertainty in the assumed hydraulic conductivity and porosity values also contributes to the uncertainty of the capture zone estimations. Both of these parameters may vary considerably, both vertically and horizontally, within an aquifer, yet both are very poorly known for aquifers in McHenry County.

As mentioned earlier, for purposes of this study, the preferred approach for assuming a hydraulic conductivity value to employ in a capture zone estimation was to base the assumed value on the nearest available pumping test result for the source aquifer. But since only 37 pumping test results are available for the shallow aquifers of McHenry County, this approach meant that, in some cases, the assumed hydraulic conductivity employed in a capture zone estimation was based on a pumping test that was many thousands of feet distant from the location of the well for which the capture zone was estimated. Such distances are great enough that the actual hydraulic conductivity at the well for which the capture zone was estimated may be substantially different from the value calculated from the remote pumping test data. Pumping test results for Aquifer 1 are not available at all, and hydraulic conductivity values for this aquifer were based on published values for materials having a composition of sand and gravel (Heath, 1983). This use of published values contributes further to the uncertainty of capture zone estimations for wells finished in this aquifer. Similarly, the assumed hydraulic conductivities of the bedrock portion of Aquifer 5 are based exclusively on published results based on statistical analysis of specific capacity values for wells finished in the shallow bedrock aquifer in northern Dlinois (Csallany and Walton, 1963). An additional problem with regard to the assumption of a reasonable hydraulic conductivity value for the bedrock portion of Aquifer 5 is that this unit, since it is composed of fractured bedrock, may be anisotropic (that is, the hydraulic conductivity may vary with direction). In fractured bedrock aquifers, for example, fracture trends typically fall into sets of subparallel fractures, and hydraulic conductivity along the fracture trends may be significantly greater than it is in other directions. Since existing hydraulic conductivity and other data do not permit an assessment of anisotropy in McHenry County aquifers, isotropic conditions have been assumed in all cases, even that of the bedrock portion of Aquifer 5.

Measurements of porosity of shallow McHenry County aquifers are not available, and, lacking such data, assumed values were based on published values for materials of comparable texture or lithology (Heath, 1983; Driscoll, 1986; Roadcap, 1990). Like hydraulic conductivity, porosity varies both horizontally and vertically within aquifers, although not to the same degree as does hydraulic conductivity. Still, the uncertainty associated with the assumption of porosity values contributes to the general uncertainty of the capture zone estimations.

An additional problem related to the use of assumed values of hydraulic conductivity and porosity in the capture zone estimations is that, even if the available data permitted the mapping of variations in hydraulic conductivity and porosity in the vicinity of the wells for which the capture zones were estimated, GWPATH will permit use of only a single value for these variables in each estimation. Thus, even if the actual hydraulic conductivity and porosity distributions in the vicinity of a well were understood, the method used to estimate the capture zone for that well could not reflect the complexity of the actual hydrology.

Assessment of Nitrate Contamination of Shallow McHenry County Ground Water

Source of Data The data on which the assessment of nitrate contamination of shallow McHenry County ground water was based were obtained from the ISWS Ground-Water Quality Database, which includes analyses of Illinois ground water conducted at laboratories operated and maintained by the ISWS and the Illinois Environmental Protection Agency (IEPA). Since the purpose of this study is to examine nitrate concentrations in the drift and shallow bedrock aquifers only, and not in the more deeply buried bedrock aquifers, the results considered here are limited to those from wells no deeper than 400 ft. This criterion yields 550 results, which are tabulated in Appendix F. The depth of 400 ft was chosen so that all wells open to glacial drift aquifers would be included in the analysis and wells open to bedrock units deeper than the Maquoketa Formation would be excluded.

Analysis The analysis of these data had as its overall goal a simple examination of nitrate concentrations in the shallow ground water of McHenry County. In addition, the relationship between nitrate contamination of ground-water samples and the depth of the source well was evaluated, and geographic trends in the occurrence of nitrate contamination were examined. For purposes of the study, a sample was considered to be contaminated if it contained nitrate as nitrogen ($N0_3^{-1}$-N) in concentrations exceeding the drinking water standard of 10 mg/L (U.S. Environmental Protection Agency, 1977).

The complete set of 550 analytical results included in Appendix F was not used in the general examination of nitrate concentrations in shallow ground water because this set of data contains numerous results from samples collected at the same well, but at different times. Inclusion of several results from multiply sampled wells would bias the sample population toward nitrate concentrations at the multiply sampled sites. A somewhat more accurate indication of nitrate concentrations in

McHenry County ground water would be presented by inclusion of only one sample from each well site. Thus, for purposes of examining nitrate concentrations in the shallow McHenry County aquifers, all but the most recently analyzed samples from each well were eliminated from the database given in Appendix F. Samples were considered to have been obtained from the same well when both well depth and location were identical. The reduced database consisting of only one analytical result from each well contained 280 results.

This reduced database was also used to examine the relationship of nitrate contamination of ground-water samples to the depth of the source well. Again, a database including several results from multiply sampled wells would bias the sample population toward nitrate concentrations at the multiply sampled wells; such multiple sampling would less accurately represent the relationship between nitrate concentration and well depth than would a database consisting of only one analytical result per well. To assess the relationship between well depth and nitrate concentration in sampled ground water, the analytical results were sorted by the depth of source well using 50-foot depth increments ranging from 1 through 400 ft. Graphs representing the distribution of nitrate concentrations in each of these depth categories were then constructed and examined for trends. The wells from which the samples were obtained were not assigned to the five principal shallow aquifers discussed elsewhere in this report. Although well depths are reported in the ISWS Ground-Water Quality Database, driller's logs are not, which makes assignment of wells to specific aquifers problematic.

For the examination of geographic trends in nitrate contamination in McHenry County, the complete set of 550 analytical results was used. The complete set was used because the examination sought to locate wells that were the source of the nitrate-contaminated samples at some point in their history; whether high nitrate concentrations occurred at multiply sampled wells repeatedly or only once was not an issue. These locations were plotted on a map and compared to the aquifer sensitivity map prepared by Curry et al. (1998).

Reporting of Nitrate Concentrations A potential problem for assessment of nitrate contamination was the fact that nitrate concentration data stored in the ISWS Ground-Water Quality Database have been reported in two ways. The ISWS has always reported nitrite and nitrate concentrations separately. IEPA laboratories used to report nitrite and nitrate concentrations separately, but since early 1979, the IEPA has reported a combined concentration of nitrite and nitrate (nitrite+nitrate).

These different reporting conventions, however, were considered to be irrelevant for two reasons. First, nitrite is typically oxidized to nitrate in ground-water systems and, because of this, is a relatively short-lived and uncommon ion in all but the most reducing subsurface environments. Second, the combined concentration of nitrite+nitrate was less than the drinking water standard for nitrate as nitrogen (10 mg/L) (U.S. Environmental Protection Agency, 1977) in all of the 212 samples for which nitrite+nitrate was reported. In all of these samples, then, the nitrate concentration must be less than the drinking water standard, and this is important because the drinking water standard was the criterion employed in this report to distinguish nitrate-contaminated samples from uncontaminated samples. If an analytical result of greater than 10 mg/L of nitrite+nitrate as nitrogen had been reported in any instance, it would not have been clear whether the nitrate concentration alone within that sample was greater than the drinking water standard for nitrate.

Data Shortcomings It should be noted that the data used to support the conclusions of this study regarding nitrate concentrations in shallow McHenry County ground water were not collected for this purpose. The wells that are the source of these data are not necessarily a random sample of actual well types, well depths, hydrogeologic conditions, or other characteristics within the county. The data are, rather, a compilation of available analytical results, and the analyses represented were conducted for purposes other than assessing regional nitrate contamination. Certain biases may be present. For example, the ISWS laboratory often conducts analyses of ground water provided by individuals who are concerned about problems with their wells. The wells might be suspected of poor water quality because of taste or odor problems, obvious deficiencies in well construction, location near a source of pollutants, or other factors. Therefore, statistical results based on a compilation of such data may be biased toward problem wells having poor water quality. The EPA laboratories, on the other hand, generally conduct analyses of ground water from public water supply wells; these wells are frequently deeper than farm/domestic supply wells and may, as a result of regulatory requirements and public concern, be better protected against some of the sources of nitrate contamination than are private wells.

DISCUSSION

Potentiometric Surface Maps

The potentiometric surface maps constructed for this report (Plates 1 through 5) show the head distribution in the five principal shallow aquifers in McHenry County. Because ground-water flows down-gradient from high head to low head, these maps also indicate ground-water flow patterns in the aquifers. In map view, ground-water flow direction in an aquifer is perpendicular to the lines connecting points of equal head (equipotentials) shown on a potentiometric map of the aquifer (Figure 14). Plates 1 through 5 show that topography and hydrostratigraphy, particularly the locations of aquifer connections, are important influences on ground-water flow in the shallow aquifers of McHenry County. The potentiometric surfaces also are influenced by ground-water withdrawals, aquifer thickness, and aquifer hydraulic conductivity.

Generally speaking, topographic features are replicated in the potentiometric surfaces of the aquifers, with the degree of replication decreasing with depth (Figure 15). Tracing ground-water flow divides in the aquifers is problematic owing to the numerous aquifer boundaries, aquifer connections, and dewatered areas within Aquifer 1. Nevertheless, a ground-water flow divide is traceable in the potentiometric surface of Aquifer 5. This feature roughly coincides with the surface-water drainage divide between the Fox and Kishwaukee Rivers. The ground-water flow divide suggested by the Aquifer 5 potentiometric surface map enters McHenry County on Marengo Ridge north of Harvard, then trends south-southeastward toward Woodstock, passing beneath the North Branch of the Kishwaukee River north-northwest of Hartand. The divide passes around the northeast side of Woodstock; it is probably deflected into this position in part as a result of pumping from Woodstock wells 8 and 9. From the east side of Woodstock, it trends south-southeastward, passing about 1 mile west of Crystal Lake, and from there it turns southwestward, passing about 1 mile northwest of Huntley. The divide passes out of McHenry County and into Kane County about 2 miles west of Huntley.

The presence of aquifer connections causes heads in the converging, but separate, aquifers to approach one another in areas proximal to the pinchout of the confining bed separating them (Figure 16).

As will be discussed, both topography and hydrostratigraphy control the locations of apparent recharge and discharge areas of the shallow aquifers.

Aquifer thickness and hydraulic conductivity can influence potentiometric surface configuration, but these influences are less obvious than those of topography and aquifer connections already discussed. Both thickness and hydraulic conductivity can influence potentiometric surface configuration because they are related to the transmissivity of an aquifer, a property that essentially describes the ability of an aquifer to transmit water. Where aquifer thickness and hydraulic conductivity are relatively high, so is transmissivity. High transmissivities favor low hydraulic gradients, which are suggested on a potentiometric surface map by widely spaced equipotentials. Variation in spacing of equipotentials can, then, reflect corresponding variation in aquifer thickness or hydraulic conductivity. Given our current poor understanding of the distribution of hydraulic

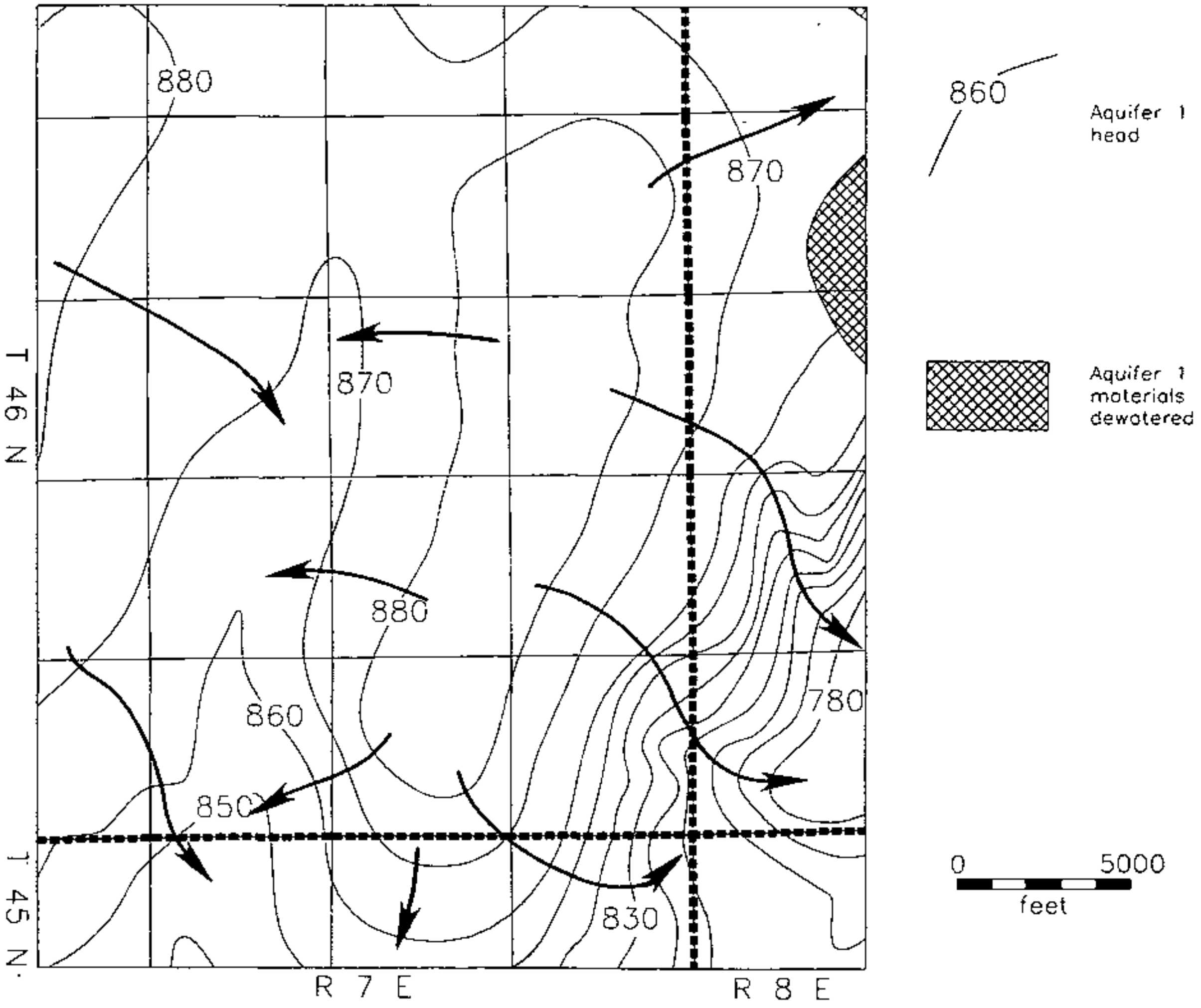

Figure 14. Detail from Plate 1 showing probable directions of ground-water flow in Aquifer 1 in north-central McHenry County as suggested by the mapped head distribution. For clarity, aquifer connections and surface-water hydrology are not included in this detail.

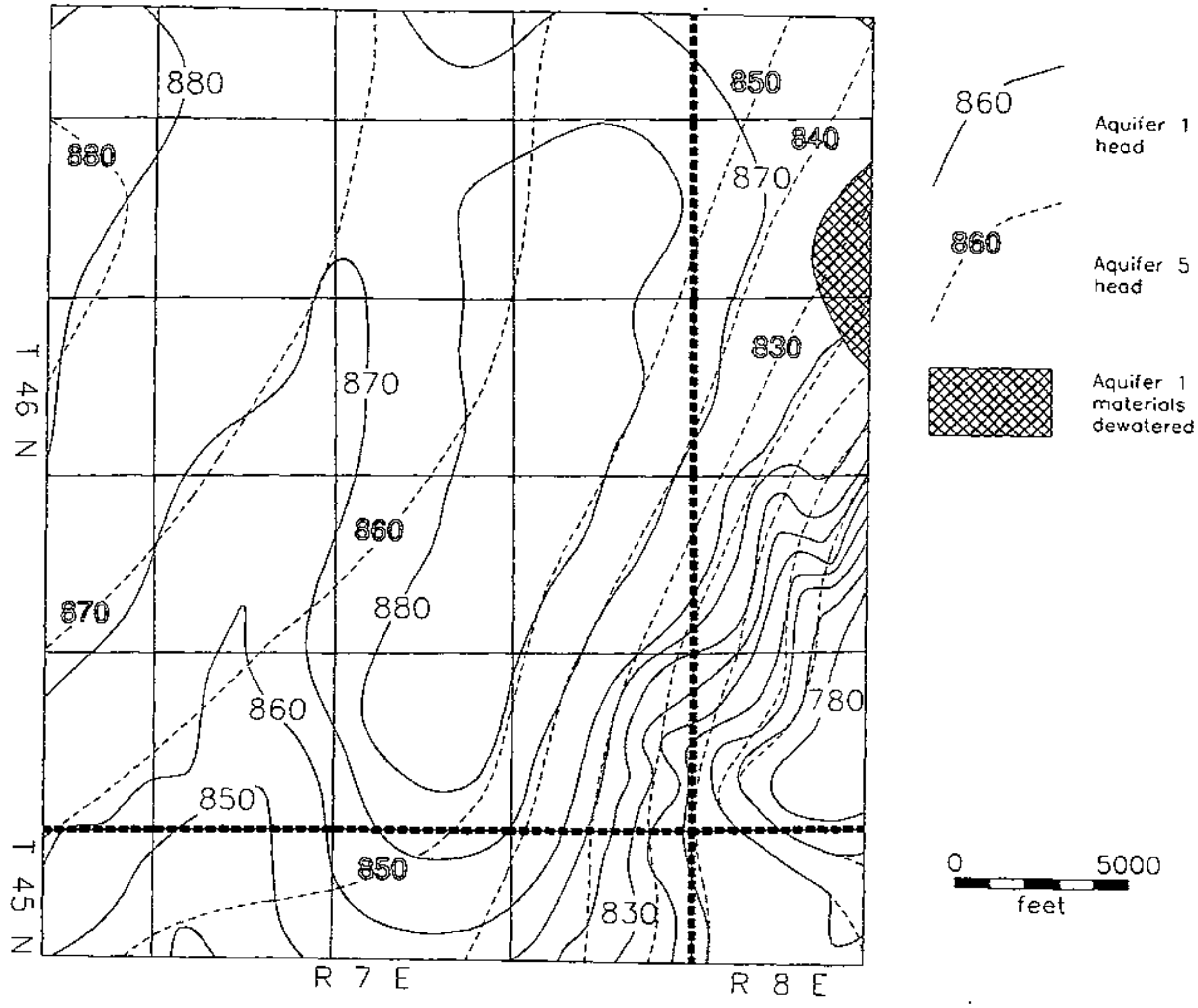

Figure 15. Detail from Plates 1 and 5 showing differing degrees of replication of land surface features in the potentiometric surfaces of Aquifers 1 and 5. The broad high area on the potentiometric surface of Aquifer 1, roughly enclosed by the 880-foot contour in the center of the figure area, replicates a similar land surface feature, but this feature is not replicated on the potentiometric surface of Aquifer 5, which is more deeply buried

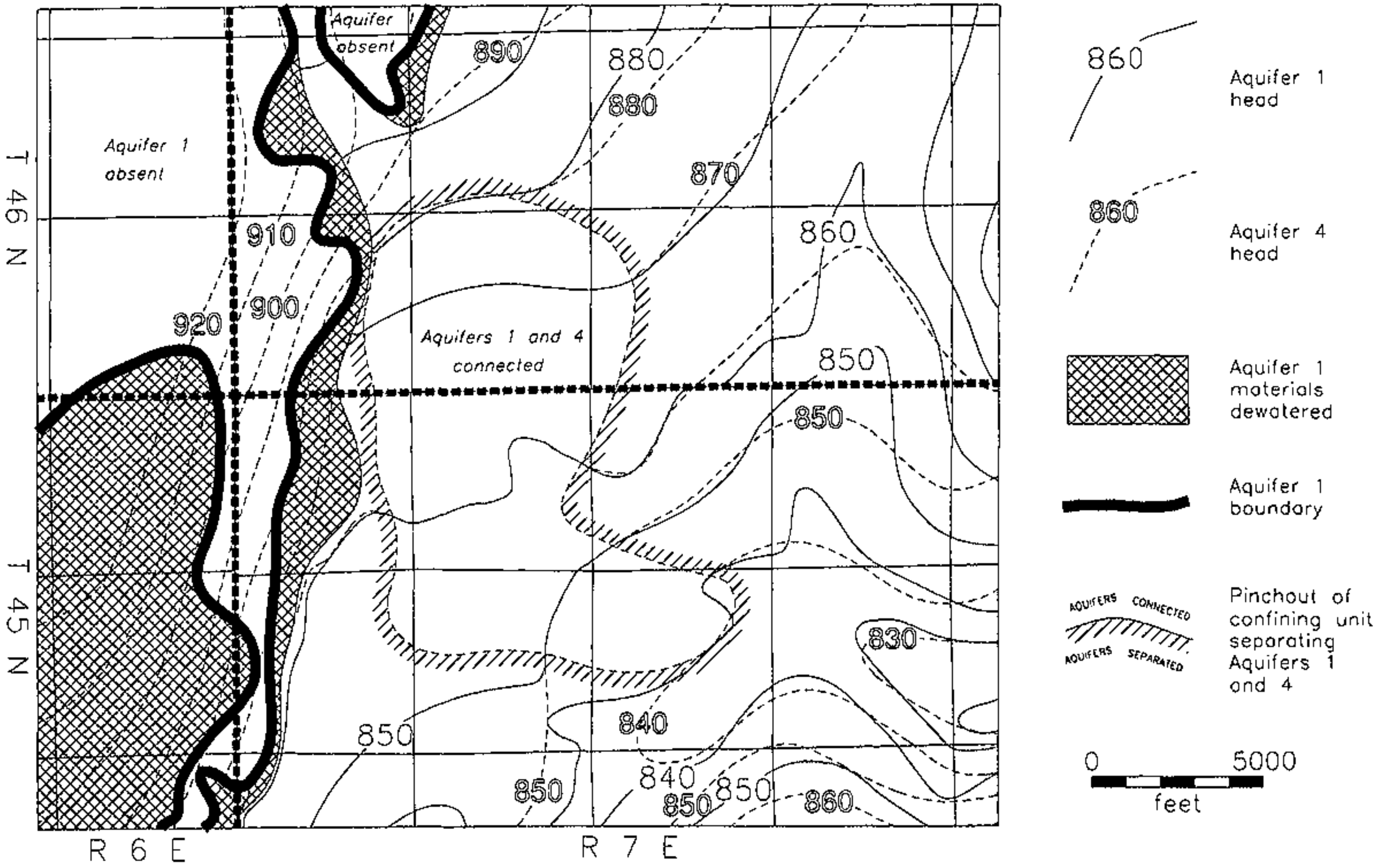

Figure 16. Detail from Plates 1 and 4 showing the effect of a connection between Aquifers 1 and 4 in an area of north-central McHenry County on the potentiometric surfaces of the converging aquifers. The connection causes heads in the aquifers to approach one another in areas proximal to the pinchout.

conductivities in the shallow aquifers of McHenry County, it is nearly impossible to convincingly link specific features of Plates 1 through 5 to variation in hydraulic conductivity, although subsurface mapping does permit some potentiometric surface features to be associated with variation in aquifer thickness.

Topography, as well as aquifer thickness, influences whether Aquifer 1 contains water at all. Most of the areas where Aquifer 1 is dewatered are located in areas of dissected topography or in topographically high areas adjacent to steep slopes, where any water entering the aquifer from above can readily drain out. Complete drainage usually occurs in areas where Aquifer 1 is relatively thin.

Aquifer Recharge and Discharge Areas Recharge and discharge areas of the aquifers cannot be precisely delineated using the maps constructed for this study, but the maps do provide clues to the locations of the discharge areas of the aquifers, particularly for the more deeply buried aquifers. The basis for identifying the discharge areas is the coincidence of converging flow lines, as suggested by the potentiometric surface maps, with the presence of water at land surface. With the exception of areas where Aquifer 1 is dewatered, recharge areas can reasonably be assumed to include all areas lying between the discharge areas. The locations of recharge and discharge areas appear to be strongly influenced by topography and hydrostratigraphic connections.

Aquifer 1 is shallow and unconfined throughout most of its distribution in McHenry County, and measured heads in Aquifer 1 coincide closely with surface-water elevations in perennial streams, lakes, and wetlands in McHenry County. It is likely that this aquifer discharges into most perennial streams, wetlands, and lakes throughout its distribution, except in areas where it is dewatered. Confirmation of this hypothesis would, however, require far more data than has been collected for this study.

The same is generally true of Aquifer 2, particularly where Aquifer 1 is absent and Aquifer 2 is the shallowest major aquifer; but again, it should be emphasized that the data do not allow clear identification of the locations of discharge areas for this shallow aquifer. The potentiometric surface configuration suggests that significant discharge of Aquifer 2 occurs through springs and seeps along a north-south trending valley in Sections 9, 16, and 21, T 44 N, R 8 E, roughly between McHenry and Crystal Lake. In many areas, ground water present in Aquifer 2 does not discharge at the surface until after it has entered Aquifer 1 in areas where the two aquifers converge. Proceeding clockwise from northwest to east of Woodstock, areas through which ground water once resident in Aquifer 2 appears to discharge through Aquifer 1 include Slough Creek, Silver Creek, Newman Creek, Nippersink Creek, Wonder Lake, and Boone Creek. Other areas through which ground water once resident in Aquifer 2 appears to discharge through Aquifer 1 include the Fox River near Algonquin, as well as the Fox River tributary downstream from the Lake in the Hills spillway, and portions of the Kishwaukee River and Kishwaukee Creek north of Huntley.

Aquifer 3 appears also to discharge principally through Aquifer 1. Areas through which ground water once resident in Aquifer 3 appears to discharge through Aquifer 1 include portions of the North Branch of Nippersink Creek and the Elizabeth Lake Drain, and Nippersink Creek downstream of its confluence with the North Branch of Nippersink Creek. Discharge from Aquifer 3 also appears to occur through Aquifer 1 into Boone Creek south of McCullom Lake.

Significant discharge from Aquifer 4 also appears to occur through Aquifer 1 where the two aquifers are connected. These areas include Piscasaw Creek, the West Branch of Piscasaw Creek, and Mokeler Creek in northwestern McHenry County; the Nippersink Creek tributary trending southwest-northeast that passes through the northern edge of Alden; several portions of Nippersink Creek including a portion extending about 3 miles south from the Wisconsin border, a portion between Hebron and Woodstock, and a portion downstream of Wonder Lake to slightly downstream of Solon Mills (omitting a section where Aquifer 4 is absent); Wonder Lake; the Elizabeth Lake Drain and the North Branch of Nippersink Creek downstream of its confluence with the Elizabeth Lake Drain; the portion of Boone Creek downstream from Section 12, T 44 N, R 7 E, to about Section 28, T 45 N, R 8 E; McCullom Lake; Thunderbird Lake and the streams and wetlands roughly 1 mile upstream and downstream of it; the Fox River from Section 23, T 43 N, R 8 E, upstream to Section 17, T 43 N, R 9 E; Silver Creek, northwest of Woodstock; the North Branch of the Kishwaukee River downstream from about Section 5, T 44 N, R 6 E; and the Kishwaukee River downstream from about Section 25, T 44 N, R 5 E.

Convergence of flow lines suggests that the following surface-water features may also receive discharge from Aquifer 4, with the discharge occurring by vertical movement of ground water across confining beds: the North Branch of the Kishwaukee River downstream from Section 27, T 46 N, R 6 E, to Section 5, T 44 N, R 6 E; Silver Creek and Nippersink Creek downstream from Section 20, T 45 N, R 7 E, to Wonder Lake; Nippersink Creek downstream from the vicinity of Solon Mills to the Chain-O'-Lakes lowland; the Kishwaukee River downstream from Section 4, T 43 N, R 7 E, to Section 1, T 43 N, R 6 E, and downstream from Section 29, T 44 N, R 6 E, to Section 25, T 44 N, R 5 E.

The Fox River and Chain-O'-Lakes lowland appear to receive discharge from Aquifer 4. As mentioned earlier, some of this discharge seems to occur through Aquifer 1 along a short section of the Fox River in southeastern McHenry County. Elsewhere, the discharge appears to occur by movement of ground water across confining beds. Note that along some portions of its length in McHenry County, the Fox River is underlain by Aquifer 4, whereas in others (principally in the east-central portion of the county), the materials which elsewhere are mapped as Aquifer 4 are included in Aquifer 5 because they rest directly on the bedrock surface.

A principal mechanism of discharge of Aquifer 5, like Aquifers 2 through 4, is upward movement of ground water where Aquifer 5 converges with Aquifer 1. Note that where Aquifer 5 converges with Aquifer 1, the glacial drift is comprised almost entirely of sand and gravel; these areas are marked with a stippled pattern on Plates 1 through 5. One such area in northeastern McHenry County includes the following surface-water features into which Aquifer 5 may discharge: Elizabeth Lake Drain, the North Branch of Nippersink Creek downstream of the Elizabeth Lake Drain, Wonder Lake and Nippersink Creek from the southern end of Wonder Lake to the vicinity of Solon Mills, the portion of Boone Creek downstream from about Section 1, T 44 N, R 7 E, to about Section 28, T 45 N, R 8 E, and McCullom Lake. Another small area underlain by sand and gravel extending from the surface to bedrock that might provide a discharge area for Aquifer 5 includes Thunderbird Lake and the streams and wetlands roughly 1 mile upstream and downstream of it.

Other discharge areas for Aquifer 5 are suggested by convergence of flow lines inferred from potentiometric surface mapping; discharge to these areas would occur through upward movement of ground water from Aquifer 5 across confining beds. These areas include Lawrence and Piscasaw Creeks in northwestern McHenry County; Silver and Nippersink Creeks downstream from about Section 20, T 45 N, R 7 E, to Wonder Lake; Nippersink Creek from the vicinity of Solon Mills to the Chain-O'-Lakes lowland; the Fox River and Chain-O'-Lakes lowland along their entire length in McHenry County; the North Branch of the Kishwaukee River downstream from about Section 5, T 44 N, R 6 E; the Kishwaukee River downstream from about Section 8, T 43 N, R 7 E; and Coon Creek in southwestern McHenry County. Confining beds so impede upward movement of ground water into some of these streams and rivers that heads in Aquifer 5 are maintained above land surface elevations in the valleys containing them. Wells finished in Aquifer 5 in these areas may flow on a seasonal or permanent basis. Rowing wells finished in Aquifer 5 are known to occur in McHenry County in low areas bordering Silver and Nippersink Creek north of Woodstock, along Nippersink Creek north of Wonder Lake, and along Nippersink Creek in Spring Grove.

Effects of Ground-Water Withdrawals Given the density of data points and the contour interval employed in constructing the potentiometric surface maps for this study, cones of depression are generally not resolvable around domestic and other low-capacity wells (that is, wells pumping less than about 100,000 gpd). The discrepancy in water levels between most high-capacity wells, as compared with the nearest low-capacity wells and with historical water level data, does suggest the presence of cones of depression around the high-capacity wells. The precise geometry of the cones of depression is generally not indicated by the available data, however.

This potential inaccuracy is a result of two factors. First, low-capacity wells that could be used as data points for clarifying cone geometry are generally not present in the vicinity of high-capacity public water supply wells (public water supply wells appear to be the only shallow high-capacity wells operating in McHenry County) because these areas are supplied by public water distribution systems. Second, water level measurements were in some instances not available from the high-capacity wells that gave rise to the cones of depression. Heads at these wells were generally based on air line measurements provided by the operators of the wells. The air line measurements are not only less accurate than the taped measurements obtained by ISWS personnel, but they were sometimes not obtained during the fall 1994 period when the other water levels used to construct Plates 1 through 5 were measured.

Most cones of depression that are resolvable on the potentiometric surface maps constructed for this study appear in the potentiometric surface map of Aquifer 5 (Plate 5 and Figure 17) because Aquifer 5 is the source aquifer for most of the high-capacity public water supply wells in McHenry County. A contributing factor to the relatively large size of these cones of depression is probably the low recharge rate to this aquifer, which is the most deeply buried of the shallow aquifers considered in this study. In 1994, wells finished in Aquifer 5 composed 65 percent of the wells pumping more than 100,000 gpd from shallow aquifers in McHenry County.

An area of apparently lowered heads, which does not appear to be linked to a single pumping well, appears to be present in Aquifer 5 in southeastern McHenry County (Figure 17). This area of lowered heads may be the cumulative effect of withdrawals from numerous domestic, industrial, and

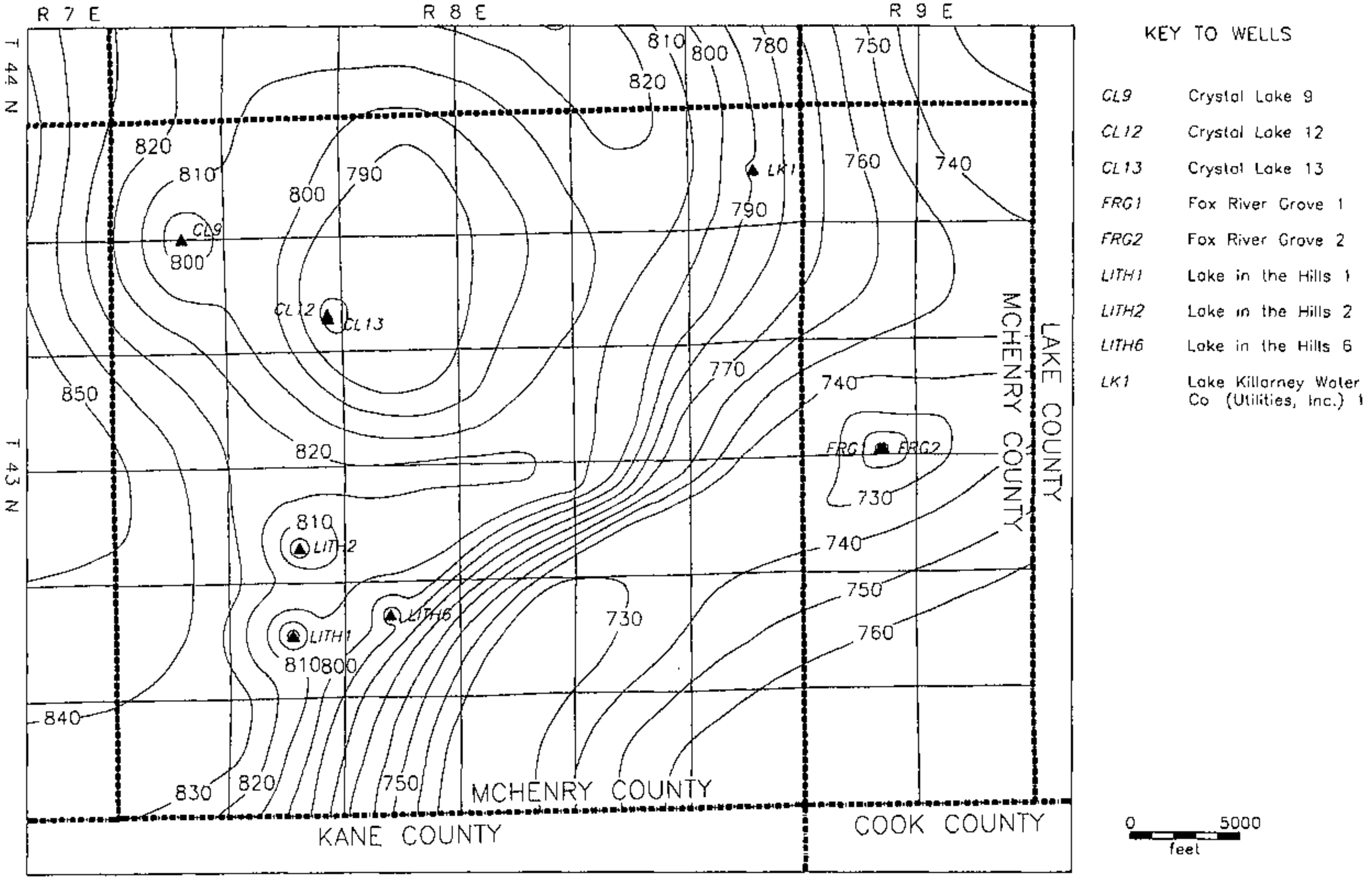

Figure 17. Detail from Plate 5 showing apparent cones of depression in Aquifer 5 surrounding public water supply wells in southeastern McHenry County. A relatively large area of seemingly lowered heads, probably not linked to withdrawals from a single pumping well, is located north and northeast of Crystal Lake wells 12 and 13.

public water supply wells in this relatively densely populated portion of the county. Still, as mentioned previously, the geometry of the area of lowered heads is unclear owing to a lack of data points.

Five-Year Capture Zone Estimations

Five-year capture zone estimations for shallow McHenry County public water supply wells pumping more than 100,000 gpd in 1994 and active before January 1, 1994, are shown in Figures 18 through 35. As mentioned earlier, a capture zone indicates the area from which each well obtains water over a period of 5 years. In view of the limitations of the methodology employed to estimate these capture zones, it is recommended that they be used for planning, rather than regulatory, purposes.

Nitrate Contamination of Shallow McHenry County Ground Water

Incidence of Nitrate Contamination Figure 36 shows the distribution of nitrate and nitrite+nitrate concentrations in 280 samples of shallow McHenry County ground water. As mentioned in the methods section of this report, the complete set of 550 analytical results included in Appendix F was not used in this analysis because this set contains results from multiple samples collected from the same well at different times. Thirty-seven of these samples (13 percent of the population) contained nitrate in concentrations exceeded the drinking water standard of 10 mg/L as nitrogen. Davis and DeWiest (1966) found that natural nitrate concentrations in ground water range from 0.1 to 10 mg/L as nitrogen, so the incidence of nitrate contamination indicated by the data examined in this study suggests an anthropogenic impact (caused by humans) to shallow groundwater quality in McHenry County. The severity of the impact is, however, debatable in view of the potential sample biases discussed in the methods section of this report. Of the 280 analytical results used to construct Figure 36, all but one were analyzed by the ISWS laboratory. As mentioned earlier, the ISWS laboratory often analyzes water samples from wells suspected of poor water quality.

Relationship of Well Depth to Nitrate Concentration The 280 analytical results were sorted by well depth to examine the relationship between nitrate concentration and well depth. Figure 37 shows the number of analytical results contained in each depth category as well as the number of results exceeding the drinking water standard for nitrate. A strong relationship between sampled well depth and nitrate contamination is apparent. Sixty-three percent of the samples obtained from wells 1 to 50 ft deep contained nitrate in concentrations exceeding the standard. This percentage drops dramatically to 4 percent for wells 51 to 100 ft deep and to 2 percent for wells 101 to 150 ft deep. None of the samples from wells deeper than 150 ft contained nitrate concentrations exceeding the drinking water standard. The strong relationship between well depth and nitrate contamination can reflect any or all of the following: (1) the vulnerability of the shallowest ground water to contamination by materials present at the surface, (2) complete denitrification at depths greater than, in most cases, 50 ft, (3) the lack of sufficient time for nitrogen that has been recently introduced at land surface (though fertilizers, livestock wastes, septic systems, etc.) to be transported to deeper portions of the saturated zone, and (4) the tendency for extremely shallow wells to be older and/or poorly constructed and consequently improperly sealed against surface runoff.

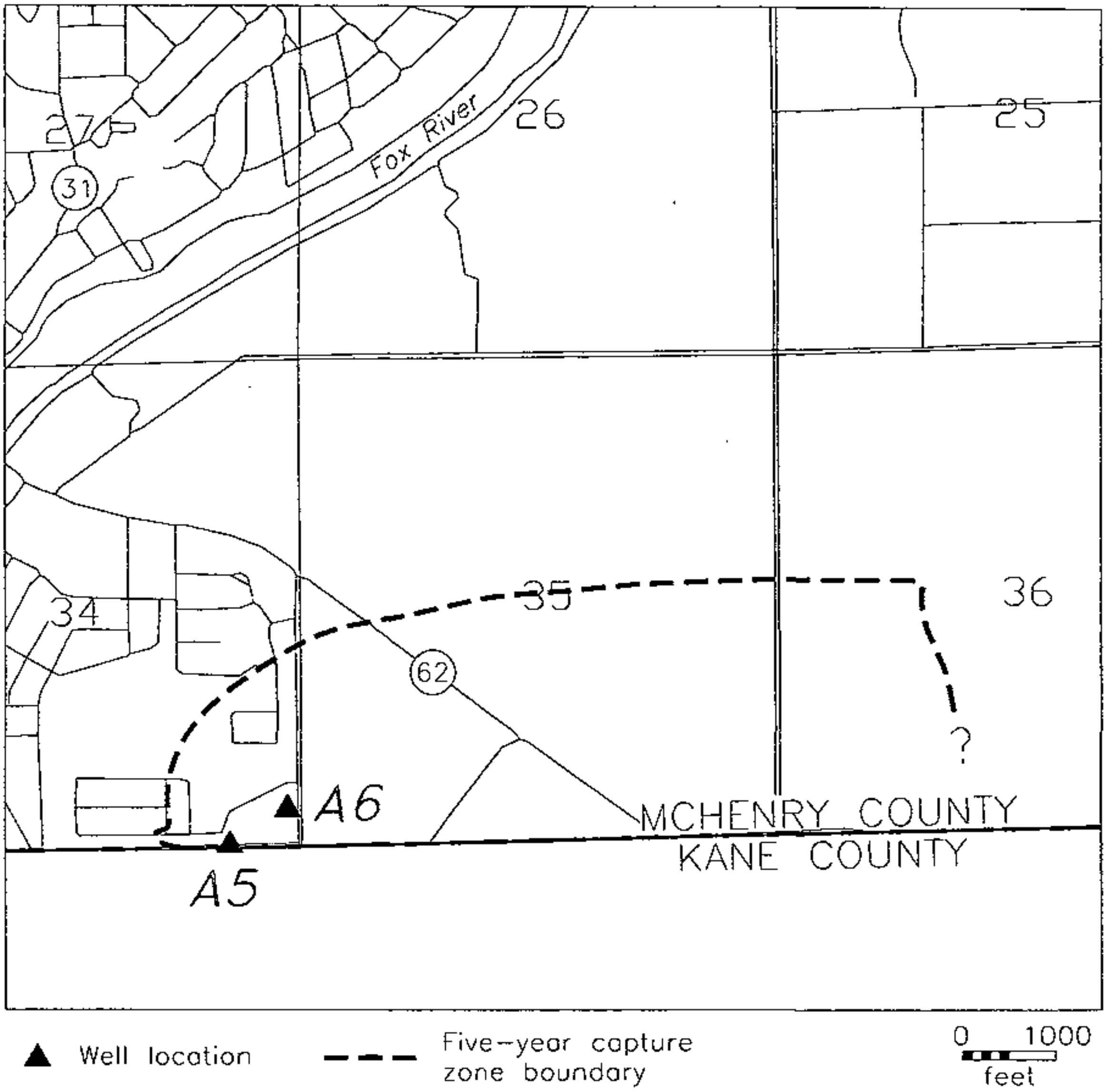

Figure 18. Partial combined estimated five-year capture zones of Algonquin wells 5 and 6 (A5 and A6), which obtain water from Aquifer 4. Only a partial estimate is available because reverse-tracked particles cannot be tracked beyond the McHenry County border. See comment in Appendix E. (Scale 1:24,000)

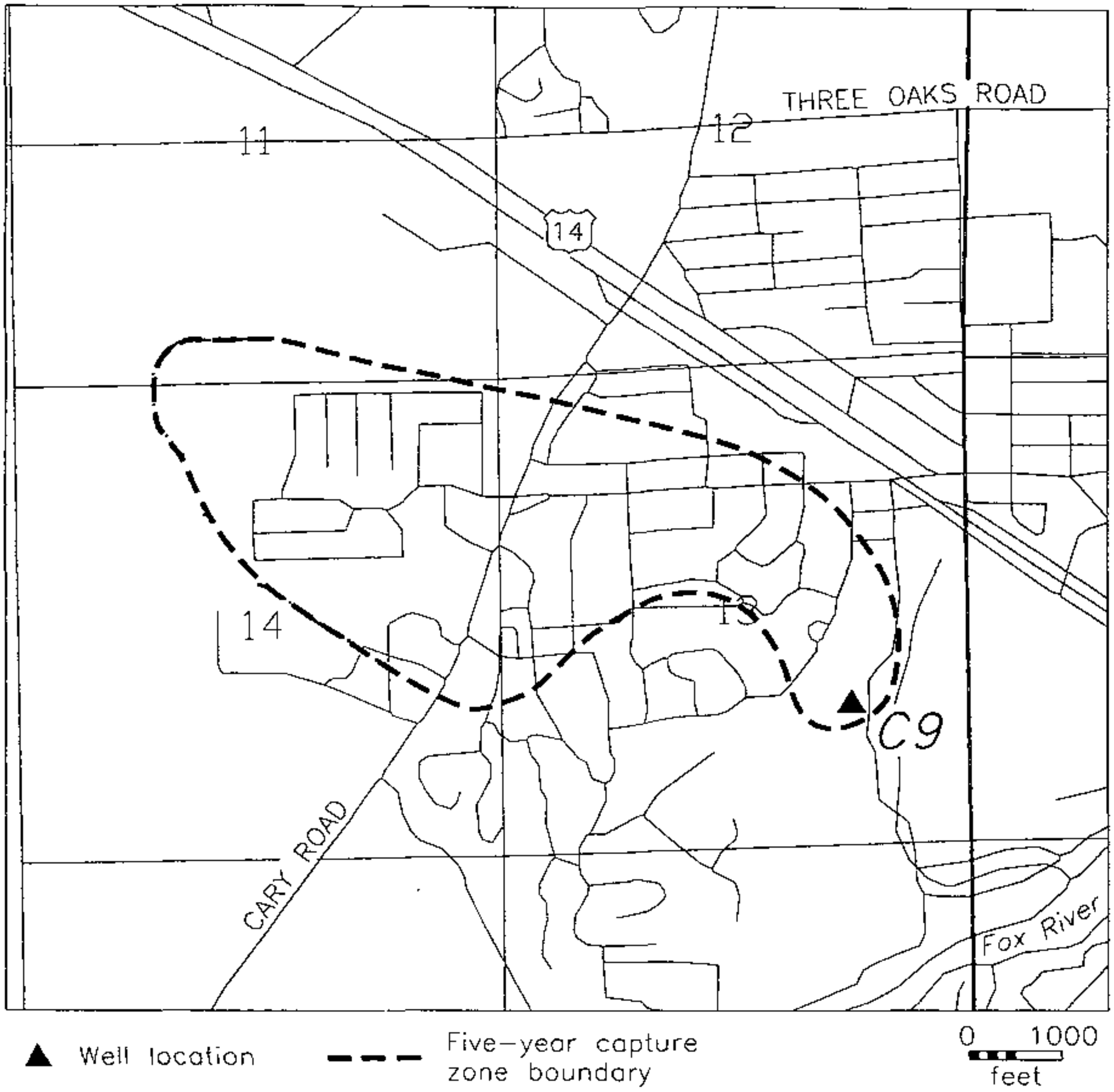

Figure 19. Estimated five-year capture zone of Cary well 9 (C9).
The well obtains water from Aquifer 1. (Scale 1:24,000)

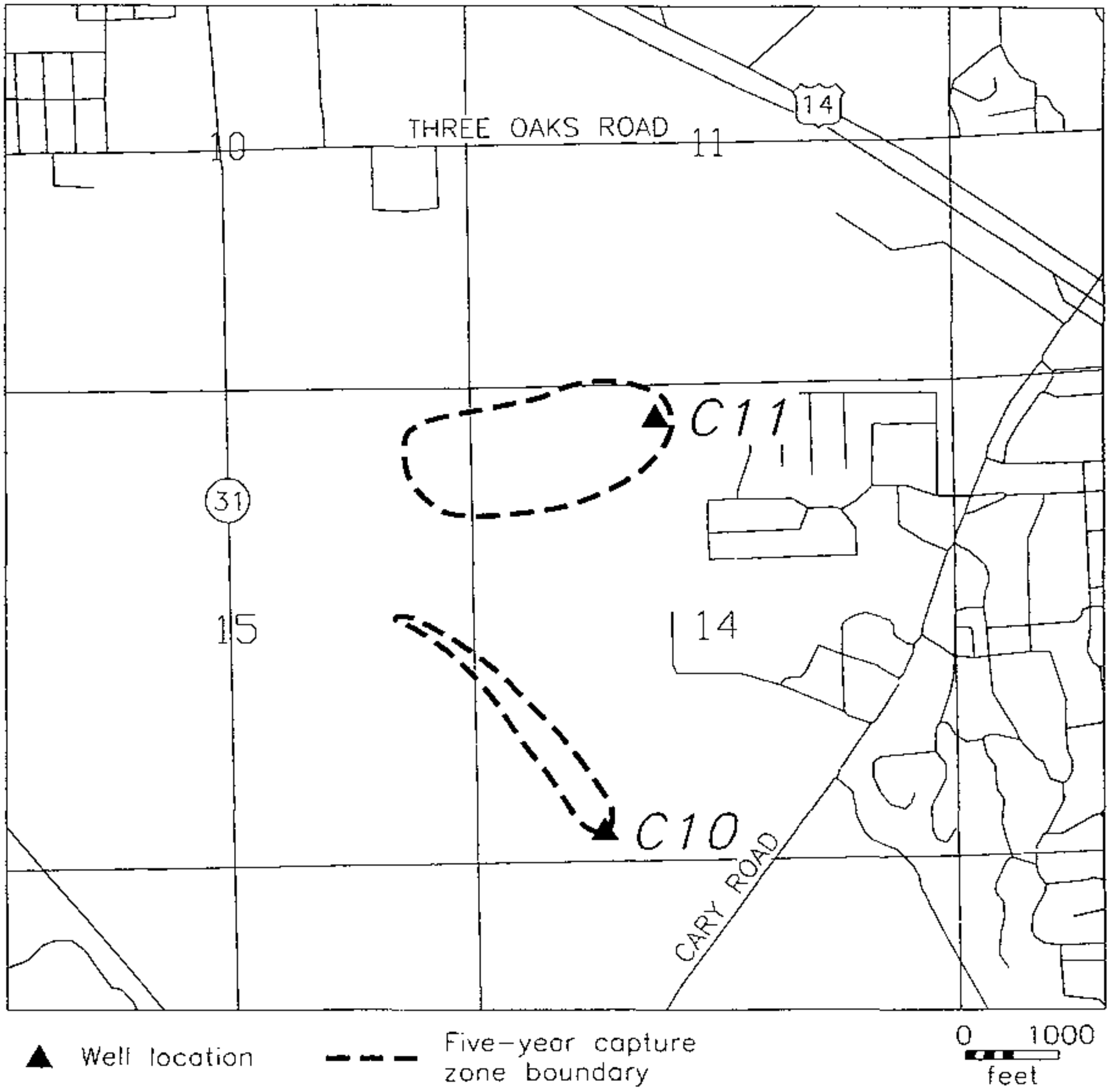

Figure 20. Estimated five-year capture zones of Cary wells 10 and 11 (C10 and C11). The wells obtain water from Aquifer 4. (Scale 1:24,000)

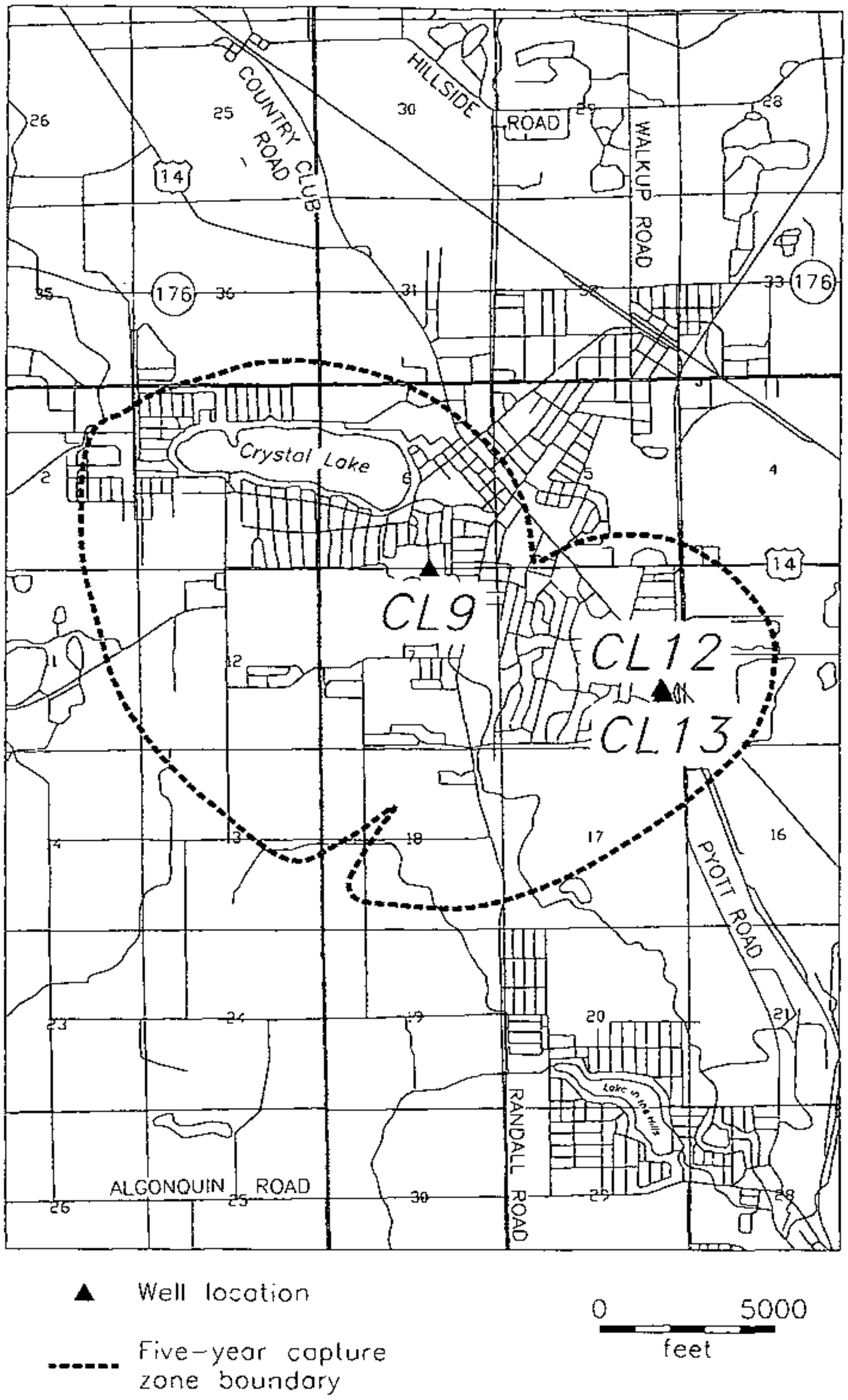

Figure 21. Combined estimated five-year capture zones of Crystal Lake wells 9, 12, and 13 (CL9, CL12, and CL13). The wells obtain water from Aquifer 5. (Scale 1:62,500)

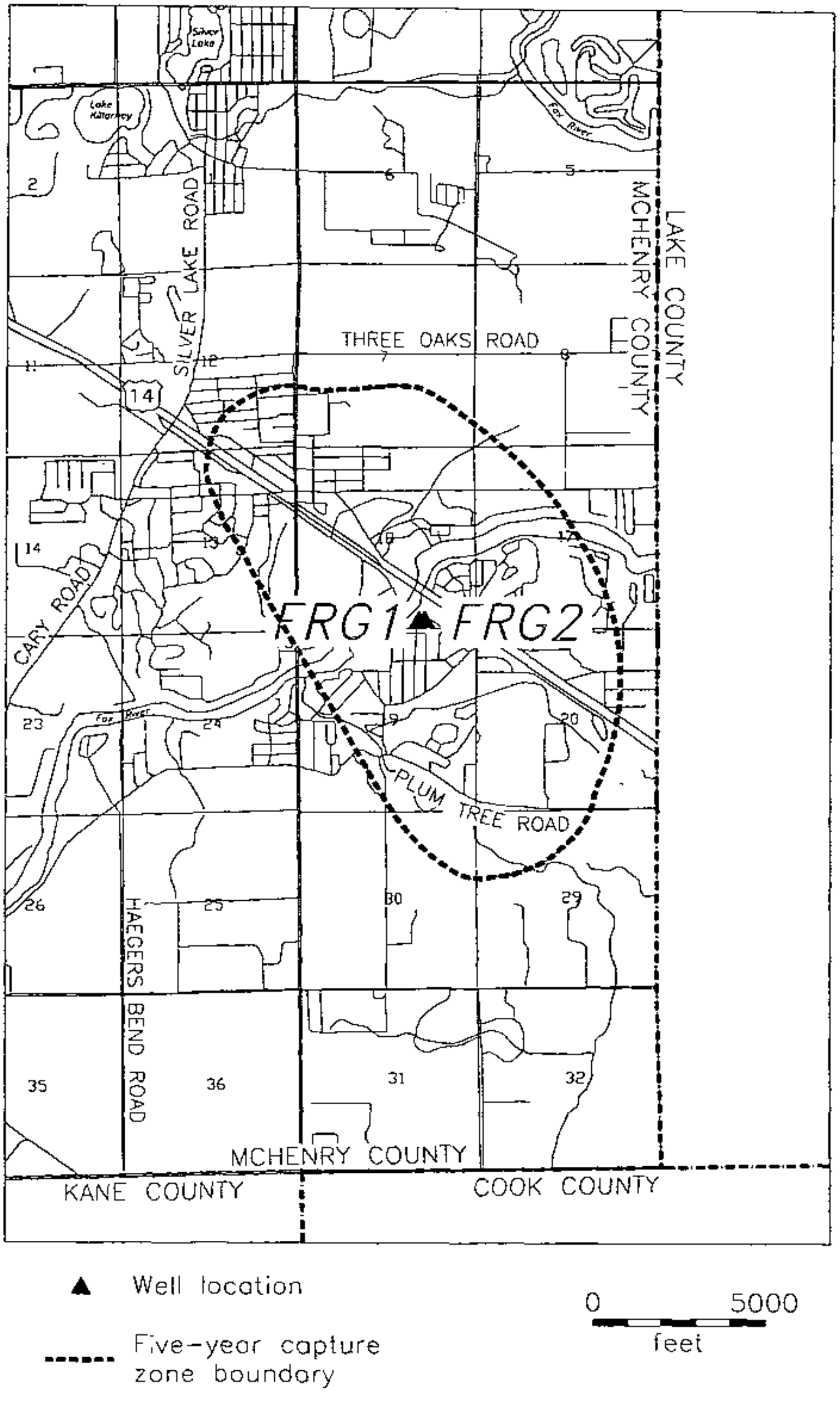

Figure 22. Combined estimated five-year capture zones of Fox River Grove wells 1 and 2 (FRG1 and FRG2). The wells obtain water from Aquifer 5. See comment in Appendix E. (Scale 1:62,500)

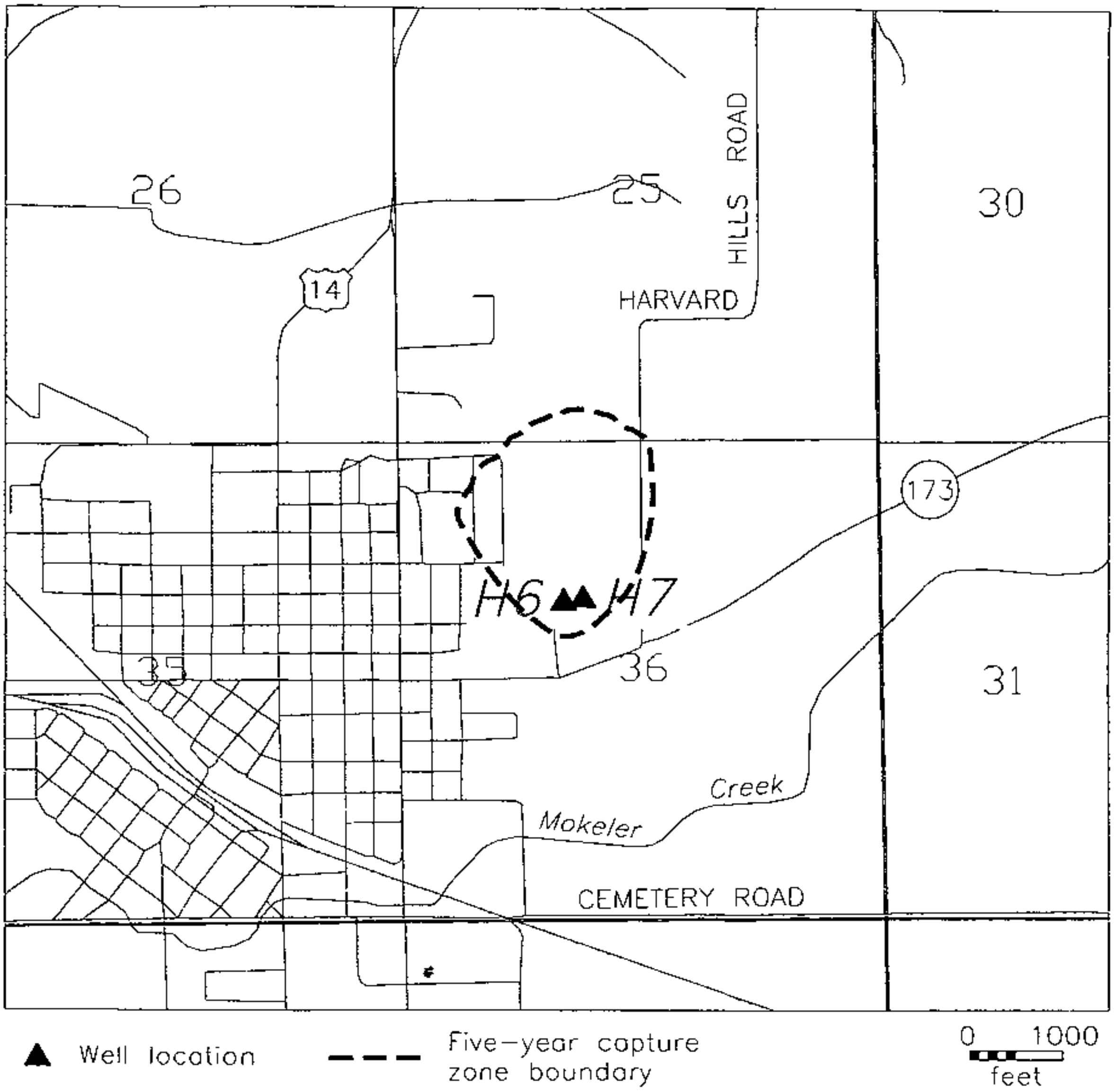

Figure 23. Combined estimated five-year capture zones of Harvard wells 6 and 7 (H6 and H7). The wells obtain water from Aquifer 5. See comment in Appendix E. (Scale 1:24,000)

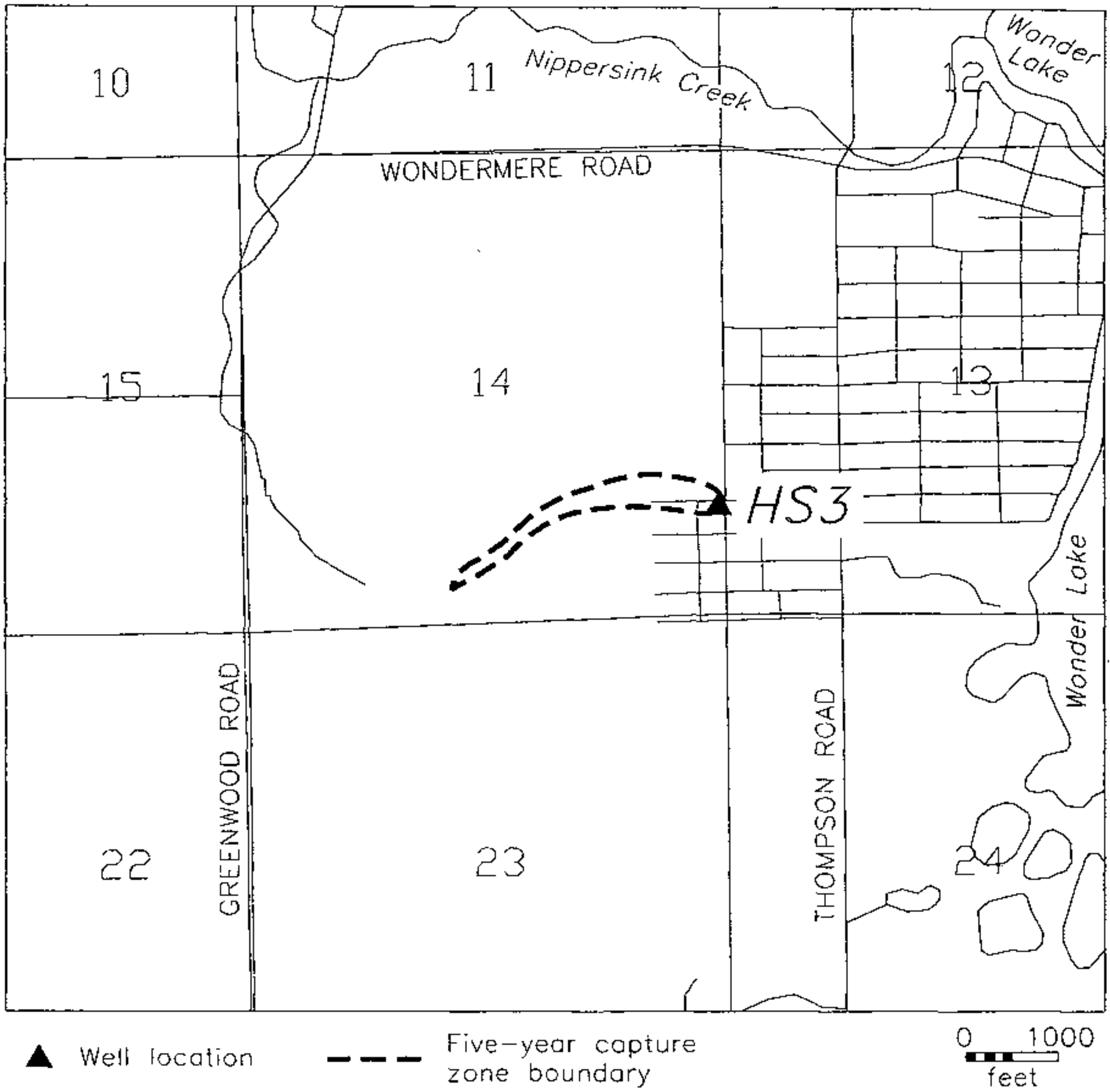

Figure 24. Estimated five-year capture zone of Northern Illinois Utilities (Highland Shores Water Co.) well 3 (HS3). The well obtains water from Aquifer 4. (Scale 1:24,000)

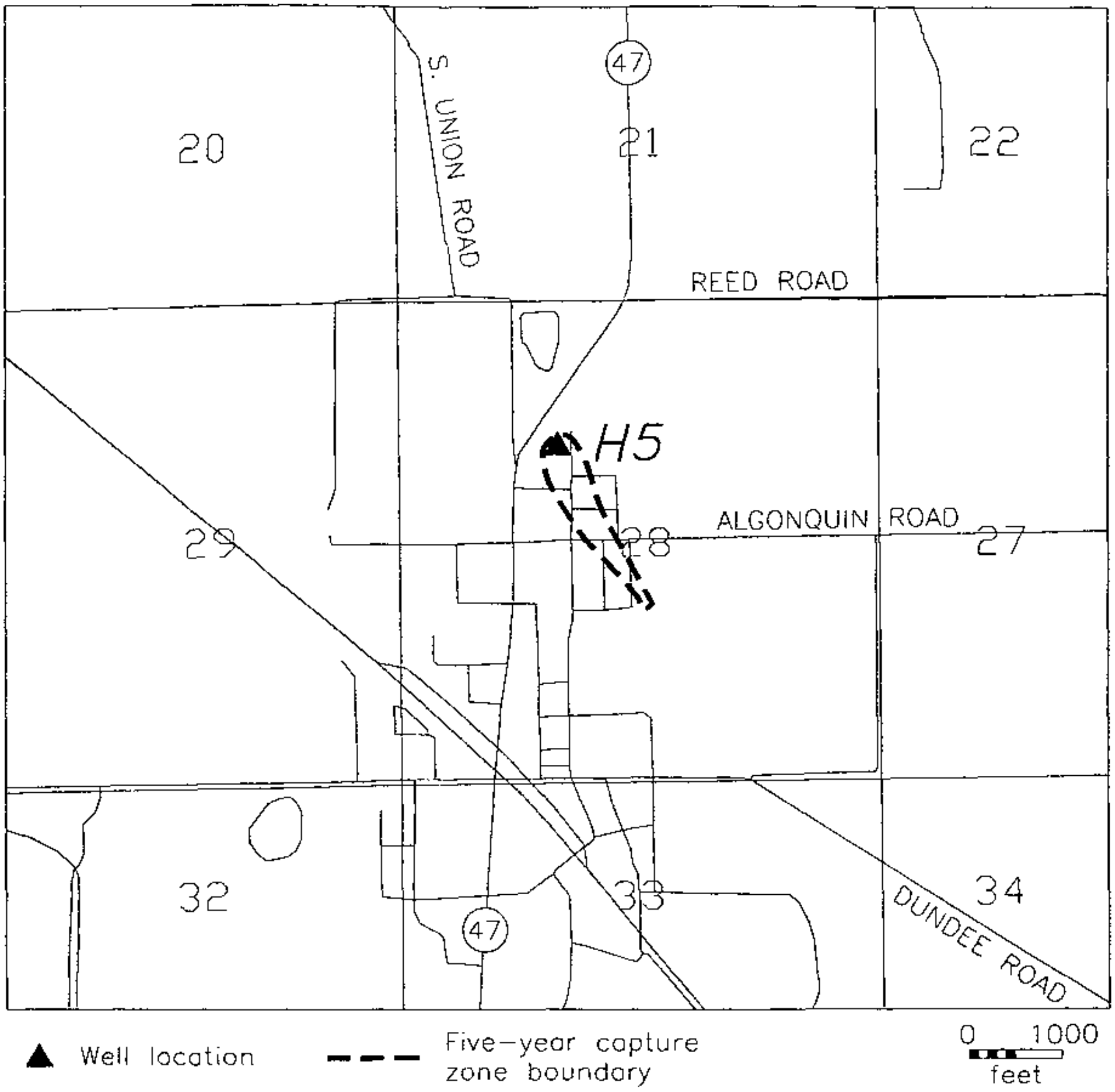

Figure 25. Estimated five-year capture zone of Huntley well 5 (H5).
The well obtains water from Aquifer 2. (Scale 1:24,000)

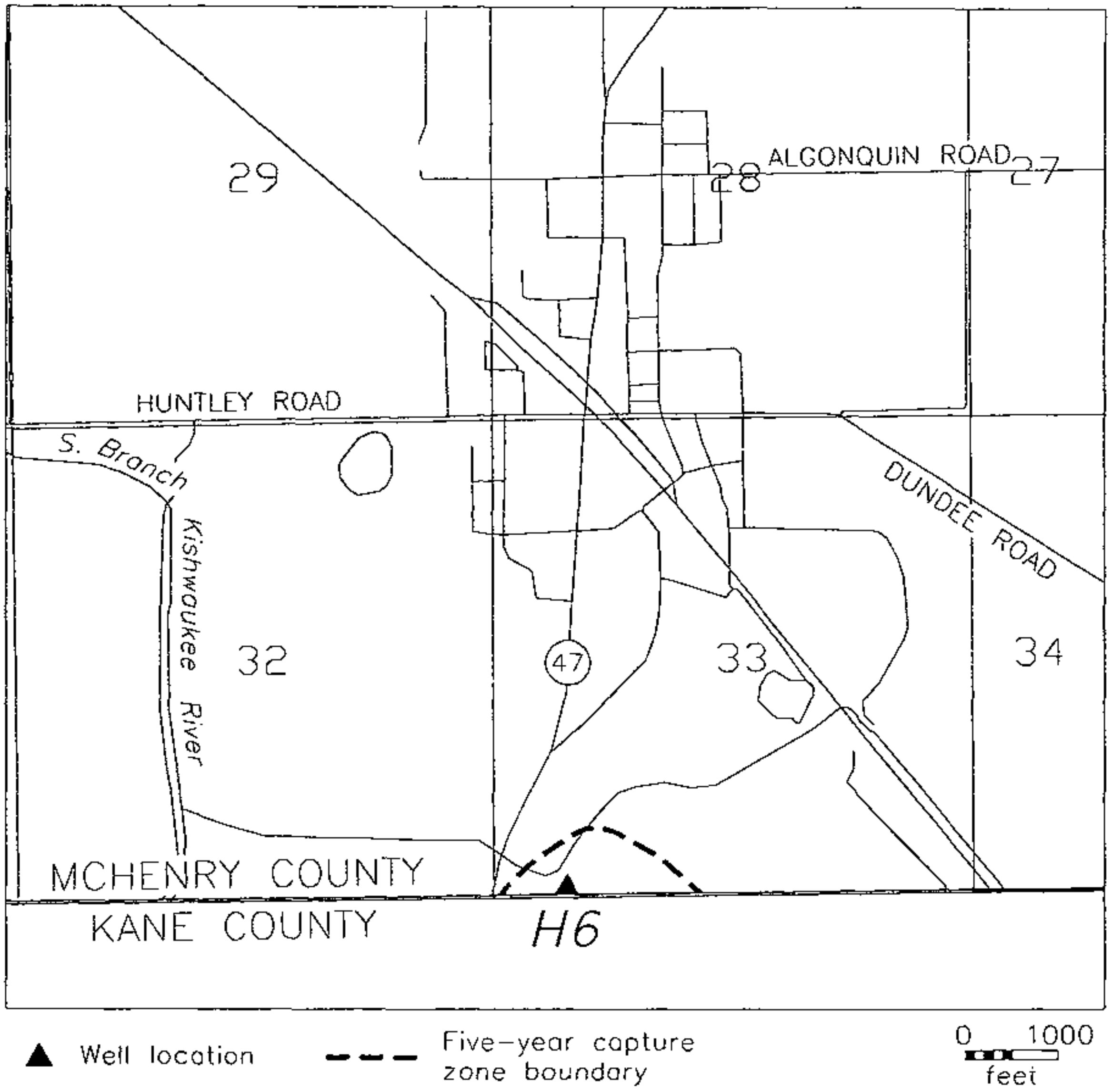

Figure 26. Partial estimated five-year capture zone of Huntley well 6 (H6). The well obtains water from Aquifer 4. Only a partial estimate of the capture zones is available because reverse-tracked particles cannot be tracked beyond the McHenry County border. (Scale 1:24,000)

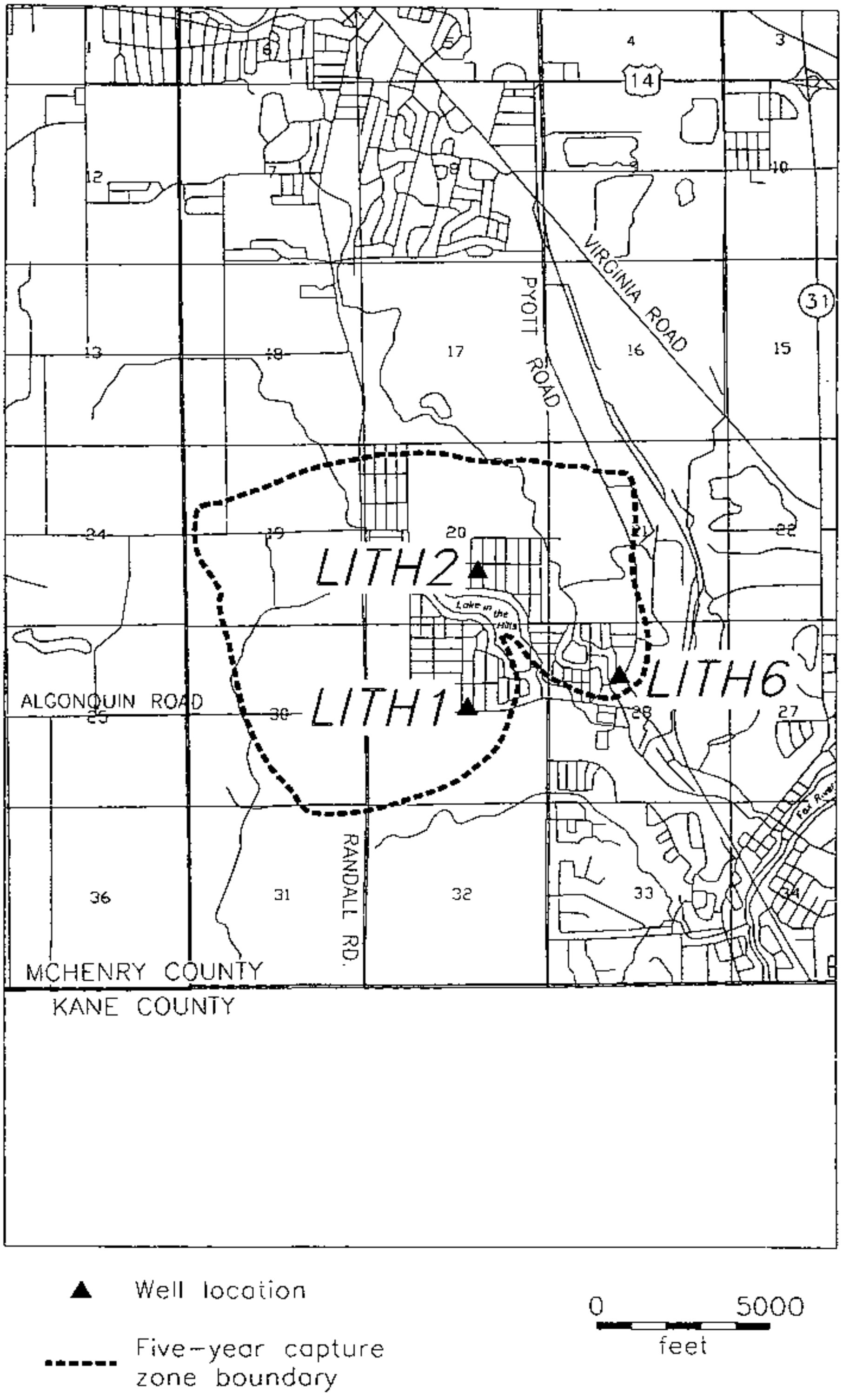

Figure 27. Combined estimated five-year capture zones of Lake in the Hillls wells 1, 2, and 6 (LITH1, LITH2, and LITH6). The wells obtain water from Aquifer 5. See comment in Appendix E. (Scale 1:62,500)

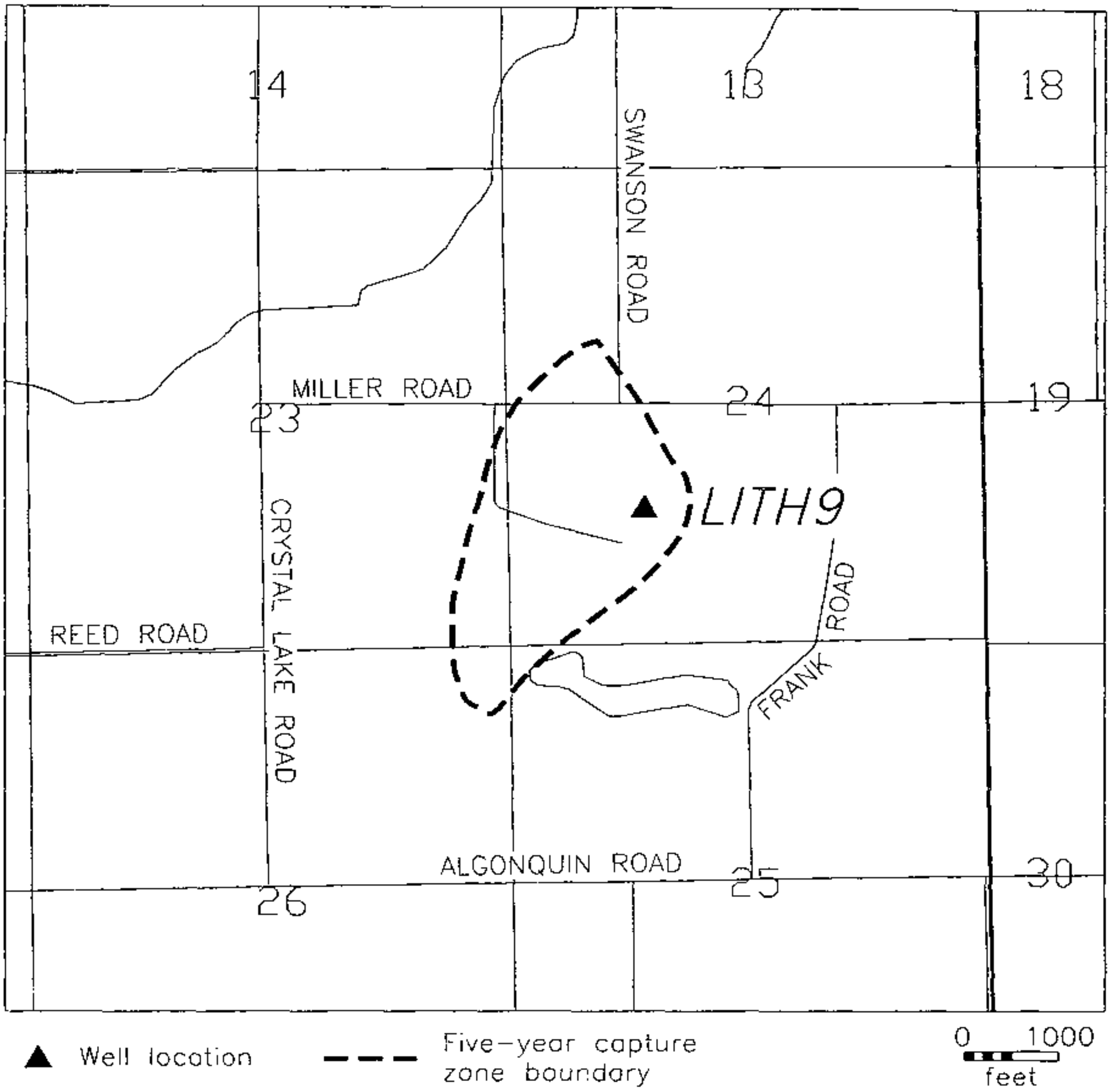

Figure 28. Estimated five-year capture zone of Lake in the Hills well 9 (LITH9). The well obtains water from Aquifer 2. (Scale 1:24,000)

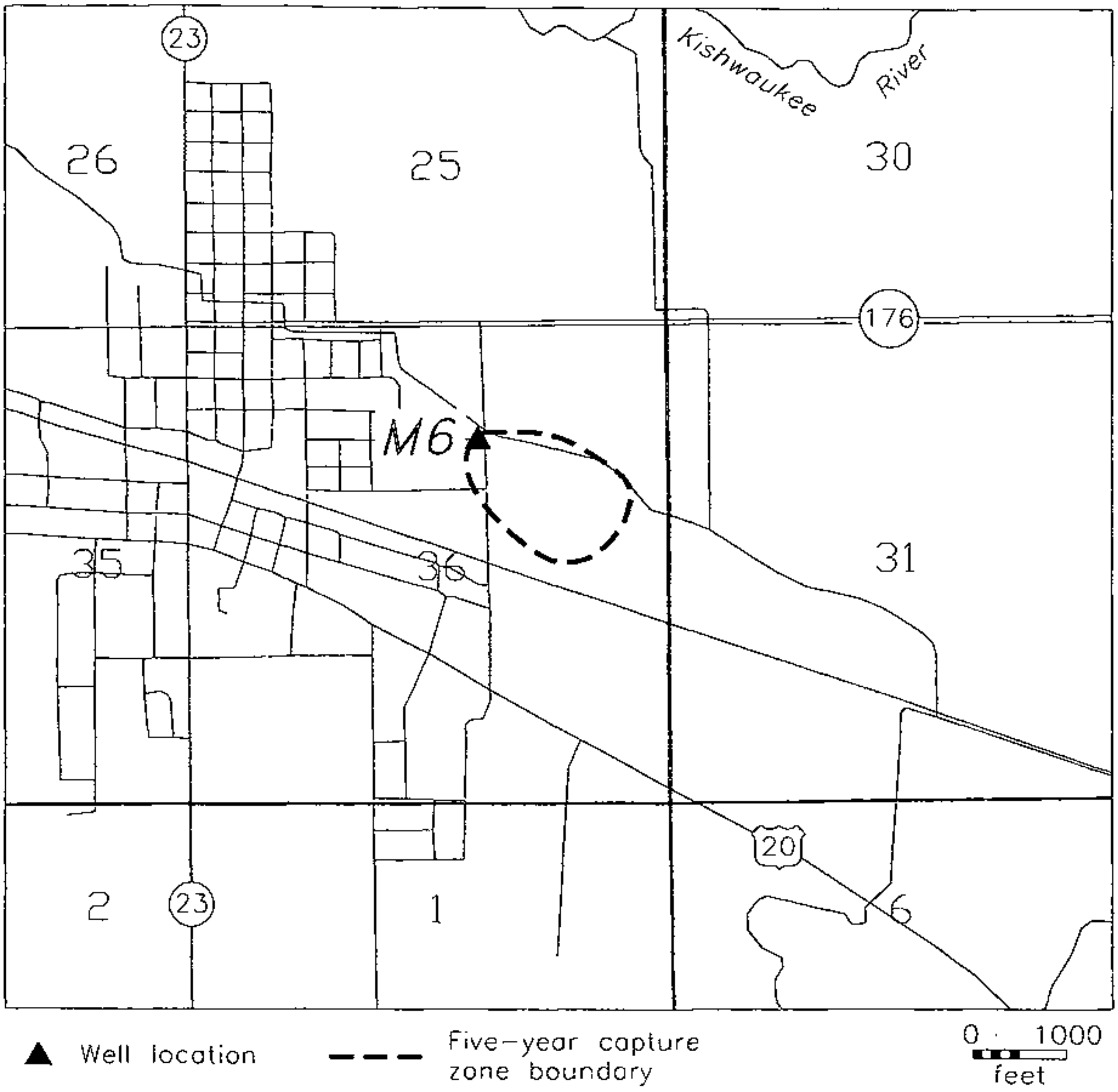

Figure 29. Estimated five-year capture zone of Marengo well 6 (M6).
The well obtains water from Aquifer 1. (Scale 1:24,000)

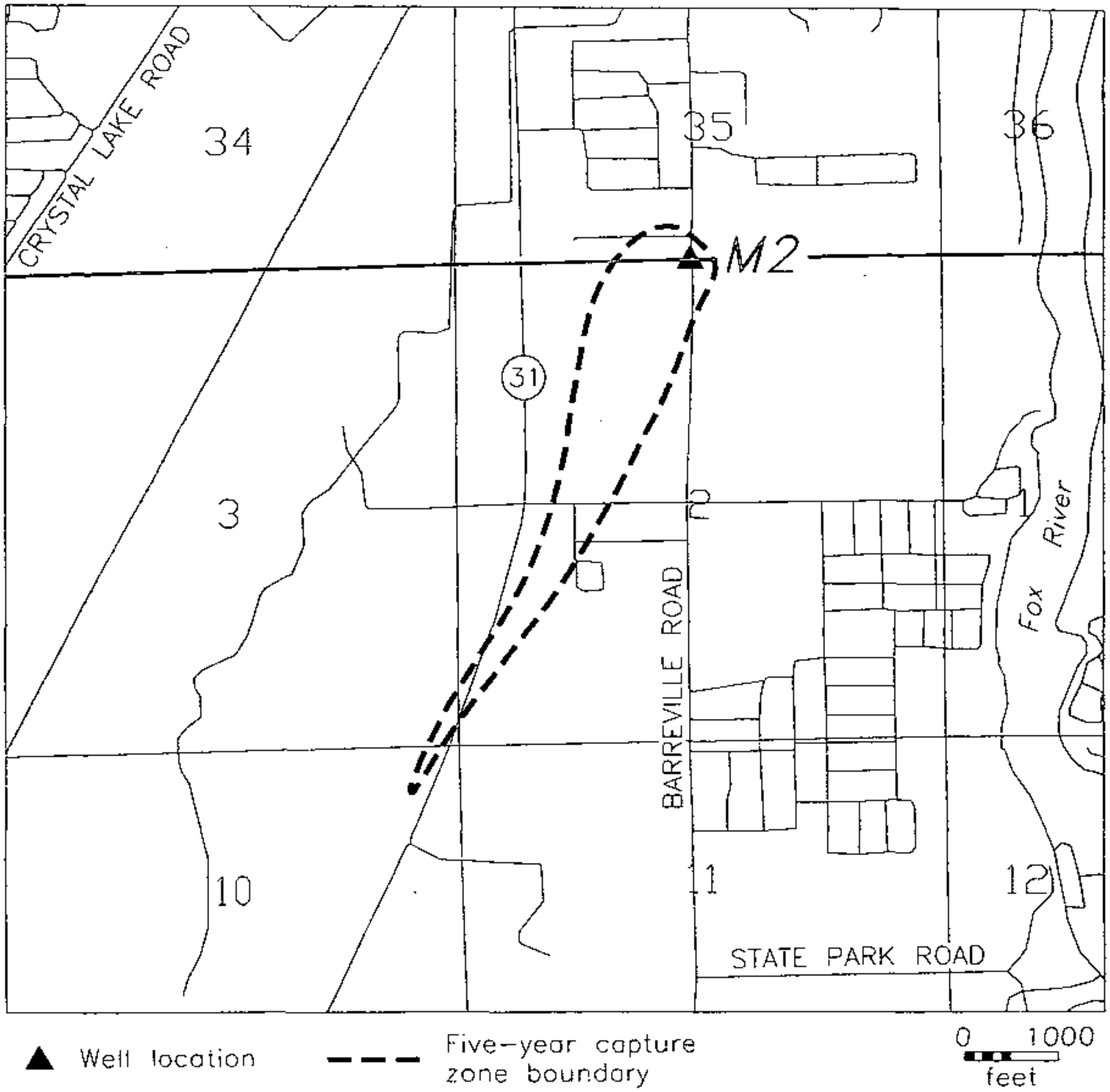

Figure 30. Estimated five-year capture zone of McHenry well 2 (M2).
The well obtains water from Aquifer 1. (Scale 1:24,000)

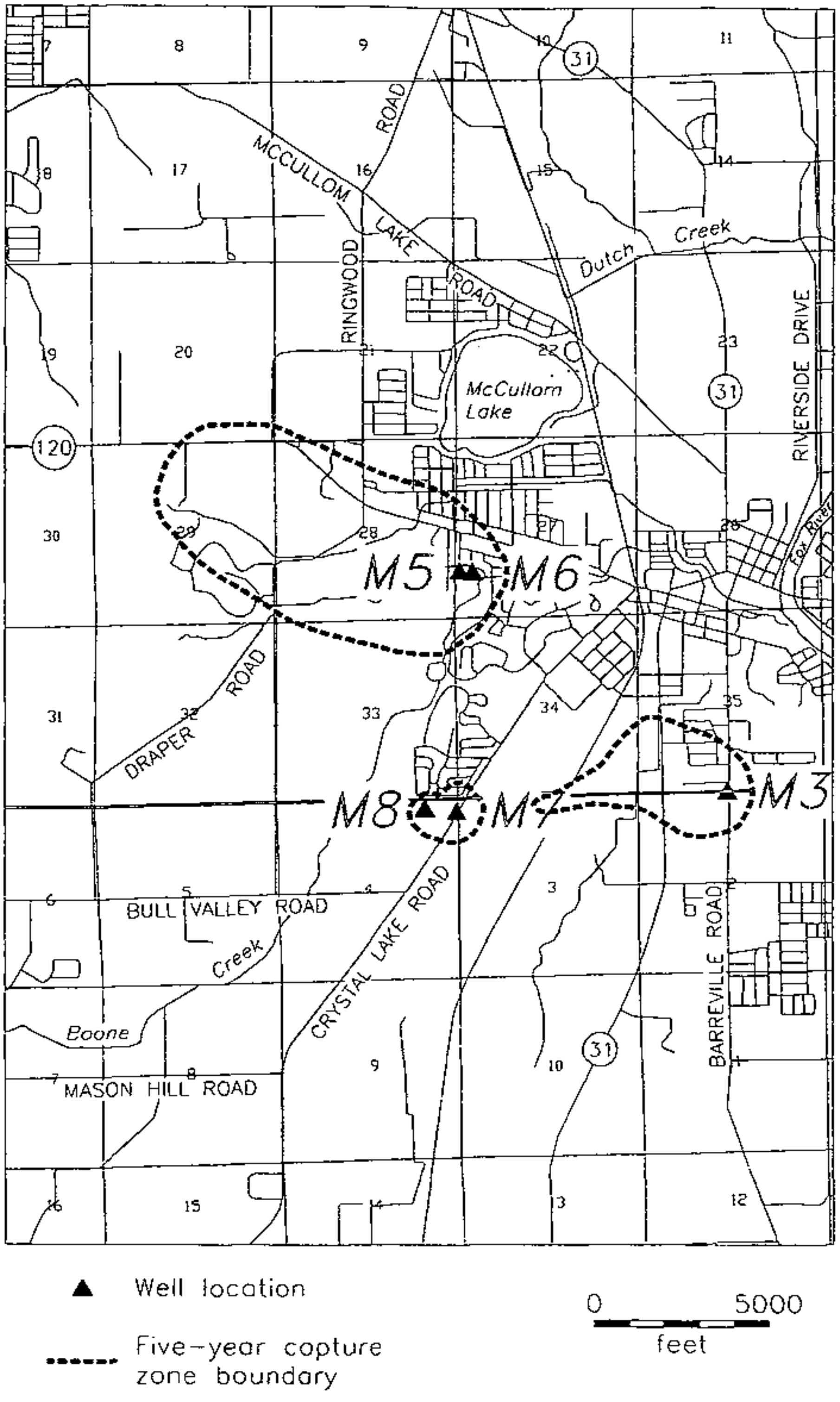

Figure 31. Combined estimated five-year capture zones of McHenry wells 3, 5, 6, 7, and 8 (M3, M5, M6, M7, and M8). The wells obtain water from Aquifer 5. See comments in Appendix E. (Scale 1:62,500)

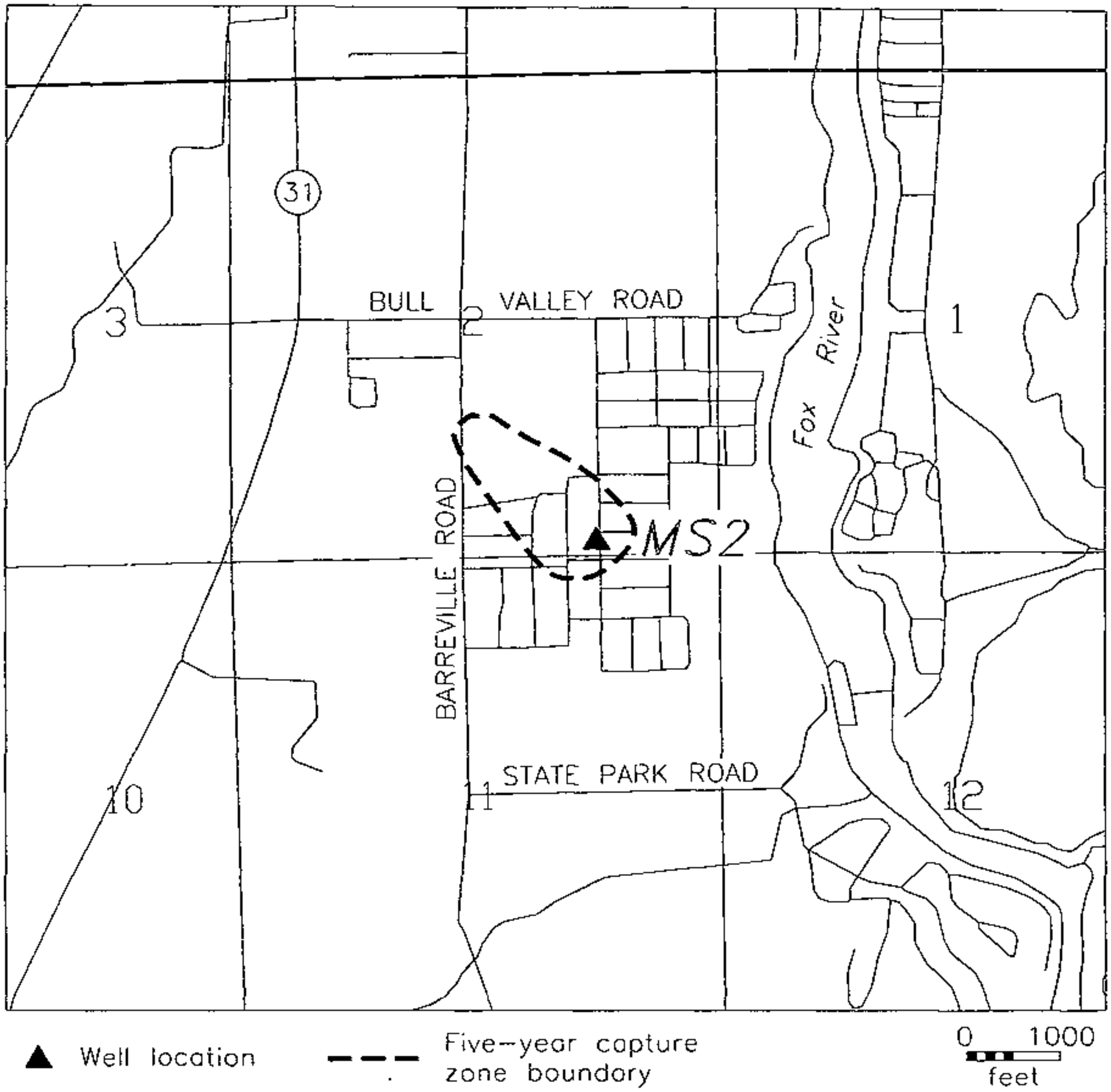

Figure 32. Estimated five-year capture zone of Northern Illinois Utilities (McHenry Shores Water Co.) well 2 (MS2). The well obtains water from Aquifer 5. (Scale 1:24,000)

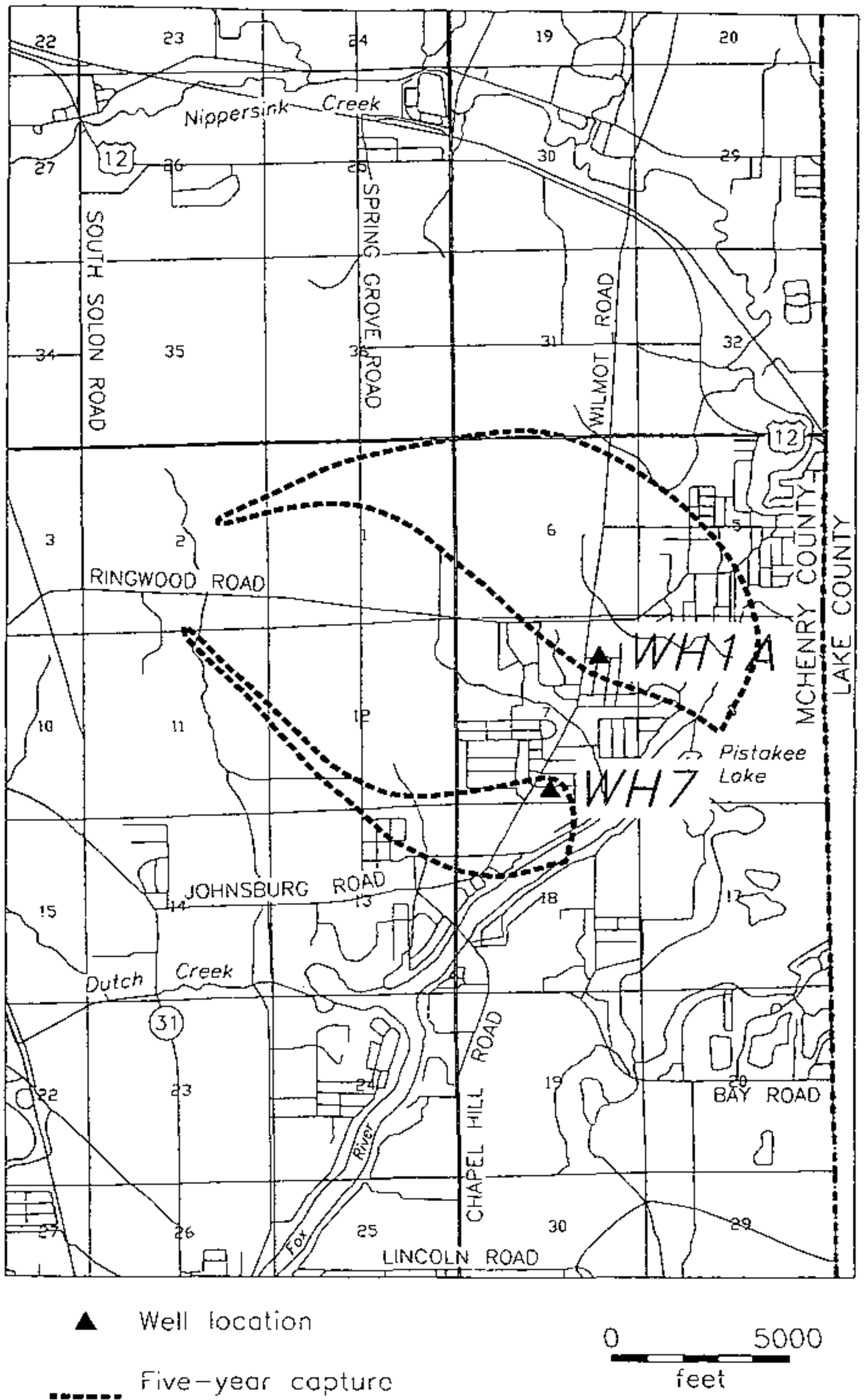

Figure 33. Estimated five-year capture zones of Utilities, Inc. (Whispering Hills Water Co.) wells 1A and 7 (WH1A and WH7). The wells obtain water from Aquifer 5. (Scale 1:62,500)

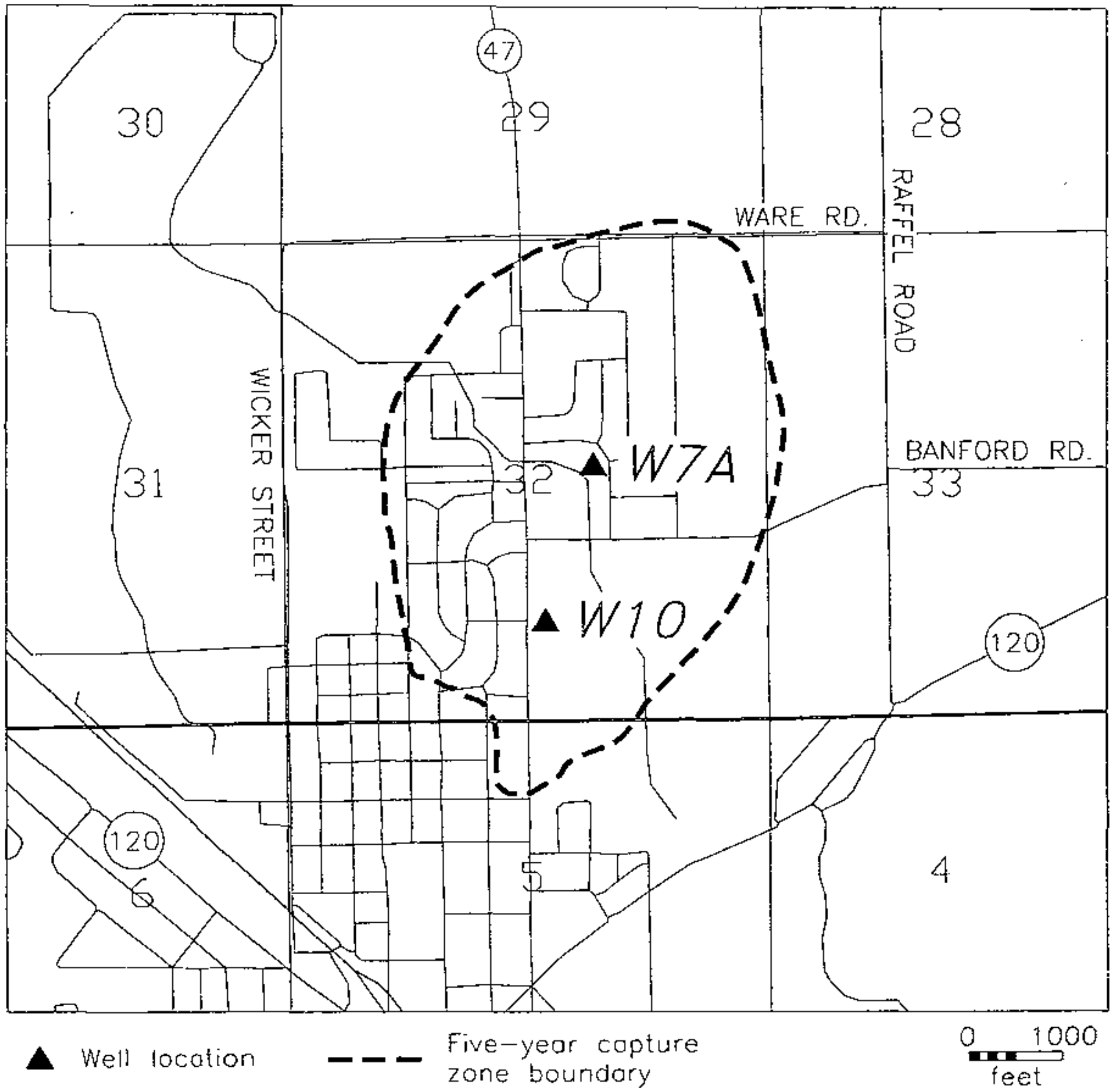

Figure 34. Combined estimated five-year capture zones of Woodstock wells 7A and 10 (W7A and W10). The wells obtain water from Aquifer 4. (Scale 1:24,000)

Figure 35. Combined estimated five-year capture zones of Woodstock wells 8 and 9 (W8 and W9, respectively). The wells obtain water from Aquifer 5. (Scale 1:24,000)

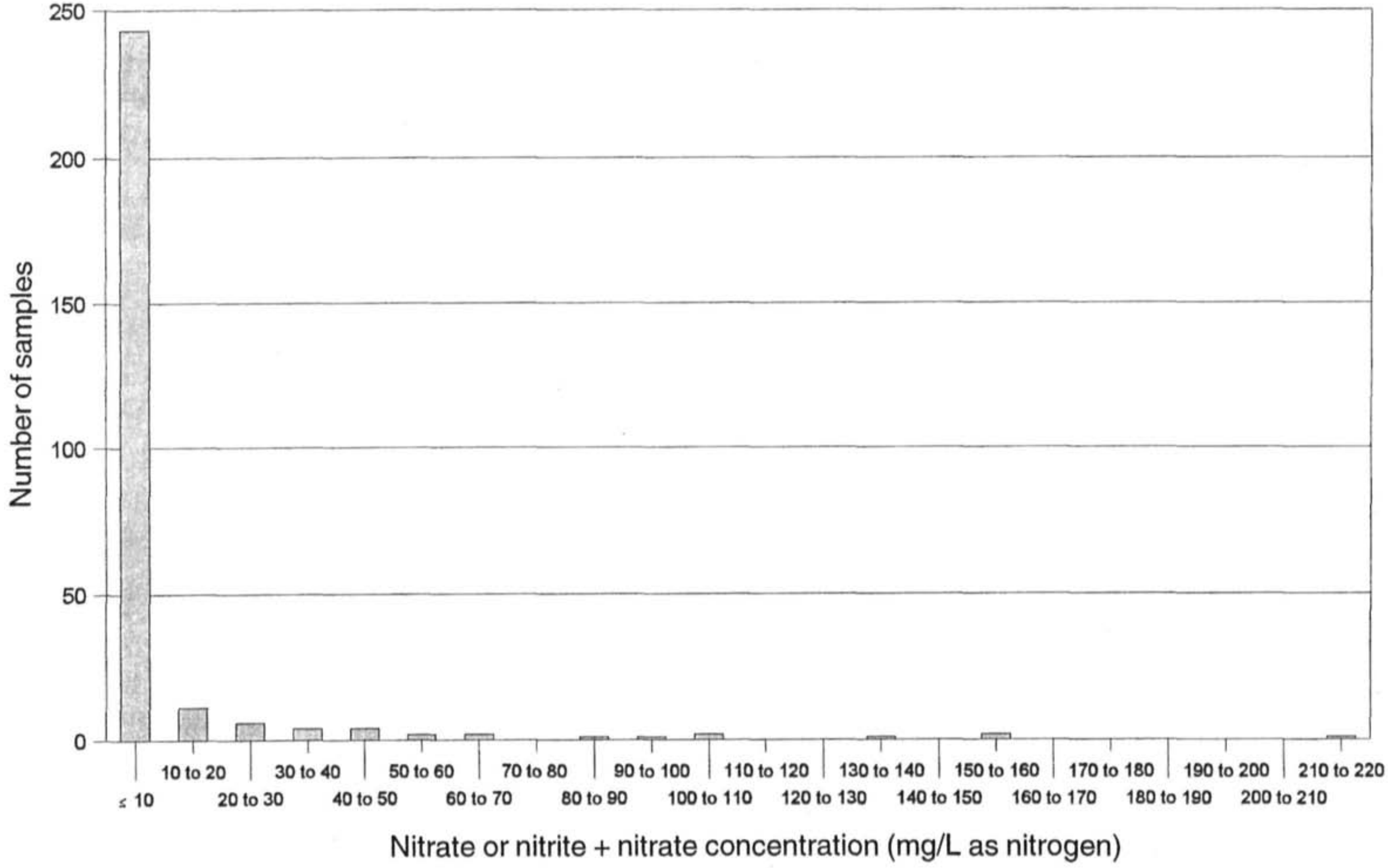

Figure 36. Distribution of nitrate and nitrite+nitrate concentrations in ground-water samples obtained from 280 shallow wells in McHenry County.

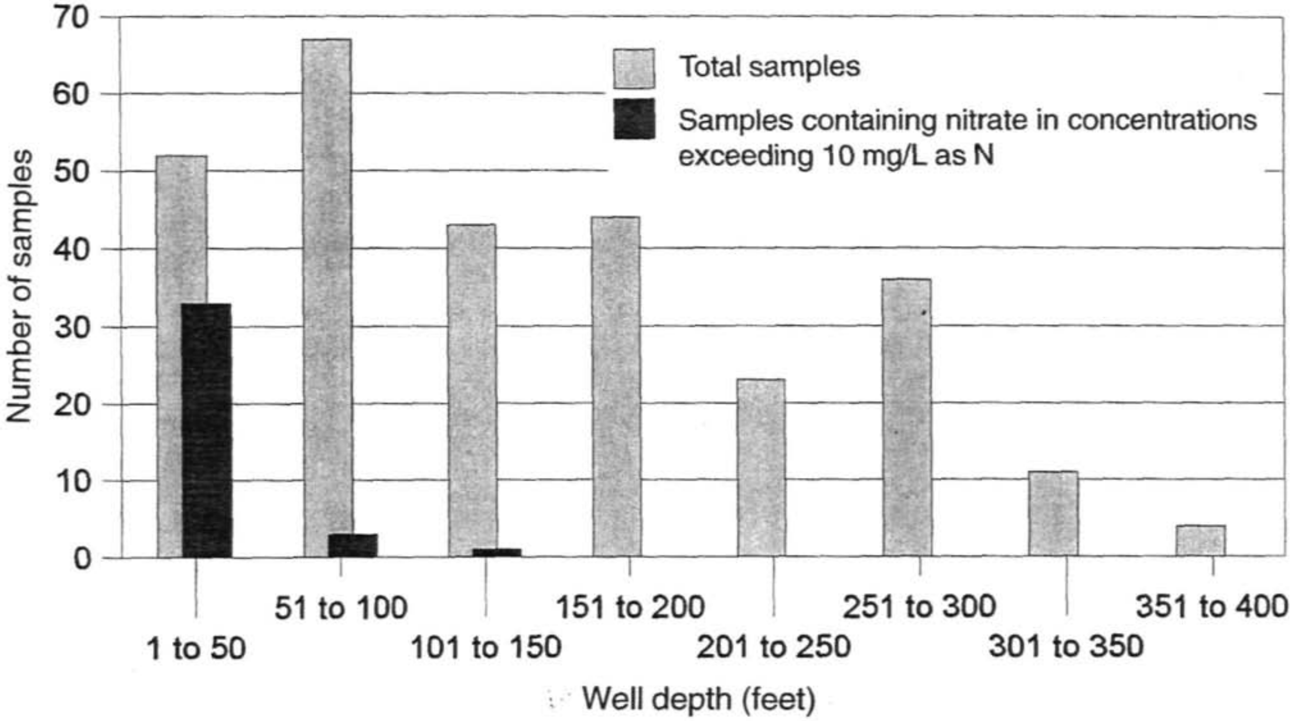

Figure 37. Relationship between well depth and nitrate contamination for ground-water samples collected from 280 shallow wells in McHenry County.

Relationship of Nitrate Contamination to Geography and Geology Figure 38 shows the locations of all shallow ground-water samples listed in Appendix F that contained nitrate in concentrations exceeding the drinking water standard of 10 mg/L nitrate as nitrogen. Note that these are the locations of all recorded incidents of nitrate contamination in shallow McHenry County ground water. If, for example, a well sampled on multiple occasions contained excessive nitrate at any time in its history, its location is plotted in Figure 38. Twenty-four of the 30 locations (or 80 percent) at which samples having excessive nitrate were collected were in the four southwesternmost townships in the county (T 43 and 44 N, R 5 and 6 E). An aquifer sensitivity map developed by Curry et al. (1998) suggests that the nitrate present in the shallow ground water in southwestern McHenry County could have entered the wells by infiltration through shallow subsurface materials rather than through some fault of well construction. Of the 24 locations at which nitrate-contaminated samples were collected in southwestern McHenry County, 19 (or 79 percent) of them are within areas identified by Curry et al. (1998) as having the highest potential for shallow aquifer contamination. More than 50 ft of sand and gravel immediately underlies land surface in this area. This permeable material at the surface allows relatively unimpeded infiltration of potential pollutants present at the surface into the shallow ground water.

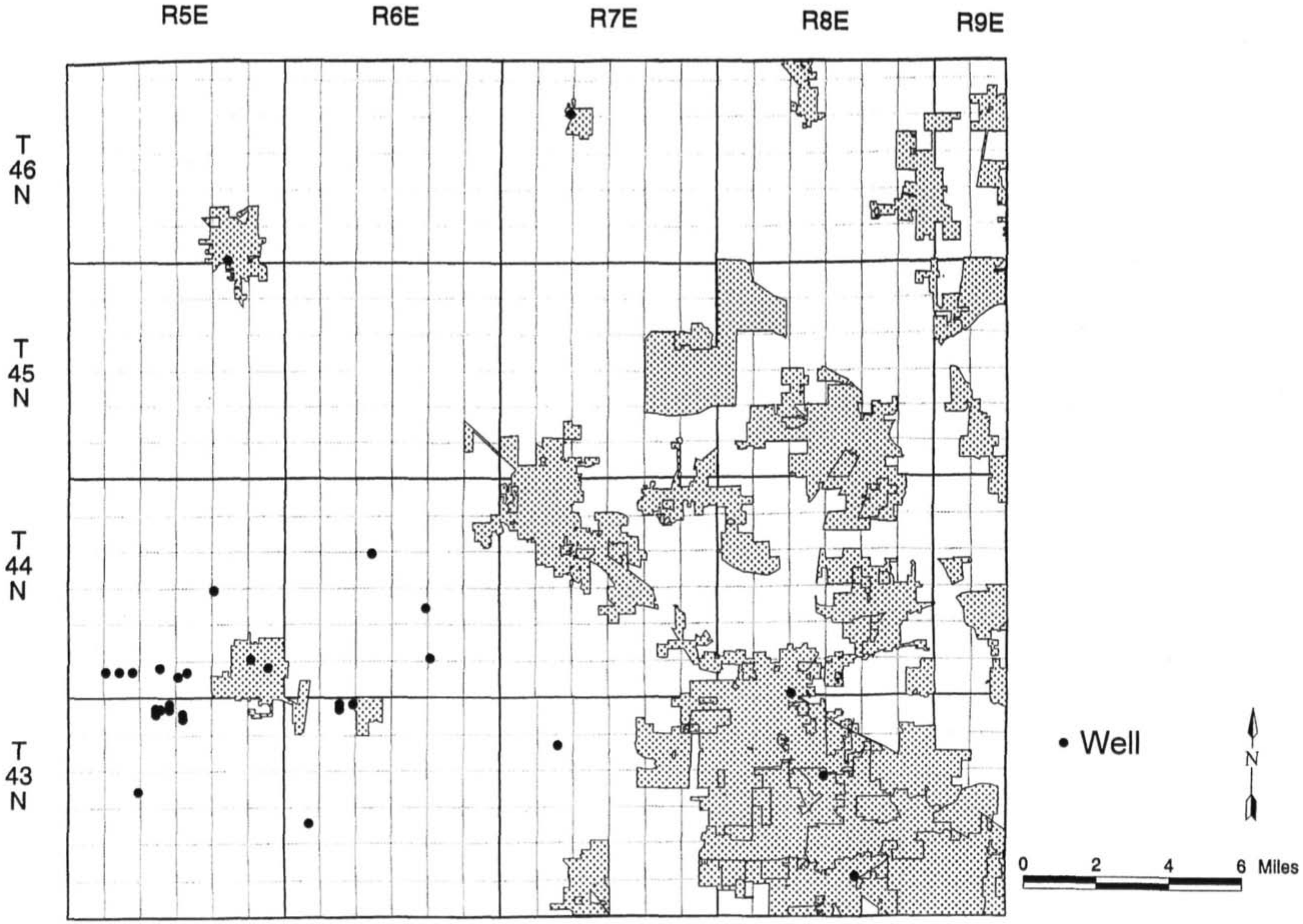

Figure 38. Locations of wells whose samples contained nitrate in concentrations exceeding the drinking water standard.

CONCLUSIONS

The potentiometric surface maps of the five principal shallow aquifers in McHenry County (Plates 1 through 5) are the principal products of this study, and the maps are the basis for the following conclusions regarding shallow ground water in McHenry County:

- In general, potentiometric surface configuration is a subdued replica of land surface topography. The potentiometric surfaces of the aquifers investigated in McHenry County become progressively more subdued, and the degree of replication of land surface topography lessens with depth of aquifer.

- Aquifer connections influence potentiometric surface configurations by causing heads in the connecting aquifers to approach one another and to become equal along the line of pinchout of the confining bed separating the aquifers.

- Ground-water withdrawals appear to have locally influenced the potentiometric surfaces, particularly in southeastern McHenry County. The presence of cones of depression in Aquifer 5 in southeastern McHenry County reflects (1) large withdrawals from the aquifer in this relatively densely populated part of the county and (2) the likelihood that Aquifer 5 receives less recharge than the other, more shallow, aquifers investigated for this study.

- In general, deeper aquifers discharge into more widely spaced and deeply incised surface-water features. For example, discharge areas for Aquifer 1 may include comparatively small ditches, ponds, and wetlands, whereas Aquifer 5 tends to discharge into larger streams, rivers, lakes, and wetlands. This generalization is complicated by the connections between aquifers. Aquifer connections underlying low-lying areas allow discharge of water from deeper aquifers regardless of the size of the surface-water features occupying these areas.

- The potentiometric surface maps, together with assumed values of hydraulic conductivity and porosity, are the basis for estimating the five-year capture zones for 33 public water supply wells in McHenry County finished in the investigated aquifers. Each capture zone is an estimation of the area of the source aquifer that contributes water to the well during a period of 5 years at normal pumping rates. Each capture zone estimation represents an area planners should prioritize for ground-water protection efforts because potential pollutants within the capture zone will move toward the well and could eventually contaminate it.

The following conclusions regarding nitrate in McHenry County ground water are based on examination of 550 analyses of ground-water samples collected from 280 wells that are 400 ft deep or less:

- Of the 280 most recently collected samples from the wells, 13 percent contained nitrate in concentrations exceeding the drinking water standard of 10 mg/L as nitrogen.

- Available data suggests that, of the 280 most recently collected samples, the shallowest wells were much more likely to be contaminated by nitrate than were the deeper wells.

Eighty-nine percent of the samples containing nitrate in concentrations exceeding the drinking water standard were collected from wells 50 ft deep or less. No nitrate-contaminated samples were collected from wells deeper than 150 ft.

- Eighty percent of the samples containing nitrate concentrations greater than 10 mg/L as nitrogen were collected in the four southwesternmost townships of McHenry County. Seventy-nine percent of these high-nitrate samples from southwestern McHenry County were collected in areas mapped by Curry et al. (1998) as having the highest potential for aquifer contamination in McHenry County. This pattern suggests that much of the nitrate contamination of ground water in McHenry County is related to leaching of nitrate into the shallow parts of the saturated zone in areas of high aquifer sensitivity, rather than to inadequate or deteriorated well construction features.

RECOMMENDATIONS FOR FURTHER STUDY

The results and limitations of the present study suggest several directions for additional study. Research efforts might focus on characterizing the cause and extent of the apparent ground-water quantity and quality problems identified in the present study. Results of these efforts might suggest measures to correct these problems and prevent other, similar problems from arising elsewhere in McHenry County. Other research might be directed toward refining the capture zones estimated for this study so as to optimally focus ground-water protection efforts.

Potentiometric surface mapping has suggested the presence of numerous cones of depression and a broad area of lowered heads in Aquifer 5 in southeastern McHenry County (Figure 17). Additional water level decline could cause disruption of water well supplies in the area. Further study could clarify the potentiometric surface configuration in the area and provide data that could be used to indicate the limitations to sustainable ground-water withdrawals from Aquifer 5. Water levels could be monitored in southeastern McHenry County by scheduled or continuous water level measurement in a network of dedicated monitoring wells or, alternatively, by implementation of scheduled mass water level measurements using existing water supply wells. Such monitoring would allow early identification of water level changes that could have serious impacts, including alteration of wetland hydrology and reduction of ground-water availability.

The present study has identified an area of southwestern McHenry County in which numerous incidents of ground-water nitrate contamination have occurred (Figure 38). Additional study could better define the magnitude and extent of nitrate contamination in this area and allow the nitrogen sources to be identified. Such an investigation might facilitate development of plans to reduce ground-water nitrate concentrations in the area.

The capture zone estimations prepared for this report are limited in their accuracy. The accuracy of these estimations could be improved by applying the same methodology used in this study, but with better inputs. Data inputs could be improved by (1) conducting pumping tests at or near wells for which site-specific data are lacking (which would allow use of more accurate hydraulic conductivity values) and (2) installing piezometers in close proximity to high-capacity wells (which would permit more refined mapping of cones of depression). Still further refinement of the capture zone estimations could be achieved by modeling ground-water flow in the vicinity of high-capacity wells using a three-dimensional approach. Three-dimensional modeling offers more reliable results than the two-dimensional approach applied in the present study. Such modeling would require (1) detailed mapping of the potentiometric surfaces of aquifers, (2) detailed mapping of aquifers and aquitards in the model domain, (3) determining the hydraulic properties of the aquifers and aquitards, and (4) estimating rates of ground-water withdrawal and recharge.

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APPENDIX A. PUMPING TEST ANALYSIS METHODS

In a controlled pumping test, ground water is pumped from a well at a closely monitored, constant rate, and water levels are simultaneously measured in the pumped well and, preferably, in one or more observation wells. Water levels are also measured after pumping has stopped. The time after the beginning or end of pumping is recorded with each water level measurement. The data obtained from controlled pumping tests may be analyzed by one or more similar graphical methods. These methods plot elapsed time since the beginning and end of pumping versus drawdown or recovery. If data are available from several observation wells, distance from the pumped well versus synchronous drawdown or recovery data can be plotted and analyzed. The plots are analyzed by comparing them to type curves developed from equations describing the relationship between the hydraulic properties of an ideal aquifer and the drawdown and recovery of water levels in the vicinity of a pumping well finished in the aquifer.

The graphical methods of pumping test analysis used in this study include those developed by Cooper and Jacob (1946) and Walton (1960). Hydraulic conductivity was also estimated from specific capacity data using the nongraphical, and less accurate, method developed by Walton (1962). This appendix describes these three methodologies together with a small amount of theoretical background.

The methodology of Cooper and Jacob (1946) can be used to evaluate the hydraulic properties of aquifers under confined conditions. The method is based on the work of Theis (1935), who introduced an analogy between the nonsteady flow of ground water and heat conduction. Theis developed the following equation (commonly known as the Theis equation) to describe radial flow toward a well pumping from an artesian aquifer:

$$s = \frac{Q}{4\pi T}W(u) \tag{1}$$

or in commonly used units,

$$s = \frac{114.6Q}{T}W(u) \tag{2}$$

where:

$$W(u) = \int_u^\infty \frac{e^{-u}}{u}du = -0.5772 + \ln u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} + \cdots \tag{3}$$

and

$$u = \frac{2693r^2S}{Tt} \tag{4}$$

where:

s = drawdown at distance r from the pumped well, in ft
Q = well discharge, in gallons per minute (gpm)
T = transmissivity, in gallons per day per foot (gpd/ft)
r = distance from pumped well to observation point, in ft
S = storage coefficient, decimal fraction
t = time since pumping began, in minutes

W(u), referred to as the well function for nonleaky artesian aquifers, has been extensively tabulated.

Theis devised a graphical procedure using superposition to solve for the aquifer properties, T and S, using equations 2 and 4, but inverting equation 4:

$$s = \frac{114.6Q}{T} W(u) \qquad (5)$$

and

$$\frac{1}{u} = \frac{Tt}{2693r^2S} \qquad (6)$$

Expanding the logarithm of both sides of these equations yields:

$$\log s = \log \left[\frac{114.6Q}{T}\right] + \log W(u) \qquad (7)$$

and

$$\log \frac{1}{u} = \log \left[\frac{T}{2693r^2S}\right] + \log t \qquad (8)$$

In equation 7, the term log [114.6Q/T] is a constant for a given pumping rate (hence, the need for a constant pumping rate during tests), so log s is directly related to log W(u). Also in equation 8, the term log [$T/2693r^2S$] is a constant for a given distance r (a selected observation well), so log 1/u is directly related to log t. Thus,

$$\log s \propto \log W(u)$$

and

$$\log t \propto \log 1/u$$

From these relationships, the well function W(u) versus 1/u can be plotted on log-log graph paper (Figure A1). Such a plot of a mathematical function is called a type curve. Likewise, from

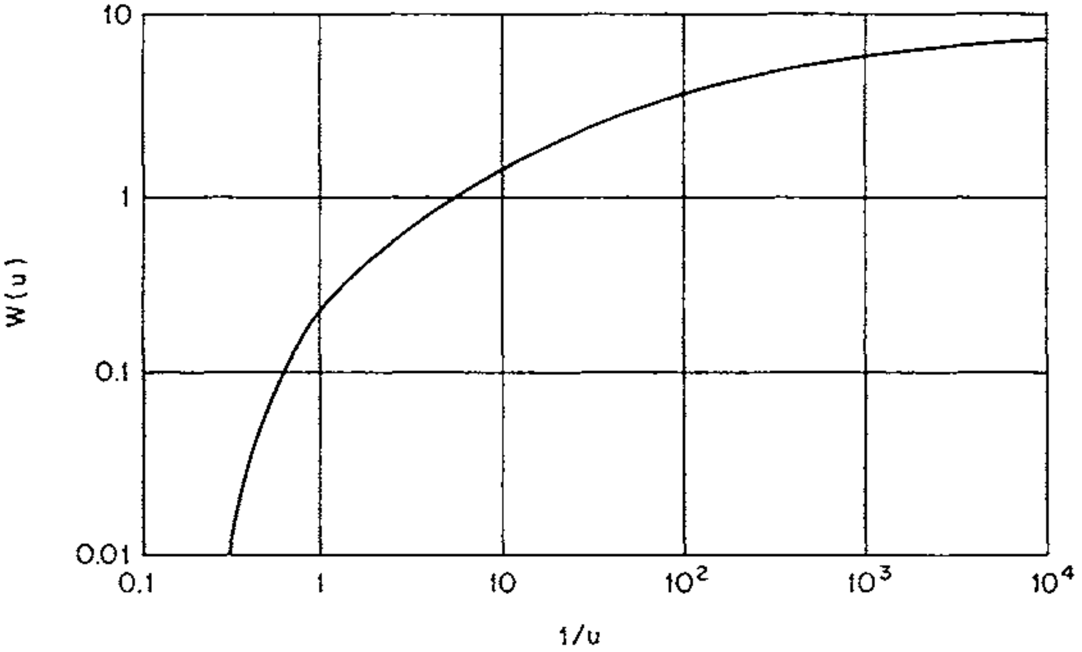

Figure A1. Theoretical curve of W(u) versus 1/u
(after Freeze and Cherry, 1979).

the data collected at each observation well, one can plot drawdown s versus time t on identical log-log paper.

The type curve is then superimposed over the field-data plot, keeping the corresponding ordinate and abscissa axes parallel, until a best fit is obtained. A convenient match point is chosen on the two graphs (usually one that includes the convenient type-curve match point of $W(u) = 1$ and $1/u = 10$). The corresponding coordinates of W(u), 1/u, s, and t are then substituted into equations 2 and 4 to solve for T and S.

In the same manner, one could make a type curve of W(u) versus u, noting the relationships between s versus W(u) and between u and r^2. For an aquifer test in which several observation wells were used, one could fit the new type curve to a field-data plot of s versus r^2 for a given time, and follow the same procedure of fitting the type curve to the field-data plot and selecting a match point.

The analytical methodology of Cooper and Jacob (1946) is often called the modified nonleaky artesian formula or simply the Jacob straight-line method. The method is based on the fact that when values of u are small (less than, say, 0.01), the sum of the series terms in equation 3 beyond In u becomes insignificant. An examination of the terms in equation 4 shows that u becomes small when r becomes small (observation wells that are relatively near the pumping well) or when t becomes large (long pumping periods).

When $u < 0.01$, field-data plots of drawdown versus log time on semilog paper will yield a straight line. The straight-line portion of the s versus t plot is extrapolated to its intersection with the zero-drawdown axis. The slope of the straight line (drawdown per log cycle) is used to solve for the transmissivity, and the zero-drawdown intercept is used to solve for the storage coefficient. Expressions for these computations derived by Cooper and Jacob (1946) are:

$$T = \frac{264Q}{\Delta s} \tag{9}$$

and

$$S = \frac{Tt_0}{4790r^2} \tag{10}$$

where:

T = transmissivity, in gpd/ft
Q = well discharge, in gpm
As = drawdown difference per log cycle, in ft
S = storage coefficient, as decimal fraction
t_0 = intersection of straight-line slope with zero-drawdown axis, in minutes
r = distance from pumped well to observation point, in ft

The Jacob straight-line method is popular because of its simplicity; however, its use is restricted to field data that satisfy the u-criterion of $u \leq 0.01$. Deviation from a straight line becomes appreciable when u exceeds approximately 0.02 (Walton, 1962).

Like the Jacob straight-line method, the methodology of Walton (1960) can be used to evaluate the hydraulic properties of aquifers under confined conditions. But unlike the Jacob straight-line method, the methodology of Walton (1960) permits evaluation of the vertical hydraulic conductivity of confining beds (K').

Leaky artesian or semiconfined conditions exist where an artesian aquifer is overlain by materials that impede the vertical movement of ground water. Artesian or confined conditions differ from leaky artesian conditions in that under artesian conditions the confining bed(s) overlying and/or underlying the aquifer completely prevent(s), rather than simply impede(s), the movement of water. Because most geologic materials are only capable of impeding the movement of water, rather than preventing it, true artesian conditions are rare in comparison to leaky artesian conditions.

Walton's (1960) methodology is based on the following equation, developed by Hantush and Jacob (1955), describing the non-steady-state drawdown distribution in a leaky artesian aquifer:

$$s = \frac{Q}{4\pi T} W(u, r/B) \tag{11}$$

or in commonly used units,

$$s = \frac{114.6Q}{T} W(u, r/B) \tag{12}$$

where:

$$u = \frac{2693 r^2 S}{Tt} \tag{13}$$

$$\frac{r}{B} = \frac{r}{\sqrt{T/(K'/m')}} \tag{14}$$

s = drawdown in observation well, in ft
r = distance from pumped well to observation well, in ft
Q = discharge, in gpm
t = time since pumping started, in minutes
T = transmissivity, in gpd/ft
S = storage coefficient, as decimal fraction

K' = vertical hydraulic conductivity of leaky confining bed, in gallons per day per square foot (gpd/ft^2)
m' = thickness of confining leaky confining bed, in ft

W(u,r/B) is referred to as the well function for leaky artesian aquifers and is defined by the following equation:

$$W(r/B) = \int_{u}^{\infty} \left(\frac{1}{u}\right) \exp(-u - r^2/4B^2u)\,du \tag{15}$$

or, evaluating the integral,

$$\begin{aligned} W(r/B) &= 2K_0(r/B) - I_0(r/B)\left[-Ei\left(-\frac{r^2}{4B^2u}\right)\right] \\ &+ \left[\exp\left(-\frac{r^2}{4B^2u}\right)\right]\Big\{0.5772 + \ln u + [-Ei(-u)] \\ &- u + u[I_0(r/B) - 1]/\frac{r^2}{4B^2} \\ &- u^2 \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \frac{(-1)^{n+m}(n-m+1)!}{(n+2)!^2} \left(\frac{r^2}{4B^2}\right)^m u^{n-m}\Big\} \end{aligned} \tag{16}$$

where:

$K_0(r/B)$ = modified Bessel function of the second kind and zero order
$I_0(r/B)$ = modified Bessel function of the first kind and zero order

W(u,r/B) has been extensively tabulated.

Walton's (1960) methodology is a graphical procedure using superposition to solve for the aquifer properties (T and S) and the vertical hydraulic conductivity of the confining bed (K'). Recall equations 12 and 13, inverting equation 13:

$$s = \frac{114.6Q}{T} W(u,r/B) \tag{17}$$

$$\frac{1}{u} = \frac{Tt}{2693\,r^2 S} \tag{18}$$

Take the logarithm of both sides and expand:

$$\log s = \log\left(\frac{114.6Q}{T}\right) + \log W(u,r/B) \tag{19}$$

$$\log\left(\frac{1}{u}\right) = \log\left(\frac{T}{2693r^2S}\right) + \log t \tag{20}$$

In equation 19, the term log (114.6 Q/T) is a constant for a given pumping rate, so log s is directly related to log W(u,r/B). Also in equation 20, the term log ($T/2693r^2S$) is a constant for a given distance r, so log (1/u) is directly related to log t. Thus, for a given aquifer, observation well, and pumping rate,

$$\log s \propto \log W(u,r/B)$$

$$\log t \propto \log(1/u)$$

The first step in solving for aquifer and confining bed properties using Walton's (1960) method is to construct a series of leaky artesian type curves by plotting W(u,r/B) versus 1/u on logarithmic paper for the practical range of u and r/B (Figure A2). Using logarithmic paper of the same scale as the type curves, observed values of s are then plotted against those of t for a given observation well. The family of type curves is then superposed on the field-data plot, keeping the corresponding ordinate and abcissa axes parallel, until a best fit with one of the type curves is obtained. In the matched position, a point at any convenient intersection of major axes on the type-curve plot is selected and marked on the time-drawdown field-data curve, noting the values of W(u,r/B) and 1/u represented by the selected axes. The point may be selected anywhere on the type-curve plot, but it is most convenient to use a point at the intersection of two major axes such as W(u,r/B) = 1 and 1/u = 10. The coordinates of the match point on both the type-curve plot [W(u,r/B) and 1/u] and field-data plot (s and t), as well as the appropriate values of Q and r, are substituted into equations 12, 13, and 14 to determine the hydraulic properties of the aquifer and confining bed.

The methodology of Walton (1962) was used in the present study to estimate aquifer hydraulic properties in cases where pumping test data could not be analyzed by either of the more accurate methods described previously. Walton (1962) derived the following equation describing the theoretical specific capacity of a well discharging at a constant rate in a homogeneous, isotropic, nonleaky artesian aquifer of infinite lateral extent:

$$Q/s = T/264\log[Tt/(2693r_w^2S) - 66.15] \tag{21}$$

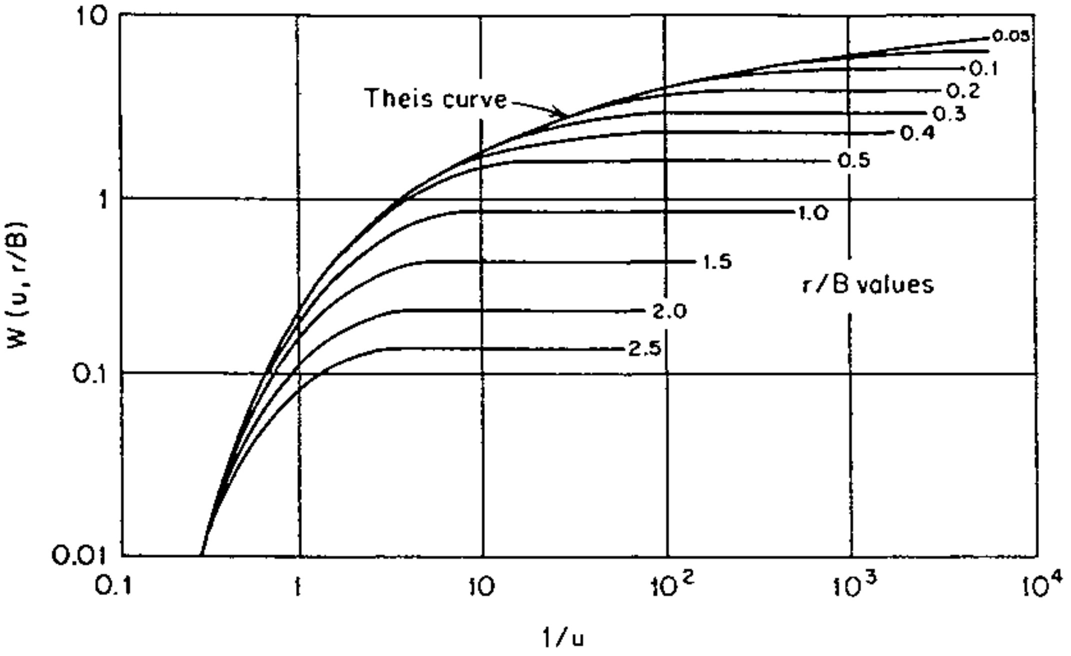

Figure A2. Theoretical curve of W(u,r/B) versus 1/u for a leaky aquifer (after Walton, 1960).

where:

Q/s = specific capacity, in gallons per minute per foot of drawdown, in gpm/ft
Q = discharge, in gpm
s = drawdown, in ft
T = transmissivity, in gpd/ft
S = storage coefficient, as decimal fraction
r_w = nominal radius of well, in ft
t = time after pumping started, in minutes

The equation, based on the modified nonleaky artesian formula (Cooper and Jacob 1946), assumes that (1) the well fully penetrates the saturated thickness of the aquifer; (2) well loss is negligible; and (3) the effective radius of the well has not been affected by drilling and development and is equivalent to the nominal radius of the well.

Solving this equation for T requires that one assume values of S and r_w on the basis of available hydrogeologic and well construction data. Q/s and t are determined from pumping test data. The equation is then solved iteratively for T.

Walton (1962) discusses the uncertainty associated with employing assumed values of S and r_w in estimating T from the specific capacity relationship. The choice of a value for S is usually based on water level and well log data. S is generally between 10^{-5} and 10^{-3} for confined aquifers. For unconfined aquifers, S is generally between 0.1 and 0.3. Because specific capacity varies with the logarithm of 1/S, however, large errors in estimated storage coefficients result in comparatively small uncertainties in transmissivity estimated from specific capacity data. The choice of a value for r_w is based on well construction data. In gravel packed wells, however, the borehole radius is significantly larger than the screen radius, and the choice of an effective r_w is therefore a compromise between borehole radius and screen radius. In addition, the processes of drilling and development may alter the materials surrounding the borehole so that the effective r_w exceeds the borehole radius. Since specific capacity varies with the logarithm of $1/r_w^2$, however, large errors in estimated r_w result in comparatively small uncertainties in transmissivity estimated from specific capacity data. For the present study, a range of appropriate values of storage coefficient and well radius were substituted into equation 21 to estimate aquifer transmissivity. The range of transmissivity values determined in this way are reported in Appendix C.

Specific capacity may be reduced by partial penetration, well loss, and hydrogeologic boundaries. Because these influences are not related to transmissivity, estimates of transmissivity based on uncorrected specific capacity data can underestimate the actual aquifer transmissivity. In many cases, the data can be corrected for these influences. Well log and well construction data provide information on the degree of penetration of a well; these data can be used to correct for partial penetration effects using methods developed by Butler (1957) and Kozeny (1933) and described by Walton (1962). Pumping test data may be corrected for well loss if data from step tests, wherein drawdown is observed in a pumped well at a range of discharge rates, are available. Step test data are usually analyzed by the techniques of Jacob (1947) or Rorabaugh (1953). Where pumping test data are suitable for identification of hydrogeologic boundaries, hydraulic properties can be determined using one of the graphical procedures described elsewhere in this appendix, and it is not necessary or desirable to estimate transmissivity using the less accurate specific capacity relationship.

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APPENDIX B. SYSTEM OF LOCATION

Locations are described using township, range, and section numbers as established by the Northwest Ordinance of 1785. This ordinance mandated that all federal lands be surveyed into vertical strips 6 miles wide, called ranges, and horizontal strips of townships, each 6 miles wide. Ranges are numbered east or west of a principal meridian (for example, Range 11 West or, alternatively, R 11 W). Township strips are numbered north or south of a base line (for example, Township 5 South or, alternatively, T 5 S). Ranges and township strips in McHenry County are surveyed relative to the Third Principal Meridian and Base Line. Ranges and township strips intersect to form tracts of land called townships, which are ideally square in shape, with sides 6 miles long and an area of 36 square miles. Townships sometimes depart from this ideal, however, mainly because of the geometric impossibility of surveying squares of uniform size, with the sides oriented in a north-south direction, on the curved surface of the earth. Townships are divided into 36 sections, each section 1 square mile in area, or 640 acres.

Subsection locations are described in this report using a coordinate system that assigns a unique combination of a number and letter to each quarter-quarter-quarter section (Figure B1). A number between 1 and 8 indicates the east-west position of the location within the section, and a letter between A and H indicates the north-south position. Thus, a unique number-letter combination designates each quarter-quarter-quarter section within a section. A standard section, which is 1 square mile in area, contains 64 quarter-quarter-quarter sections, each 10 acres in area. These tracts are referred to as 10-acre plots in this report. The north-south length of irregular sections is sometimes greater than 1 mile, necessitating the use of number-letter combinations such as 3J or 8H.

A complete location description includes section, township, and range numbers, as well as the subsection designation. The section number and subsection designation are separated by aperiod (Figure B1). The county name is sometimes included as well.

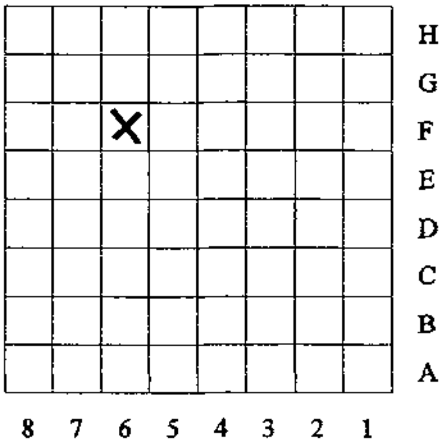

Figure B1. Division of a section into 64 quarter-quarter-quarter sections, each 10 acres in area, which are designated by a unique number-letter combination. The quarter-quarter-quarter section marked by X would be indicated by the number-letter combination 6F.

APPENDIX C. RESULTS OF PUMPING TESTS OF SHALLOW WELLS IN AND NEAR MCHENRY COUNTY

Table C1 gives results of analysis of data collected during 37 pumping tests of shallow wells in and near McHenry County. The pumping test data analyzed for this appendix were collected by the Illinois State Water Survey or by private drillers and consulting engineers and subsequently submitted to the Illinois State Water Survey. Tests of wells finished in the Midwest Bedrock Aquigroup, or "deep sandstone" aquifer, were not examined for this study. Additional tests of shallow aquifers were eliminated from consideration because of concerns about the quality of the collected data.

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Table C1. Results of Pumping Tests of Shallow Wells in and near McHenry County

	Test Data				*Location*			
Pumped Well	*Start Date*	*Duration (minutes)*	*Pumping Rate (gpm)*	*Well Type*	*T*	*R*	*Section*	*10-Acre Plot*
Algonquin 7	10/29/1991	930	909	PW	42N	8E	3	\C
Lake in the Hills 9	NR	465	580	PW	43N	7E	24	6C
Huntley 4	11/11/1953	855	317	PW	43N	7E	33	6H
Crystal Lake 9	09/10/1986	1,440	506	PW	43N	8E	6	4A
Crystal Lake 12	12/01/1987	1,457	603	PW	43N	8E	8	5A
Crystal Lake 13	02/24/1987	1,380	603	PW	43N	8E	8	5A
				OW	43N	8E	8	5A
Cary 12	02/25/1993	1,440	603	PW	43N	8E	14	5C
Cary (Fox Trail Development) 10	11/09/1981	915	500	PW	43N	8E	14	6A
Lake in the Hills 8	NR	330	110	PW	43N	8E	21	5A
Algonquin 3	04/21/1970	780	305	PW	43N	8E	33	4H
Algonquin 6	12/04/1984	1,450	751	PW	43N	8E	34	1A
Algonquin 5	08/07/1978	1,020	400	PW	43N	8E	34	2A
Fox River Grove 2	09/10/1956	120	257	PW	43N	9E	18	3A
Marengo 4	01/04/1962	250	400	PW	44N	5E	25	8A
D. Hill Nursery 1	06/04/1985	49	800	PW	44N	6E	34	1E
Woodstock 3	09/07/1939	NR	NR	PW	44N	7E	5	7D
Woodstock 8	06/28/1989	2,880	734	PW	44N	7E	6	1G
TC Industries, Inc. 1	04/14/1960	365	403	PW	44N	8E	22	5C

Table C1. Continued

Pumped Well	*Aquifer*	*Aquifer Thickness (ft)*	*Analytical Results*				*Analytical Method*
			T (ft^2/d)	*K(fi/d)*	*S*	*K' (ft/d)*	
Algonquin 7	5(a)	≥ 44	7,400	≤170			1
Lake in the Hills 9	2	29	3,200-4,300	110-150			3
Huntley 4	2	≥ 23	3,100	≤130			1
Crystal Lake 9	5(a)	22	2,800-3,400	130-150			3
Crystal Lake 12	5(b)		2,500				1
Crystal Lake 13	5 (b)		2,900				1
	5 (b)		5,400				1
Cary 12	5(a)	37	19,000-27,700	510-750			3
Cary (Fox Trail Development) 10	4	≥ 27	4,400-5,600	≤210			3
Lake in the Hills 8	5(b)		400-500				3
Algonquin 3	5(a)	≥ 20	3,400	≤180			1
Algonquin 6	4	20	35,400	1,800			1
Algonquin 5	4	≥ 14	3,400	≤240			1
Fox River Grove 2	5(b)		1,600-2,100				3
Marengo 4	4	>35	7,400-10,900	≤310			3
D. Hill Nursery 1	4	35	19,600-29,500	560-840			3
Woodstock 3	5(a)	≥ 50	7,100	≤140			1
Woodstock 8	5(a)	≥ 23	8,000	≤350			1
TC Industries, Inc. 1	5(a)	≥ 41	1,700	≤40			1

Table C1. Continued

Pumped Well	Test Data			Well Type	Location			
	Start Date	Duration (minutes)	Pumping Rate (gpm)		T	R	Section	10-Acre Plot
TC Industries, Inc. 2	12/16/1966	450	418	PW	44N	8E	22	5C
TC Industries, Inc. 3	12/06/1966	490	415	PW	44N	8E	22	5C
Crystal Lake 10	06/08/1987	1,447	506	PW	44N	8E	33	3F
Crystal Lake 14	12/02/1992	960	600	PW	44N	8E	33	3G
Crystal Lake 11	09/10/1987	1,464	603	PW	44N	8E	33	4F
				OW	44N	8E	33	3F
National Grain Yeast Co. 3	11/06/1940	300	150	PW	44N	8E	33	8A
Island Lake 4-10	09/08/1989	1,440	151	PW	44N	9E	20	7D
				OW	44N	9E	20	7D
Island Lake 7	01/12/1993	350	252	PW	44N	9E	20	7F
				OW	44N	9E	20	7F
				OW	44N	9E	20	7F
Island Lake 6	03/27/1990	1,440	772	PW	44N	9E	21	5D
Woodstock 5	09/19/1960	4,140	1,043	OW	45N	7E	32	2B
				OW	45N	7E	32	2C
				OW	45N	7E	32	3C
				OW	45N	7E	32	3C
				OW	45N	7E	32	4B
				OW	45N	7E	32	4C
Woodstock 7A	06/06/1989	1,440	1,226	PW	45N	7E	32	3E
Oakwood Shores Subdivision 2	11/16/1959	60	250	PW	45N	8E	18	3C
McHenry 9	08/13/1992	1,440	860	PW	45N	8E	26	2H

Table C1. Continued

Pumped Well	*Aquifer*	*Aquifer Thickness (ft)*	*Analytical Results*				*Analytical Method*
			T (ft²/d)	*K (ft/d)*	*S*	*K' (ft/d)*	
TC Industries, Inc. 2	5(a)	≥ 51	2,300	≤40			1
TC Industries, Inc. 3	5(a)	≥ 46	1,300	≤30			1
Crystal Lake 10	5(b)		1,300				1
Crystal Lake 14	4	14	940	70			1
Crystal Lake 11	4	≥ 15	1,900	≤120			1
	5(b)		1,300		1.7×10^{-3}		2
National Grain Yeast Co. 3	5(b)		1,300				1
Island Lake 4-10	5(a)	14	4,800	340			1
	5(a)	18	3,900	220			1
Island Lake 7	5(a)	29	4,600	160			1
	5(b)		2,800				1
	5(a)	23	3,200	140			1
Island Lake 6	5(a)	≥ 78	19,700	≤250			1
Woodstock 5	5(a)	≥ 50	7,100	≤140	5.3×10^{-4}	0.002	2
	5(a)	≥ 46	7,400	≤160	1.7×10^{-4}	0.002	2
	5(a)	≥ 54	7,600	≤140	2.8×10^{-4}	0.002	2
	5(a)	≥ 54	8,000	≤150	3.6×10^{-4}	0.002	2
	5(a)	≥ 50	7,600	≤150	3.0×10^{-4}	0.002	2
	5(a)	≥ 49	7,500	≤150	2.7×10^{-4}	0.002	2
Woodstock 7A	4	≥ 20	6,700	≤330			1
Oakwood Shores Subdivision 2	5(a)	≥ 45	3,600-4,800	≤110			3
McHenry 9	5(b)		7,000				1

Table C1. Continued

	Test Data				*Location*			
Pumped Well	*Start Date*	*Duration (minutes)*	*Pumping Rate (gpm)*	*Well Type*	*T*	*R*	*Section*	*10-Acre Plot*
McHenry 5	05/17/1974	720	500	PW	45N	8E	27	8C
Harvard 4	03/26/1946	50	200	PW	46N	5E	35	5A
Harvard 7	08/15/1986	480	579	PW	46N	5E	36	5F
Harvard 8	06/07/1993	720	252	PW	46N	5E	36	8D
Shagbark Chalet Condominiums 1 (TW 2-64)	10/01/1964	100	100	PW	46N	6E	14	8D
Spring Grove Fish Hatchery 2	07/11/1972	126	133	OW	46N	8E	25	2H

Abbreviations: NR = not reported PW = pumped well OW = observation well

Notes: Wells finished in Aquifer 5 are divided into two categories, 5(a) and 5(b). Wells finished in Aquifer 5(a) are finished only in the basal unconsolidated aquifer materials and do not penetrate the underlying bedrock. For such wells, the aquifer thickness reported in this appendix is that of the unconsolidated aquifer materials penetrated by the well. The thickness of the underlying bedrock, which is effectively a part of Aquifer 5, is not known, and no attempt is made to include this interval in the aquifer thickness reported in this appendix. It should be noted that the hydraulic conductivity determined from the pumping test data collected at wells assigned to Aquifer 5(a) may overestimate the actual hydraulic conductivity of the basal outwash in which the wells are screened. Wells assigned to Aquifer 5(b) are both screened in the basal unconsolidated materials and open to some portion of the uppermost bedrock underlying these materials. Because the effective thickness of the bedrock interval contributing water to Aquifer 5 is uncertain, no aquifer thickness or hydraulic conductivity is reported for wells finished in Aquifer 5(b).

Analytical results reported are transmissivity (T), hydraulic conductivity (K), storage coefficient (S), and vertical hydraulic conductivity of confining beds (K').

Analytical methods are those of (1) Cooper and Jacob (1946), (2) Walton (1960), and (3) Walton (1962).

Table C1. Concluded

Pumped Well	*Aquifer*	*Aquifer Thickness (ft)*	*Analytical Results*				*Analytical Method*
			T(ft^2/d)	*K(ft/d)*	*S*	*K'(ft/d)*	
McHenry 5	5(a)	≥ 23	2,500	≤110			1
Harvard 4	5(a)	22	1,300	60			1
Harvard 7	5(a)	≥ 25	5,000	≤200			1
Harvard 8	5(a)	16	2,400	150			1
Shagbark Chalet Condominiums 1 (TW 2-64)	4	≥ 20	2,500-3,800	≤190			3
Spring Grove Fish Hatchery 2	5(a)	≥ 77	19,600	≤250			1

APPENDIX D. ACTIVE SHALLOW PUBLIC WATER SUPPLY WELLS IN MCHENRY COUNTY (1994)

Table D1 provides location, construction, and pumpage data for all shallow McHenry County public water supply wells reported as being in active service during 1994. The source of the pumpage figures and the status of the wells given in this appendix are the annual reports submitted to the Illinois State Water Survey's Illinois Water Inventory Program by water supply operators in the state. Note that this appendix does not include wells that water supply operators list as being on standby or emergency status or that are similarly reported as unused despite not being abandoned. In a few cases, the appendix includes new wells which were listed as active by water supply operators but which were not brought into service by the close of 1994.

Table Dl. Active Shallow Public Water Supply Wells in McHenry County

	Location					
Well	*T*	*R*	*Section*	*10-Acre Plot*	*Depth (ft)*	*Aquifer*
Union 2	43N	6E	4	5F	192	5
Lakewood 1	43N	7E	11	4F	395	5
Lake in the Hills 9	43N	7E	24	6C	108	2
Lake in the Hills 10	43N	7E	26	5F	127	2
Huntley 5	43N	7E	28	6F	95	2
Huntley 101	43N	7E	33	1G	200	5
Huntley 102	43N	7E	33	1G	194	5
Huntley 103	43N	7E	33	1G	85	4
Huntley 6	43N	7E	33	7A	154	4
Utilities, Inc. (Killarney Water Co.) 1	43N	8E	1	4D	335	5
Crystal Heights Association 2	43N	8E	4	4G	320	5
Crystal Lake 9	43N	8E	6	4A	205	5
Crystal Lake 12	43N	8E	8	1C	250	5
Crystal Lake 13	43N	8E	8	1C	250	5
Oakbrook Estates Mobile Home Park 1	43N	8E	10	2G	182	4 (see notes)
Northern Illinois Utilities, Inc. (Crystal Clear Water Co.) 2	43N	8E	10	8G	271	5
Cary 9	43N	8E	13	2C	124	1
Cary 3	43N	8E	13	7B	155	4
Cary 12	43N	8E	14	5C	163	5
Cary 11	43N	8E	14	1G	127	4
Lake in the Hills 2	43N	8E	20	4C	347	5
Lake in the Hills 8	43N	8E	21	5A	300	5
Cary 10	43N	8E	23	6E	194	4

Table D1. Continued

Well	*Annual Withdrawals gallons/(Year)*	*Maximum Daily Withdrawals gallons/(Year)*	*Year Drilled*
Union 2	9,109,220 (1992)	NR	1934
Lakewood 1	19,230,800 (1989)	180,500 (1989)	1971
Lake in the Hills 9	NR	NR	1992
Lake in the Hills 10	NR	NR	1994
Huntley 5	44,990,700 (1991)	NR	1969
Huntley 101	NR	NR	1979
Huntley 102	NR	NR	1979
Huntley 103	NR	NR	1979
Huntley 6	118,283,000 (1991)	533,750 (1991)	1979
Utilities, Inc. (Killarney Water Co.) 1	32,434,914 (1994)	140,267 (1994)	NR
Crystal Heights Association 2	NR	NR	1987
Crystal Lake 9	145,635,000 (1994)	399,000 (1994)	1986
Crystal Lake 12	103,500,000 (1993)	576,000 (1994)	1986
Crystal Lake 13	132,972,000 (1993)	648,000 (1994)	1987
Oakbrook Estates Mobile Home Park 1	6,267,000 (1994)	NR	NR
Northern Illinois Utilities, Inc. (Crystal Clear Water Co.) 2	23,430,000 (1994)	NR	1961
Cary 9	89,506,000 (1994)	484,000 (1994)	1981
Cary 3	34,147,000 (1994)	193,000 (1994)	1956
Cary 11	164,209,000 (1994)	669,000 (1994)	1990
Cary 12	not in service in 1994		1993
Lake in the Hills 2	NR	NR	1948
Lake in the Hills 8	NR	NR	1991
Cary 10	123,834,000 (1994)	528,000 (1994)	1981

Table D1. Continued

Well	*Location*				*Depth* **(ft)**	*Aquifer*
	T	*R*	*Section*	*10-Acre Plot*		
Algonquin 0 (see notes)	43N	8E	27	2E	NA	NA
Algonquin 1	43N	8E	27	2E	165	5
Lake in the Hills 6	43N	8E	28	5F	104	5
Lake in the Hills 1	43N	8E	29	4E	257	5
Algonquin 6	43N	8E	34	1A	152	4
Algonquin 5	43N	8E	34	2A	131	4
Fox River Grove 1	43N	9E	18	3A	140	5
Fox River Grove 2	43N	9E	18	3A	120	5
Marengo 7	44N	5E	36	1F	58	1
Marengo 6	44N	5E	36	4G	87	1
Woodstock 4	44N	7E	5	7D	205	5
Woodstock 8	44N	7E	6	1G	166	5
Woodstock 9	44N	7E	6	1H	175	5
Northern Illinois Utilities, Inc. (McHenry Shores Water Co.) 1	44N	8E	2	1B	180	5
Northern Illinois Utilities, Inc. (McHenry Shores Water Co.) 2	44N	8E	2	2A	135	5
McHenry 7	44N	8E	4	1H	240	5
McHenry 8	44N	8E	4	2H	203	5
Deering Oaks Subdivision 1	44N	8E	27	8C	280	5
Deering Oaks Subdivision 2	44N	8E	27	8D	178	5
Utilities, Inc. (Walkup Woods Water Co.) 2	44N	8E	29	4C	325	5
Royal Oaks Mobile Home Park 1	44N	8E	31	7H	80	1 (see notes)

Table D1. Continued

Well	*Annual Withdrawals gallons/(Year)*	*Maximum Daily Withdrawals gallons/(Year)*	*Year Drilled*
Algonquin 0	48,050,000 (1994) (see notes)	557,000 (1994) (see notes) "	1895
Algonquin 1			1955
Lake in the Hills 6	NR	NR	1980
Lake in the Hills 1	NR	NR	1948
Algonquin 6	204,491,000 (1994)	1,289,000 (1994)	1984
Algonquin 5	87,598,000 (1994)	878,000 (1994)	1978
Fox River Grove 1	110,503,000 (1994)	600,000 (1994)	1928
Fox River Grove 2	47,723,000 (1994)	580,000 (1994)	1956
Marengo 7	2,088,800 (1994)	NR	1993
Marengo 6	167,761,500 (1994)	NR	1976
Woodstock 4	0 (1994)	not applicable	1948
Woodstock 8	259,684,200 (1994)	1,267,200 (1994)	1989
Woodstock 9	158,030,400 (1994)	1,353,600 (1994)	1991
Northern Illinois Utilities, Inc. (McHenry Shores Water Co.) 1	8,607,300 (1994)	NR	1954
Northern Illinois Utilities, Inc. (McHenry Shores Water Co.) 2	37,896,500 (1994)	NR	1957
McHenry 7	128,101,000 (1994)	NR	1981
McHenry 8	67,938,000 (1994)	NR	1985
Deering Oaks Subdivision 1	941,000 (1994)	11,000 (1994)	1946
Deering Oaks Subdivision 2	1,116,000 (1994)	15,000 (1994)	1954
Utilities, Inc. (Walkup Woods Water Co.) 2	21,071,119 (1994)	76,965 (1994)	1972
Royal Oaks Mobile Home Park	2,628,000 (1994)	NR	NR

Table D1. Continued

Well	*Location*				*Depth (ft)*	*Aquifer*
	T	*R*	*Section*	*10-Acre Plot*		
Crystal Lake 10	44N	8E	32	3F	258	5
Crystal Lake 14	44N	8E	33	2G	243	5
Crystal Lake 11	44N	8E	33	4F	237	5
Prairie Ridge Association 1	44N	8E	34	2B	360	5
C and A Water Corporation 1	44N	9E	5	5G	220	5 (see notes)
Community Service Corporation 4	44N	9E	18	4A	120	5 (see notes)
Island Lake Water Co. A-6	44N	9E	20	1D	122	5
Island Lake 4-6	44N	9E	20	7D	146	5
Island Lake 4-10	44N	9E	20	7D	145	5
Nunda Utility Co. 1	44N	9E	29	6D	189	5
Valley Hi Nursing Home 3	45N	6E	23	7C	195	5
Northern Illinois Utilities, Inc. (Wonder Lake Water Co.) 1	45N	7E	13	5E	180	4
Northern Illinois Utilities, Inc. (Highland Shores Water Co.) 1	45N	7E	13	6C	220	4
Northern Illinois Utilities, Inc. (Highland Shores Water Co.) 3	45N	7E	14	1B	167	4
Woodstock 7A	45N	7E	32	3E	114	4
Woodstock 10	45N	7E	32	4B	107	4
Claremont Hills Subdivision 1	45N	8E	14	6F	290	5

Table D1. Continued

Well	*Annual Withdrawals gallons/(Year)*	*Maximum Daily Withdrawals gallons/(Year)*	*Year Drilled*
Crystal Lake 10	50,319,000(1994)	648,000 (1994)	1987
Crystal Lake 14	42,890,000 (1994)	648,000(1994")	1992
Crystal Lake 11	58,793,000 (1994)	648,000(1994)	1987
Prairie Ridge Association 1	3,285,000 (1994)	19,000(1994)	1977
C and A Water Corporation 1	1,105,585(1990)	3,029 (1990)	1952
Community Service Corporation 4	17,466,000(1994)	52,000(1994)	NR
Island Lake Water Co. A-6	10,741,000(1994)	NR	1940
Island Lake 4-6	10,619,500 (1994)	126,000 (1994)	1989
Island Lake 4-10	8,120,500(1994)	116,000 (1994)	1989
Nunda Utility Co. 1	10,956,000(1990)	NR	1948
Valley Hi Nursing Home 3	6,217,600 (1994)	25,900 (1994)	1990
Northern Illinois Utilities, Inc. (Wonder Lake Water Co.) 1	1,650,000(1993)	NR	1955
Northern Illinois Utilities, Inc. (Highland Shores Water Co.) 1	27,275,600 (1994)	NR	1952
Northern Illinois Utilities, Inc. (Highland Shores Water Co.) 3	44,956,100(1994)	NR	1988
Woodstock 7A	277,211,000(1994)	1,317,600(1994)	1989
Woodstock 10	186,619,000(1994)	1,411,200 (1994)	1991
Claremont Hills Subdivision 1	10,129,800(1991)	NR	1970

Table D1. Continued

Well	*Location*				*Depth (ft)*	*Aquifer*
	T	*R*	*Section*	*10-Acre Plot*		
Northern Illinois Utilities, Inc. (Wooded Shores Subdivision) 2	45N	8E	18	3B	222	5
Eastwood Manor Subdivision 2	45N	8E	25	4D	220	5
McHenry 9	45N	8E	26	2H	205	5
McHenry 5	45N	8E	27	8C	95	5
McHenry 6	45N	8E	27	8C	131	5
McHenry 2	45N	8E	35	5A	60	1
McHenry 3	45N	8E	35	5A	185	5
Utilities, Inc. (Whispering Hills Water Co.) 1A	45N	9E	7	2G	303	5
Utilities, Inc. (Whispering Hills Water Co.) 3	45N	9E	7	3E	255	5
Utilities, Inc. (Whispering Hills Water Co.)7	45N	9E	7	4A	168	5
Johnsburg 1	45N	9E	7	7A	261	5
Harvard 7	46N	5E	36	5F	144	5
Harvard 6	46N	5E	36	6F	197	5
Harvard 8	46N	5E	36	8D	110	5
Hebron 4	46N	7E	17	1H	125	1
Richmond 1	46N	8E	9	4B	170	5
Richmond 2	46N	8E	9	4F	144	5

Abbreviations: NR = not reported NA = not applicable

Notes: Annual and maximum daily withdrawal figures are based on figures reported to the Illinois Water Inventory Program for 1994 or, when not reported for 1994, for the most recent year preceding 1994.

Table D1. Concluded

Well	*Annual Withdrawals gallons/(Year)*	*Maximum Daily Withdrawals gallons/(Year)*	*Year Drilled*
Northern Illinois Utilities, Inc.. (Wooded Shores Subdivision) 2	20,187,000(1994)	NR	1959
Eastwood Manor Subdivision 2	NR	NR	1972
McHenry 9	94,835,000 (1994)	NR	1992
McHenry 5	113,492,000(1994)	NR	1974
McHenry 6	102,450,000 (1994)	NR	1978
McHenry 2	117,570,000(1994)	NR	1960
McHenry 3	57,418,000(1994)	NR	1968
Utilities, Inc. (Whispering Hills Water Co.) 1A	49,069,000(1994)	238,323 (1994)	1984
Utilities, Inc. (Whispering Hills Water Co.) 3	6,198,000(1994)	76,129 (1994)	1974
Utilities, Inc. (Whispering Hills Water Co.) 7	96,869,000 (1994)	402,323 (1994)	1990
Johnsburg 1	1,994,100(1993)	47,400 (1993)	1992
Harvard 7	128,869,000 (1994)	529,000 (1994)	1986
Harvard 6	136,401,000(1994)	609,000 (1994)	1963
Harvard 8	not in service in 1994		1993
Hebron 4	33,500,000(1994)	150,000 (1994)	1983
Richmond 1	15,661,800 (1994)	124,400 (1994)	1927
Richmond 2	30,528,100(1994)	170,900(1994)	1956

Driller's logs are not available for Oakbrook Estates Mobile Home Park 1, Royal Oaks Mobile Home Park 1, C and A Water Corporation 1, and Community Service Corporation 4. Aquifer assignments for these wells are based on well depth.

Algonquin well 0 is an infiltration tile system rather than a well in the conventional sense of the term. Therefore, no well depth or aquifer assignment is given.

Reported pumpage from Algonquin wells 0 and 1 is the combined total from both wells. Individual totals are not available.

APPENDIX E. NOTES ON CAPTURE ZONE ESTIMATIONS

Algonquin wells 5 and 6 Algonquin wells 5 and 6 are only about 700 ft apart, yet pumping test data collected at the wells indicate widely divergent values of hydraulic conductivity (≤240 ft/d at well 5 and 1,800 ft/d at well 6). This divergence suggests considerable lateral variation in texture of the source aquifer of the wells. In the absence of additional data suggesting the actual distribution of hydraulic conductivity values within the source aquifer in the vicinity of the wells, then, a hydraulic conductivity of 1,000 ft/d was employed in the capture zone estimations of the wells. This is an approximate average of the results of pumping tests at the wells.

Crystal Lake wells 10, 11, and 14 Five-year capture zones for Crystal Lake wells 10, 11, and 14 were not estimated because data reported to the Illinois Water Inventory Program (IWIP) by the operator indicate that these wells were not brought into service sufficiently in advance of the mass water level measurement in fall 1994 to assure that steady-state conditions had been established by that date. Comparison of annual pumpage for 1994 and 1995 reported to the ISWS for Crystal Lake wells 10, 11, and 14 suggests that the wells were brought into service in about August 1994. Measurements taken by the operator at wells 10 and 11 show a decline in static water level from 815 to about 765 ft msl in well 10 and about 835 ft to about 815 ft msl in well 11 between February and December 1995; these measurements provide support for the assertion that steady-state conditions had not yet been reached at these wells in fall 1994; water level measurements from well 14 were not reported. The operator reported static water levels in December 1996 of about 805 ft and 802 ft msl in wells 10 and 11, respectively.

Fox River Grove wells 1 and 2 The estimated hydraulic conductivity of the lower, carbonate portion of Aquifer 5, which was used in other capture zone estimations (40 ft/d) of wells finished in Aquifer 5, was not considered to be representative of the bedrock at Fox River Grove wells 1 and 2. Pumping test data from well 2 (about 160 ft east of well 1) indicate a hydraulic conductivity of about 10 to 20 ft/d for Aquifer 5 in area of the wells. This is presumed to be a composite hydraulic conductivity reflecting contributions of ground water to well 2 from both the upper, unconsolidated portion of Aquifer 5 and the lower, carbonate portion. If this value is truly a composite, the actual hydraulic conductivities of the basal unconsolidated materials and underlying dolomite must be greater and lesser, respectively, than the composite value. Thus, it is likely that the actual hydraulic conductivity of the lower portion of Aquifer 5 in this area is less than 20 ft/d. Pumping test data from Algonquin well 7 suggest a hydraulic conductivity of about 170 ft/d for the upper, unconsolidated portion of Aquifer 5. Assuming porosities of 0.225 and 0.04 for the upper and lower portions of Aquifer 5, respectively, the ratio of hydraulic conductivity to porosity is greater for the upper portion of Aquifer 5 than for the lower portion. The capture zone estimations of Fox River Grove wells 1 and 2 therefore employed a hydraulic conductivity of 170 ft/d and a porosity of 0.225.

Harvard wells 6 and 7 It should be noted that the assignment of the sand and gravel deposits supplying Harvard wells 6 and 7 (located about 200 ft apart) to Aquifer 5 is somewhat uncertain. The log of well 6 clearly indicates that the screened outwash deposits in this well do not rest on bedrock, and the similarity in elevation between the screened outwash interval supplying water to well 7 to that of the upper screened interval in well 6 suggests that the outwash supplying water to well 7 does not rest on bedrock either. Logs of these and other wells in the area suggest that wells 6 and 7 are screened in outwash within diamicton of the Glasford and/or Winnebago Formations (the Glasford/Winnebago aquifer of Curry et al., 1998), and that these outwash intervals, together with the bedrock surface, converge with one another at a distance no greater than about 5,000 ft west of the well locations, so that the supplying intervals are incorporated into a basal outwash deposit that rests on the bedrock surface. The capture zone estimates of the two wells included in this report are accurate to the extent that heads in the screened Glasford and/or Winnebago outwash intervals supplying the wells are similar to the mapped potentiometric surface of Aquifer 5 appearing in Plate 5. In constructing Plate 5, this report assumed that heads in Harvard wells 6 and 7 (although the wells are finished in outwash deposits that are not in contact with, the bedrock surface) are representative of heads in the uppermost bedrock and in any basal outwash or rubble zone present in the area. This assumption was based largely on observations that the outwash intervals appear to be incorporated into a true basal outwash deposit a short distance west of the well locations and that measured heads in Harvard wells 6 and 7 are similar to those in area wells that are finished in bedrock or basal sand and gravel.

Lake in the Hills wells 1 and 2 Logs are not available for these wells. Woller and Sanderson (1976) report that these wells are open to the Silurian dolomite and Maquoketa Formation; therefore, assumed hydraulic conductivity and porosity values employed in the capture zone estimations of the wells were based on the procedures for Aquifer 5 as described in the methods sections of this report.

McHenry well 6 Neither a driller's log of McHenry well 6 nor detailed construction information showing screened and open intervals in the well is available. A log is available for McHenry well 5, however, which is screened in Aquifer 5 and is located about 400 ft west of well 6. The similarity in depth of well 6 to McHenry well 5, together with the fact that the wells are at a similar elevation, suggest that well 6 also obtains water from Aquifer 5.

McHenry wells 3, 7, and 8 McHenry wells 3, 7, and 8 penetrate farther into the bedrock than most other wells finished in Aquifer 5 for which capture zones were estimated. The logs of wells 3, 7, and 8 indicate that the wells are open to 56, 95, and 47 ft of carbonate bedrock, respectively. Although water levels from these wells were used in the construction of the potentiometric surface map of Aquifer 5 (Plate 5) and although that map was used in estimating five-year capture zones for the wells, it is possible, given the depth of bedrock penetration of the wells, that heads in the wells may not be representative of the basal unconsolidated aquifer materials and hydraulically connected uppermost bedrock that are included in Aquifer 5 in this report. If the fracture systems supplying water to wells 3, 7, and 8 do not have an efficient hydraulic connection to the basal unconsolidated aquifer materials and uppermost bedrock, the potentiometric surface map and capture zone estimations may not be accurate. The degree to which the heads in the wells are similar to those nearer the bedrock surface is a function of the degree of interconnection of fractures supplying water to the wells with those present in the uppermost bedrock immediately underlying the bedrock surface.

McHenry well 9 A five-year capture zone for McHenry well 9 was not estimated because data reported by the operator through IWIP indicate that the well was not brought into service sufficiently in advance of the mass water level measurement in fall 1994 to assure that steady-state conditions had been established by that date. Comparison of 1994 and 1995 total withdrawals reported to the

ISWS through IWIP suggests that McHenry well 9 was to be brought into service in about June 1994. Water level measurements from the well show a decline in static water levels in the well that provides support for the assertion that steady-state conditions had not been reached before fall 1994. In November 1994, the ISWS measured a static water level of about 739 ft msl in McHenry well 9. Measurements taken by the operator show the static water level in the well to have been at about 727 and 724 ft above sea level in February and December 1995, respectively.

Despite the fact that a capture zone was not estimated for the well, it also should be mentioned here that McHenry well 9 penetrates 152 ft of carbonate bedrock, which is greater than any other public water supply well assigned to Aquifer 5. Given this depth of bedrock penetration, it is possible that the head in well 9 may not be representative of the basal unconsolidated aquifer materials and hydraulically connected uppermost bedrock that are included in Aquifer 5 in this report. If the fracture systems supplying water to well 9 do not have efficient hydraulic connection to the basal unconsolidated aquifer materials and uppermost bedrock, the potentiometric surface map may not be accurate. The degree to which the head in well 9 is similar to heads nearer the bedrock surface is a function of the degree of interconnection of fractures supplying water to the wells with those present in the uppermost bedrock immediately underlying the bedrock surface.

Utilities, Inc. (Whispering Hills Water Co.) 1A Utilities, Inc. (Whispering Hills Water Co.) well 1A penetrates farther into the bedrock than most other wells finished in Aquifer 5 for which capture zones were estimated. The log of well 1A indicates that it is open to 63 ft of carbonate bedrock. Although the water level in this well was used in the construction of the potentiometric surface map of Aquifer 5 (Plate 5) and although that map was used in estimating the five-year capture zone for well 1A, it is possible, given the depth of bedrock penetration of the well, that the head in well 1A may not be representative of the basal unconsolidated aquifer materials and hydraulically connected uppermost bedrock that is included in Aquifer 5 in this report. If the fracture systems supplying water to well 1A do not have an efficient hydraulic connection to the basal unconsolidated aquifer materials and uppermost bedrock, the potentiometric surface map and capture zone estimation may not be accurate. The degree to which the head in well 1A is similar to those nearer the bedrock surface is a function of the degree of interconnection of fractures supplying water to the well with those present in the uppermost bedrock immediately underlying the bedrock surface.

Reference

Woller, D.M., and E.W. Sanderson. 1976. *Public Groundwater Supplies in McHenry County.* Illinois State Water Survey Bulletin 60-19.

APPENDIX F. NITRATE CONCENTRATIONS IN MCHENRY COUNTY GROUND WATER

Table Fl contains the results of nitrate analyses of ground-water samples obtained from shallow wells in McHenry County. The source of these data is the Illinois State Water Survey's Ground-Water Quality Database, which contains analytical results obtained by laboratories operated and maintained by the Illinois State Water Survey (ISWS) and the Illinois Environmental Protection Agency (IEPA). Since the purpose of Appendix F is to provide data for analysis that is pertinent only to the shallow ground water in McHenry County, it is limited to analytical results from wells that are 400 ft deep or less. These are 550 separate analytical results. The appendix includes many analytical results from ground-water samples obtained from the same well on several separate dates.

The division of the shallow aquifers of McHenry County into five hydrostratigraphic units, as has been employed elsewhere in this report, is not attempted with the aquifers supplying the wells listed in Table Fl. A distinction is made, however, between wells finished in sand and gravel aquifers and those finished in bedrock aquifers; this assignment is based on data included in the ISWS Ground-Water Quality Database. In rare instances, wells are finished in both sand and gravel and bedrock aquifers.

Since early 1979, the IEPA laboratory has reported a combined concentration of nitrite (NO_2^{-1}) and nitrate (NO_3^{-1}). Prior to this date, the IEPA laboratory reported NO_3^{-1} concentrations separately from those of NO_2^{-1}. The ISWS has always reported concentrations of NO_3^{-1} and NO_2^{-1} separately. The two categories of reported concentrations, nitrate (NO_3^{-1}) and nitrite+nitrate ($NO_2^{-1}+NO_3^{-1}$), are included in separate columns of the table.

Table F1. Nitrate Concentrations in McHenry County Ground Water

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	05E	03	2H	ISWS	06/71	20	sand and gravel	0.400	NR
43N	05E	03	7D	ISWS	06/71	18	sand and gravel	48.300	NR
43N	05E	03	7E	ISWS	06/71	28	sand and gravel	39.500	NR
43N	05E	03	7E	ISWS	06/20/72	28	sand and gravel	45.100	NR
43N	05E	03	7E	ISWS	06/20/72	22	sand and gravel	73.600	NR
43N	05E	03	7E	ISWS	06/17/74	28	sand and gravel	29.800	NR
43N	05E	03	7E	ISWS	06/17/74	22	sand and gravel	68.600	NR
43N	05E	03	7E	ISWS	06/06/75	22	sand and gravel	26.100	NR
43N	05E	03	7E	ISWS	06/13/77	210	sand and gravel	0.700	NR
43N	05E	04	2F	ISWS	06/71	18	sand and gravel	64.500	NR
43N	05E	04	2G	ISWS	03/71	22	sand and gravel	176.000	NR
43N	05E	04	2G	ISWS	06/71	22	sand and gravel	187.000	NR
43N	05E	04	2G	ISWS	06/20/72	22	sand and gravel	202.700	NR
43N	05E	04	2G	ISWS	06/07/73	25	sand and gravel	159.000	NR
43N	05E	04	2G	ISWS	06/17/74	22	sand and gravel	116.000	NR
43N	05E	04	2G	ISWS	06/06/75	22	sand and gravel	110.000	NR
43N	05E	04	2G	ISWS	06/13/77	22	sand and gravel	102.000	NR
43N	05E	04	4F	ISWS	03/71	25	sand and gravel	51.900	NR
43N	05E	04	5E	ISWS	03/71	20	sand and gravel	17.000	NR
43N	05E	04	5E	ISWS	06/71	20	sand and gravel	35.500	NR
43N	05E	04	5F	ISWS	06/71	25	sand and gravel	63.100	NR
43N	05E	08	5D	ISWS	06/06/75	55	sand and gravel	0.300	NR
43N	05E	09	5E	ISWS	06/71	16	sand and gravel	1.700	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	05E	17	1D	ISWS	03/71	33	sand and gravel	13.700	NR
43N	05E	20	1H	ISWS	03/71	160	bedrock	0.600	NR
43N	05E	32	5A	ISWS	03/71	80	sand and gravel	0.800	NR
43N	06E	04	5F	ISWS	09/17	16	sand and gravel	3.600	NR
43N	06E	04	5F	ISWS	04/19	16	sand and gravel	2.100	NR
43N	06E	04	5F	IEPA	01/30/80	192	bedrock	NR	<0.100
43N	06E	04	5F	IEPA	11/06/81	192	bedrock	NR	<0.100
43N	06E	04	5F	ISWS	03/01/82	192	sand and gravel	1.100	NR
43N	06E	04	5F	IEPA	05/23/85	192	bedrock	NR	<0.100
43N	06E	04	5F	IEPA	10/16/89	192	bedrock	NR	<0.100
43N	06E	04	5H	ISWS	07/69	80	sand and gravel	2.800	NR
43N	06E	04	5H	IEPA	02/01/72	92	sand and gravel	1.300	NR
43N	06E	04	5H	IEPA	02/05/76	80	sand and gravel	1.300	NR
43N	06E	04	5H	IEPA	05/17/76	93	sand and gravel	0.600	NR
43N	06E	04	5H	IEPA	12/28/77	93	sand and gravel	0.620	NR
43N	06E	04	5H	IEPA	11/14/78	80	sand and gravel	1.800	NR
43N	06E	04	5H	IEPA	05/05/80	80	sand and gravel	NR	0.200
43N	06E	04	5H	IEPA	08/27/87	80	sand and gravel	NR	0.140
43N	06E	04	5H	IEPA	08/27/87	80	sand and gravel	NR	0.150
43N	06E	04	5H	IEPA	10/16/89	80	sand and gravel	NR	0.180
43N	06E	04	6G	ISWS	03/62	80	sand and gravel	0.400	NR
43N	06E	05	1G	ISWS	03/71	28	sand and gravel	100.000	NR
43N	06E	05	4F	ISWS	06/71	24	sand and gravel	139.000	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	06E	05	4F	ISWS	06/71	21	sand and gravel	151.000	NR
43N	06E	05	4G	ISWS	06/71	28	sand and gravel	104.000	NR
43N	06E	05	4G	ISWS	06/17/74	28	sand and gravel	37.000	NR
43N	06E	08	8G	ISWS	10/17/72	261	bedrock	0.600	NR
43N	06E	09	8F	ISWS	03/71	210	sand and gravel	1.300	NR
43N	06E	10	5E	ISWS	03/71	190	sand and gravel	0.900	NR
43N	06E	15	6G	ISWS	03/71	180	sand and gravel	0.400	NR
43N	06E	19	3E	ISWS	03/71	137	sand and gravel	17.100	NR
43N	07E	06	2E	ISWS	05/37	166	bedrock	1.700	NR
43N	07E	08	4F	ISWS	05/37	21	sand and gravel	11.900	NR
43N	07E	10	6A	ISWS	07/60	106	sand and gravel	1.600	NR
43N	07E	11	4E	ISWS	08/09/72	395	bedrock	0.300	NR
43N	07E	11	4E	IEPA	07/24/74	395	bedrock	0.100	NR
43N	07E	11	4F	IEPA	01/31/77	395	bedrock	0.000	NR
43N	07E	11	4F	IEPA	11/20/78	395	bedrock	<0.400	NR
43N	07E	11	4F	IEPA	01/14/81	395	bedrock	NR	<0.100
43N	07E	11	4F	IEPA	09/26/83	395	bedrock	NR	0.110
43N	07E	11	4F	IEPA	08/21/85	395	bedrock	NR	<0.100
43N	07E	16	4E	ISWS	05/37	185	bedrock	1.100	NR
43N	07E	23	5G	ISWS	11/32	300	bedrock	0.400	NR
43N	07E	25	3D	ISWS	09/34	84	sand and gravel	0.300	NR
43N	07E	28	6F	ISWS	10/69	95	sand and gravel	0.600	NR
43N	07E	28	6F	IEPA	11/18/71	95	sand and gravel	0.000	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-AcrePlot*						
43N	07E	28	6F	IEPA	10/21/75	95	sand and gravel	0.800	NR
43N	07E	28	6F	IEPA	04/19/76	95	sand and gravel	0.200	NR
43N	07E	28	6F	IEPA	03/20/78	95	sand and gravel	0.000	NR
43N	07E	28	6F	IEPA	04/08/80	95	sand and gravel	NR	<0.100
43N	07E	28	6F	IEPA	04/19/82	95	sand and gravel	NR	<0.100
43N	07E	28	6F	IEPA	05/23/85	95	sand and gravel	NR	<0.100
43N	07E	30	3C	ISWS	05/37	142	bedrock	1.900	NR
43N	07E	33	4H	ISWS	01/68	78	sand and gravel	0.300	NR
43N	07E	33	5G	ISWS	05/37	75	sand and gravel	2.300	NR
43N	07E	33	6G	ISWS	08/46	54	sand and gravel	2.800	NR
43N	07E	33	6H	ISWS	07/47	69	sand and gravel	1.900	NR
43N	07E	33	6H	ISWS	11/53	63	sand and gravel	0.900	NR
43N	07E	33	6H	IEPA	10/21/75	61	sand and gravel	0.000	NR
43N	07E	33	6H	IEPA	11/21/86	63	sand and gravel	NR	<0.100
43N	07E	33	6H	IEPA	10/02/89	63	sand and gravel	NR	<0.100
43N	07E	33	7A	ISWS	11/29/79	154	sand and gravel	0.300	NR
43N	07E	33	7A	IEPA	04/19/82	154	sand and gravel	NR	<0.100
43N	07E	33	7A	IEPA	11/21/86	154	sand and gravel	NR	0.110
43N	07E	33	7A	IEPA	11/21/86	154	sand and gravel	NR	0.120
43N	08E	01	4D	IEPA	05/24/76	250	bedrock	0.000	NR
43N	08E	01	4D	IEPA	07/05/78	250	bedrock	0.000	NR
43N	08E	01	4D	IEPA	09/02/80	335	bedrock	NR	0.200
43N	08E	01	6H	ISWS	06/30	195	sand and gravel	1.800	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-AcrePlot*						
43N	08E	01	8D	ISWS	11/64	250	bedrock	0.400	NR
43N	08E	01	8D	IEPA	05/12/80	250	bedrock	NR	<0.100
43N	08E	01	8D	IEPA	11/15/82	250	bedrock	NR	<0.100
43N	08E	03	1G	ISWS	01/09/74	84	sand and gravel	0.300	NR
43N	08E	04	4G	IEPA	05/13/80	278	bedrock	NR	<0.100
43N	08E	04	4G	IEPA	06/03/82	278	bedrock	NR	<0.100
43N	08E	06	1E	ISWS	07/48	48	sand and gravel	0.300	NR
43N	08E	06	1E	IEPA	04/21/75	48	sand and gravel	0.700	NR
43N	08E	06	1E	IEPA	08/14/85	45	sand and gravel	NR	0.200
43N	08E	10	2G	IEPA	12/05/86	150	sand and gravel	NR	<0.100
43N	08E	10	2G	IEPA	07/12/90	150	sand and gravel	NR	<0.010
43N	08E	10	8G	IEPA	06/08/76	270	sand and gravel	0.200	NR
43N	08E	10	8G	IEPA	04/22/80	271	sand and gravel	NR	<0.100
43N	08E	10	8G	IEPA	05/17/82	271	sand and gravel	NR	<0.100
43N	08E	10	8G	IEPA	09/26/85	271	sand and gravel	NR	<0.100
43N	08E	12	2E	ISWS	05/62	122	sand and gravel	1.000	NR
43N	08E	12	4H	ISWS	05/31	229	bedrock	1.200	NR
43N	08E	13	1G	ISWS	09/16	300	bedrock	1.400	NR
43N	08E	13	1G	ISWS	11/22	300	bedrock	1.200	NR
43N	08E	13	2D	ISWS	04/19/84	108	sand and gravel	<0.300	NR
43N	08E	13	2D	IEPA	11/14/86	105	sand and gravel	NR	<0.100
43N	08E	13	7B	ISWS	11/56	155	sand and gravel	0.600	NR
43N	08E	13	7B	IEPA	05/26/72	155	sand and gravel	0.000	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	08E	13	7B	IEPA	04/26/76	155	bedrock	0.100	NR
43N	08E	13	7B	IEPA	02/20/79	155	sand and gravel	0.040	NR
43N	08E	13	7B	IEPA	05/12/80	155	sand and gravel	NR	<0.100
43N	08E	13	7B	IEPA	05/19/82	155	sand and gravel	NR	<0.100
43N	08E	13	7B	IEPA	11/14/86	155	sand and gravel	NR	<0.100
43N	08E	14	6A	IEPA	11/14/86	194	sand and gravel	NR	<0.100
43N	08E	14	6A	IEPA	11/14/86	194	sand and gravel	NR	<0.100
43N	08E	16	1G	ISWS	05/37	65	sand and gravel	24.800	NR
43N	08E	20	4C	IEPA	01/24/72	347	bedrock	0.000	NR
43N	08E	20	4C	IEPA	01/09/79	327	bedrock	0.040	NR
43N	08E	20	4C	IEPA	06/30/82	347	bedrock	NR	<0.100
43N	08E	24	2D	ISWS	08/31	143	sand and gravel	0.000	NR
43N	08E	24	2E	ISWS	10/33	94	sand and gravel	0.300	NR
43N	08E	24	3E	ISWS	12/30	94	sand and gravel	1.100	NR
43N	08E	24	3F	ISWS	05/35	106	sand and gravel	1.400	NR
43N	08E	24	4E	ISWS	03/31	106	bedrock	1.500	NR
43N	08E	24	5H	ISWS	03/26/73	100	sand and gravel	0.400	NR
43N	08E	26	2F	ISWS	07/30	285	bedrock	0.600	NR
43N	08E	26	8D	ISWS	05/37	84	sand and gravel	1.800	NR
43N	08E	27	2A	IEPA	11/07/71	5	sand and gravel	13.600	NR
43N	08E	27	2E	IEPA	03/28/78	170	bedrock	7.900	NR
43N	08E	27	2E	IEPA	11/05/80	165	bedrock	NR	<0.100
43N	08E	27	2E	IEPA	05/24/82	165	bedrock	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	08E	27	2E	IEPA	04/18/84	165	bedrock	NR	<0.100
43N	08E	27	2E	IEPA	10/09/84	165	bedrock	NR	<0.100
43N	08E	27	2E	IEPA	11/13/84	165	bedrock	NR	<0.100
43N	08E	27	2E	IEPA	03/15/85	165	bedrock	NR	<0.100
43N	08E	27	2E	IEPA	03/26/91	165	bedrock	NR	<0.010
43N	08E	27	2E	IEPA	06/13/91	165	bedrock	NR	<0.010
43N	08E	27	2E	IEPA	09/04/91	165	bedrock	NR	<0.010
43N	08E	27	2E	IEPA	12/11/91	165	bedrock	NR	<0.010
43N	08E	27	2E	IEPA	03/25/92	165	bedrock	NR	<0.010
43N	08E	27	2E	IEPA	06/10/92	165	bedrock	NR	<0.010
43N	08E	28	5F	IEPA	10/26/71	120	sand and gravel	0.000	NR
43N	08E	28	5F	IEPA	07/24/72	160	sand and gravel	0.000	NR
43N	08E	28	5F	IEPA	04/01/81	114	sand and gravel	NR	<0.100
43N	08E	28	5F	IEPA	06/11/91	113	sand and gravel	NR	<0.010
43N	08E	29	4E	IEPA	01/24/72	327	bedrock	0.000	NR
43N	08E	29	4E	IEPA	04/03/79	257	bedrock	NR	1.000
43N	08E	29	4E	IEPA	04/29/81	257	bedrock	NR	<0.100
43N	08E	29	4E	IEPA	06/30/82	257	bedrock	NR	<0.100
43N	08E	29	4E	IEPA	11/19/86	257	bedrock	NR	<0.100
43N	08E	29	4E	IEPA	06/11/91	257	bedrock	NR	<0.010
43N	08E	33	4E	ISWS	12/68	188	sand and gravel	4.500	NR
43N	08E	33	4H	ISWS	05/70	188	sand and gravel	1.900	NR
43N	08E	33	4H	ISWS	03/15/72	189	sand and gravel	0.900	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
43N	08E	33	4H	IEPA	04/07/76	155	sand and gravel	0.000	NR
43N	08E	33	4H	IEPA	11/05/80	188	sand and gravel	NR	<0.100
43N	08E	34	3A	ISWS	08/08/78	131	sand and gravel	0.500	NR
43N	08E	34	3A	IEPA	12/08/80	131	sand and gravel	NR	<0.100
43N	08E	34	3A	IEPA	02/02/83	131	sand and gravel	NR	<0.100
43N	08E	34	3A	IEPA	11/17/86	131	sand and gravel	NR	<0.100
43N	09E	08	6A	ISWS	08/36	170	sand and gravel	1.800	NR
43N	09E	17	2F	ISWS	11/36	50	sand and gravel	1.200	NR
43N	09E	17	2F	ISWS	11/36	23	sand and gravel	0.600	NR
43N	09E	17	2F	ISWS	11/36	95	sand and gravel	0.900	NR
43N	09E	18	2A	IEPA	09/20/71	120	sand and gravel	0.000	NR
43N	09E	18	3A	ISWS	01/29	145	bedrock	0.000	NR
43N	09E	18	3A	ISWS	07/47	145	bedrock	0.700	NR
43N	09E	18	3A	IEPA	09/20/71	145	sand and gravel	0.000	NR
43N	09E	18	3A	IEPA	04/03/78	148	bedrock	0.000	NR
43N	09E	18	3A	IEPA	04/28/80	120	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	04/28/80	140	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	06/01/82	120	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	06/02/82	140	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	07/01/85	120	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	07/01/85	140	bedrock	NR	<0.100
43N	09E	18	3A	IEPA	12/17/86	120	bedrock	NR	<0.100
43N	09E	18	4F	ISWS	04/58	20	sand and gravel	1.800	NR

Table F1. Continued

Well Location				Laboratory	Analysis Date (mo/yr) or (mo/day/yr)	Well Depth (ft)	Aquifer Type	Nitrate Concentration (mg/L as N)	Nitrite + Nitrate Concentration (mg/L as N)
T	*R*	*Section*	*10-AcrePlot*						
43N	09E	18	8C	IEPA	12/11/91	124	sand and gravel	NR	0.010
43N	09E	20	6H	ISWS	05/37	36	sand and gravel	4.000	NR
43N	09E	32	1E	ISWS	05/30	147	sand and gravel	1.200	NR
44N	05E	05	8D	ISWS	03/71	40	sand and gravel	0.800	NR
44N	05E	10	1A	ISWS	07/68	136	bedrock	1.200	NR
44N	05E	13	1G	ISWS	06/14/77	280	sand and gravel	0.900	NR
44N	05E	16	6E	ISWS	05/64	65	sand and gravel	1.000	NR
44N	05E	23	8H	ISWS	06/08/73	18	sand and gravel	11.900	NR
44N	05E	25	8A	ISWS	10/13	15	sand and gravel	23.800	NR
44N	05E	25	8A	ISWS	07/47	21	sand and gravel	12.600	NR
44N	05E	25	8A	ISWS	08/61	170	bedrock	0.700	NR
44N	05E	25	8A	ISWS	08/61	170	bedrock	1.000	NR
44N	05E	25	8A	ISWS	01/62	112	sand and gravel	1.000	NR
44N	05E	25	8A	ISWS	01/62	112	sand and gravel	1.200	NR
44N	05E	25	8A	IEPA	10/19/71	100	sand and gravel	0.400	NR
44N	05E	25	8A	IEPA	01/06/75	100	sand and gravel	0.400	NR
44N	05E	25	8A	ISWS	02/10/76	100	sand and gravel	0.700	NR
44N	05E	25	8A	IEPA	06/01/76	99	sand and gravel	1.200	NR
44N	05E	25	8A	IEPA	10/09/85	100	sand and gravel	NR	<0.100
44N	05E	32	2F	ISWS	06/12/80	38	sand and gravel	2.200	NR
44N	05E	32	2F	ISWS	06/12/80	22	sand and gravel	31.800	NR
44N	05E	32	5F	ISWS	06/71	15	sand and gravel	54.900	NR
44N	05E	32	5F	ISWS	06/71	30	sand and gravel	21.100	NR
44N	05E	32	5F	ISWS	06/20/72	30	sand and gravel	21.900	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
44N	05E	32	5F	ISWS	06/07/73	10	sand and gravel	104.000	NR
44N	05E	32	5F	ISWS	06/07/73	30	sand and gravel	40.200	NR
44N	05E	32	5F	ISWS	06/17/74 J	15	sand and gravel	41.900	NR
44N	05E	32	5F	ISWS	06/17/74	25	sand and gravel	45.500	NR
44N	05E	32	5F	ISWS	06/06/75	30	sand and gravel	36.300	NR
44N	05E	32	5F	ISWS	06/13/77	30	sand and gravel	13.900	NR
44N	05E	32	5F	ISWS	06/13/77	31	sand and gravel	0.200	NR
44N	05E	32	8F	ISWS	06/13/77	40	sand and gravel	18.800	NR
44N	05E	33	4G	ISWS	06/12/80	25	sand and gravel	53.300	NR
44N	05E	33	7E	ISWS	06/17/74	20	sand and gravel	9.500	NR
44N	05E	33	8E	ISWS	06/17/74	30	sand and gravel	0.000	NR
44N	05E	34	6F	ISWS	06/20/72	25	sand and gravel	217.300	NR
44N	05E	34	6F	ISWS	06/20/72	18	sand and gravel	81.500	NR
44N	05E	34	8E	ISWS	06/07/73	22	sand and gravel	48.600	NR
44N	05E	34	8F	ISWS	06/07/73	23	sand and gravel	49.700	NR
44N	05E	34	8F	ISWS	06/07/73	23	sand and gravel	4.600	NR
44N	05E	35	6E	ISWS	01/16/84	60	sand and gravel	<0.300	NR
44N	05E	36	4B	ISWS	02/62	85	sand and gravel	0.600	NR
44N	05E	36	4E	ISWS	07/02/76	87	sand and gravel	2.400	NR
44N	05E	36	*AG*	ISWS	03/62	85	sand and gravel	2.200	NR
44N	05E	36	4G	ISWS	03/71	25	sand and gravel	17.900	NR
44N	05E	36	4G	IEPA	10/19/71	85	sand and gravel	7.000	NR
44N	05E	36	4G	IEPA	01/06/75	85	sand and gravel	3.300	NR
44N	05E	36	4G	ISWS	02/10/76	85	sand and gravel	2.700	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
44N	05E	36	4G	IEPA	04/25/78	85	sand and gravel	0.150	NR
44N	05E	36	4G	IEPA	06/13/79	87	sand and gravel	NR	1.000
44N	05E	36	4G	IEPA	06/28/81	87	sand and gravel	NR	0.800
44N	05E	36	4G	IEPA	05/24/82	85	sand and gravel	NR	<0.100
44N	05E	36	4G	IEPA	09/20/83	85	sand and gravel	NR	0.360
44N	05E	36	4G	IEPA	11/12/86	88	sand and gravel	NR	1.400
44N	05E	36	4G	IEPA	11/12/86	85	sand and gravel	NR	0.660
44N	06E	08	8A	ISWS	03/71	70	sand and gravel	0.400	NR
44N	06E	16	5H	ISWS	01/24/73	15	sand and gravel	36.800	NR
44N	06E	22	1D	ISWS	01/30/79	60	sand and gravel	0.600	NR
44N	06E	22	1D	ISWS	01/18/83	20	sand and gravel	26.100	NR
44N	06E	26	8A	ISWS	03/71	23	sand and gravel	5.100	NR
44N	06E	26	8A	ISWS	07/71	23	sand and gravel	15.600	NR
44N	07E	02	8H	ISWS	07/31/78	140	sand and gravel	0.600	NR
44N	07E	05	7D	ISWS	11/22	196	sand and gravel	1.200	NR
44N	07E	05	7D	ISWS	12/33	196	sand and gravel	0.900	NR
44N	07E	05	7D	ISWS	12/33	206	sand and gravel	0.900	NR
44N	07E	05	7D	ISWS	09/39	198	sand and gravel	0.900	NR
44N	07E	05	7D	ISWS	07/47	198	sand and gravel	1.100	NR
44N	07E	05	7D	IEPA	04/17/72	196	sand and gravel	0.400	NR
44N	07E	05	7D	IEPA	12/15/80	205	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	03/19/81	196	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	09/19/83	197	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	09/19/83	198	sand and gravel	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-AcrePlot*						
44N	07E	05	7D	IEPA	09/19/83	206	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	07/02/85	196	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	09/04/85	205	sand and gravel	NR	<0.100
44N	07E	05	7D	IEPA	06/09/92	205	sand and gravel	NR	<0.010
44N	07E	06	1G	IEPA	06/09/92	166 .	sand and gravel	NR	<0.010
44N	07E	17	8D	ISWS	06/66	212	sand and gravel	0.800	NR
44N	07E	25	1B	ISWS	04/75	255	bedrock	0.700	NR
44N	07E	25	5B	ISWS	04/75	255	bedrock	0.900	NR
44N	08E	02	1B	IEPA	01/29/72	180	sand and gravel	0.000	NR
44N	08E	02	1B	ISWS	07/06/72	180	sand and gravel	0.700	NR
44N	08E	02	1B	IEPA	11/02/81	180	bedrock	NR	<0.100
44N	08E	02	1B	IEPA	06/01/82	180	bedrock	NR	<0.100
44N	08E	02	1B	IEPA	07/15/86	180	bedrock	NR	<0.100
44N	08E	02	2A	IEPA	01/29/72	135	sand and gravel	0.000	NR
44N	08E	02	2A	ISWS	07/06/72	135	sand and gravel	0.800	NR
44N	08E	02	2A	IEPA	02/03/76	135	sand and gravel	0.000	NR
44N	08E	02	2A	IEPA	02/06/78	135	sand and gravel	0.000	NR
44N	08E	02	2A	IEPA	04/22/80	135	sand and gravel	NR	<0.100
44N	08E	02	2A	IEPA	05/17/82	135	sand and gravel	NR	<0.100
44N	08E	02	2A	IEPA	08/13/85	135	sand and gravel	NR	<0.100
44N	08E	05	4G	IEPA	11/05/71	178	sand and gravel	0.000	NR
44N	08E	12	5E	ISWS	07/13/82	44	sand and gravel	0.500	NR
44N	08E	12	5F	ISWS	04/59	47	sand and gravel	0.800	NR
44N	08E	12	5F	IEPA	12/20/71	47	sand and gravel	0.400	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
44N	08E	12	5F	IEPA	08/01/76	47	sand and gravel	0.000	NR
44N	08E	22	4B	ISWS	12/66	98	sand and gravel	0.000	NR
44N	08E	22	4C	ISWS	10/66	134	bedrock	0.300	NR
44N	08E	22	4C	ISWS	12/66	127	sand and gravel	0.600	NR
44N	08E	22	5C	ISWS	05/60	123	sand and gravel	0.000	NR
44N	08E	22	5D	ISWS	11/24/81	132	sand and gravel	<0.500	NR
44N	08E	27	4B	ISWS	06/21/77	178	sand and gravel	0.600	NR
44N	08E	27	8C	IEPA	12/29/80	280	bedrock	NR	<0.100
44N	08E	27	8C	IEPA	02/15/83	280	bedrock	NR	<0.100
44N	08E	27	8C	IEPA	11/18/86	280	bedrock	NR	<0.100
44N	08E	27	8D	IEPA	04/12/76	200	sand and gravel	0.100	NR
44N	08E	27	8D	IEPA	03/28/78	200	sand and gravel	0.000	NR
44N	08E	27	8D	IEPA	05/28/80	178	sand and gravel	NR	<0.100
44N	08E	27	8D	IEPA	05/19/82	178	sand and gravel	NR	<0.100
44N	08E	27	8D	IEPA	11/18/86	178	sand and gravel	NR	<0.100
44N	08E	29	2C	ISWS	02/26/73	325	bedrock	0.900	NR
44N	08E	29	5C	IEPA	01/31/72	272	bedrock	0.000	NR
44N	08E	29	7B	IEPA	01/31/77	325	sand and gravel	0.000	NR
44N	08E	29	7B	IEPA	01/31/77	276	sand and gravel	0.400	NR
44N	08E	29	7B	IEPA	12/09/86	272	sand and gravel	NR	<0.100
44N	08E	29	7C	IEPA	11/20/78	325	bedrock	<0.400	NR
44N	08E	29	7C	IEPA	01/14/81	325	bedrock	NR	<0.100
44N	08E	29	7C	IEPA	02/10/83	325	bedrock	NR	<0.100
44N	08E	29	7C	IEPA	12/09/86	325	bedrock	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-AcrePlot*						
44N	08E	31	7H	IEPA	12/05/86	80	sand and gravel	NR	<0.100
44N	08E	31	7H	IEPA	12/05/86	258	bedrock	NR	<0.100
44N	08E	33	5A	ISWS	03/63	371	bedrock	1.100	NR
44N	08E	33	81	IEPA	04/21/75	285	bedrock	0.400	NR
44N	08E	33	8A	ISWS	05/69	60	sand and gravel	56.800	NR
44N	08E	33	8A	ISWS	05/69	319	bedrock	2.300	NR
44N	08E	33	8A	ISWS	05/69	62	sand and gravel	16.700	NR
44N	08E	33	8A	ISWS	04/71	60	sand and gravel	19.500	NR
44N	08E	33	8A	ISWS	04/71	62	sand and gravel	24.600	NR
44N	08E	33	8A	ISWS	04/71	319	bedrock	0.700	NR
44N	08E	33	8B	ISWS	11/22	280	bedrock	1.700	NR
44N	08E	33	8B	IEPA	12/17/80	280	5050	NR	<0.100
44N	08E	33	8B	IEPA	12/10/86	280	bedrock	NR	<0.100
44N	08E	33	8H	ISWS	10/14	279	bedrock	1.300	NR
44N	08E	34	2B	IEPA	05/19/82	360	bedrock	NR	<0.100
44N	08E	34	2B	IEPA	11/18/86	360	bedrock	NR	<0.100
44N	09E	05	4G	IEPA	09/29/83	220	sand and gravel	NR	0.120
44N	09E	05	4G	IEPA	09/02/87	280	sand and gravel	NR	<0.100
44N	09E	05	8F	ISWS	07/29/76	162	sand and gravel	0.500	NR
44N	09E	06	1D	ISWS	07/29/76	88	sand and gravel	0.300	NR
44N	09E	06	3B	ISWS	07/29/76	83	sand and gravel	0.600	NR
44N	09E	06	4A	ISWS	07/29/76	95	sand and gravel	0.300	NR
44N	09E	06	4F	ISWS	07/29/76	60	sand and gravel	0.300	NR
44N	09E	06	4F	ISWS	07/13/82	64	sand and gravel	0.600	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
44N	09E	07	4G	ISWS	07/29/76	62	sand and gravel	1.100	NR
44N	09E	07	4H	ISWS	07/29/76	71	sand and gravel	0.500	NR
44N	09E	18	2B	ISWS	11/27/73	85	sand and gravel	0.200	NR
44N	09E	18	3F	ISWS	04/56	103	sand and gravel	0.500	NR
44N	09E	18	3F	IEPA	11/09/71	225	bedrock	0.000	NR
44N	09E	18	3F	IEPA	05/10/72	97	sand and gravel	0.000	NR
44N	09E	18	3F	IEPA	04/29/80	108	sand and gravel	NR	<0.100
44N	09E	18	3F	IEPA	06/01/82	108	sand and gravel	NR	<0.100
44N	09E	18	3F	IEPA	12/04/86	108	sand and gravel	NR	<0.100
44N	09E	29	6A	ISWS	04/31	117	sand and gravel	1.800	NR
44N	09E	29	6D	IEPA	04/24/78	189	bedrock	0.000	NR
44N	09E	29	6D	IEPA	07/05/78	189	bedrock	0.000	NR
44N	09E	29	6D	IEPA	05/17/82	189	bedrock	NR	<0.100
44N	09E	29	6D	IEPA	03/18/87	189	bedrock	NR	<0.100
44N	09E	29	7B	ISWS	04/31	111	sand and gravel	0.900	NR
45N	05E	32	4H	ISWS	02/26/74	208	sand and gravel	0.500	NR
45N	06E	23	8C	IEPA	12/08/86	110	sand and gravel	NR	<0.100
45N	07E	13	5E	IEPA	08/07/73	180	sand and gravel	0.000	NR
45N	07E	13	5E	IEPA	06/08/76	180	sand and gravel	0.000	NR
45N	07E	13	5E	IEPA	07/10/78	180	sand and gravel	0.900	NR
45N	07E	13	5E	IEPA	04/21/80	180	sand and gravel	NR	<0.100
45N	07E	13	5E	IEPA	05/19/82	180	sand and gravel	NR	<0.100
45N	07E	13	5E	IEPA	08/13/85	180	sand and gravel	NR	<0.100
45N	07E	13	5E	IEPA	09/04/91	180	sand and gravel	NR	0.040

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
45N	07E	13	6C	IEPA	01/10/72	160	sand and gravel	0.000	NR
45N	07E	13	6C	IEPA	03/14/73	160	sand and gravel	0.000	NR
45N	07E	13	6C	IEPA	06/15/73	220	bedrock	0.000	NR
45N	07E	13	6C	IEPA	06/08/76	220	bedrock	0.000	NR
45N	07E	13	6C	IEPA	06/05/78	220	sand and gravel	0.000	NR
45N	07E	13	6C	IEPA	04/21/80	220	sand and gravel	NR	<0.100
45N	07E	13	6C	IEPA	05/19/82	220	sand and gravel	NR	<0.100
45N	07E	13	6C	IEPA	02/19/87	220	sand and gravel	NR	<0.100
45N	07E	14	1C	ISWS	11/64	260	sand and gravel	0.400	NR
45N	07E	14	1C	IEPA	06/08/76	203	sand and gravel	0.000	NR
45N	07E	14	1C	IEPA	06/05/78	260	sand and gravel	0.000	NR
45N	07E	14	1C	IEPA	04/21/80	260	sand and gravel	NR	<0.100
45N	07E	14	1C	IEPA	05/19/82	260	sand and gravel	NR	<0.100
45N	07E	20	5D	ISWS	06/75	27	bedrock	0.400	NR
45N	07E	32	3C	ISWS	09/60	189	sand and gravel	0.800	NR
45N	07E	32	3C	IEPA	04/26/76	189	sand and gravel	0.000	NR
45N	07E	32	3C	IEPA	07/19/78	189	sand and gravel	0.000	NR
45N	07E	32	3C	IEPA	12/15/80	189	sand and gravel	NR	<0.100
45N	07E	32	3C	IEPA	02/14/83	189	sand and gravel	NR	<0.100
45N	07E	32	3C	IEPA	07/02/85	189	sand and gravel	NR	<0.100
45N	07E	32	3D	ISWS	05/61	114	sand and gravel	2.900	NR
45N	07E	32	3D	IEPA	07/19/78	114	sand and gravel	0.000	NR
45N	07E	32	3D	IEPA	12/15/80	114	sand and gravel	NR	<0.100
45N	07E	32	3D	IEPA	02/14/83	114	sand and gravel	NR	<0.100

Table F1. Continued

Well Location				Laboratory	Analysis Date (mo/yr) or (mo/day/yr)	Well Depth (ft)	Aquifer Type	Nitrate Concentration (mg/L as N)	Nitrite + Nitrate Concentration (mg/L as N)
T	R	Section	10-Acre Plot						
45N	07E	32	3D	IEPA	06/09/92	114	sand and gravel	NR	<0.010
45N	07E	32	3E	IEPA	03/07/73	114	sand and gravel	0.000	NR
45N	07E	32	4C	ISWS	11/60	193	sand and gravel	1.100	NR
45N	07E	32	4C	IEPA	02/02/72	193	sand and gravel	2.400	NR
45N	07E	32	4C	IEPA	04/27/76	192	sand and gravel	0.000	NR
45N	07E	32	4C	IEPA	07/19/78	192	sand and gravel	0.000	NR
45N	07E	32	4C	IEPA	02/14/83	192	sand and gravel	NR	<0.100
45N	07E	32	4C	IEPA	05/07/84	193	sand and gravel	NR	<0.100
45N	07E	32	4C	IEPA	03/26/85	193	sand and gravel	NR	<0.100
45N	07E	32	4C	IEPA	06/09/92	115	sand and gravel	NR	<0.010
45N	07E	32	5C	ISWS	03/60	127	sand and gravel	6.200	NR
45N	07E	33	6B	ISWS	06/75	75	sand and gravel	0.400	NR
45N	07E	33	7C	ISWS	05/60	200	sand and gravel	0.800	NR
45N	08E	05	3D	ISWS	11/64	93	sand and gravel	0.400	NR
45N	08E	07	5C	ISWS	02/23/75	198	sand and gravel	0.400	NR
45N	08E	09	NR	ISWS	10/41	200	sand and gravel	1.500	NR
45N	08E	13	1E	ISWS	09/39	110	sand and gravel	0.500	NR
45N	08E	14	5E	IEPA	08/22/72	290	bedrock	0.000	NR
45N	08E	14	6F	IEPA	09/01/82	290	bedrock	NR	<0.100
45N	08E	14	6F	IEPA	04/22/80	290	bedrock	NR	<0.100
45N	08E	14	8H	IEPA	10/30/72	290	bedrock	0.000	NR
45N	08E	18	3B	IEPA	06/07/78	210	sand and gravel	0.000	NR
45N	08E	18	3B	IEPA	04/21/80	222	sand and gravel	NR	<0.100
45N	08E	18	3B	IEPA	05/18/82	222	sand and gravel	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
45N	08E	18	3B	IEPA	08/13/85	222	sand and gravel	NR	<0.100
45N	08E	18	3C	IEPA	03/14/73	215	sand and gravel	0.000	NR
45N	08E	18	3C	ISWS	10/01/75	222	sand and gravel	0.900	NR
45N	08E	18	7B	IEPA	06/08/76	204	sand and gravel	0.000	NR
45N	08E	18	7B	IEPA	11/02/81	87	sand and gravel	NR	1.800
45N	08E	25	2A	IEPA	11/09/71	180	sand and gravel	0.000	NR
45N	08E	25	2A	IEPA	04/12/76	300	sand and gravel	0.200	NR
45N	08E	25	2A	IEPA	08/20/85	180	bedrock	NR	<0.100
45N	08E	25	4D	IEPA	04/12/76	300	sand and gravel	0.100	NR
45N	08E	25	4D	IEPA	01/31/79	220	sand and gravel	0.350	NR
45N	08E	25	4D	IEPA	07/08/80	220	sand and gravel	NR	<0.100
45N	08E	25	4D	IEPA	04/07/81	220	sand and gravel	NR	<0.100
45N	08E	25	4D	IEPA	09/22/83	220	sand and gravel + bedrock	NR	0.100
45N	08E	25	4D	IEPA	08/20/85	220	sand and gravel + bedrock	NR	<0.100
45N	08E	25	4D	IEPA	10/01/90	220	sand and gravel + bedrock	NR	<0.010
45N	08E	25	NR	IEPA	06/09/82	110	sand and gravel	NR	<0.100
45N	08E	26	4A	ISWS	08/18	71	sand and gravel	0.000	NR
45N	08E	26	5A	IEPA	11/13/86	82	sand and gravel	NR	<0.100
45N	08E	27	5G	IEPA	11/03/71	95	sand and gravel	0.000	NR
45N	08E	27	5G	IEPA	06/15/76	81	sand and gravel	0.000	NR
45N	08E	27	5G	IEPA	07/11/78	85	sand and gravel	0.090	NR

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
45N	08E	27	5G	IEPA	04/21/80	85	sand and gravel	NR	<0.100
45N	08E	27	5G	IEPA	05/18/82	85	sand and gravel	NR	<0.100
45N	08E	27	6G	IEPA	06/06/74	86	sand and gravel	0.300	NR
45N	08E	27	6G	IEPA	07/10/78	86	sand and gravel	0.040	NR
45N	08E	27	6G	IEPA	12/19/79	210	bedrock	NR	0.000
45N	08E	27	6G	IEPA	04/21/80	210	bedrock	NR	<0.100
45N	08E	27	6G	ISWS	10/02/80	210	bedrock	0.500	NR
45N	08E	27	6G	IEPA	05/18/82	210	bedrock	NR	<0.100
45N	08E	27	8C	IEPA	03/27/78	94	bedrock	0.000	NR
45N	08E	27	8C	ISWS	04/04/78	131	bedrock	0.250	NR
45N	08E	27	8C	IEPA	04/16/80	94	sand and gravel	NR	<0.100
45N	08E	27	8C	IEPA	02/07/82	131	bedrock	NR	0.180
45N	08E	27	8C	IEPA	11/13/86	131	bedrock	NR	0.110
45N	08E	27	8C	IEPA	11/13/86	95	sand and gravel	NR	<0.100
45N	08E	27	8C	IEPA	10/20/92	131	bedrock	NR	<0.010
45N	08E	27	NR	ISWS	09/56	85	sand and gravel	1.000	NR
45N	08E	35	5A	ISWS	07/60	60	sand and gravel	0.700	NR
45N	08E	35	5A	IEPA	10/26/71	185	bedrock	0.000	NR
45N	08E	35	5A	IEPA	03/28/74	60	sand and gravel	1.400	NR
45N	08E	35	5A	ISWS	06/10/74	60	sand and gravel	1.500	NR
45N	08E	35	5A	IEPA	04/28/76	185	bedrock	0.000	NR
45N	08E	35	5A	IEPA	03/27/78	185	bedrock	0.000	NR
45N	08E	35	5A	IEPA	04/21/78	60	sand and gravel	0.000	NR
45N	08E	35	5A	IEPA	04/16/80	60	sand and gravel	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
45N	08E	35	5A	IEPA	04/16/80	185	sand and gravel + bedrock	NR	<0.100
45N	08E	35	5A	IEPA	05/24/82	185	sand and gravel + bedrock	NR	<0.100
45N	08E	35	5A	IEPA	05/24/82	60	sand and gravel	NR	0.160
45N	08E	35	5A	IEPA	08/20/85	185	sand and gravel + bedrock	NR	<0.100
45N	08E	35	5A	IEPA	11/13/86	60	sand and gravel	NR	0.310
45N	09E	05	3D	IEPA	03/21/73	202	sand and gravel	0.000	NR
45N	09E	05	3D	IEPA	05/18/76	300	sand and gravel	0.000	NR
45N	09E	05	3D	IEPA	07/05/78	300	sand and gravel	0.000	NR
45N	09E	05	3D	IEPA	09/04/80	202	sand and gravel	NR	<0.100
45N	09E	05	3D	IEPA	12/09/86	93	sand and gravel	NR	<0.100
45N	09E	05	3D	IEPA	12/09/86	202	sand and gravel	NR	<0.100
45N	09E	05	4D	IEPA	05/18/76	300	sand and gravel	0.000	NR
45N	09E	07	2G	ISWS	11/64	303	bedrock	0.700	NR
45N	09E	07	2G	IEPA	08/24/73	303	bedrock	0.000	NR
45N	09E	07	2G	IEPA	11/08/78	303	bedrock	<0.400	NR
45N	09E	07	2G	IEPA	12/10/80	303	bedrock	NR	<0.100
45N	09E	07	2G	IEPA	12/09/86	303	bedrock	NR	<0.100
45N	09E	07	3B	IEPA	02/14/84	303	bedrock	NR	<0.100
45N	09E	07	3E	IEPA	10/19/78	255	bedrock	<0.400	NR
45N	09E	07	3E	IEPA	01/21/81	255	bedrock	NR	<0.100
45N	09E	07	3E	IEPA	02/15/84	255	bedrock	NR	<0.100

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
45N	09E	07	3E	IEPA	08/19/85	255	bedrock	NR	<0.100
45N	09E	07	8B	IEPA	02/15/84	294	bedrock	NR	<0.100
45N	09E	07	8D	ISWS	11/64	294	bedrock	0.600	NR
45N	09E	07	8D	IEPA	02/16/72	294	sand and gravel	0.000	NR
45N	09E	07	8D	IEPA	03/21/73	294	sand and gravel	0.000	NR
45N	09E	07	8D	IEPA	11/08/78	294	bedrock	<0.400	NR
45N	09E	07	8D	IEPA	12/09/86	294	bedrock	NR	<0.100
46N	05E	01	5D	ISWS	05/38	67	sand and gravel	0.700	NR
46N	05E	33	8A	ISWS	05/38	120	bedrock	5.200	NR
46N	05E	33	8B	ISWS	07/06/78	141	bedrock	0.600	NR
46N	05E	33	8B	ISWS	12/04/80	141	bedrock	0.200	NR
46N	05E	35	5A	ISWS	09/69	71	sand and gravel	13.400	NR
46N	05E	35	5A	ISWS	05/38	71	sand and gravel	11.500	NR
46N	05E	35	5A	ISWS	09/69	69	sand and gravel	2.300	NR
46N	05E	35	5A	IEPA	03/14/73	68	sand and gravel	7.900	NR
46N	05E	35	5A	IEPA	10/18/76	90	sand and gravel	11.000	NR
46N	05E	35	5A	IEPA	10/18/76	100	sand and gravel	8.800	NR
46N	05E	35	5A	IEPA	10/18/76	90	sand and gravel	0.000	NR
46N	05E	35	5A	IEPA	09/27/78	68	sand and gravel	9.200	NR
46N	05E	35	5A	IEPA	09/27/78	71	sand and gravel	8.800	NR
46N	05E	35	5A	IEPA	09/27/78	69	sand and gravel	11.000	NR
46N	05E	35	5A	IEPA	12/15/80	71	sand and gravel	NR	<0.100
46N	05E	35	5A	IEPA	12/15/80	69	sand and gravel	NR	2.900
46N	05E	35	5A	IEPA	12/15/80	68	sand and gravel	NR	2.900

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
46N	05E	35	5A	IEPA	02/28/83	68	sand and gravel	NR	2.600
46N	05E	35	5A	IEPA	02/28/83	69	sand and gravel	NR	0.120
46N	05E	35	5A	IEPA	02/28/83	71	sand and gravel	NR	3.900
46N	05E	35	5A	IEPA	04/25/84	68	sand and gravel	NR	2.700
46N	05E	35	5A	IEPA	10/09/84	68	sand and gravel	NR	2.600
46N	05E	35	5A	IEPA	11/13/84	68	sand and gravel	NR	2.600
46N	05E	35	5A	IEPA	03/26/85	68	sand and gravel	NR	2.400
46N	05E	35	5A	IEPA	06/11/85	69	sand and gravel	NR	<0.100
46N	05E	35	5A	IEPA	06/11/85	71	sand and gravel	NR	3.100
46N	05E	35	5B	ISWS	05/58	68	sand and gravel	0.900	NR
46N	05E	36	5B	ISWS	09/69	68	sand and gravel	6.000	NR
46N	05E	36	5F	ISWS	12/66	197	bedrock	0.200	NR
46N	05E	36	6F	ISWS	04/65	197	sand and gravel	0.800	NR
46N	05E	36	6F	ISWS	09/69	197	sand and gravel	1.300	NR
46N	05E	36	6F	IEPA	03/14/73	201	sand and gravel	0.000	NR
46N	05E	36	6F	IEPA	10/18/76	290	sand and gravel	0.400	NR
46N	05E	36	6F	IEPA	12/15/80	197	sand and gravel	NR	2.600
46N	05E	36	6F	IEPA	02/28/83	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	04/25/84	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	10/09/84	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	11/13/84	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	03/26/85	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	12/18/89	197	sand and gravel	NR	<0.100
46N	05E	36	6F	IEPA	03/27/91	197	sand and gravel	NR	<0.010

Table F1. Continued

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
46N	05E	36	6F	IEPA	06/17/91	197	sand and gravel	NR	<0.010
46N	05E	36	6F	IEPA	09/10/91	197	sand and gravel	NR	<0.010
46N	05E	36	6F	IEPA	12/05/91	197	sand and gravel	NR	0.030
46N	05E	36	6F	IEPA	03/11/92	197	sand and gravel	NR	<0.010
46N	05E	36	6F	IEPA	06/17/92	197	sand and gravel	NR	<0.010
46N	05E	36	6F	IEPA	09/14/92	197	sand and gravel	NR	<0.010
46N	05E	36	8F	ISWS	12/62	147	sand and gravel	0.900	NR
46N	06E	09	7D	ISWS	06/05/74	304	sand and gravel	0.300	NR
46N	07E	08	1A	IEPA	05/18/82	278	sand and gravel	NR	7.500
46N	07E	08	1A	IEPA	11/21/86	278	sand and gravel	NR	7.800
46N	07E	17	1H	IEPA	11/21/86	278	sand and gravel	NR	1.300
46N	07E	18	1E	ISWS	01/25/73	275	sand and gravel	0.200	NR
46N	08E	09	4B	IEPA	10/26/71	158	sand and gravel	1.300	NR
46N	08E	09	4B	IEPA	02/09/78	150	bedrock	0.000	NR
46N	08E	09	4B	IEPA	04/30/80	170	sand and gravel	NR	0.300
46N	08E	09	4B	IEPA	06/22/82	170	sand and gravel	NR	0.330
46N	08E	09	4B	IEPA	06/27/85	170	sand and gravel	NR	<0.100
46N	08E	09	4F	ISWS	04/56	144	sand and gravel	0.200	NR
46N	08E	09	4F	IEPA	12/02/75	160	sand and gravel	0.220	NR
46N	08E	09	4F	IEPA	02/01/78	144	sand and gravel	0.000	NR
46N	08E	09	4F	IEPA	04/30/80	144	sand and gravel	NR	<0.100
46N	08E	09	4F	IEPA	06/22/82	144	sand and gravel	NR	0.110
46N	08E	09	4F	IEPA	06/27/85	144	sand and gravel	NR	0.190
46N	08E	16	3G	ISWS	03/70	30	sand and gravel	2.600	NR

Table F1. Concluded

Well Location				*Laboratory*	*Analysis Date (mo/yr) or (mo/day/yr)*	*Well Depth (ft)*	*Aquifer Type*	*Nitrate Concentration (mg/L as N)*	*Nitrite + Nitrate Concentration (mg/L as N)*
T	*R*	*Section*	*10-Acre Plot*						
46N	08E	16	3G	ISWS	03/70	30	sand and gravel	4.600	NR
46N	08E	25	1H	ISWS	08/71	45	sand and gravel	0.700	NR
46N	08E	25	1H	ISWS	02/02/73	82	sand and gravel	0.100	NR
46N	08E	25	1H	ISWS	02/02/73	82	sand and gravel	0.300	NR
46N	08E	25	2H	ISWS	07/30/76	78	sand and gravel	0.800	NR
46N	08E	25	2H	ISWS	07/30/76	82	sand and gravel	0.700	NR
46N	08E	25	2H	ISWS	07/30/76	82	sand and gravel	0.500	NR

Abbreviations: T = township R = range IEPA = Illinois Environmental Protection Agency
ISWS = Illinois State Water Survey NR = not reported