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Groundwater Studies for Water Supply Planning In Kendall County, Illinois

George S. Roadcap, Scott C. Meyer, Walton R. Kelly, H. Allen Wehrmann, Yu-Feng Lin

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Center for Groundwater Science
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Abstract

Kendall County is currently dependent on groundwater to supply all of its communities, industries, and rural residents. With a county population estimated to grow from nearly 100,000 in 2007 to 190,000 by 2030 and 280,000 by 2050, a path to sustainable growth needs to incorporate sound planning and management decisions regarding groundwater availability and use within the county. To assist the county with planning, the Illinois State Water Survey conducted a series of investigations that included: a) measurement of water levels in the different aquifers, b) assessment of the groundwater quality in shallow wells, and c) assessment of the impacts of growing water demands on the groundwater resources using digital groundwater flow models. The groundwater resources of Kendall County can be divided into three units: 1) the sand and gravel aquifer in the northwestern corner of the county that is used by Plano, 2) the shallow bedrock aquifers in the southwest and northeast corners of the county that are used by Newark and several smaller supplies, and 3) the deep sandstone aquifers that occur throughout the county (and the northeastern Illinois region) and account for 75 percent of the county's water use and serve Oswego, Yorkville, Montgomery, and Joliet.

Water levels from the deep sandstone aquifers appear to be split by the Sandwich Fault Zone which cuts across the center of the county from northwest to southeast. The deepest water levels, often going below sea level, occur north and east of the fault near the large cones of depressions centered in the Aurora and Joliet areas. South of the fault, water levels in the sandstones are several hundred feet higher than north of the fault, suggesting that any northward flow towards the pumping centers is being cut off by the fault acting as a flow barrier.

Groundwater quality in the Shallow Bedrock Aquifer and sand and gravel aquifers in Kendall County is generally very good. With the exception of some elevated chloride values possibly due to road salt runoff, human activities have not caused significant contamination of these aquifers. Contaminants associated with agricultural activities (nitrate and atrazine) were generally below analytical detection limits. Water quality was found to be a function of both well depth and overlying till thickness, with generally better quality in deeper wells underlying thicker till deposits that protect aquifers from potentially contaminating activities.

For the Kendall County groundwater assessment, the authors significantly modified and recalibrated the previous regional groundwater flow model developed to include the hydraulic effects of the Sandwich Fault and the interconnections between the deep aquifers caused by the wells themselves. To estimate the effects of the increased water demand, a baseline, a high, and a low pumping scenario were simulated using the groundwater flow model out to the year 2050. Model results from all three scenarios indicate that water levels in the deep aquifers will continue to decline and potentially reach levels that adversely affect water supplies. A significant model result is that areas of the Ancell sandstone become completely dewatered, exacerbating drawdowns even further and potentially reducing well yields. A modified baseline scenario was created with additional future wells that were able to mitigate much of the adverse impacts. An area of concern for dewatering in all of the scenarios is the industrial corridor along the Des Plaines River in Will County. Because the Ancell sandstone is near the surface in southern Kendall County, any groundwater development should include an assessment of the impact of high-capacity and multi-aquifer wells on the surrounding private wells.

Introduction

Kendall County (Figure 1) is entirely dependent on groundwater to supply its communities, industries, and rural residents. Although the Fox River passes through the county and could potentially be used as a source of water supply, it is currently not being used. Therefore, a sustainable Kendall County must be based, in large part, on sound planning and management decisions regarding groundwater availability and use within the county.

In 2003, an assessment of the county's surface water and groundwater resources was initiated by the U.S. Geological Survey (USGS), in cooperation with the Kendall County Soil and Water Conservation District and Kendall County municipalities. The USGS presented a compilation of previous investigations of the region's water resources by numerous county, state, and federal research and regulatory agencies supplemented with limited new data collected from three new supply wells drilled for the City of Yorkville (Kay et al., 2005). An awareness of the link between sound groundwater management and a sustainable future prompted the county to approach the Illinois State Water Survey (ISWS) and Illinois State Geological Survey (ISGS) to provide additional technical information and support for the management and protection of their groundwater resources.

In response, the surveys proposed a series of investigations designed to provide information relevant to the long-term availability and sensitivity to contamination of groundwater resources in Kendall County. While these investigations will not provide answers to site-specific wellfield management or groundwater remediation questions, they do provide a county-wide evaluation and scientifically-based summary of what is known based on the latest available and newly collected information. The groundwater model developed for Kendall County can be used in the future to address alternative pumping scenarios and determine the possible impacts of future groundwater development at additional locations not addressed in this report.

This report summarizes results from studies performed by the ISWS and a separate report provides the details of ISGS investigations (Keefer et al., 2013). This report includes a section on observed groundwater levels (observations listed in Appendix A) and groundwater quality (with chemical results in Appendix B). The fourth chapter presents a description of the groundwater flow model of the aquifers supplying Kendall County and the model calibration results. The fifth chapter presents the flow model results. The last chapter provides a summary of the results of all the investigations. Emphasis is placed on the results of simulations of groundwater withdrawals from aquifers beneath Kendall County and, by default, the northeastern Illinois region. The sandstone aquifers (the Ancell and Ironton-Galesville sandstones) underlie all of northeastern Illinois; as such, large withdrawals from outside Kendall County have major impacts within Kendall County. Kendall County's principal Quaternary sand and gravel aquifers lie essentially only within the Fox River basin; significant sand and gravel deposits do not exist elsewhere in Kendall County.

Figure 1. Location map

The Kane County Development Department commissioned the ISWS and ISGS to conduct a broad assessment of groundwater and surface water resources in support of water supply planning efforts within Kane County. The objectives of that study were to clarify the relationships between aquifers and streams and to quantify the effects of current and future groundwater development. The study assimilated a wide variety of newly collected and archived hydrogeologic data into “models” or computer programs that simulate groundwater flow.

One of the flow models developed for Kane County formed the basis of a regional groundwater model for this planning study. This flow model was revised for the 11-county (Boone, Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, McHenry, and Will Counties) northeastern Illinois water supply planning effort (Meyer et al., 2012). The model was revised again for this project to address certain issues uncovered in the data collection effort and in previous modeling work. Because over 75 percent of the county's groundwater supply is derived from sandstone aquifers that are utilized regionally across northeastern Illinois and southeastern Wisconsin, and because withdrawals from communities and industries outside the county have impacts within Kendall County, the use of such a large model is necessary. This report discusses the development, application, and results of simulations using this revised computer model to evaluate the impacts from historical and possible future groundwater pumping scenarios on the six municipal supplies in Kendall County that contributed to this effort (Joliet, Minooka, Montgomery, Oswego, Plano, and Yorkville). A seventh community contributing to the project, Millbrook, does not have a municipal supply. Although the model has been modified, the same water demand scenarios developed for the 11-county northeastern Illinois water supply planning effort, including those developed for Kendall County, were simulated to assess the impacts of meeting those demands on aquifers serving the county, and thus assess Kendall County's groundwater future. A portion of the future demand for Joliet, Montgomery, Oswego, Plano, and Yorkville was spread out to the new water supply wells completed since 2004.

Acknowledgments

Principal sponsors of this project include the Kendall County Board, the City of Joliet, the Village of Minooka, the Village of Millbrook, the Village of Montgomery, the Village of Oswego, the City of Plano, and the City of Yorkville. The advice and cooperation of Jeff Wilkins, Kendall County Administrator, is greatly appreciated. Angela Zubko, Senior Planner in the Kendall County Department of Planning, Building & Zoning herded the report through its final stages. Significant additional support was provided by the State of Illinois General Revenue Fund. This report was prepared under the general supervision of Mike Demissie, ISWS Director.

Several ISWS researchers and support staff contributed to this project. Sandie Osterbur assisted in the assembly of private water well records for water level measurement and sampling. Tim Bryant assembled groundwater withdrawal data and municipal well information from the ISWS Illinois Water Inventory Program database. Randy Locke assisted in the selection of wells in which to measure groundwater levels, travel logistics, and data access. Randy, Kevin Rennels, and Steve Burch (now retired) measured the groundwater levels in wells in and around Kendall County. Kevin Rennels assisted in the interpretation of well logs. Sam Panno (ISGS) and Tom Holm helped in sample collection and reviewed the water quality section of the final report. Dan Webb, Lauren Sievers, Ruth Ann Nichols, and Sofia Lazovsky provided chemical analyses. Lisa Sheppard edited this report and Sara Olson reviewed the report's graphic elements.

Special thanks go to all the private well owners and community operators who allowed measurement or sampling of their wells. The views expressed in this report are those of the authors and do not necessarily reflect the views of the sponsors or the ISWS.

How Much Groundwater is Available in Kendall County?

This is a common question asked of the authors during previous and ongoing studies across northeastern Illinois and across the whole state. Unfortunately, an answer is not straightforward and must rely upon a number of assumptions or predictions regarding the future of water resource use and influences on water use, such as economics, throughout northeast Illinois (and quite possibly southeast Wisconsin). As background for those readers not familiar with groundwater, a discussion of groundwater concepts is provided in Meyer et al. (2012) and a glossary is on the ISWS water supply planning webpage.

The collective groundwater withdrawals from a network of wells spread across not only Kendall County, but also across all of northeastern Illinois and southeastern Wisconsin, caused the subsurface water pressure (head) in the source aquifers to decline. These head declines, in turn, cause water levels in wells to decline (drawdown), leading to increased pumping expenses and decreased well yields, decreased groundwater discharge to streams causing reduced stream baseflow, reduced water levels in lakes and wetlands, reduced saturated conditions in wetlands, and changes in vegetation. In some settings, reduced heads can result in decreased groundwater quality requiring expensive treatment.

How much water is available long-term—that is, the sustainable pumping rate—depends not only on the ability of the aquifers beneath Kendall County to yield water, but also on how water level and quality changes affect the environment and public acceptability of environmental impacts (Bredehoeft et al., 1982; Alley et al., 1999; Bredehoeft, 2002; Devlin and Sophocleus, 2005). Moreover, changes to the environment resulting from groundwater withdrawals constantly shift as recharge rates adjust to pumping and climate change, as new wells are constructed and pumped, as old wells are abandoned, and as pumping rates at operating wells are increased or decreased to meet water demands. Lastly, the availability of groundwater is very much related to the price the public is willing to pay for groundwater. If it is willing to pay the expense of desalinization of deep groundwater, for example, more groundwater could be made available. Complicating the issue of expenses is the fact that the cost of providing water is constantly changing under the influence of changing technologies and other factors.

In this study, then, instead of generating single-value estimates of groundwater availability, a groundwater flow model was employed to simulate plausible future pumping conditions and quantify impacts under those scenarios of future groundwater development. The model results are best used as a screening tool to provide a sense of the locations and magnitudes of groundwater pumping impacts. The results are useful for identifying areas for further data collection and for possible long-term monitoring, and the model itself is useful for assessing impacts from historical pumping as well as alternative pumping strategies possibly directed toward reducing future impacts.

Generalized Hydrogeologic Setting

The aquifers available to Kendall County (Figures 2 through 6) include the following:

- Sandstone Aquifers. Deep bedrock layers consisting principally of sandstone that are, for purposes of this study, referred to as the Ancell Unit, Ironton-Galesville Unit, and Mt. Simon Unit. South of the Sandwich Fault in Kendall County the authors also include the Ancell Unit sandstone. Kendall County immediately underlies the bedrock surface and is part of the Shallow Bedrock Aquifer;

- Shallow Bedrock Aquifer. A layer of weathered bedrock encompassing the uppermost 25 to 125 ft of the bedrock surface; and

- Sand and Gravel Aquifers. Several discontinuous layers of unconsolidated sand and gravel contained in the Quaternary Unit overlying the Shallow Bedrock Aquifer.

Sandstone and sand and gravel aquifers are aquifers mainly by virtue of the primary porosity and permeability of the materials comprising them. The Shallow Bedrock Aquifer, on the other hand, is, throughout most of its extent, an aquifer by virtue of secondary porosity that developed by weathering of the bedrock near the bedrock surface. Throughout most of its extent in northeastern Illinois, the Shallow Bedrock Aquifer consists of weathered dolomite in the upper portions of the Silurian-Devonian Carbonate Unit, Maquoketa Unit, and Galena-Platteville Unit. Where it consists of dolomite assigned to these three lithostratigraphic units, the Shallow Bedrock Aquifer encompasses about the uppermost 25 to 125 ft of bedrock (Meyer et al., 2009); this is the depth to which weathering has resulted in secondary porosity within the units.

As shown in Figures 4 through 6, the physical separation between the Shallow Bedrock Aquifer and the sandstone aquifers does not exist in an area of north-central Illinois southwest of the Sandwich Fault Zone. In this area, which includes west-central Kendall County, geologic uplift has resulted in erosion and removal of younger rocks, leaving the Ancell Unit and older rocks exposed at the bedrock surface (Figure 2). Where it is present at the bedrock surface, the Ancell Unit is considered by the authors to be part of the Shallow Bedrock Aquifer. Rocks as old as the Potosi-Franconia Unit are exposed at the bedrock surface on the south side of the Sandwich Fault Zone in north-central Illinois (Willman and others, 1967), and because weathering has resulted in development of secondary porosity in these units, principally dolomite in composition, the upper parts of these units are in this report considered to be part of the Shallow Bedrock Aquifer. Where the Ancell Unit is present at the bedrock surface, the authors include the entire Ancell Unit together with the uppermost 25 to 125 ft of underlying units (the Prairie du Chien-Eminence Unit and, possibly, the Potosi-Franconia Unit) in the Shallow Bedrock Aquifer. Where the Ancell is buried beneath younger bedrock units, the authors include the uppermost 25 to 125 ft of bedrock in the Shallow Bedrock Aquifer; this includes all or part of the Silurian-Devonian Carbonate Unit, Maquoketa Unit, and Galena-Platteville Unit, with the possible addition of the Ancell Unit. Where the Ancell has been completely removed by erosion in north-central Illinois, the uppermost 25 to 125 ft of the Prairie du Chien-Eminence Unit and Potosi-Franconia Units are included in the Shallow Bedrock Aquifer.

In most of northeastern Illinois, the Shallow Bedrock Aquifer and the Ancell Unit sandstone aquifers are separated by a laterally extensive and relatively impermeable interval underlying the Shallow Bedrock Aquifer, justifying a distinction between shallow aquifers (the sand and gravel aquifers and the Shallow Bedrock Aquifer) and the deep aquifers (the sandstone aquifers) (Meyer et al., 2009). In west-central Kendall County, however, as well as in other parts of the region such as southern Wisconsin, the rocks above the Ancell Unit have been removed by erosion. Since the separation between the Shallow Bedrock Aquifer and the sandstone aquifers is not present in west-central Kendall County south of the Sandwich Fault Zone, the shallow and deep aquifer nomenclature is not employed in this report, although it is applicable in most of Kendall County.

In Kendall County, as in most of northeastern Illinois, sandstone of the Mt. Simon Unit is not used as an aquifer because the water in it is considered too salty for most purposes. The authors wish to point out that should desalination become economically feasible at some time in the future, the Mt. Simon may be considered an alternative source of water.

Wells in Kendall County

As mentioned in the Introduction, Kendall County is 100 percent dependent upon groundwater for water supply. A review of water well records maintained by the ISWS provides detailed information on the variety of wells in the county. Two principal well types are summarized: wells used for domestic supply (e.g., rural farm and subdivision wells) and high-capacity wells used for industrial, commercial, irrigation, and municipal supplies.

ISWS records of nearly 5,000 domestic wells in the county formed the basis of the well depth histogram that appears in Figure 7. Domestic well depths range from less than 50 feet to over 900 feet with a median average depth of 200 feet. The bimodal distribution of the well depths suggests most wells tap either a sand and gravel aquifer or the Shallow Bedrock Aquifer within 400 feet of land surface or a sandstone aquifer at depths generally greater than 500 to 600 feet below land surface.

Records for just over 100 high-capacity wells in Kendall County formed the basis of the histogram appearing in Figure 8. These wells are generally much deeper but range in depth from less than 50 ft to 1,550 ft. Median depth is 348 ft, 148 ft deeper than the domestic wells. These wells, too, show a bimodal distribution, actually a separation, with most wells less than 700 ft deep, no wells between 900 and 1,250 ft deep, and several wells in the 1,300- to 1,500-ft depth range. Such deep wells, however, are typically open (not cased) along nearly the entire length of the well shaft, allowing water into the well bore from any water-bearing zone penetrated. Many of these wells were pumped at rates exceeding 200 gallons per minute (gpm) when drilled, and in several cases more than 1,000 gpm. Table 1 summarizes the active community wells serving Kendall County and wells serving Joliet (in Will County) and Montgomery (in Kane County). Note that Joliet has several wells in Kendall County and Minooka has wells in Will and Grundy County. Plano is the only community not using the sandstone aquifers, instead utilizing sand and gravel deposits largely situated along Big Rock Creek.

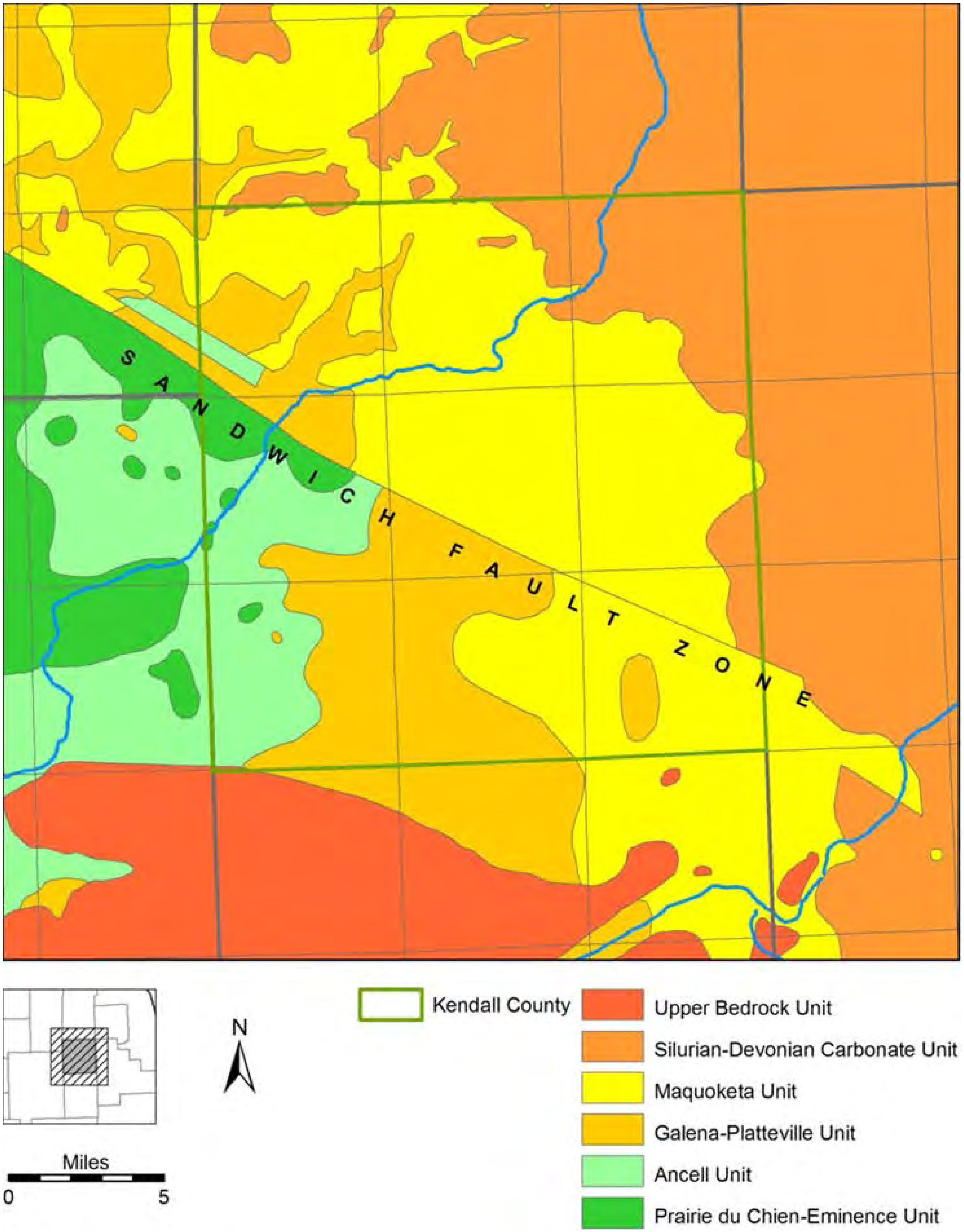
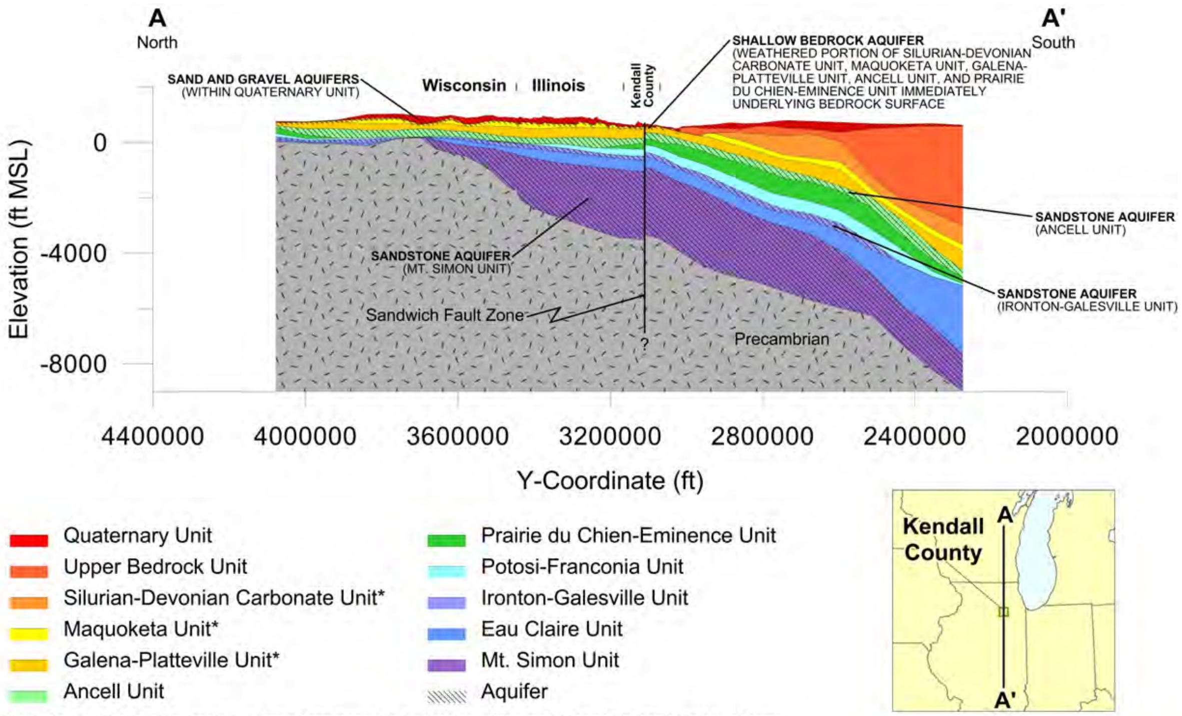
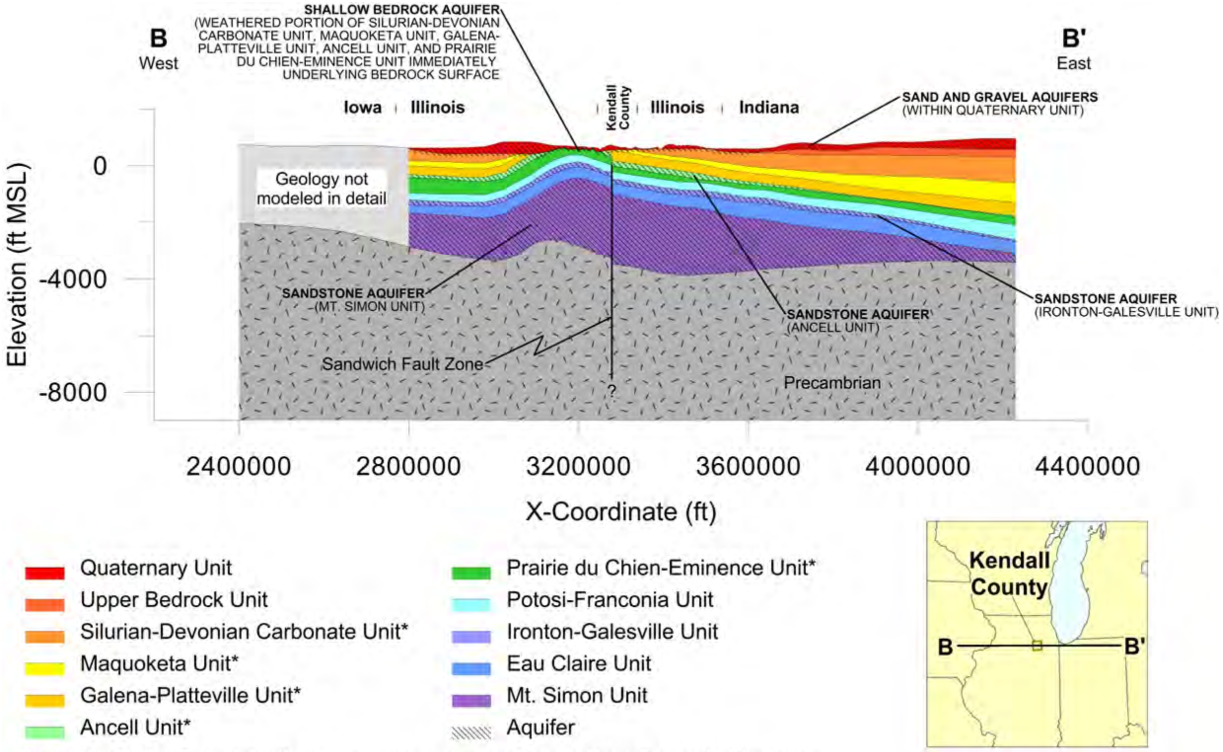


Figure 2. Bedrock surface hydrogeology of Kendall County area



*Included in Shallow Bedrock Aquifer where near the bedrock surface and Upper Bedrock Unit is absent.

Figure 3. North-south cross section showing regional hydrostratigraphic units



*Included in Shallow Bedrock Aquifer where near the bedrock surface and Upper Bedrock Unit is absent.

Figure 4. West-east cross section showing regional hydrostratigraphic units

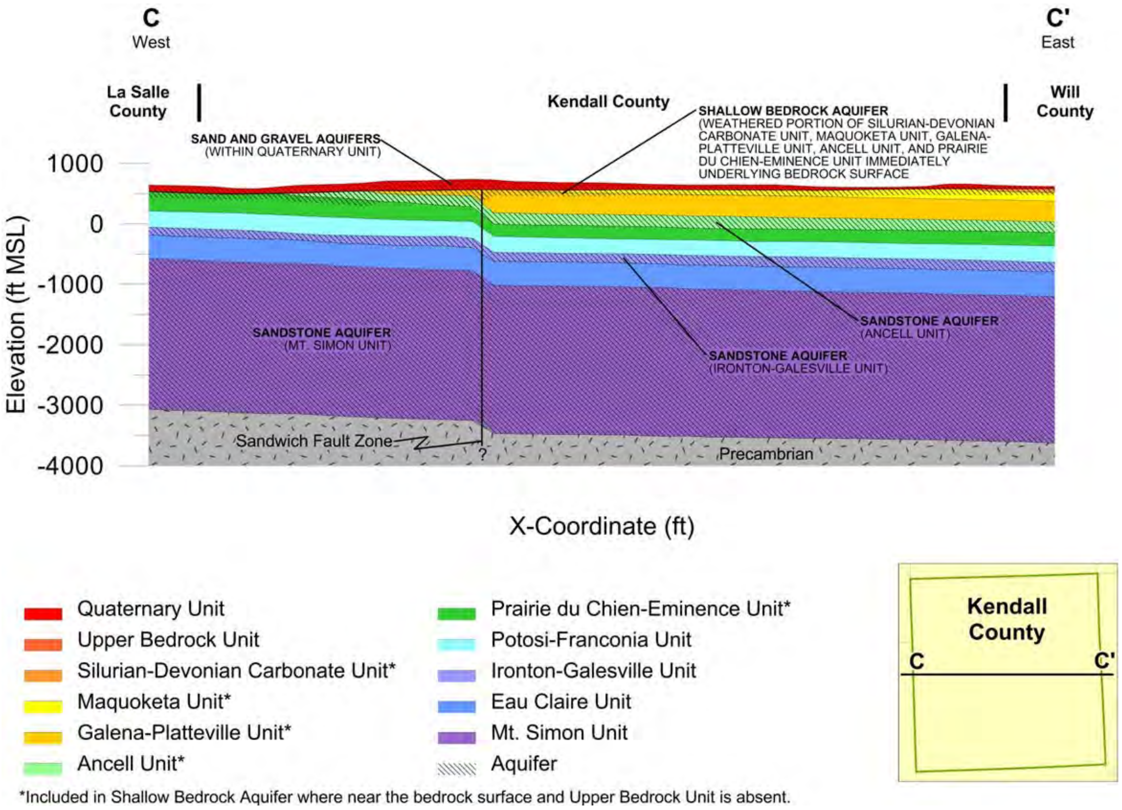


Figure 5. Detail from cross section B-B' (Figure 4) showing hydrostratigraphic units

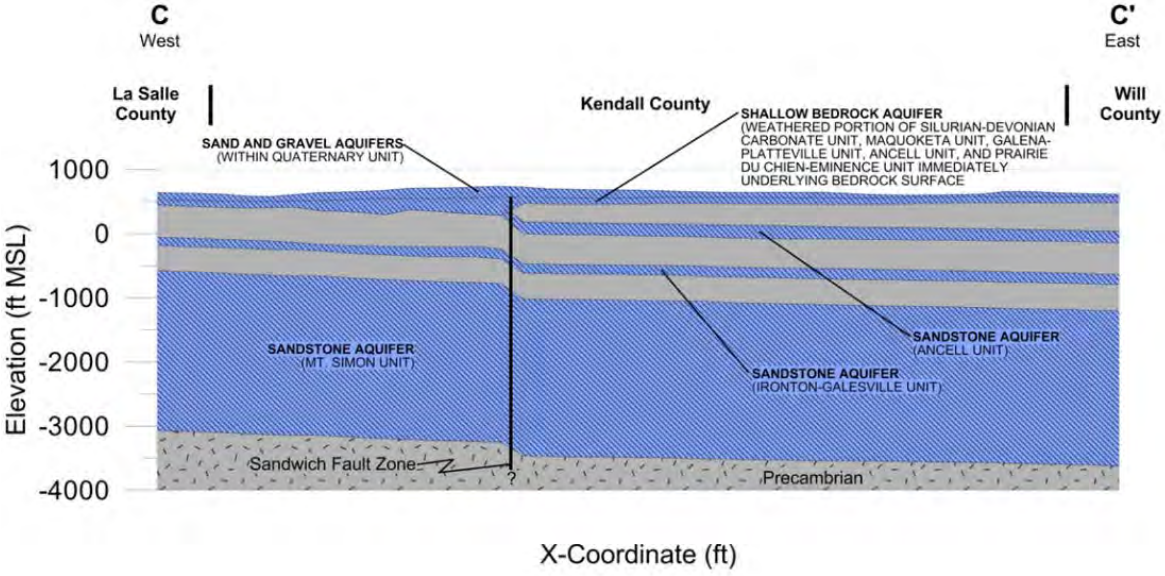


Figure 6. Detail from cross section C-C' (Figure 5) showing aquifers in Kendall County

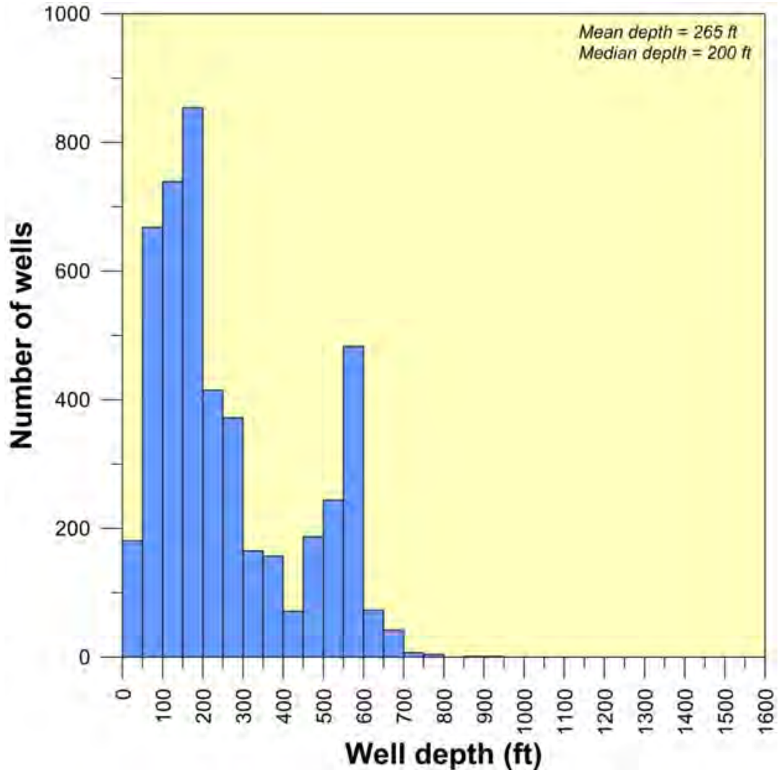


Figure 7. Histogram of domestic well depth in Kendall County

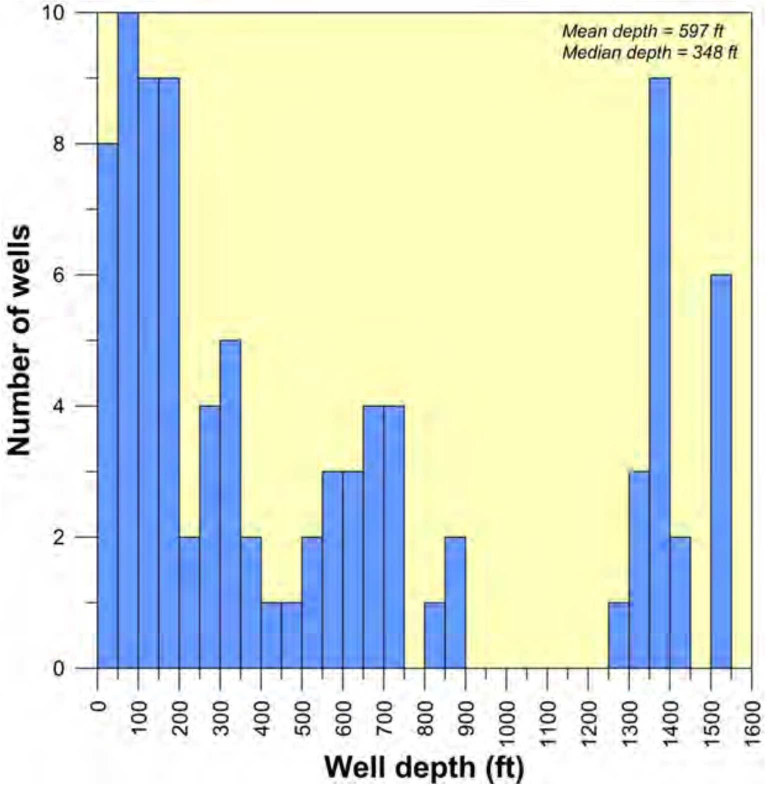


Figure 8. Histogram of high-capacity well depth in Kendall County

Table 1. Active Community Wells Serving Kendall County in 2012

Owner (county location of well)	*Local ID*	*Year Completed*	*Depth (ft)*	*Initial Rate (gpm)*
Fox Lawn Subdivision	1	1966	715	Unknown
Illinois Amer. Hollis Park	1	1972	200	Unknown
Illinois Amer. Hollis Park	2	2009	225	Unknown
Illinois Amer. Marina Valley	1	1963	187	Unknown
Illinois Amer. Marina Valley	2	1972	700	Unknown
Joliet (Will County)	1	1907	1621	1000
Joliet (Will County)	3	1924	1536	675
Joliet (Will County)	4	1924	1608	700
Joliet (Will County)	5	1937	1608	1225
Joliet (Will County)	6	1950	1656	1135
Joliet (Will County)	7	1950	1700	1000
Joliet (Will County)	8	1949	1660	1000
Joliet (Will County)	9	1964	1671	1059
Joliet (Will County)	10	1970	1572	1200
Joliet (Will County)	11	1975	1623	875
Joliet (Will County)	12	1975	1557	1150
Joliet (Will County)	15	1997	1566	1100
Joliet (Will County)	16	1999	1520	1136
Joliet (Will County)	17	2000	1525	269
Joliet (Will County)	18	2000	1460	1000
Joliet (Kendall County)	20	2003	1556	806
Joliet (Kendall County)	21	2003	1555	976
Joliet (Will County)	22	2005	1618	708
Joliet (Will County)	23	2005	1655	807
Joliet (Will County)	24	2006	1663	1360
Joliet (Kendall County)	25	2005	1533	Unknown
Joliet (Kendall County)	27	2006	1523	1119
Joliet (Kendall County)	28	2006	1554	Unknown
Joliet (Will County)	29	2009	1548	1102
Joliet (Will County)	30	2012	1635	951
Joliet (Will County)	201	1950	125	350
Joliet (Will County)	202	1950	90	550
Joliet (Will County)	204	1950	115	320
Joliet (Will County)	301	2006	127	571
Joliet (Will County)	302	2005	100	622
Joliet (Will County)	303	2006	83	613
Joliet (Will County)	304	2005	121	807
Joliet (Will County)	305	2005	90	826
Minooka (Grundy County)	3	1965	1508	325
Minooka (Grundy County)	4	1973	725	225
Minooka (Will County)	6	1987	50	600
Minooka (Will County)	7	1988	50	600
Minooka (Kendall County)	8	2005	1520	1500
Minooka (Grundy County)	9	2005	1601	Unknown
Minooka (Will County)	10	2000	41	70

Table 1. Active Community Wells Serving Kendall County in 2012

Owner (county location)	*Local ID*	*Year Completed*	*Depth (ft)*	*Initial Rate (gpm)*
Montgomery (Kane County)	3	1957	1336	550
Montgomery (Kane County)	4	1958	1353	690
Montgomery (Kane County)	8	1975	1378	1200
Montgomery (Kane County)	10	1986	87	260
Montgomery (Kane County)	11	1987	59	260
Montgomery (Kane County)	12	1990	190	500
Montgomery (Kane County)	13	1990	183	500
Montgomery (Kane County)	14	2002	1403	1119
Montgomery (Kane County)	15	2011	1411	1205
Morgan Creek Estates	1	1978	642	Unknown
Morgan Creek Estates	2	2006	48	50
Newark (Kendall County)	2	1964	287	100
Newark (Kendall County)	3	1973	336	100
Oswego (Kendall County)	3	1957	1372	950
Oswego (Kendall County)	4	1964	1396	700
Oswego (Kendall County)	6	1992	1392	Unknown
Oswego (Kendall County)	7	1997	1535	Unknown
Oswego (Kendall County)	8	2001	1440	1450
Oswego (Kendall County)	9	2004	1514	1224
Oswego (Kendall County)	10	2004	1397	1397
Oswego (Kendall County)	11	2009	1403	1305
Plano (Kendall County)	3	1960	39.5	350
Plano (Kendall County)	4	1966	36.5	500
Plano (Kendall County)	5	1966	40.75	950
Plano (Kendall County)	7	1998	91	506
Plano (Kendall County)	8	2004	97	N/a
Plano (Kendall County)	9	2005	117	N/a
Storybook Highlands Subdivision	1	1975	354	Unknown
Yorkville (Kendall County)	3	1960	1335	800
Yorkville (Kendall County)	4	1976	1393	1245
Yorkville (Kendall County)	7	2004	1527	950
Yorkville (Kendall County)	8	2004	1384	1313
Yorkville (Kendall County)	9	2004	1368	1261
Yorkville (Kendall County)	10	2007	1427	N/a

Observed Water Levels

In 2006, ISWS researchers measured water levels in 210 wells in Kendall County and adjacent areas. In this report, the collected data are shown in spot head maps (maps showing the measured head adjacent to a symbol marking the location of the measurement), and some are used as the basis for a generalized potentiometric map of the Shallow Bedrock Aquifer and overlying sand and gravel aquifers. A potentiometric map is a contour map of the potentiometric surface of a hydrostratigraphic unit (Fetter, 1988) and illustrates hydraulic head—the level to which water will rise in tightly cased wells open to that unit. Such maps can be constructed for both confined and unconfined aquifers. Head values are represented with equipotentials, a type of contour line that connects points of equal head and represent head values. Because groundwater flows from high head to low head, directions of groundwater flow are perpendicular to equipotentials. Contour values are expressed as elevations above a datum plane, commonly mean sea level. This report refers to hydraulic head simply as head, and other components of head are not considered. Observed heads and potentiometric maps are useful for many purposes, including the following:

- Developing a conceptual understanding of groundwater flow in a region;
- Calibrating groundwater flow models;
- Documenting water level conditions at a point in time against which future measured water levels may be compared in order to demonstrate and assess a change.

Water levels were measured in Kendall County and adjacent parts of surrounding counties. Head data were collected in areas outside of Kendall County to help develop a more complete understanding of groundwater movement within the county.

Potentiometric surfaces of the shallowest aquifers roughly imitate land-surface topography. Nearly all topography, including small hills and valleys, is replicated in the potentiometric surfaces of shallow aquifers, with only minor dampening of the relief. Dampening increases in deeper aquifers, so that only large-scale topographic features are replicated in the potentiometric surfaces of deeply buried aquifers.

Heads rise and fall in response to groundwater withdrawals, recharge, evaporation and transpiration, and, in the case of confined aquifers, aquifer loading from the addition or subtraction of water in the soil (Freeze and Cherry, 1979). Heads often follow a seasonal cycle that is most noticeable in shallow aquifers and at locations distant from large pumping centers, where pumping effects do not overwhelm natural cycles. Natural declines in heads usually begin in late spring and continue throughout summer and early fall. Heads begin to rise in late fall and peak during the spring, when groundwater recharge from rainfall and snowmelt has its greatest effect (Visocky and Schicht, 1969).

Methods

Well Selection

Between May 31, 2006 and January 10, 2007, ISWS staff measured water levels in 210 wells in the Kendall County area (see Figure 9 and Appendix A). Water levels in some of these wells had been measured by the ISWS for previous studies, although they were remeasured for the present study. Many of the wells shown in the northern two tiers of townships in the mapping area (Figure 9) were previously employed for potentiometric mapping in Kane County (Locke and Meyer, 2007). Wells open to the sandstone aquifers throughout the mapping area have been employed for periodic potentiometric surface mapping studies of the aquifers in northeastern Illinois (e.g., Burch, 2008). The use of wells employed in previous studies relieved ISWS staff of much of the need to locate additional wells, obtain owner permission for use of these wells, and survey the locations of new wells, since these tasks had already been completed for the wells used in previous studies. Use of previously measured wells also creates a record of water levels at specific locations, useful for assessing changes.

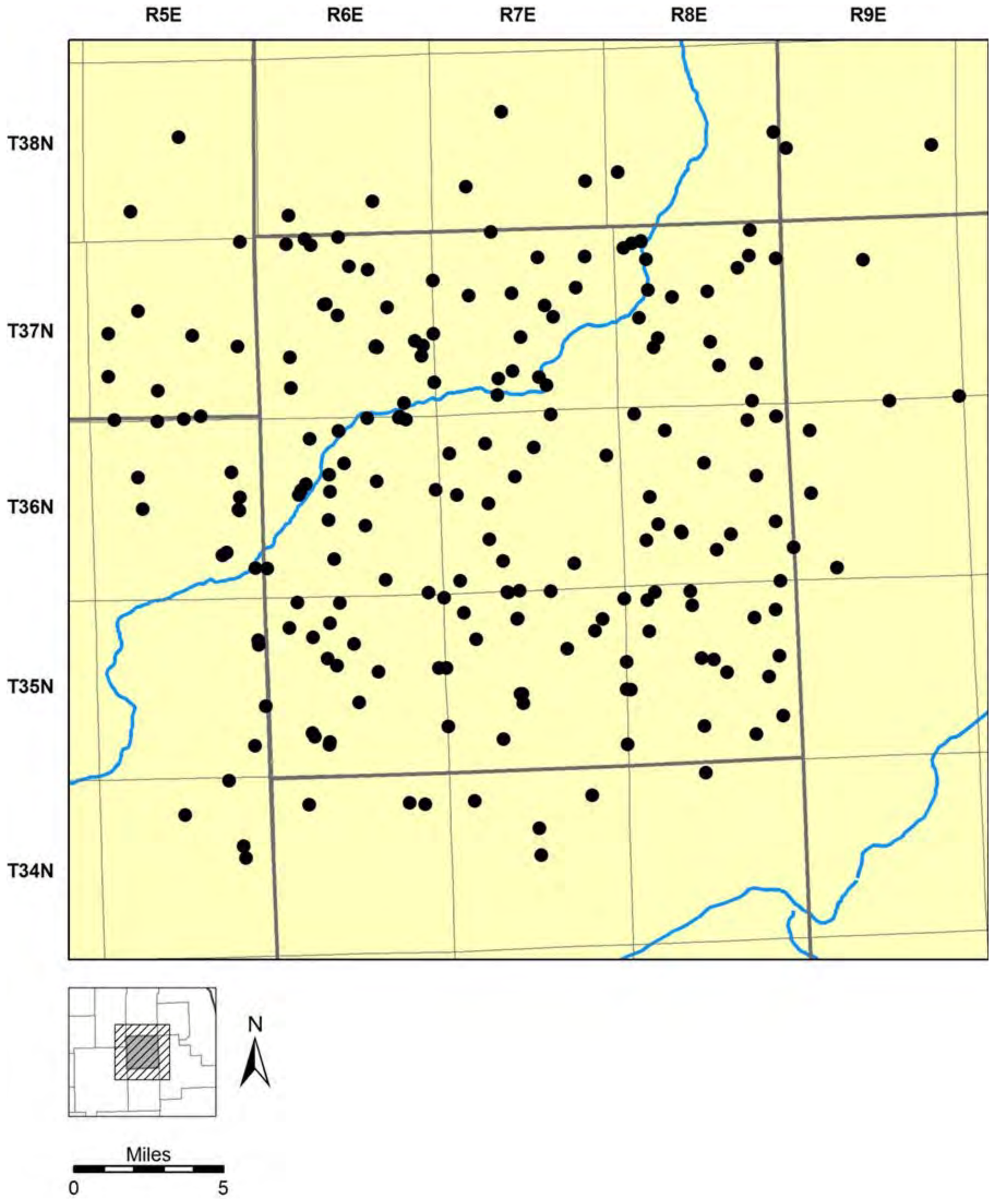


Figure 9. Locations of water level measurements, May 2006-January 2007

In other areas, however, it was necessary to find wells that had not been measured in any previous ISWS studies. Copies of well completion reports on file at the ISWS were used to identify candidate wells. Many completion reports could not be matched to an actual field location owing to inaccurate or imprecise completion report descriptions. Where field locations could be matched to well completion reports, general guidelines were employed for selection of wells for water level measurement. For example, newer wells were favored over older ones. The goal of the well selection process was to develop a network of regularly spaced wells covering all aquifers in the Kendall County mapping area. Water levels in all public water system wells and in all high-capacity self-supplied industrial/commercial and irrigation wells were additionally sought out for this study. These wells were identified using the ISWS Illinois Water Inventory Program (IWIP) database.

For each well not previously employed in an ISWS study, a site visit was made to verify the location and suitability of the candidate well and to request permission from the well owner to use the well for head measurement. If owner permission was granted, data collection was facilitated using an electronic form that was completed on-site. Use of the electronic form facilitated consistent data entry and compilation into a database of the obtained head measurements and related data.

Head Measurements

Water levels were measured during site visits made between May 31, 2006 and January 10, 2007. If the well was employed in previous ISWS studies, the measurement was typically obtained following a telephone call in which the owner was asked for permission to use the well in the present study. ISWS standard operating procedures were employed for measurement of water levels, and measurements were recorded on paper and on electronic forms.

Depth to water in most domestic, commercial, and industrial wells was measured with a disinfected steel measuring tape, although in a few cases an electric dropline was used. The measuring point (the reference point for depth to water measurements) was, in most cases, the top of the casing after removing the well cap. In other cases, removal of the well cap was not required, and the top of the vent tube, vent hole, or access port was employed as the measuring point. The actual measuring point used was noted on the electronic field form. All head measurements made with a steel measuring tape were recorded to the nearest 0.01 ft and are likely accurate within ±0.1 ft.

The depth to water in 28 wells (13 percent of the 210 water levels measured) was measured with an air line, a length of tubing attached to the column pipe in the well. Measurement with an air line is accomplished by displacing water in the tube using a tire pump or other compressed air source. Air pressure in the tube is then read from a gage open to the tube, and the height above the bottom of the air line of an equivalent column of water is calculated. Measurements of water depth made by air line were recorded to the nearest foot. Accuracy of air line measurements is typically linked to the type of gage used. Typical gages register air pressures up to 100, 200, or 300 pounds per square inch (psi), which equal 230, 460, or 690 ft of water, respectively. Burch (2002) reported gage accuracy within 1 percent in the center of gage range (2.3 and 6.9 ft in 100- and 300-psi gages, respectively) and within 2 percent at full deflection (4.6 and 13.8 ft in 100- and 300-psi gages, respectively). Based on the gage types and water levels encountered, most air line measurements obtained for this project have an estimated accuracy of ±5 ft. Because of its greater accuracy, the steel-tape method of water level measurement is preferred by the authors above the air line method, and ISWS used the steel-tape approach whenever possible.

Field personnel followed procedures to ensure they were measuring the static, or resting, head in each well. After obtaining a steel tape measurement, personnel waited several minutes before taking a second measurement. In most cases, the second measurement was within ±0.02 ft of the first one and was considered adequate verification that the head in the well was not changing significantly. However, if the second measurement differed from the first by more than ±0.10 ft, an effort was made to determine the source of the variation. Variations often resulted from recovery of the water level well following a period of recent use (i.e., the water level was rising after the well pump had shut off). In those cases, the well was allowed to recover for about 15 minutes, and the measurement process was repeated until agreement was within the ±0.10 ft tolerance. Multiple water level measurements were not taken in wells in which the air line method of water level measurement was used. Relevant remarks were included on the field form and reviewed later as field data were entered into the project database. Appendix A lists selected well characteristics and head measurements for wells visited for this study.

Most head mapping studies rely on synoptic measurement of water levels (that is, water level measurements are collected in as brief a time span as possible) (e.g., Meyer, 1998; Locke and Meyer, 2007), but this study did not. Synoptic mapping typically requires two phases of effort, each phase requiring a field visit to wells in the network. Site visits during the first phase, called the inventory phase by Locke and Meyer (2007), are conducted for purposes of well network development and documentation. Work tasks include obtaining owner permission for use of the well, inspecting the well to establish its suitability for water level measurement, possibly taking a preliminary water level measurement, and surveying the well location. The inventory phase of the head mapping study conducted in the Kane County area described by Locke and Meyer (2007), which resulted in development of a network of 1,010 wells, lasted about 17 months. During the second phase of effort, called the synoptic phase by Locke and Meyer (2007), site visits were focused on a single task: obtaining a water level measurement as efficiently as possible. During the synoptic phase of the Kane County mapping study, water levels were measured in all wells of the 1,010-well network in about six weeks. The reasoning behind measuring heads synoptically is to reduce map uncertainty resulting from constantly fluctuating water levels; however, synoptic studies can be expensive owing to the significant man hours required to repeat visits to numerous wells and to measure water levels as quickly as possible during the synoptic measurement phase.

To reduce costs, the present study did not rely on synoptic measurement of water levels but instead relied on measurements obtained over a period of 224 days (about 7.4 months). For this study, the water level measurement used for head mapping was obtained during the same site visit when owner permission was obtained, surveying conducted, etc. That is, wells were visited only a single time.

Thus the maps developed from these measurements have an associated uncertainty owing to water level fluctuation during the 7.4-month period of measurement, which the authors refer to as temporal variability. The temporal variability of shallow aquifer heads during the 7.4-month period of measurement is inferred from the head data collected by Locke and Meyer (2007), who recorded heads obtained during both the inventory and synoptic phases of the potentiometric mapping study in the Kane County area. In the study of Locke and Meyer, the temporal variability of head measurements obtained 7.4±1 months apart at 31 wells in the Kane County area was ±5.1 ft. Temporal head variability in the deep aquifers is more challenging to quantify using existing data. Groundwater flow modeling suggests that deep heads are much less influenced by recharge and stream levels than shallow heads (Meyer et al., 2009). Nicholas et al. (1987) noted that temporal variability in deep heads in northeastern Illinois appears to be correlated with seasonal pumping and is as little as ±1.5 ft at locations distant from pumping. Temporal variability in deep heads may be much greater near pumping centers (Burch, 2002).

Determination of Well Locations and Measuring Point Elevations. Global positioning system (GPS) equipment was used to survey the location of wells not previously surveyed for other ISWS studies. Trimble™ GPS units connected to handheld computers were used for this purpose. Because of the relatively large size and low relief of the study area, uncorrected, autonomous GPS locations were considered sufficiently representative of well location. The maximum horizontal error of these positions is expected to be within ±100 ft, but a more typical accuracy may be ±20 ft.

Heads were calculated at each well by subtracting the observed depth to water in the well from an estimate of the elevation of the measuring point. Measuring point elevation was determined by adding the length of well casing above land surface (i.e., stickup) to an estimated land-surface elevation. Land surface elevations within Kane County were determined through analysis of a 2-ft digital contour map (personal communication with Tom Nicoski, Director, Kane County GIS Technologies Department, June 2003). Those determinations are estimated to be accurate within ±2 ft. Outside of Kane County, 1:24,000 digital raster graphics (DRGs) of topographic maps produced by the USGS were used for visual estimation of elevation. Elevations determined using DRGs may have maximum errors within ±20 ft, but more typically will be accurate within ±5 ft. Locke and Meyer (2007) examined the uncertainty of land surface elevations determined from Trimble™ GPS plus DRGs with those determined from high-quality GPS at 72 wells in McHenry County. They concluded that 92 percent of the elevations determined from Trimble™ GPS plus DRGs were within ±5.0 ft of the high-quality GPS elevation, with a mean absolute error of 2.5 ft.

The determinations of well location and measuring point elevation discussed here contribute to the uncertainty of the head measurements determined from them. Horizontal positions were measured by uncorrected GPS and are accurate within ±100 ft. Measuring point stickups were measured with a folding ruler and recorded to the nearest tenth of a foot. Because of unevenness of the land surface at well heads, those measurements are likely to be accurate within ±0.3 ft.

Head Measurement Uncertainty. By summing the component uncertainties discussed in the preceding sections, it is possible to estimate the error in head measurements obtained for this project (Table 2). These errors differ with the circumstances of measurement ranging between 3.9 ft (deep head measurements obtained with a steel tape inside Kane County) and ±15.4 ft (shallow head measurements obtained by air line outside Kane County). Readers should note that the uncertainty of measurements from sandstone wells near pumping wells could be considerably more than the values given in Table 2, but these uncertainties are not quantified owing to the absence of reliable data.

Table 2. Head Measurement Uncertainty

Component	*Uncertainty (ft)*					
	Measurements from wells open only to the sand and gravel aquifers and Shallow Bedrock Aquifer			*Measurements from wells open to the sandstone aquifers*		
	Steel tape or electric dropline		*Air line*	*Steel tape or electric dropline*		*Air line*
	Inside Kane County	*Outside Kane County*	*Outside Kane County*	*Inside Kane County*	*Outside Kane County*	*Outside Kane County*
Depth-to-water measurement	±0.1	±0.1	±5	±0.1	±0.1	±5
Temporal head variability	±5.1	±5.1	±5.1	±1.5*	±1.5*	±1.5*
Stickup measurement	±0.3	±0.3	±0.3	±0.3	±0.3	±0.3
Elevation estimation	±2	±5	±5	±2	±5	±5
Total	±7.5	±10.5	±15.4	±3.9	±4.8	±11.8
No. of Measurements	7	154	14	0	16	19

*For wells distant from pumping. For sandstone wells near pumping centers, temporal head variability is not quantified but may be considerably more than ±1.5 ft.

Aquifer Assignments

Because heads differ vertically within the subsurface, measures were taken to ensure that wells were segregated correctly on the basis of source aquifer. The determination of source aquifer is based on logs of the wells recorded on well completion records filed at the ISWS, on well depth, and on a three-dimensional geological model of the subsurface developed by the ISWS as a basis for groundwater flow modeling in the region. Table 3 gives counts of wells by aquifer, and Figures 10 through 12 show the distributions of wells throughout the study area.

Table 3. Observed Water Levels in Kendall County Area, May 2006-January 2007

Aquifer(s)	*No. of wells in study area*	*No. of wells in Kendall County*
Sand and gravel aquifers	22	17
Shallow Bedrock Aquifer	153	113
Sandstone aquifers	35	27
Total	**210**	**157**

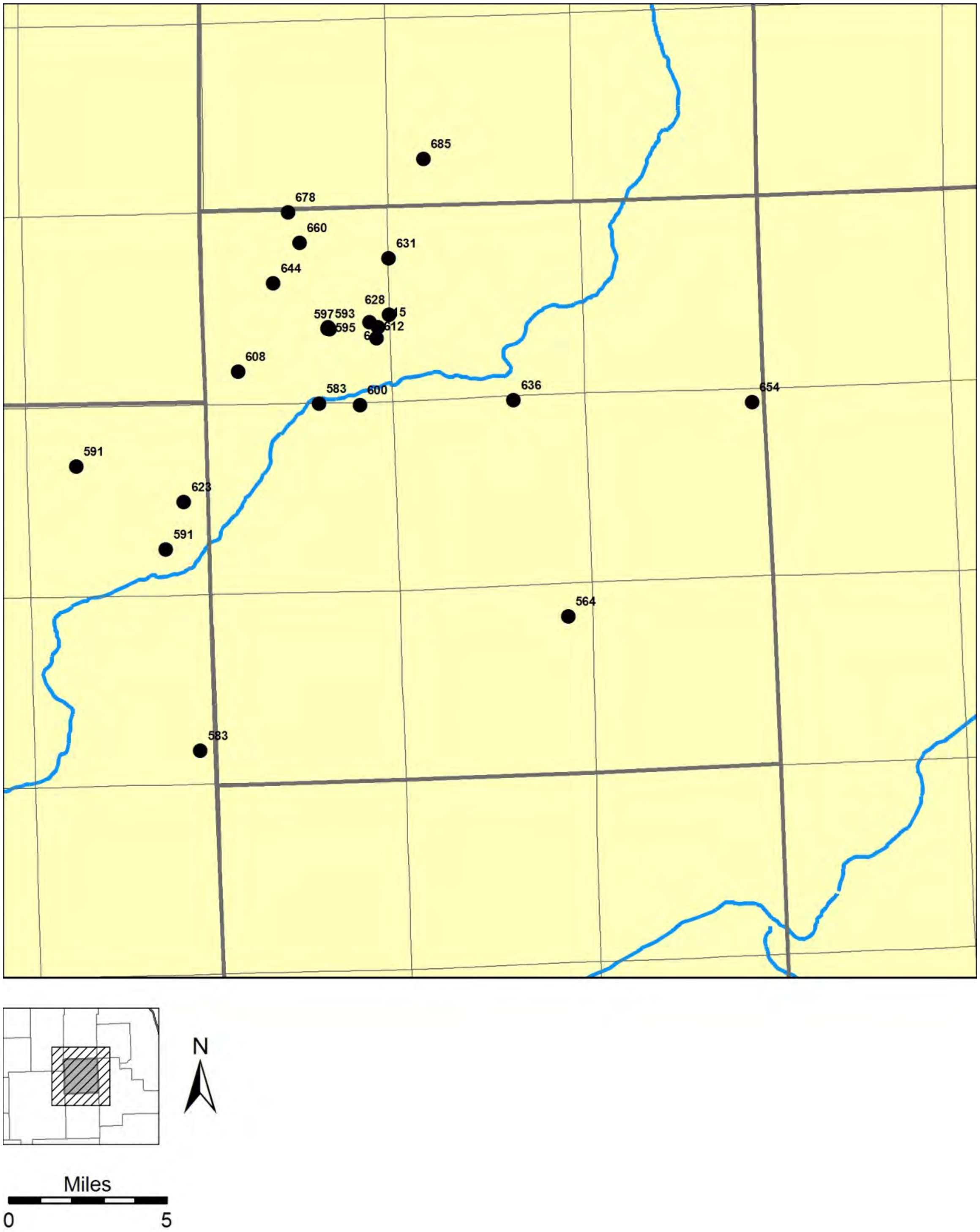


Figure 10. Observed heads in sand and gravel aquifers, May 2006-January 2007 (ft asl)

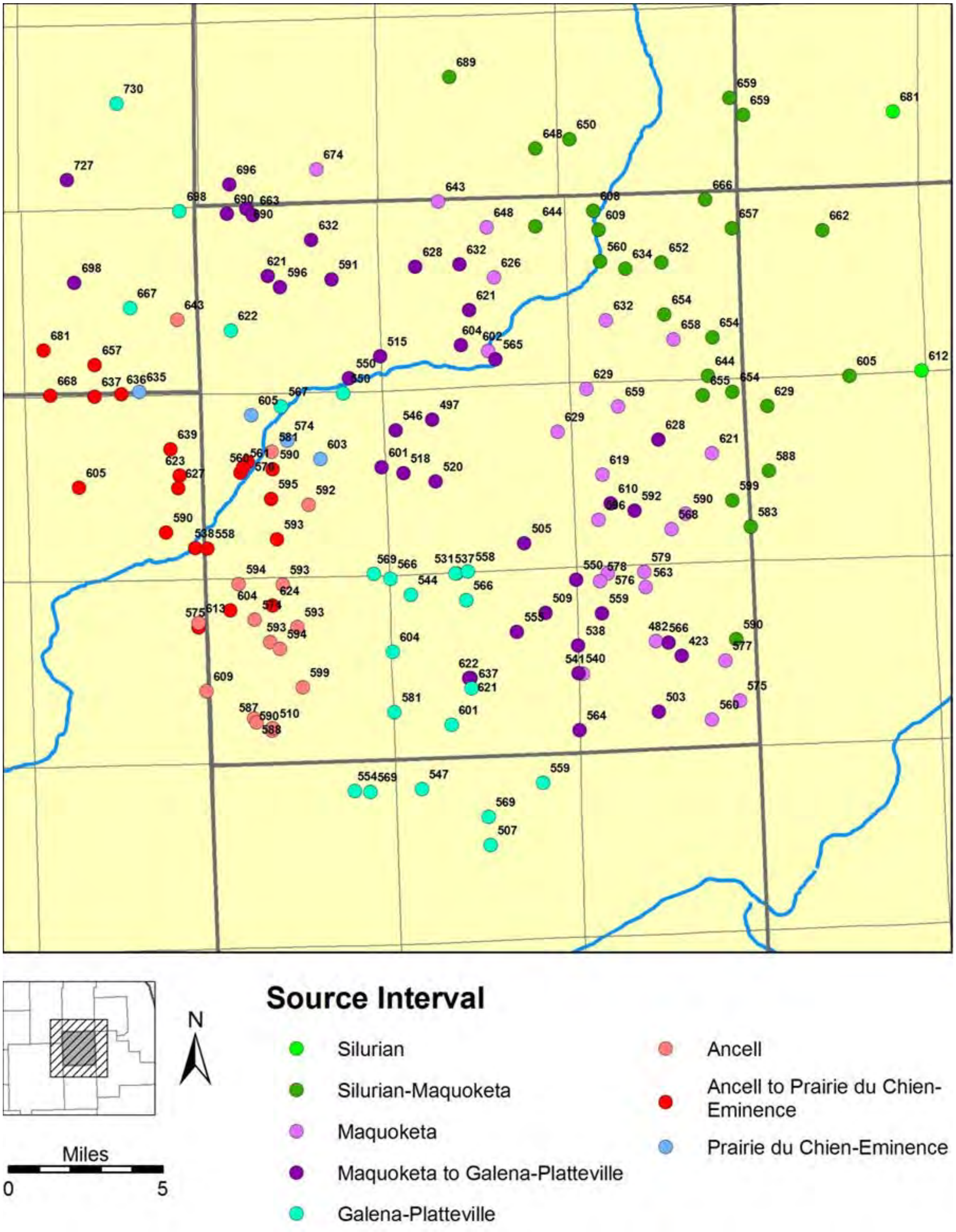


Figure 11. Observed heads in the Shallow Bedrock Aquifer, May 2006-January 2007 (ft asl)

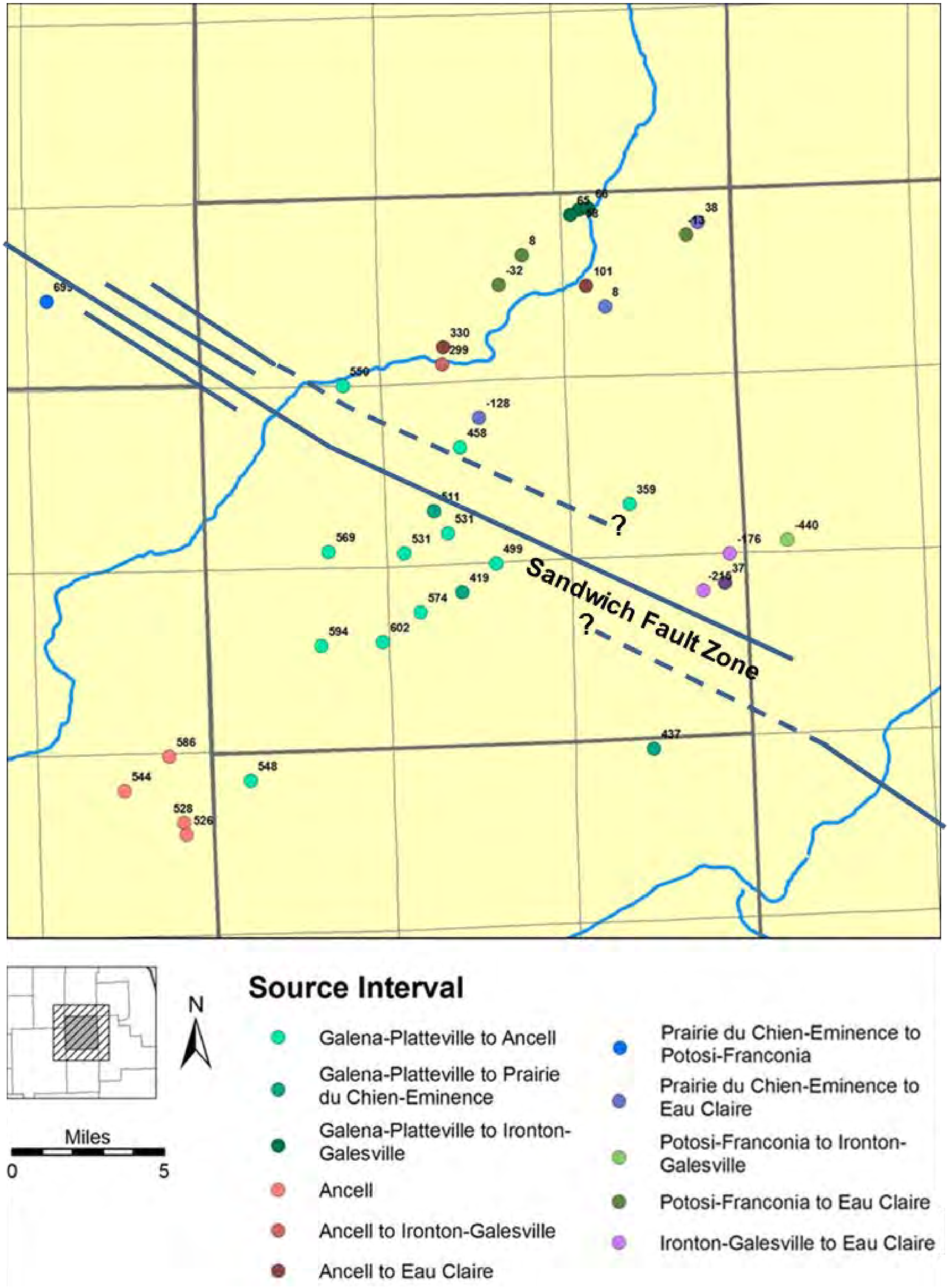


Figure 12. Observed heads in the sandstone aquifers, May 2006-January 2007 (ft asl)

Potentiometric Map Development

Owing to the relatively few numbers of measurements from specific hydrostratigraphic units, water levels (as heads) are first presented on uncontoured maps (Figures 10 through 12). A generalized potentiometric map of the Shallow Bedrock Aquifer and overlying sand and gravel aquifers was then created using measurements from 171 wells tapping those units. The small number of measurements from wells open to the sandstone aquifers (35) did not permit development of a potentiometric map of these aquifers. Aggregation of head data from the Shallow Bedrock Aquifer and sand and gravel aquifers to develop a shallow potentiometric map is justified by mapping in McHenry County (Meyer, 1998) and Kane County (Locke and Meyer, 2007), which suggests similarity between heads in these aquifers owing to similar aquifer elevations, connectivity with surface waters, and frequent connections between aquifers.

The potentiometric map was developed by plotting the calculated heads on a base map and then contouring them. The contouring process is essentially one of interpolating heads in areas lying between irregularly spaced head observations. Contouring may be done manually or with computer programs employing automated routines. For this report, the potentiometric map was constructed using computer methods that are effective, rapid, and systematic for purposes of error checking, outlier identification, data exploration, and data presentation. Interpolation of observed shallow heads was conducted using a kriging routine in the Geostatistical Analyst extension of ArcGIS software version 9.3 (Environmental Systems Research Institute, 2009). Working maps were generated to review the observed and interpolated head data. Anomalous head observations were identified and reviewed for quality and consistency with nearby observations. If a measurement was suspected of being inaccurate, inconsistent, or unrepresentative, it was retained or rejected, following review, on the basis of professional judgment. A measurement could be rejected as inaccurate, inconsistent, or unrepresentative for a number of reasons. For example, field notes may indicate an unclear measurement because of condensation or bacterial fouling on the steel tape. Field notes might also suggest fluctuating water levels indicative of operation of the well’s pump during or shortly before the water level measurement. In other cases, field notes or a well completion report might indicate that a measurement is inconsistent with previous measurements from the well or with measurements from nearby wells. A well completion report might cast doubt on the depth or open interval of a measured well, thus calling into question the aquifer to which a head observation from the well is assigned for purposes of potentiometric mapping. Factors such as these were considered when screening anomalous head observations. Ultimately, four measurements were rejected from the set of data used to develop the generalized shallow potentiometric map.

Several assumptions were made to allow contouring of the shallow head data. The aggregated shallow surface potentiometric mapping unit (Figure 6) is assumed to be laterally continuous. Hydraulic connectivity with surface water was not assumed, and surface water elevations were not employed to constrain interpolation of the potentiometric surface. Potentiometric contour lines were generated by ordinary kriging. The interpolation errors (standard kriging errors) of the potentiometric surface are within 20 ft of the actual values for greater than about 60 percent of Kendall County. Where data are sparse, interpolation errors increase to a maximum of about 28 ft.

Discussion of Shallow Bedrock Aquifer Potentiometric Map

The resulting shallow potentiometric map (Figure 13) suggests several influences on shallow groundwater flow in the county, including land surface elevation, connectivity with surface water, lateral variation in transmissivity, and pumping. Still, readers should understand that the process whereby the map was generated is limited in its capacity to represent actual heads, particularly in areas remote from measurement locations. The contouring algorithm, although offering consistency, rapidity, and reproducibility, is a statistical procedure that does not attempt to simulate the physical processes governing groundwater flow, treating the head measurements as it would any other numerical data.

Generally speaking, topographic features are replicated in the potentiometric surfaces of aquifers, the degree of replication decreasing with depth. Major topographic features of Kendall County (Figure 14) are replicated in the configuration of the shallow potentiometric map shown in Figure 13. These include high elevations in the Elburn Moraine Complex and along parts of the Marseilles and Minooka Moraines. In addition, low elevations along the Fox River and along Aux Sable Creek and its forks in southeastern Kendall County are reflected by low heads in the potentiometric map.

Although surface water elevations were not employed in developing the map shown in Figure 13, relatively lower heads along the Fox River and Aux Sable Creek and its forks in southeastern Kendall County suggest connectivity with surface water in Kendall County. In measured wells within a mile of the Fox River, the water levels were generally within 10 ft of the river elevations shown on the USGS topographic maps, suggesting that the river is hydraulically connected to the shallow aquifer throughout its length in Kendall County. Potentiometric surface mapping and modeling of shallow groundwater flow in Kane County and adjacent areas has demonstrated the importance of the Fox River as a major discharge point for groundwater (Meyer et al., 2009). The measured heads along the three branches of Aux Sable Creek generally do not match the surface water elevations except in the area around the confluence of the three branches. A denser network of measurements and time-series data from observation wells would be needed to determine the degree of interconnection between the groundwater and the creek. South of the confluence area, the potentiometric surface could be dropping to the much lower elevation of Aux Sable Creek and the Illinois River in Grundy County.

The map is marked by a belt of lower heads trending northwest to southeast across from central to southeast Kendall County. This area of low heads roughly corresponds with the Sandwich Fault and the area where the Shallow Bedrock Aquifer comprises predominantly shaly, relatively impermeable rocks of the Maquoketa Unit. It is possible that the reduced heads reflect the low transmissivity of the Shallow Bedrock Aquifer where pumpage from even domestic wells could cause steep, narrow cones of depression to form surrounding the individual wells measured for this study. Alternatively, wells in this central area may be completed into the Galena-Platteville dolomite where they could be impacted by the lower water levels in the underlying Ancell unit, whose heads are dropping off towards of the cone-of-depression in the sandstones centered at Joliet. It is also possible that the lower heads could be caused by groundwater moving down the Sandwich Fault into the deeper units where the heads have been greatly lowered by pumping. The vertical permeability of the fault is unknown; however, chemical evidence (see Dissolved Solids discussion) suggests groundwater has previously moved

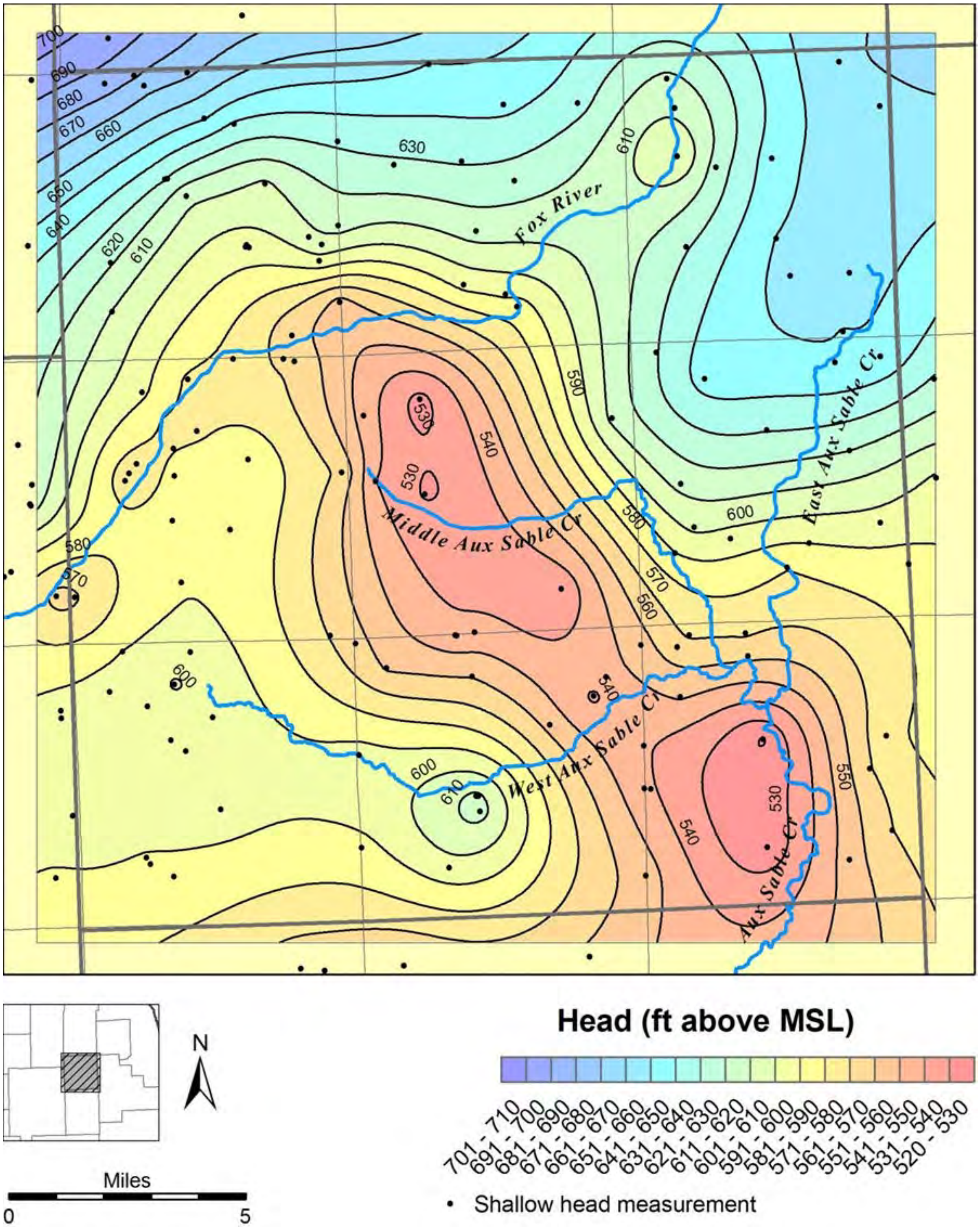


Figure 13. Potentiometric surface of the sand and gravel aquifers and Shallow Bedrock Aquifer, May 2006-January 2007, with selected streams labeled

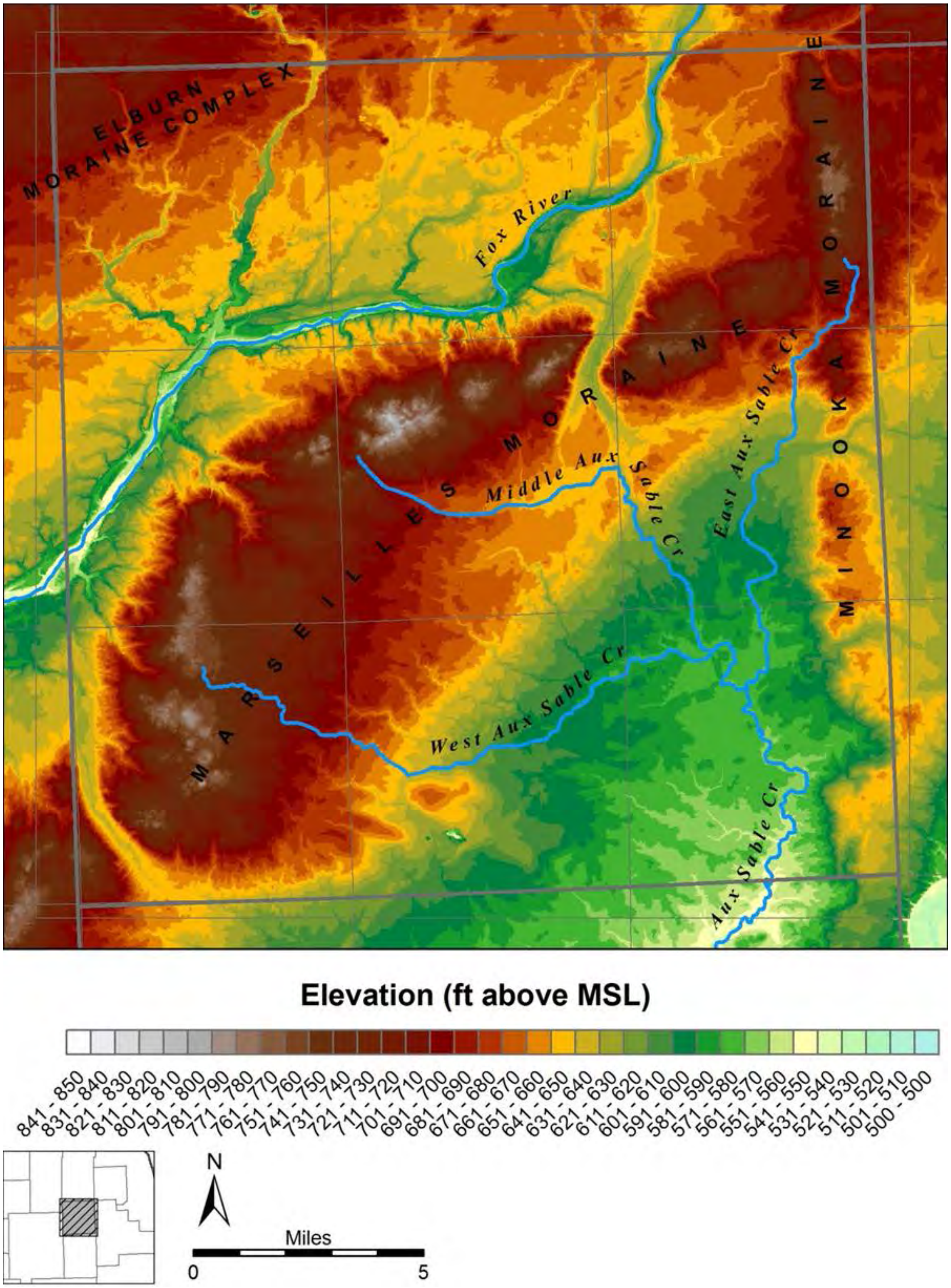


Figure 14. Topography of Kendall County, with selected streams and physiographic features labeled

upward through the fault, and flow directions may have changed from upward to downward with the growth of the cone of depression in the deep aquifer.

The widely spaced equipotentials (lines connecting points of equal head) shown in Figure 13 in west-central and southwestern Kendall County may reflect the high transmissivity of the Ancell Unit sandstone, which comprises the Shallow Bedrock Aquifer in those areas. Since a highly transmissive material presents less of a barrier to groundwater flow than a low transmissivity material, heads tend to be more consistent laterally, and, reflecting this, equipotentials are widely spaced.

Kay et al. (2005) mapped heads in sand and gravel aquifers and the Shallow Bedrock Aquifer of Kendall County on the basis of static water levels reported on well completion reports at the time of drilling. They included water levels only from wells that were completed between about 1980 and 2000. These maps are roughly similar to Figure 13 in that they display a general pattern of heads that is a subdued replica of topography, with higher heads in upland areas and a tendency toward lower heads in low elevation areas along the Fox River and Aux Sable Creek. It should be understood that maps of Kay et al. (2005), based as they are on water levels reported on well completion reports, are subject to uncertainties stemming from the unsystematic water level measurement and documentation procedures of the numerous drillers submitting data via well completion reports, temporal water level variations over a 20-year period, and inaccuracies in determination and documentation of well locations (which would be reflected in head estimates, since these require elevations determined on the basis of the reported locations).

Discussion of Deep Sandstone Aquifer Water Levels

The water level data from the deep sandstone aquifers (Figure 12) exhibit enough variability that it does not lend itself well to the construction of a potentiometric surface map on the scale of Kendall County; however, several trends are clearly evident in the data. The deepest water levels, often going below sea level, occur in the north and east portions of the county near the large cones of depressions caused by the pumpage in the Aurora and Joliet areas (Burch, 2008).

South of the Sandwich Fault, water levels in the sandstones are several hundred feet higher than north of the fault, suggesting that any northward flow towards the pumping centers is being cut off by the fault. Where the Sandwich Fault has been mapped in DeKalb and Will Counties (Kolata et al., 1978) occurs as a series of parallel faults in a 2-mile wide zone. The location and number of faults in Kendall County is difficult to determine because of the thick tills overlying the bedrock. Through most of Kendall County the vertical offset along the fault is greater than the individual thicknesses of the Ancell or Iron-Galesville sandstones, thus locally dividing the aquifers into two separate systems. Moving horizontally along the fault zone into DeKalb or Will Counties, the vertical displacement lessens and the individual sandstones become reconnected. Mapping by Burch (2002) shows contours bending in the areas of the fault in Kendall County, although in that study Burch did not include the fault in the contour process. Evidence from the shallow water levels and the chemistry suggest that there is vertical flow along the fault; however, the vertical transmissivity along the fault should be much smaller than the horizontal transmissivities of the sandstones.

South of the fault, the Ancell sandstone is at or near the surface and forms part of the Shallow Bedrock Aquifer. In this area the potential for recharge is much greater than north of the fault where the sandstone is deeply buried and overlain by the Maquoketa Unit. The potential also exists for a direct hydraulic connection to the Fox River in western Kendall County where the Ancell sandstone is at the bedrock surface (Figure 2). Although the Ironton-Galesville sandstone does not outcrop in the area, the few wells completed into the unit show high water levels similar to those in the Ancell sandstone. The potential for recharge and the high water levels suggest that sandstones in southern Kendall County could substantially contribute to the available water supply of the county.

Although there are no wells completed into the Mt. Simon sandstone south of the fault, the fault probably has little effect on flow in the Mt. Simon because the thickness of the unit is greater than the displacement on the fault.

A water level measured in the deep wells screened across multiple aquifers represents either a single head value for all the aquifers or a composite head if water is actively being transferred though the well between aquifers with different heads. Given that there are over 800 known deep sandstone wells in the Chicago area and that many have been around for more than 100 years, it is likely that any head differences between the aquifers have largely equalized and the heads for the Ancell and the Ironton-Galesville aquifers should be very similar. Where there are adjacent wells screened in different deep sandstones, such as at the USGS Zion observation wells in Lake County, little to no head difference is observed. Cascading water has been anecdotally reported in deep wells that are also screened in the shallow Silurian dolomite; however, these deep wells tend to occur in areas where the shallow dolomite is not productive enough to supply the well itself.

Shallow Groundwater Quality

As discussed in the previous section, ISWS scientists measured water levels in more than 200 wells in Kendall County in 2006. A preliminary evaluation of the quality of groundwater in the Shallow Bedrock Aquifer and sand and gravel (unconsolidated) aquifers (hereafter referred to as shallow groundwater quality) in Kendall County was done soon afterwards, with samples collected from 19 of these wells for water quality analyses. Sampling methodology and analytical results are presented in the following section.

Investigation objectives were to (1) provide a "snapshot" of shallow groundwater quality in Kendall County; (2) compare shallow groundwater quality from urbanized vs. rural parts of the county; (3) compare groundwater quality of the Shallow Bedrock Aquifer vs. sand and gravel aquifers; (4) produce a baseline of shallow groundwater quality for comparison with results of future sampling; and (5) produce data that will help ISWS scientists model groundwater flow and estimate aquifer recharge rates.

Methods

Well Selection

Funding was available to sample approximately 20 wells. ISWS scientists had previously inventoried approximately 230 wells in Kendall County for measuring groundwater levels. In order to assess shallow groundwater quality, a depth limit of 250 ft was imposed, leaving 111 potential wells. Upon inspection by ISWS scientists, a small number of wells in poor condition were eliminated from consideration because of their potential vulnerability to contamination from leaking along the well bore or from contaminants in the well components.

Because only about 20 wells would be sampled, it was decided to focus on the more developed northern half of the county. The Sandwich Fault Zone forms a natural boundary, crossing the county from the northwest to the southeast, and only wells north of the fault zone were considered (Figure 15). This left 83 potential wells for sampling. North of the Sandwich Fault Zone are five geographic units within Kendall County based on USGS topographic quadrangles: Aurora South, Plano, Plattville, Yorkville, and Yorkville Southeast.

In order to have a proportional representation of wells with respect to depths and source aquifers, two additional restrictions on well selection were imposed. Within each quadrangle, approximately the same percentage of wells were chosen for sampling as occurred in the overall list representing the Shallow Bedrock Aquifer vs. sand and gravel aquifers, and wells less than 100 ft deep vs. wells 100 to 250 ft deep. For example, if approximately 60 percent of wells in a particular quadrangle were finished in the Shallow Bedrock Aquifer, then for every five wells selected for sampling, three would be finished in the Shallow Bedrock Aquifer. After imposing these geographic, depth, and aquifer constraints on the well selection process, wells were selected randomly within each geographic unit. It was not possible to sample some of these selected wells, however. In some cases permission was denied or the well owner could not be contacted. In other cases, all accessible taps were connected to treatment devices and therefore unsuitable for the study. Each rejected well was replaced, when possible, by a well with similar location, depth, and aquifer characteristics. In the end, 19 wells were sampled. Location, depth, and source aquifer of each well sampled are shown in Table 4 and Figure 15.

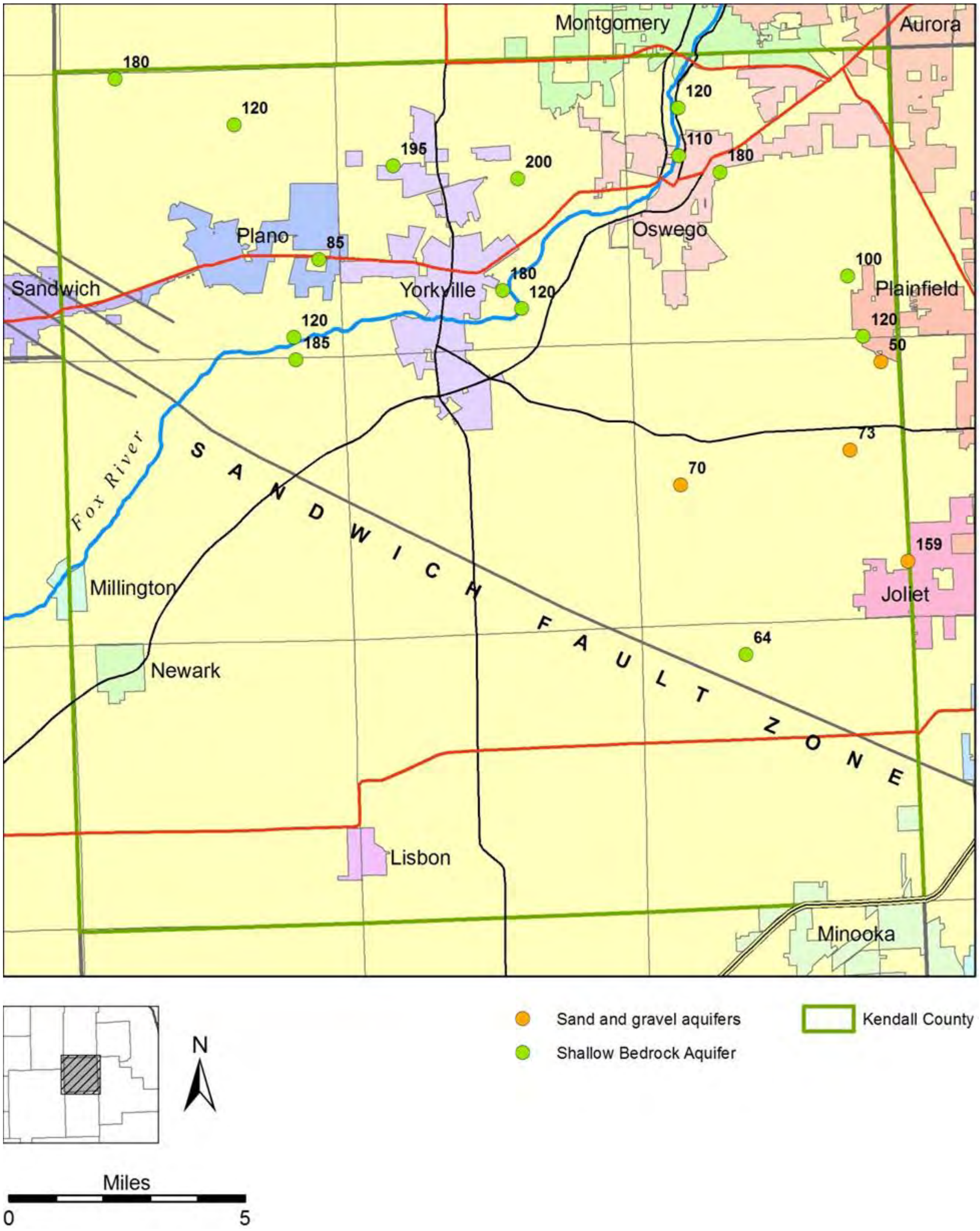


Figure 15. Kendall County map showing wells sampled, major roads, major cities, Fox River, and the Sandwich Fault Zone. Wells depths given in feet.

Table 4. Wells Sampled in the Study

Well ID	*Depth (ft)*	*Source Aquifer*	*Municipality*	*Township*	*Range*	*Section*
163	120	Bedrock	Bristol	37N	7E	15
12	159	Unconsolidated	Little Rock	37N	6E	5
33	64	Bedrock	Minooka	35N	8E	4
7	120	Bedrock	Oswego	37N	8E	8
83	110	Bedrock	Oswego	37N	8E	17
87	180	Bedrock	Oswego	37N	8E	26
89	85	Bedrock	Oswego	37N	8E	16
199	180	Bedrock	Oswego	36N	8E	1
221	185	Bedrock	Plainfield	36N	8E	14
224	200	Bedrock	Plainfield	36N	8E	25
2	195	Bedrock	Plano	37N	7E	17
15	120	Bedrock	Plano	37N	6E	35
88	70	Unconsolidated	Plano	37N	5E	32
159	180	Bedrock	Plano	37N	6E	10
1	100	Bedrock	Yorkville	37N	7E	34
115	50	Unconsolidated	Yorkville	37N	7E	27
169	73	Unconsolidated	Yorkville	36N	6E	2
222	120	Bedrock	Yorkville	36N	8E	20
233	120	Bedrock	Yorkville	37N	6E	12

Sample Collection

A multi-probe instrument was used for measuring temperature, specific conductance (SpC), pH, platinum-electrode oxidation-reduction potential (ORP), and dissolved oxygen (DO). Manufacturer's directions (Mini-Sonde®, Hydrolab, Austin, TX) were used to calibrate the instrument before each sampling trip. Prior to sampling, phosphoric acid (H_3PO_4) was added to the dissolved organic carbon (DOC) bottles.

Wells were sampled from outside taps indicated by owners to be upstream of any treatment. A flow splitter was attached to the tap. A garden hose was connected to one branch of the connector, and a Hydrolab® flow cell was connected to the other branch. The tap was turned to the maximum flow, and most of the flow went through the hose. Temperature, pH, and the other variables were monitored until the readings stabilized. Readings were considered stable if the change in 60 seconds was less than 0.1°C, SpC of 5 percent of the initial value, pH of 0.02, and ORP of 5 millivolts (mV). Readings typically stabilized within 5 to10 minutes except for DO, which often continued to drift downward. The DO probe responds very slowly to DO concentrations below ~1 milligram per liter (mg/L); if the DO reading fell to below ~0.5 mg/L and was still falling, it was assumed that the DO was undetectable.

After recording the readings, the flow cell was disconnected from the sampling line to collect samples. One of the sampling crew, the only one to handle sample bottles, put on powder-free gloves. Unfiltered samples were collected to measure hydrogen sulfide (H_2S) and atrazine.

The sample tube then was connected to a 0.45 micrometer (μm) filter capsule, and filtered samples were collected to measure metals, anions, alkalinity, and ammonium-nitrogen (NH_4-N). Nitric acid (HNO_3) was added to the metals sample (1.25 milliliters or mL to 250 mL bottle) after sample collection. The flow splitter then was removed from the tap, and an unfiltered sample for analysis of coliform bacteria was collected directly from the tap in a sterile Whirl-Pak® bag. The tap was flame sterilized prior to sample collection. After all samples were collected, bottles were stored in a cooler with ice. A summary of sample containers and preservatives is found in Table 5.

Field analyses of H_2S were done at the time of sample collection using a portable colorimetric testing kit (CHEMetrics, Inc., Calverton, VA). A plastic sample cup was used to collect 25 mL of water. The sample was stirred after adding three drops of activator solution (ferric chloride in concentrated HCl). Immediately an ampule containing N,N-dimethyl-p-phenylene diamine was opened in the bottom of the cup, which was inverted several times until the solution had a uniform color. After waiting five minutes, the ampule was inserted into a portable colorimeter to determine H_2S concentration. The sampling crew also noted if the water had a sulfide odor.

Table 5. Sample Containers, Preservatives, and Holding Times

Analyte	*Container*	*Preservative (%)*	*Filtered*	*Holding Time (days)*
Metals	HDPE	0.2 HNO_3	Yes	180
Anions/alkalinity	HDPE	None	Yes	2
NH_4-N	HDPE	0.2 H_2SO_4	Yes	24
DOC	Glass	0.5 H_3PO_4	Yes	ASAP
Atrazine	Glass	None	No	14
Coliform Bacteria	Whirl-Pak® bag	None	No	ASAP

Notes: Preservative percentage was by volume of concentrated high-purity acid.
Holding time for DOC was not specified for acidified samples.

Sampling Quality Assurance

Duplicate samples were collected from one well per day to test for analytical replicability. For each sampling trip, a set of blanks containing deionized water was collected prior to departure and analyzed with the samples. These blanks were prepared to check if the sampling procedures (i.e., filtering, acidification, and storage) introduced solutes. Chain-of-custody sheets were completed at the end of each sampling day to keep track of the samples during the analytical process and ensure that sample holding times were not exceeded.

Chemical Analyses

The ISWS Public Service Laboratory (PSL) in Champaign conducted most of the chemical analyses using standard methods (www.sws.uiuc.edu/chem/ias/). Anions were analyzed by ion chromatography, metals by inductively coupled plasma-atomic emission spectrometry, alkalinity by titration, NH_4-N by colorimetry, DOC by carbon analyzer, and arsenic by graphite furnace atomic absorption spectrometry with Zeeman background correction.

Semi-quantitative atrazine analyses were done using an immunoassay test (Hach®) in which 0.5 mL of sample and 0.5 mL of an atrazine enzyme conjugate solution were pipetted into a cuvette and allowed to react for 20 minutes. The liquid in the sample then was discarded, and 0.5 mL of color developing solution was pipetted into the cuvette and allowed to react for 10 minutes. Then 0.5 mL of a solution to stop the reaction was added to the cuvette and mixed. The cuvette then was inserted into a colorimeter (wavelength = 450 nanometers) for comparison with 0.5 and 3.0 micrograms per liter (µg/L) atrazine standards. This test does not differentiate between various triazines and metabolites, although it detects their presence to differing degrees.

A presence/absence test (Hach®) was conducted for total coliform and *E. coli* bacteria by adding 100 mL of sample to a bottle containing bromcresol purple broth with MUG (4 methylumbelli-feryl-β-D-glucuronide). Sample color was checked after incubating the sample at 35°C for 24 to 48 hours. A color change from reddish purple to yellow or yellow brown indicated a presumptive positive for total coliform bacteria. If there was no color change, the sample was incubated for an additional 24 hours. If there was still no color change, the test was recorded as negative for total coliform bacteria. Presumptive positive samples were examined under long-wave ultraviolet light. Samples that fluoresced were recorded as positive for *E. coli* bacteria.

ISWS Groundwater Quality Database

Sample data collected in this study were supplemented with data from the ISWS Groundwater Quality Database (GWQDB), which contains historical water quality data dating back to the late 1890s for samples from both public and domestic wells. Most of the samples stored in the GWQDB have been submitted by well owners, who usually collect samples from domestic wells in containers provided by and mailed to the ISWS PSL for analyses of inorganic water quality. The GWQDB was searched for data from Kendall County domestic wells less than 250 feet deep. To minimize possible temporal changes in groundwater quality, only GWQDB sample data collected since 2000 were used. Seven GWQDB samples met these criteria and are included in some of the graphs and data analysis.

Results and Discussion

Complete chemical results appear in Appendix B. All well owners received individual sampling results in January 2008. Chemical results for the seven GWQDB samples also are in Appendix B.

Water quality data primarily are collected to determine if contaminants need to be removed from the water to make it safe for consumption. The U.S. Environmental Protection Agency (USEPA) has promulgated maximum contaminant levels (MCLs) for about 100 inorganic and organic chemicals, microorganisms, disinfectants and disinfection products, and radionuclides (United States Environmental Protection Agency, 2008). Most of these MCLs are primary standards for which potentially undesirable health effects have been identified when the standards are exceeded. These standards apply only to public water supplies and are legally enforceable. Secondary standards exist for 15 contaminants, primarily inorganic chemicals that may cause aesthetic or cosmetic problems; they are not enforceable. Analyses done at the ISWS for this study included 21 constituents on either the primary or secondary standard lists (Table

6); copper and fluoride have both primary and secondary MCLs. The analytical detection limits for antimony and lead were greater than their primary MCLs.

Table 6. Primary and Secondary Drinking Water MCLs for Contaminants Analyzed in this Study (mg/L except for pH)

Primary Standards	*MCL*	*Potential Health or Other Effects*
Arsenic	0.010	Skin damage; problems with circulatory systems; increased cancer risk
Atrazine	0.003	Cardiovascular or reproductive problems
Barium	2	Increase in blood pressure
Beryllium	0.004	Intestinal lesions
Cadmium	0.005	Kidney damage
Chromium	0.1	Allergic dermatitis
Copper	1.3	Short-term exposure: gastrointestinal distress Long-term exposure: liver or kidney damage
Fluoride	4.0	Bone disease and tooth discoloration in children
Nitrate-nitrogen	10	Infants below 6 months of age could become seriously ill and may die if untreated for shortness of breath and blue-baby syndrome
Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems
Total coliforms	0	Not a health threat in itself, but used to indicate presence of other potentially harmful bacteria
Secondary Standards		
Aluminum	0.05 - 0.2	Colored water
Chloride	250	Salty taste
Copper	1.0	Metallic taste; blue-green staining
Fluoride	2.0	Tooth discoloration
Iron	0.3	Rusty color; sediment; metallic taste; reddish or orange stains
Manganese	0.05	Black to brown color; black staining; bitter metallic taste
pH	6.5 - 8.5	<6.5: bitter metallic taste; corrosion; >8.5: slippery feel; soda taste; deposits
Sulfate	250	Salty taste
Total Dissolved Solids	500	Hardness; deposits; colored water; staining; salty taste
Zinc	5	Metallic taste

Groundwater quality data also are collected to elucidate geochemical conditions within the source aquifer. Use of these data, along with geological, hydrologic, and biological data, helps scientists to understand processes that may affect the fate and transport of contaminants, mineral dissolution/precipitation reactions, aquifer recharge rates, etc.

Dissolved Solids and Major Ions

Total dissolved solids (TDS) in a water sample can be determined in several ways. First, it can be directly measured by filtering, drying, and weighing a known volume of sample. Second, specific conductance, which is measured at the time of sample collection, can be used as a proxy for TDS. Specific conductance is the measure of how water conducts an electric current. Because the presence of charged ionic species makes a solution conductive, specific conductance is an indirect measure of the amount of dissolved minerals in water. For most groundwater samples, the concentration of TDS can be calculated by multiplying the specific conductance by a value between 0.5 and 0.6 (Hem, 1989). Finally, TDS can be calculated by summing all the dissolved species measured analytically. This is a straightforward calculation except for bicarbonate (HCO_3^-). Bicarbonate is determined by dividing alkalinity by 0.82, and then the HCO_3^- is converted by a gravimetric factor (0.4917) that assumes that half of it is volatilized as carbon dioxide (CO_2) and water (H_2O) before it is summed with the other ions (Hem, 1989). For the samples collected in this study, TDS was determined by the summation of dissolved species. For samples from the GWQDB, measured TDS was used.

TDS concentrations of nine of the 19 sampled wells and two of the seven samples in the GWQDB exceeded the secondary MCL of 500 mg/L (Figure 16). The largest value (890 mg/L) was from a well finished in a sand and gravel (unconsolidated) aquifer, which also happened to be the shallowest well sampled (50 ft). Its TDS was considerably higher than the next largest value (645 mg/L). Samples from three of the four wells finished in sand and gravel aquifers had values above the MCL. There was no obvious geographic pattern to TDS values, except that samples collected in and around Oswego all had values greater than 500 mg/L.

TDS (and specific conductance) values are primarily a function of the concentrations of major ions in solution: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), chloride (Cl^-), HCO_3^-, and sulfate (SO_4^{2-}). The major ion data were plotted on a Piper diagram (Figure 17). The major ion chemistry varied from a Ca-Mg-HCO_3^- to a Na-HCO_3^- composition. There was an inverse relationship for Na versus Ca and Mg (Figure 18).

In order to further investigate the spatial pattern for Na concentrations, the search of the GWQDB was expanded to find samples from wells with depths up to 750 ft. These additional samples were selected in part to see if there was a depth control on Na concentrations. There appear to be two areas where Na concentrations are elevated, adjacent to the Fox River, especially upstream of Plano, and along the Sandwich Fault Zone (Figure 19). These are areas where upward movement of groundwater may be occurring. Drilling logs for the sampled wells indicate there are shale deposits interbedded with and overlying the limestone aquifer. Groundwater from the Shallow Bedrock Aquifer and sand and gravel aquifers discharges into the Fox River, and as the water migrates up through the clay-rich shales, cation exchange apparently occurs, with Ca^{2+} and Mg^{2+} in solution being replaced by Na^+. Thus groundwater discharging to the Fox River in this area should have relatively elevated levels of Na.

The Sandwich Fault Zone may also be an area of upward flow (Figure 19). Rocks on the southern side of the fault zone have been uplifted relative to the northern side, and this movement may have caused impermeable units to intersect the aquifers, forcing upward flow of groundwater. More sampling of wells in close proximity to the fault zone would help determine this.

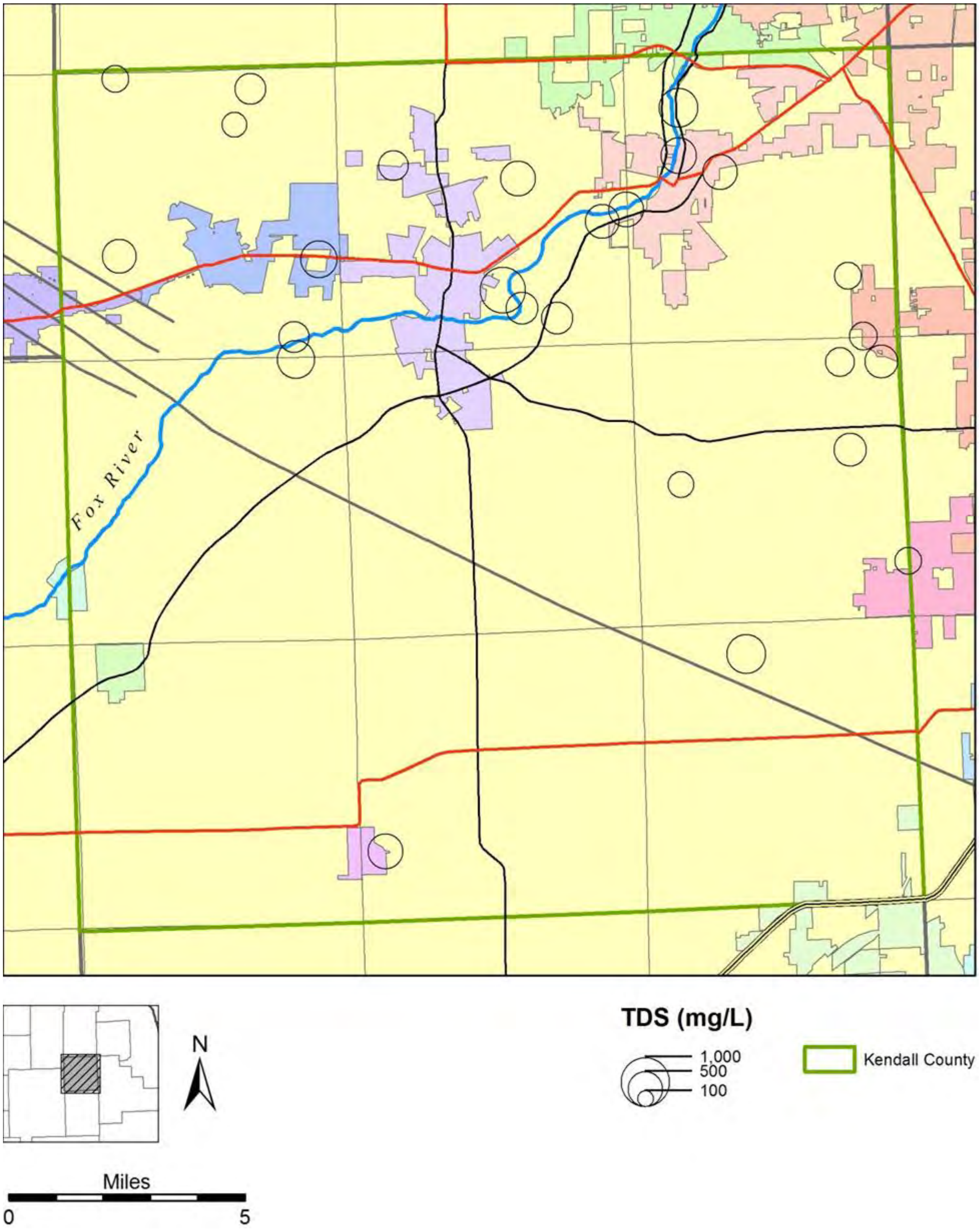


Figure 16. TDS concentrations in sampled wells and GWQDB samples

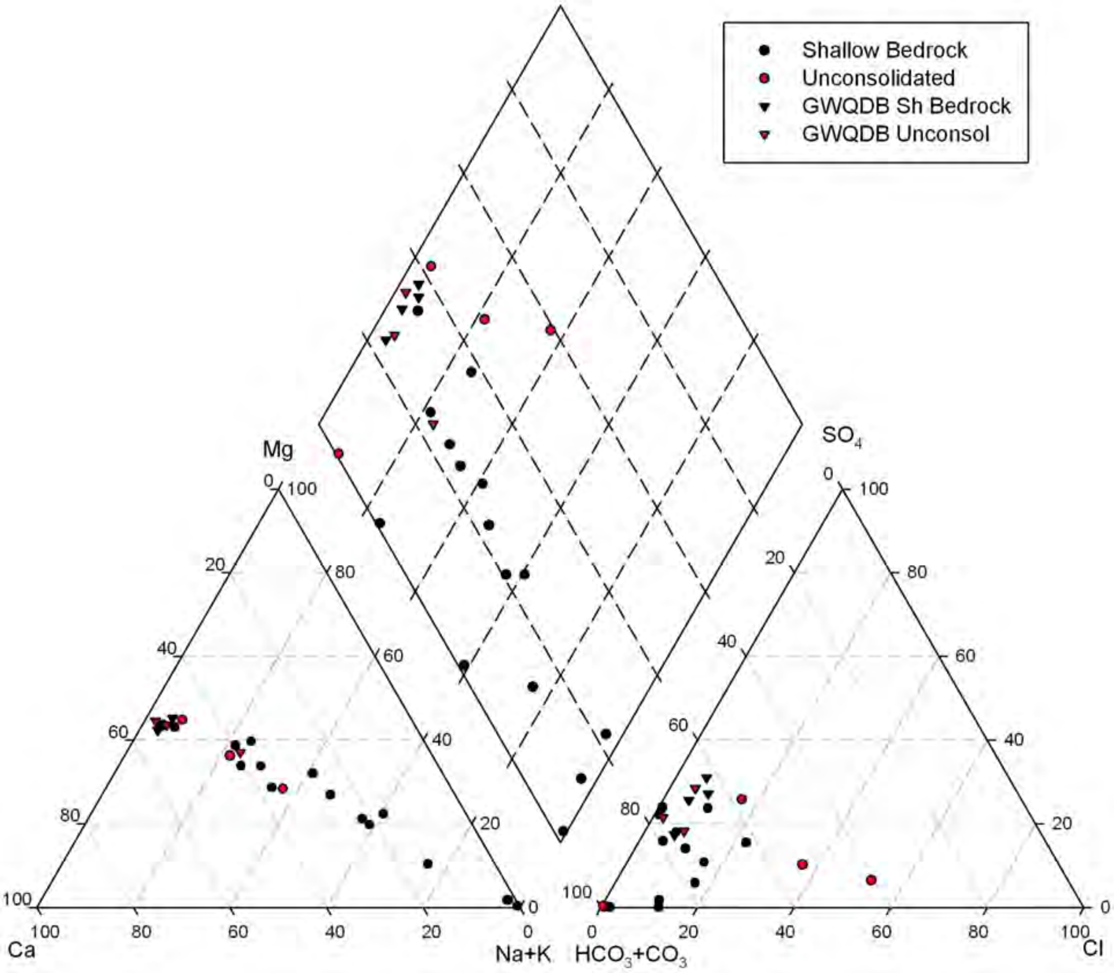


Figure 17. Piper diagram showing major ion chemistry of water samples

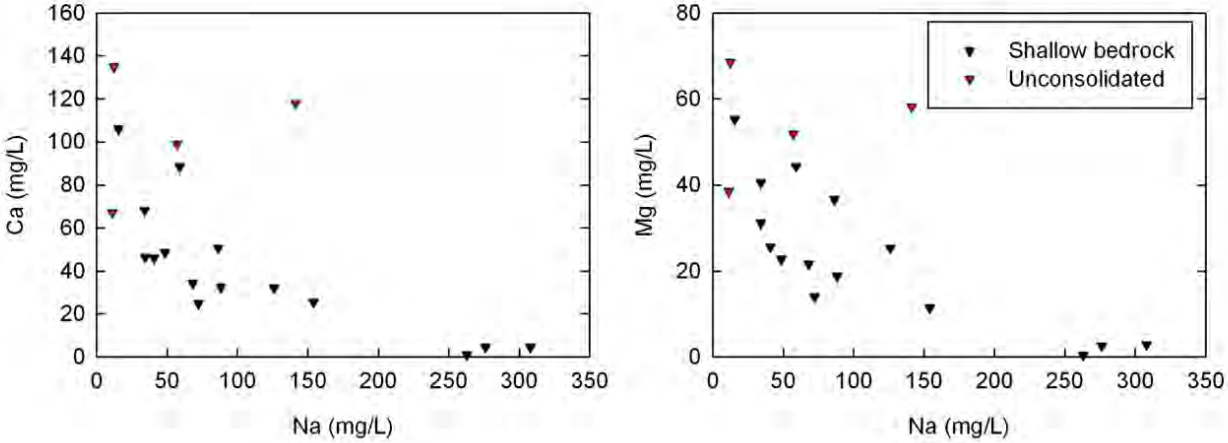


Figure 18. Calcium and magnesium concentrations versus sodium concentrations for sampled wells

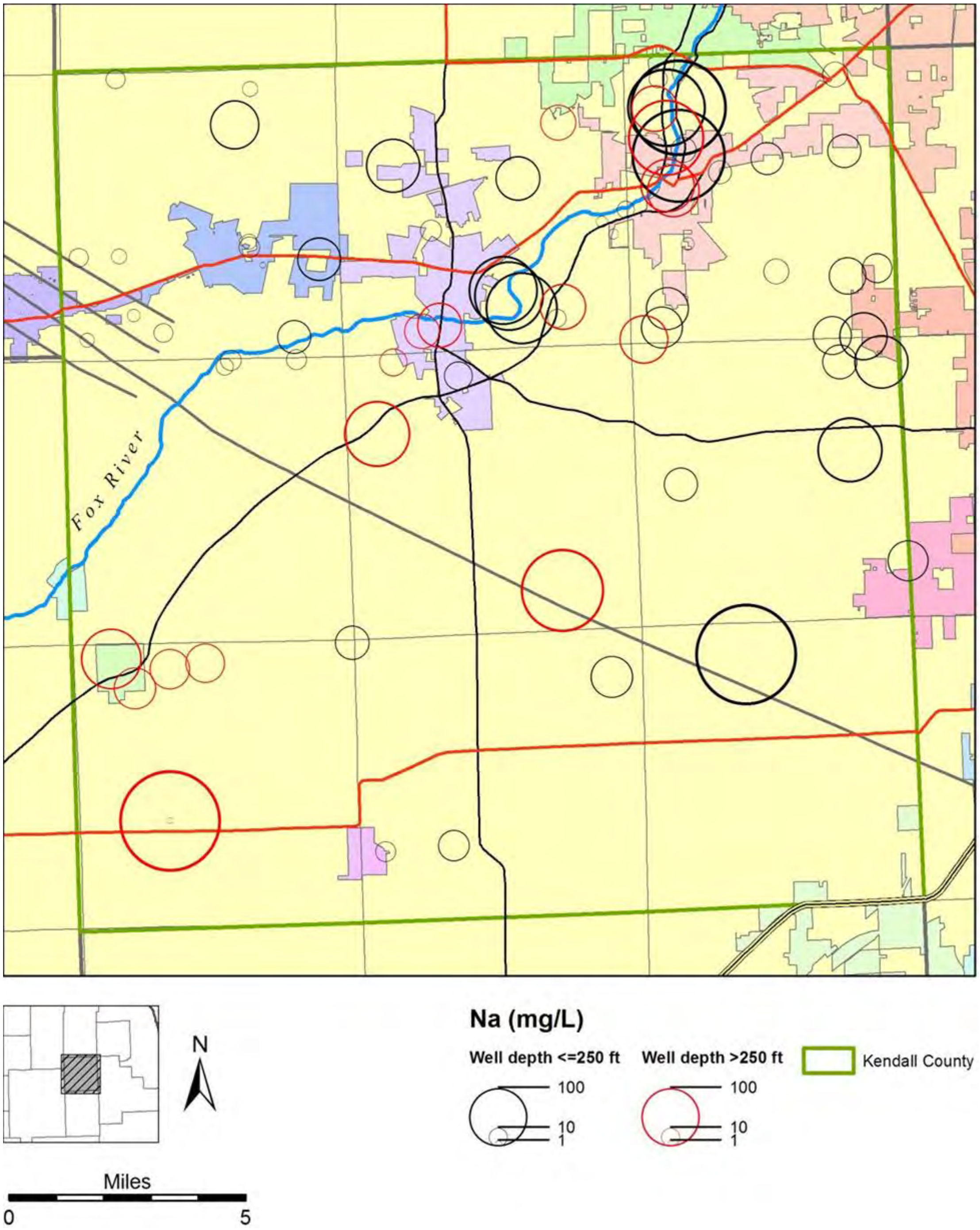


Figure 19. Sodium concentrations in sampled wells and GWQDB samples.
Samples differentiated by well depth

Chloride (Cl^-) concentrations have been found to be elevated in the Shallow Bedrock Aquifer and sand and gravel aquifers in many parts of the Chicago region, primarily due to road salt runoff (Kelly and Wilson, 2008). Chloride concentrations were for the most part not elevated in Kendall County (Figure 20). Panno et al. (2006) determined that Cl^- concentrations greater than 15 mg/L in shallow groundwater in northeastern Illinois is indicative of human contamination (primary sources include road salt, sewage/septic, and livestock manure). Eight of the 19 collected samples and one of the seven samples from the GWQDB had Cl^- concentrations less than 15 mg/L. Two of the collected samples had concentrations greater than 100 mg/L (149 and 307 mg/L). Both of these wells were finished in sand and gravel aquifers, were two of the shallowest wells, and were located near U.S. Route 34; thus they may have been affected by road salt runoff. The secondary MCL for Cl^- is 250 mg/L.

Because the most important sources of Cl^-, particularly road salt runoff, are at the land surface, well depth and nearness to major roads should be important variables controlling Cl^- concentrations. Depth was an important control, as all the samples with concentrations greater than 30 mg/L were from wells 120 ft or less (Figure 21). While the two wells with the highest Cl^- concentrations were near a major road, other wells adjacent to major roads did not have particularly elevated concentrations (Figure 20). A plot of Na vs. Cl^- shows that most of the samples from the Shallow Bedrock Aquifer are stoichiometrically enriched in Na (Figure 22). This is consistent with the hypothesis that cation exchange is increasing Na concentrations in solution without affecting Cl^- concentrations. On the other hand, samples from wells open to sand and gravel aquifers plot close to the 1:1 line, suggesting halite (road salt or water softener discharge) is likely the main source of Cl^- for these samples.

Oxidation-Reduction Conditions

An important control on biogeochemical processes in groundwater is oxidation-reduction (redox) conditions in the aquifer. Redox reactions are chemical reactions that transfer electrons from one ion to another. Because surface waters have abundant oxygen due to contact with the atmosphere, conditions there are usually oxidizing. Oxygen in groundwater, however, is limited and often removed before it is transported very far due to the oxidation of organic matter and iron, and conditions are usually reducing. Oxygen removed from groundwater is not easily replaced, so other compounds are used in oxidation reactions. These other compounds, referred to as electron acceptors, include nitrate (NO_3^-), ferric iron, and SO_4^{2-}.

The values of most of the redox-sensitive parameters (DO, ORP, NO_3^-, iron, manganese, SO_4^{2-}, H_2S, and NH_4-N) indicate mild to strong reducing conditions in the Shallow Bedrock Aquifer and sand and gravel (unconsolidated) aquifers. Reducing conditions in shallow, unconfined aquifers in Illinois are not uncommon. Buried organic matter is abundant in soils and surficial glacial deposits, and oxidation of these compounds removes oxygen from water during aquifer recharge. Reduction of iron oxyhydroxide minerals, also common in glacial deposits, occurs under moderately reducing conditions and increases dissolved iron concentrations in groundwater. Iron concentrations in 7 of the 19 collected samples (37 percent) exceeded the secondary MCL of 0.3 mg/L, and 2 samples exceeded 1 mg/L.

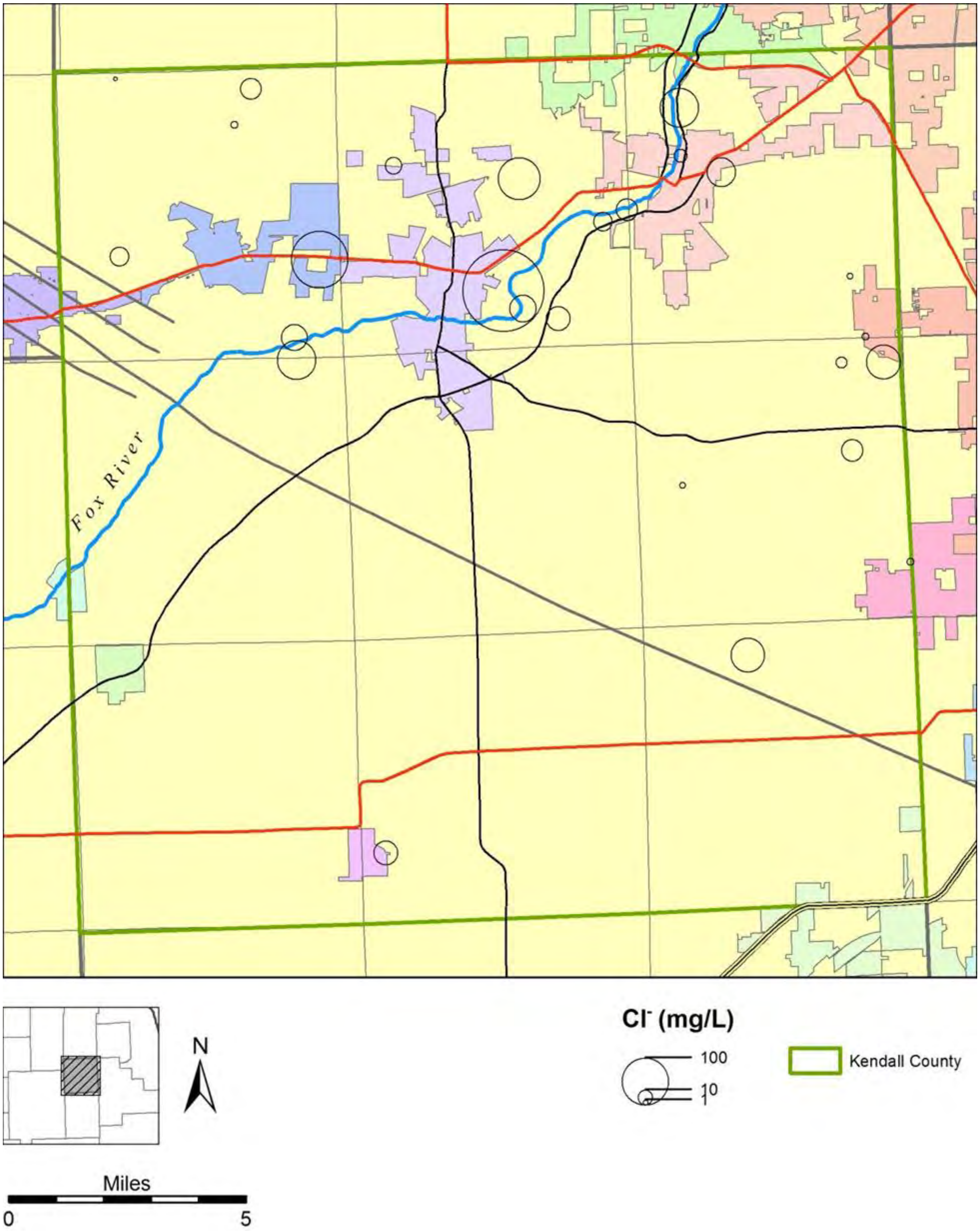


Figure 20. Chloride concentrations in sampled wells and GWQDB samples

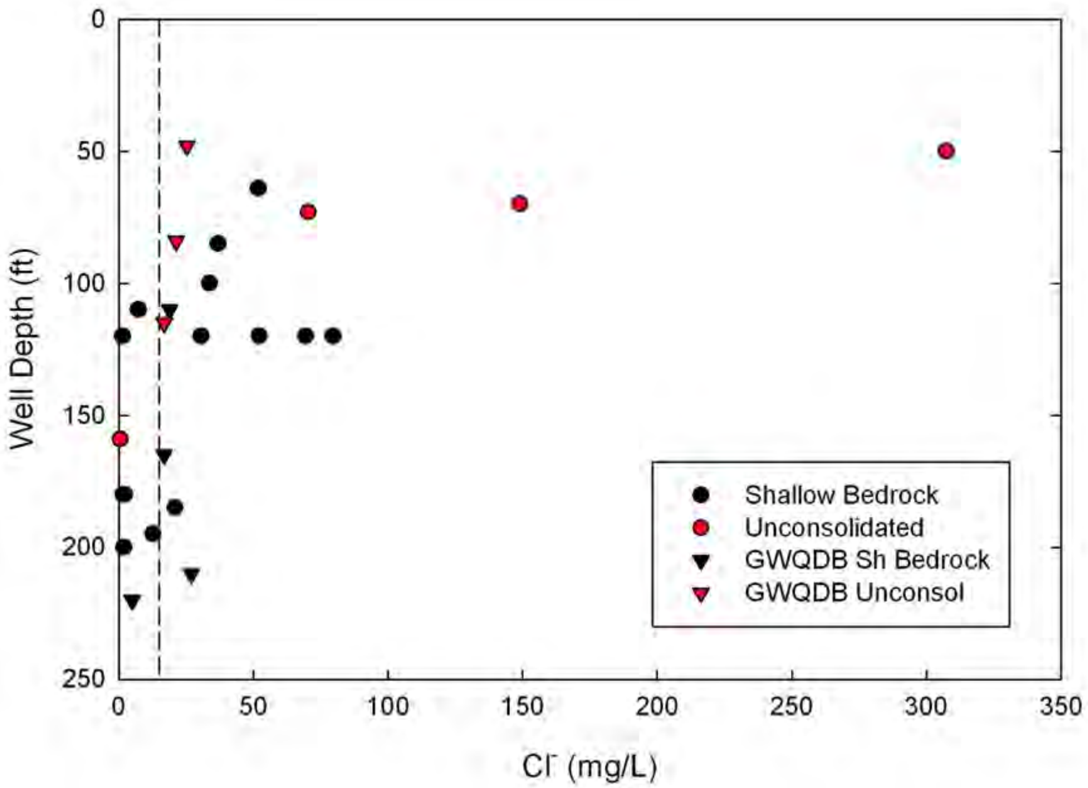


Figure 21. Chloride concentrations as a function of well depth. Dashed line represents upper limit of background Cl⁻ concentrations (15 mg/L).

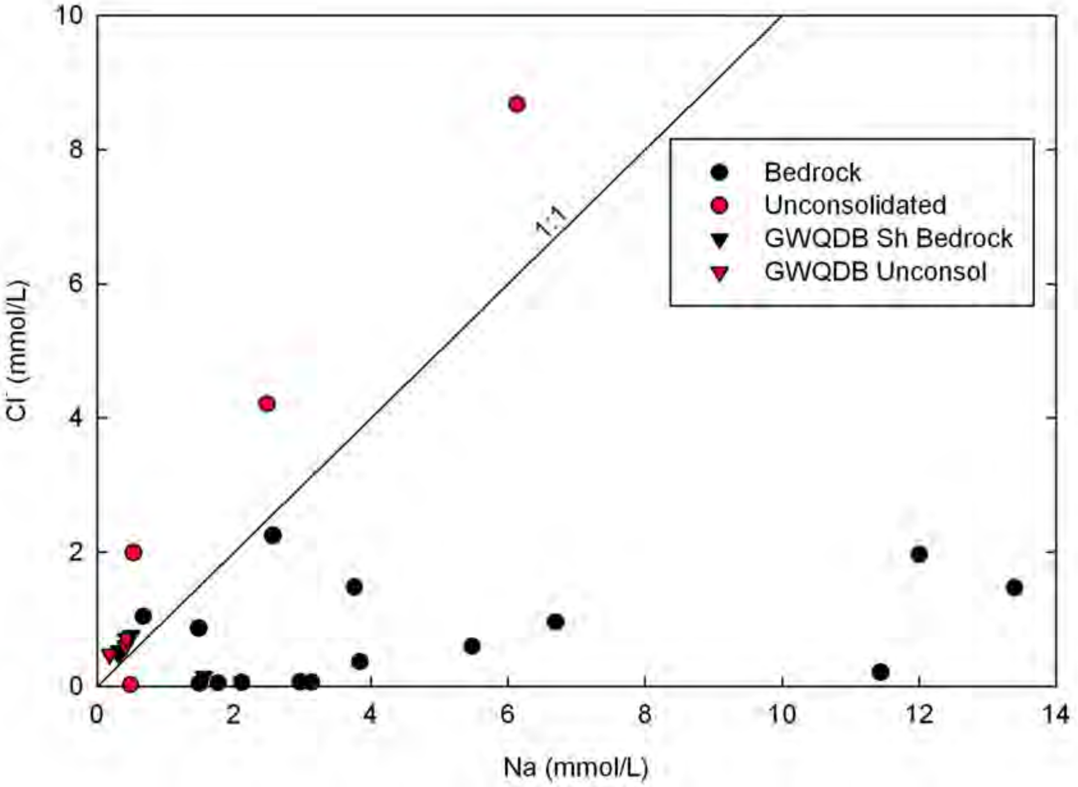


Figure 22. Chloride versus Na concentrations. Equimolar line is shown.

One sample, from well 115, had an elevated DO concentration (3.4 mg/L). This was the shallowest well sampled with evidence of surface contamination (elevated Cl^-). The elevated DO concentration suggests rapid recharge from the surface.

Under strongly reducing conditions, SO_4^{2-} is reduced, producing H_2S. Sulfate was less than 1 mg/L in 5 samples, and its absence suggests removal by SO_4^{2-}-reducing bacteria. Hydrogen sulfide was detected in seven of the wells, and most of the samples from these wells had detectable SO_4^{2-}, indicating active SO_4^{2-} reduction. The wells with the largest concentrations of H_2S also had the lowest (most reducing) ORP values. Production of H_2S can cause iron and other metals to precipitate out of solution as sulfide minerals within the aquifer, and samples with detectable H_2S had little or no iron and vice versa (Figure 23).

For most of the measured parameters, except iron, zinc, and NO_3^-, there was no difference in chemistry between wells with and without detectable hydrogen sulfide. The five samples with detectable zinc and the three samples with detectable NO_3^- were found in wells without detectable H_2S. The production of H_2S would be expected to remove Zn from solution by mineral precipitation. The presence of NO_3^- suggests oxidizing or mildly reducing conditions, and it is removed, mainly by denitrification, once conditions become more strongly reducing.

Atrazine

Atrazine, the most commonly applied row-crop herbicide in Illinois in recent decades, also is considered to be the most environmentally persistent pesticide in the Midwest (Goolsby, 1991). Atrazine was not detected in any samples (< 0.5 µg/L). This is not surprising because atrazine readily adsorbs to clay minerals and organic matter in soils and unconsolidated glacial deposits in the shallow subsurface. Thus atrazine transport is generally limited in groundwater systems.

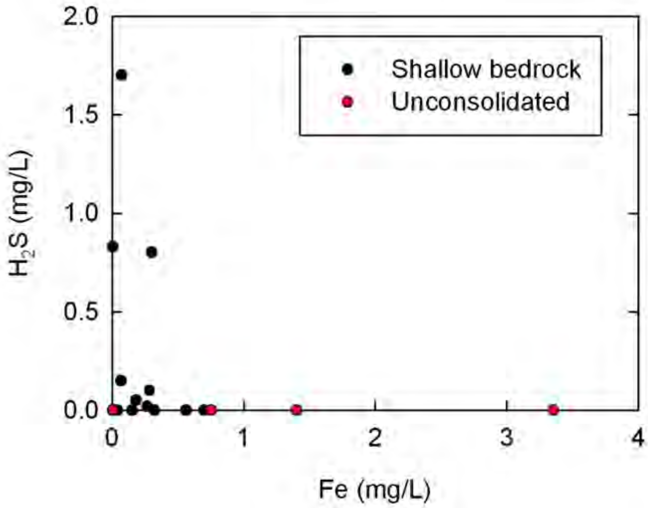


Figure 23. Hydrogen sulfide concentrations versus dissolved Fe for sampled wells

Nitrate

Elevated nitrate-nitrogen (NO_3-N) is common in groundwater in agricultural regions, due to leaching of synthetic fertilizer and natural soil nitrogen from the soil zone. Nitrate migrates fairly rapidly in many aquifers. However, only 3 of the 19 samples and two of the seven GWQDB samples had detectable NO_3-N (> 0.07 mg/L). Only two of the samples had concentrations greater than 0.5 mg/L. The highest concentration measured was 8.73 mg/L in well 115, which also had an elevated DO and a Cl^- concentration greater than 300 mg/L, all evidence of surface contamination. The observation of generally low NO_3-N concentrations is similar to what was found in the Shallow Bedrock Aquifer and sand and gravel aquifers in Kane County (Kelly, 2005), although different from what other researchers have found in similar settings throughout the state. For example, a large number of wells in McHenry County have NO_3-N concentrations above the MCL (Hwang et al., 2007).

There are several potential explanations for the lack of NO_3^- found in the shallow groundwater in Kendall County. Possibly most of the NO_3^- reaching the groundwater is denitrified. In the presence of a suitable electron donor, such as organic matter, microorganisms readily reduce NO_3^- to nitrogen gas under moderately reducing conditions:

$$4NO_3^- + 5CH_2O + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O$$

where CH_2O is a generic representation of organic matter. As discussed above, the aquifers were generally under reducing conditions, with abundant organic carbon as the most common source of electrons for denitrification. The presence of H_2S in many wells indicates strongly reducing conditions, and the absence of NO_3^- in those samples would be expected. The three sampled wells with detectable NO_3-N had the lowest measured iron concentrations (< 0.009 mg/L), suggesting conditions not sufficiently reducing to reduce iron.

Another possible explanation for the lack of NO_3^- in the groundwater is that much of Kendall County farmland is tile drained. Thus most of the surface-derived NO_3^- may be transported to streams and drainage ditches rather than remaining in the groundwater. Still another contributor to the lack of NO_3^- in aquifers may be the increasing use of best management practices, such as buffer strips along ditches and streams, wetland construction, water table management, etc. Without widespread historical NO_3^- data for Kendall County, however, it is impossible to know how much of a factor this may be.

Coliform Bacteria

Seven of the sampled wells had both detectable total coliform and *E. coli* bacteria, including three of the four shallowest wells and three of the four wells finished in sand and gravel (unconsolidated) aquifers. Samples with detectable bacteria also tended to have relatively high concentrations of Cl^-, alkalinity, iron, silica, and barium, and relatively lower concentrations of Na, potassium, H_2S, and lithium, and lower ORP values. The presence of *E. coli* indicates contamination by human or animal waste, and the tendency for samples from the Shallow Bedrock Aquifer and sand and gravel aquifers to have detectable *E. coli* indicates these aquifers are more susceptible to contamination by waste. The presence of coliform bacteria is usually a local problem, either due to poor wellhead protection or contamination in the well or water distribution system. All well owners were informed that the analysis method used was not approved for regulatory purposes, and were instructed to contact the county health department if they wanted their well more rigorously tested for coliform bacteria.

Other Contaminants

In addition to TDS, chloride, and iron, other ions that were above their MCL in some samples included manganese and fluoride. Four well samples had manganese levels above the 0.05-mg/L MCL. Three of these wells that were finished in sand and gravel (unconsolidated) aquifers also had the three highest measured iron concentrations (wells 12, 88, and 169). Manganese and iron often exhibit similar trends, and there was a slight positive correlation between these two metals ($r^2 = 0.23$; Figure 24).

Fluoride concentrations were relatively high in some of these samples compared to other shallow groundwater in Illinois. Two samples had concentrations exceeding the primary MCL of 4 mg/L, and a third exceeded the secondary MCL of 2 mg/L. Thirteen of the samples exceeded 0.5 mg/L, all from wells finished in the Shallow Bedrock Aquifer. The three samples with the highest concentrations were from wells located in the area where the Maquoketa is the uppermost bedrock, and thus they had a greater influence of shale. There was a positive correlation between fluoride and sodium ($r^2 = 0.54$; Figure 25). It appears that in areas where there is upward migration of groundwater and/or influence of shales, fluoride is introduced into solution as well as sodium.

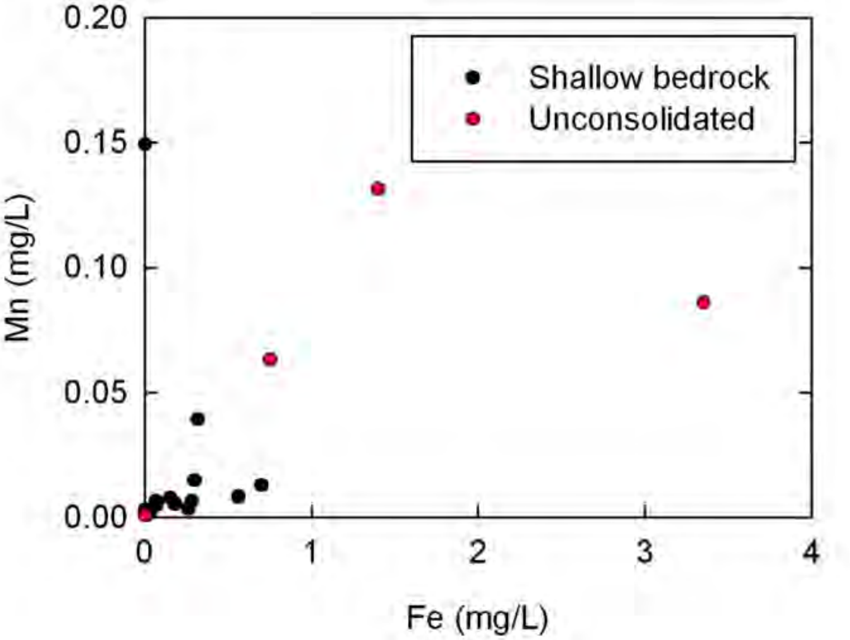


Figure 24. Manganese versus iron concentrations for sampled wells

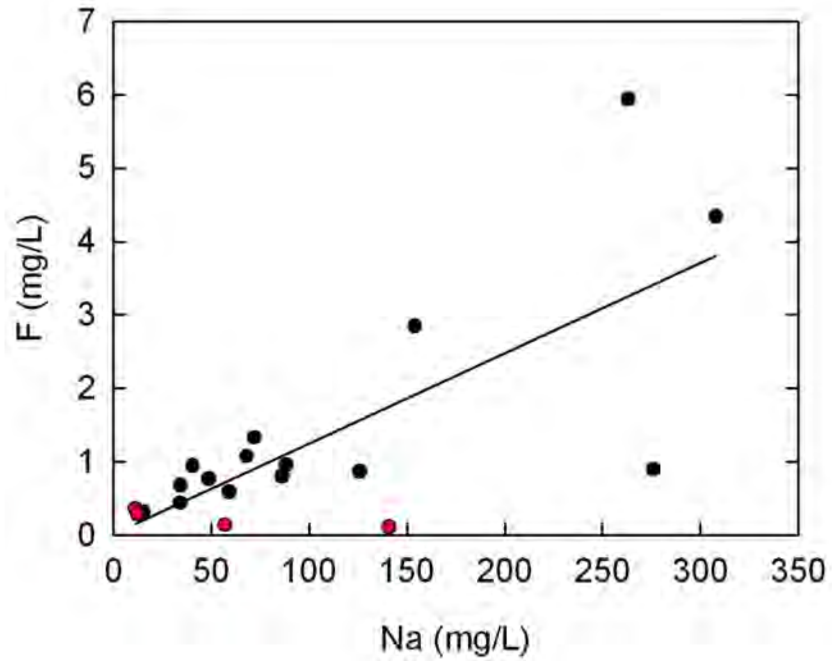


Figure 25. Fluoride versus Na concentrations for sampled wells. Regression line shown ($r^2 = 0.54$)

No other contaminants were detected above their MCLs (Table 6). Barium was detected in all wells, but always well below the 2-mg/L MCL, with the highest concentration being 0.211 mg/L. Concentrations of the toxic metals arsenic, beryllium, cadmium, chromium, and selenium were always below their analytical detection limits. Copper was detected in seven samples, but at concentrations well below the MCL of 1.3 mg/L (highest measured value 0.00589 mg/L).

Water Quality as a Function of Well Depth and Aquifer Sensitivity

In general, the shallower a well, the more susceptible it is to surface-derived contamination. For example, Kelly and Wilson (2008) observed that municipal wells less than 100 ft deep in the Chicago region had greater chloride concentrations than wells between 100 and 200 ft deep, primarily due to road-salt runoff. In addition, the thicker the deposits of low permeable material that overly an aquifer, the less sensitive the aquifer is to surface-derived contamination. In order to determine if there were significant differences in groundwater quality based on well depths or aquifer sensitivity, the data were divided into two subsets several different ways based on the following criteria: (1) well depth ≤ 100 ft and > 100 ft; (2) well depth ≤ 120 ft and > 120 ft; (3) well casing depth ≤ 63 ft and > 63 ft; and (4) thickness of till overlying aquifers ≤ 32 ft and > 32 ft. Casing depths and till thicknesses were determined from individual drilling well logs. The 100-ft well depth was selected because that value has been used in other studies (Kelly, 2005; Kelly and Wilson, 2008). The other depths/thicknesses were selected because there appeared to be natural divisions in the data with approximately equal numbers of samples greater or less than these values (Table 7). The data were evaluated using the Mann-Whitney rank sum test (non-parametric version of t-test) at the 95 percent confidence level.

The different groupings of data generally showed the same results (Table 7). Specific conductance, alkalinity, and Cl^- were significantly higher in samples from shallower, less well protected wells, while NH_4-N concentrations were significantly lower in these samples (Figures 26 and 27). The major cations (Ca, Mg, Na) had higher concentrations in these samples as well, although the differences were generally not significant. As discussed earlier, relatively elevated Cl^- concentrations in samples from shallower wells were expected, assuming the source was road-salt runoff. Redox conditions in the deeper wells tended to be more reducing as evidenced by the significantly higher concentrations of NH_4-N. Iron, DOC, and hydrogen sulfide also were generally higher and ORP lower in the deeper wells, but the differences were not significant. Concentrations of surface-derived contaminants are thus a function of both aquifer sensitivity and spatial location. Well protected aquifers, as evidenced by relatively thick overlying till deposits, seem to have good water quality, but samples from some wells in poorly protected aquifers also had good quality. Wells located outside urban areas and away from major roads tended to have the best water quality (Figures 16 and 20).

Table 7. Statistical Results for Mann-Whitney Tests

Variable	*Value (ft)*	*N shallow*	*N deep*	*Significant Differences*
Well depth	100	6	13	**SpC**, **Ca**, **Cl^-**, NH_4-N, Sr, **Zn**
Well depth	120	12	7	**SpC**, **alkalinity**, **Cl^-**
Casing depth	63	11	7	**SpC**, **alkalinity**, **Cl^-**, NH_4-N
Till thickness	32	11	7	**SpC**, **alkalinity**, **Cl^-**, NH_4-N

Notes: Values are depths or thicknesses distinguishing shallow from deep wells.
N are number of values in data sets.
Parameters in bold were significantly greater in shallower wells or thinner till thickness.

Water Quality as a Function of Source Aquifer Material

Water quality data also were divided into two groups based on the source aquifer material: Shallow Bedrock Aquifer versus sand and gravel aquifers. Because there were only four sampled wells screened in sand and gravel aquifers, samples from the GWQDB were also considered for this analysis. This gave 19 wells finished in the Shallow Bedrock Aquifer and 7 finished in sand and gravel aquifers. Wells finished in sand and gravel aquifers were expected to be more susceptible to surface-derived contaminants because they had significantly shallower depths. They are also generally overlain by thinner low permeability till deposits.

Concentrations of SpC, Ca, Mg, manganese, and barium were significantly greater in samples from wells finished in sand and gravel aquifers, and concentrations of fluoride and boron were significantly greater in samples from wells finished in the Shallow Bedrock Aquifer. Median concentrations of alkalinity, Cl^-, and SO_4^{2-} were higher in samples from wells finished in sand and gravel aquifers, but the differences were not significant. Sodium was higher in samples from wells finished in the Shallow Bedrock Aquifer. Barium may be relatively elevated in the sand and gravel aquifers due to the greater amount of barium in sand and gravel, primarily in feldspars, versus the Shallow Bedrock Aquifer, which is primarily fractured limestone [$CaCO_3$], dolomite [$CaMg(CO_3)_2$], and shale north of the Sandwich Fault Zone (Kay et al., 2005). It is unclear why there would be differences in boron as a function of aquifer type, although this difference was also observed in Kane County (Kelly, 2005).

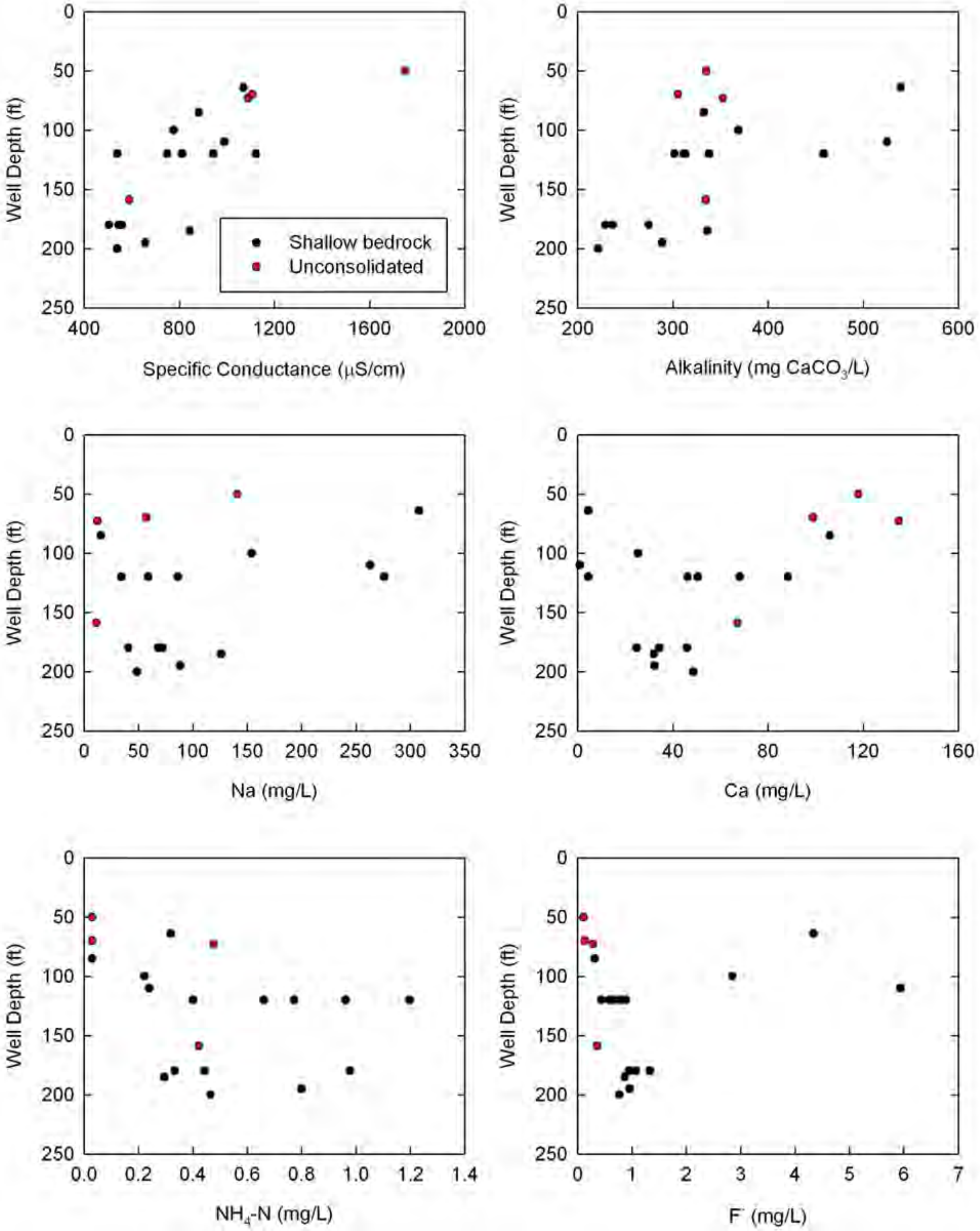


Figure 26. Concentrations of various parameters as a function of well depth for sampled wells

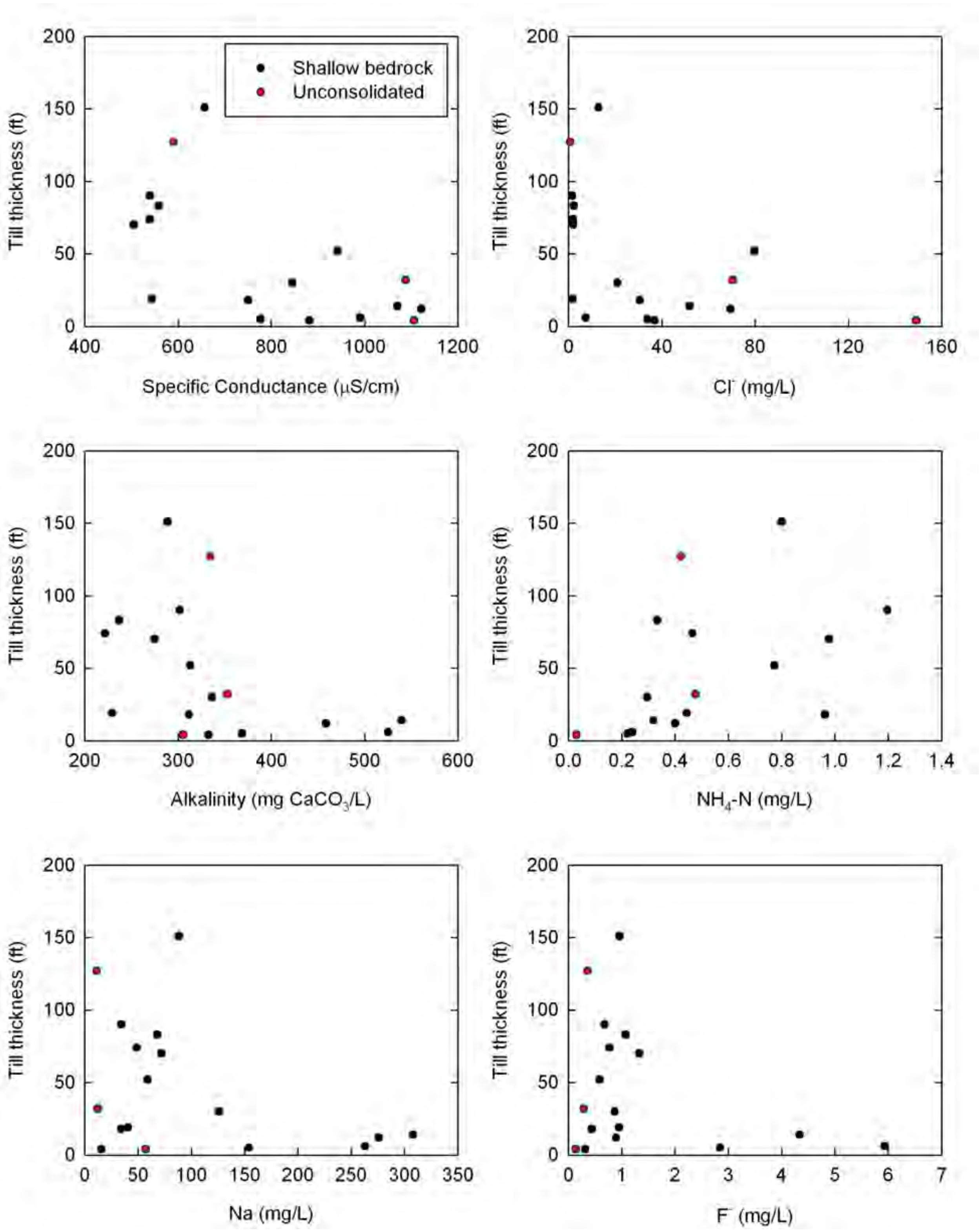


Figure 27. Concentrations of various parameters as a function of overlying till thickness for sampled wells

Summary

Groundwater quality in the Shallow Bedrock Aquifer and sand and gravel (unconsolidated) aquifers in Kendall County is generally very good. Human activities have not caused significant contamination of these aquifers. Contaminants associated with agricultural activities (nitrate and atrazine) were generally below analytical detection limits. Chloride, which is elevated in the Shallow Bedrock Aquifer and sand and gravel aquifers in many parts of northeastern Illinois due to road salt runoff, is generally not elevated in Kendall County. There were, however, two sampled wells with concentrations > 100 mg/L, both near a major road (U.S. Route 34), so the potential for road salt contamination exists. Water quality was a function of both well depth and overlying till thickness, with generally better quality in deeper wells and thicker till deposits.

The only natural contaminants of concern are fluoride and sodium. Sodium is not a health concern except for people on low sodium diets. These two ions appear to be related, with elevated levels found in two areas: near the Fox River and near the Sandwich Fault zone. These may be areas where upward flow of water from deeper bedrock units is discharging to the Shallow Bedrock Aquifer and sand and gravel aquifers, and the elevated fluoride and sodium levels may be due to this more saline water or ion exchange in shales. Iron and manganese concentrations were elevated in some samples, a common occurrence in the Shallow Bedrock Aquifer and sand and gravel aquifers of Illinois. This is mainly an aesthetic concern (staining). Experiences in many parts of the world, including northeastern Illinois, show that urbanization can contaminate shallow aquifers. In Kane County, for example, just north of Kendall County, shallow groundwater quality in the eastern, urban part of the county is significantly worse than in the western, rural part of the county.

Groundwater Flow Model Description

Understanding the relationships among groundwater resources, the relationship between groundwater and surface waters, and their responses to withdrawals requires a quantitative approach that assimilates the available observations and knowledge, computes flow rates and water levels, and projects these into the future for alternative water use scenarios. For the present study, these requirements are met using a computer model of groundwater flow, which is a set of interrelated mathematical equations that represent the aquifers and streams, solved using a computer program. The model uses the finite-difference method, a mathematical technique that divides the aquifer into a grid of blocks to solve the equations representing groundwater flow through porous media.

The groundwater flow model of this study uses MODFLOW 2000, a computer code developed by the USGS (McDonald and Harbaugh, 1988) that has become a widely accepted standard for modeling fresh water aquifers. MODFLOW 2000 reads data files describing the area of interest, sets up the equations representing groundwater flow, pumping, and the interactions of groundwater and surface water, and solves for the estimated hydraulic head and flow. MODFLOW 2000 can simulate steady-state conditions, in which hydraulic head and groundwater flow no longer change because they are at equilibrium with the distribution and rates of water inflow and outflow. MODFLOW 2000 can also simulate transient conditions, in which heads and fluxes change with time as they adjust to new pumping wells or changes in withdrawal rates, recharge, river levels, etc. The pre- and post-processing software programs Groundwater VISTAS® and SURFER® were used to assist in the use of MODFLOW2000.

For the Kendall County groundwater assessment, the authors significantly modified and recalibrated the regional flow model developed for the 11-county northeastern Illinois water supply planning effort (Meyer et al., 2012). That model was developed by expanding the 20-layer regional model developed for Kane County (Meyer et al., 2009) to 22 layers to accept a more detailed five-layer representation of the Quaternary deposits within a polygonal area surrounding the Illinois portion of the Fox River watershed (Fox River watershed geologic mapping domain in Figure 28). For this study, the two layers representing the Galena-Platteville Unit were combined to eliminate mass balance errors caused by dry model cells. The 21-layer model simulates groundwater flow in all geological materials from land surface down to the impermeable crystalline Precambrian basement (Table 8). This includes the bedrock aquifers in the northern half of Illinois and in portions of Indiana, Michigan, and Wisconsin. Each layer has a variable thickness distribution based on geology. Layers 1, 2, and 6 do not occur in Kendall County. The model employs a variable horizontal resolution, its highest resolution area being a rectangular nearfield covering all of northeastern Illinois, where cells have horizontal dimensions of 2,500 ft (Figure 29). The grid contains 226 rows and 174 columns with a total of 806,183 active model cells. The model is most accurate within the detailed nearfield region that encompasses northeastern Illinois. The extent of the model permits simulating distant influences on flow in the sandstone aquifers, including the pumping and recharge in Wisconsin and discharge to the Illinois River near LaSalle. The effects of high-density groundwater on flow in the deep sandstones in central Illinois and in Michigan are not addressed with the model. For a detailed explanation of the model construction and the hydraulic conductivity zones for the bedrock units, see Meyer et al. (2009).

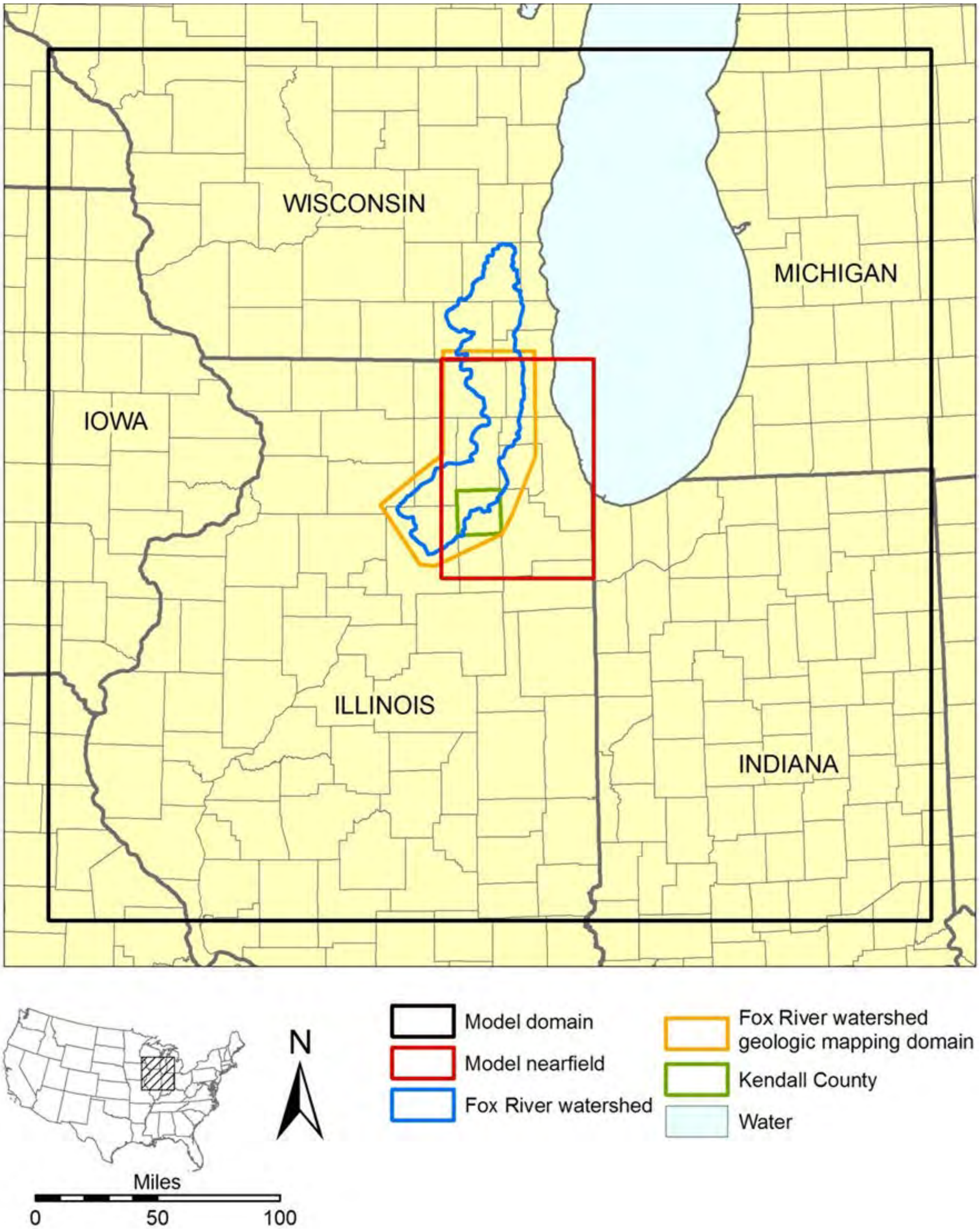


Figure 28. Groundwater flow model domain, Fox River watershed outline, and Fox River watershed geologic mapping domain

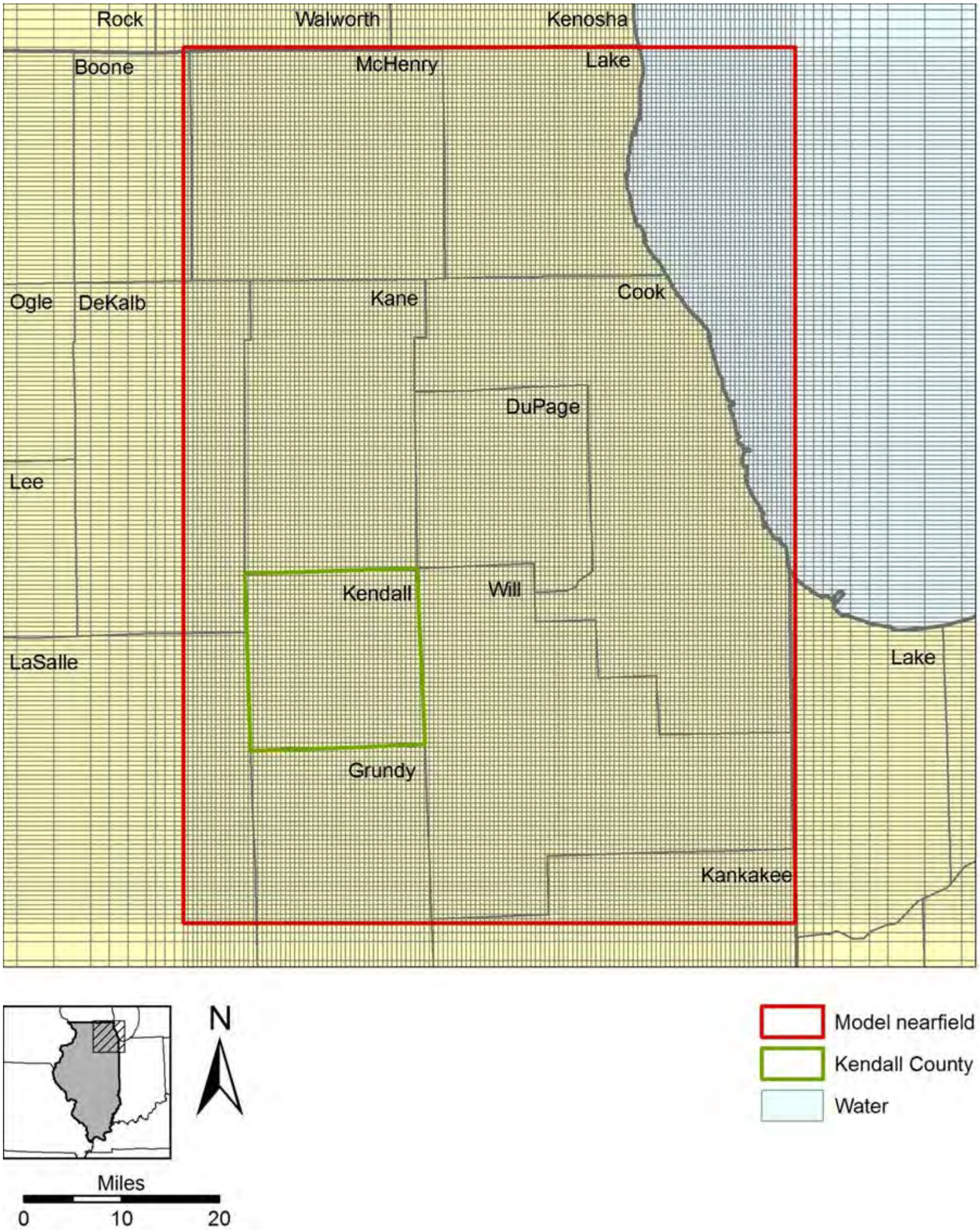


Figure 29. Detail of nearfield grid of groundwater flow model

Table 8. Layer Scheme of the Northeastern Illinois Regional Groundwater Flow Model

Hydrostratigraphic Unit			
Other Areas	*Fox River Watershed*	*Model Layer*	*Principal Hydraulic Conductivity Zones In Kendall Co.*
Quaternary Unit	Fine-Grained Unit 1	1	-
	Coarse-Grained Unit 1	2	-
	Fine-Grained Unit 2	3	73, 83
	Fine-Grained Unit 3	4	73, 83
	Coarse-Grained Unit 2	5	74, 84
Upper Bedrock Unit		6	-
Silurian-Devonian Carbonate Unit		7	14
		8	14
		9	14
Maquoketa Unit		10	15
		11	16
Galena-Platteville Unit		12	23, 26
Ancell Unit (St. Peter sandstone)		13	29
Prairie du Chien-Eminence Unit		14	3, 28
Potosi-Franconia Unit		15	3, 42
Ironton-Galesville Unit		16	40
Eau Claire Unit		17	42, 47
Mt. Simon Unit		18	43, 45
		19	43
		20	43
		21	43

To better characterize groundwater flow in Kendall County and improve the calibration of the model, the Sandwich Fault was added as a low-permeability barrier in layers 13 to 17 to minimize flow through the sandstone aquifers where they have been completely offset (Figure 30; zone 4 on Figure 31; Table 9). This barrier helps to reproduce the observed heads (Figure 12) with the model by maintaining relatively high water levels on the south side of the fault and relatively low water levels on the north side. The approximate potentiometric surfaces on either side of the fault for the Ancell sandstone are shown in Figure 30. The chemistry and the shallow bedrock water levels suggest that there may be some vertical movement of water along the fault; however, this vertical movement is insufficient to equalize the heads in the offset aquifers. Flow in the Mt. Simon sandstone is probably unaffected by the fault because its thickness is much greater than the offset along the fault. However, there could be permeable zones within the Mt. Simon that are offset. Between the fault and the Fox River the water level data indicate that there is sufficient recharge to create a hydraulic mound in the Ancell sandstone. This mound separates flow towards the Fox River from flow towards the cone-of-depression centered in Joliet.

The act of developing the deep sandstone aquifers changed the hydraulics of the flow system by puncturing hundreds, if not thousands, of open holes through the different confining layers. Although there are no historic data, heads in the different sandstones were probably similar prior to development. Assuming that it is impossible for a deep well completed with an open borehole to have more than one water level, the inter-aquifer transfer of water within the borehole causes each saturated aquifer to locally have the same head (Bennett et al., 1982). To represent the transfer of water between the aquifers by the uncased wells, a zone with a high vertical hydraulic conductivity was added to the confining layer between the Ancell and Ironton-Galesville sandstone (zone 3 on Figure 31; Table 9). This approach acts to equalize the head in the two aquifers in a manner similar to the way Mandle and Kontis (1992) treated the inter-aquifer transfer of groundwater in their model of the sandstones. This approach corroborates with the water level data collected by Nicholas et al. (1982) at the USGS Zion test wells which show less than 4 feet of head difference between the Ancell and Ironton-Galesville aquifers.

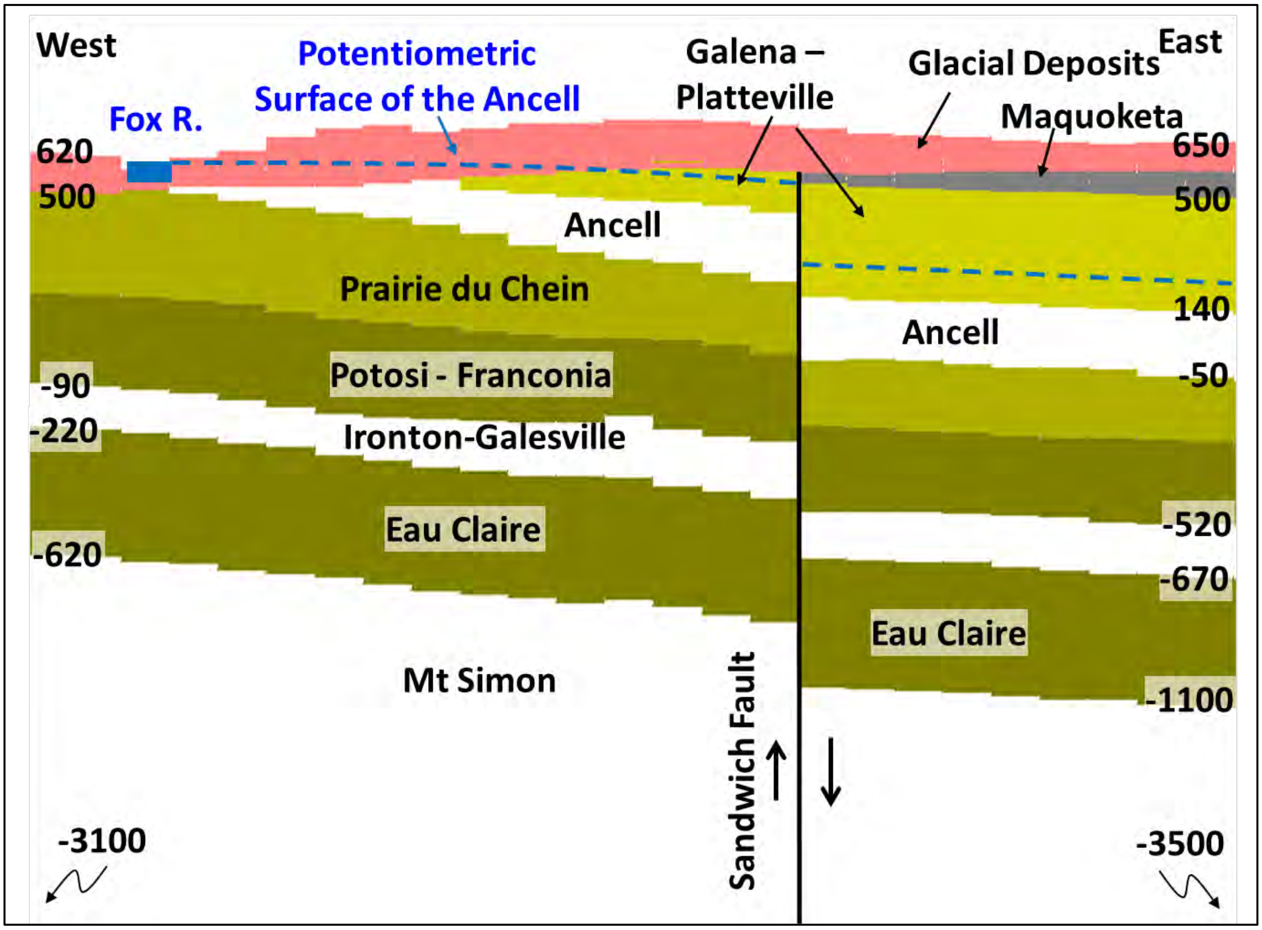


Figure 30. Model cross section across the Sandwich Fault through central Kendall County (corresponds to the west half of Figure 4)

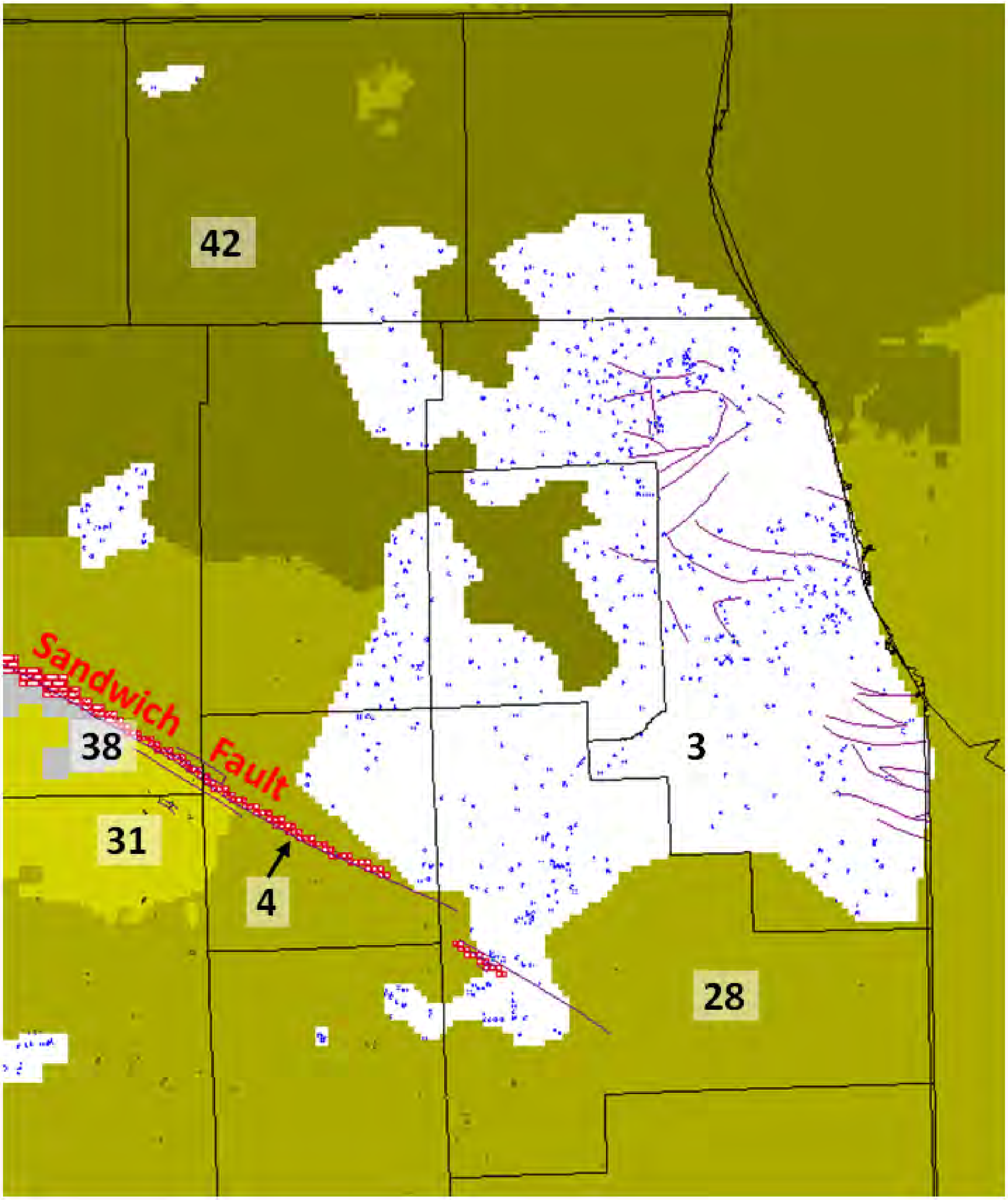


Figure 31. Hydraulic conductivity distribution and zone numbers for layer model 14 (see Table 9). Blue dots indicate wells open to both the Ancell and Ironton-Galesville sandstones.

Table 9. Calibrated Hydraulic Conductivity Values (ft/d)

Zone	*Meyer et al. (2009)*		*Meyer et al. (2012)*		*Current Study*	
	K_x	K_z	K_x	K_z	K_x	K_z
2	140	2.8	**300**	**6.0**	300	6.0
3	not used	not used	not used	not used	0.0068	10
4	not used	not used	not used	not used	1.0×10^{-4}	1.0×10^{-4}
6	1.6	0.016	**2.2**	**0.027**	**1.2**	0.027
8	4.8	0.048	**3.7**	**0.039**	3.7	0.039
9	13	0.13	**16**	**0.63**	16	0.63
11	2.1×10^{-4}	2.1×10^{-6}	**1.5×10^{-4}**	2.2×10^{-6}	1.5×10^{-4}	2.2×10^{-6}
12	6.8×10^{-4}	6.8×10^{-6}	6.8×10^{-4}	6.8×10^{-6}	**0.0068**	**6.8×10^{-4}**
13	1.0	0.0010	1.0	0.0010	**4.0**	**0.10**
14	4.0	0.010	**1.0**	**0.0030**	**20**	**2.0**
15	0.094	9.4×10^{-4}	**0.0064**	**3.3×10^{-5}**	0.0064	**5.5×10^{-4}**
16	4.0×10^{-4}	6.6×10^{-6}	4.0×10^{-4}	6.6×10^{-6}	4.0×10^{-4}	**1.4×10^{-5}**
23	5.0	0.17	**0.30**	**0.0099**	0.30	**5.5×10^{-4}**
26	0.05	6.2×10^{-4}	0.05	6.2×10^{-4}	0.05	**5.5×10^{-5}**
28	0.79	5.3×10^{-4}	0.79	5.3×10^{-4}	0.79	5.3×10^{-4}
29	1.5	0.075	1.5	0.075	**6.2**	**0.60**
30	7.2	0.36	**5.4**	**0.27**	5.4	0.27
31	4.8	0.16	**2.1**	**0.047**	2.1	0.047
37	3.0	0.059	3.0	0.059	3.0	0.059
38	5.7	0.19	5.7	0.19	5.7	0.19
40	5.2	0.01	5.3	**0.11**	**4.0**	0.11
41	7.1	0.14	7.1	0.14	7.1	0.14
42	0.0068	6.8×10^{-6}	0.0068	6.8×10^{-6}	0.0068	6.8×10^{-6}
43	0.43	0.0029	0.43	0.0029	**0.53**	0.0029
44	3.6	0.072	3.6	0.072	3.6	0.072
45	4.2	0.028	4.2	0.028	4.2	0.028
46	7.6	0.050	7.6	0.050	7.6	0.050
47	0.72	0.014	0.72	0.014	0.72	0.014
73	not used	not used	0.020	0.23	0.020	0.23
74	not used	not used	33	0.26	33	0.26
83	not used	not used	6.9	0.043	6.9	0.043
84	not used	not used	160	8.0	160	8.0

Note: Bold indicates a change in value from the previous model version

The high vertical conductivity zone was not applied directly to the Galena-Platteville dolomite and Maquoketa Shale confining layers that separate the Silurian dolomite from the deep aquifer. Instead, the vertical hydraulic conductivity of the Maquoketa Shale (zone 16 in Table 9) was increased as part of the calibration process. Observed heads in the deep aquifers are below the bottom of the Silurian dolomite formation over much of northeastern Illinois, indicating that an insufficient amount of water is being transferred from the dolomite down to the deep sandstones to maintain equal heads. A primary reason for this may be the mutual exclusivity of Silurian dolomite wells and deep sandstone wells. In areas where the Silurian dolomite is highly permeable, such as central DuPage County or northeastern Will County, it is used as the primary aquifer and there are few, if any, deep sandstone wells (Figure 31). In addition, the shallow bedrock in many of the deep wells is cased off to prevent caving of the shales. Anecdotal reports of water cascading down some of the boreholes open to both aquifers indicate that some transfer of water is occurring.

The hydrogeological framework of the groundwater flow model (that is, the hydrogeological model consisting of estimates of top and bottom elevation for each of the 21 model layers) was developed by computer processing of data from a wide variety of published and unpublished sources. For bedrock units (model layers 6-21) and for the Quaternary Unit outside of the Fox River Watershed Geologic Mapping Domain, sources and processing techniques are discussed by Meyer et al. (2009), except that the Quaternary Unit for the present study was divided into five layers of equal thickness as opposed to the three discussed by Meyer et al. (2009). For areas within the Fox River Watershed Geologic Mapping Domain, geological data for the bedrock surface and overlying Quaternary deposits were compiled from a range of completed and ongoing high-, moderate-, and low-resolution mapping. Three-dimensional interpolated surfaces from high-resolution studies by Dey et al. (2007) (Kane County area), the Central Great Lakes Geologic Mapping Coalition (Lake County), and Smith (ISGS, personal communication) (Kendall County) were incorporated directly into the model. The northern three townships of Kendall County fall within the domain of the more detailed 16-layer model of the Quaternary deposits and the shallow bedrock aquifers of Kane County (Meyer et al. 2009).

The groundwater flow model simulates all major current and historic groundwater withdrawals in northeastern Illinois and the surrounding areas, which could plausibly influence groundwater flow in northeastern Illinois. Flow into and out of major surface water features are represented using the MODFLOW River and Drain packages, and the Drain package is used to simulate agricultural and urban drainage systems. So that the model accurately represents hydrogeological conditions within the model domain, data employed for characterization of layer elevations, parameters, and boundary conditions are based to the extent possible on a wide range of published and unpublished observations. Parameters such as hydraulic conductivity and recharge rates are specified on a zoned basis. The model has been calibrated so that it reproduces observed estimates of head and base flow within the uncertainty of these observations. The model facilitates analysis of predevelopment conditions and the impacts of historical and future scenarios of groundwater development, and it readily permits insight into cause-and-effect relationships pertaining to groundwater flow. A more detailed discussion of the model development can be found in Meyer et al. (2009).

Model Calibration

The cone of depression in the deep aquifer system has developed over a 150-year period with significant changes in pumping rates and pumping locations. Due to these transient effects and the release of additional water from storage in the portions of the Galena-Platteville and Ancell Formations, it was necessary to calibrate the model in transient mode instead of steady-state mode. The initial time step for each model run used steady-state conditions to generate starting heads representing predevelopment conditions in 1864. The transient time steps then proceed in 5-year steps up to 1964 when 1-year steps are used through 2005. After 2005, a 5-year time step is used throughout the predictions out to the year 2050. A total of 72 time steps are used in the model.

The model was calibrated by comparing predicted heads to observed heads in 222 deep sandstone wells measured in 2000 by Burch (2002) in addition to the 16 predevelopment water levels used by Meyer et al. (2009). To reduce spatial bias in the 2000 dataset, water levels from adjacent wells at the same facility were averaged to create a single model target. The 2007 water levels and historic water levels from production wells at Yorkville, Oswego, Montgomery, Newark, Joliet, and Aurora were also used in visual comparisons of the transient modeled heads. The year 2000 data were used instead of the 2007 regional data also collected by Burch (2008) because of the low water levels at Joliet wells #25, #27, and #28 in southeastern Kendall County. Further study of these wells is necessary before they can be included in the model because of their close proximity to the Sandwich Fault. Where the fault has been observed near the town of Sandwich and in Joliet, it occurs as a series of parallel faults. If the three Joliet wells are completed in different fault blocks within the zone, there could be multiple barrier effects exacerbating the drawdown.

The hand-contoured potentiometric surface map created by Burch (2002) is shown in Figure 32 and the model predicted heads for the Ancell unit are shown in Figure 33. The residuals between observed and models calculated heads for 222 data points from 2000 are shown on Figure 34. The observed map appears to have significantly more detail because it honors each data point with minimal averaging; however, the mapped heads do not form a hydraulic flownet where mass of water is preserved everywhere in the system. Because the model preserves mass, the contours on Figure 33 are smoother without any sharp bends except near a well or a permeability contrast. The effect on heads caused by the Sandwich Fault was not incorporated into the observed head map. The residual error map (Figure 34) shows values within 100 feet over most of northeastern Illinois. The largest under-predicted water levels in the model (up to 150 ft) occur near Elgin in eastern Kane County. The largest over-predicted error (-215 ft) occurs at Citizens Utilities Fernway well #3 in southwestern Cook County. This well was measured using an air line and there are no surrounding measurements to corroborate the low measured level. A lack of pumpage in the immediate area to produce a low water level suggests that this data point may be unreliable.

The mean residual error for all 238 target heads was 1.60 ft and the absolute residual mean error was 36.6 ft. The maximum errors range from -215 ft to 152 ft. As shown in Figure 35, there were no large errors or systematic deviations from the 1:1 line. Because these errors are low compared to the 1,000-ft range in water levels and because of inherent errors associated with the observed heads, significant improvement to the head calibration is unlikely without additional data. For their model of the larger Lake Michigan Basin, Feinstein et al. (2010) used points off the contours of the 2000 water level map for calibration so the reported error values are not directly comparable.

An example of the transient calibration is shown in Figure 36 for water level data from the 1,335-foot deep Yorkville well #3. Also included on this graph are water levels from the estimated 1864 and 1895 potentiometric surface maps created by Suter et al. (1959) and historical records for the 590-foot deep Yorkville well #1. Prior to 1938, Yorkville well #1 was under flowing artesian conditions. Additional graphs for the other target wells around Kendall County are shown in the results section with the future prediction scenarios.

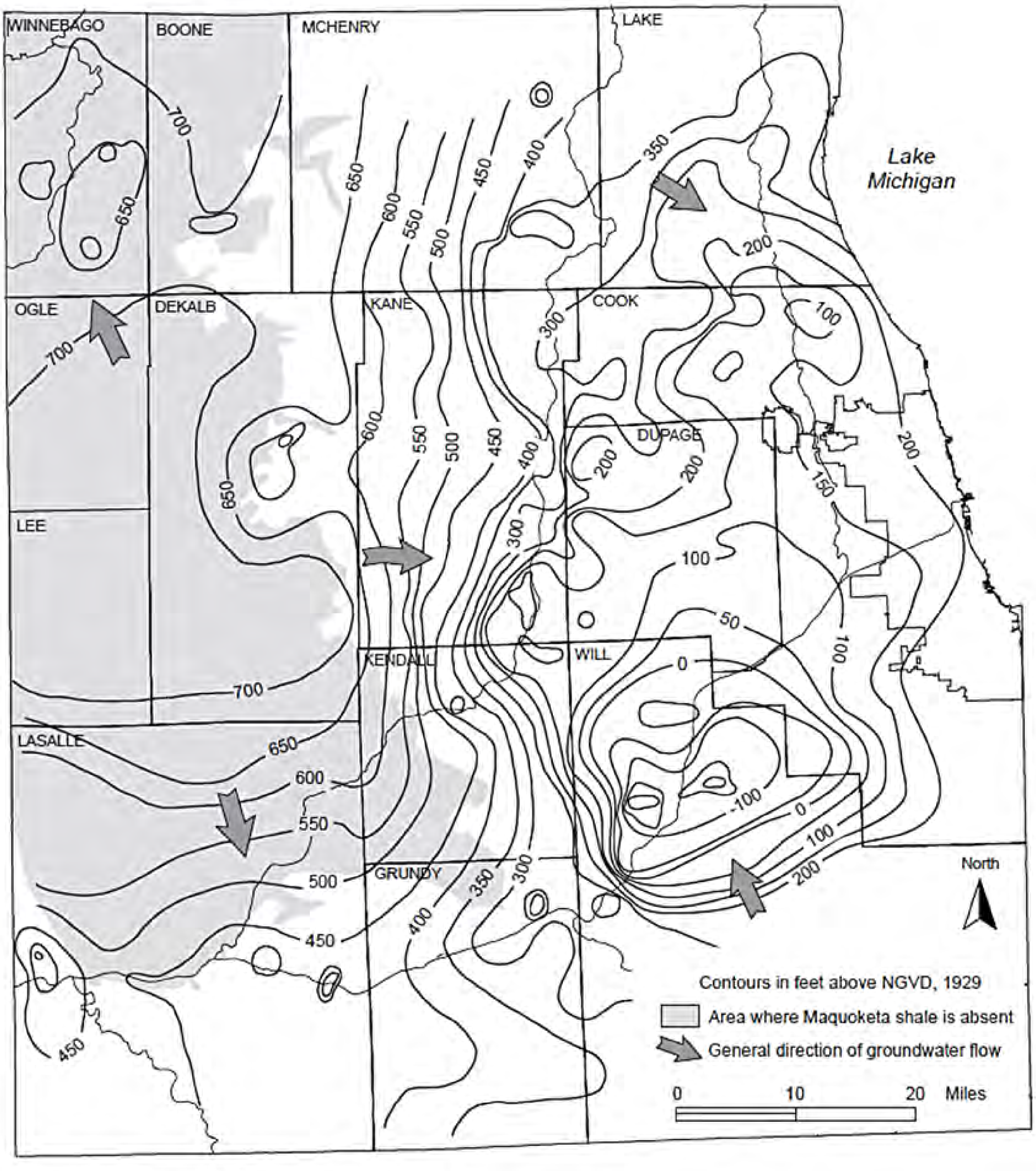


Figure 32. Potentiometric surface of the deep bedrock aquifers in northeastern Illinois, fall 2000 (from Burch 2002)

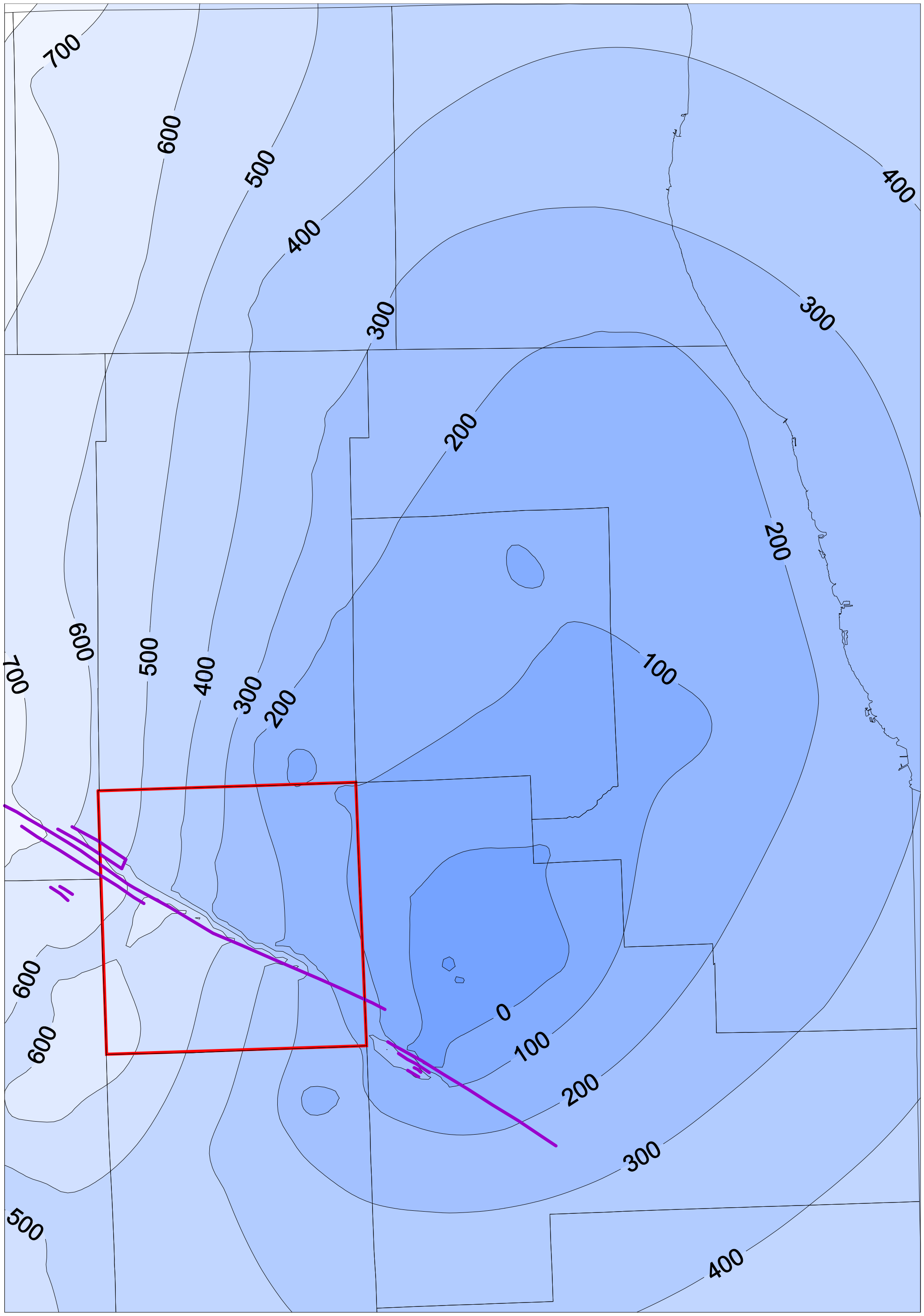


Figure 33. Modeled potentiometric surface (feet asl) of the deep bedrock aquifers in northeastern Illinois, fall 2000. Purple lines show Sandwich Fault Zone.

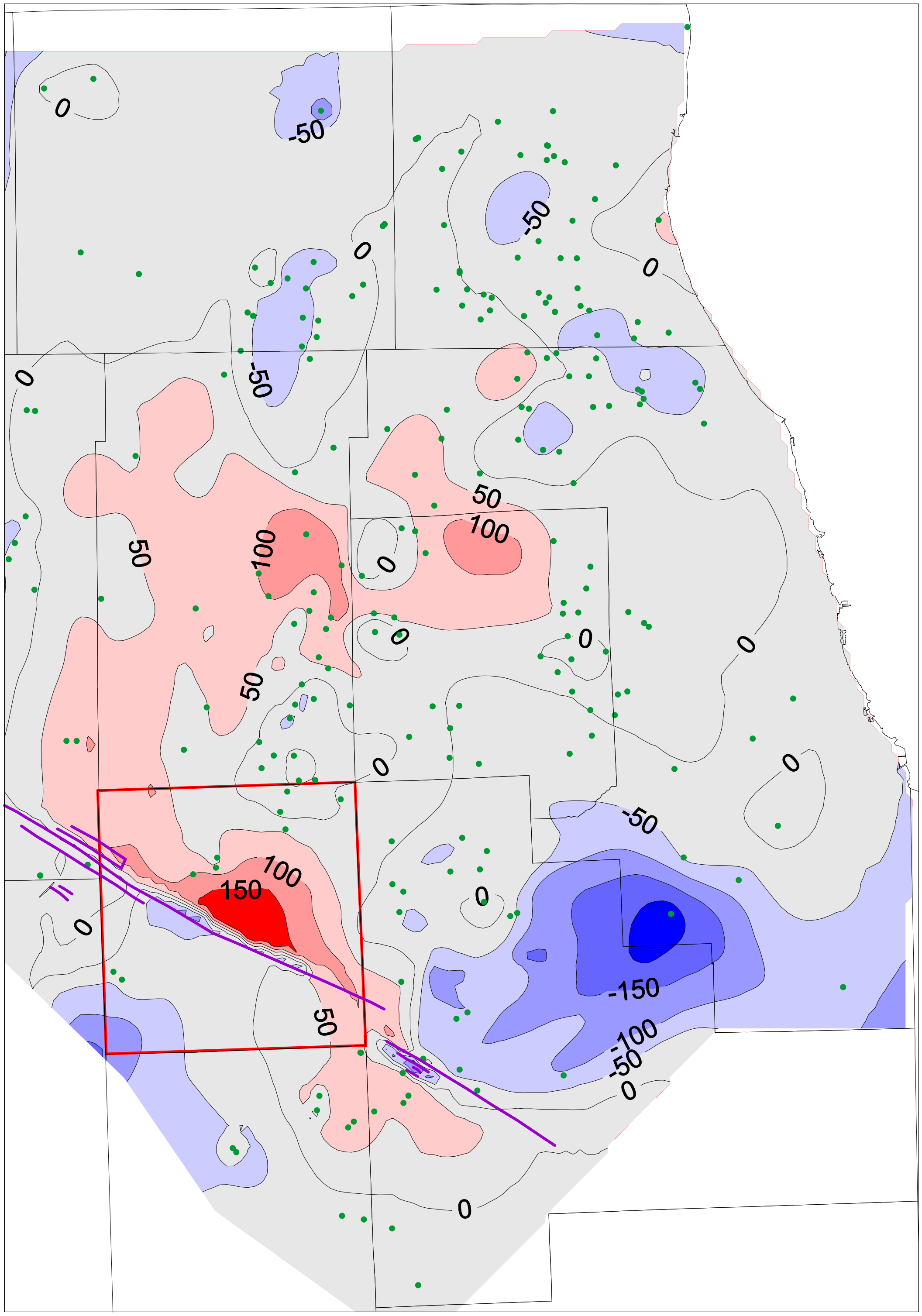


Figure 34. Distribution of residual errors (feet) between model calculated heads and observed heads (green dots) measured by Burch (2002) in 2000. Purple lines show Sandwich Fault Zone.

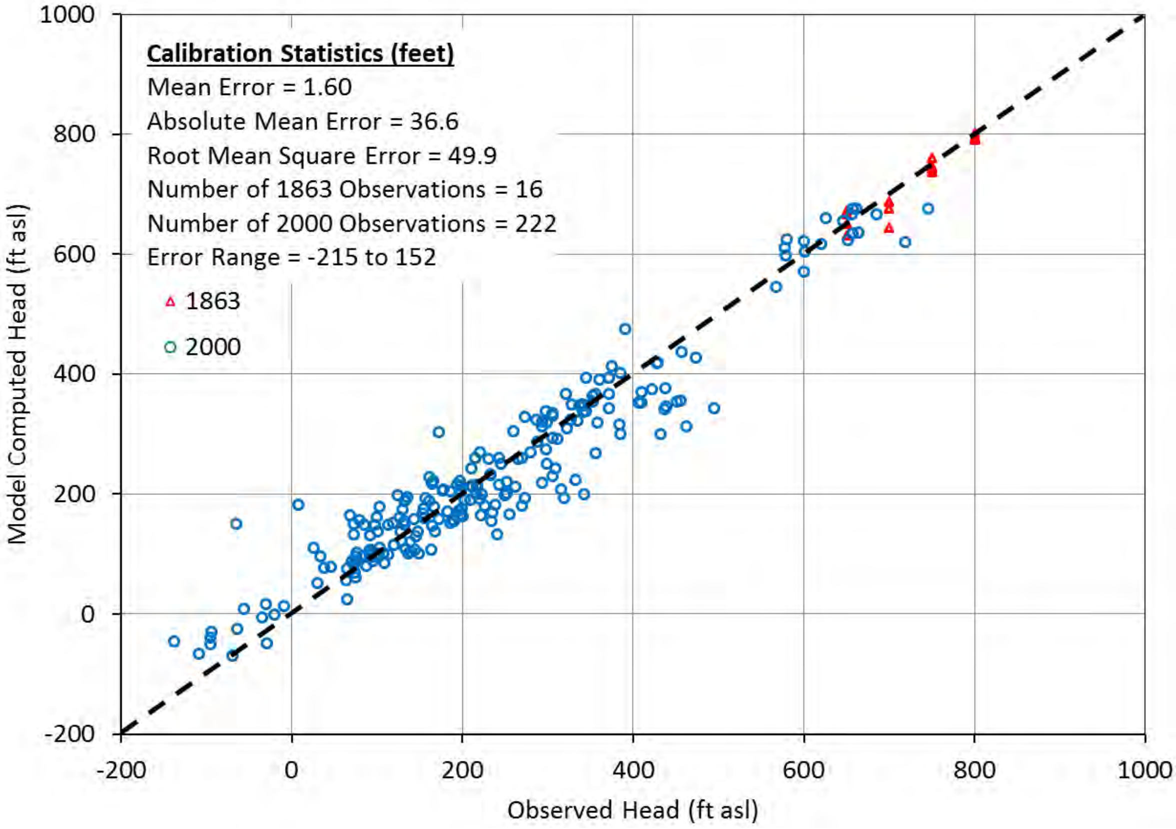


Figure 35. Model calculated heads versus observed heads

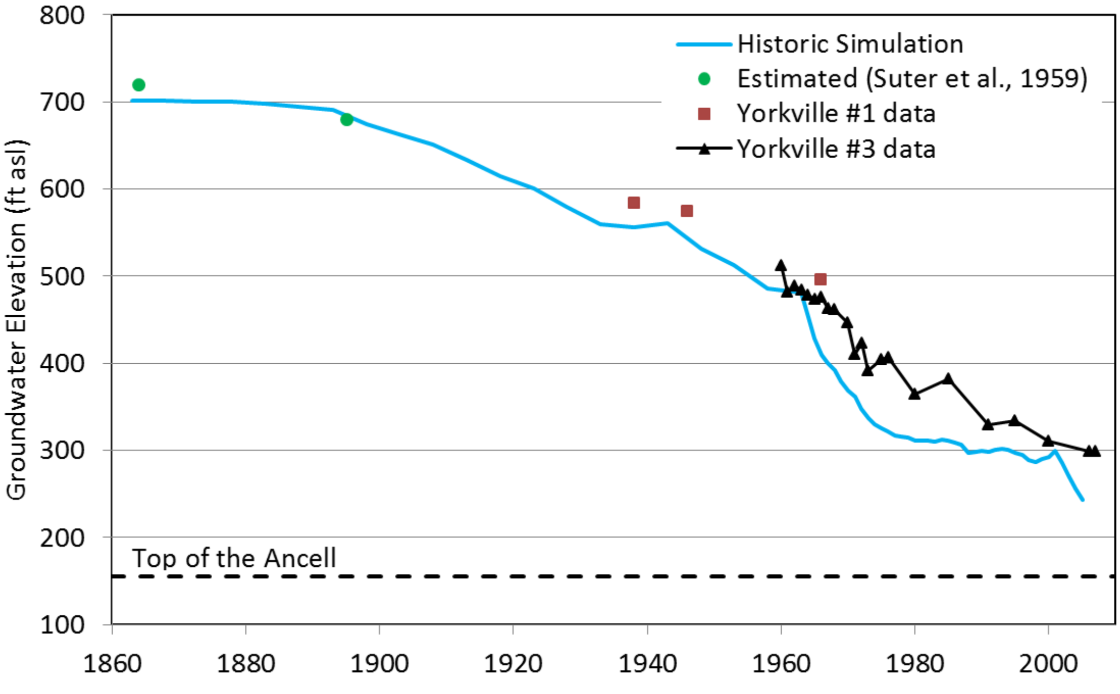


Figure 36. Calculated and observed heads at Yorkville well #3

When a well goes dry in the model, the pumpage is no longer simulated and the surrounding heads in the model become much higher than expected. To prevent unrealistic cell dewatering and loss of pumpage in the transient model runs, the pre-1963 historical pumpage from the seven pumping centers used in previous models (Prickett and Longquist, 1971; Burch, 1991; Meyer et al., 2009; Feinstein et al., 2010; and Meyer et al., 2012) was redistributed to surrounding wells (Figure 37). For the Aurora, Batavia, Elgin, Joliet, Elmhurst, and Des Plaines pumping centers, the historical pumpage was divided amongst the nearest wells within an 8 mile radius that were active in 1964. For the Chicago pumping center there was an insufficient number of active wells in 1964 to support the 40 million gallons per day (Mgd) of pumpage that occurred in the 1940s without the modeled wells going dry. Therefore, the pumpage was evenly redistributed to all of the known public and industrial wells in central Cook County for the 1900-1963 time steps in the transient simulation.

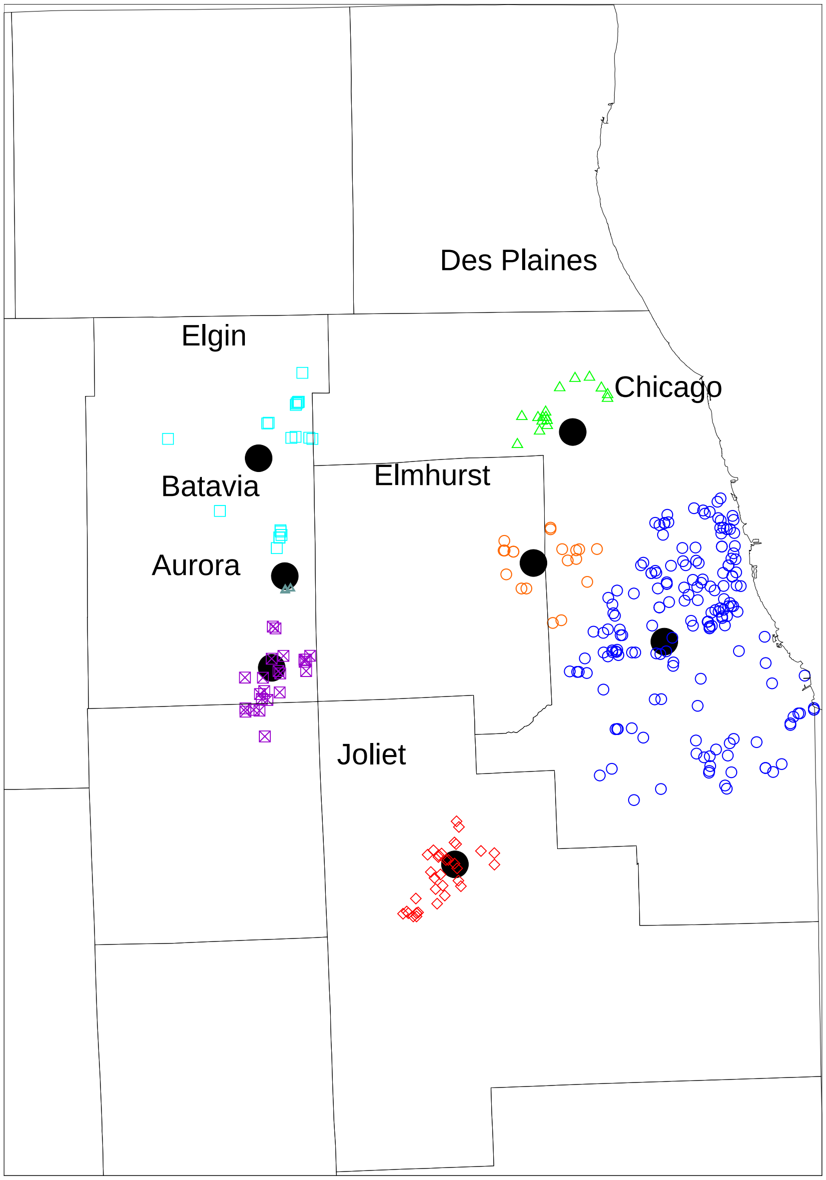


Figure 37. Location of wells used to redistribute the pumpage from the seven pre-1963 pumping centers

The calibrated hydraulic conductivities (K) for the principal hydrostratigraphic units and secondary zones in the model are listed in Tables 8 and 9 and, other than the zones shown on Figure 31, essentially follow the distributions described and shown graphically in Meyer et al. (2009) or described in Meyer et al. (2012). Hydraulic conductivity values were modified deterministically during the calibration process using the results from the four previous models. The major changes to the conductivities of the deep bedrock system include increasing the horizontal K value (zone 29) for the Ancell unit and the vertical K value (zone 16) for the Maquoketa Shale. These two changes increase the amount of water entering in deep sandstones and flowing towards the production wells and were necessary to make the model match the 2000 head targets and prevent the large-scale loss in modeled pumpage from wells artificially going dry.

The transmissivity of deep sandstone wells in Kendall County is largely a function of transmissivities of the Ancell (St. Peter) and Ironton-Galesville sandstones. A map of the modeled transmissivity of the deep system from the Galena-Platteville dolomite down to the Ironton-Galesville sandstone (model layers 12 to 16) is shown on Figure 38. The Mt. Simon sandstone contributes to the overall transmissivity of the system, although in Kendall County the Eau Claire Formation acts as a confining layer. North of Kendall County in northern Kane, northern Cook, Lake, and McHenry Counties, the Eau Claire is not modeled as a confining layer (see Figure 33 in Meyer et al., 2009) and as a result the Eau Clare and the Mt. Simon aquifer can contribute water to wells completed in the Ironton-Galesville aquifer. Because of its relatively uniform thickness, the modeled transmissivity of the Mt. Simon aquifer adds approximately 1,200 ft^2/d to the values across northeastern Illinois shown on Figure 38. The modeled transmissivity for the deep aquifer system in Kendall County is 10 percent to 20 percent less than the values used by Burch (1991) for the Ancell (St. Peter) to Mt. Simon layers and 30 percent to 45 percent greater than the values used by Meyer et al. (2012) for the Galena-Platteville to Ironton-Galesville layers.

The K values for the Silurian dolomite were also increased to the values used in the local-scale model of Kane County (Meyer et al., 2009) to prevent production wells from artificially going dry in Will, DuPage, and McHenry Counties. Because the shallow glacial sand aquifers south of the Fox River in Kendall County are too isolated and scattered, they are not currently being used for water supply; therefore the hydraulic properties of the Quaternary units were not recalibrated. North of the Fox River, the finer horizontal and vertical resolution of the local-scale Kane County model (Meyer et al., 2009) provides more accurate results.

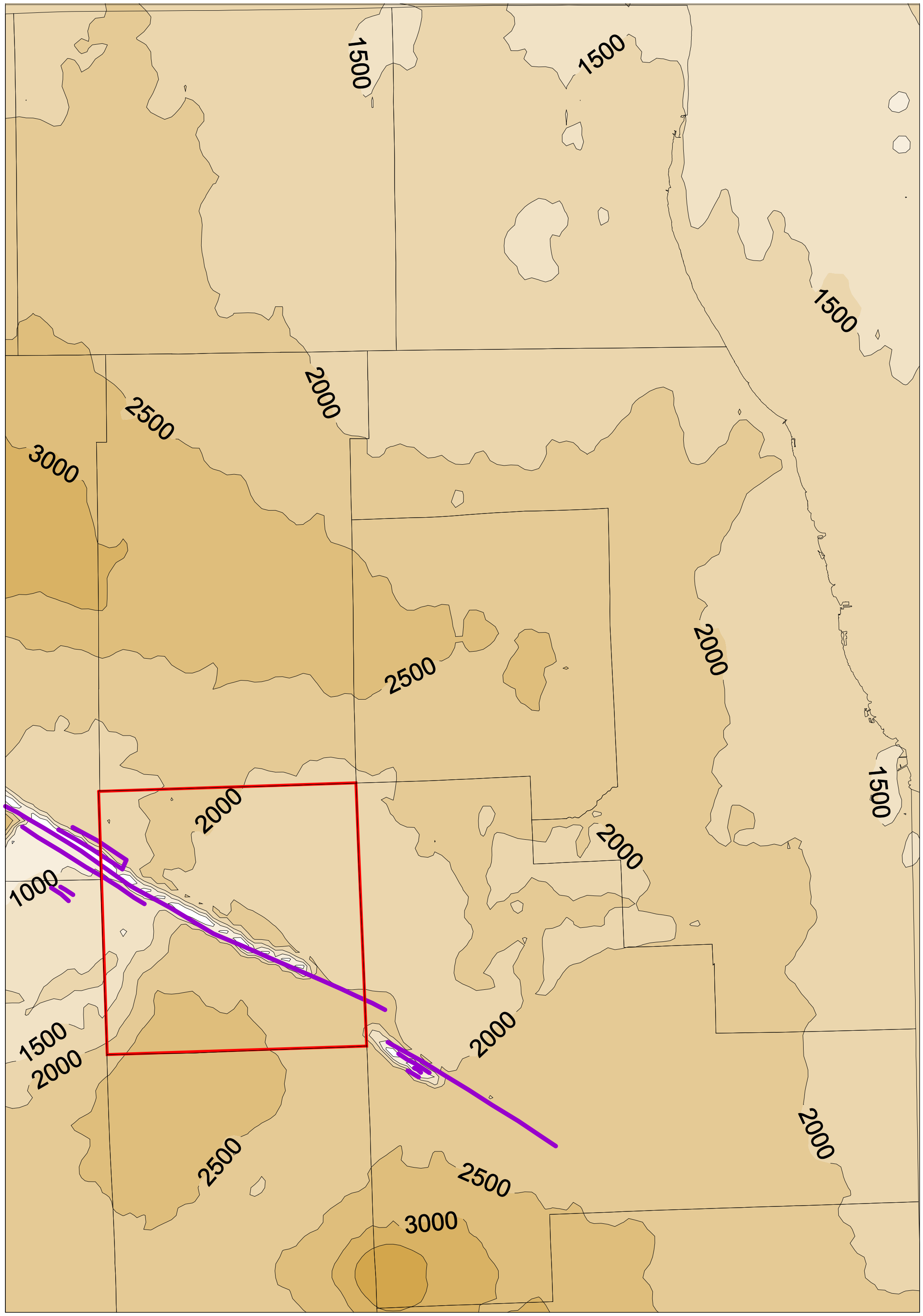


Figure 38. Transmissivity of the combined Ancell and Ironton-Galesville Aquifers (ft^2/d). Purple lines show Sandwich Fault Zone.

Simulated Groundwater Withdrawals

The discussion of the simulated groundwater withdrawals are divided into the three principal aquifer groupings serving Kendall County and northeastern Illinois: the Quaternary Unit (glacial sand and gravels principally occurring north of Fox River in Kendall County), the shallow bedrock aquifers (comprised principally by the Silurian dolomite in the northeastern corner of Kendall County), and the deep sandstone aquifer (comprised principally by the St. Peter and Ironton-Galesville sandstones). Because the glacial sand and gravel aquifers are often hydraulically connected to the shallow bedrock aquifers, these two systems are collectively referred to as the shallow system. The reader is referred to Meyer et al. (2009) and Meyer et al. (2012) for additional discussion of the groundwater withdrawals used as input for model simulation.

Groundwater withdrawal data were compiled for a total of approximately 8,300 wells (Figures 39 through 44) in the study area, and a total of 6,222 wells were used in the model. The wells near Peoria were not used in the model because the coarse far-field grid of the model could not accurately represent the aquifer conditions. Additional wells were dropped from the model if the maximum reported pumpage was less than 5 gallons per minute. The sources of historical Illinois withdrawal data employed in this study include hardcopy records and estimates (covering the period 1864-1963); estimates from hardcopy records on file at the ISWS (covering the period 1964-1979); an electronic database, maintained by the ISWS, of withdrawal data compiled largely from owner-reported withdrawal measurements and estimates (covering the period 1980-2005); and estimates for years of non-reporting to the ISWS by facility owners (also covering the period 1980-2005).

The withdrawal data, which include well locations and source interval (i.e., model layer) determinations in addition to annual withdrawal rates, cover much of Illinois and parts of Indiana and Wisconsin adjacent to northeastern Illinois. The geographic, hydrogeological, and temporal scope of the withdrawals represented in the model is considered to be sufficiently comprehensive to adequately represent the major influences on groundwater flow in the model nearfield of northeastern Illinois. Existing databases of groundwater withdrawals in the model domain were reviewed, and if omissions in these databases were judged to be significant to modeling groundwater flow in the model nearfield, withdrawal data were assumed in order to address the omissions.

The geographic scope of the withdrawals simulated in the model includes the central and northern portions of Illinois and Indiana and the southern portion of Wisconsin. Withdrawals in Michigan are not represented. Withdrawals from wells open to the sandstone aquifers in Illinois and Indiana are sometimes omitted owing to the irregular availability of historical withdrawal data, as discussed in Meyer et al. (2009). Because it is unlikely that withdrawals from distant wells open only to hydrostratigraphic units overlying the Ancell Unit (the shallower portion of the subsurface) would affect heads in the model nearfield, such wells in Illinois and Indiana are represented only if they are located within the following USGS hydrologic units in the immediate vicinity of northeastern Illinois: 7090001, 4040003, 7120006, 4040002, 7120004, 7090006, 7120003, 4040001, 7120007, 7120001, 7130001, 7120005, and 7130002. This area is referred to as the shallow aquifers withdrawal accounting region (SAWAR), as shown in Figure

39. Wells open only to the Galena-Platteville and overlying hydrostratigraphic units are referred to in this report as shallow wells.

Pre-1964 withdrawals in Illinois and Indiana from shallow wells within the SAWAR are not represented, and 1964-2005 withdrawals from these wells are irregularly represented. Such withdrawals in Illinois during the period 1964-1979 are represented only for the portion of the SAWAR within the following counties: Boone, Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, LaSalle, Lee, McHenry, Ogle, Will, and Winnebago. Withdrawals from shallow wells within the entire Illinois portion of the SAWAR are represented in the model for the period 1980-2005. Withdrawals from shallow wells within the Indiana portion of the SAWAR are represented in the model only for the period 1985-2005. Withdrawals from shallow wells in southeastern Wisconsin are represented for the period 1864-2005. Data from other parts of Wisconsin are not available.

In this report, wells open to the subsurface interval underlying the Galena-Platteville Unit, regardless of whether they are open to the Galena-Platteville Unit, are referred to as deep wells. Deep wells represented in the model are shown in Figure 40. The time period represented by these withdrawals differs by state. Withdrawals from deep wells during the period 1964-1979 in Illinois that are represented in the model are limited to wells located in the following 20 northern Illinois counties: Boone, Carroll, Cook, DeKalb, DuPage, Grundy, Jo Daviess, Kane, Kankakee, Kendall, Lake, La Salle, Lee, McHenry, Ogle, Rock Island, Stephenson, Whiteside, Will, and Winnebago. Most withdrawals from deep wells in the state occur within this area. Withdrawals from Illinois deep wells during the period 1980-2005 are represented in the entire portion of Illinois within the regional model domain.

Because the mineralized water from deep wells in Indiana is unacceptable for most uses, the units below the Galena-Platteville dolomite are largely unused in that state. Only a single deep well in Indiana is represented in the model because it is the only one included in a database of groundwater withdrawals obtained from the Indiana Department of Natural Resources (personal communication, Mark Basch, 2002). The withdrawal record for this well covers the period 1985-2005. Deep wells completed below the Galena-Platteville dolomite in southeastern Wisconsin are represented for the period 1864-2005 in this data set. Data from other parts of Wisconsin are not available.

The completeness of the withdrawal dataset is not known, but it is based on sources that sought, and continue to seek, to document withdrawals from all community and non-community public water system wells, and high-capacity wells supplying commercial, industrial, and agricultural facilities having a pumping capacity greater than 100,000 gallons per day. As such, the data are believed to be a reasonably complete representation of groundwater withdrawals in the region. Estimates are included for wells during years when it is probable that the wells were in use, but withdrawal data were not collected. The accuracy of the data is not known, but it is likely that the reported measurements are accurate to within ±10 percent of the actual value (United States Department of the Interior Bureau of Reclamation, 1997). The sources, processing, and uncertainty of the withdrawal data are discussed in detail in Appendix B of Meyer et al. (2009).

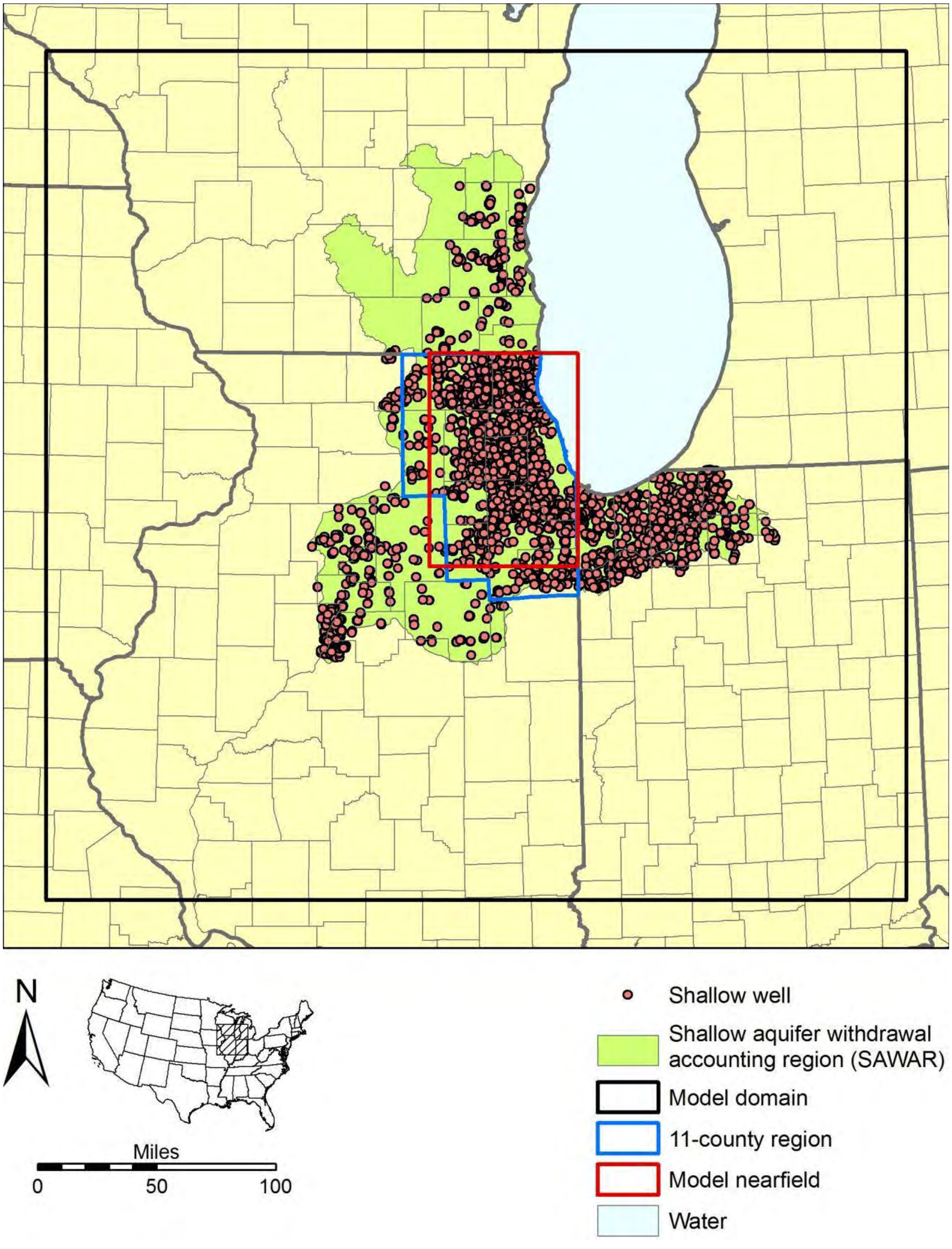


Figure 39. Shallow wells in the Quaternary Unit and shallow bedrock units represented in the groundwater flow model (from Meyer et al., 2012)

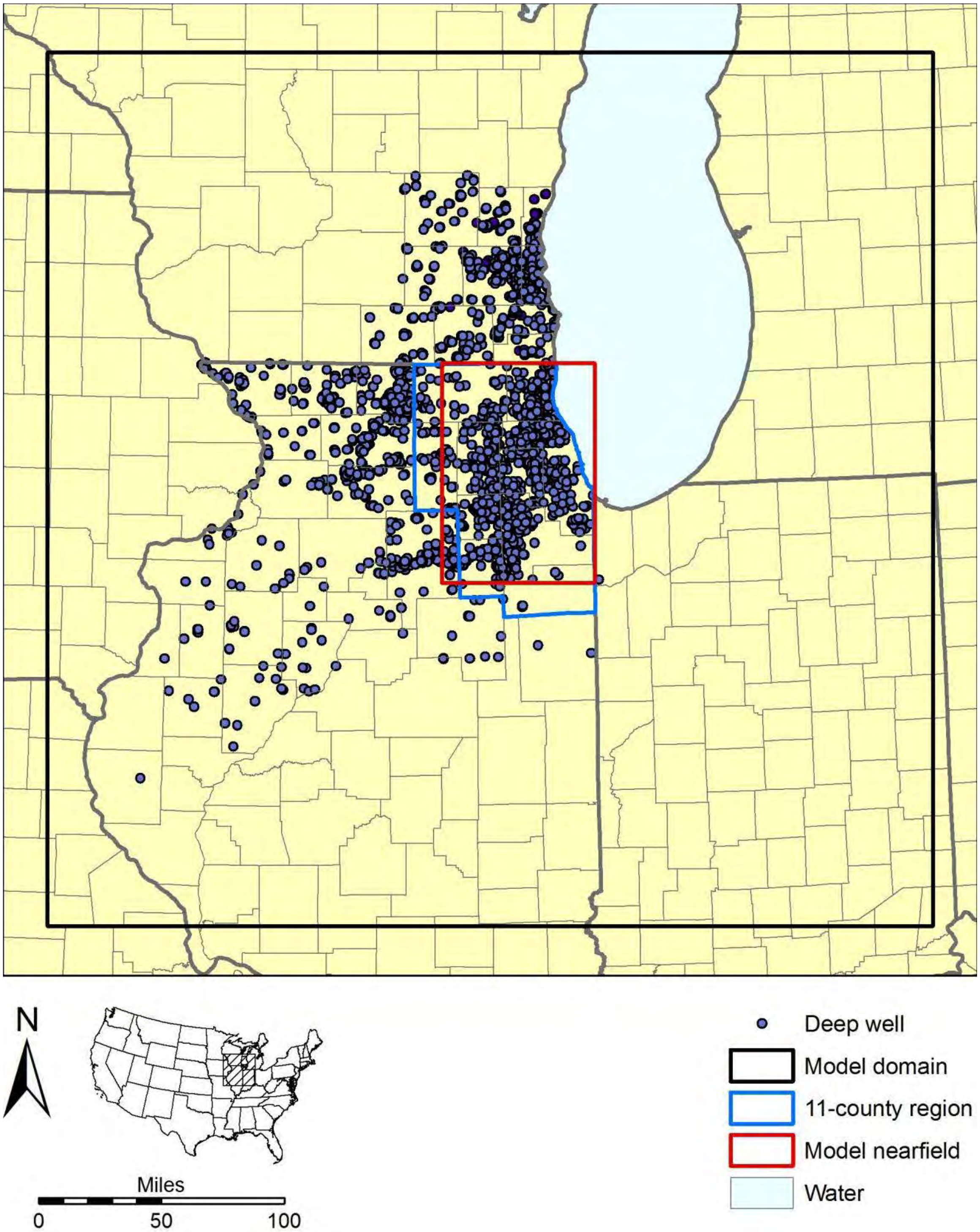


Figure 40. Deep wells represented in the groundwater flow model (from Meyer et al., 2012)

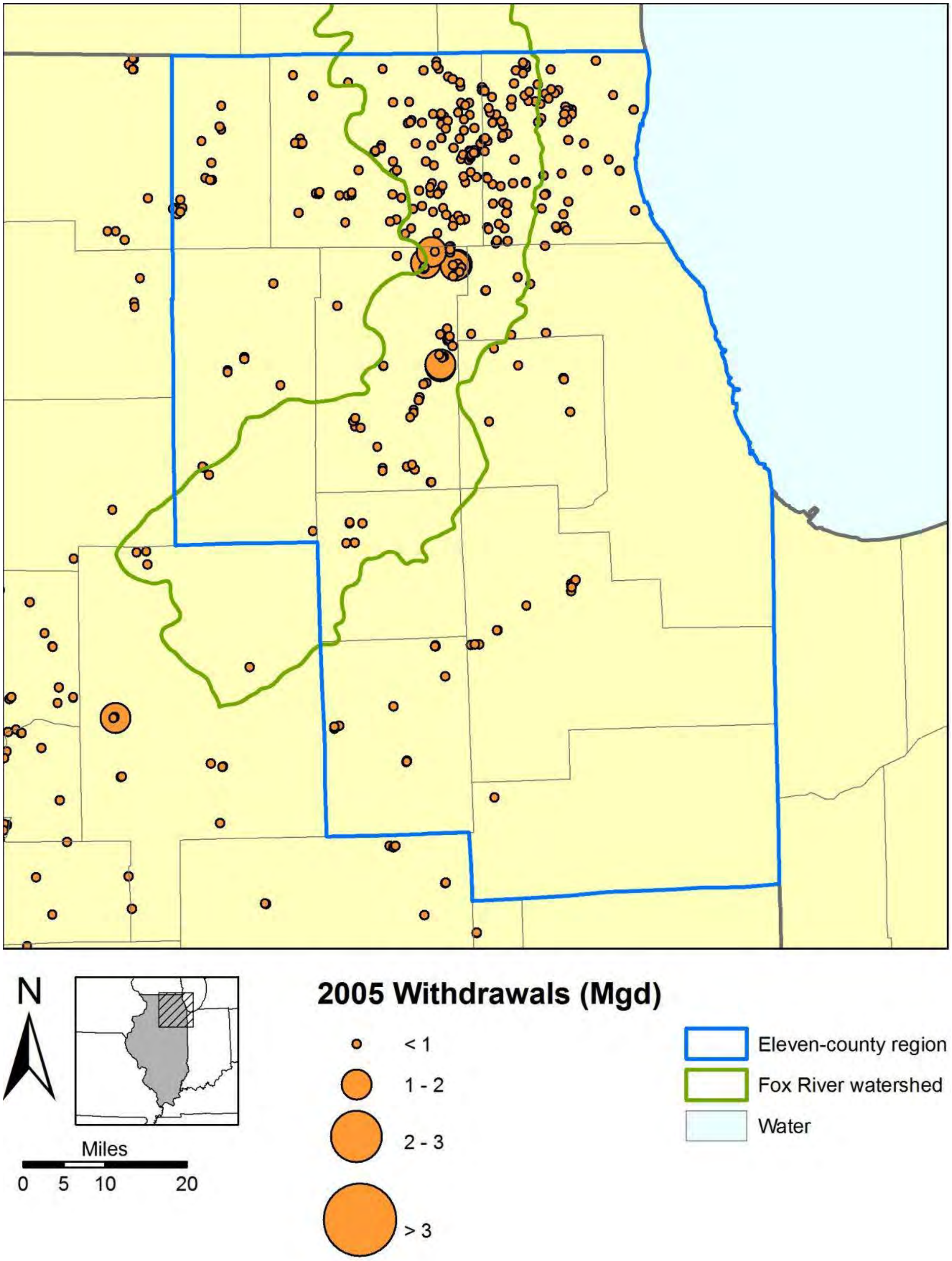


Figure 41. Simulated 2005 withdrawals from sand and gravel wells in northeastern Illinois (from Meyer et al., 2012)

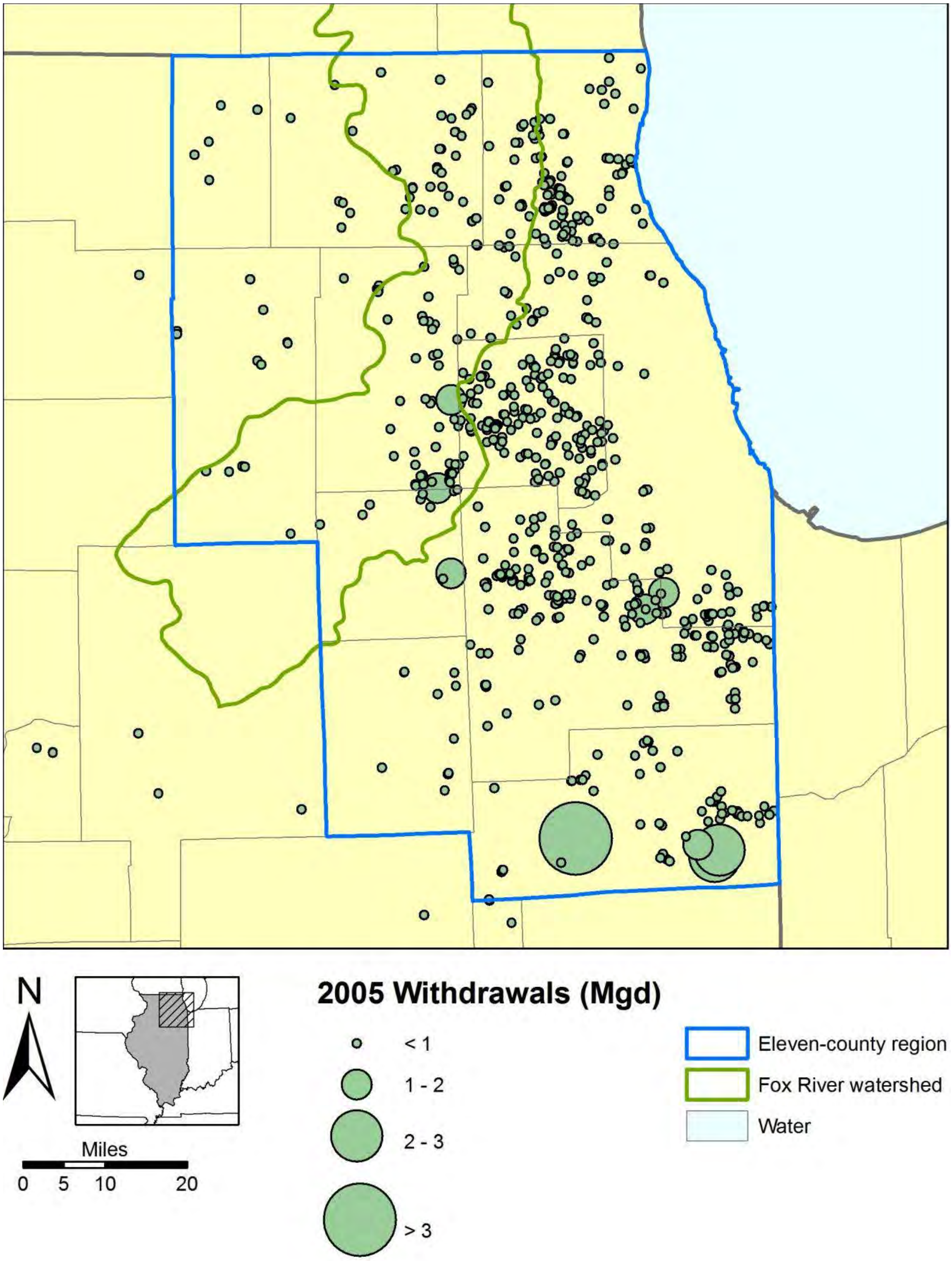


Figure 42. Simulated 2005 withdrawals from the shallow bedrock wells in northeastern Illinois (from Meyer et al., 2012)

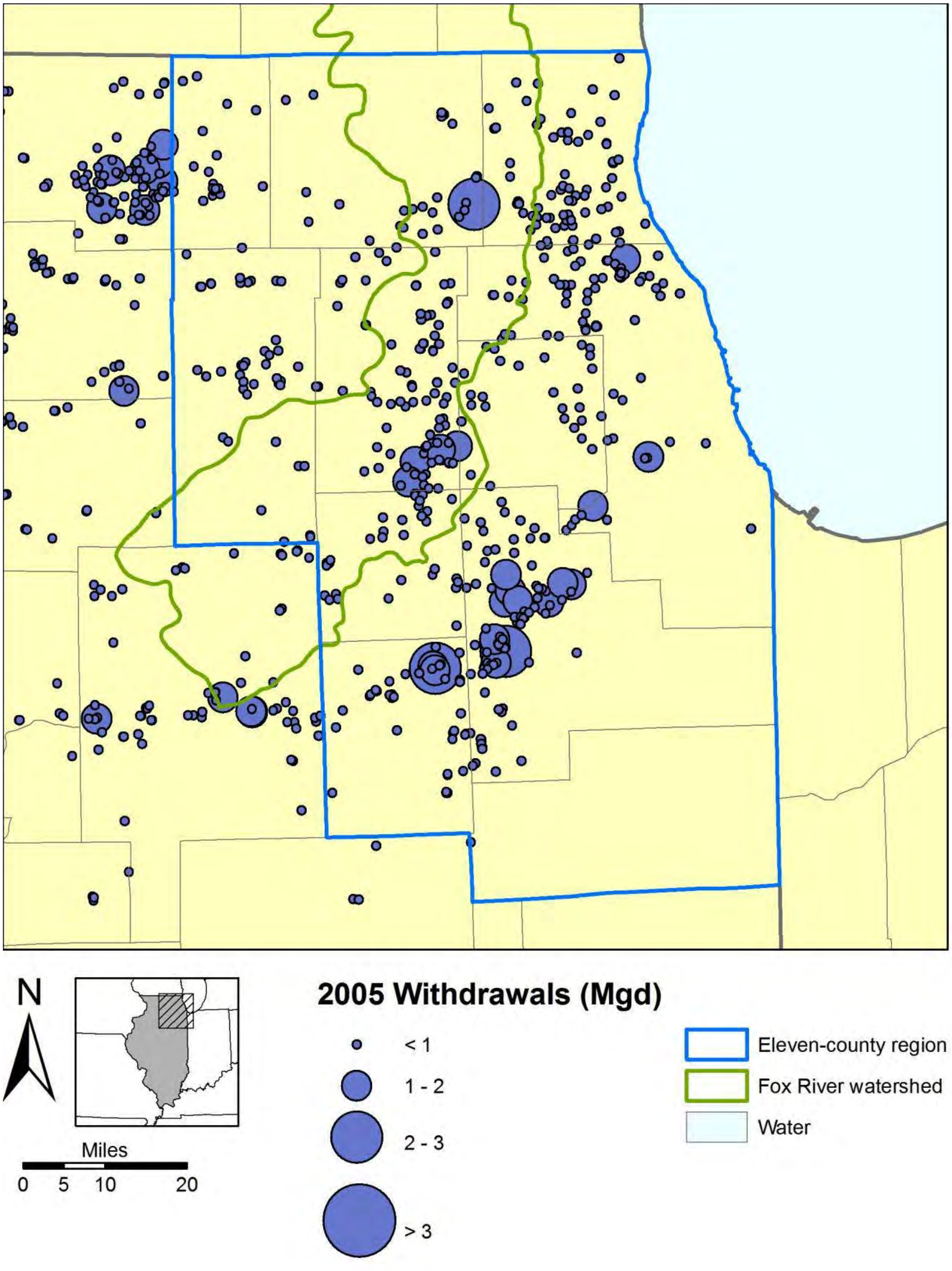


Figure 43. Simulated 2005 withdrawals from the deep sandstone wells in northeastern Illinois (from Meyer et al., 2012)

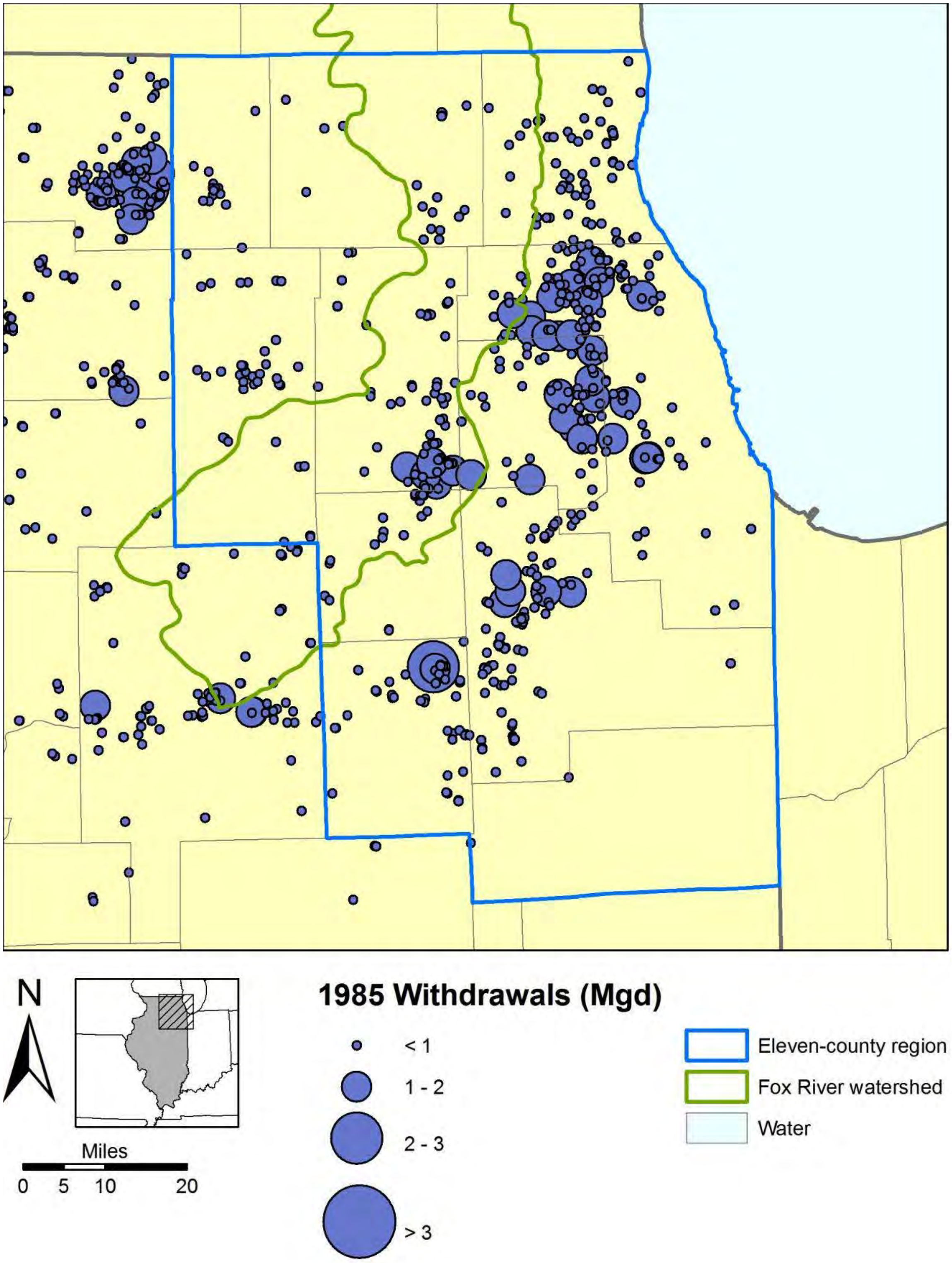


Figure 44. Simulated 1985 withdrawals from the deep sandstone wells in northeastern Illinois (from Meyer et al., 2012)

Groundwater withdrawals in northeastern Illinois have declined since the 1980s, largely as a consequence of public water systems in Cook, DuPage, and Lake Counties shifting from groundwater to Lake Michigan as a source of water, but also because of improvements in efficiency, reduction of leakage, and deindustrialization (Figure 45). The largest annual declines in total groundwater withdrawals occurred in the early 1990s, when many public water systems in DuPage County and Lake County were shifted to water piped in from Lake Michigan. This shift is apparent in a comparison of the distribution of pumping between 1985 and 2005 (Figures 43 and 44). Declines in withdrawals from the sandstone aquifers and the shallow bedrock aquifers have been greater than from the sand and gravel aquifers, principally because many of the public water systems that use the sand and gravel are in the Fox River watershed and further from Lake Michigan. The shallow aquifers are also more susceptible to contamination, and there are many documented cases of contamination in the suburbs, including cases in Lisle, Downers Grove, Crestwood, and Sauk Village (Illinois Environmental Protection Agency website).

Groundwater withdrawals in Kendall County are a small percentage of withdrawals in the northeastern Illinois region (Figure 46), but they have increased tremendously, more than doubling from 1995 to 2005. This increase in part reflects the large population increase in the county during this period, from about 45,000 in 1995 to about 79,000 in 2005. Most of the increased groundwater withdrawals were obtained from the sandstone aquifers.

Future Pumping Scenarios

According to the United States Census Bureau, Kendall County's population is estimated to grow from nearly 100,000 in 2007 to 190,000 by 2030 and 280,000 by 2050 (Figure 47). To estimate the effects of the increased water demand associated with both county and regional population growth, as well as projected increases in per capita water demand, three different scenarios of increasing pumping were simulated using the groundwater flow model for the period 2005 to 2050. The three scenarios represent a reasoned and plausible range of future water withdrawals. The low withdrawal scenario is called the Less Resource Intensive scenario (LRI) and the high withdrawal scenario is called the More Resource Intensive (MRI) scenario. Between these is a moderate water withdrawal scenario called the Baseline (BL) scenario (also called the Current Trend scenario in CMAP, 2010; and by Dziegielewski and Chowdhury, 2008). The scenarios were developed by Dziegielewski and Chowdhury (2008) for the Northeastern Illinois Regional Water Supply Planning Group (RWSPG) using statistical and other quantitative methods and based on estimates of future socioeconomic conditions in the region. The model may be adapted to simulate a wide range of other pumping scenarios as well.

Dziegielewski and Chowdhury (2008) developed scenario demand estimates for each of the 11 counties of northeastern Illinois for five water use sectors: public water supply, industrial and commercial, agriculture and irrigation, thermoelectric power generation, and self-supplied domestic. These county-level demands were allocated to individual points of withdrawal (wells) by Dziegielewski and Chowdhury and provided to ISWS researchers in spreadsheet form to facilitate their adaptation for model input. Sector withdrawals for each demand scenario for Kendall County are summarized in Tables 10 through 12.

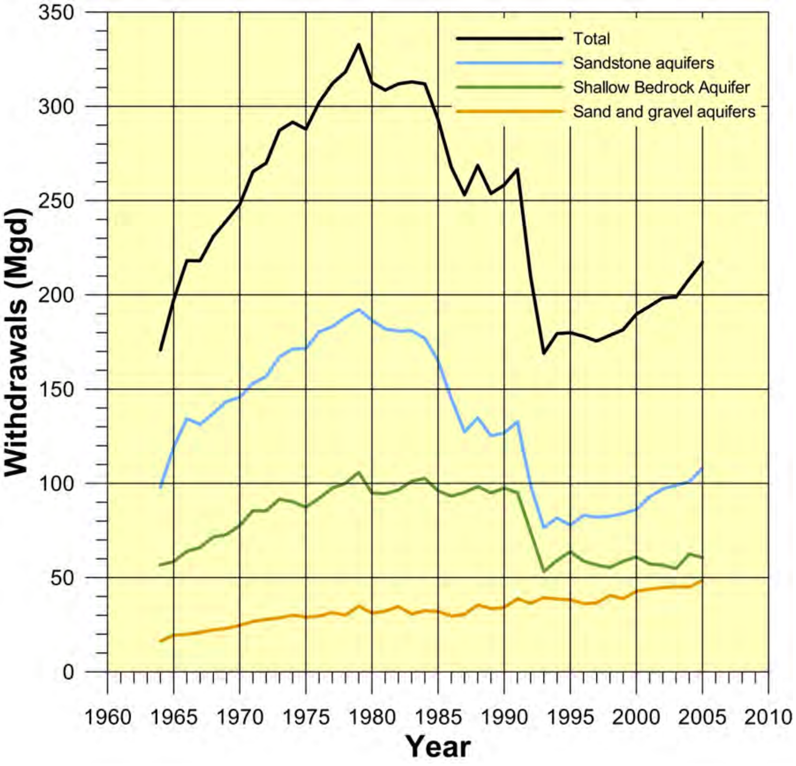


Figure 45. Simulated groundwater withdrawals in the 11-county northeastern Illinois region, 1964-2005

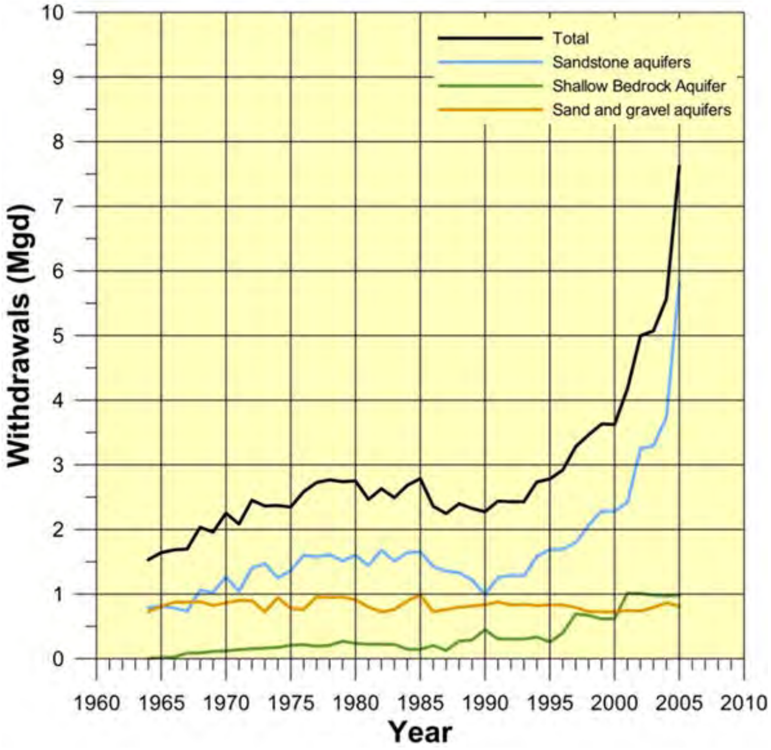


Figure 46. Simulated groundwater withdrawals in Kendall County, 1964-2005

A number of important assumptions were necessary to aid in assigning county-level demands to specific wells for use as model input:

- For the three different scenarios no new points of withdrawal were added beyond those wells operating in 2005. All additional future demands were instead assigned to those existing 2005 wells. Because the scenario demands were summarized at the county level by water use sector, those demand withdrawals were allocated to known sector wells within each county. As discussed with the model results, new wells were added in a "Modified" Baseline scenario.

- All future public water supply and industrial/commercial point withdrawals were based upon their relative percentage of use reported in 2005. For example, according to ISWS records, Minooka operated four wells in 2005 to meet an average daily demand of 864,000 gallons per day; two sand and gravel wells provided 66 percent of the total and two sandstone wells supplied the other 34 percent. Similarly, in 2005 Aurora pumped an average of 18.1 Mgd, of which 59 percent was groundwater from wells (~52 percent from sandstone wells, 7 percent from the Shallow Bedrock Aquifer and sand and gravel aquifers) and 41 percent was from the Fox River. Those relative percentages were maintained in all three demand scenarios out to 2050. Future pumpage was reapportioned to new wells put into operation between 2005 and 2012 in Kendall County.

- Applying additional future demand to existing public, industrial, and commercial wells will exceed some actual well pumping capacities (based upon 24-hour operation at the rated pump capacity). This will not create a problem in the model if additional new wells drilled to accommodate such exceedances occur within the grid spacing of the flow model nearfield (2,500 ft), thus essentially adding that demand to the same model well. However, water users are likely to site new wells at greater distances to strategically distribute groundwater withdrawals and reduce impacts to below critical levels in the most affected areas. The pumpage increases were unsupportable for five industrial supplies and one community well (Romeoville well #13) located outside of Kendall County, so the modeled pumpage for these six sites was held constant at 2005 levels.

- Future agriculture/irrigation demands were assigned to existing agriculture/irrigation wells, but additional withdrawals were limited to the pumping capacity of the well. In some cases, this meant not all the county agriculture/irrigation demand could be allocated. Depending on the demand scenario, from 14.5 to 22.0 Mgd in 2050 irrigation demand across the 11 counties was left unallocated. For Kendall County, this amounted to only 1.31 to 2.35 Mgd unallocated (Tables 10 through 12). Allocated withdrawals are illustrated in Figures 48 through 50.

- Domestic self-supplied withdrawals (i.e., rural domestic wells) were not simulated. This amounted to from 37.3 to 49.3 Mgd in 2050 demand across the 11-county region but only 2.25 to 2.97 Mgd in Kendall County (Tables 10 through 12). The authors believe there is no satisfactory way to model the tens of thousands of small-capacity (typically <20 gpm) wells distributed across the 11-county area. Further, the authors believe these wells will have minimal influence on regional water levels as simulated by this groundwater model.

Tables 10 through 12 show Kendall County groundwater withdrawals for the BL, LRI, and MRI demand scenarios, respectively. Included in these tables are the unallocated demands for agriculture/irrigation and domestic self-supplied. Allocated groundwater withdrawals for Kendall County are shown in Figures 48 through 50. Historical withdrawals and scenario demands for the communities of Joliet, Minooka, Montgomery, Newark, Oswego, Plano, and Yorkville are shown in Figures 51 through 57, respectively. The spatial and temporal distributions of groundwater withdrawals across all of northeastern Illinois, by aquifer, are shown of Figures 58 through 60 for the Baseline scenario.

Because seven years of new water use data have been reported to the IWIP program since Dziegielewski and Chowdhury (2008) made their projections, a rough early evaluation of the projections can be made. Because of the 2009 economic recession, the droughts of 2011 and 2012, and variable development between the different communities, the authors expect some variance in the reported values from the projections. A comparison of the reported water use for 2012 to an average of the 2010 and 2015 Baseline (BL) projections shows mixed results. Water use at Minooka, Oswego, and Newark were in line with projections. Greater reported versus projected water use occurred at Yorkville (1.78 vs 1.57 Mgd), Montgomery (2.45 vs 2.07 Mgd), and Joliet (17.6 vs 15.8 Mgd) and lesser reported versus projected water use occurred at Plano (0.72 vs 0.85 Mgd).

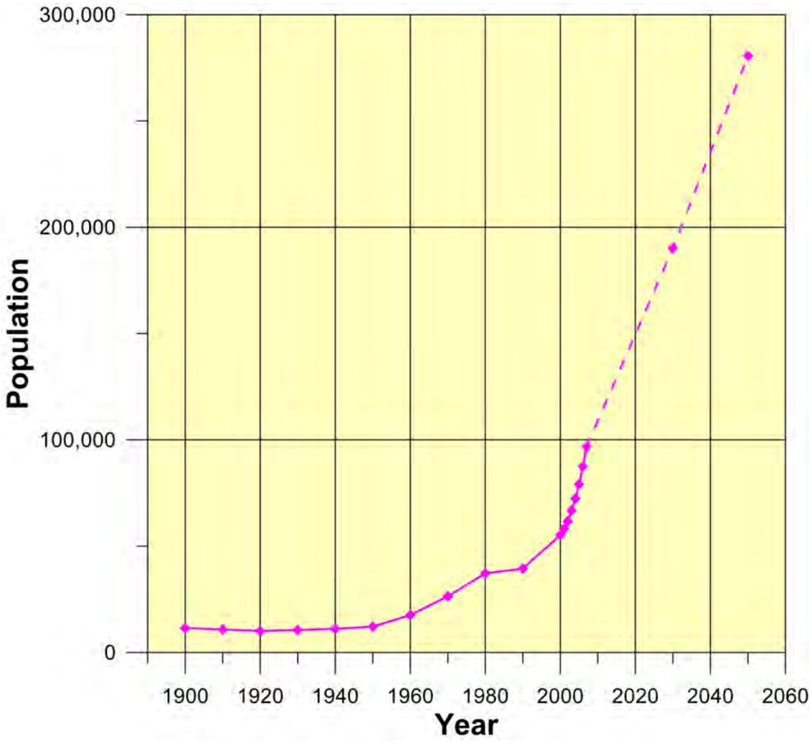


Figure 47. Historical and projected population of Kendall County, 1900-2050 (Dziegielewski and Chowdhury, 2008; United States Census Bureau, 1995; United States Census Bureau, 2009)

Table 10. Kendall County Groundwater Withdrawals Allocated to Wells (and Left Unallocated), BL Scenario, 2010 – 2050

Year	*Public Supply*	*Industrial/ Commercial*	*Agriculture/ Irrigation*	*Total Allocated*	*Unallocated Ag/Irrigation*	*Unallocated Domestic*
2010	5.34	0.55	2.72	8.61	1.10	2.29
2015	7.01	0.64	2.86	10.51	1.21	2.32
2020	9.07	0.75	3.00	12.82	1.33	2.35
2025	11.60	0.87	3.15	15.63	1.46	2.37
2030	14.71	1.01	3.32	19.04	1.59	2.39
2035	16.44	1.18	3.48	21.10	1.73	2.41
2040	18.36	1.38	3.67	23.40	1.88	2.44
2045	20.48	1.61	3.86	25.95	2.03	2.46
2050	22.84	1.87	4.07	28.78	2.20	2.48

Table 11. Kendall County Groundwater Withdrawals Allocated to Wells (and Left Unallocated), LRI Scenario, 2010 – 2050

Year	*Public Supply*	*Industrial/ Commercial*	*Agriculture/ Irrigation*	*Total Allocated*	*Unallocated Ag/Irrigation*	*Unallocated Domestic*
2010	4.69	0.45	2.63	7.77	1.03	2.17
2015	5.61	0.50	2.67	8.78	1.06	2.19
2020	6.75	0.55	2.71	10.01	1.09	2.20
2025	8.14	0.60	2.75	11.49	1.13	2.21
2030	9.81	0.67	2.79	13.27	1.17	2.21
2035	10.63	0.74	2.83	14.20	1.20	2.22
2040	11.54	0.82	2.87	15.23	1.23	2.23
2045	12.53	0.92	2.92	16.36	1.27	2.24
2050	13.61	1.03	2.97	17.60	1.31	2.25

Table 12. Kendall County Groundwater Withdrawals Allocated to Wells (and Left Unallocated), MRI Scenario, 2010 – 2050

Year	*Public Supply*	*Industrial/ Commercial*	*Agriculture/ Irrigation*	*Total Allocated*	*Unallocated Ag/Irrigation*	*Unallocated Domestic*
2010	5.49	0.78	2.73	9.00	1.11	2.54
2015	7.37	0.95	2.89	11.21	1.23	2.61
2020	9.74	1.15	3.04	13.94	1.36	2.67
2025	12.71	1.40	3.21	17.32	1.50	2.72
2030	16.41	1.68	3.40	21.49	1.65	2.77
2035	18.67	2.02	3.58	24.27	1.80	2.82
2040	21.20	2.42	3.79	27.41	1.97	2.87
2045	24.05	2.89	4.01	30.95	2.15	2.92
2050	27.24	3.45	4.25	34.94	2.35	2.97

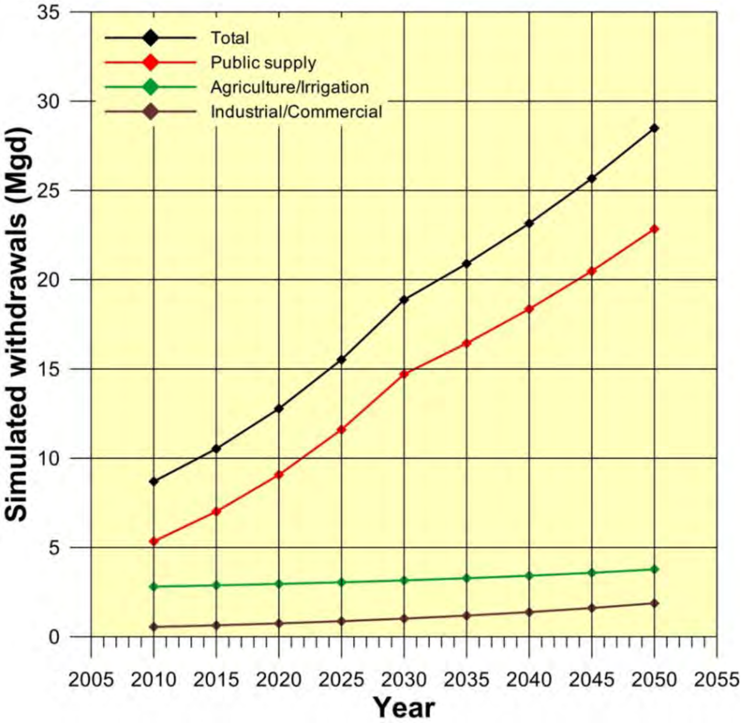


Figure 48. Total allocated withdrawals in Kendall County to 2050, BL scenario

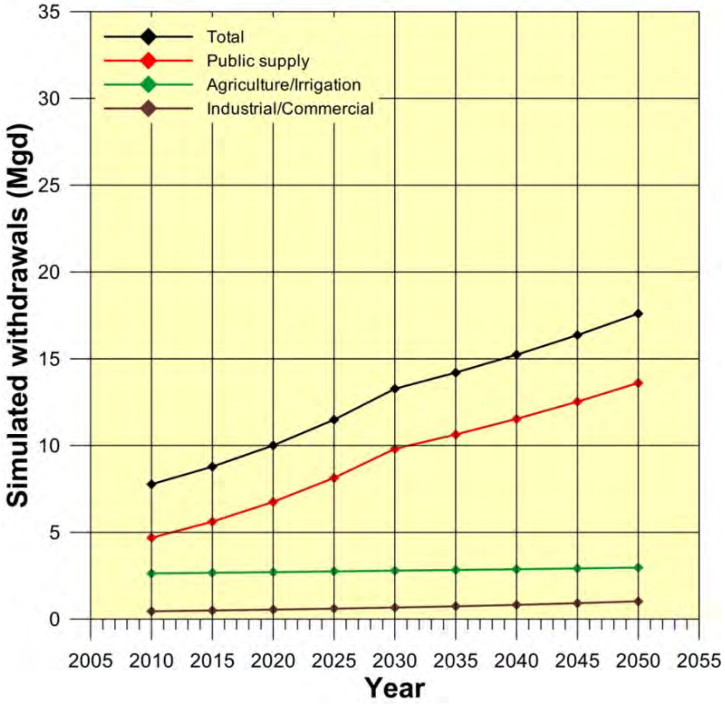


Figure 49. Total allocated withdrawals in Kendall County to 2050, LRI scenario

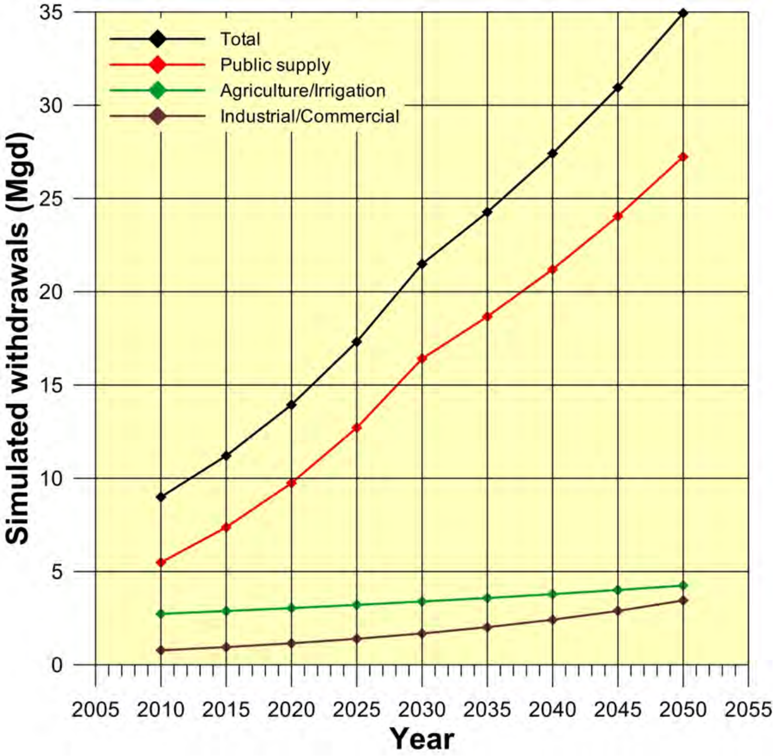


Figure 50. Total allocated withdrawals in Kendall County to 2050, MRI scenario

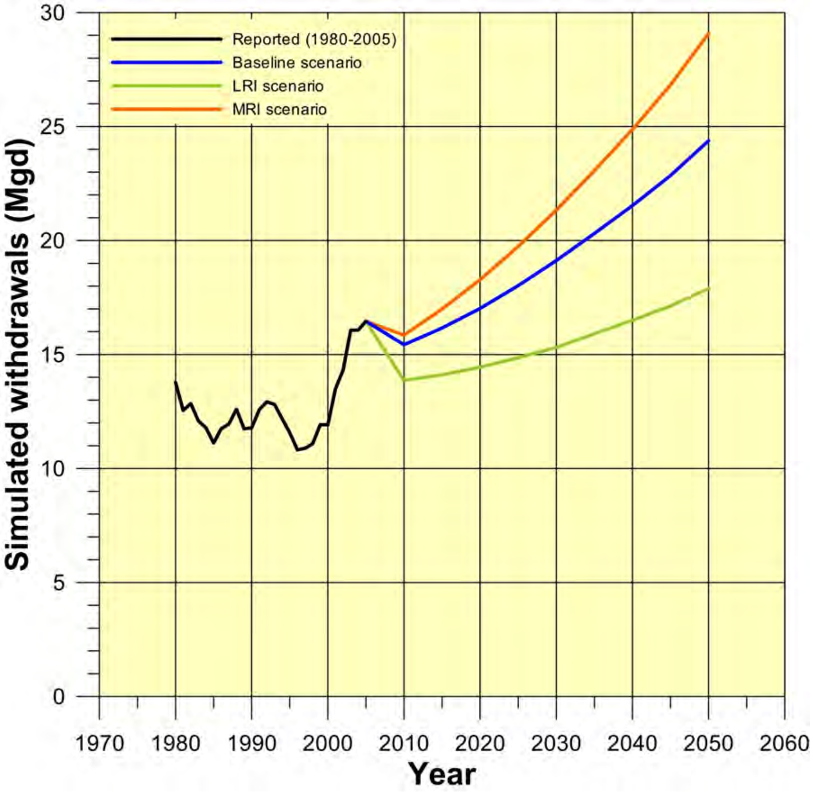


Figure 51. Historical and projected water demand, Joliet public water system

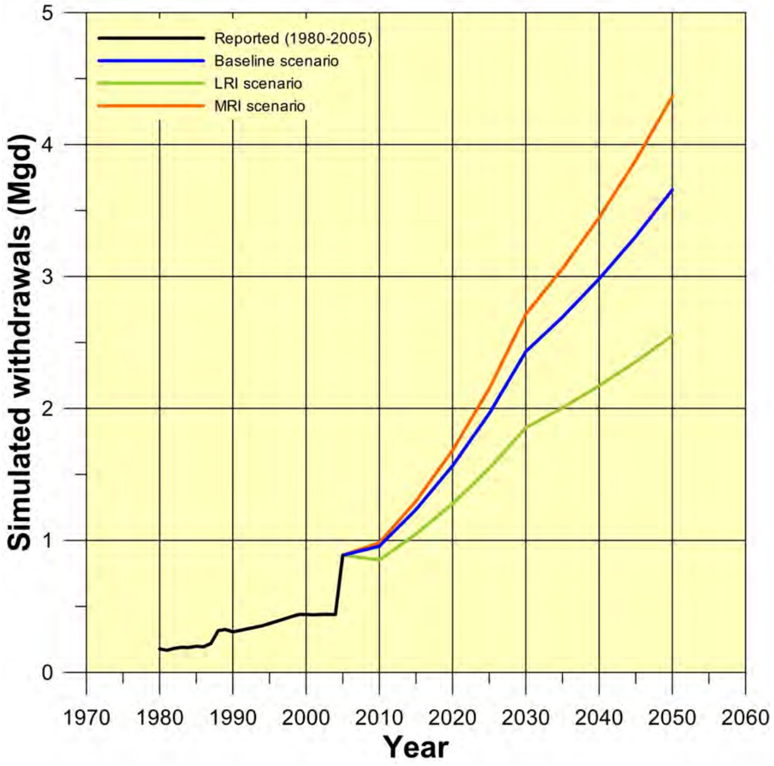


Figure 52. Historical and projected water demand, Minooka public water system

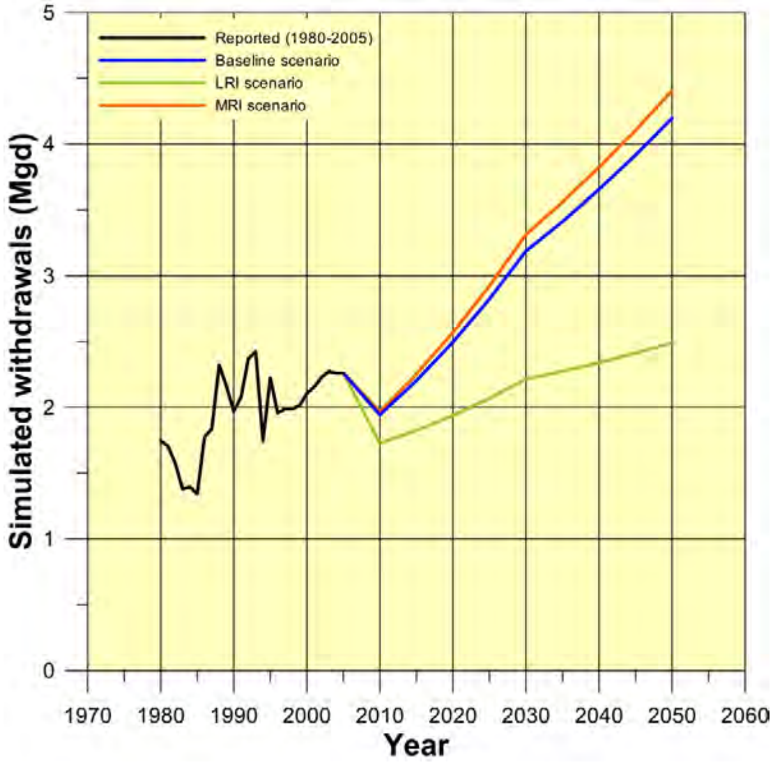


Figure 53. Historical and projected water demand, Montgomery public water system

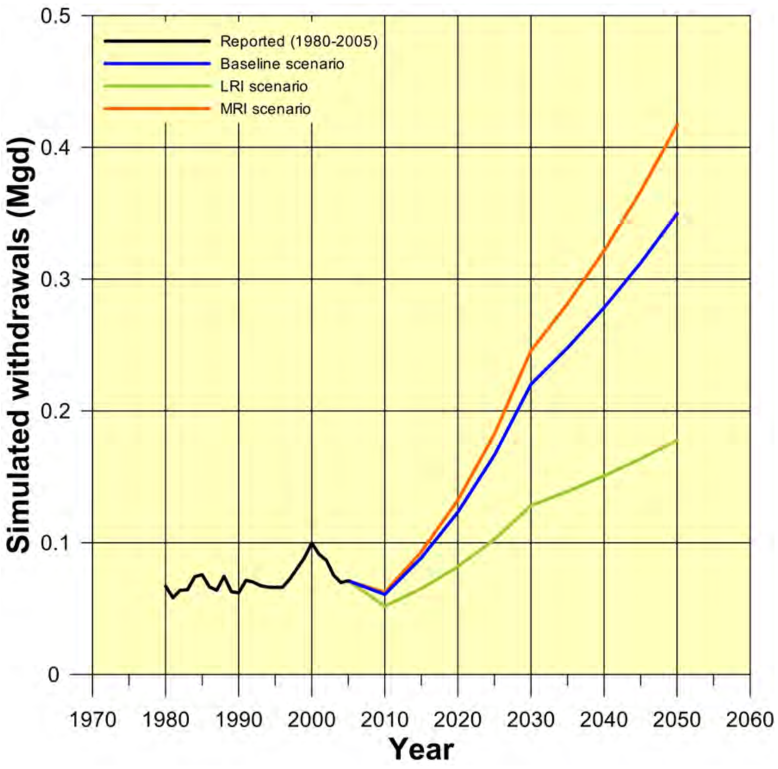


Figure 54. Historical and projected water demand, Newark public water system

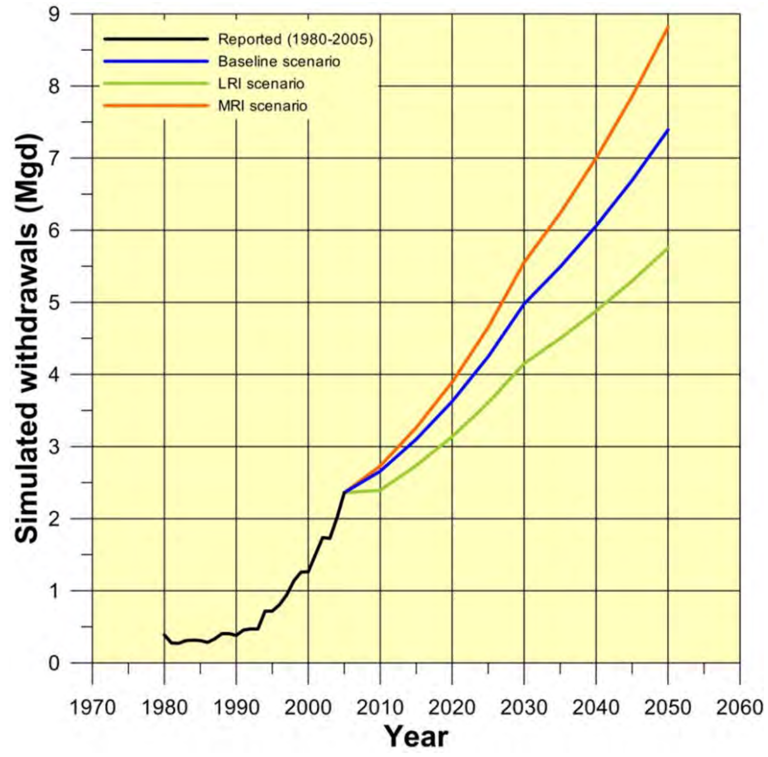


Figure 55. Historical and projected water demand, Oswego public water system

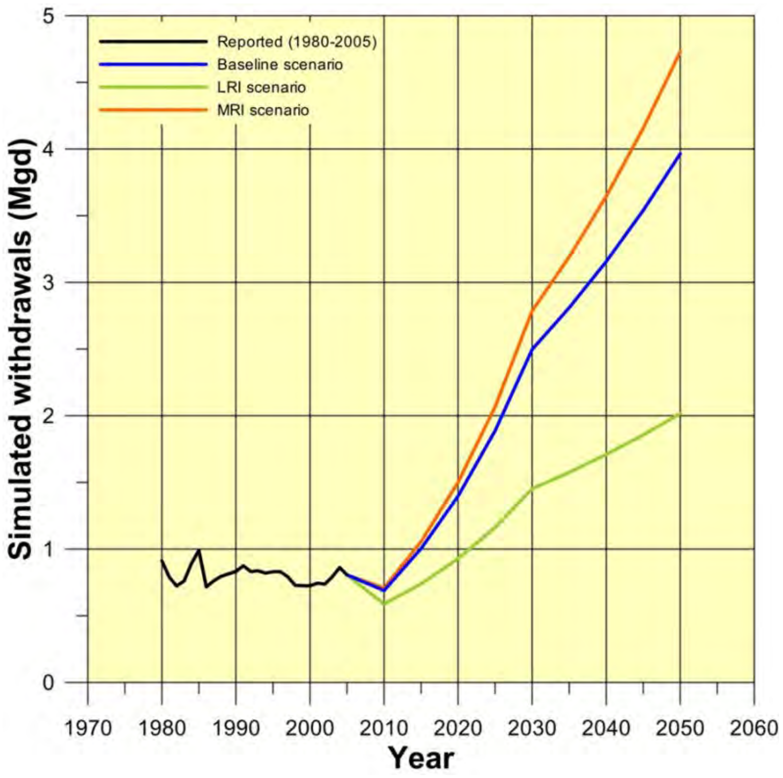


Figure 56. Historical and projected water demand, Plano public water system

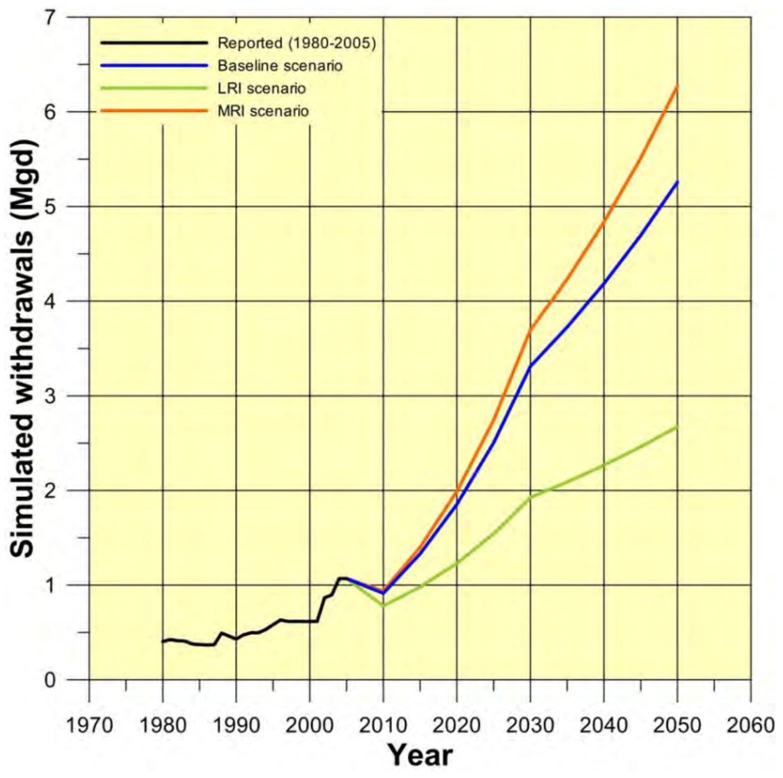


Figure 57. Historical and projected water demand, Yorkville public water system

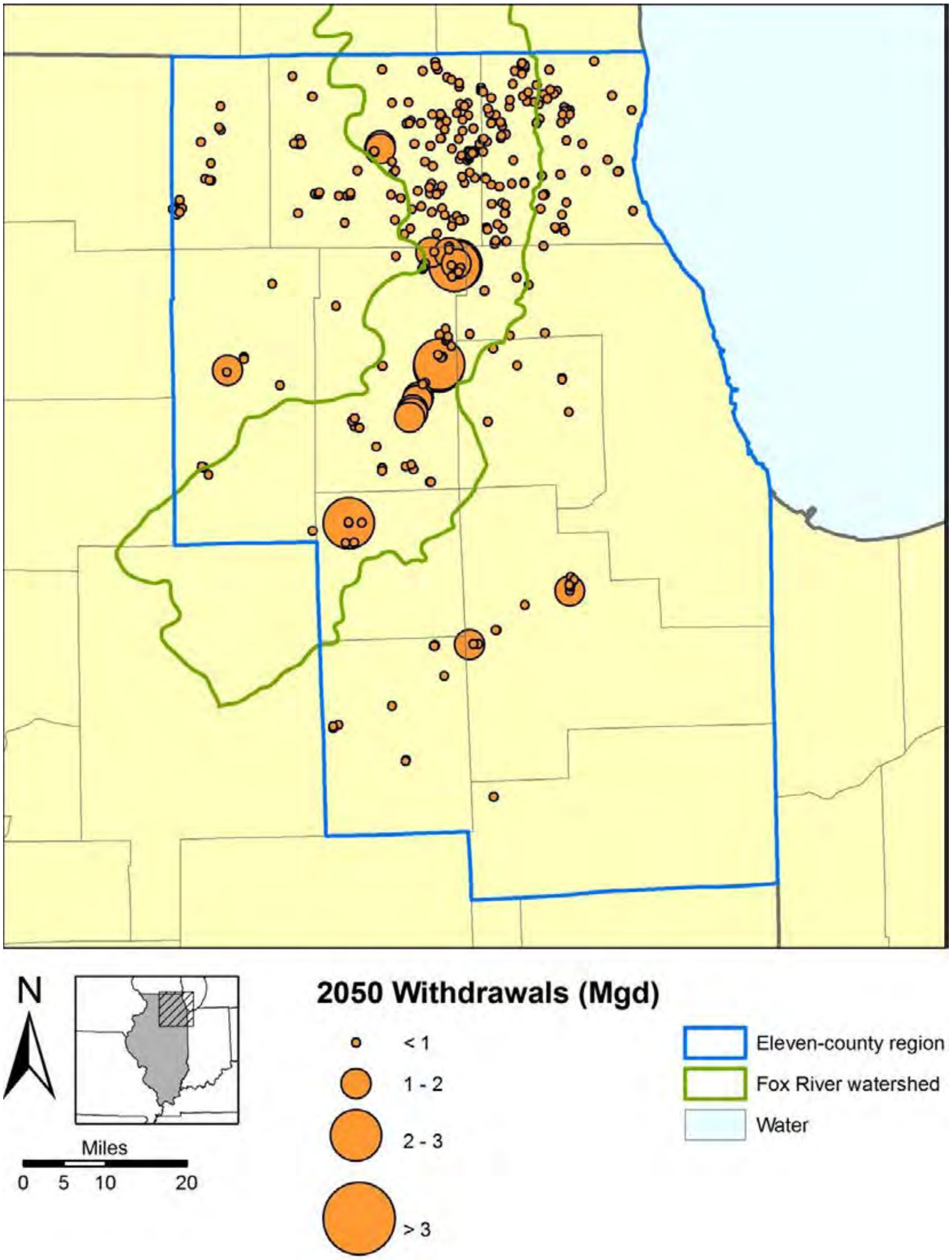


Figure 58. Simulated 2050 withdrawals from the sand and gravel wells in northeastern Illinois in the Baseline scenario (from Meyer et al., 2012)

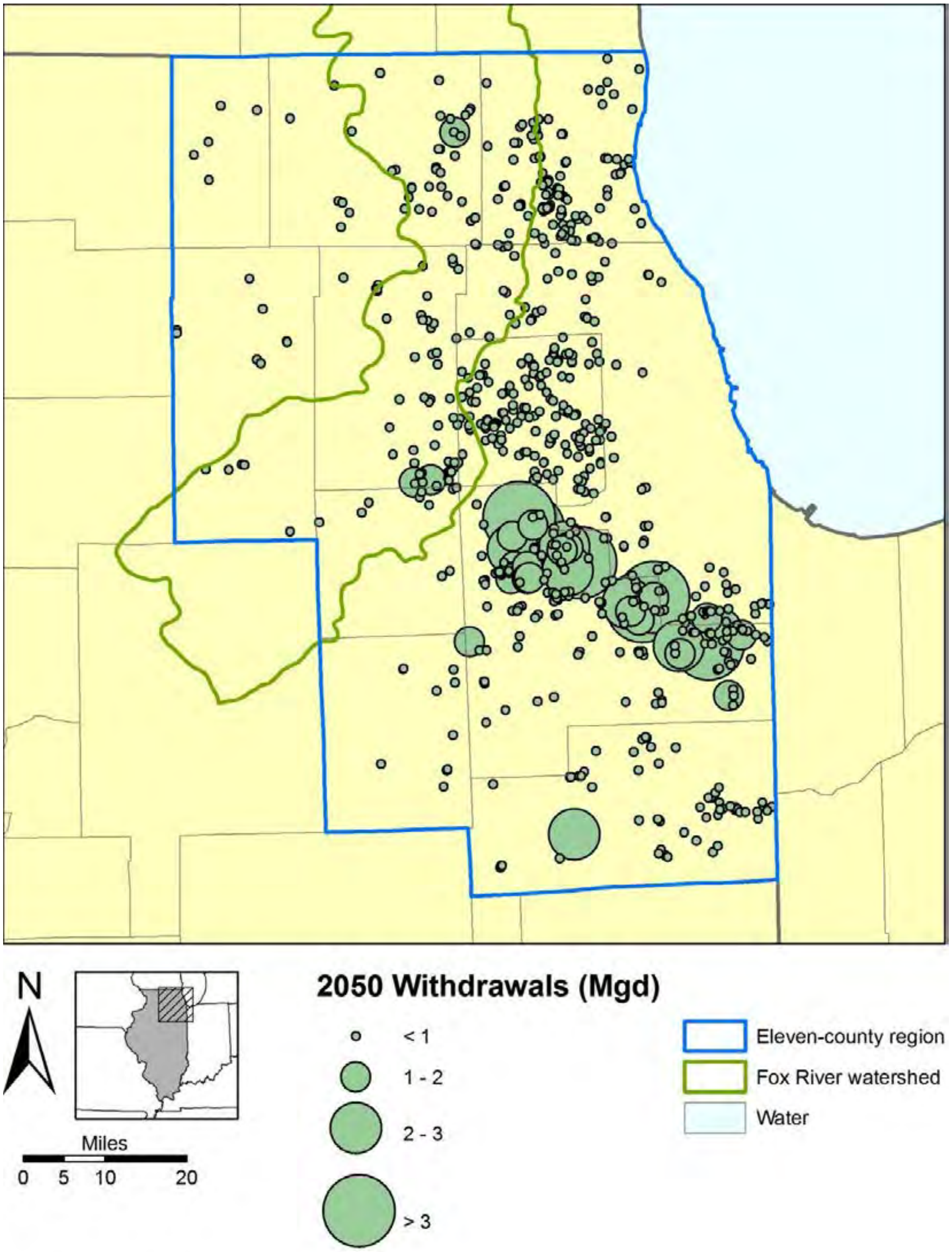


Figure 59. Simulated 2050 withdrawals from the shallow bedrock wells in northeastern Illinois in the Baseline scenario (from Meyer et al., 2012)

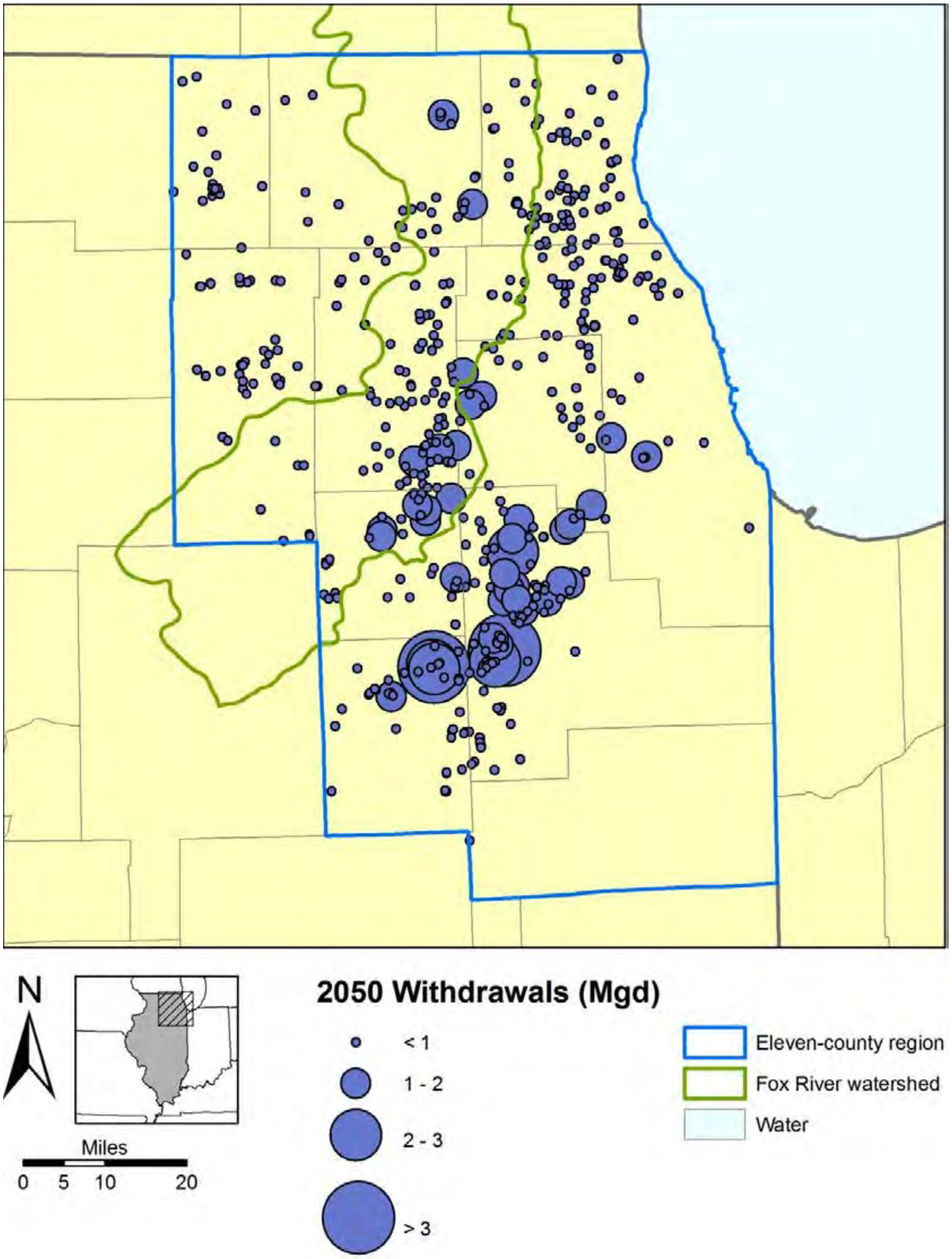


Figure 60. Simulated 2050 withdrawals from the deep sandstone wells in northeastern Illinois in the Baseline scenario (from Meyer et al., 2012)

Projected Impacts of Current and Future Demands

The simulations of historical groundwater conditions and the estimated future groundwater pumping conditions with the calibrated flow model provide insights on the hydraulic behavior of the aquifer system and the sustainability of increasing demands. Because the deep sandstone aquifer is the dominant source of water in Kendall County and the surrounding area, the focus of the model calibration effort and model analysis is on this system. Less emphasis in this section is placed on the Quaternary sands and gravels and on the shallow bedrock aquifer because of relatively low water use and because the main area of interest is also covered by the local-scale model developed by Meyer et al. (2009) for the greater Kane County area. Plano is the sole community in the county using the sands for supply, and several golf clubs and sod farms have the only large-capacity wells in shallow bedrock units above the Ancell Unit.

The model is divided into 72 transient steps over four different periods starting with an initial steady-state simulation of pre-development conditions. The first transient period in the model starts in 1864, when large-scale pumping is considered to have begun in northeastern Illinois, and proceeds to 1963 in 20 five-year times steps. The second transient period starts in 1964, when data from individual wells become available, and proceeds to 2005 in 42 one-year steps. The final transient period covers the future demand scenarios from 2010 to 2050 using nine five-year time steps. Pumpage in the future scenarios was reapportioned to the new wells completed between 2006 and 2012.

The surface waters in the model area are represented with river and drain packages in MODLOW. The recharge package in MODFLOW was used to simulate the infiltration of precipitation into the upper surface of the model. A discussion of all the boundary conditions and the values used in the model are found in Meyer et al. (2009). The model was solved using the preconditioned conjugant gradient (PCG2) in GroundwaterVISTAS® with a head convergence criterion of 0.0001 feet and a residual criterion of 200 ft^3/d.

For both historical and future simulations, the discussion and illustrations in this section emphasize the following:

- Drawdown in the shallow aquifers in northern Kendall County,
- Temporal change in natural groundwater discharge to streams within the Fox River watershed,
- Simulated drawdown in the Ancell Unit throughout northern Kendall County and surrounding areas of northeastern Illinois,
- Simulated available head above the top of the Ancell Unit,
- Simulated drawdown in the Ironton-Galesville Unit in southern Kendall County, and
- Temporal change in simulated heads.

The authors believe that these types of model output are best used as a screening tool to provide a sense of the locations and magnitudes of groundwater pumping impacts. The results are useful for identifying areas for further data collection and for possible long-term monitoring.

The model itself is useful for assessing impacts from historical pumping as well as alternative pumping strategies possibly directed toward reducing future impacts.

Analysis of the Shallow Aquifers

The principal shallow sand and gravel aquifers of the Quaternary Unit used for water supply occur north of the Fox River in Kendall County (Figure 41) (Kay et al., 2005; Keefer et al., 2013). As shown on the potentiometric surface map (Figure 13), groundwater in this aquifer flows south from Kane and DeKalb Counties and discharges to the Fox River. Complicating this flow system are the incised tributaries of Blackberry, Rob Roy, Big Rock, and Little Rock Creeks, which likely act as both recharge and discharge points while controlling the water table elevation. Because of the need for finer resolution to adequately model this portion of the aquifer system, the Kane County local-scale model (Meyer et al., 2009) was used instead of the larger-scale model developed as part of this study to assess the more regional deep sandstone aquifer. Similarly, the use of the Silurian dolomite within the Shallow Bedrock Aquifer for water supply also occurs within the domain of the local-scale model with the exception of two irrigation wells in the east-central part of the county (Figure 42).

For northern Kendall County the regional model divides the Quaternary Unit into five layers (Table 8) with a horizontal grid cell size of 2,500 ft by 2,500 ft. In contrast, the local-scale model uses 14 layers and a cell size of 660 ft by 660 ft. For a more complete comparison of the shallow aquifer portions of the two models, see Meyer et al. (2012). The parameters for the shallow aquifer layers in the regional model as presented by Meyer et al. (2012) were not recalibrated for this study. The results of the local-scale and the regional models are generally similar with the predicted percentage losses in stream flow for the Big Rock Creek watershed being nearly identical for the historical period.

The shallow sand and gravel aquifers are well connected with the Shallow Bedrock Aquifer and combined can form a highly permeable unit with transmissivity values that can exceed 10,000 ft^2/d in northwestern Kendall County (Figure 61). As a result of the high transmissivity and the interaction of the aquifers with the Fox River and the four tributary creeks, the model results do not show areas with significant regional drawdowns (Figures 62 and 63). In addition, many of the shallow wells have less than 30 ft of available head (head above the top of the aquifer or pump setting), which greatly limits their pumping capacities. By contrast, the total transmissivity of the deep sandstone aquifer is four times lower (Figure 38) than that of the shallow aquifer, but the deep wells can have hundreds of feet of available drawdown so they can have much larger pumping capacities. For example, Plano well #7 was drilled 91 feet into sand and gravel with a reported specific capacity of 16.8 gallons per minute per foot of drawdown (gpm/ft) and approximately 50 ft of available head, thus making for a theoretical well capacity of 840 gpm. By comparison, the Yorkville well #7 was drilled 1,527 ft deep into the Ironton-Galesville sandstone with a reported specific capacity of 2.93 gpm/ft and approximately 860 ft of available head, thus making for a much greater theoretical well capacity of 2,730 gpm.

The development of the original Plano wellfield (labeled on Figure 61) within the floodplain of Big Rock Creek does not make any long-term analysis of the sustainability of the wellfield very meaningful. As shown in Figure 62, the model does not show the formation of a large cone of depression from the wellfield due to the downward leakage of water from the creek. Measurements by Locke and Meyer (2007) and by the City of Plano (from IWIP surveys) have shown fairly consistent non-pumping water levels in the city wells at levels close to that of the creek. With 30 feet of saturated sand, the wells could be susceptible to long-term drawdown. However, the drawdowns are unlikely to accumulate from year to year due to flooding along the creek, bringing the groundwater levels back up to "full." The drawdown at this wellfield does not appreciably increase in the future pumping scenarios. Additional field work to examine groundwater/surface water interactions and a much finer model grid (<40 ft) is needed to model the aquifer more accurately.

The new Plano wellfield (wells #7 to #9) is located two miles east of Big Rock Creek so it does not have the same benefit of local leakage and flooding to minimize drawdowns at the wells. However, leakage from Big Rock Creek and Rob Roy Creek will help to contain the regional spread of the cone of depression. Under the Baseline scenario, the predicted 5-foot drawdown contour at the new wellfield extends radially outward about one-half mile (Figure 63). Local hydrogeological conditions will likely be a greater factor in determining how the shallow sand and gravels can be developed than concerns over regional drawdowns.

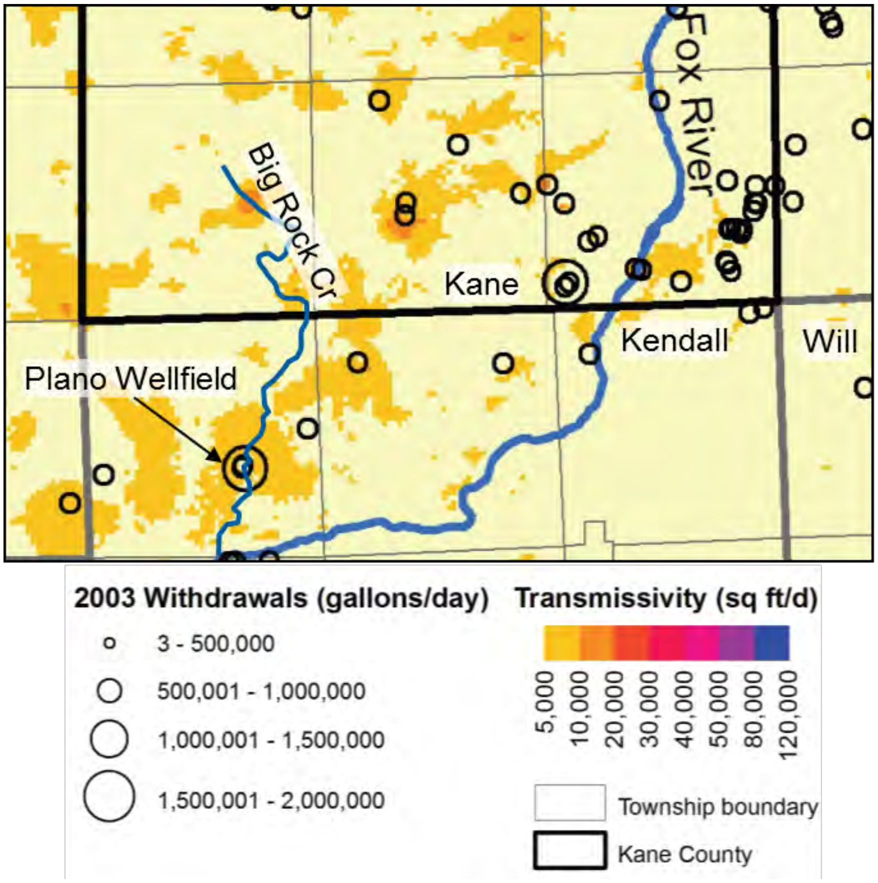


Figure 61. Transmissivity of shallow materials in southern Kane and northern Kendall Counties, with 2003 withdrawals superimposed (from Meyer et al., 2009)

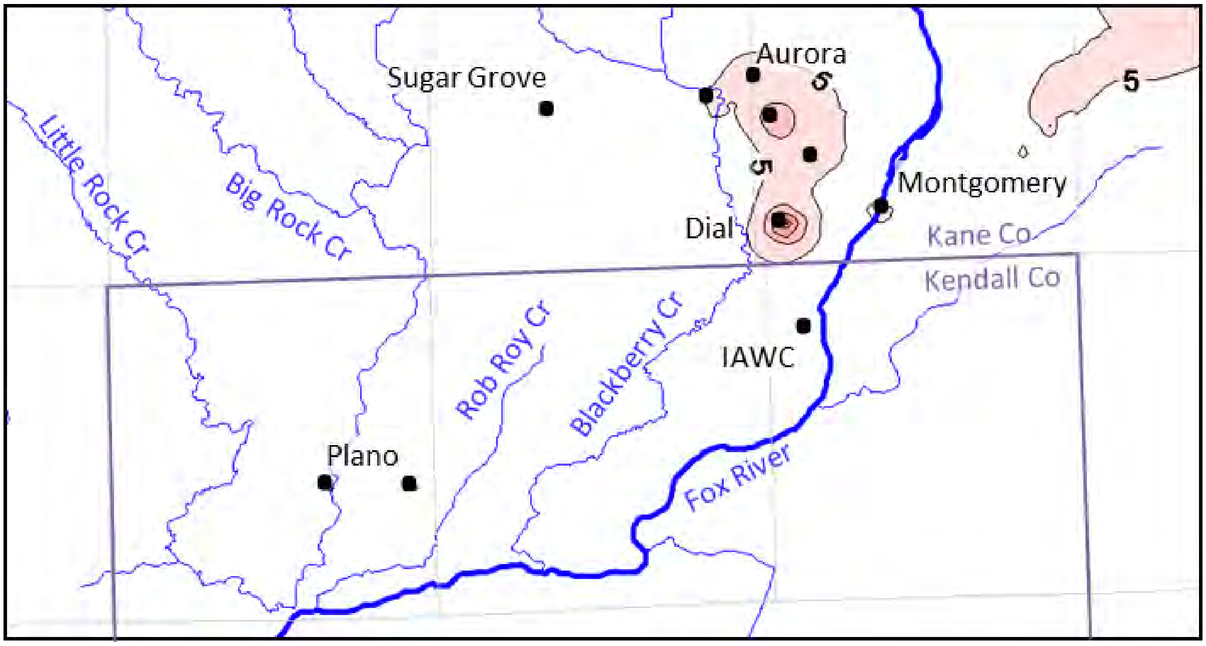


Figure 62. Simulated drawdown from pre-development to 2005 in the shallow aquifers of northern Kendall and southern Kane Counties

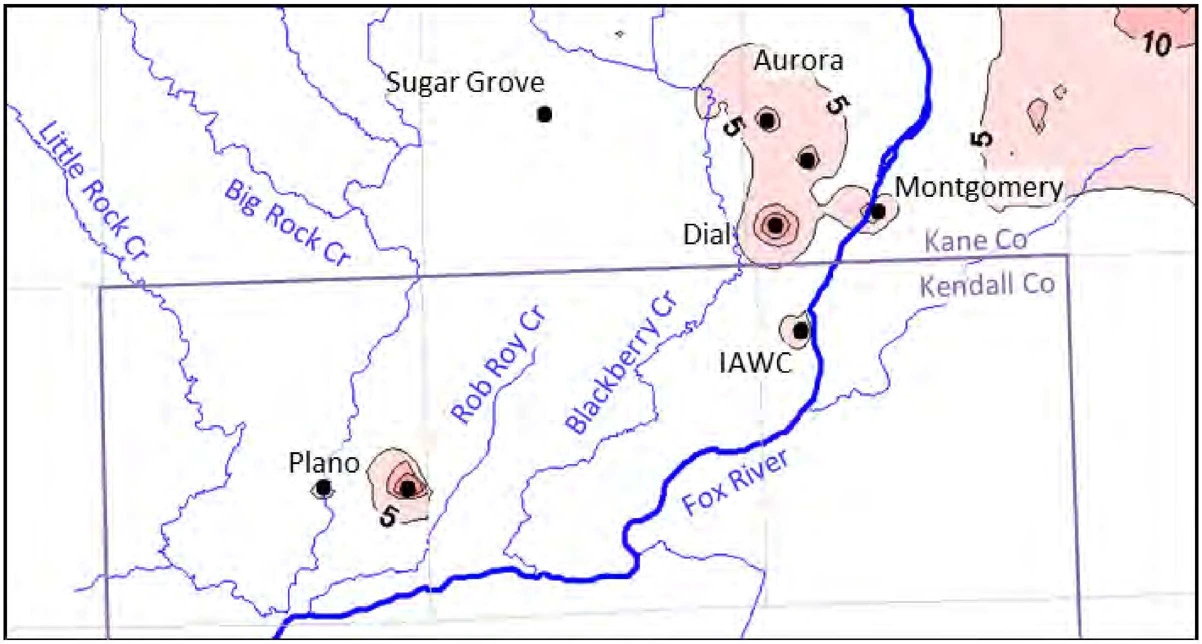


Figure 63. Simulated drawdown from pre-development to 2050 for the Baseline Scenario in the shallow aquifers of northern Kendall and southern Kane Counties

Like the sand and gravel aquifers, the future demand scenarios do not show the formation of significant drawdowns in the Shallow Bedrock Aquifer. Because there were a lack of commercial and industrial wells in Kane County when Dziegielewski and Chowdhury (2008) estimated future demands, existing wells were assigned unrealistically high future withdrawal rates. For example, in the Baseline scenario the wells at the Dial facility were previously assigned rates for 2050 that were 3.4 times the 2005 rates. In the northeast Illinois model (Meyer et al., 2012) the Dial wells, along with many others, went dry because they could not sustain the high pumping rates. Because the water use by Dial has been fairly constant since the early 1990s, the future demands were kept constant at the 2005 rates. With the use of these constant rates coupled with decreased demands on the Shallow Bedrock Aquifer by Sugar Grove and Aurora, significant changes in drawdowns were not predicted in the model for northeastern Kendall County (Figure 63).

Analysis of Natural Groundwater Discharge to Streams

Drawdown is reduced by the capture of streamflow, so drawdown in the shallow aquifers, while significant in limited areas, is not as widespread as in the deep aquifers because the shallow aquifers have a greater degree of connectivity to surface water than do the deep aquifers. Model simulations suggest that pumping from shallow wells, with resultant capture of streamflow, can significantly reduce natural groundwater discharge to streams in some areas. Streamflow capture occurs by two mechanisms: (1) by diversion into shallow wells of recharge that would otherwise discharge to streams, and (2) by direct inducement of streamflow to leak from stream channels.

Because of the good agreement between the Kane County local-scale model (Meyer et al., 2009) and the regional model (Meyer et al., 2012) for predicting stream losses in Kendall County, the results of the regional model are shown here to give the reader a wider perspective. Overall, model analysis suggests that natural groundwater discharge to streams in the Illinois portion of the Fox River watershed declined from predevelopment rates by 7 and 9 percent in 1985 and 2005, respectively, reflecting increased pumping of shallow groundwater in the basin. These reductions are not evenly distributed across the watershed because local hydrogeology and pumping are irregularly distributed. Fox River sub-basins overlapping Kendall County and included in the analysis are illustrated in Figure 64, and reductions throughout the Illinois portion of the Fox River watershed are shown in Figures 65 and 66. Reductions in simulated groundwater discharge to streams from pre-development (pre-1864) to 2005 range from 2 to 11 percent in the sub-basins overlapping Kendall County with an overall decline of about 6 percent. In 2005 the greatest simulated reductions in the Kendall County area occurred in Blackberry Creek and Big Rock Creek, which extend far into Kane County. Analysis from the local-scale model (Meyer et al., 2009) suggests that most of the loss in Big Rock Creek occurs in Kendall County along the stretch near Plano.

Simulation of future pumping scenarios suggests that, overall, natural groundwater discharge in the Illinois portion of the Fox River basin could be reduced by 8 to 10 percent from predevelopment rates in 2025 and by 9 to 12 percent in 2050 (Meyer et al., 2012). Figure 66 shows the losses for the Baseline pumping scenario out to the year 2050. The pattern of reductions within the Fox River watershed resembles the 2005 pattern. The greatest simulated reductions in sub-basins overlapping Kendall County occur in the watershed of Blackberry Creek (sub-basin 11), where model simulations suggest reductions of 10 to 11 percent in 2025 and 11 to 13 percent in 2050, depending on the pumping scenario. Readers should note that most of this sub-basin is in Kane County, not Kendall County, and the reduction in simulated natural groundwater discharge may reflect withdrawals from wells in Kane County.

Reductions in natural groundwater discharge may not be observable or easily recognized. On the main stem of the Fox River (sub-basins 33, 62, and 64 in the Kendall County area), for example, increasing discharges of wastewater effluent may compensate for base flow reductions. Reductions will be most noticeable during low flow periods on tributary streams that do not receive effluent. Historically, perennial streams may begin to go dry and may do so already (without historical stream data, it will not be obvious). Dry periods of ephemeral streams have the potential to become more frequent and extend for longer periods. Changes in natural groundwater discharge resulting from pumping may also be masked by other alterations of the hydrologic cycle that are not modeled in this study. Most importantly, these include changes in groundwater discharge accompanying alterations of land cover. For example, urbanization is accompanied both by increasing impermeable surfaces—a factor which potentially reduces both groundwater recharge and discharge—and by increasing imports of water to the shallow subsurface through leaking pipe networks—a factor which may increase recharge.

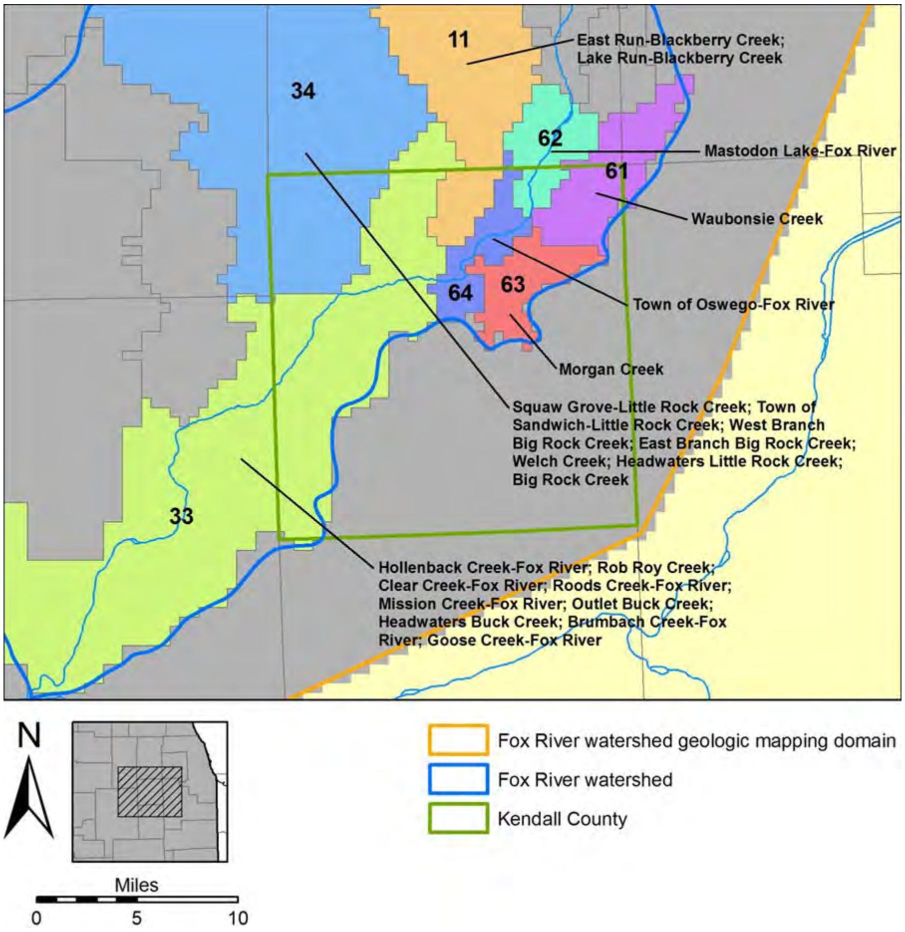


Figure 64. Fox River sub-basins overlapping Kendall County

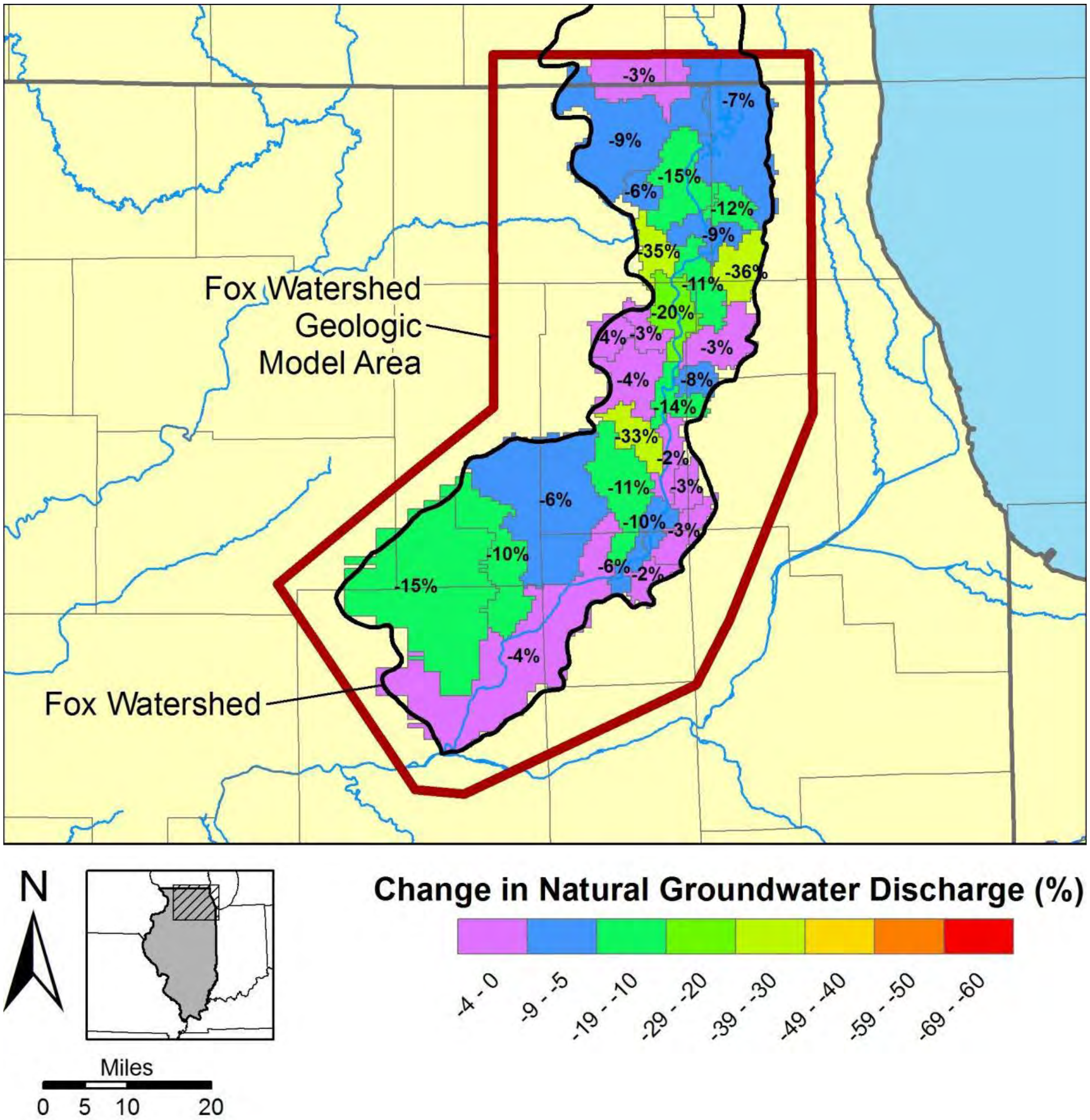


Figure 65. Change in natural groundwater discharge from pre-development to 2005 in the Fox River watershed (from Meyer et al., 2012)

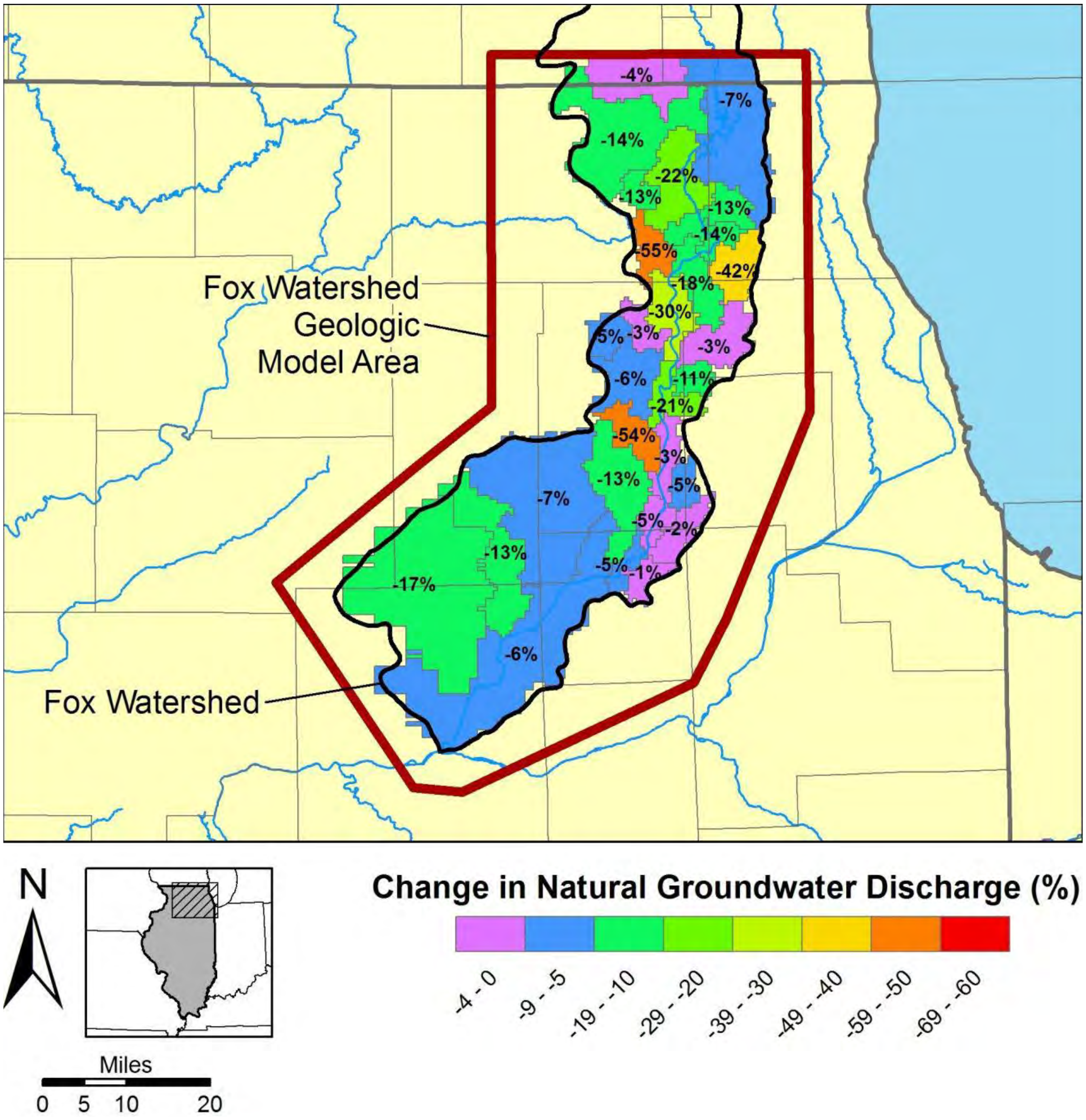


Figure 66. Change in natural groundwater discharge (pre-development to 2050) in the Fox River watershed for the Baseline Scenario (from Meyer et al., 2012)

Analysis of the Deep Sandstone Aquifers

The presence of relatively impermeable rocks overlying the sandstone aquifers greatly reduces the exchange of water between these deep aquifers and the shallow aquifers. Circulation within the sandstone aquifers thus occurs on a regional scale, with most recharge into the aquifers in Illinois occurring in Boone, DeKalb, Livingston, and southern Kendall Counties, where the relatively impermeable Maquoketa shale is absent. Under predevelopment conditions, groundwater in the sandstone aquifers underlying northeastern Illinois discharged to the upper Illinois River and the lower Fox River, along with upward leakage to Lake Michigan. Presently, discharge from the sandstone aquifers in the region is dominated by flow to wells throughout northeastern Illinois. Because the deep wells outside Kendall County greatly affect water levels within the county, the figures presented in this section include all of northeastern Illinois.

Hydrologic Conditions in 2005

The hydrologic conditions in the deep aquifer predicted by the model for 2005 are shown in Figures 67 through 76. The model heads compare well to the measured potentiometric surface map for 2007 (Burch, 2008), although the measurements show water levels 50 to 100 feet lower in Aurora, Oswego, Joliet, and central DuPage County. As discussed in the model calibration section, the measured water levels from some of the Joliet wells in Kendall County are very low and may be adversely impacted by their proximity to the fault zone. Some of the differences between the modeled 2005 heads and the measured 2007 water levels shown by Burch (2008) may be due to differences in pumpage between the two years and collection of the measurements during fall when water levels are typically lower.

The modeled heads and drawdowns for the Ancell sandstone (Figures 67 and 72) and the Ironton-Galesville sandstone (Figures 68 and 73) are similar except in southwestern Kendall County where the Ancell heads are predicted to be as much as 200 feet higher than the Ironton-Galesville heads (Figure 70). The similarity between the two surfaces for most of northeastern Illinois is due to the high vertical hydraulic conductivity zone (Figure 31) used to represent the aquifer interconnections caused by the wells open to both units. South of the Sandwich fault in Kendall County there are no known wells interconnecting the two aquifers so the heads begin to diverge. The heads in the Ancell sandstone become higher because in far western Kendall County the unit is at the bedrock surface (Figure 2) and can receive recharge directly from the shallow aquifers and possibly some stream segments. Lacking this same source of recharge, the heads in the Ironton-Galesville are lower due to drawdown from regional pumpage.

The modeled heads and drawdowns for the Mt. Simon sandstone (Figures 69 and 74) show the center of the cone of depression to be in the northeastern corner of DuPage County. This offset in drawdown from the Ironton-Galesville sandstone is due to the conceptualization of the intervening Eau Clare confining unit and the distribution of wells completed into the Mt. Simon (Figure 71). Cutting across northeastern Illinois in a line from southwestern Kane County to northeastern Cook County is a geologic facies change in the Eau Clare Formation (Willman et al., 1975; Meyer et al., 2009) where the assigned vertical hydraulic conductivity to the north jumps by four orders of magnitude (Table 9), causing the heads in the Mt. Simon sandstone to behave as an extension of those in the Ironton-Galesville sandstone. A small area of northern DuPage and Cook Counties was also assigned a high vertical hydraulic conductivity due to the large number of wells completed into the Mt. Simon sandstone. These results show that the Mt. Simon sandstone is an important source of water for all of northeastern Illinois.

South of the facies change in Kendall and Will Counties, the Eau Clare Formation is modeled as a tight confining layer, so the deep cone of depression in the upper sandstones is not reflected in the Mt. Simon and the modeled head differences are as much as 500 feet (Figure 71). Unfortunately, very little data on the hydraulic characteristics of the Eau Clare Formation exist, and it is possible that the facies change occurs more gradually over several counties than as a sharp line. Water level data from the Mt. Simon also do not exist in Kendall and Will Counties so there is no way to validate how groundwater flow in the Mt. Simon is behaving in this area. The City of Aurora has had as many as 13 wells completed into the Mt. Simon, but only one of those wells is still in use and has not been sealed. Use of these deep Mt. Simon wells was discontinued due to high chloride concentrations and generally brackish water quality. Water quality records show chloride concentrations in Aurora well #8 dropped from 1,040 mg/L in 1943 to 11 mg/L in 1959 after the bottom 780 feet of the well open to the Mt. Simon sandstone was plugged off in 1948.

The amount of drawdown in the deep sandstones of northeastern Illinois is dramatic due to the high water use in an aquifer system with a relatively low transmissivity and the large amount of available head (see discussion in the shallow aquifer analysis above). The cone of depression is centered on Joliet where heads have been reduced by more than 700 feet to elevations below sea level (Figures 67 and 72). A secondary center to the cone of depression occurs around the pumping center at Aurora. From a practical viewpoint, the main issue with the deep water levels is the increased electrical costs of lifting the water hundreds of feet. However, if the head drops below the top of the aquifer, as it has started to do in areas around Joliet and Aurora (Figure 75), the saturated aquifer thickness decreases, leading to a decrease in transmissivity and even further increases in drawdown. With the Ancell sandstone accounting for roughly half of the transmissivity of the deep wells around Kendall County, the dewatering of the aquifer will cause the wells to experience a drop in productivity. If the productivity of a well could be maintained while the Ancell sandstone is completely desaturated, then the resulting drawdown created in the Ironton-Galesville sandstone by that well would be doubled. In a small area of southwestern Kendall County, the Ancell sandstone is partially saturated under natural conditions without any nearby pumpage. As shown in Figure 76, heads in the Ironton-Galesville sandstone are 500 feet or more above the top of this lower sandstone formation.

There are additional potential problems associated with the decline of Ancell Unit heads near to and below the top of the Ancell Unit. Studies of the Ancell in the Green Bay area of Wisconsin (Schreiber et al., 2000) suggest that exposure to oxygen of a thin interval at the top of the Ancell Unit containing sulfide minerals has caused a dramatic increase in arsenic concentrations. Further study of the Ancell in the Chicago region is required to establish whether the arsenic-bearing sulfide mineral layer is present in the region and whether declining heads could cause the release of arsenic from it. Because many wells in northeastern Illinois are open to both the Ancell Unit and the Ironton-Galesville Unit, desaturation of the Ancell Unit could increase the proportion of Ironton-Galesville groundwater withdrawn from these multiple-aquifer wells. This may change the quality of the pumped water due to different concentrations of dissolved constituents including radium and barium (Gilkeson et al., 1983).

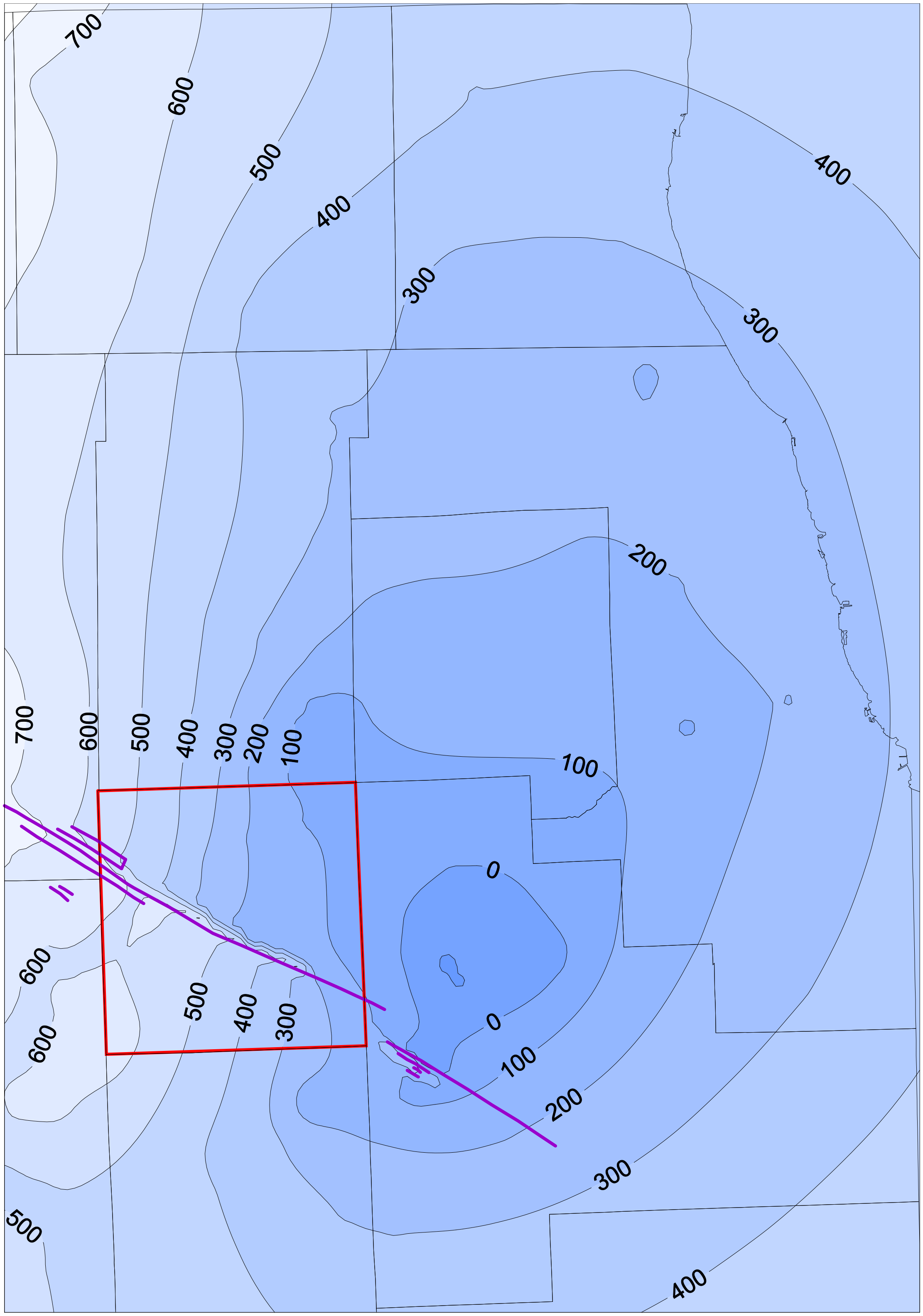


Figure 67. Predicted heads (ft asl) in 2005 for the Ancell sandstone. Purple lines show Sandwich Fault Zone.

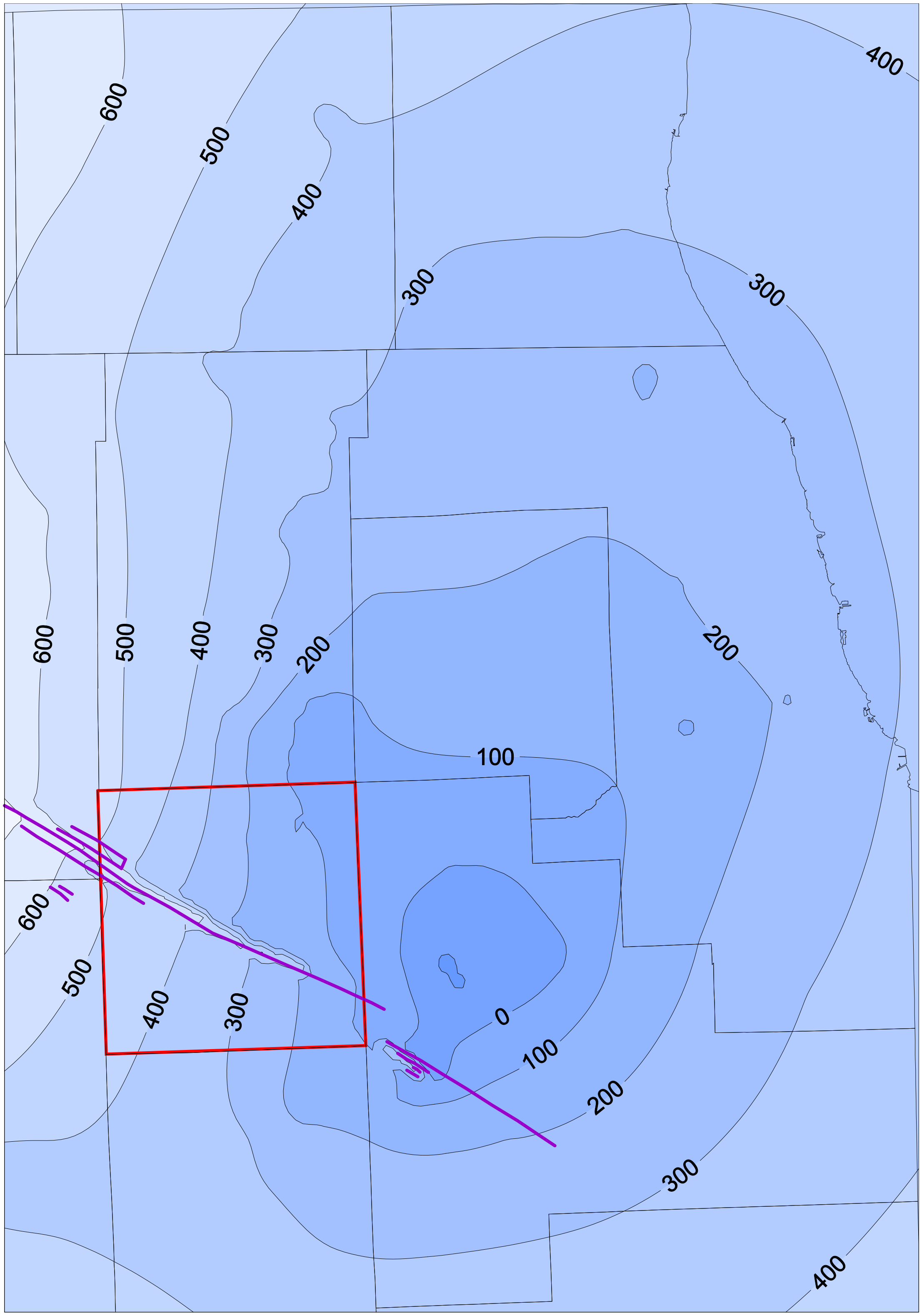


Figure 68. Predicted heads (ft asl) in 2005 for the Ironton-Galesville sandstone. Purple lines show Sandwich Fault Zone.

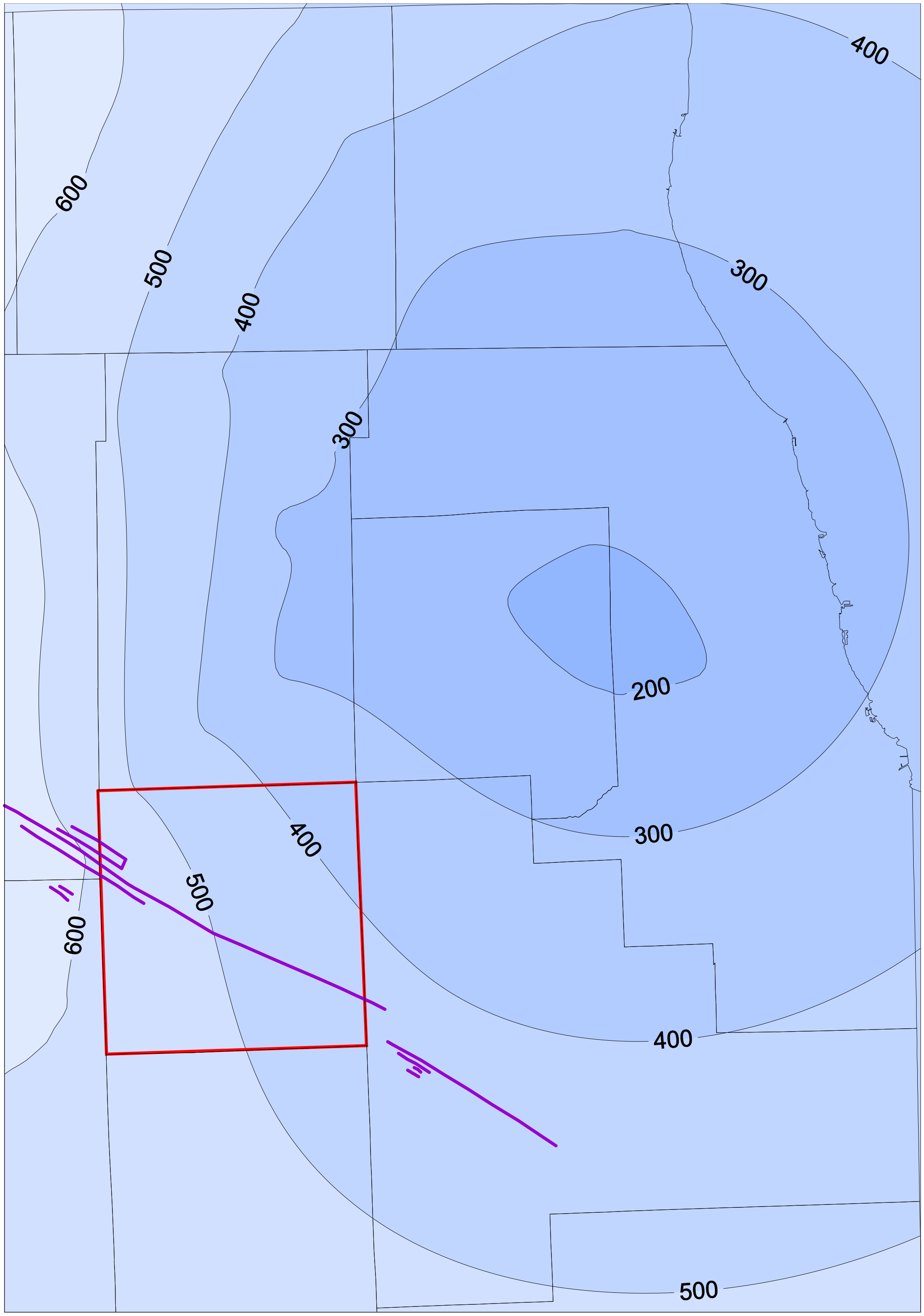


Figure 69. Predicted heads (ft asl) in 2005 for the Mt. Simon sandstone

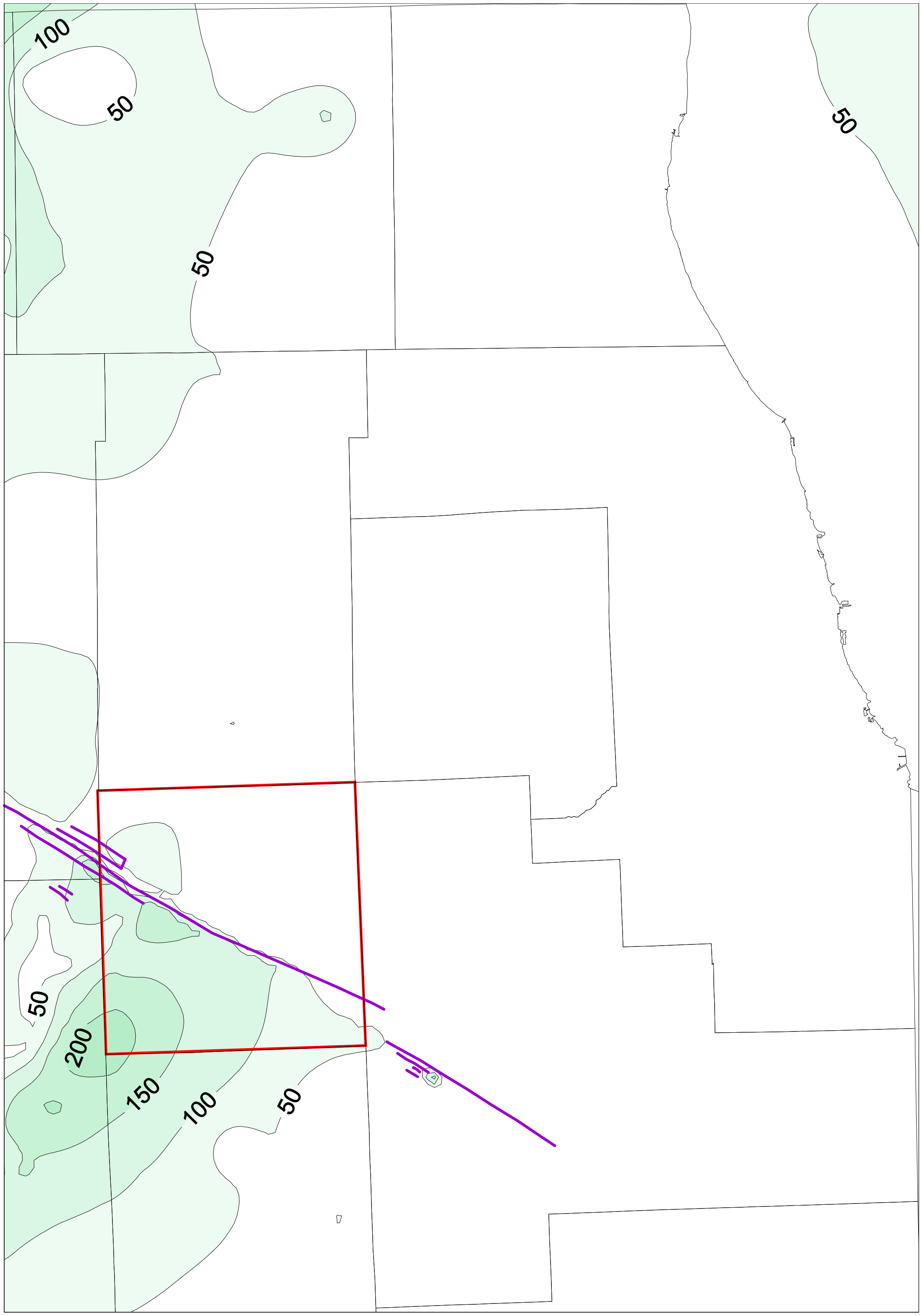


Figure 70. Predicted head difference (ft) in 2005 between the Ancell and Ironton-Galesville sandstones

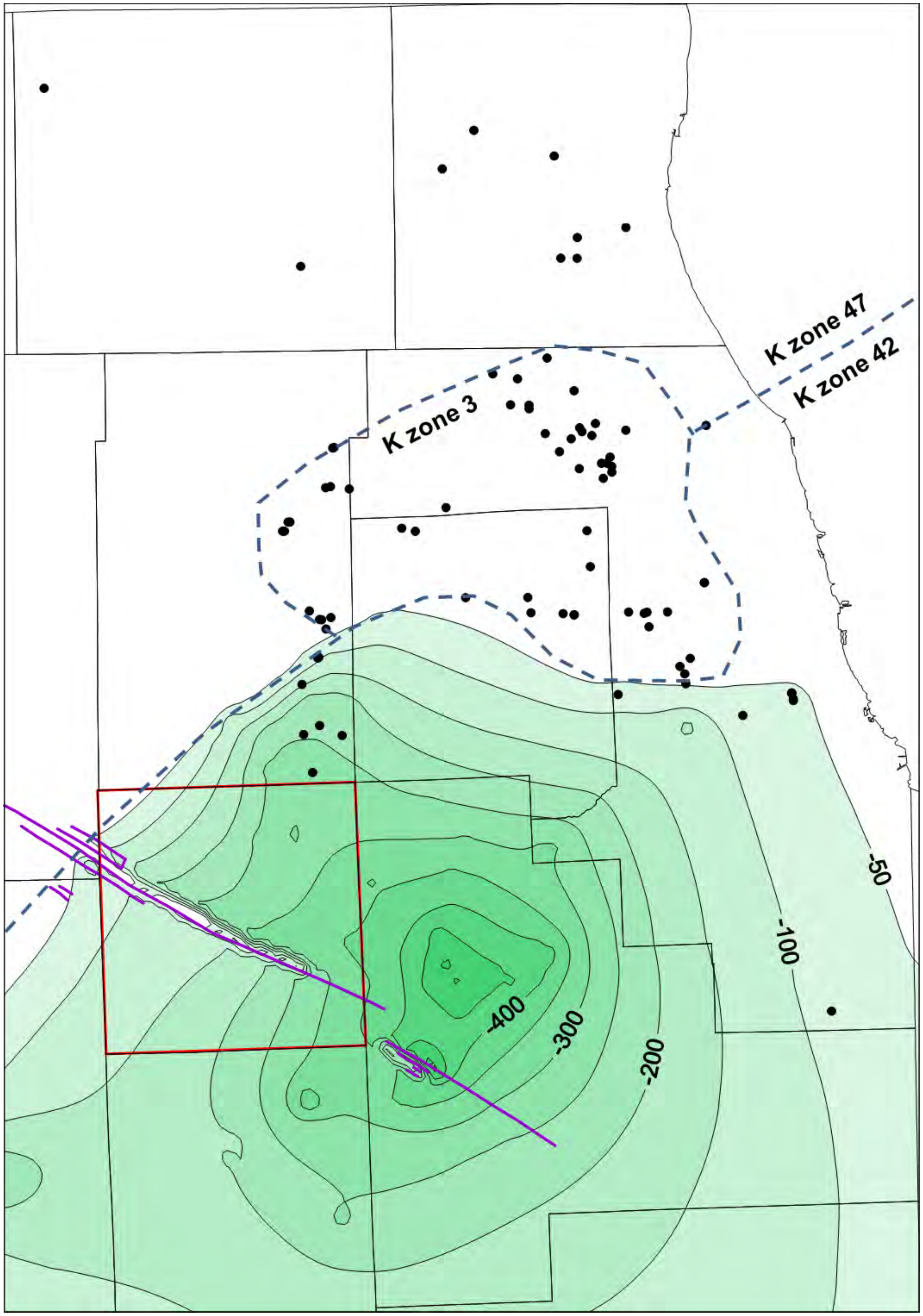


Figure 71. Predicted head difference (ft) in 2005 between the Ironton-Galesville and Mt. Simon sandstones. Black dots represent Mt Simon wells and dashed blue lines delineate K zones of the intervening Eau Clare Formation.

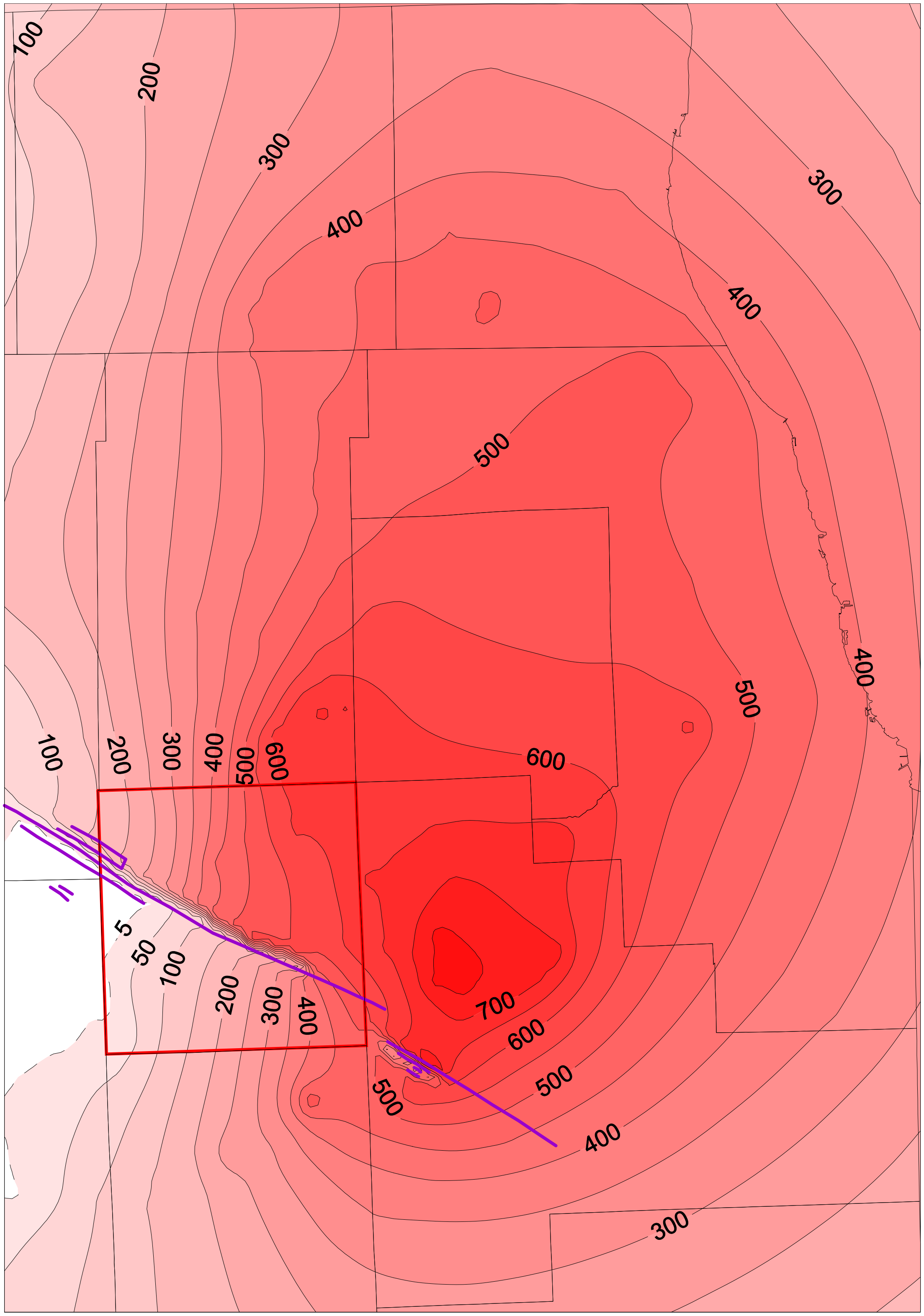


Figure 72. Predicted drawdown (ft) from predevelopment to 2005 in the Ancell sandstone

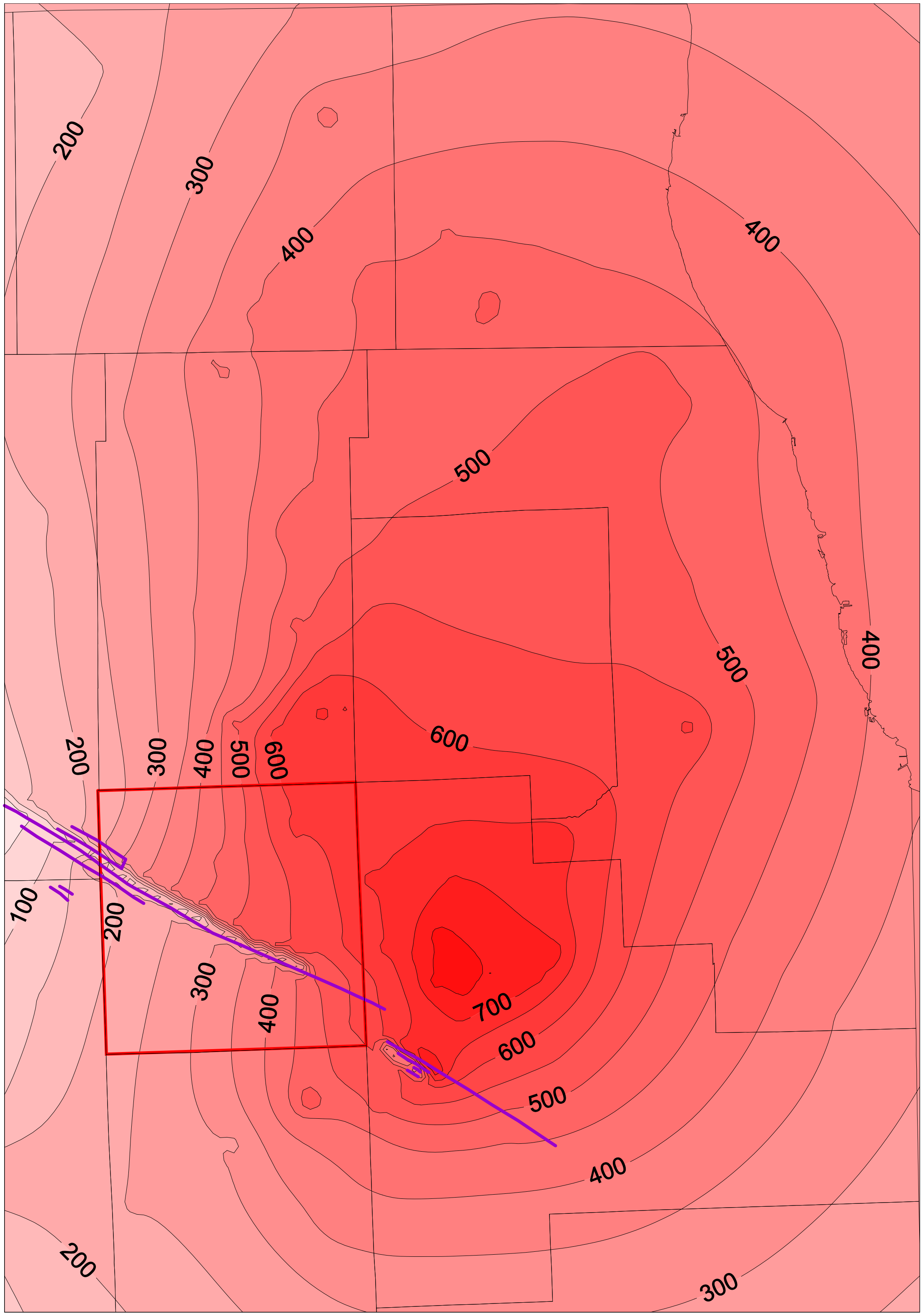


Figure 73. Predicted drawdown (ft) from predevelopment to 2005 in the Ironton-Galesville sandstone

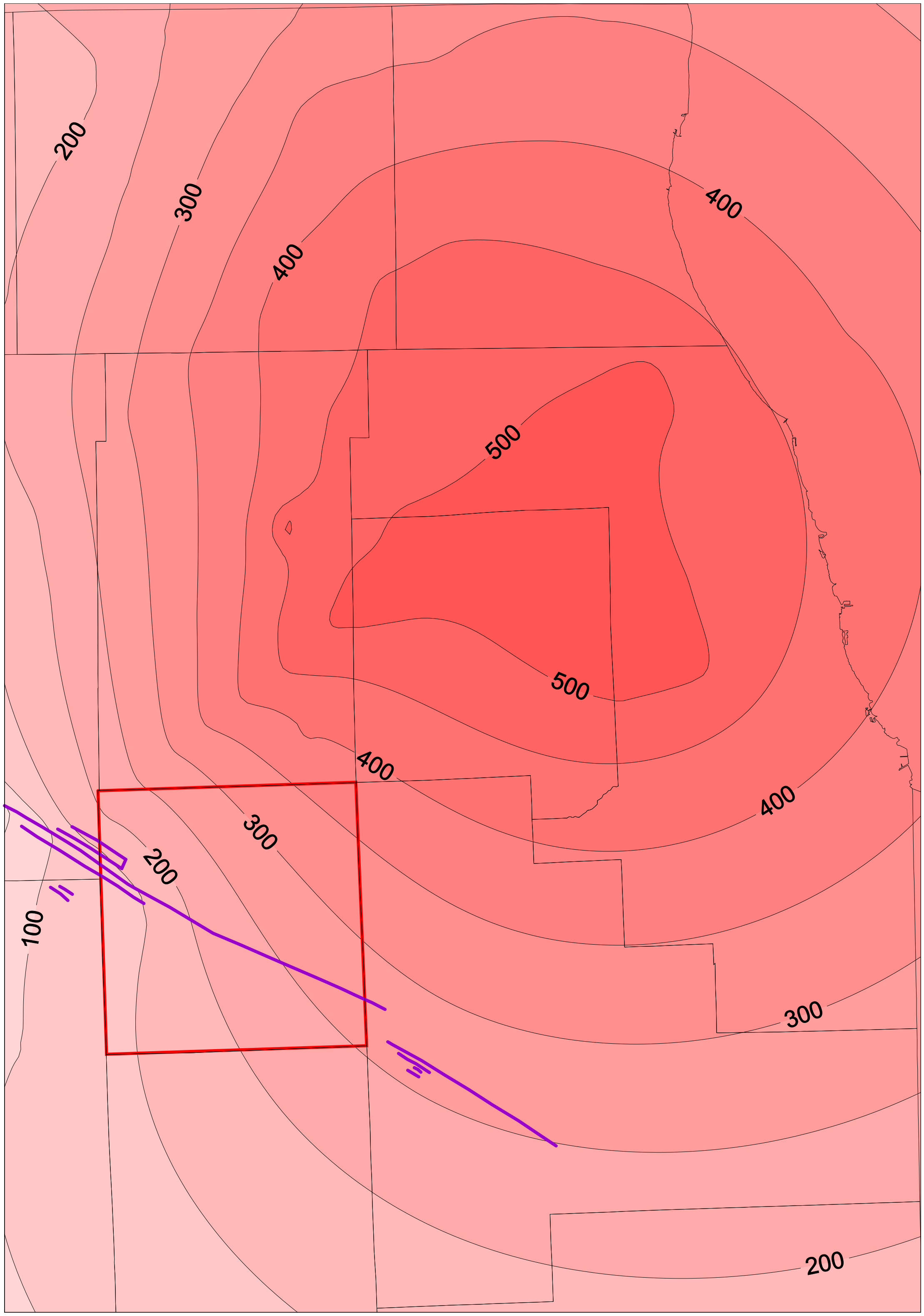


Figure 74. Predicted drawdown (ft) from predevelopment to 2005 in the Mt. Simon sandstone

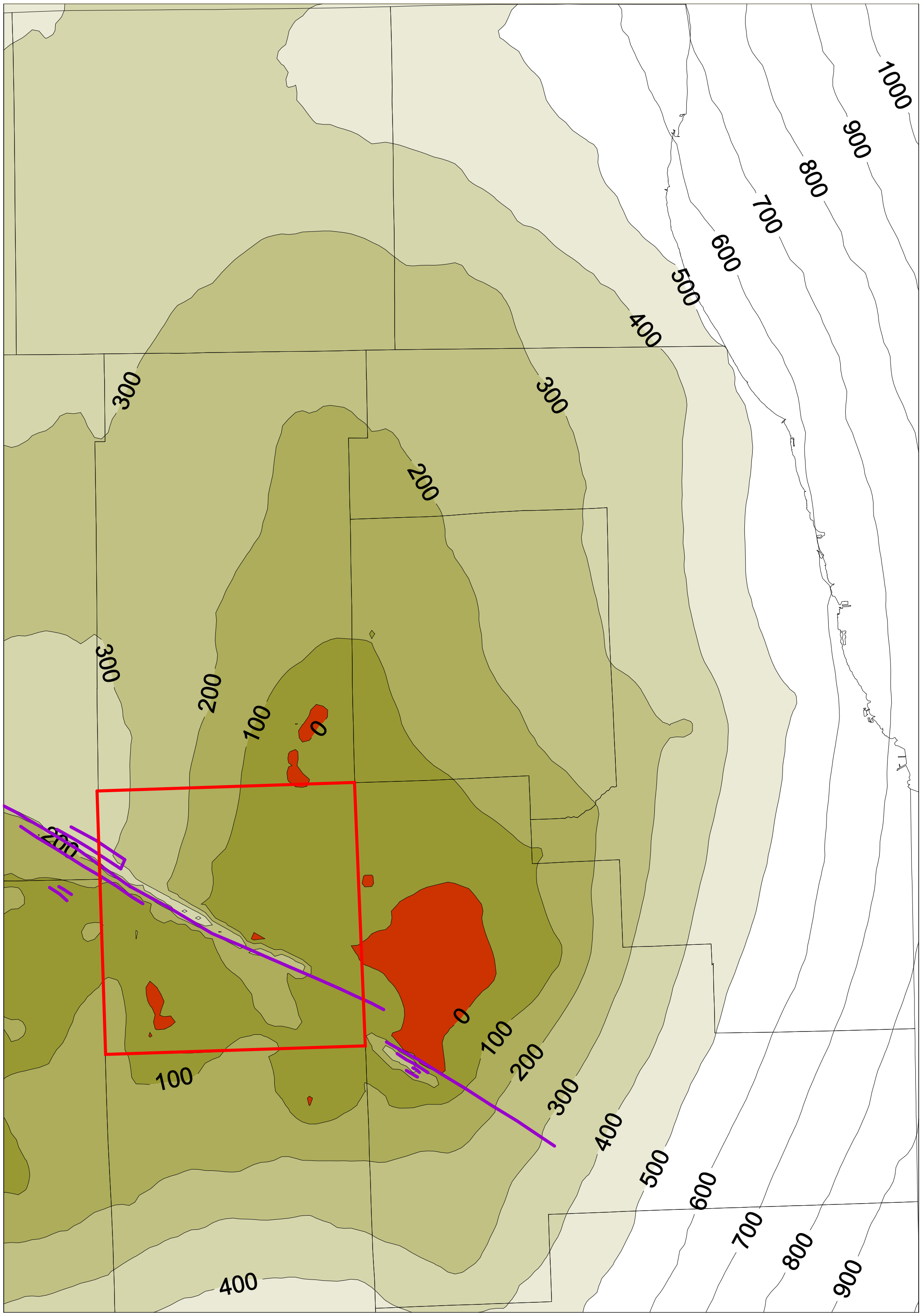


Figure 75. Available head (ft) above the top of the Ancell sandstone in 2005

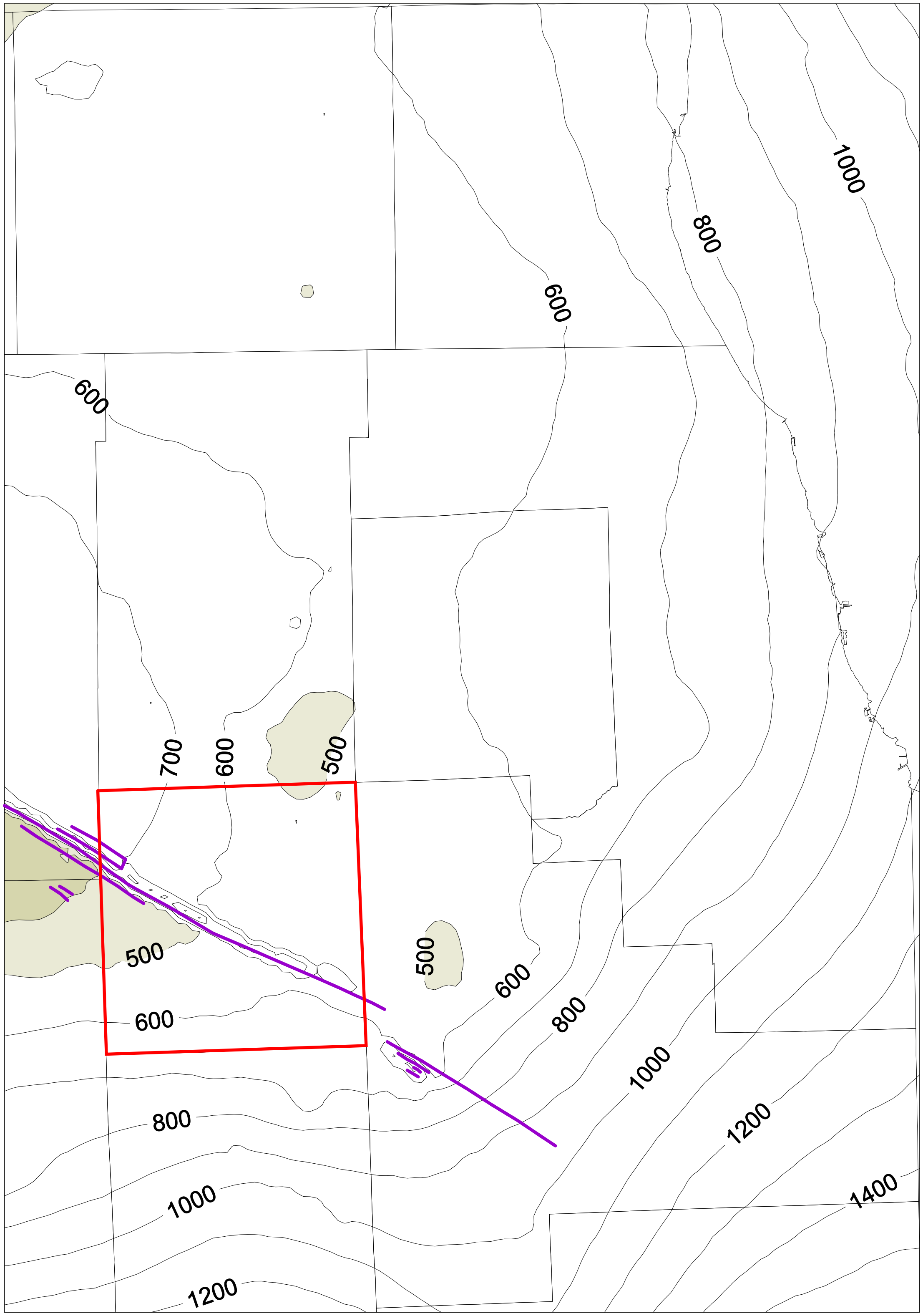


Figure 76. Available head (ft) above the top of the Ironton-Galesville sandstone in 2005

Modified Baseline Scenario

The model results of the future use scenarios, presented in the next section, revealed problems of aquifer dewatering with the expanded use of the deep aquifer out to the year 2050. Some of these problems are caused by Dziegielewski and Chowdhury's (2008) reliance on using only existing wells in the model to handle the future growth in water demand. In reality, the communities of Kendall County will likely continue to drill new wells out to 2050. Therefore, a "Modified Baseline" scenario was tested with the model where new hypothetical wells were added for Oswego, Yorkville, and Joliet (Figure 77) to handle some of the pumpage for the regular Baseline scenario. Because there are many factors that go into locating wells and an infinite number of scenarios that could be tested, the Modified Baseline scenario is presented here as an example and not as any recommendation on the part of the authors for the location of future wells.

For the Modified Baseline scenario, four hypothetical wells were added for Oswego on the south and east sides of town where they would be spread out further from the eight existing Oswego wells, the Yorkville wells to the west, and the Montgomery, Aurora, and Caterpillar wells to the north. The future pumpage for Oswego was divided equally between the 12 wells. To take advantage of the higher water levels on the south side of Sandwich fault (Figure 30), two new hypothetical wells for Yorkville and three new hypothetical wells for Joliet were added in this area. The future pumpage for Yorkville was arbitrarily divided into 40 percent for the two new wells south of the fault and 60 percent for the existing five wells north of the fault. For Joliet, the pumpage for wells #20, #25, and #27 were moved from the cluster of wells in far eastern Kendall County to the new locations south of the fault.

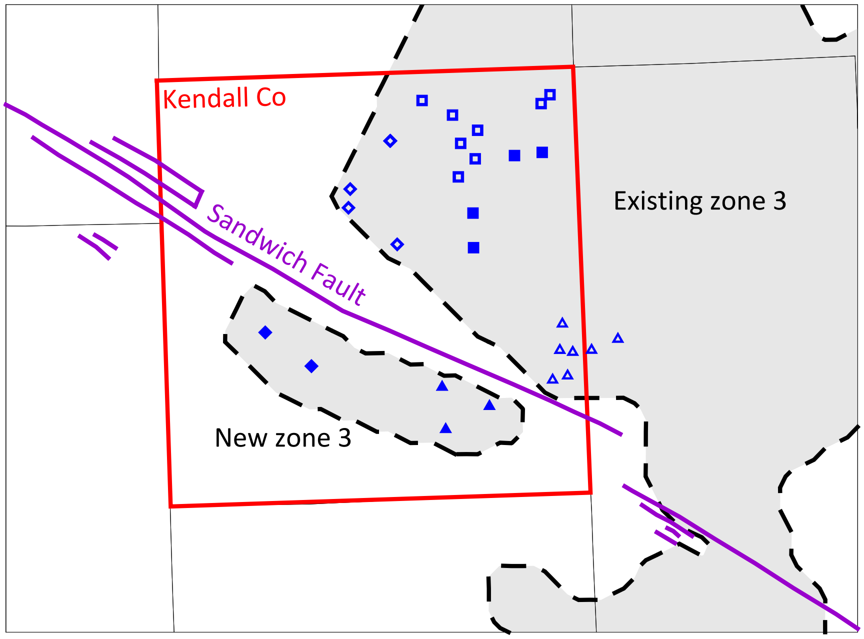


Figure 77. Location of hypothetical wells and high vertical hydraulic conductivity zone 3 for the Modified Baseline scenario. Diamonds represent Yorkville wells, squares represent Oswego wells, triangles represent the Joliet west wells, and filled symbols represent hypothetical wells.

The act of drilling new wells south of the Sandwich Fault in Kendall County could potentially change the local hydrology by connecting the Ancell and Ironton-Galesville sandstone together through the open boreholes where there is currently no known interconnection. Like with the existing deep wells throughout the rest of northeastern Illinois, the new wells would act to equilibrate water levels between the two aquifers. Water levels in the Ironton-Galesville sandstone would rise and water levels in the Ancell would fall, eliminating the predicted head difference shown in Figure 70. To model the effect of new aquifer interconnection caused by these hypothetical wells, the high vertical hydraulic conductivity zone (Figure 31) was expanded to the area around the wells (Figure 77). This hydraulic connection was only simulated for the future time steps.

Impacts of Future Use Scenarios

The model results of the three future use scenarios, Least Resource Intensive, Baseline, and More Resource Intensive, plus the Modified Baseline, show that water levels in the deep aquifers of Kendall County will continue to decline and potentially reach levels that adversely affect the water supplies. Theses impacts are presented in this section with head maps in Figures 78 and 79, drawdown maps in Figures 80 through 89, head difference maps in Figures 90 and 91, available head maps in Figures 92 through 95, and hydrographs at specific locations in Figures 96 to 103.

The predicted heads and drawdowns in 2050 for northeastern Illinois under Baseline conditions (Figures 78 through 81) continue to show the center of the regional cone-of-depression in Joliet with a secondary center in Aurora. Compared to 2005 (Figures 67 and 72), the Aurora center will shift slightly southward into Kendall County in 2050 and encompass the Oswego wells. Elsewhere in the region, water levels are predicted to decline in northeastern Kane County and southeastern McHenry County but recover slightly in northeastern Cook County.

A significant model result that shows up in all the head, drawdown, and available head maps for the Ancell sandstone is the areas of complete aquifer dewatering. In the Baseline scenario these areas occur around all of the Oswego wells, some of the Yorkville wells, some of the Joliet wells in eastern Kendall County, and other Joliet and industrial wells along the Des Plaines River in Will County (Figures 78, 82, and 92). Groundwater flowing towards these areas in the Ancell sandstone is captured by other wells and/or diverted downward into the Ironton-Galesville sandstone. The drawdown created by the Baseline scenario (Figure 82) shows the dewatered areas at the centers of where drawdown has increased from 2005 to 2050. As the head in the Ancell sandstone drops below the top of the sandstone, the transmissivity also drops, causing a pumping well to get a greater portion of its water from the Ironton-Galesville sandstone where it causes much greater drawdowns (Figure 83). To prevent the loss in pumpage in the dewatered areas due to dry model cells, the modeled wells were not screened in the Ancell sandstone explicitly. This accommodation did not affect the model results because of the strong aquifer interconnection between the two sandstones in areas of the model where there are deep wells.

The results from the Least Resource Intensive scenario show less drawdown than the Baseline scenarios and no dewatering of the Ancell sandstone in Kendall County (Figures 84 and

85). However, even under a lower pumpage scenario, an area of dewatering still occurs at some of the industrial wells near the Sandwich Fault Zone in Will County. This result underscores the need to understand how the Sandwich Fault Zone influences groundwater flow. Interestingly, the area of partial dewatering of the Ancell sandstone (zero line of Figure 93) is only slightly smaller for the Least Resource Intensive scenario than for the Baseline Scenario (Figure 92) and may be due to the non-linearity of the drop in transmissivity with increasing pumpage.

For the Most Resource Intensive case, the areas of Ancell sandstone dewatering are much larger and the resultant drawdowns in the Ironton-Galesville sandstone are much greater (Figures 86 and 87). Because of these problems, developing the aquifer at this rate would not be sustainable from a water supply perspective. The drawdown in the Ironton-Galesville sandstone at Oswego is predicted to be over 350 ft. With these large losses in head, the pumping capacities of the individual wells will drop dramatically and necessitate the installation of larger pumps or additional wells. The loss in well capacities is not accounted for in the model and would require iteratively changing pumping rates each time step and obtaining the specific pump information from each well. Use of the multi-node well package developed for MODFLOW may help to resolve this problem for some of the wells in future modeling efforts.

North of the Sandwich Fault in Kendall County, the results of the Modified Baseline scenario (Figures 88 and 89) show significantly reduced drawdowns around the existing wells in both the Ancell and Ironton-Galesville sandstones as compared to the Baseline scenario (Figures 90 and 91). The Ancell sandstone remained partially saturated at Oswego and Yorkville and was completely dewatered at only one of the Joliet wells in eastern Kendall County (Figure 95). South of the fault, the drawdown in Ancell is greater in the Modified Baseline scenario than the regular Baseline scenario because of the pumpage from the five hypothetical wells for Yorkville and Joliet and downward leakage into the Ironton-Galesville sandstone. Because the five wells will act to equalize the head between the two aquifers, the head in the Ironton-Galesville sandstone actually increases even though there are wells pumping from it (Figures 89 and 91). The head in areas where the two aquifers are interconnected in the model is controlled by the Ancell sandstone because it is close to the surface where it receives a much greater amount of recharge.

The areas south of the Sandwich Fault where the head in the Ancell sandstone drops below the top of the aquifer become more widespread in the Modified Baseline Scenario (Figures 92 and 95), creating potential conflicts with any private wells that may be completed only in the upper portions of the Ancell sandstone. To keep supplying water, these wells may need to have their pumps lowered or be redrilled to a greater depth near the bottom of the sandstone. Any development of the Ancell sandstone in southern Kendall County should include an assessment of water levels, pump settings, and depths of the surrounding private wells. An alternative may be to complete new wells into only the Ironton-Galesville sandstone in this area.

Hydrographs illustrate temporal changes in simulated heads in the Ancell sandstone at seven locations in and around Kendall County (Figures 96 to 103). The hydrographs include simulated historical heads and simulated future heads for each of the four demand scenarios. Observed historical head (water level) data collected from the respective community wells also are presented on each hydrograph. Dashed horizontal lines show the approximate elevation of the top and bottom of the Ancell sandstone at each location. With the exception of Newark, all of the hydrographs show a head decline of several hundred feet over the past 100 years to levels around the top of the Ancell sandstone. Going forward in the model simulation, the predicted heads at these six sites are within the Ancell sandstone with the spread in head between the Least Resource Intensive and More Resource Intensive scenarios of around 100 feet. When the Ancell sandstone starts to become completely dewatered, such as occurs in the More Resource Intensive scenario at Yorkville (Figure 100), the head decrease becomes sharper due to the decrease in transmissivity. The Modified Baseline scenario shows significantly improved head levels over the Baseline scenario at Montgomery, Oswego, and Yorkville (Figures 98 through 100), but slightly lower heads than even the More Resource Intensive scenario at Newark (Figure 103).

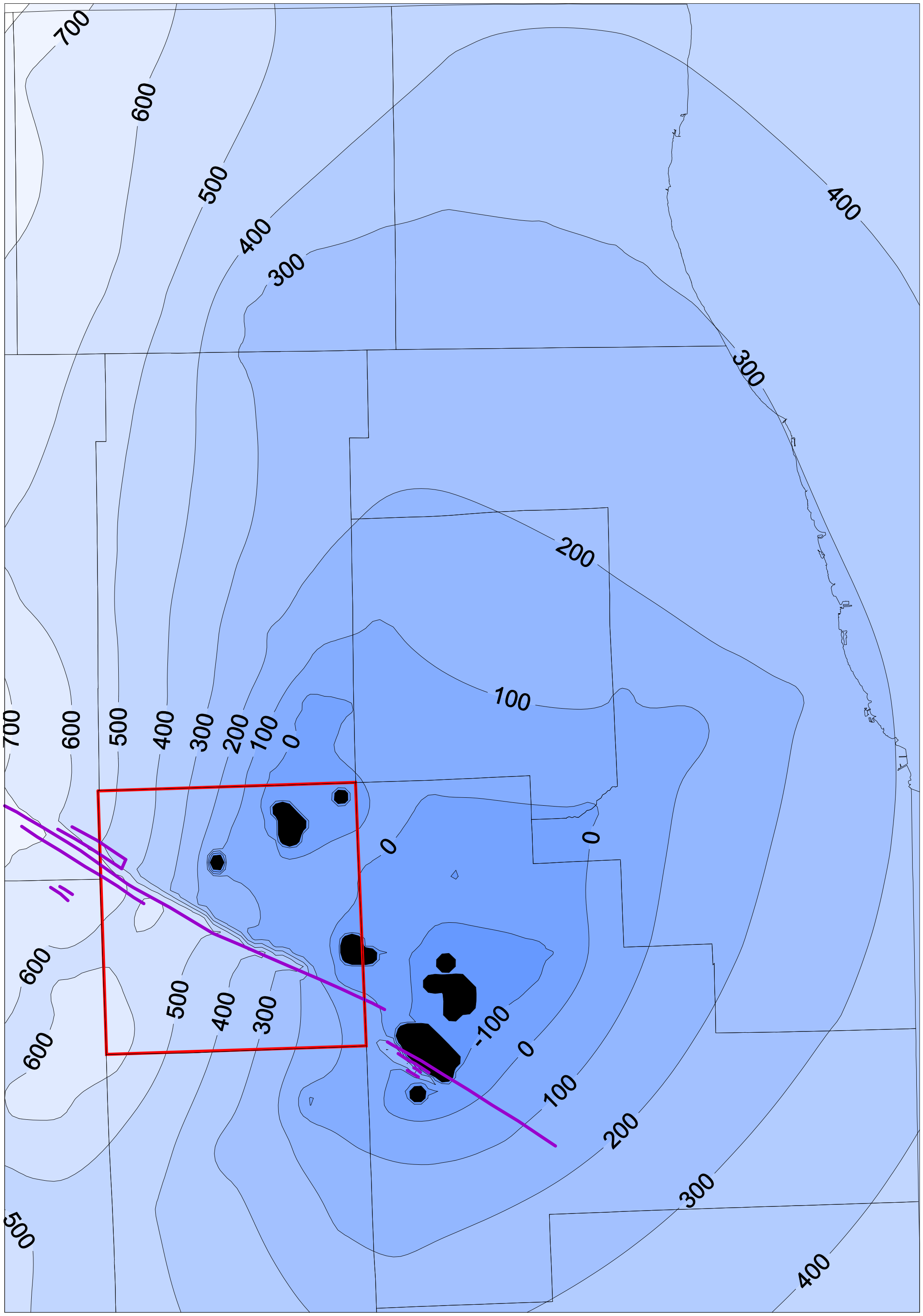


Figure 78. Predicted heads (ft asl) in the Ancell sandstone in 2050 for the Baseline scenario. Black areas indicate complete dewatering. Purple lines show Sandwich Fault Zone

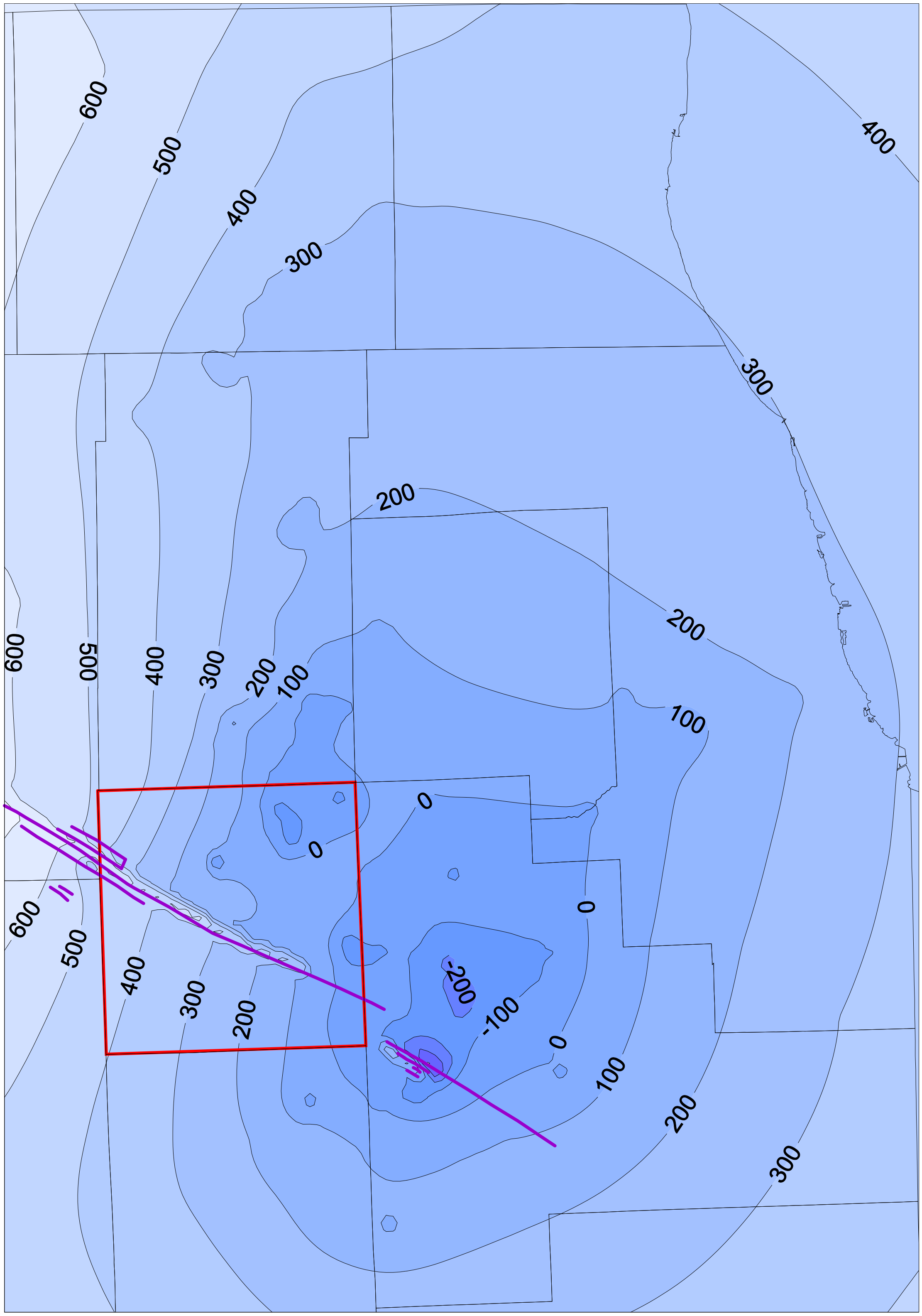


Figure 79. Predicted heads (ft asl) in the Ironton-Galesville sandstone in 2050 for the Baseline scenario

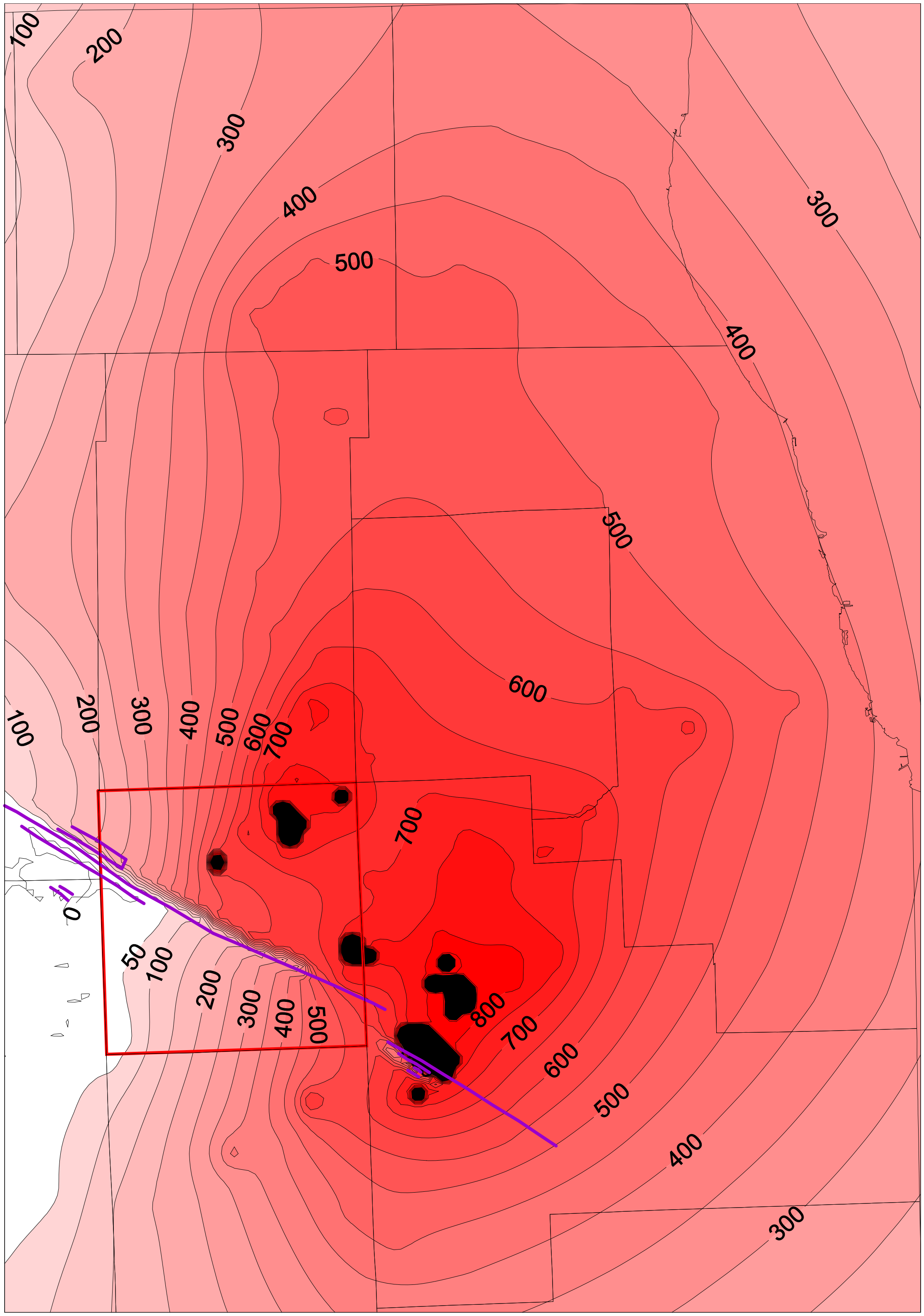


Figure 80. Predicted drawdown (ft) in the Ancell sandstone from pre-development to 2050 for the Baseline scenario. Black areas indicate complete dewatering

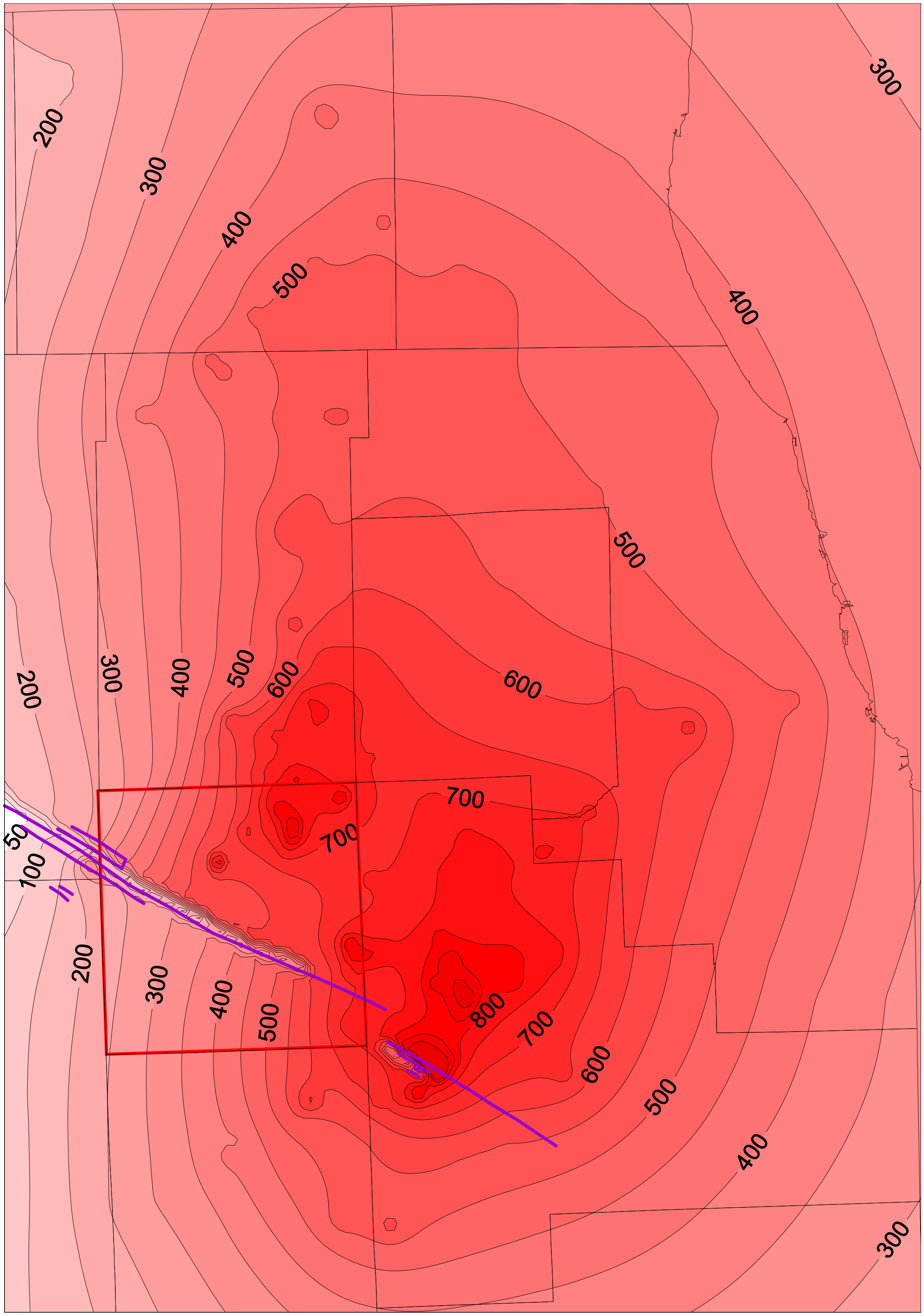


Figure 81. Predicted drawdown (ft) in the Ironton-Galesville sandstone from pre-development to 2050 for the Baseline scenario

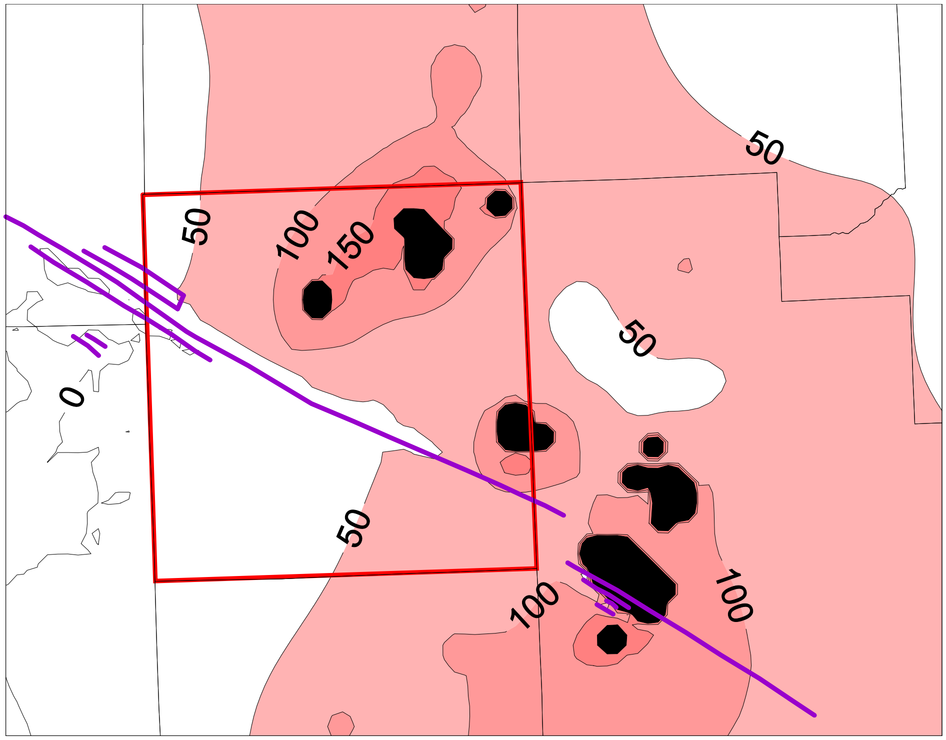


Figure 82. Predicted drawdown (ft) in the Ancell sandstone from 2005 to 2050 for the Baseline scenario. Black areas indicate complete dewatering

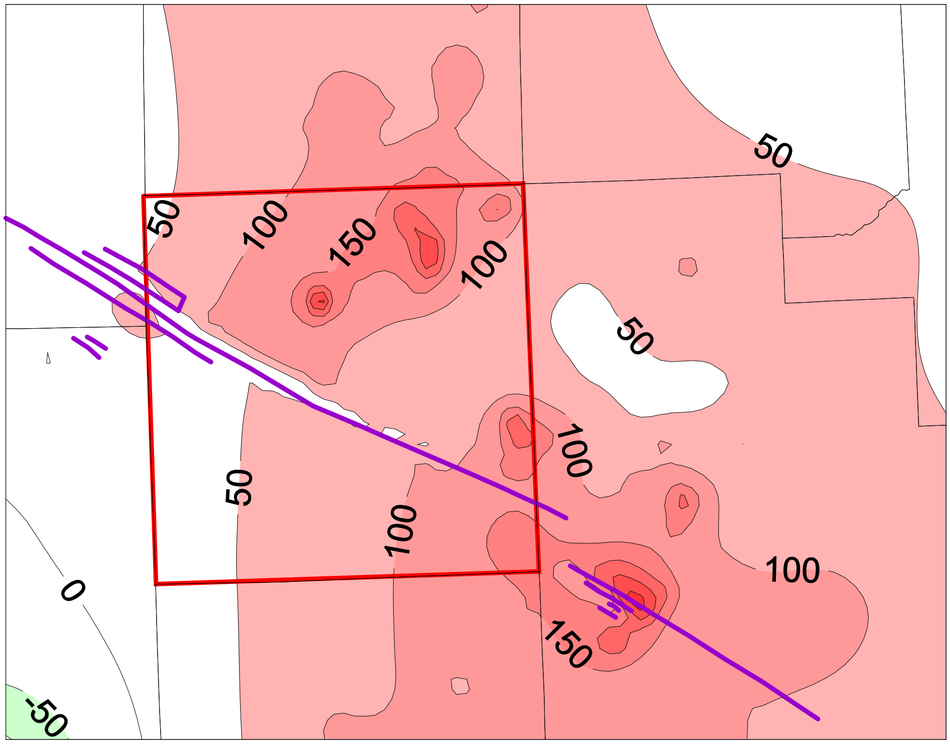


Figure 83. Predicted drawdown (ft) in the Ironton-Galesville sandstone from 2005 to 2050 for the Baseline scenario.

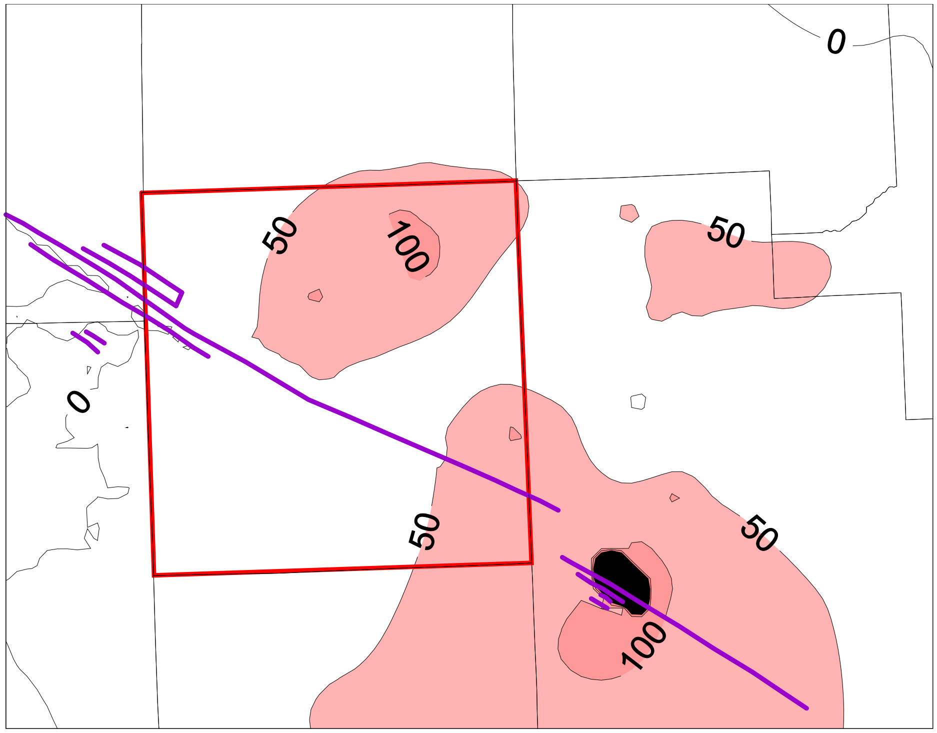


Figure 84. Predicted drawdown (ft) in the Ancell sandstone from 2005 to 2050 for the Least Resource Intensive scenario. Black areas indicate complete dewatering

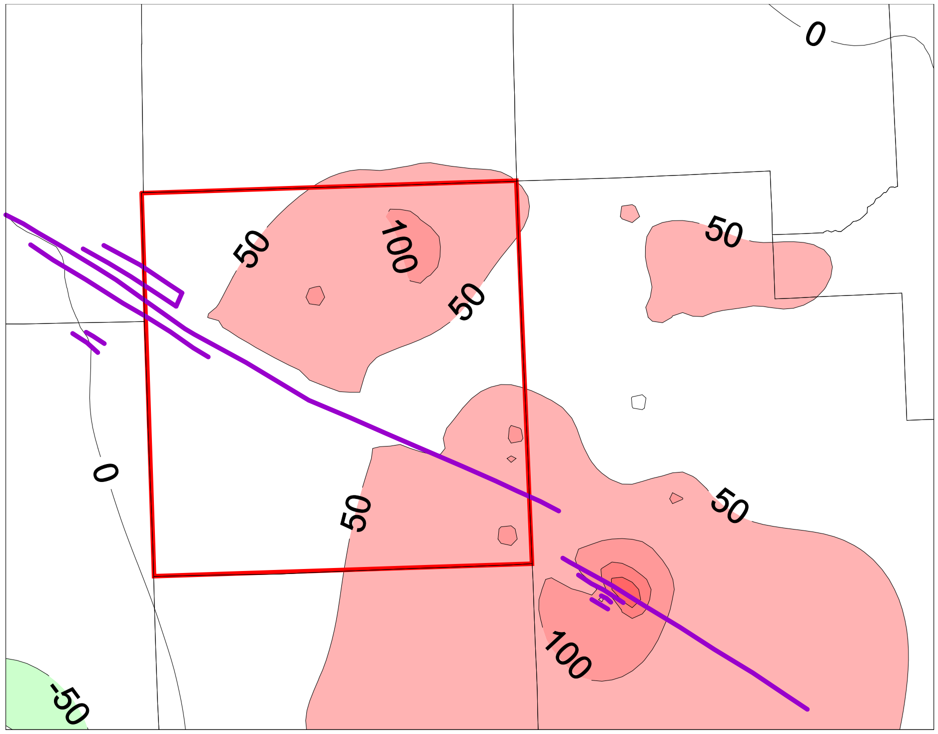


Figure 85. Predicted drawdown (ft) in the Ironton-Galesville sandstone from 2005 to 2050 for the Least Resource Intensive scenario

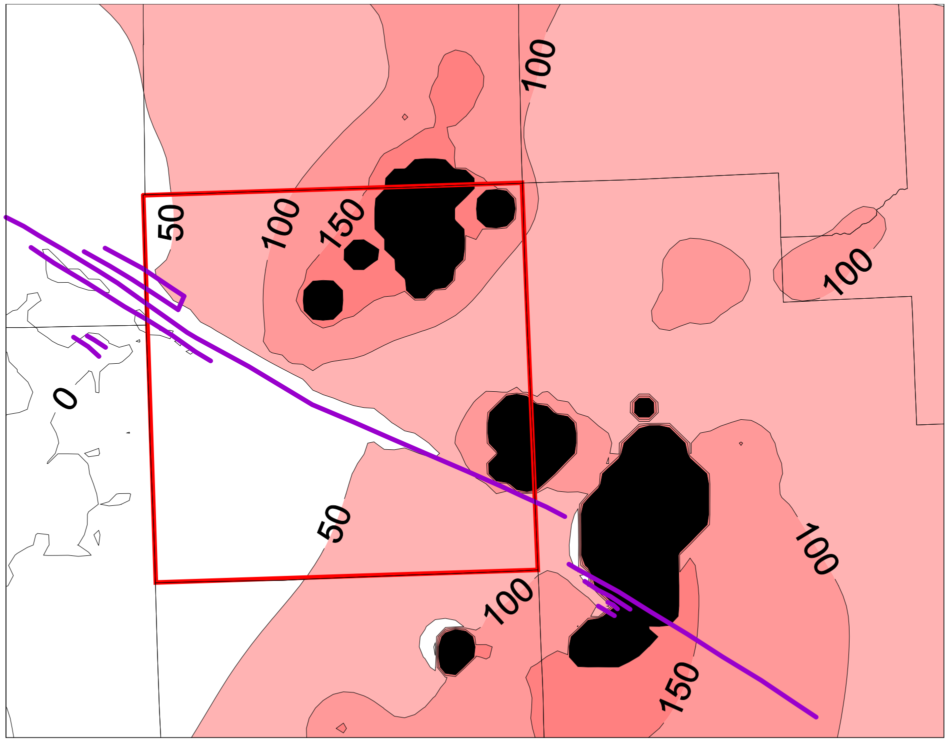


Figure 86. Predicted drawdown (ft) in the Ancell sandstone from 2005 to 2050 for the Most Resource Intensive scenario. Black areas indicate complete dewatering

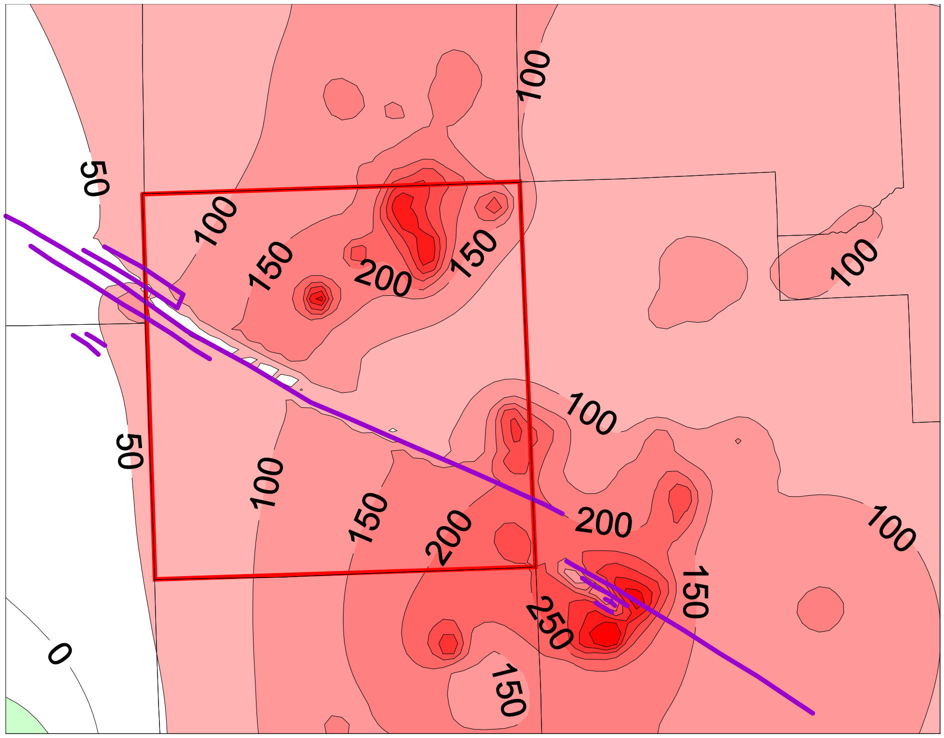


Figure 87. Predicted drawdown (ft) in the Ironton-Galesville sandstone from 2005 to 2050 for the Most Resource Intensive scenario

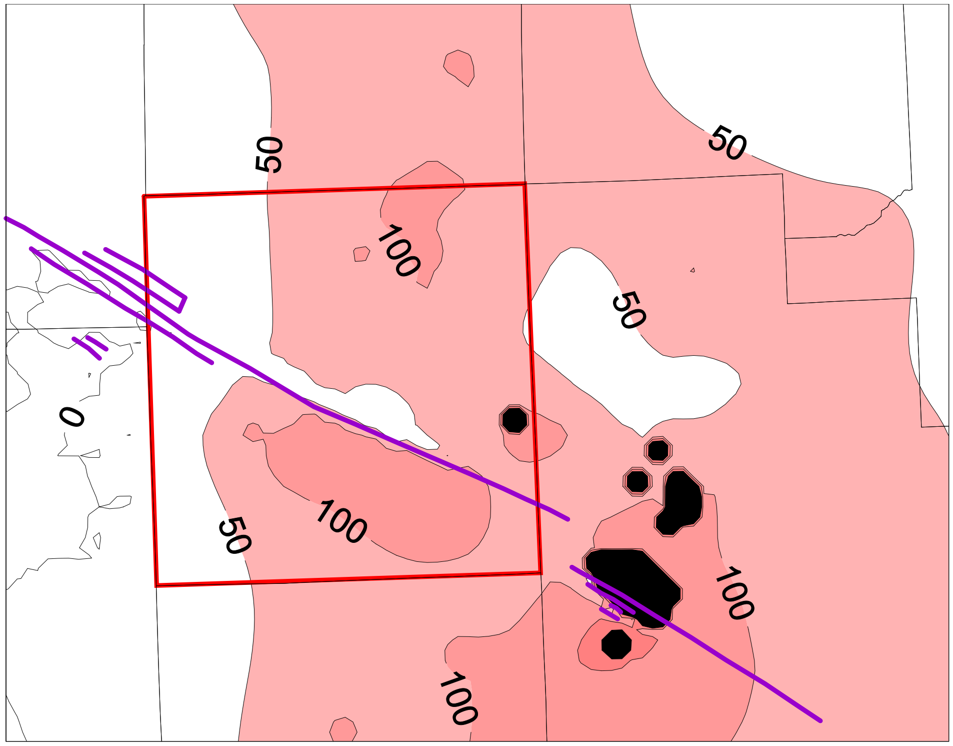


Figure 88. Predicted drawdown (ft) in the Ancell sandstone from 2005 to 2050 for the Modified Baseline scenario. Black areas indicate complete dewatering

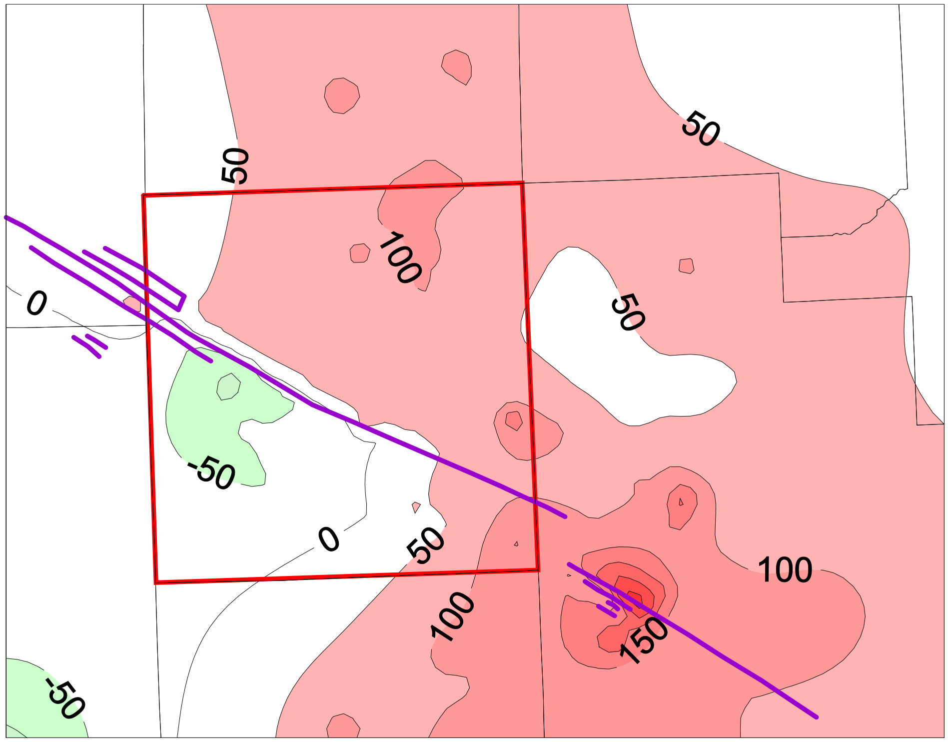


Figure 89. Predicted drawdown (ft) in the Ironton-Galesville sandstone from 2005 to 2050 for the Modified Baseline scenario

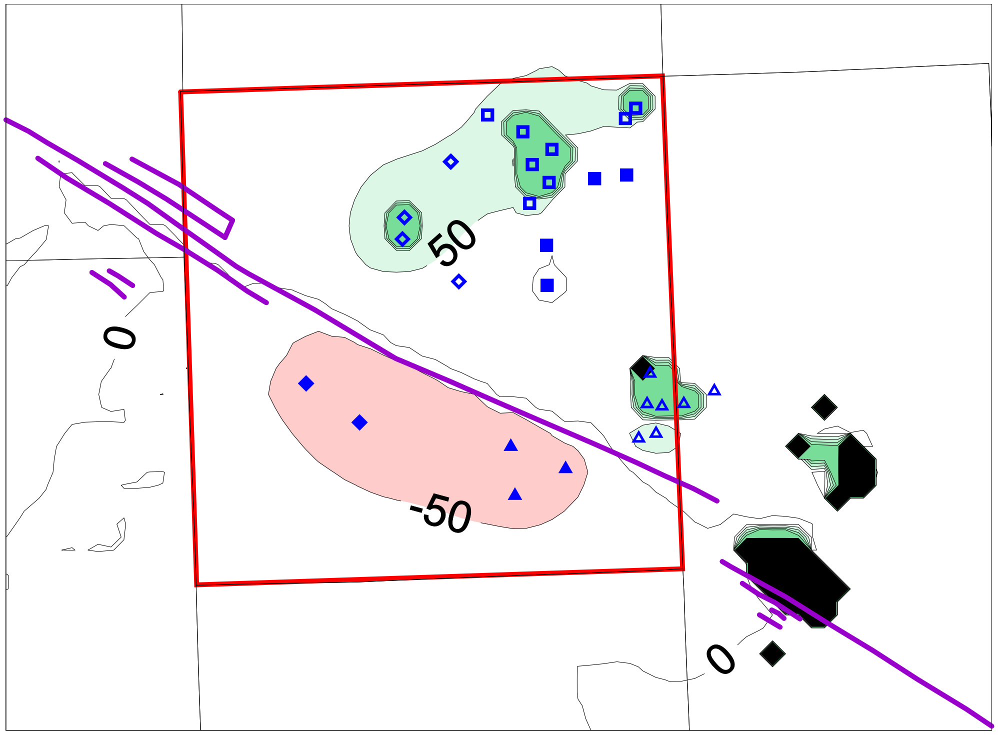


Figure 90. Head difference (ft) in the Ancell sandstone between the Modified Baseline and Baseline scenarios for 2050. See Figure 77 for explanation of symbols. Black areas indicate complete dewatering

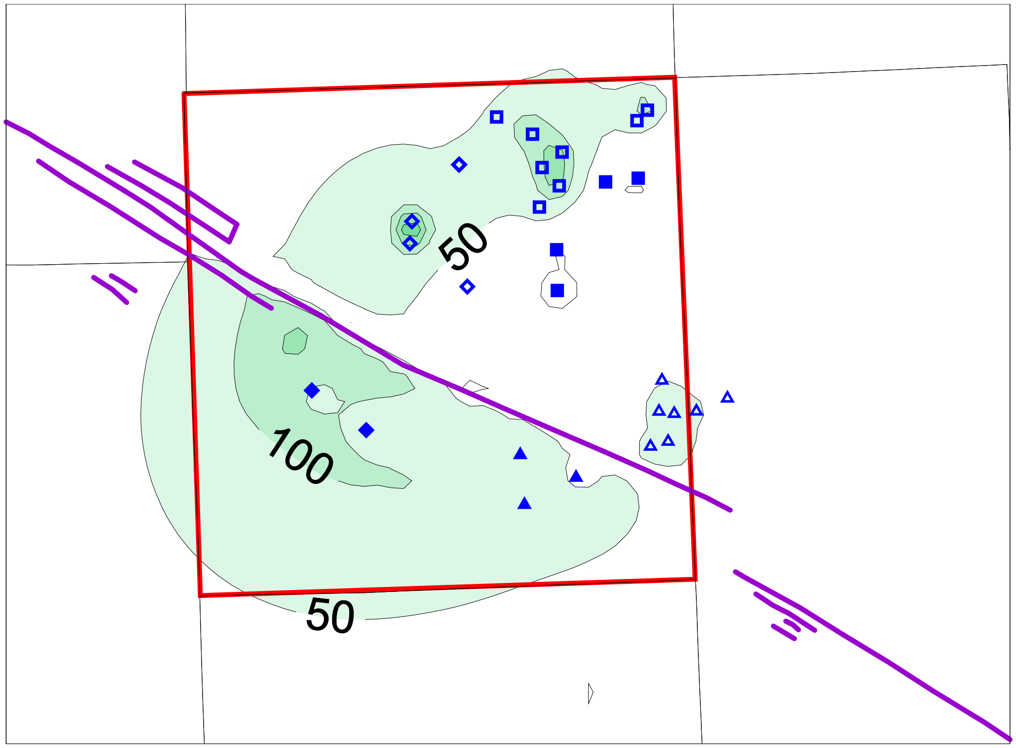


Figure 91. Head difference (ft) in the Ironton-Galesville sandstone between the Modified Baseline and Baseline scenarios for 2050. See Figure 77 for explanation of symbols.

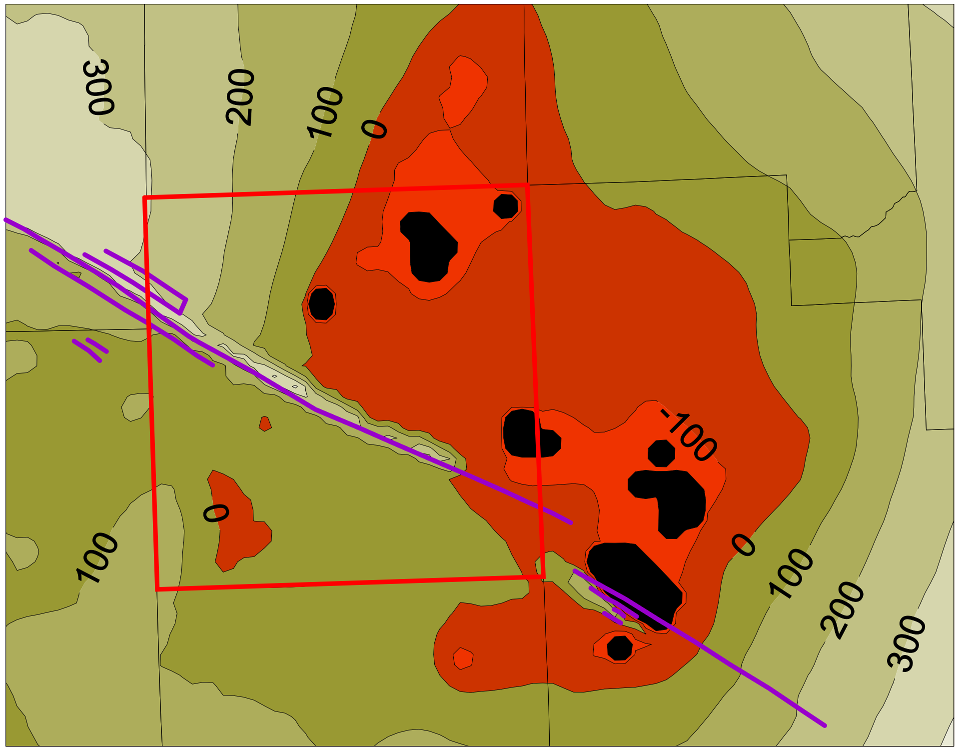


Figure 92. Predicted available head (ft) above the top of the Ancell sandstone in 2050 for the Baseline scenario. Black areas indicate dewatering

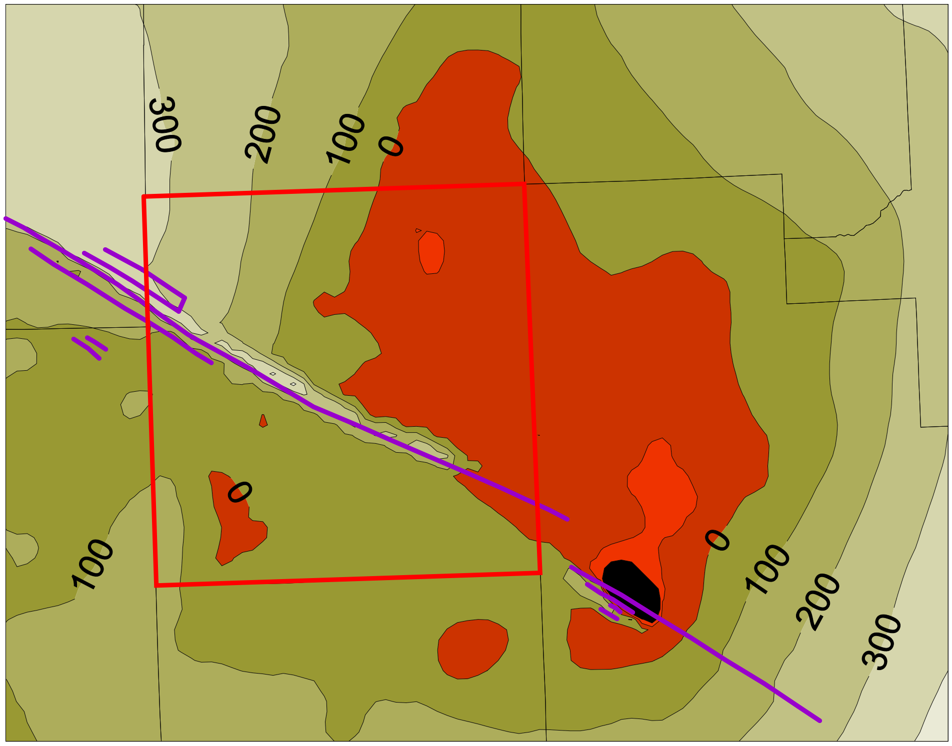


Figure 93. Predicted available head (ft) above the top of the Ancell sandstone in 2050 for the Least Resource Intensive scenario. Black areas indicate dewatering

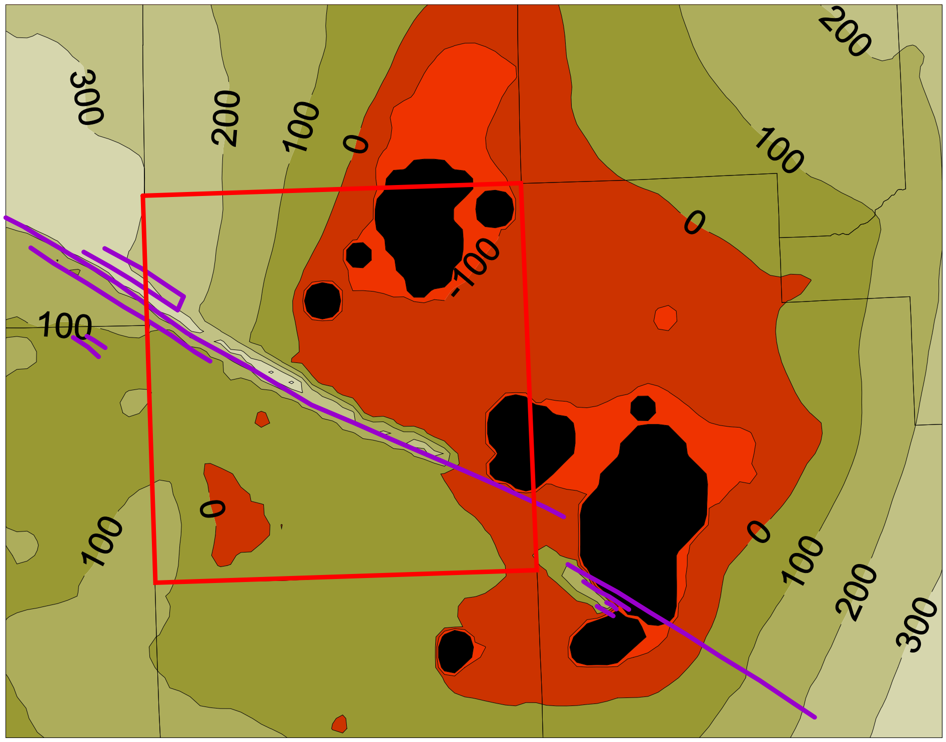


Figure 94. Predicted available head (ft) above the top of the Ancell sandstone in 2050 for the Most Resource Intensive scenario. Black areas indicate dewatering

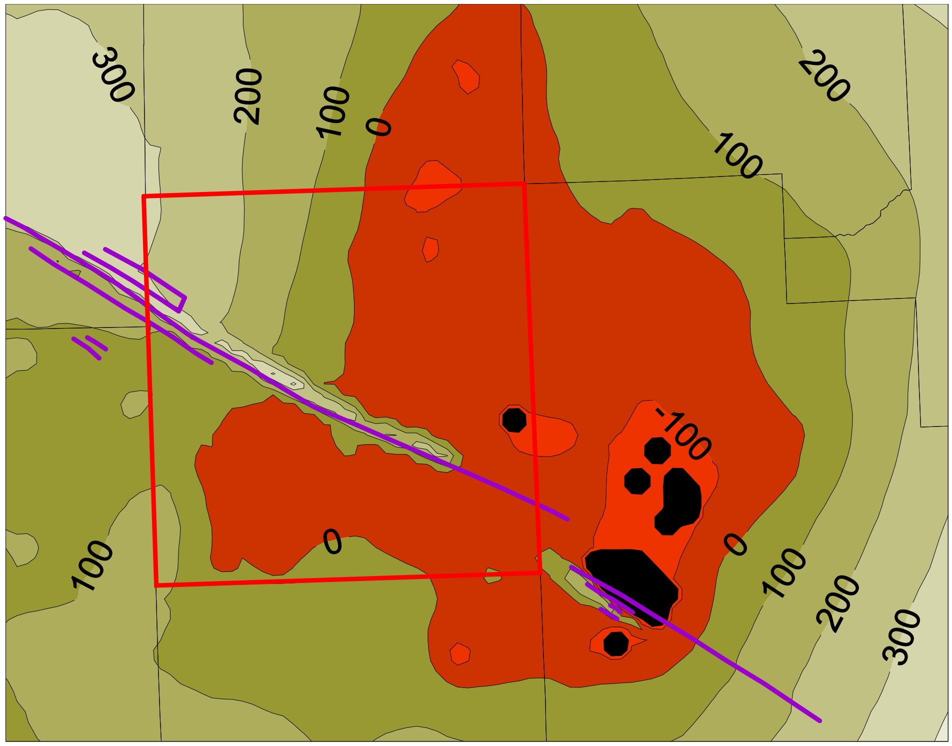


Figure 95. Predicted available head (ft) above the top of the Ancell sandstone in 2050 for the Modified Baseline scenario. Black areas indicate dewatering

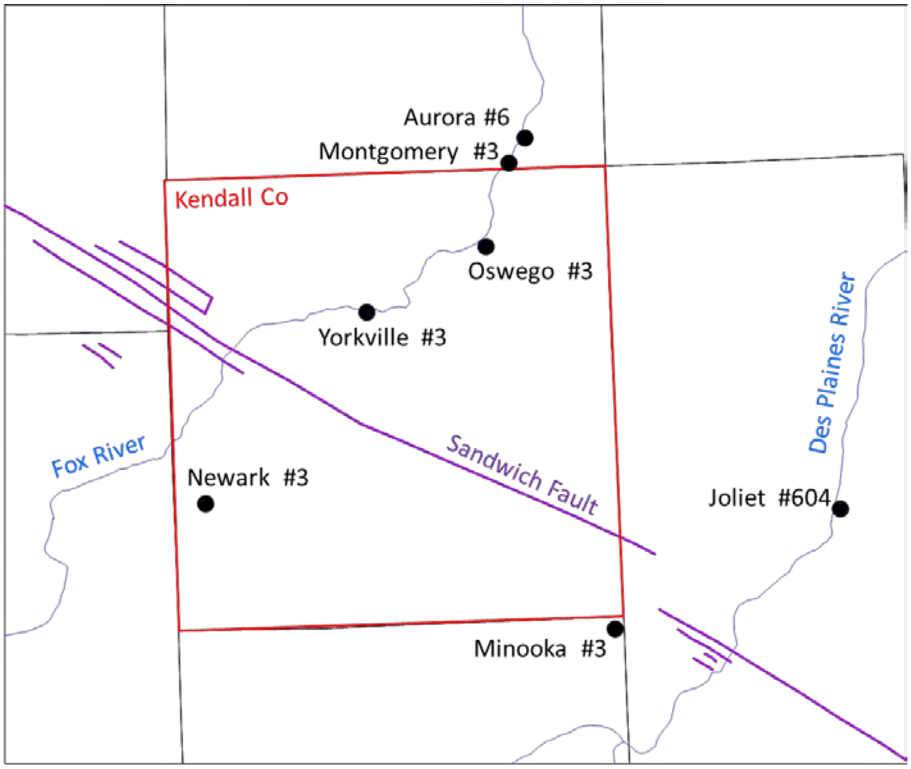


Figure 96. Location of simulated hydrographs for the Ancell sandstone

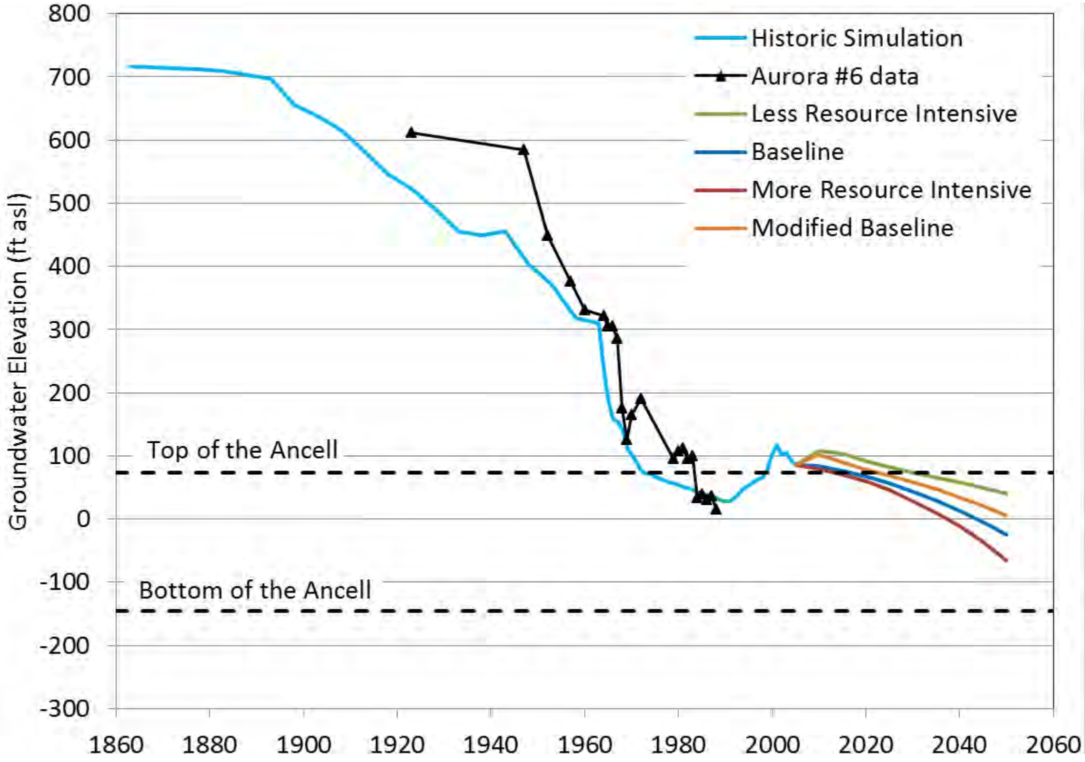


Figure 97. Simulated and observed heads in the Ancell sandstone at Aurora

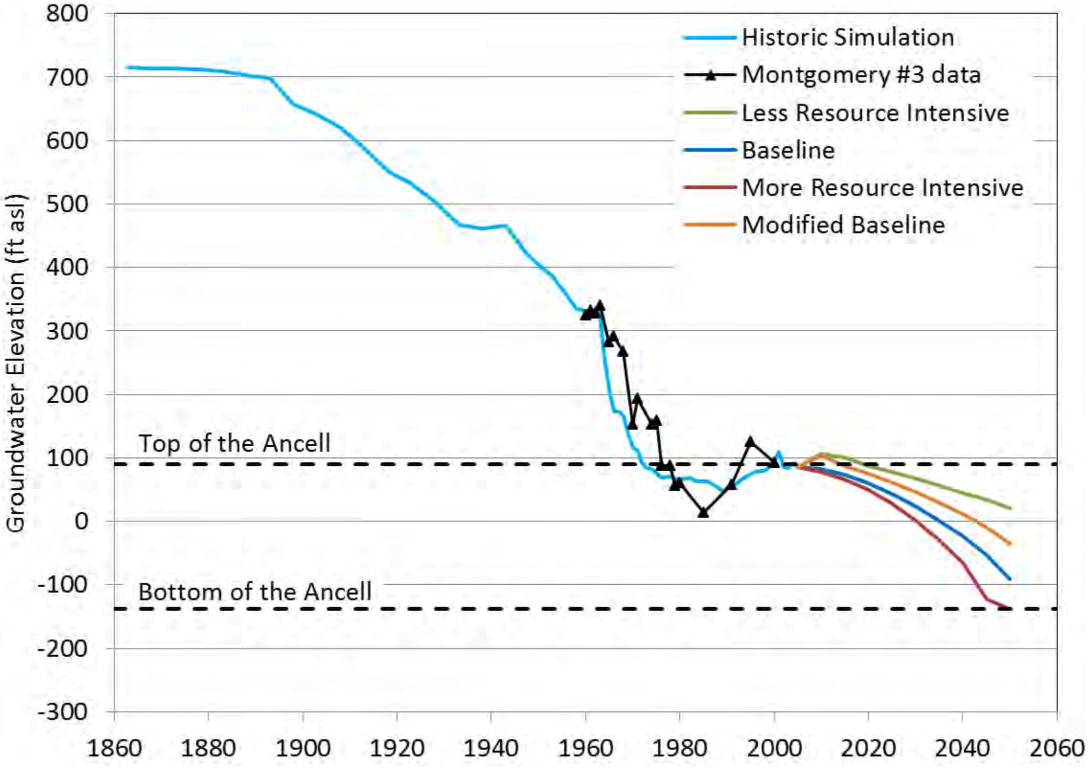


Figure 98. Simulated and observed heads in the Ancell sandstone at Montgomery

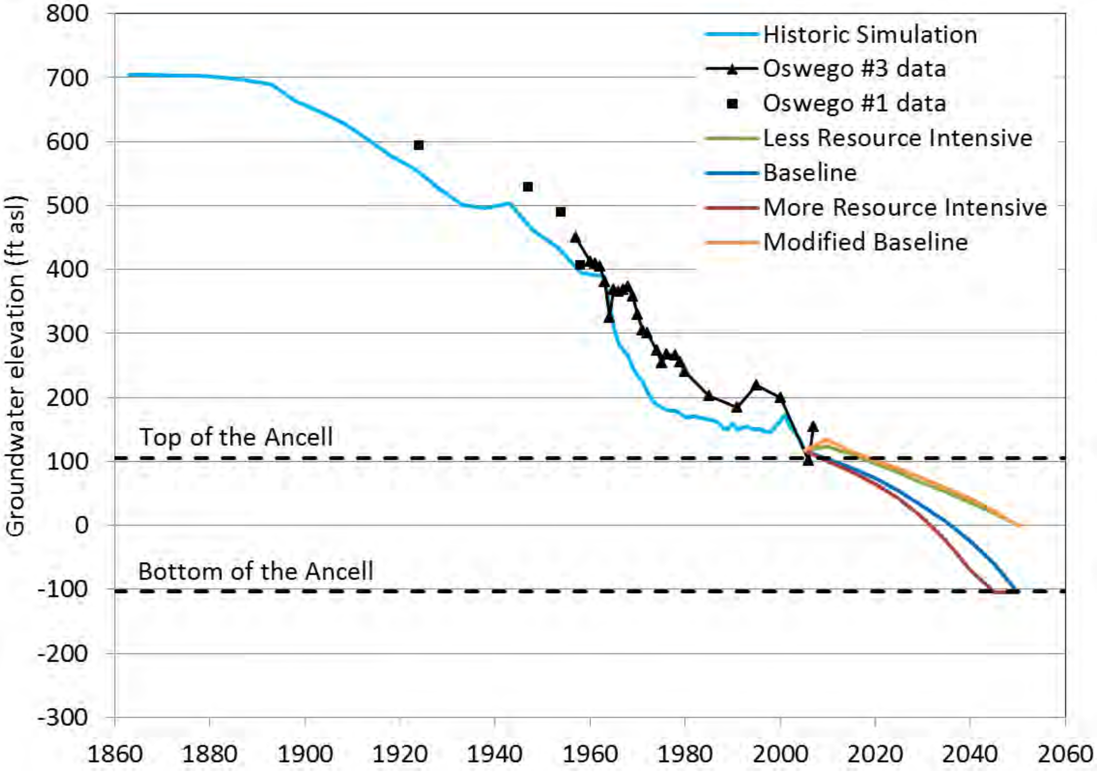


Figure 99. Simulated and observed heads in the Ancell sandstone at Oswego

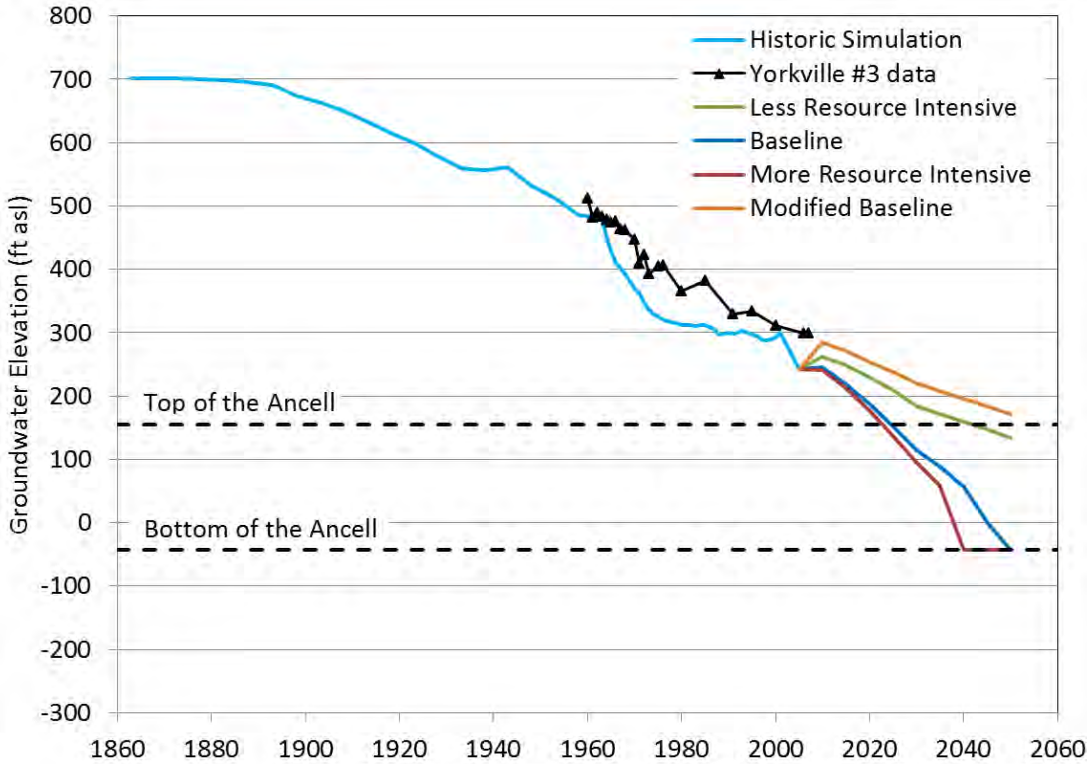


Figure 100. Simulated and observed heads in the Ancell sandstone at Yorkville

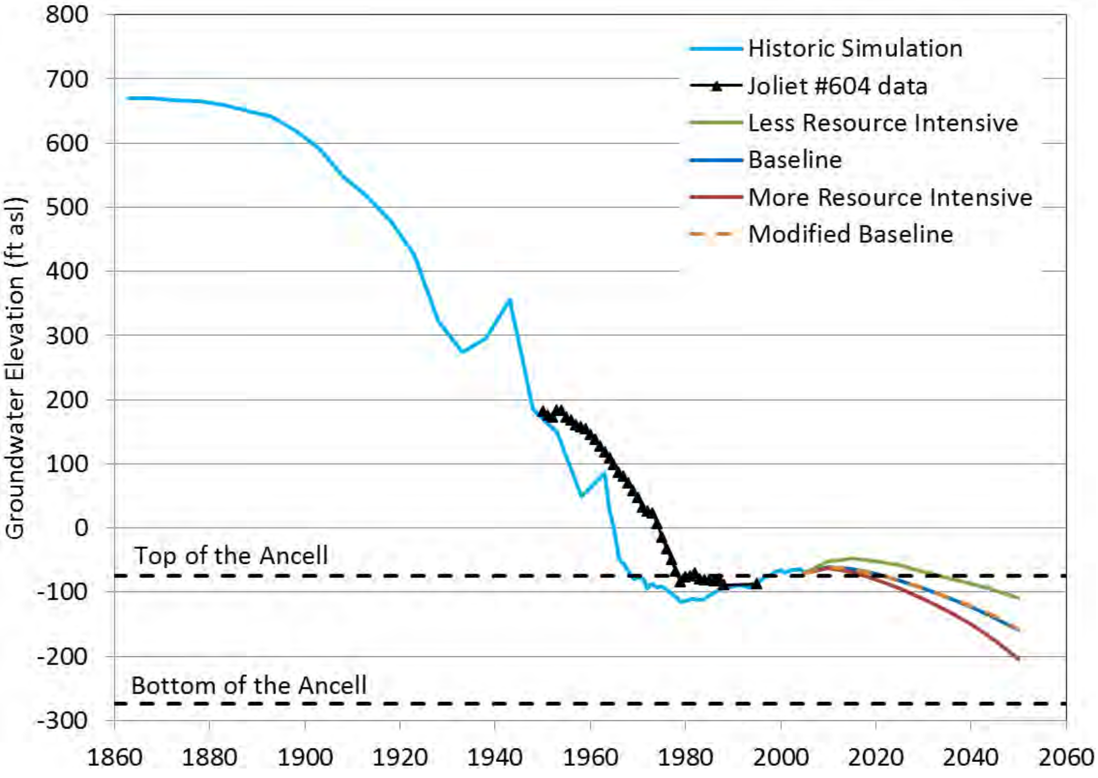


Figure 101. Simulated and observed heads in the Ancell sandstone at Joliet

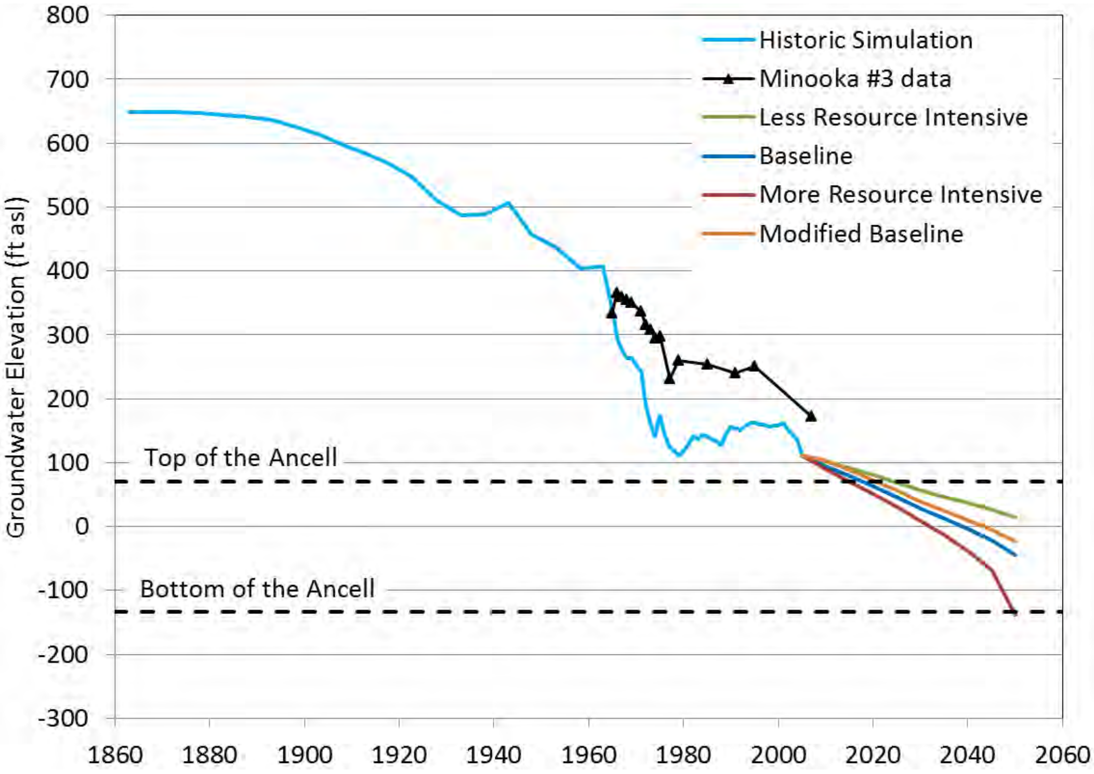


Figure 102. Simulated and observed heads in the Ancell sandstone at Minooka

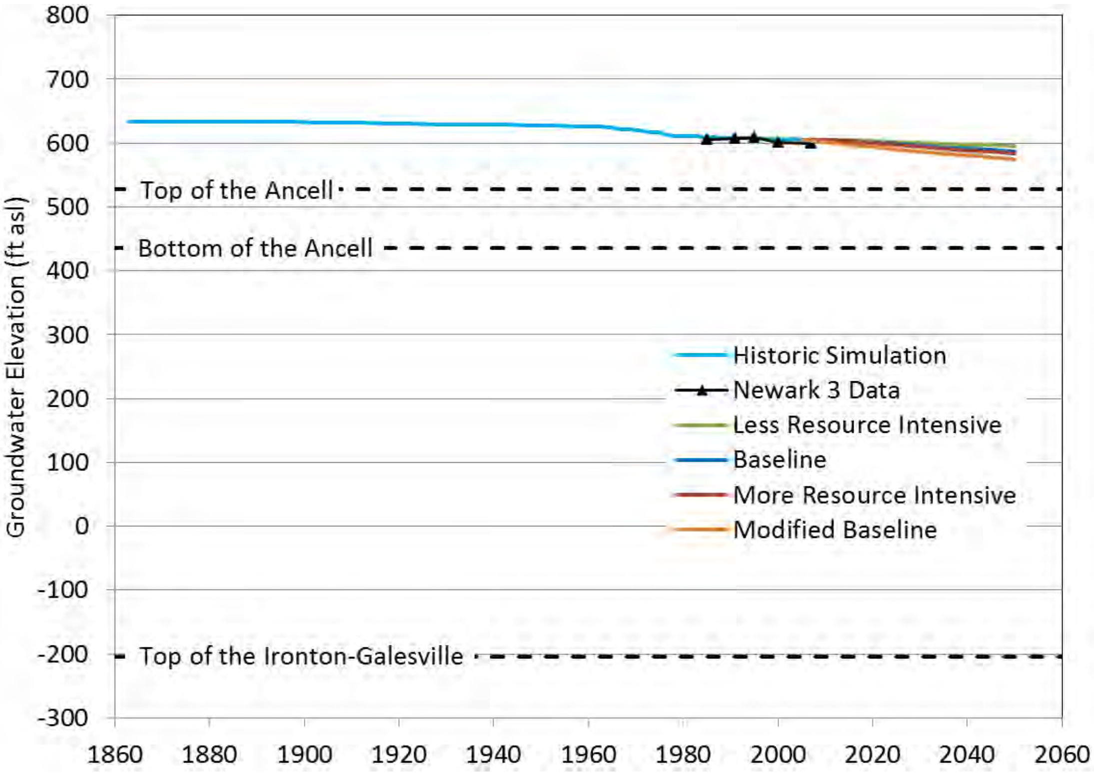


Figure 103. Simulated and observed heads in the Ancell sandstone at Newark

Summary and Conclusions

Kendall County is entirely dependent on groundwater to supply its residents, communities, and industries. No surface water resources are currently in the county. Therefore, a sustainable growth strategy must be based on sound planning and management decisions regarding groundwater availability and use within the county. Approximately three-quarters of the groundwater used in the county is pumped from the deep aquifers (the Ancell and Ironton-Galesville sandstones) that underlie all of northeastern Illinois; as such, large withdrawals from outside Kendall County have major impacts within the county. The water level decline has occurred regionally across all of northeastern Illinois with the greatest drop of over 800 ft centered in Joliet. In southwestern Kendall County the Ancell sandstone is at the top of the bedrock surface where it can be reached with shallow wells. The principal Quaternary sand and gravel aquifers in the county lie to the north of the Fox River in the Plano area. Significant sand and gravel deposits do not exist elsewhere in Kendall County.

Reported groundwater withdrawals from the larger capacity public, commercial, and agricultural wells in the county have grown from 3 million gallons per day (Mgd) in 1995 to 7 Mgd in 2005. By 2050, withdrawals have been projected to increase, depending on a range of assumptions affecting future water demand, to between 18 and 35 Mgd. Recognizing the strain that a rapidly growing population would place on its water resources, Kendall County contracted with the Illinois State Water and Geological Surveys to conduct a number of studies designed to collect new data regarding the county's geology and groundwater resources. This report presents the results of the Illinois State Water Survey's investigations. These studies include a) documentation of groundwater levels in the county's aquifers, b) documentation of groundwater quality in shallow wells within the county, and c) assessment of the impacts of growing water demands on the county's groundwater resources using digital groundwater flow models. This work was being done simultaneously with other ongoing studies in northeastern Illinois until the data collection effort and the modeling revealed that the behavior of groundwater flow in Kendall County did not fit the previous narrative. Thus, the groundwater flow model was reconstructed to better match both new and historical data and in the process changed the resulting predictions not only for Kendall County, but also all of northeastern Illinois.

Measurement of Groundwater Levels

ISWS staff measured water levels in 210 wells in the Kendall County area. After segregating the data into one of three aquifer categories (22 in sand and gravel, 153 in shallow bedrock, and 35 in sandstone), the data for each aquifer type were plotted on maps. Data from the sand and gravel and shallow bedrock wells were combined into a generalized potentiometric surface map of the county's shallow aquifer system. The map suggests several influences on shallow groundwater flow in the county, including land surface elevation, connectivity with surface water, lateral variation in transmissivity, and pumping. Higher heads occur in topographically high areas and lower heads occur in groundwater discharge areas along the Fox River and the lower reaches of Aux Sable Creek in southeastern Kendall County. Lower heads also occur in the central part of the county, which could be due to changes in transmissivity, the influence of pumpage to the east, and/or the movement of water down the fault.

Water level data from the deep sandstone aquifers appear to be split by the Sandwich Fault Zone. The deepest water levels, often going below sea level, occur north and east of the fault near the large cones of depression centered in the Aurora and Joliet areas. South of the fault, water levels in the sandstones are several hundred feet higher than that north of the fault, suggesting that any northward flow towards the pumping centers is being cut off by the fault acting as a flow barrier. The vertical movement of the faulting was enough to offset the sandstone layers completely in the central and western portions of the county. These data suggest that the Sandwich Fault greatly influences groundwater flow in the region and needs to be incorporated into the model.

Groundwater Quality

A preliminary evaluation of the quality of groundwater in the Shallow Bedrock Aquifer and sand and gravel (unconsolidated) aquifers was completed. TDS concentrations of nine of the 19 sampled wells and two of the seven samples in the GWQDB exceeded the secondary MCL of 500 mg/L. The largest value (890 mg/L) was from a well finished in a sand and gravel (unconsolidated) aquifer, which also happened to be the shallowest well sampled (50 ft). There was no obvious geographic pattern to TDS values, except that samples collected in and around Oswego all had values greater than 500 mg/L. Chloride concentrations were, for the most part, not elevated in Kendall County. Eight of the 19 collected samples and one of the seven samples from the GWQDB had Cl^- concentrations less than 15 mg/L. Two of the collected samples had concentrations greater than 100 mg/L (149 and 307 mg/L). Both of these wells were finished in sand and gravel aquifers, were two of the shallowest wells, and were located near U.S. Route 34; thus they may have been affected by road salt runoff. Elevated nitrate-nitrogen (NO_3-N) is common in groundwater in agricultural regions; however, only 3 of the 19 samples and only two of the seven GWQDB samples had detectable NO_3-N (> 0.07 mg/L). Only two of the samples had concentrations greater than 0.5 mg/L. The highest concentration measured was 8.73 mg/L. The MCL for NO_3-N is 10 mg/L. Atrazine was not detected in any samples.

Groundwater quality in the Shallow Bedrock Aquifer and sand and gravel aquifers in Kendall County is generally very good. Based on the relatively few samples collected across the county and results contained in the ISWS GWQDB, human activities have not caused significant contamination of these aquifers. Contaminants associated with agricultural activities (nitrate and atrazine) were generally below analytical detection limits. Chloride, which is elevated in the Shallow Bedrock Aquifer and sand and gravel aquifers in many parts of northeastern Illinois due to road salt runoff, is generally not elevated in Kendall County. Water quality was found to be a function of both well depth and overlying till thickness, with generally better quality in deeper wells underlying thicker till deposits that protect aquifers from potentially contaminating activities. Specific conductance, alkalinity, and Cl^- were significantly higher in samples from shallower, less well-protected wells, while NH_4-N concentrations were significantly lower in these samples. The major cations (Ca, Mg, Na) had higher concentrations in these samples as well, although the differences were generally not significant.

Groundwater Flow Model and Future Use Scenarios

The 21-layer model simulates groundwater flow in all geological materials from land surface down to the impermeable crystalline Precambrian basement and includes the bedrock aquifers in the northern half of Illinois and in portions of Indiana, Michigan, and Wisconsin. The model was run using a transient simulation for the period from 1864, when pumpage began in Chicago, through the end of the future pumping scenarios in 2050. Pumpage after 1963 is represented by 6,222 wells in northeastern Illinois and the surrounding area.

To better characterize groundwater flow in Kendall County and improve the calibration of the model, the Sandwich Fault Zone was added as a low-permeability barrier to minimize flow through the sandstone aquifers where they have been completely offset. This barrier helps to reproduce the observed heads with the model by maintaining relatively high water levels on the south side of the fault and relatively low water levels on the north side. To represent the transfer of water between the aquifers by the thousands of uncased wells in northeastern Illinois, a zone with a high vertical hydraulic conductivity was added to the confining layer between the Ancell and Ironton-Galesville sandstones. This approach acts to equalize the head in the two aquifers in a manner similar to the way Mandle and Kontis (1992) treated the inter-aquifer transfer of groundwater in their model of the sandstones. To prevent cell dewatering and loss of pumpage in the transient model runs as experienced in previous models, the pre-1963 pumpage from the seven individual pumping centers was redistributed to multiple wells surrounding each center.

The model was calibrated by comparing predicted heads to observed heads in 222 deep sandstone wells measured in 2000 by Burch (2002) in addition to the 16 predevelopment water levels used by Meyer et al. (2009). The 2007 water levels and historic water levels from production wells at Yorkville, Oswego, Montgomery, Newark, Joliet, and Aurora were also used in visual comparisons of the transient modeled heads. The mean residual error for all 238 target heads was 1.60 feet and the absolute residual mean error was 36.6 feet. There were no large errors or systematic deviations in the calculated versus observed heads. Because these errors are low compared to the 1,000-foot range in water levels and because of inherent errors associated with the observed heads, significant improvement to the head calibration is unlikely without additional data. Hydraulic conductivity (K) values were modified deterministically during the calibration process using the results from the four previous models. The major changes to the conductivities of the deep bedrock system include increasing the horizontal K value for the Ancell sandstone and the vertical K value for the Maquoketa Shale. These two changes increase the amount of water entering in deep sandstones and flowing towards the production wells and were necessary to make the model match the 2000 head targets and prevent the large-scale loss in modeled pumpage from wells artificially going dry. The modeled transmissivity for the deep aquifer system in Kendall County is 10 to 20 percent less than the values used by Burch (1991) for the Ancell (St. Peter) to Mt. Simon layers and 30 to 45 percent greater than the values used by Meyer et al. (2012) for the Galena-Platteville to Ironton-Galesville layers.

Kendall County’s population is estimated to grow from nearly 100,000 in 2007 to 190,000 by 2030 and 280,000 by 2050. To estimate the effects of the increased water demand associated with both county and regional population growth, as well as projected increases in per capita water demand, three different scenarios of increasing pumping were simulated using the groundwater flow model for the period 2005 to 2050. The three scenarios represent a reasoned and plausible range of future water withdrawals. The low withdrawal scenario is called the Less Resource Intensive scenario (LRI) and the high withdrawal scenario is called the More Resource Intensive (MRI) scenario. Between these is a moderate water withdrawal scenario called the Baseline (BL) scenario. The scenarios were developed by Dziegielewski and Chowdhury (2008) for the Northeastern Illinois Regional Water Supply Planning Group (RWSPG) using statistical and other quantitative methods and based on estimates of future socioeconomic conditions in the region.

The model results of the future use scenarios revealed problems of aquifer dewatering with the expanded use of the deep aquifer out to the year 2050. Some of these problems are caused by Dziegielewski and Chowdhury's (2008) reliance on using only existing wells in the model to handle future growth in water demand. In reality, the communities of Kendall County will likely continue to drill new wells out to 2050. Therefore, a "Modified Baseline" scenario was tested with the model where new hypothetical wells were added for Oswego, Yorkville, and Joliet to handle some of the pumpage for the regular Baseline scenario. Four hypothetical wells were added for Oswego on the south and east sides of town where they would be spread out further from existing production wells. To take advantage of the higher water levels on the south side of the Sandwich fault, two new hypothetical wells for Yorkville and three new hypothetical wells for Joliet were added in this area.

Analysis of Shallow Aquifers

The analysis of the shallow aquifers focused on the northern part of Kendall County and Plano, the principle user of the aquifer. The analysis was aided by the use of the finer resolution local-scale model created for the greater Kane County area by Meyer et al. (2009). The shallow sand and gravel aquifers are well connected with the Shallow Bedrock Aquifer and combined to form a highly permeable unit with transmissivity values that can exceed 10,000 ft^2/d in northwestern Kendall County. As a result of the high transmissivity and the interaction of the aquifers with the Fox River and the four tributary creeks, the model results do not show areas with significant regional drawdowns. In addition, many of the shallow wells have less than 30 ft of available head, which greatly limits their pumping capacities. By contrast, the total transmissivity of the deep sandstone aquifer is four times lower than that of the shallow aquifer, but the deep wells can have hundreds of feet of available drawdown so they can have much larger pumping capacities. For example, Plano well #7 was drilled 91 ft into sand and gravel with a reported specific capacity of 16.8 gpm/ft and approximately 50 ft of available head, thus making for a theoretical well capacity of 840 gpm. By comparison, the Yorkville well #7 was drilled 1,527 ft deep into the Ironton-Galesville sandstone with a reported specific capacity of 2.93 gpm/ft and approximately 860 ft of available head, thus making for a much greater theoretical well capacity of 2,730 gpm.

The development of the original Plano wellfield within the floodplain of Big Rock Creek makes any long-term analysis of the sustainability of the wellfield not very meaningful. The model does not show the formation of a large cone of depression from the wellfield due to the downward leakage of water from the creek. Past measurements have shown fairly consistent non-pumping water levels in the city wells at levels close to that of the creek. By contrast, the new Plano wellfield located two miles east of Big Rock Creek does not have the same benefit of local leakage to minimize drawdowns at the wells. However, leakage from Big Rock Creek and Rob Roy Creek will help to contain the regional spread of the cone of depression. Under the Baseline scenario, the predicted 5-foot drawdown contour for 2050 at the new wellfield extends radially outward about one-half mile. Local hydrogeological conditions will likely be a greater factor than concerns over regional drawdowns in determining how the shallow sand and gravels can be developed.

Reductions in simulated groundwater discharge to streams from pre-development (pre-1864) to 2005 range from 2 to 11 percent in the sub-basins of the Fox River watershed overlapping Kendall County with an overall decline of about 6 percent. In 2005 the greatest simulated reductions in the Kendall County area occurred in Blackberry Creek and Big Rock Creek, which extend far into Kane County. Model analysis suggests that most of the loss in Big Rock Creek occurs in Kendall County along the stretch near Plano. The patterns in reduction of groundwater discharge within the Fox River watershed resemble the 2005 pattern. The greatest simulated reductions in sub-basins overlapping Kendall County occur in the watershed of Blackberry Creek, where model simulations suggest reductions of 11 to 13 percent in 2050, depending on the pumping scenario. Readers should note that most of this sub-basin is in Kane County, not Kendall County, and the reduction in simulated natural groundwater discharge may reflect withdrawals from wells in Kane County.

Analysis of Deep Sandstone Aquifers

The presence of relatively impermeable rocks overlying the sandstone aquifers greatly reduces the exchange of water between these deep aquifers and the shallow aquifers. Circulation within the sandstone aquifers thus occurs on a regional scale, with most recharge into the aquifers in Illinois occurring in Boone, DeKalb, Livingston, and southern Kendall Counties, where the relatively impermeable Maquoketa shale is absent. Under predevelopment conditions, groundwater in the sandstone aquifers underlying northeastern Illinois discharged to the upper Illinois River and the lower Fox River, along with some upward leakage to Lake Michigan. Presently, discharge from the sandstone aquifers in the region is dominated by flow to wells throughout northeastern Illinois.

The modeled heads and drawdowns for 2005 in the Ancell sandstone and the Ironton-Galesville sandstone are similar except in southwestern Kendall County where the Ancell heads are predicted to be as much as 200 feet higher than the Ironton-Galesville heads. The similarity between the two surfaces for most of northeastern Illinois is due to the high vertical hydraulic conductivity zone used to represent the aquifer interconnections caused by the wells open to both units. South of the Sandwich Fault Zone in Kendall County, there are no known wells interconnecting the two aquifers so the heads begin to diverge. The heads in the Ancell sandstone become higher because in far western Kendall County the unit is at the bedrock surface and can receive recharge directly from the shallow aquifers and possibly some stream segments. Lacking this same source of recharge, the heads in the Ironton-Galesville are lower due the drawdown from regional pumpage.

The amount of drawdown in the deep sandstones of northeastern Illinois is dramatic due to the high water use in an aquifer system with a relatively low transmissivity and the large amount of available head. The cone of depression is centered on Joliet where heads have been reduced by more than 700 ft to elevations below sea level. A secondary center to the cone of depression occurs around the pumping center at Aurora. From a practical viewpoint, the main issue with the deep water levels is the increased electrical costs of lifting the water hundreds of feet. However, if the head drops below the top of the aquifer, as it has started to do in areas around Joliet and Aurora, the saturated aquifer thickness decreases, leading to a decrease in transmissivity and even further increases in drawdown. With the Ancell sandstone accounting for roughly half of the transmissivity of the deep wells around Kendall County, the dewatering of the aquifer will cause the wells to experience a drop in productivity and drawdown in the Ironton-Galesville to greatly increase. In a small area of southwestern Kendall County, the Ancell sandstone is partially saturated under natural conditions without any nearby pumpage. Heads in the Ironton-Galesville sandstone are 500 feet or more above the top of this lower sandstone formation.

The model results of the three future use scenarios, Least Resource Intensive, Baseline, and More Resource Intensive, plus the Modified Baseline, show that water levels in the deep aquifers of Kendall County will continue to decline and potentially reach levels that adversely affect water supplies. The predicted heads and drawdowns in 2050 for northeastern Illinois under Baseline conditions continue to show the center of the regional cone-of-depression in Joliet with a secondary center in Aurora. Compared to 2005, the Aurora center will shift slightly southward into Kendall County in 2050 and encompass the Oswego wells. A significant model result that shows up in all the head, drawdown, and available head maps for the Ancell sandstone are the areas of complete aquifer dewatering. In the Baseline scenario these areas occur around all of the Oswego wells, some of the Yorkville wells, some of the Joliet wells in eastern Kendall County, and other Joliet and industrial wells along the Des Plaines River in Will County. Groundwater flowing towards these areas in the Ancell sandstone is captured by other wells and/or diverted downward into the Ironton-Galesville sandstone. The drawdown created by the Baseline scenario shows the dewatered areas at the centers of where drawdown has increased from 2005 to 2050. As the head in the Ancell sandstone drops below the top of the sandstone, the transmissivity also drops, causing a pumping well to get a greater portion of its water from the Ironton-Galesville sandstone where it causes much greater drawdowns.

For the Most Resource Intensive case, the areas of Ancell sandstone dewatering are much larger and the resultant drawdowns in the Ironton-Galesville sandstone are much greater. Because of these problems, developing the aquifer at this rate would not be sustainable from a water supply perspective. The drawdown in the Ironton-Galesville sandstone at Oswego is predicted to be over 350 feet. With these large losses in head, the pumping capacities of the individual wells will drop dramatically and necessitate the installation of larger pumps or additional wells. The results from the Least Resource Intensive scenario show less drawdown than the Baseline scenarios and no dewatering of the Ancell sandstone in Kendall County. However, even under a lower pumpage scenario, an area of dewatering still occurs at some of the industrial wells near the Sandwich Fault Zone in Will County. This result underscores the need to understand how the Sandwich Fault Zone influences groundwater flow.

North of the Sandwich Fault Zone in Kendall County, the results of the Modified Baseline scenario show significantly reduced drawdowns around the existing wells in both the Ancell and Ironton-Galesville sandstones as compared to the Baseline scenario. The Ancell sandstone remained partially saturated at Oswego and Yorkville and was completely dewatered at only one of the Joliet wells in eastern Kendall County. South of the fault, the drawdown in the Ancell is greater in the Modified Baseline scenario than the regular Baseline scenario because of the pumpage from the five hypothetical wells for Yorkville and Joliet and downward leakage into the Ironton-Galesville sandstone. Because the five wells will act to equalize the head between the two aquifers, the head in the Ironton-Galesville sandstone actually increases even though there are wells pumping from it. The head in areas where the two aquifers are interconnected in the model is controlled by the Ancell sandstone because it is close to the surface where it receives a much greater amount of recharge.

The areas south of the Sandwich Fault where the head in the Ancell sandstone drops below the top of the aquifer become more widespread in the Modified Baseline Scenario, creating potential conflicts with any private wells that may be completed only in the upper portions of the Ancell sandstone. To keep supplying water, these wells may need to have their pumps lowered or be redrilled to a greater depth near the bottom of the sandstone. Any development of the Ancell sandstone in southern Kendall County should include an assessment of water levels, pump settings, and depths of the surrounding private wells. An alternative may be to complete new wells only into the Ironton-Galesville sandstone in this area.

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Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
178	269119	Ancell	Ancell	LaSalle	34N	5E	2	4h	300	771	586	Steel tape
190	259465	Ancell	Ancell	LaSalle	34N	5E	10	8g	290	752	544	Steel tape
179	291359	Ancell	Ancell	LaSalle	34N	5E	13	2e	300	691	526	Steel tape
180		Ancell	Ancell	LaSalle	34N	5E	14	1f	368	701	528	Steel tape
171	321795	Galena-Pl.	Galena-Pl.	Grundy	34N	6E	2	3a	138	612	554	Steel tape
172	301890	Galena-Pl.	Ancell	Grundy	34N	6E	5	6a	300	672	548	Steel tape
173	268396	Galena-Pl.	Galena-Pl.	Grundy	34N	6E	12	7h	160	608	569	Steel tape
226	246654	Galena-Pl.	Galena-Pl.	Grundy	34N	7E	2	2a	200	576	559	Steel tape
227	301891	Galena-Pl.	Galena-Pl.	Grundy	34N	7E	6	2a	140	598	547	Steel tape
225	56042	Galena-Pl.	Galena-Pl.	Grundy	34N	7E	9	1a	240	583	569	Steel tape
236	56270	Galena-Pl.	Galena-Pl.	Grungy	34N	7E	15	8a	150	564	507	Steel tape
141	404703	Galena-Pl.	Prairie du C.	Grundy	34N	8E	4	3f	480	556	437	Dropline
181	361136	Ancell	Prairie du C.	LaSalle	35N	5E	12	3d	200	641	575	Steel tape
182	343899	Ancell	Ancell	LaSalle	35N	5E	12	3e	130	641	613	Steel tape
183	349514	Ancell	Ancell	LaSalle	35N	5E	24	1c	200	713	609	Steel tape
189	237160	Quaternary	Quaternary	LaSalle	35N	5E	25	5a	220	734	583	Steel tape
142	76393	Ancell	Ancell	Kendall	35N	6E	4	4f	200	767	593	Steel tape
146	358829	Ancell	Ancell	Kendall	35N	6E	5	8g	277	651	594	Steel tape
58	378202	Ancell	Prairie du C.	Kendall	35N	6E	7	2h	245	671	604	Steel tape
143	262547	Ancell	Ancell	Kendall	35N	6E	8	5c	265	736	574	Steel tape
150	313208	Ancell	Ancell	Kendall	35N	6E	9	4b	430	756	593	Steel tape
147	313203	Galena-Pl.	Ancell	Kendall	35N	6E	13	1f	300	687	602	Steel tape
144	76409	Ancell	Ancell	Kendall	35N	6E	15	2d	260	742	594	Steel tape
177	238535	Ancell	Ancell	Kendall	35N	6E	16	6g	250	762	594	Steel tape
145	76412	Ancell	Ancell	Kendall	35N	6E	16	8h	260	773	593	Steel tape
149	259051	Ancell	Ancell	Kendall	35N	6E	22	8c	245	753	599	Steel tape
153	286020	Ancell	Ancell	Kendall	35N	6E	28	8a	260	702	590	Steel tape
175	290995	Ancell	Ancell	Kendall	35N	6E	28	8a	400	711	510	Steel tape
174	282679	Ancell	Ancell	Kendall	35N	6E	29	4b	240	711	587	Steel tape

Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
152	282685	Ancell	Ancell	Kendall	35N	6E	29	4c	240	712	588	Steel tape
41	174113	Maquoketa	Galena-Pl.	Kendall	35N	7E	1	1f	160	594	550	Steel tape
44	362274	Galena-Pl.	Ancell	Kendall	35N	7E	3	4h	520	653	499	Steel tape
128	412049	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	4	5a	277	665	566	Steel tape
129	405532	Galena-Pl.	Prairie du C.	Kendall	35N	7E	4	5a	685	661	419	Air line
45	282687	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	4	8h	180	673	531	Steel tape
46	76491	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	4	8h	210	672	537	Steel tape
47	362324	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	6	4d	240	696	544	Steel tape
148	76389	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	6	8h	207	704	566	Steel tape
48	344679	Galena-Pl.	Ancell	Kendall	35N	7E	7	1d	240	681	574	Steel tape
50	372956	Maquoketa	Galena-Pl.	Kendall	35N	7E	11	2e	200	592	509	Steel tape
42	349209	Quaternary	Quaternary	Kendall	35N	7E	12	7h	62	594	564	Steel tape
55	76519	Maquoketa	Galena-Pl.	Kendall	35N	7E	13	1h	105	592	538	Steel tape
49	372945	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	14	8h	200	606	555	Steel tape
51	284543	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	18	8e	200	680	604	Steel tape
53		Galena-Pl.	Galena-Pl.	Kendall	35N	7E	21	4b	120	654	637	Steel tape
176	76529	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	21	4e	260	641	622	Steel tape
52		Galena-Pl.	Galena-Pl.	Kendall	35N	7E	21	4f	90	638	621	Steel tape
54	341681	Maquoketa	Galena-Pl.	Kendall	35N	7E	24	1e	140	593	540	Steel tape
38	76542	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	29	2a	80	621	601	Steel tape
39	77139	Galena-Pl.	Galena-Pl.	Kendall	35N	7E	30	8e	180	666	581	Steel tape
56	370149	Maquoketa	Galena-Pl.	Kendall	35N	7E	36	1f	100	582	564	Steel tape
119	411965	Ironton-G.	Eau Claire	Kendall	35N	8E	1	5h	1554	662	-176	Air line
33	77260	Maquoketa	Maquoketa	Kendall	35N	8E	4	5c	64	583	563	Steel tape
23	77168	Maquoketa	Maquoketa	Kendall	35N	8E	4	5g	100	592	579	Steel tape
26		Maquoketa	Maquoketa	Kendall	35N	8E	5	6g	70	593	576	Steel tape
25	77183	Maquoketa	Maquoketa	Kendall	35N	8E	5	7f	62	591	578	Steel tape
28	303396	Maquoketa	Galena-Pl.	Kendall	35N	8E	8	8a	180	589	559	Steel tape
123	411893	Ironton-G.	Eau Claire	Kendall	35N	8E	11	4g	1533	604	-215	Air line

Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
122	411964	Ironton-G.	Mt. Simon	Kendall	35N	8E	12	7h	1523	628	37	Air line
29	77202	Maquoketa	Maquoketa	Kendall	35N	8E	13	6d	145	620	590	Steel tape
57	379499	Maquoketa	Galena-Pl.	Kendall	35N	8E	15	4a	200	577	423	Steel tape
27		Maquoketa	Galena-Pl.	Kendall	35N	8E	15	7d	240	574	566	Steel tape
35	77211	Maquoketa	Maquoketa	Kendall	35N	8E	16	3e	102	582	482	Steel tape
40	244199	Maquoketa	Maquoketa	Kendall	35N	8E	19	8f	15	592	541	Steel tape
30	77238	Maquoketa	Maquoketa	Kendall	35N	8E	23	1b	47	591	577	Steel tape
31	362275	Maquoketa	Maquoketa	Kendall	35N	8E	25	5d	110	643	575	Steel tape
36	379531	Maquoketa	Galena-Pl.	Kendall	35N	8E	28	3c	160	568	503	Steel tape
34	267859	Maquoketa	Maquoketa	Kendall	35N	8E	35	5g	59	591	560	Steel tape
167	359752	Prairie du C.	Prairie du C.	LaSalle	36N	5E	4	3h	180	680	637	Steel tape
165	309868	Quaternary	Quaternary	LaSalle	36N	5E	8	1a	83	625	591	Steel tape
157	80472	Prairie du C.	Prairie du C.	LaSalle	36N	5E	11	1a	130	656	639	Steel tape
198	359747	Prairie du C.	Prairie du C.	LaSalle	36N	5E	13	7c	260	644	623	Steel tape
164	303574	Prairie du C.	Prairie du C.	LaSalle	36N	5E	17	1a	170	642	605	Steel tape
155	259488	Prairie du C.	Prairie du C.	LaSalle	36N	5E	24	7h	160	643	627	Steel tape
156	252468	Quaternary	Quaternary	LaSalle	36N	5E	24	7h	65	642	623	Steel tape
154	361143	Prairie du C.	Prairie du C.	LaSalle	36N	5E	25	2a	116	561	538	Steel tape
196	298072	Prairie du C.	Prairie du C.	LaSalle	36N	5E	26	3e	140	621	590	Steel tape
166	326697	Quaternary	Quaternary	LaSalle	36N	5E	26	7c	55	611	591	Steel tape
169	362331	Quaternary	Quaternary	Kendall	36N	6E	2	1h	73	640	600	Steel tape
21	358207	Galena-Pl.	Galena-Pl.	Kendall	36N	6E	2	3h	280	637	550	Steel tape
22	369294	Galena-Pl.	Ancell	Kendall	36N	6E	2	3h	460	637	550	Steel tape
106	402082	Quaternary	Quaternary	Kendall	36N	6E	3	3h	84	629	583	Steel tape
168	77432	Galena-Pl.	Galena-Pl.	Kendall	36N	6E	4	3e	54	573	567	Steel tape
184	411292	Ancell	Prairie du C.	Kendall	36N	6E	4	6b	438	734	624	Air line
111	269107	Prairie du C.	Prairie du C.	Kendall	36N	6E	5	3h	140	632	605	Steel tape
109	379554	Ancell	Prairie du C.	Kendall	36N	6E	9	2d	260	603	574	Steel tape
17		Ancell	Ancell	Kendall	36N	6E	9	7b	120	613	581	Steel tape

Appendix A. Observed Water Levels

ID	***ISWS P number***	***Uppermost contributing unit***	***Lowermost contributing unit***	***County***	***Town-ship***	***Range***	***Sec-tion***	***Plot***	***Well depth (ft)***	***Eleva-tion (ft MSL)***	***Head (ft MSL)***	***Method***
110	209909	Galena-Pl.	Galena-Pl.	Kendall	36N	6E	13	2e	187	747	601	Steel tape
112	293526	Galena-Pl.	Ancell	Kendall	36N	6E	15	2g	260	692	603	Steel tape
192	374982	Ancell	Prairie du C.	Kendall	36N	6E	16	6e	300	614	590	Steel tape
113	309149	Prairie du C.	Prairie du C.	Kendall	36N	6E	17	4g	140	597	570	Steel tape
188	412176	Prairie du C.	Prairie du C.	Kendall	36N	6E	17	5e	120	576	561	Dropline
186	412175	Prairie du C.	Prairie du C.	Kendall	36N	6E	17	8c	140	582	560	Steel tape
197	374620	Ancell	Prairie du C.	Kendall	36N	6E	21	6e	220	670	595	Steel tape
194	285271	Ancell	Ancell	Kendall	36N	6E	22	4d	265	720	592	Steel tape
195	310885	Ancell	Prairie du C.	Kendall	36N	6E	28	5b	360	712	593	Steel tape
200	364628	Ancell	Prairie du C.	Kendall	36N	6E	31	8h	240	608	558	Steel tape
193	77524	Galena-Pl.	Ancell	Kendall	36N	6E	35	8e	230	733	569	Steel tape
191	229418	Galena-Pl.	Galena-Pl.	Kendall	36N	6E	36	4a	200	710	569	Steel tape
235	312771	Quaternary	Quaternary	Kendall	36N	7E	3	2h	44	666	636	Steel tape
234	77553	Maquoketa	Galena-Pl.	Kendall	36N	7E	5	4a	355	727	497	Steel tape
170	77660	Maquoketa	Galena-Pl.	Kendall	36N	7E	7	5f	280	723	546	Steel tape
202	411219	Prairie du C.	Eau Claire	Kendall	36N	7E	10	1g	1527	765	-128	Air line
233	230816	Maquoketa	Maquoketa	Kendall	36N	7E	12	4d	120	669	629	Steel tape
107	402075	Galena-Pl.	Ancell	Kendall	36N	7E	16	5g	750	727	458	Dropline
231	329408	Galena-Pl.	Galena-Pl.	Kendall	36N	7E	18	4c	320	710	518	Steel tape
230	276102	Maquoketa	Galena-Pl.	Kendall	36N	7E	20	4h	240	704	520	Steel tape
237	210575	Galena-Pl.	Ancell	Kendall	36N	7E	29	1a	340	681	531	Steel tape
229	366604	Galena-Pl.	Prairie du C.	Kendall	36N	7E	29	4g	543	693	511	Steel tape
130	412050	Galena-Pl.	Ancell	Kendall	36N	7E	31	5d	500	695	531	Air line
228	77753	Galena-Pl.	Galena-Pl.	Kendall	36N	7E	33	5a	150	671	558	Steel tape
232	230815	Maquoketa	Galena-Pl.	Kendall	36N	7E	35	6h	385	650	505	Steel tape
209		Quaternary	Quaternary	Kendall	36N	8E	1	4e	70	682	654	Dropline
199	265249	Maquoketa	Maquoketa	Kendall	36N	8E	1	7h	180	682	644	Steel tape
211	284539	Maquoketa	Maquoketa	Kendall	36N	8E	2	4d	220	687	655	Steel tape
210	263384	Maquoketa	Maquoketa	Kendall	36N	8E	5	2b	160	722	659	Steel tape

Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
212	304132	Maquoketa	Maquoketa	Kendall	36N	8E	6	2g	220	727	629	Steel tape
220	356152	Maquoketa	Galena-Pl.	Kendall	36N	8E	10	8a	265	639	628	Steel tape
221	206262	Maquoketa	Maquoketa	Kendall	36N	8E	14	2e	185	641	621	Steel tape
223	77867	Maquoketa	Galena-Pl.	Kendall	36N	8E	20	4a	200	616	610	Steel tape
222	77868	Maquoketa	Maquoketa	Kendall	36N	8E	20	7h	120	654	619	Steel tape
224	245378	Silurian	Maquoketa	Kendall	36N	8E	25	1b	200	641	583	Steel tape
214	324156	Silurian	Maquoketa	Kendall	36N	8E	25	5h	165	661	599	Steel tape
216	230391	Maquoketa	Maquoketa	Kendall	36N	8E	27	1f	125	601	590	Steel tape
134	411441	Maquoketa	Maquoketa	Kendall	36N	8E	27	5a	150	590	568	Air line
132	411437	Galena-Pl.	Ancell	Kendall	36N	8E	28	7f	900	601	359	Air line
133	411438	Maquoketa	Galena-Pl.	Kendall	36N	8E	28	7g	180	602	592	Dropline
213	287012	Maquoketa	Maquoketa	Kendall	36N	8E	29	8d	62	612	596	Steel tape
20	361178	Silurian	Maquoketa	Will	36N	9E	3	4h	205	624	605	Steel tape
19	156941	Silurian	Maquoketa	Will	36N	9E	6	3a	195	646	629	Steel tape
18	300662	Silurian	Maquoketa	Will	36N	9E	19	3h	180	628	588	Steel tape
126	405554	Potosi-Fran.	Ironton-G.	Will	36N	9E	32	4d	1566	620	-440	Air line
75	252804	Galena-Pl.	Galena-Pl.	DeKalb	37N	5E	1	5h	280	712	698	Steel tape
71	41125	Galena-Pl.	Galena-Pl.	DeKalb	37N	5E	16	8g	165	732	698	Steel tape
79	329715	Prairie du C.	Potosi-Fran.	DeKalb	37N	5E	20	8h	220	724	699	Steel tape
69	258678	Galena-Pl.	Galena-Pl.	DeKalb	37N	5E	22	2g	170	697	667	Steel tape
82	343156	Galena-Pl.	Galena-Pl.	DeKalb	37N	5E	24	6d	205	687	643	Steel tape
68	206796	Prairie du C.	Prairie du C.	DeKalb	37N	5E	28	3a	140	679	657	Steel tape
80	41147	Prairie du C.	Prairie du C.	DeKalb	37N	5E	30	1e	140	698	681	Steel tape
81	41149	Prairie du C.	Prairie du C.	DeKalb	37N	5E	32	7a	135	682	668	Steel tape
76	41153	Prairie du C.	Prairie du C.	DeKalb	37N	5E	34	5a	200	667	636	Steel tape
70	301971	Prairie du C.	Prairie du C.	DeKalb	37N	5E	35	8a	160	670	635	Steel tape
158	78014	Quaternary	Quaternary	Kendall	37N	6E	3	7a	100	678	660	Steel tape
5	77980	Quaternary	Quaternary	Kendall	37N	6E	4	2h	119	700	678	Steel tape
11	77986	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	5	1g	280	712	663	Steel tape

Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
12	238605	Maquoketa	Galena-Pl.	Kendall	37N	6E	5	6h	159	715	690	Steel tape
13	77988	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	5	8g	222	721	690	Steel tape
159	300128	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	10	2h	180	691	632	Steel tape
8	78042	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	14	5f	260	662	591	Steel tape
14	78062	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	16	2d	100	650	596	Steel tape
9	77998	Quaternary	Quaternary	Kendall	37N	6E	16	6g	68	669	644	Steel tape
10	78009	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	16	6g	180	670	621	Steel tape
7	78109	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	20	7b	165	660	622	Steel tape
100	406657	Quaternary	Quaternary	Kendall	37N	6E	23	8c	40	610	595	Air line
101	406653	Quaternary	Quaternary	Kendall	37N	6E	23	8c	41	607	597	Air line
102	406655	Quaternary	Quaternary	Kendall	37N	6E	23	8c	37	607	593	Air line
98	411847	Quaternary	Quaternary	Kendall	37N	6E	24	3c	91	643	615	Air line
96	411413	Quaternary	Quaternary	Kendall	37N	6E	24	3d	84	654	628	Air line
88	305739	Quaternary	Quaternary	Kendall	37N	6E	24	4a	70	649	612	Steel tape
99	411910	Quaternary	Quaternary	Kendall	37N	6E	24	5e	115	634	611	Air line
238	349203	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	25	1a	340	625	515	Steel tape
6	306986	Quaternary	Quaternary	Kendall	37N	6E	29	7a	95	639	608	Steel tape
15	206772	Galena-Pl.	Galena-Pl.	Kendall	37N	6E	35	1d	120	575	550	Steel tape
114	230811	Maquoketa	Maquoketa	Kendall	37N	7E	1	8a	120	655	644	Steel tape
93	78297	Maquoketa	Maquoketa	Kendall	37N	7E	3	5a	130	660	648	Steel tape
92	78301	Maquoketa	Maquoketa	Kendall	37N	7E	5	1h	124	665	643	Steel tape
162	78304	Quaternary	Quaternary	Kendall	37N	7E	7	8e	98	674	631	Steel tape
160	326090	Maquoketa	Galena-Pl.	Kendall	37N	7E	9	4a	120	646	632	Steel tape
95	411220	Potosi-Fran.	Eau Claire	Kendall	37N	7E	11	3a	1384	651	8	Air line
203	411221	Potosi-Fran.	Eau Claire	Kendall	37N	7E	15	2b	1368	649	-32	Air line
163	287453	Maquoketa	Maquoketa	Kendall	37N	7E	15	3e	120	643	626	Steel tape
2	78477	Galena-Pl.	Galena-Pl.	Kendall	37N	7E	17	8h	195	652	628	Steel tape
3	230408	Maquoketa	Galena-Pl.	Kendall	37N	7E	21	2d	260	642	621	Steel tape
115		Maquoketa	Maquoketa	Kendall	37N	7E	27	6b	50	617	602	Steel tape

Appendix A. Observed Water Levels

ID	*ISWS P number*	*Uppermost contributing unit*	*Lowermost contributing unit*	*County*	*Town-ship*	*Range*	*Sec-tion*	*Plot*	*Well depth (ft)*	*Eleva-tion (ft MSL)*	*Head (ft MSL)*	*Method*
4	292649	Maquoketa	Galena-Pl.	Kendall	37N	7E	28	4c	260	638	604	Steel tape
94	406660	Ancell	Eau Claire	Kendall	37N	7E	28	8b	1393	630	330	Air line
201	406662	Ancell	Ironton-G.	Kendall	37N	7E	32	1e	1335	589	299	Air line
1	76572	Maquoketa	Galena-Pl.	Kendall	37N	7E	34	3g	100	585	565	Steel tape
84	230131	Maquoketa	Maquoketa	Kendall	37N	8E	2	1f	140	697	666	Steel tape
206	402068	Galena-Pl.	Ironton-G.	Kendall	37N	8E	5	6e	1325	632	66	Air line
207	412196	Maquoketa	Maquoketa	Kendall	37N	8E	5	6e	137	633	608	Air line
136	402069	Galena-Pl.	Ironton-G.	Kendall	37N	8E	5	8e	1379	661	65	Air line
138	402071	Galena-Pl.	Ironton-G.	Kendall	37N	8E	6	5d	1328	660	58	Air line
77	342799	Maquoketa	Maquoketa	Kendall	37N	8E	8	5h	120	623	609	Steel tape
204	405468	Prairie du C.	Eau Claire	Kendall	37N	8E	11	1h	1535	738	38	Air line
104	411617	Potosi-Fran.	Eau Claire	Kendall	37N	8E	11	4e	1514	712	-13	Air line
161	238519	Silurian	Maquoketa	Kendall	37N	8E	12	3g	180	702	657	Steel tape
91	76837	Silurian	Maquoketa	Kendall	37N	8E	15	5h	105	669	652	Steel tape
89	76841	Silurian	Maquoketa	Kendall	37N	8E	16	6e	85	652	634	Steel tape
83	76854	Maquoketa	Maquoketa	Kendall	37N	8E	17	5h	110	608	560	Steel tape
103	400077	Prairie du C.	Eau Claire	Kendall	37N	8E	20	3c	1440	662	8	Air line
205	406670	Ancell	Eau Claire	Kendall	37N	8E	20	8h	1378	641	101	Air line
86	229527	Maquoketa	Maquoketa	Kendall	37N	8E	22	5a	140	683	654	Steel tape
87	303542	Maquoketa	Maquoketa	Kendall	37N	8E	26	1c	180	733	654	Steel tape
85	76940	Maquoketa	Maquoketa	Kendall	37N	8E	27	2c	180	730	658	Steel tape
90	244178	Silurian	Maquoketa	Kendall	37N	8E	29	4h	180	659	632	Steel tape
60	218273	Silurian	Maquoketa	Will	37N	9E	9	2f	170	694	662	Steel tape
59	160376	Silurian	Silurian	Will	37N	9E	36	2a	145	621	612	Steel tape
66	340014	Galena-Pl.	Galena-Pl.	DeKalb	38N	5E	15	5d	200	741	730	Steel tape
67	41309	Galena-Pl.	Galena-Pl.	DeKalb	38N	5E	32	4h	210	742	727	Steel tape
72	295546	Maquoketa	Maquoketa	Kane	38N	6E	26	8a	100	679	674	Steel tape
74	189323	Maquoketa	Galena-Pl.	Kane	38N	6E	32	7f	240	713	696	Steel tape
65	65834	Maquoketa	Maquoketa	Kane	38N	7E	9	4a	100	701	689	Steel tape

Appendix A. Observed Water Levels

ID	ISWS P number	Uppermost contributing unit	Lowermost contributing unit	County	Town-ship	Range	Sec-tion	Plot	Well depth (ft)	Eleva-tion (ft MSL)	Head (ft MSL)	Method
62	65923	Silurian	Maquoketa	Kane	38N	7E	25	6e	140	671	648	Steel tape
64	228897	Quaternary	Quaternary	Kane	38N	7E	29	6e	96	709	685	Steel tape
78	321812	Silurian	Maquoketa	Kane	38N	8E	13	2a	160	711	659	Steel tape
63	241461	Silurian	Maquoketa	Kane	38N	8E	30	5h	100	682	650	Steel tape
61	181825	Maquoketa	Maquoketa	DuPage	38N	9E	19	6d	120	715	659	Steel tape
73	288296	Silurian	Silurian	DuPage	38N	9E	24	7d	85	707	681	Steel tape

Appendix B. Complete Chemical Results for Wells Sampled

Sample No.	Well ID	Depth (ft)	Source Aquifer	Date	T (C)	SpC (µS/cm)	pH	ORP (mV)	DO	H_2S	Total Col.	*E. coli*	Atrazine	Hardness
1	169	73	Unconsolidated	9/5/2007	16.3	1088	6.79	96	0.4	0	POS	POS	<0.5	619
2	15	120	Bedrock	9/5/2007	14.9	750	6.79	60	0.4	0.8	NEG	NEG	<0.5	337
3	88	70	Unconsolidated	9/5/2007	17.0	1106	6.84	120	0.3	0	NEG	NEG	<0.5	460
4	2	195	Bedrock	9/5/2007	12.1	657	7.04	25	0.4	1.7	NEG	NEG	<0.5	158
5	159	180	Bedrock	9/5/2007	14.2	505	7.14	76	0.4	0.02	NEG	NEG	<0.5	119
6	12	159	Unconsolidated	9/5/2007	12.6	590	6.98	77	0.3	0	POS	POS	<0.5	326
7	163	120	Bedrock	9/5/2007	14.3	942	6.78	123	0.3	0	NEG	NEG	<0.5	403
8	115	50	Unconsolidated	9/5/2007	14.7	1749	6.66	280	3.4	0	POS	POS	<0.5	534
9	1	100	Bedrock	9/5/2007	12.5	777	7.23	86	0.3	0.05	POS	NEG	<0.5	111
10	89	85	Bedrock	9/5/2007	13.8	882	6.71	316	0.7	0	NEG	NEG	<0.5	492
11	87	180	Bedrock	9/5/2007	14.3	544	7.06	115	0.4	0.1	POS	POS	<0.5	220
12	199	180	Bedrock	9/5/2007	16.6	559	7.09	325	7.7	0	NEG	NEG		174
12(dup)	199	180	Bedrock	9/5/2007							POS	POS	<0.5	180
14	233	120	Bedrock	9/5/2007	11.8	812	7.08	75	0.4	0	NEG	NEG	<0.5	277
16	83	110	Bedrock	9/10/2007	12.6	990	8.56	241	0.3	0	NEG	NEG	<0.5	4
17	77	120	Bedrock	9/10/2007	16.5	1122	7.98	-2	0.3	0.83	NEG	NEG	<0.5	22
18	224	200	Bedrock	9/10/2007	12.1	540	7.05	139	0.3	0	NEG	NEG	<0.5	214
19	221	185	Bedrock	9/10/2007	16.9	845	7.09	64	0.4	0.15	POS	POS	<0.5	184
20	222	120	Bedrock	9/10/2007	11.7	540	7.18	75	0.3	0	POS	POS	<0.5	243
21	33	64	Bedrock	9/10/2007	15.8	1070	7.69	72	0.3	0	POS	NEG	<0.5	23
21(dup)	33	64	Bedrock	9/10/2007										25

Note: All samples were below detection for As (0.002 mg/L), Be (0.00055), Cd (0.012), Co (0.013), Pb (0.041), Sb (0.059), Se (0.131), Sn (0.070), Ti (0.00056), and V (0.047). Results in mg/L unless stated otherwise.

Appendix B. Complete Chemical Results for Wells Sampled

Sample No.	Al	B	Ba	Ca	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	S
1	0.0236	0.085	0.144	135	<0.00079	3.35	1.42	0.0161	68.5	0.0860	<0.022	12.3	0.042	<0.063	54.3
2	0.0121	0.509	0.0714	68.2	0.00094	0.301	15.1	0.0406	40.5	0.0147	<0.022	34.2	0.023	<0.063	20.4
3	0.0196	<0.023	0.0915	98.9	<0.00079	0.755	3.26	0.0121	51.8	0.0631	<0.022	57.2	0.017	<0.063	19.9
4	0.0043	0.609	0.0373	32.4	0.00498	0.0723	12.2	0.0527	18.8	0.0051	<0.022	88.3	<0.014	<0.063	20.1
5	0.0037	1.36	0.0112	24.8	<0.00079	0.266	11.4	0.0777	14.0	0.0035	<0.022	72.1	<0.014	<0.063	0.372
6	0.0134	0.043	0.211	67.2	<0.00079	1.40	2.08	0.0097	38.4	0.131	<0.022	11.3	0.017	0.088	0.336
7	0.0163	0.336	0.0580	88.4	<0.00079	0.323	6.55	0.0163	44.3	0.0392	<0.022	59.1	0.028	<0.063	26.5
8	0.0219	0.054	0.0901	118	0.00170	0.0084	2.58	0.0061	58.1	<0.0015	<0.022	141	0.027	<0.063	17.6
9	<0.0022	1.12	0.00545	25.5	<0.00079	0.182	8.30	0.0442	11.4	0.0054	<0.022	154	<0.014	<0.063	2.53
10	0.0195	0.090	0.123	106	0.00589	<0.0059	2.33	0.0139	55.3	0.149	<0.022	15.6	0.036	<0.063	39.3
11	0.0083	1.06	0.0378	46.0	0.00107	0.285	2.72	0.0182	25.6	0.0065	0.084	40.7	0.021	<0.063	22.8
12	0.0194	0.880	0.0333	34.3	0.00297	<0.0059	6.43	0.0266	21.6	0.0030	0.040	68.2	<0.014	<0.063	22.4
12(dup)	0.0189	0.880	0.0350	35.4	0.00287	0.0083	6.41	0.0259	22.2	0.0038	0.050	65.1	<0.014	<0.063	24.1
14	0.0082	0.983	0.0839	50.6	<0.00079	0.563	3.81	0.0266	36.6	0.0082	<0.022	86.4	<0.014	<0.063	13.6
16	<0.0022	2.30	0.00134	0.970	<0.00079	0.0111	3.13	0.0482	0.4	<0.0015	<0.022	263	<0.014	<0.063	<0.217
17	<0.0022	1.25	0.00358	4.54	<0.00079	0.0069	6.08	0.0702	2.58	0.0018	<0.022	276	<0.014	<0.063	11.6
18	0.0116	0.931	0.0481	48.5	0.00355	0.154	4.95	0.0178	22.7	0.0078	0.048	48.7	0.015	<0.063	23.7
19	0.0044	1.01	0.0320	32.1	<0.00079	0.0682	7.24	0.0434	25.3	0.0062	<0.022	126	0.017	<0.063	26.1
20	0.0096	0.639	0.134	46.3	<0.00079	0.702	3.26	0.0109	31.1	0.0128	<0.022	34.4	<0.014	<0.063	<0.217
21	<0.0022	2.06	0.0741	4.48	<0.00079	0.0386	4.22	0.0339	2.82	0.0028	<0.022	308	<0.014	<0.063	<0.217
21(dup)	<0.0022	1.92	0.0838	4.81	<0.00079	0.0480	4.16	0.0292	3.26	0.0027	<0.022	276	<0.014	<0.063	<0.217

Appendix B. Complete Chemical Results for Wells Sampled

Sample No.	Si	Sr	Tl	Zn	Alkalinity ($CaCO_3$)	NH_4-N	F^-	Cl^-	NO_3-N	SO_4^{2-}	DOC	calculated TDS
1	8.48	0.372	<0.017	0.0228	353	0.48	0.29	70.5	<0.07	151	0.75	621
2	4.41	1.25	0.018	<0.0073	312	0.96	0.44	30.7	<0.07	55.8	0.41	403
3	6.25	0.155	<0.017	<0.0073	305	<0.06	0.14	149	<0.07	56.2	0.24	573
4	3.84	0.830	<0.017	<0.0073	289	0.80	0.96	12.9	<0.07	55.5	0.38	367
5	3.86	0.598	<0.017	<0.0073	275	0.98	1.33	2.06	<0.07	0.64	<0.21	265
6	7.66	0.489	<0.017	<0.0073	335	0.42	0.36	0.77	<0.07	0.95	0.67	293
7	6.25	0.472	<0.017	<0.0073	313	0.77	0.59	79.7	<0.07	74.6	0.91	513
8	8.68	0.132	<0.017	0.0159	335	<0.06	0.11	307	8.73	50.8	0.59	890
9	3.65	0.136	<0.017	<0.0073	369	0.22	2.84	33.9	<0.07	6.82	0.32	428
10	7.39	0.419	<0.017	0.0322	333	<0.06	0.31	36.9	0.39	115	1.00	504
11	6.77	0.802	<0.017	<0.0073	229	0.44	0.95	1.75	<0.07	69.8	0.89	307
12	4.55	0.513	<0.017	0.0767	237	0.33	1.07	2.36	0.12	65.4	0.71	321
12(dup)	4.71	0.532	<0.017	0.0774	233	0.34	1.04	2.30	0.12	70.1	0.58	322
14	6.77	0.804	<0.017	<0.0073	338	0.66	0.80	52.3	<0.07	47.6	0.78	451
16	3.84	0.0173	<0.017	<0.0073	525	0.24	5.93	7.37	<0.07	<0.31	0.56	543
17	5.60	0.0638	<0.017	<0.0073	459	0.40	0.89	69.5	<0.07	32.9	0.70	624
18	4.70	0.482	<0.017	<0.0073	222	0.47	0.77	1.98	<0.07	65.5	1.08	307
19	4.36	0.602	<0.017	<0.0073	336	0.29	0.87	21.0	<0.07	76.8	0.82	459
20	6.87	0.575	<0.017	<0.0073	302	1.20	0.68	1.51	<0.07	<0.31	2.24	273
21	3.99	0.0787	<0.017	0.0157	539	0.32	4.34	52.0	<0.07	<0.31	0.50	645
21(dup)	3.81	0.0875	<0.017	0.0239	542	0.31	4.42	52.3	<0.07	<0.31	0.78	615

Appendix B. Complete Chemical Results for Water Samples from the ISWS Groundwater Quality Database.

Lab No.	Depth (ft)	Twn	Rng	Sect	Date	Lab pH	Al,t	As,t	B,t	Ba,t	Ca,t	Cr,t	Cu,t	Fe,t	Mg,t	Mn,t	Na,t
232916	110	37N	06E	02	10/3/2002	7.70		1.2	0.02	0.08	91.0	<0.007	<0.01	1.83	43.4	0.07	7.30
233415	210	35N	07E	30	9/1/2003	7.55		< 0.58	0.106	0.027	91.1	<0.007	0.2		50.7	0.007	11.5
233706	185	37N	06E	20	3/22/2004	7.51		1.1	0.028	0.216	96.9	<0.007	0.087		48.8	0.058	7.28
233732	84	37N	07E	24	4/9/2004	7.59	0.49	1.61	0.051	0.099	109	<0.007	0.007		54.7	0.121	9.49
234379	115	37N	07E	24	10/1/2005	7.77		1.74	0.015	0.072	88.3	<0.012	<0.011		45.0	0.068	4.28
234759	48	37N	07E	35	5/16/2006	7.73		< 0.95	0.071	0.055	87.8	<0.012	<0.011		45.2	0.048	9.91
235138	220	36N	08E	02	4/17/2007	7.58		< 0.95	0.751	0.034	52.2	<0.0058	0.0044		29.8	0.0049	35.9

Lab No.	Ni,t	SiO_2.t	Zn,t	Alkalinity	F^-,d	Cl^-,d	NO_3-N,d	SO_4^{2-},d	TDS
232916	<0.013		0.130	310	0.30	18.9	< 0.06	67.9	410
233415	0.026		0.102	283	0.15	27.0	2.0	115	501
233706	<0.013		0.140	305	0.24	16.8	< 0.07	109	480
233732	<0.013		0.005	292	0.24	21.3	0.09	139	518
234379	<0.03		0.016	298	0.18	17.0	< 0.07	123	493
234759	<0.03		<0.009	326	0.23	25.3	< 0.07	77.5	430
235138	<0.014	10.8	<0.0073	253	0.67	5.1	< 0.07	68.5	359

Note: Results in mg/L except for pH. t = total (unfiltered), d = dissolved.