Appendix B. Development of Withdrawal Database

B.1. Data Sources

B.1.1. Illinois

B.1.1.1. Data Obtained from Previous Modeling Studies

Withdrawal rates for Illinois wells during the period 1864 through 1963 were obtained as an electronic file from Stephen L. Burch of the Illinois State Water Survey (ISWS) (personal communication, 2002). Data derived from this source represent withdrawals from deep wells that were active during this period. Pumping activity is represented by seven idealized pumping centers, with pumping totals equivalent to aggregated total deep well withdrawals from surrounding areas. These aggregated withdrawals are intended to represent those within the area of Cook, DuPage, northern Grundy, Kane, Kendall, Lake, McHenry, and Will Counties, Illinois.

These data were employed in a previous modeling study by Burch (1991). Burch had obtained the values from an even earlier modeling study by Prickett and Lonnquist (1971), who appear to have approximated the 1864-1958 values from plots of withdrawal rates published by Suter et al. (1959) and based the 1959-1963 withdrawal rates on pumping data collected by the ISWS. Prickett and Lonnquist (1971) also augmented the pumping records published by Suter et al. (1959) by adding a time record of approximate withdrawal rates at a seventh pumping center (Batavia) to the previous six pumping centers, each referred to by city name (Chicago, Joliet, Elmhurst, Des Plaines, Elgin, and Aurora) (Figure B-1).

B.1.1.2. Hardcopy Data

Hardcopy records of groundwater withdrawals in 20 northern Illinois counties, compiled by the ISWS, were entered into a computer database and employed to represent groundwater withdrawals in Illinois during 1964 through 1979 (Figure B-2). These withdrawal records represent wells supplying community and non-community public water systems; commercial and industrial facilities; and irrigation systems for nurseries, athletic fields, and golf courses, but not grain crops such corn and soybeans. The records were the basis for discussions of groundwater withdrawals in northern Illinois appearing in ISWS reports published in the 1960s, 1970s, and 1980s (Sasman and Baker, 1966; Sasman et al., 1962a; Sasman et al., 1974; Sasman et al., 1973; Sasman et al., 1982; Sasman et al., 1977; Sasman et al., 1967; Sasman et al., 1961; Sasman et al., 1962b).

All records of withdrawals from deep wells in the hardcopy dataset were included in the modeling database. Records of withdrawals from shallow wells were included in the modeling database only if the wells are located within the area of the shallow aquifer withdrawal accounting region (SAWAR), a region delineated for this project using the natural hydrologic boundaries of watersheds and enclosing the regional model nearfield (Figure B-3). The SAWAR was employed to limit the scope of the database to include shallow wells only if the wells are near enough to the nearfield of the regional model that they would be likely to influence groundwater flow in the area. The SAWAR was trimmed to exclude a small area of the watershed-delimited area in extreme southwestern Michigan.

B.1.1.3. ISWS Public-Industrial-Commercial Survey (PICS) Database

Withdrawal rates for Illinois wells within the regional model domain during the period 1980 through 2003 were obtained from the ISWS Public-Industrial-Commercial Survey (PICS) Database (Figure B-4). This Microsoft Access (Microsoft Corporation, 2003a) database is compiled from withdrawal data collected annually through the ISWS Illinois Water Inventory Program (IWIP) by voluntary submission of a form tailored to each (known) major water user in the state. For the year 2000, IWIP received a 70 percent return on inquiries sent to 2832 facilities. Withdrawals are estimated for non-respondents on the basis of data submitted during previous years, so that a fairly complete water use picture for any one year is compiled. Large changes in reported water use (> 10 percent) from one year to the next trigger a follow-up call to the facility operator to verify the accuracy of the reported withdrawal rates and to inquire about reasons for growth or decline.

All records of withdrawals from deep wells were included in the modeling database, but records of withdrawals from shallow wells were included in the modeling database only if the wells are located within the SAWAR (Figure B-3).

B.1.1.4. Assumed Withdrawals from Additional Deep Wells in Northeastern Illinois

Withdrawal rates from other Illinois wells were estimated for the years 1864 through 2003. Withdrawals were estimated for deep wells represented by records in the ISWS Private Well Database, a database generally containing records of low-capacity wells supplying households and commercial facilities. Withdrawals were not estimated for shallow wells because about 85 to 90 percent of groundwater withdrawn from such wells is estimated to be returned to the shallow units via on-site wastewater disposal (Pebbles, 2003; United States Environmental Protection Agency Region V, 1975), with little net effect on groundwater flow.

B.1.2. Indiana

All withdrawal data for Indiana wells were obtained from a database of groundwater withdrawals purchased from the Indiana Department of Natural Resources in June 2003 (personal communication, 2003). All records of withdrawals from deep wells in the Indiana database were included in the modeling database, although only a single such well was recorded in the database. Records of withdrawals from shallow wells were included in the modeling database only if the wells are located within the SAWAR (Figure B-3). The database is limited to records of withdrawals during the years 1985 through 2002. Earlier records of withdrawals from Indiana wells are not available.

B.1.3. Wisconsin

Withdrawal rates for wells in Wisconsin were obtained from groundwater flow model input files received from the Wisconsin Geological and Natural History Survey (personal communication, 2002) and developed to model groundwater flow in southeastern Wisconsin as described by Feinstein et al. (2005a; 2005b). These files represent average annual withdrawal rates from wells only in southeastern Wisconsin for 1864 through 2002. Withdrawal rates in the files are aggregated into time steps of durations ranging from 5 to 20 years.

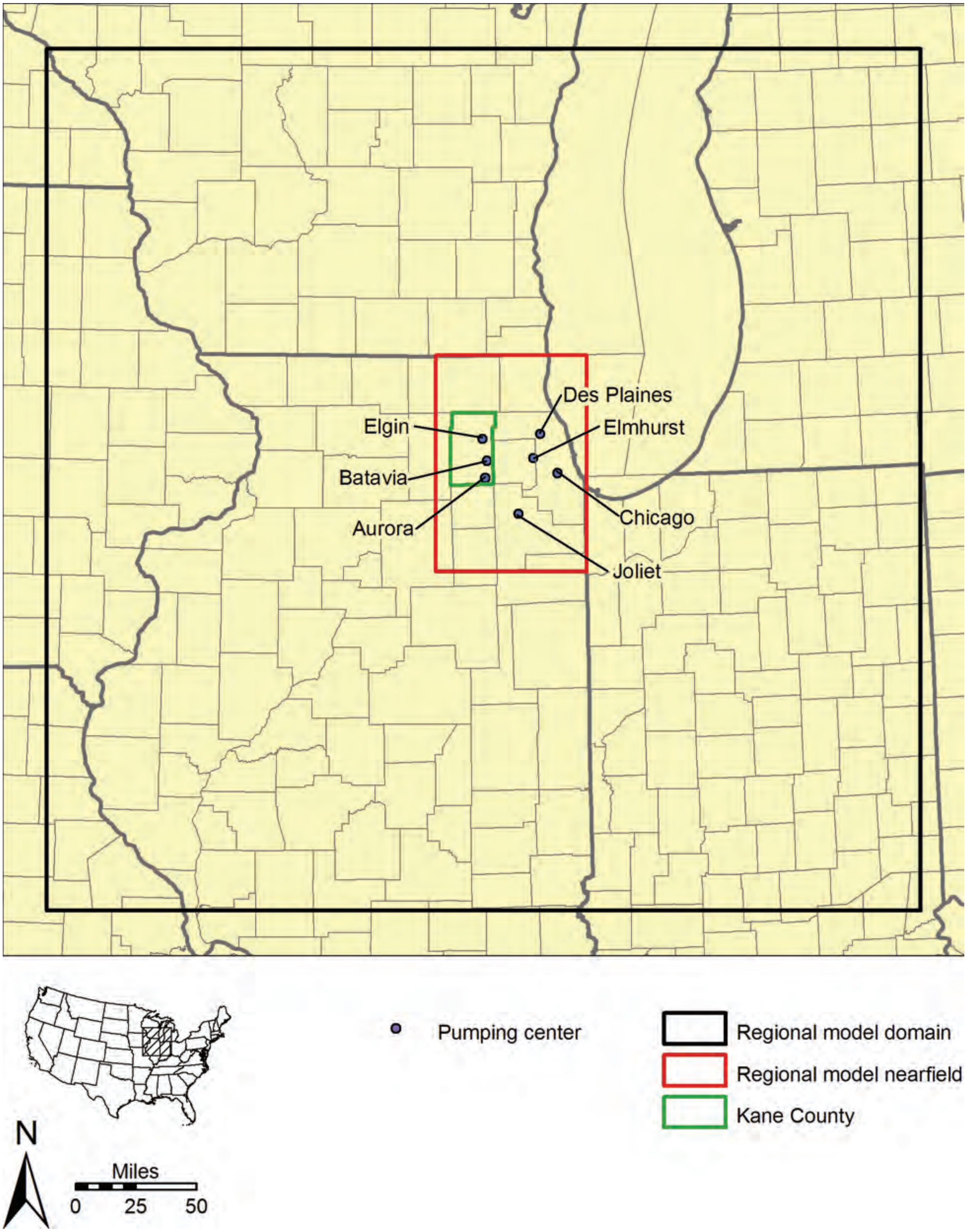

Figure B-1. Locations of pumping centers represented by Illinois withdrawal data derived from earlier modeling studies.

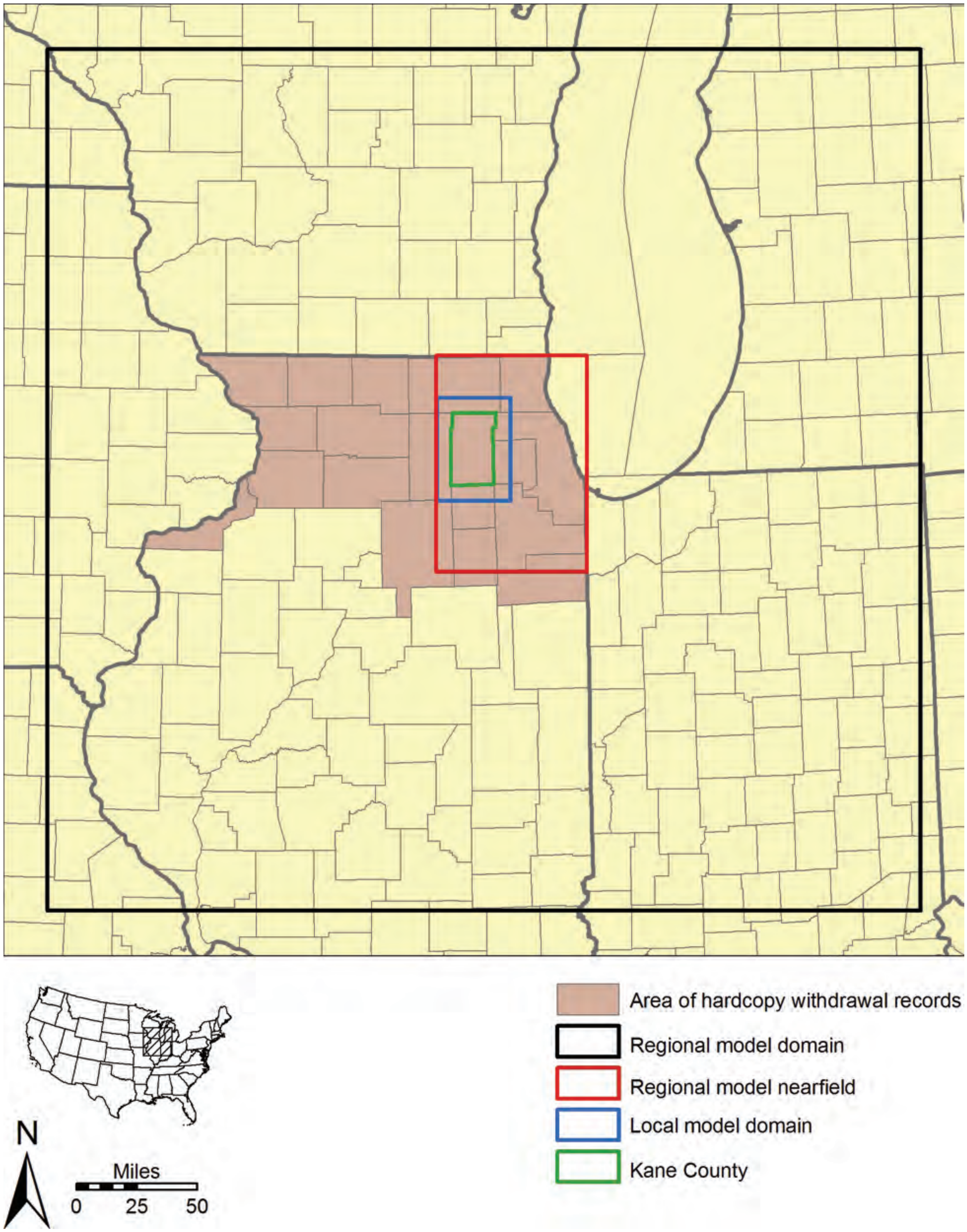

Figure B-2. Area of hardcopy withdrawal records used to represent groundwater withdrawals in Illinois from 1964 through 1979.

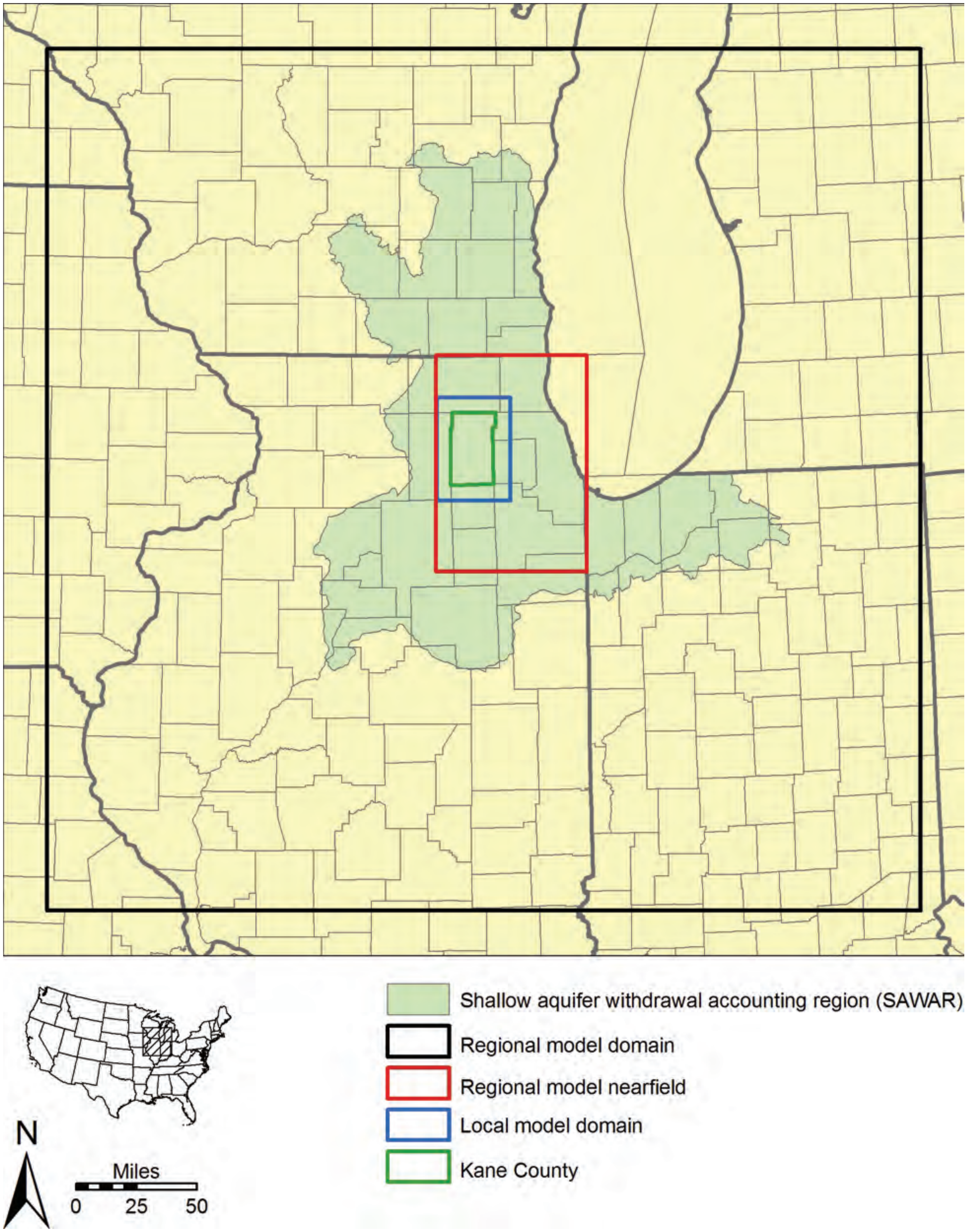

Figure B-3. Shallow aquifer withdrawal accounting region (SAWAR).

B.2. Data Processing

B.2.1. Illinois

B.2.1.1. Data Obtained from Previous Modeling Studies

Withdrawal data provided by Burch (personal communication, 2002) specified pumping center locations as row and column coordinates for his model (Burch, 1991). These location coordinates were converted to the ILLIMAP coordinate system in the present study using Appendix B in Burch's report (Burch, 1991), which lists ILLIMAP *x*- and *y*-coordinates for the rows and columns in his model.

Withdrawal totals for the seven pumping centers covered by the dataset showed withdrawals from the hydrostratigraphic units between the top of the Ancell Unit and the bottom of the Ironton-Galesville Unit. The withdrawal totals did not include the component of water contributed from overlying and underlying units to the wells represented in the dataset, many of which were open to bedrock units as shallow as the Silurian-Devonian Carbonate Unit and as deep as the Mt. Simon Unit (Suter et al., 1959). The withdrawal totals were therefore increased, using data given in Suter et al.(1959) to reflect water contributed to the wells by units above the Ancell Group and below the Ironton-Galesville Sandstone. Plots of pumping through time at the six pumping centers described by Suter et al. (1959) (their Figure 36, page 61) suggest that the proportion of water derived from the overlying and underlying units is approximately constant through time. For the present study, total rates of groundwater withdrawal at the pumping centers were based on the 1958 proportions given in Figure 37 (page 62) of Suter et al. (1959) (Table B-1). Since the Batavia pumping center was not considered by Suter et al. (1959), total groundwater withdrawals were based on the average of the proportion of groundwater pumped from the Ancell to Ironton-Galesville interval estimated by Suter et al. for the nearby Elgin and Aurora pumping centers. A total of 700 annual withdrawal records was obtained from the data compiled for previous modeling studies.

Since the pumping centers are meant to simulate deep wells open to all aquifers from the top of the Silurian-Devonian Carbonate Unit downward through the Mt. Simon Unit, the seven pumping centers were assumed to be open to model layers 5 through 17. The source interval was assumed to extend no deeper than model layer 17 since only the upper portion of the Mt. Simon Unit contains fresh water in Illinois (Illinois State Water Survey and Hittman Associates, 1973; Schicht et al., 1976; Suter et al., 1959).

B.2.1.2. Hardcopy Data

Data from the hardcopy records employed to represent groundwater withdrawals in Illinois from 1964 through 1979 were entered into electronic spreadsheets using Microsoft Excel (Microsoft Corporation, 2003b) and then imported into a Microsoft Access database application (Microsoft Corporation, 2003a) for additional data processing. The hardcopy records represent withdrawals from 3223 wells.

The entered withdrawal records required augmentation with (1) *x*- and *y*-coordinates in the ILLIMAP projection (see Table B-1) of the wells represented in the hardcopy records; and (2) characterization of the source interval of the represented wells. If the wells were included in the network of wells that were the source of water-level measurements for shallow-aquifer potentiometric-surface mapping in Kane County (Locke and Meyer, 2005), the *x*- and *y*-coordinates were based on surveying conducted for the mapping effort. Otherwise, the coordinates and open-interval characterizations were obtained from existing ISWS electronic databases, if records of the wells were included in these other databases. In instances wherein records of the wells were not present in the other databases, or wherein the existing databases do not include records of the wells, assumptions were made to compensate for the missing data. The two existing ISWS databases consulted for the project are (1) the PICS (Public-Industrial-Commercial) Database, a database generally containing records of high-capacity wells supplying public water systems and self-supplied industrial and commercial facilities (see Section B.1.1.3); and (2) the Private Well Database, a database generally containing records of low-capacity wells supplying households and commercial facilities. Although the populations of wells recorded in these two databases are generally mutually exclusive, a small overlap exists, and in the event that a record of the same well appears in both databases, preference was given to the data included in the more detailed PICS Database. A hardcopy record of withdrawals from a well was linked to an entry in the PICS or Private Well Database on the basis of information on the hardcopy record, which usually included the following: owner name; local well identification number; location description giving county name, township, range, section, and 10-acre plot (Appendix I); dates of drilling and abandonment; and a rough characterization of the open interval. Of the 3223 wells represented by the hardcopy withdrawal records, 2728 (85 percent) are represented by records in the PICS Database, and 456 (14 percent) are represented in the Private Well Database, leaving only 39 wells (1 percent) not recorded in either database.

Although both the PICS and Private Well Databases contain fields for ILLIMAP *x*- and *y*-coordinates, these fields are not always completed. When the fields are completed, the basis for the coordinate determinations is not documented, but interviews with ISWS staff indicate that most of these entries are computer estimates based on reported location descriptions giving county name, township, range, section, and 10-acre plot (Appendix I), as well as footages from section corners sometimes reported on well records. In a few cases, the coordinates are based on optical surveying. If the fields are completed in the PICS and/or Private Well Databases for a well represented by a hardcopy withdrawal record, the *x*- and *y*-coordinates were copied, giving preference to the entries in the PICS Database in the event that the well is recorded in both databases. If ILLIMAP coordinates are not listed in the PICS and Private Well Databases, the coordinates were estimated using ISWS and ISGS computer programs that base coordinate determinations on county name, township, range, section, and 10-acre plot (Appendix I). The estimated coordinates correspond to the center of the described 10-acre plot. It was necessary to use both ISWS and ISGS programs to generate ILLIMAP coordinates, since the ISWS program, which was given preference, was not yet functional for all areas of Illinois. In a few cases, a plot designator was missing from all location descriptions, both in the hardcopy withdrawal record and the existing ISWS electronic databases. In such cases, the ISWS files were searched for location information permitting identification of the 10-acre plot in which the well is located. If such information was not available, coordinates were calculated for the center of the section in which the well is located. In still rarer cases, both section and plot designators were not available, thus coordinates were calculated for the center of the township in which the well is located. As mentioned in the preceding paragraph, if the well location was surveyed for purposes of potentiometric surface mapping (Locke and Meyer, 2005), the *x*- and *y*-coordinates assigned to the well were based on surveying conducted for the mapping effort.

For the 39 wells represented by hardcopy withdrawal records that are not recorded in either the ISWS PICS or Private Well Databases, computer estimates of the *x*- and *y*-coordinates of the wells were developed using location data included on the hardcopy withdrawal records. These annotations are typically adequate for estimation of coordinates, but in some cases they do not identify the 10-acre plot in which the well is located. In these cases, coordinates were calculated for the center of the section in which the well is located, as discussed in the preceding paragraph.

Source interval characterizations, in the form of four-digit aquifer codes consistent with ISWS conventions (Appendix F), were assigned to the wells recorded in the ISWS PICS Database on the basis of entries in a field in that database containing such codes. This field is not always completed, however, and many aquifer codes used in the PICS Database denote unspecified stratigraphic units within an interval encompassing several stratigraphic units, requiring substitution of a secondary aquifer code (here referred to as a *project aquifer code*) denoting a specific interval directly translatable to the layer scheme of the regional model. For example, the aquifer code *6080* is often employed in the PICS Database to indicate a source interval understood to be the interval commonly recognized in Illinois as the "deep bedrock"—an interval including any unit underlying the Ordovician Maquoketa Group (including the Eau Claire Formation and Mt. Simon Sandstone, despite the fact that the two-character code *80* is meant to denote Cambrian units above the Eau Claire Formation). Of the 2728 wells having hardcopy withdrawal records covering the period 1964-1979 and appearing in the PICS Database, 190 had been assigned such nonspecific aquifer codes in the PICS Database. Each of these wells was researched using hardcopy well logs and other records on file at the ISWS, electronic database records of nearby wells, annotations on the withdrawal records themselves, and available geologic mapping in order to substitute a project aquifer code that could be directly translated to a source interval characterization based on the layer scheme of the regional model (Table B-3). Of the 2728 wells having hardcopy withdrawal records and appearing in the PICS Database, 12 had been assigned no aquifer code in the PICS Database. These wells were similarly researched, and a project aquifer code was assumed that could be directly translated to the layer scheme of the regional model.

The 456 wells having hardcopy withdrawal records and are recorded in the ISWS Private Well Database were assigned a four-digit aquifer code consistent with ISWS conventions (Appendix F) as an intermediate step toward characterizing the source intervals using the model layer scheme of the regional model. These assignments were based principally on hardcopy well logs and other records on file at the ISWS, annotations on the withdrawal records themselves, and available geologic mapping. Similarly, the 39 wells not recorded in either the ISWS PICS or Private Well Databases were assigned annotations on the hardcopy withdrawal records and well construction conventions in nearby areas, most notably at the facility served by the well.

Four-digit ISWS standard aquifer codes, which were specific enough to permit translation to the regional model layer scheme, were assigned to the 3223 wells represented by the hardcopy records containing 1964-1979 withdrawal data. These codes were then translated to open interval characterizations referencing the regional model layer scheme. Open intervals were characterized by identifying the uppermost and lowermost model layers to which each well is open based on the key shown in Table B-4. Several assumptions guided this translation. First, wells assigned aquifer codes denoting an open interval in the Quaternary Unit were considered to be open to model layers 2 and 3, but not model layer 1—the uppermost one-third of the Unit. Without consulting records of the many wells open to the Quaternary Unit, we consider it improbable that most of these wells are open to the shallowest Quaternary materials. Second, wells assigned aquifer codes indicating an open interval extending into the Elmhurst Member of the Eau Claire Formation or Mt. Simon Formation were assumed to be open to model layer 17, which represents the upper one-fourth of the Mt. Simon Unit (equivalent to the Mt. Simon Formation).

Although it is possible that some of these wells do not penetrate the Mt. Simon Formation, without consulting numerous individual well logs the authors assume that most or all of the wells do penetrate the Mt. Simon Formation. Third, wells assigned four-digit aquifer codes indicating that exposure to any stratigraphic unit represented by multiple model layers (other than the Quaternary Unit and Mt. Simon Unit as discussed above) are considered to be open to all of the layers representing that unit. For example, wells assigned code 61 are assumed to be exposed to both model layers 8 and 9, representing the Maquoketa Group.

A total of 37,800 annual withdrawal records were obtained from the hardcopy data. The distribution of the wells covered by these data is shown in Figure B-5 and Figure B-6.

Table B-1. Proportion of Groundwater Derived from (1) Ancell Unit through Ironton-Galesville Unit (Column D) and (2) Units above Ancell Unit and Below Ironton-Galesville Unit (Column E) at Northeastern Illinois Pumping Centers (Suter et al., 1959)

Pumping Center	***Column A: 1958 Total, Silurian-Devonian Carbonate Unit through Mt. Simon Unit (ft^3/d) (Suter et al., 1959)[1]***	***Column B: 1958 Total, Ancell Unit through Ironton-Galesville Unit (ft^3/d) (Suter et al., 1959)[1]***	***Column C: Ratio of 1958 Totals [A/B])***	***Column D: Proportion Derived From Ancell Unit through Ironton-Galesville Unit (%) [B/(A+B)]***	***Column E: Proportion Derived From Units Above Ancell Unit and Below Ironton-Galesville Unit (%) [A/(A+B)]***
Aurora	1871800	976010	1.92	52%	48%
Chicago	3128580	1470700	2.13	47%	53%
Des Plaines	909160	467950	1.94	51%	49%
Elgin	1082970	548170	1.98	51%	49%
Elmhurst	1310260	708610	1.85	54%	46%
Joliet	1871800	1550920	1.21	83%	17%

[1]Figure 37, page 62 (Suter et al., 1959)

Table B-2. Watersheds Included in the Shallow Aquifer Withdrawal Accounting Region (SAWAR)

Eight-Digit Hydrologic Unit Code	***Cataloging Unit Name (Seaber et al., 1987)***
07090001	Upper Rock. Illinois, Wisconsin.
04040003	Milwaukee. Wisconsin.
07120006	Upper Fox. Illinois, Wisconsin.
04040002	Pike-Root. Illinois, Wisconsin.
07120004	Des Plaines. Illinois, Wisconsin.
07090006	Kishwaukee. Illinois, Wisconsin.
07120003	Chicago. Illinois, Indiana.
04040001[1]	Little Calumet-Galien. Illinois, Indiana, Michigan.
07120007	Lower Fox. Illinois.
07120001[1]	Kankakee. Illinois, Indiana, Michigan.
07130001	Lower Illinois-Senachwine Lake. Illinois.
07120005	Upper Illinois. Illinois.
07130002	Vermilion. Illinois.

[1]Trimmed to exclude portion of watershed in Michigan

Table B-3. Project Aquifer Codes Substituted for Nonspecfic Aquifer Codes Appearing in ISWS PICS Database

Nonspecific Aquifer Code from PICS Database	*Project Aquifer Code*	*Number of Wells*
__97	6697	3
6060	6366	10
6060	6666	2
6070	6370	3
6080	6161	1
6080	6166	1
6080	6365	4
6080	6366	49
6080	6381	3
6080	6383	2
6080	6387	54
6080	6393	23
6080	6397	2
6080	6566	4
6080	6666	7
6080	6681	1
6080	6687	7
6080	6693	2
6080	6697	2
6080	7087	1
6080	7187	2
6087	6387	1
6090	6393	6
6093	6393	1
6097	6397	1
__66	6366	1
__97	6697	3

Table B-4. Characterization of Source Interval Based on ISWS Aquifer Code

Project Aquifer Code	*Uppermost Model Layer*	*Lowermost Model Layer*
0101	2	3
0104	2	3
0105	2	3
0106	2	3
0109	2	3
0150	2	7
0156	2	7
0161	2	9
0163	2	11
0165	2	11
0166	2	12
2020	4	4
2061	4	9
2063	4	11
2065	4	11
2066	4	12
3040	4	4
4051	4	7
4066	4	12
4087	4	15
5050	5	7
5063	5	11
5065	5	11
5066	5	12
5156	5	7
5161	5	9
5163	5	11
5166	5	12
5171	5	13
5173	5	13
5193	5	16
5555	5	7
5556	5	7
5650	5	7
5656	5	7
5661	5	9
5663	5	11
5665	5	11
5666	5	12
5671	5	13
5675	5	13
5680	5	15

Table B-4. Characterization of Source Interval Based on ISWS Aquifer Code (Continued)

Project Aquifer Code	***Uppermost Model Layer***	***Lowermost Model Layer***
5681	5	14
5683	5	14
5687	5	15
5693	5	16
5697	5	17
6065	10	11
6066	10	12
6161	8	9
6163	8	11
6165	8	11
6166	8	12
6171	8	13
6175	8	13
6187	8	15
6193	8	16
6197	8	17
6363	10	11
6365	10	11
6366	10	12
6370	10	13
6370	10	13
6371	10	13
6373	10	13
6375	10	13
6381	10	14
6383	10	14
6387	10	15
6393	10	16
6397	10	17
6565	10	11
6566	10	12
6573	10	13
6575	10	13
6581	10	14
6587	10	15
6593	10	16
6597	10	17
6666	12	12
6670	12	13
6671	12	13
6673	12	13
6675	12	13

Table B-4. Characterization of Source Interval Based on ISWS Aquifer Code (Continued)

Project Aquifer Code	*Uppermost Model Layer*	*Lowermost Model Layer*
6681	12	14
6683	12	14
6687	12	15
6693	12	16
6697	12	17
7073	13	13
7075	13	13
7080	13	15
7087	13	15
7093	13	16
7097	13	17
7171	13	13
7173	13	13
7175	13	13
7177	13	13
7181	13	14
7187	13	15
7193	13	16
7197	13	17
7373	13	13
7375	13	13
7377	13	13
7381	13	14
7387	13	15
7393	13	16
7575	13	13
7581	13	14
7587	13	15
7593	13	16
7597	13	17
7777	13	13
7787	13	15
7793	13	16
7797	13	17
8181	13	14
8187	13	15
8193	13	16
8197	13	17
8387	14	15
8393	14	16
8397	14	17
8787	15	15

Table B-4. Characterization of Source Interval Based on ISWS Aquifer Code (Concluded)

Project Aquifer Code	***Uppermost Model Layer***	***Lowermost Model Layer***
8793	15	16
8797	15	17
9397	16	17
9797	17	17

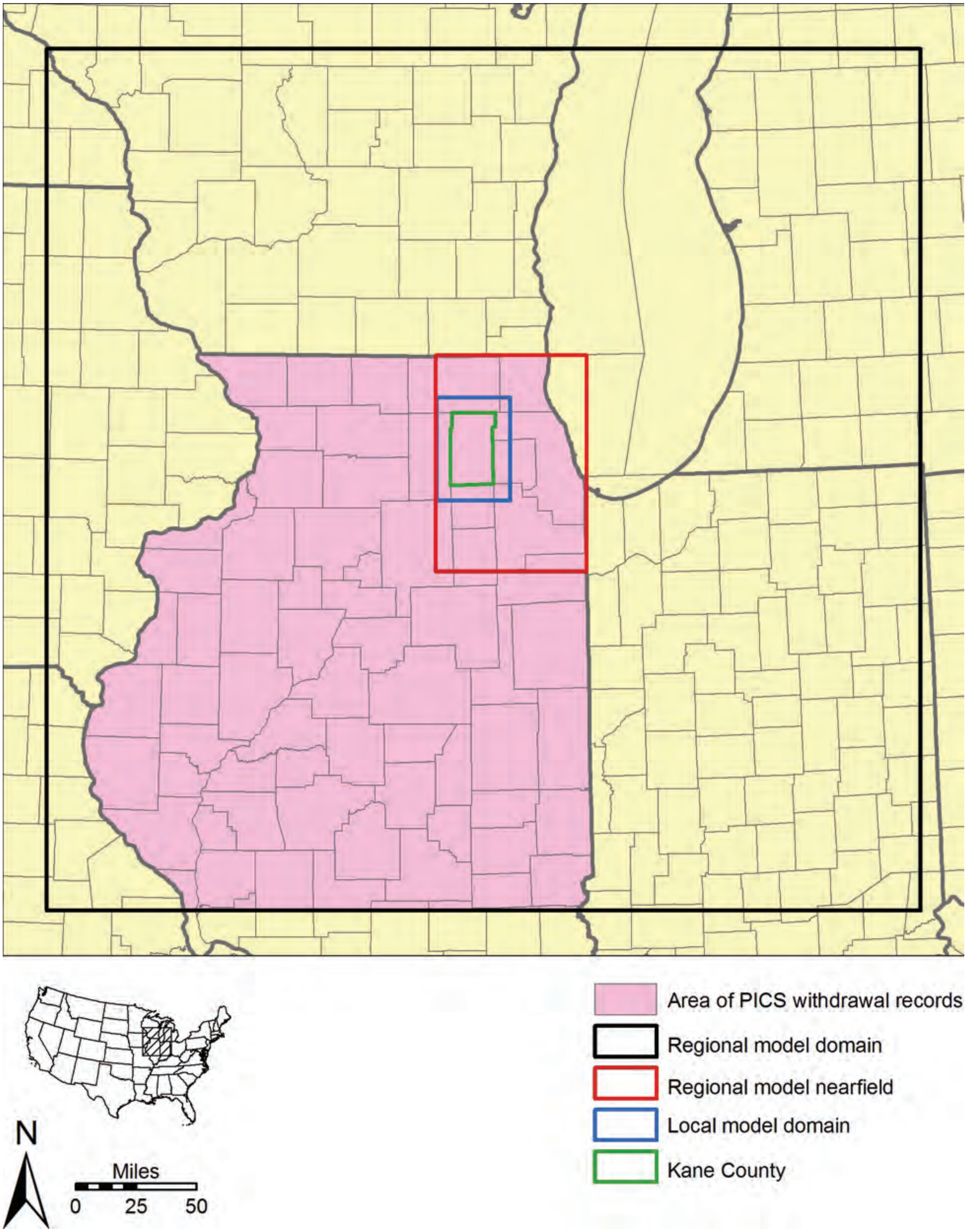

Figure B-4. Area of withdrawal records obtained from the ISWS PICS Database used to represent groundwater withdrawals in Illinois from 1980 through 2003.

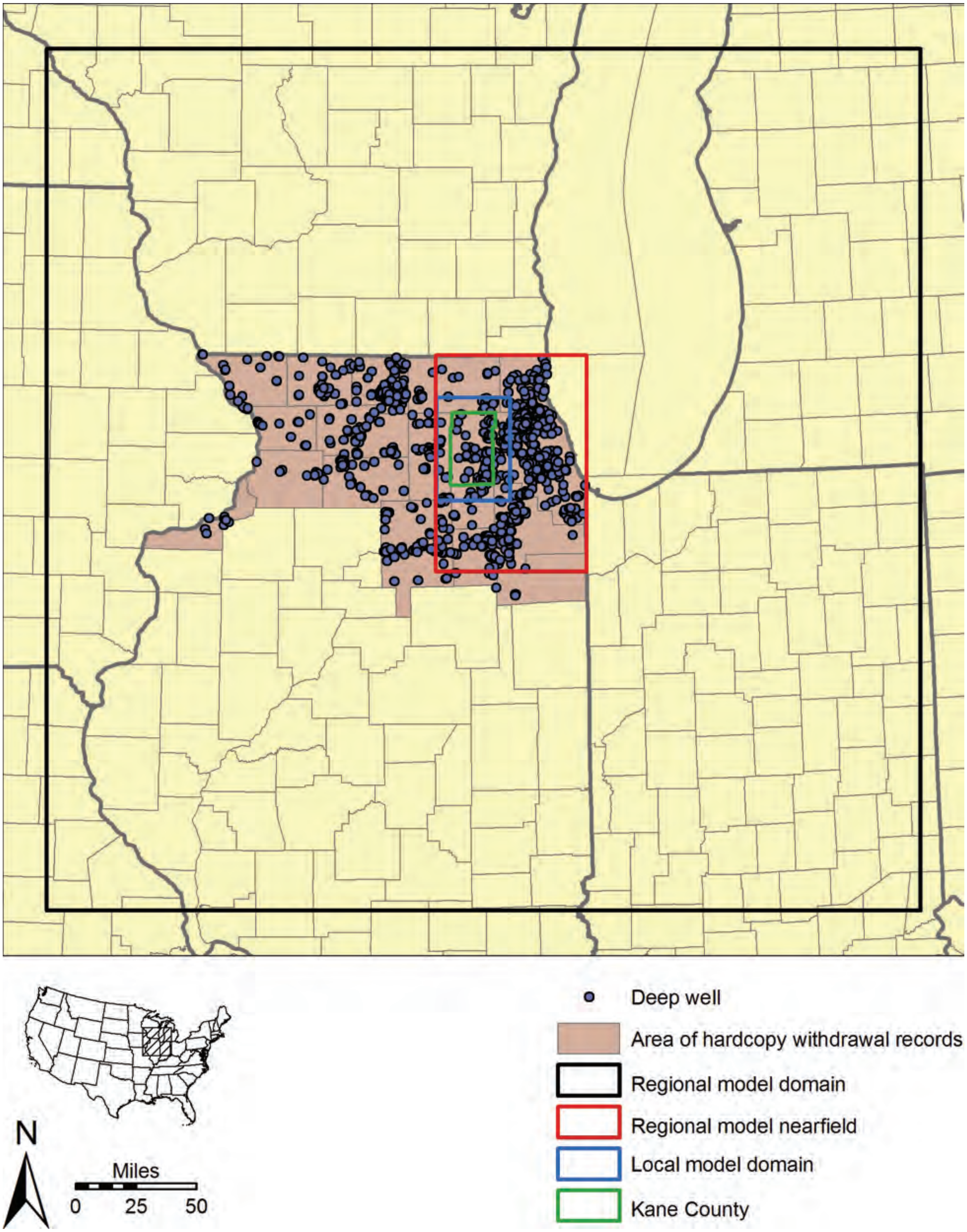

Figure B-5. Deep wells in Illinois having withdrawals documented by hardcopy records spanning the period 1964-1979.

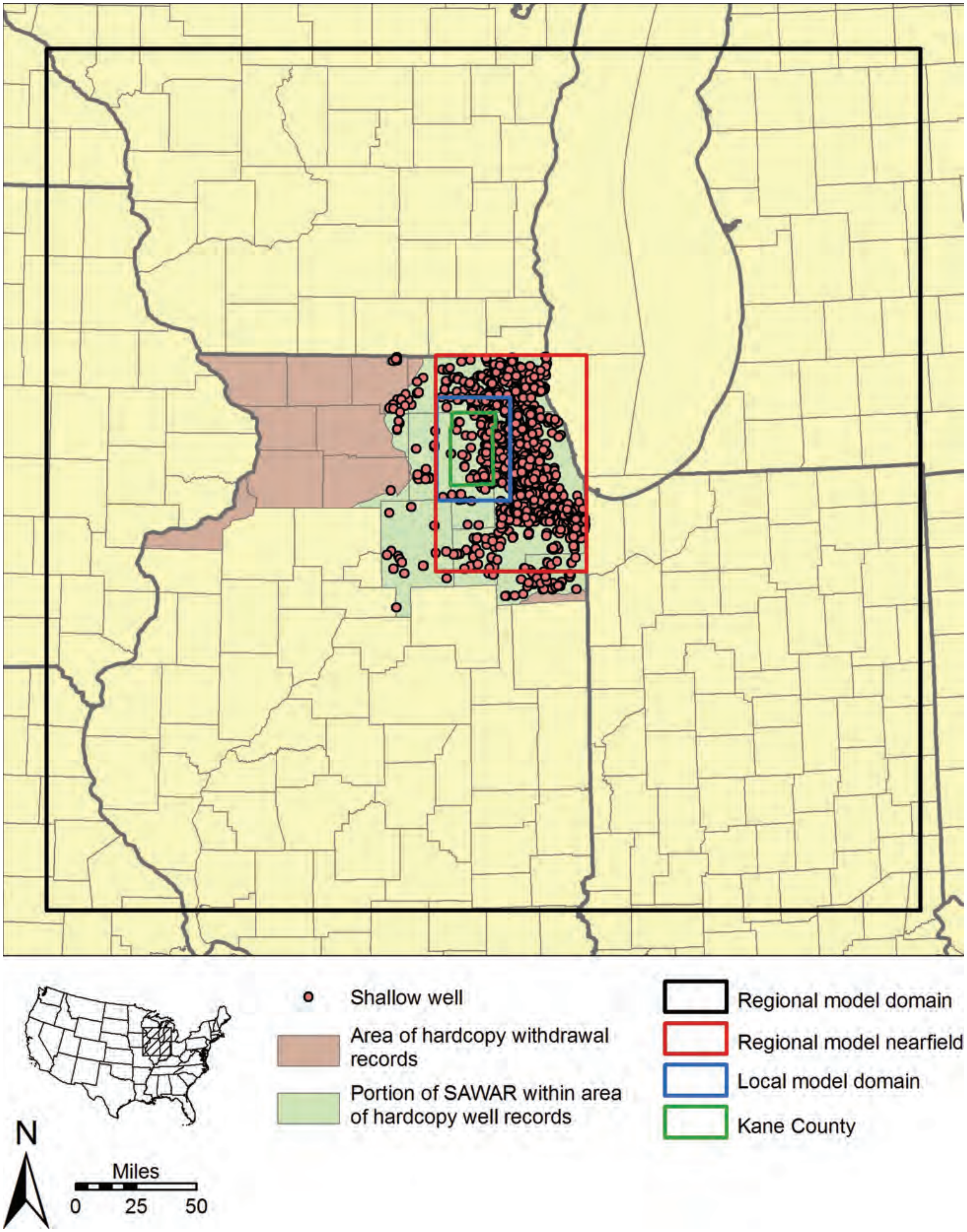

Figure B-6. Shallow wells in Illinois having withdrawals documented by hardcopy records spanning the period 1964-1979.

B.2.1.3. ISWS Public-Industrial-Commercial Survey (PICS) Database

Withdrawal data derived from the ISWS PICS Database were processed in much the same way as the hardcopy-derived data discussed in the previous section. In order to employ the data in project groundwater flow modeling, many withdrawal records obtained by querying the PICS Database required augmentation with (1) ILLIMAP *x*- and *y*-coordinates and (2) characterization of the source interval of the represented wells. The PICS Database contains ILLIMAP coordinates for many, but not all, of the wells represented in it, and these coordinates are employed in project modeling if available; it was necessary to estimate the missing coordinates. Similarly, ISWS aquifer codes (Appendix F) are contained in the PICS Database for some, but not all, wells. If suitably specific, these aquifer codes were employed directly for source interval characterization, but—as discussed in the preceding section—many of the aquifer codes used in the PICS Database denote unspecified stratigraphic units within an interval encompassing several stratigraphic units. For wells for which the PICS Database contains a non-specific aquifer code, it was necessary to substitute a project aquifer code denoting a specific interval that is directly translatable to the layer scheme of the regional model.

If ILLIMAP coordinates were not listed in the PICS Database, they were estimated using ISWS and ISGS computer programs that base coordinate determinations on county name, township, range, section, and 10-acre plot (Appendix I), as discussed in the preceding section on 1964-1979 Illinois withdrawal data derived from hardcopy sources. If a well location was surveyed for purposes of potentiometric surface mapping (Locke and Meyer, 2005), the *x*- and *y*-coordinates assigned to the well are based on surveying conducted for the mapping effort.

Using the same approach discussed in the preceding section, source interval characterizations, in the form of four-digit aquifer codes consistent with ISWS conventions (Appendix F), were assigned to withdrawal records obtained from the ISWS PICS Database on the basis of entries in a field in that database containing such codes. The PICS Database entries were used without alteration if they were specific enough to permit direct translation to the regional model layer scheme. Based on research of hardcopy well logs and other records on file at the ISWS, electronic database records of nearby wells, and available geologic mapping, project aquifer codes were substituted for nonspecific aquifer codes in the PICS Database. Of the 5222 wells for which withdrawal records were obtained from the PICS Database, 192 were assigned such nonspecific aquifer codes in the database. Each of these wells was assigned a project aquifer code that could be directly translated to a source interval characterization based on the layer scheme of the regional model (Figure B-3). Of the 5222 wells for which withdrawal records were obtained from the PICS Database, 84 were assigned no aquifer code in the PICS Database. A project aquifer code was also assumed for these wells.

In order to more completely represent recent groundwater use in the Illinois portion of the regional model domain, groundwater withdrawals were estimated for the years 1980 through 2003 for selected wells listed in the ISWS PICS Database, using an automated procedure. Withdrawals were estimated for wells during years when a facility (for example, a public water system or industrial/commercial facility) did not report withdrawals to the ISWS. The PICS Database contains a field indicating the status of a well and containing a one-character code such as *A* (abandoned), *U* (unused), *E* (emergency), etc. This field was employed to further restrict the population of wells for which estimates were developed to wells having a status code of *I* (in use). Application of the above criteria resulted in the identification of a population of wells for which withdrawal estimates were needed and, for each well, a year or years for which withdrawal estimates were needed.

Estimates of annual withdrawals were developed for 1323 of the 5222 wells for which withdrawal data were obtained from the PICS Database. Alternatively, 8379 estimates were developed for this project from the PICS Database data, as compared to 86,306 reported withdrawal values used for this project from the database. An estimation window was defined for each of these wells using initiation and sealing dates contained in the PICS Database as the first and last years of the window. In cases wherein these fields are not completed, the first year of the estimation window was assumed to be 1980 and the last year was assumed to be 2003. Estimates were developed using one of three different approaches designed for the following situations (Figure B-7): (1) the estimate was for one or more years at the start of the estimation window, with reported withdrawals available only for later years; (2) the estimate was for one or more years at the end of the estimation window, with reported withdrawals available only for earlier years; or (3) the estimate was for one or more years within the estimation window, with reported withdrawals available for both earlier and later years. Withdrawals for years at the start of the estimation window were estimated to be equal to the first year of reported withdrawals for the well. Similarly, withdrawals for years at the end of the estimation window were estimated to be equal to the last year of reported withdrawals. Withdrawals for years within the estimation window, with reported withdrawals available for both earlier and later years, were estimated by linear interpolation. Figure B-8 shows the sum of estimated withdrawals based on ISWS PICS Database records and the total of the estimates and the reported withdrawal values obtained from the PICS Database for the project.

Distribution of wells covered by the PICS Database withdrawal records and associated estimates are shown in Figure B-9 and Figure B-10.

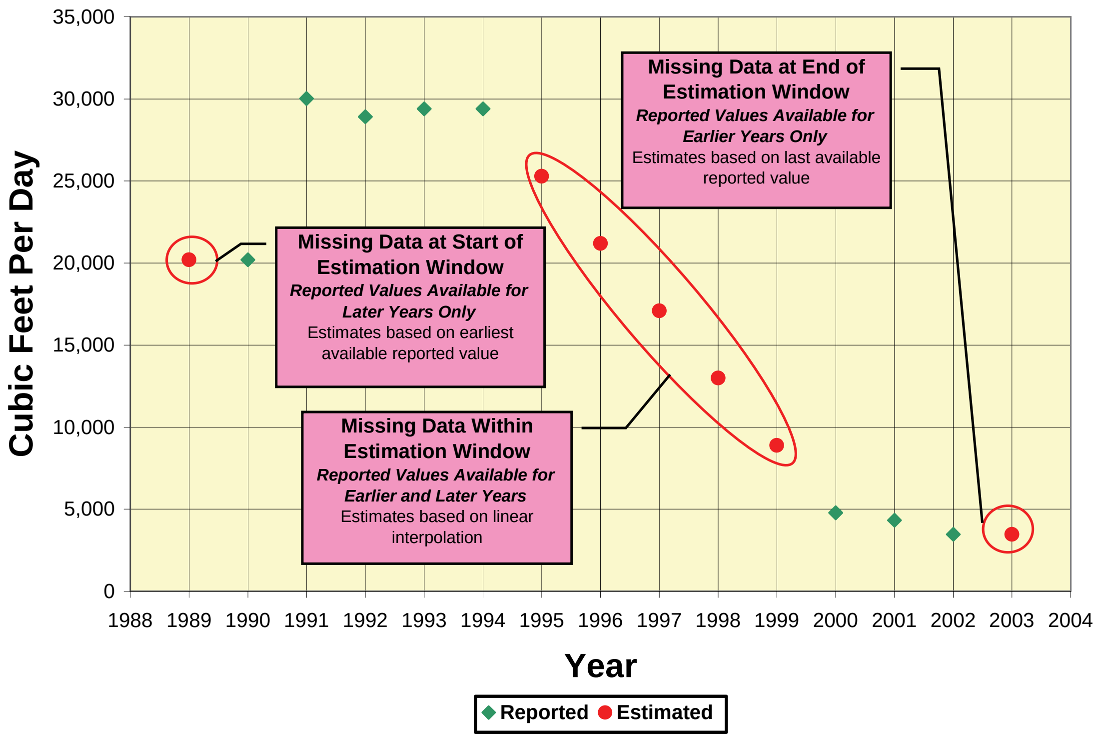

Figure B-7. Example of methods used for estimation of 1980-2003 Illinois withdrawals for years of non-reporting by facilities to the Illinois Water Inventory Program, which provides data to the ISWS PICS Database.

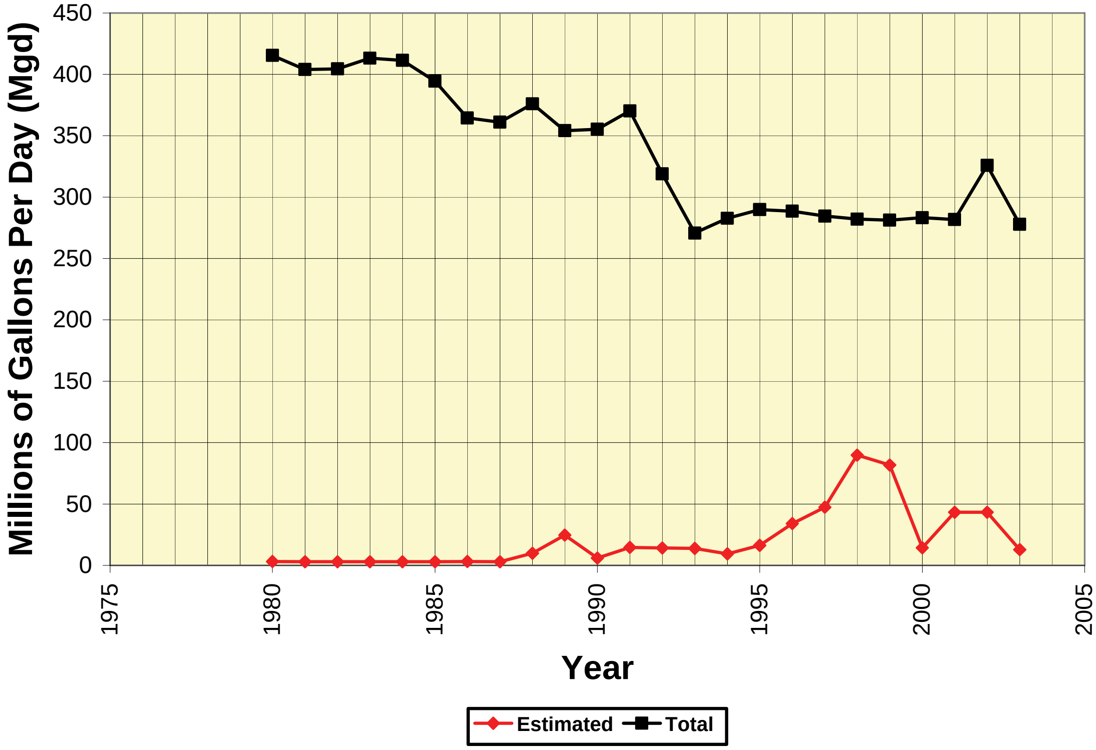

Figure B-8. Estimated withdrawals from wells recorded in ISWS PICS Database represented in the regional model, 1980-2003, and total withdrawals, including both reported and estimated withdrawals.

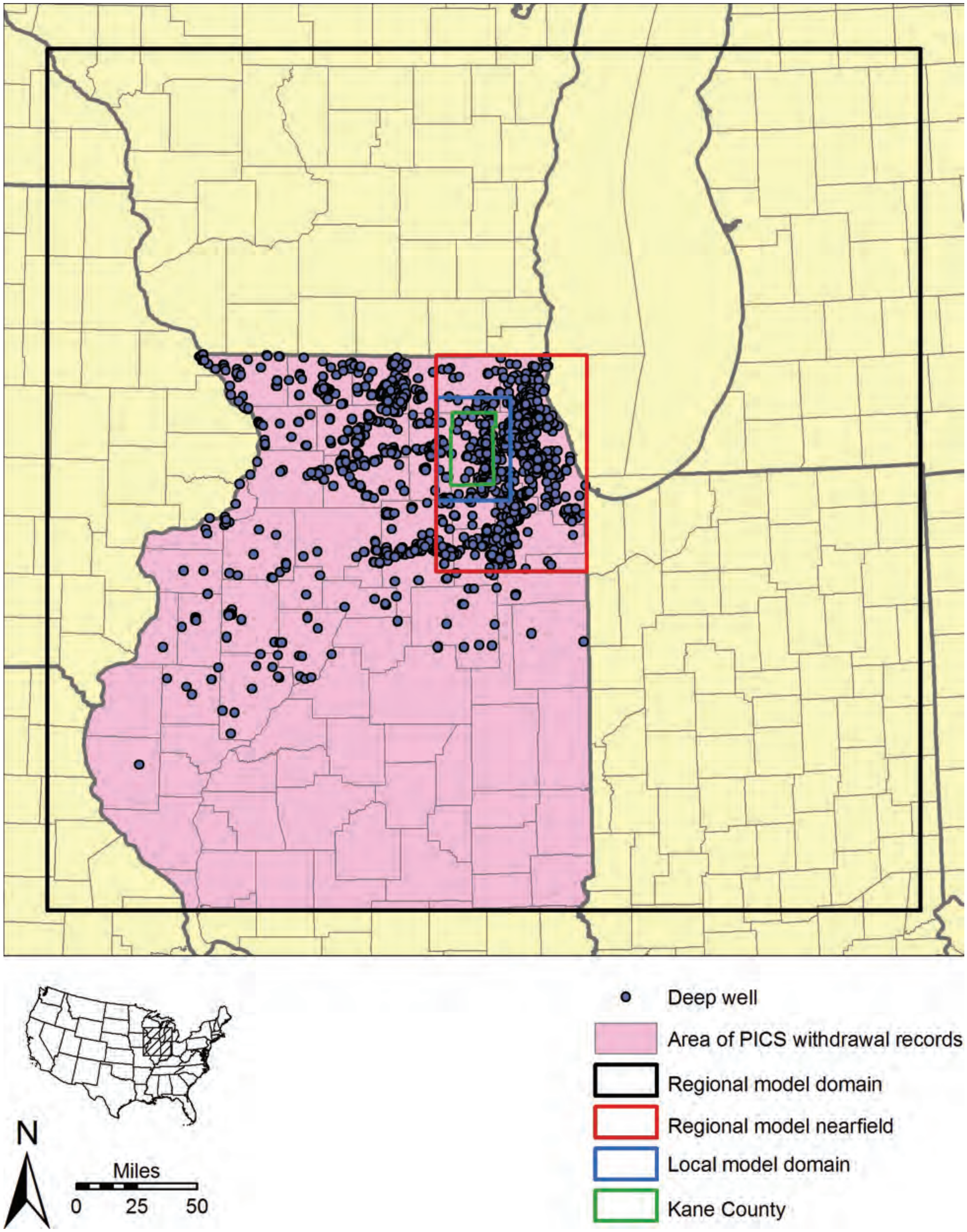

Figure B-9. Deep wells in Illinois having 1980-2003 withdrawals documented by ISWS PICS Database.

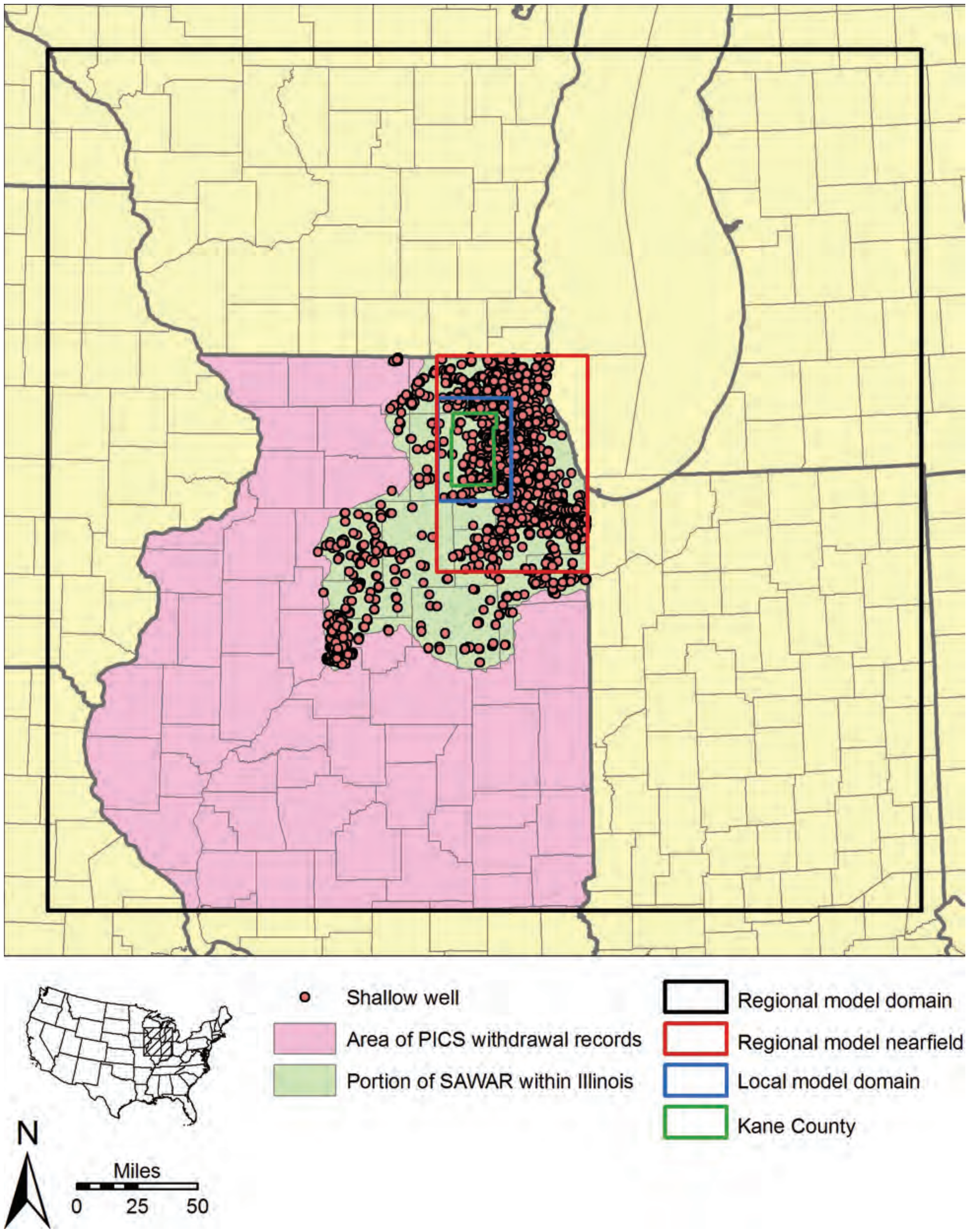

Figure B-10. Shallow wells in Illinois having 1980-2003 withdrawals documented by ISWS PICS Database.

B.2.1.4. Assumed Withdrawals from Deep Domestic Wells in Northeastern Illinois

The ISWS Private Well Database was queried to obtain a list of domestic and commercial water-supply wells within counties partially or completely contained within the nearfield of the regional groundwater flow model (the Illinois counties of Boone, Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, LaSalle, McHenry, and Will). The query results were reduced to a manageable size by applying rough depth criteria to remove records of wells of insufficient depth to penetrate the bottom of the Galena-Platteville Unit. Thus records of wells in Cook, Lake, and Will Counties were removed from the list if their depth was less than 500 feet (ft), and records of wells in DuPage, Kane, and McHenry Counties were removed if they were shallower than 400 ft. Stricter criteria were applied later to eliminate additional wells not penetrating the bottom of the Galena-Platteville Unit. All wells in Boone, DeKalb, Grundy, Kankakee, Kendall, and LaSalle Counties were retained in the query results.

If not already included in the query results, ILLIMAP *x*- and *y*-coordinates were estimated for these wells using ISWS and ISGS computer programs that base coordinate determinations on county name, township, range, section, and 10-acre plot (Appendix I). The estimated coordinates correspond to the center of a 10-acre plot.

These coordinates permitted the query results, modified to remove shallow wells, to be imported and plotted in ArcGIS, converted to shapefile format and further modified. First, the query results were reduced by removing all records of wells located outside the regional model nearfield. Second, a spatial join was executed to add estimates of the elevation of the top of each regional model layer, and the bottom of model layer 20, to the attribute table of the shapefile of wells within the regional model nearfield. The approximate bottom elevation of each of the wells included in the shapefile was calculated by subtracting the well depth from the top elevation of model layer 1 (land surface). Wells having a bottom elevation less than the top elevation of model layer 12 (the bottom of the Platteville Group) were selected from the shapefile and then exported as another shapefile representing only sub-Platteville domestic and commercial water-supply wells in the regional model nearfield.

Further data processing was necessary to characterize the open intervals of the deep wells and permit their inclusion in the regional groundwater flow model. Ideally, open intervals could be characterized using casing depth and well depth data, both of which are represented by fields in the ISWS Private Well Database. Unfortunately—though well depth is known for all of the 3762 wells in the shapefile of deep wells—casing-depth data is available only for 903 of these wells. Therefore, the relationship between the open interval of the 903 wells having both casing and well depth data was examined to determine the most likely open interval in the wells lacking casing depth data. This relationship was analyzed independently for each of the Quaternary subcrop belts present in the regional model nearfield and, where Pennsylvanian rocks are present in the nearfield, for each Pennsylvanian subcrop belt. Employing elevation data for land-surface and the tops of the hydrostratigraphic units used in the regional groundwater flow model, differences in elevation between casing bottom, well bottom, and the tops of the hydrostratigraphic units were calculated for each of the 903 wells having documented casing and wells depths. Median differences in elevation were calculated from these data; from these medians, the most probable open interval was deduced for deep wells in each subcrop belt (Table B-5, Table B-6). All wells lacking casing depth data in the ISWS Private Well Database were then segregated by subcrop belt, and the uppermost model layer of the open interval of typical deep wells in that well's subcrop belt (Table B-7) was assumed to be the uppermost model layer of each of these wells. Well depth data were available for all 3762 wells, and the lowermost model layer to which the well was open was determined by comparing the difference in elevation between the well bottom and the tops of the hydrostratigraphic units. The lowermost model layer to which the well was open was assumed to be the deepest model layer for which this elevation difference was zero or negative. For example, if well bottom elevation was estimated at 100 ft above mean sea level (MSL) at a location where the tops of model layers 12 and 13 were at elevations of 150 ft and 50 ft above MSL, respectively, the lowermost model layer to which the well is open was assumed to be model layer 12. The elevation difference between the well bottom and the top of this layer would be -50 ft, while the difference between the well bottom and the top of model layer 13 would be +50 ft.

After augmenting the file of 3762 deep wells with x- and y-coordinates and open interval characterizations, the file was reduced to only those recognized as domestic wells in the ISWS Private Well Database. Thus, irrigation and commercial/industrial wells—wells already included in the withdrawal database for the project—were removed from the file. This reduced the number of wells represented in the file to 3060 (Figure B-11).

Withdrawal rates for the wells are based on linear interpolation of estimates of per-capita self-supplied domestic water use developed at five-year increments for the period 1960-2000 by the United States Geological Survey (USGS) and reported by Dziegielewski et al. (2005) (Figure B-12), together with the assumption that each well supplies 3.4 people (Illinois Department of Energy and Natural Resources, 1998). Pre-1960 per-capita withdrawal rates are assumed to have been equal to the 1960 rate determined by linear interpolation of the USGS estimates [5.2 cubic feet per day (ft^3/d)], but per capita rates between 1960 and 2003 are assumed to have increased in a linear fashion from 5.2 to 13.6 ft^3/d. Withdrawals from the wells were assumed to have occurred for the entire year of drilling and to have been zero during the year of sealing. The ISWS Private Well Database reliably includes the year of drilling of these wells, but a field devoted to housing sealing date data is completed for only a small minority of wells. If the sealing date was not available, the well was assumed to be in service through the year 2003. Per-capita self-supplied domestic water use rates for the period 2005-2050, based on linear interpolation of the 1960-2000 USGS estimates, are employed in pumping forecasts discussed in Appendix G.

Table B-5. Median Distance Between Casing Bottom and Top of Hydrostratigraphic Units for Deep Wells Listed in the ISWS Private Well Database in Northeastern Illinois

Subcrop Belt (OverlyingUnit/ Underlying Unit)	*No. of Wells*	*Median Distance (ft) Between Casing Bottom and Top of Hydrostratigraphic Unit*										
		QT*	***UB***	***SD***	***MQ***	***GP***	***AN***	***PE***	***PF***	***IG***	***EC***	***MS***
QT/SD*	77	-420	-288	-287	-201	-37	300	478	641	827	954	1367
UB/SD	0											
QT/MQ	466	-273.5	-170	-169	-166	-41	318	600	684	903	1034	1442
UB/MQ	17	-163	-124	-51	-48	12	351	610	918	1255	1418	1866
QT/GP	29	-145	-30	-29	-26	-24	179	409	669	963	1106	1508
UB/GP	76	-226	-135.5	-36.5	-33.5	-31.5	71.5	354.5	697	1021.5	1183.5	1594
QT/AN	91	-155	-66	-65	-62	-60	-58	-13	352	628	786	1175
UB/AN	5	-279	-95	-46	-43	-41	-39	146	550	833	974	1385
QT/PE	142	-103.5	-32.5	-31.5	-28.5	-26.5	-24.5	-23.5	314	587	748.5	1134.5

*See Figure 25 for key to acronyms

Table B-6. Median Distance Between Well Bottom and Top of Hydrostratigraphic Units for Deep Wells Listed in the ISWS Private Well Database in Northeastern Illinois

Subcrop Belt (OverlyingUnit/ Underlying Unit)	*No. of Wells*	*Median Distance (ft) Between Well Bottom and Top of Hydrostratigraphic Unit*										
		QT*	***UB***	***SD***	***MQ***	***GP***	***AN***	***PE***	***PF***	***IG***	***EC***	***MS***
QT/SD*	77	-800	-649	-648	-579	-399	-50	125	274	446	589	998
UB/SD	0											
QT/MQ	466	-640	-543	-542	-539	-392	-34	232	326	525	640	1042
UB/MQ	17	-560	-551	-454	-451	-397	-62	205	518	849	1021	1468
QT/GP	29	-440	-350	-349	-346	-344	-85	119	374	654	804	1192
UB/GP	76	-360	-261.5	-185	-182	-180	-59	176	570	892.5	1047	1481.5
QT/SP	91	-200	-102	-101	-98	-96	-94	-58	288	577	716	1110
UB/SP	5	-360	-197	-127	-124	-122	-120	54	463	753	894	1305
QT/PJ	142	-140	-69.5	-68.5	-65.5	-63.5	-61.5	-60.5	270	545	699.5	1087.5

*See Figure 25 for key to acronyms

Table B-7. Assumed Open Intervals of Deep Wells in Northeastern Illinois Lacking Casing-Depth Data Based on Data in Table B-5 and Table B-6

Subcrop Belt (OverlyingUnit/ Underlying Unit)	***Assumed Open Interval***	
	Uppermost Model Layer	***Lowermost Model Layer***
QT/SD*	10	12
UB/SD	10	12
QT/MQ	10	12
UB/MQ	8	12
QT/GP	10	12
UB/GP	10	12
QT/SP	13	13
UB/SP	12	12
QT/PJ	13	13

*See Figure 25 for key to acronyms

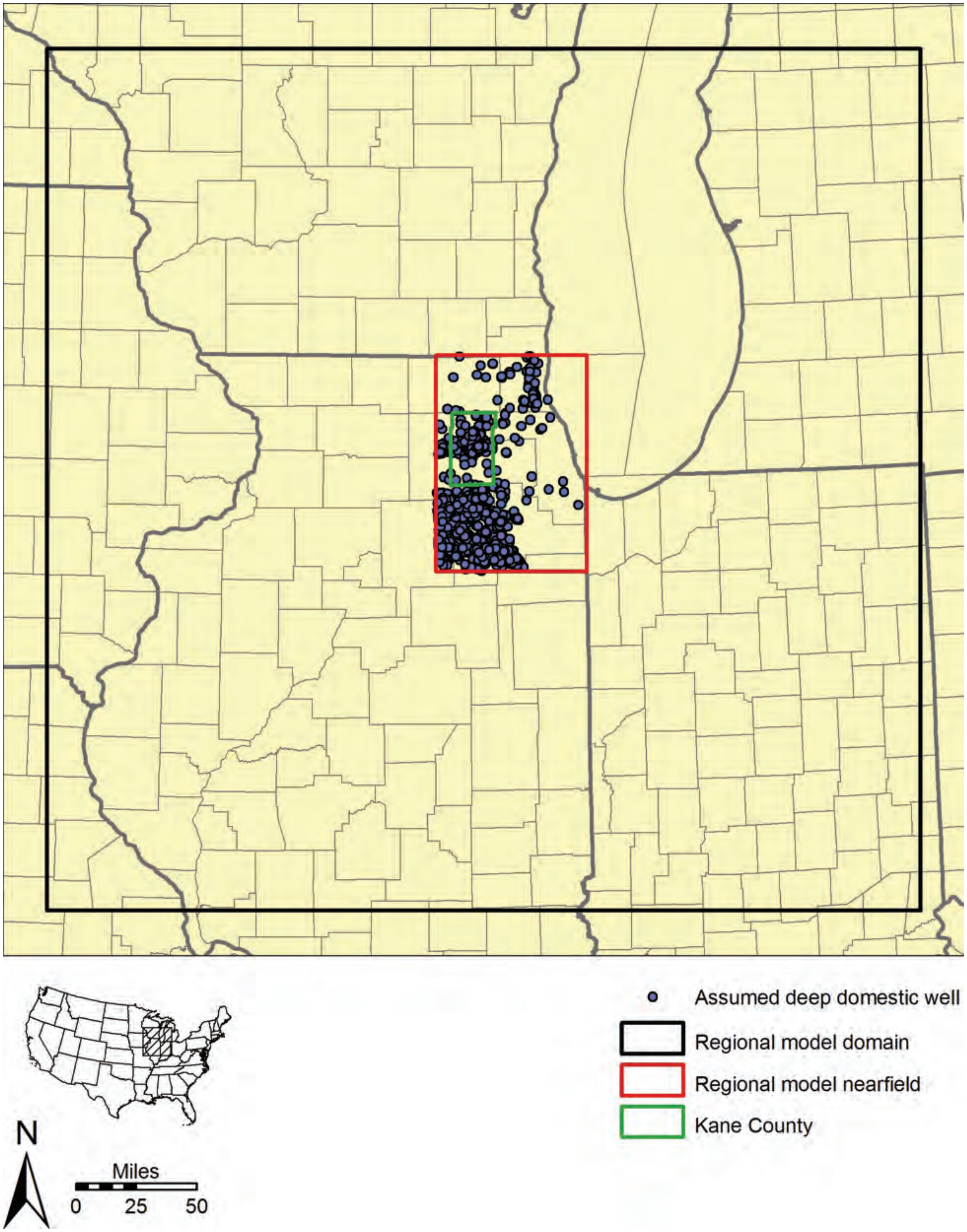

Figure B-11. Deep domestic wells.

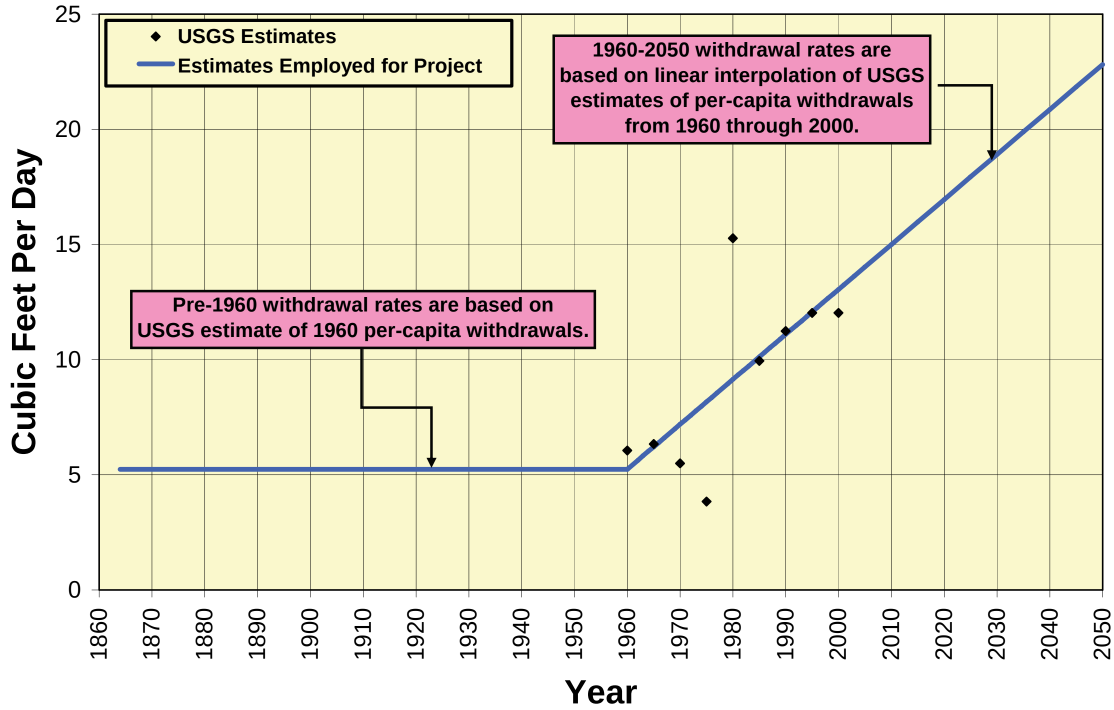

Figure B-12. Estimated per-capita self-supplied domestic withdrawal rates.

B.2.2. Indiana

Data purchased from the Indiana Department of Natural Resources mainly required processing to assign the represented wells ILLIMAP *x*- and *y*-coordinates and to characterize the open intervals of the wells using model layers.

The Indiana withdrawal database contained fields for the *x*- and *y*-coordinates of wells, but these coordinates were referenced to the NAD 1927 UTM Zone 16N projection and coordinate system used by the State of Indiana. A GIS procedure was employed to generate ILLIMAP coordinates for the Indiana wells. First, the Indiana wells were saved as an ArcGIS point-shapefile format referencing their native UTM projection and coordinate system. This shapefile was then imported into an ArcGIS data frame that had been assigned the ILLIMAP projection and coordinate system. Next, the imported data were exported as a point-shapefile referenced to the ILLIMAP system. Finally, fields for the ILLIMAP *x*- and *y*-coordinates were added to the attribute table of this shapefile, and these fields were populated using VBA scripts to calculate x- and y-coordinates of the data points.

The open intervals of the Indiana wells were characterized using aquifer codes consistent with ISWS standards (see Appendix F) that could be directly translated to a characterization referencing the layers of the regional groundwater flow model (Table B-4). These aquifer codes were assigned on the basis of a rough characterization of the open intervals of the wells by the

Indiana authorities, on the depths of the wells as indicated by the database as received, and on regional geological information.

Indiana wells represented in the withdrawal database are shown in Figure B-13 and Figure B-14. Only a single deep Indiana well is included in the database.

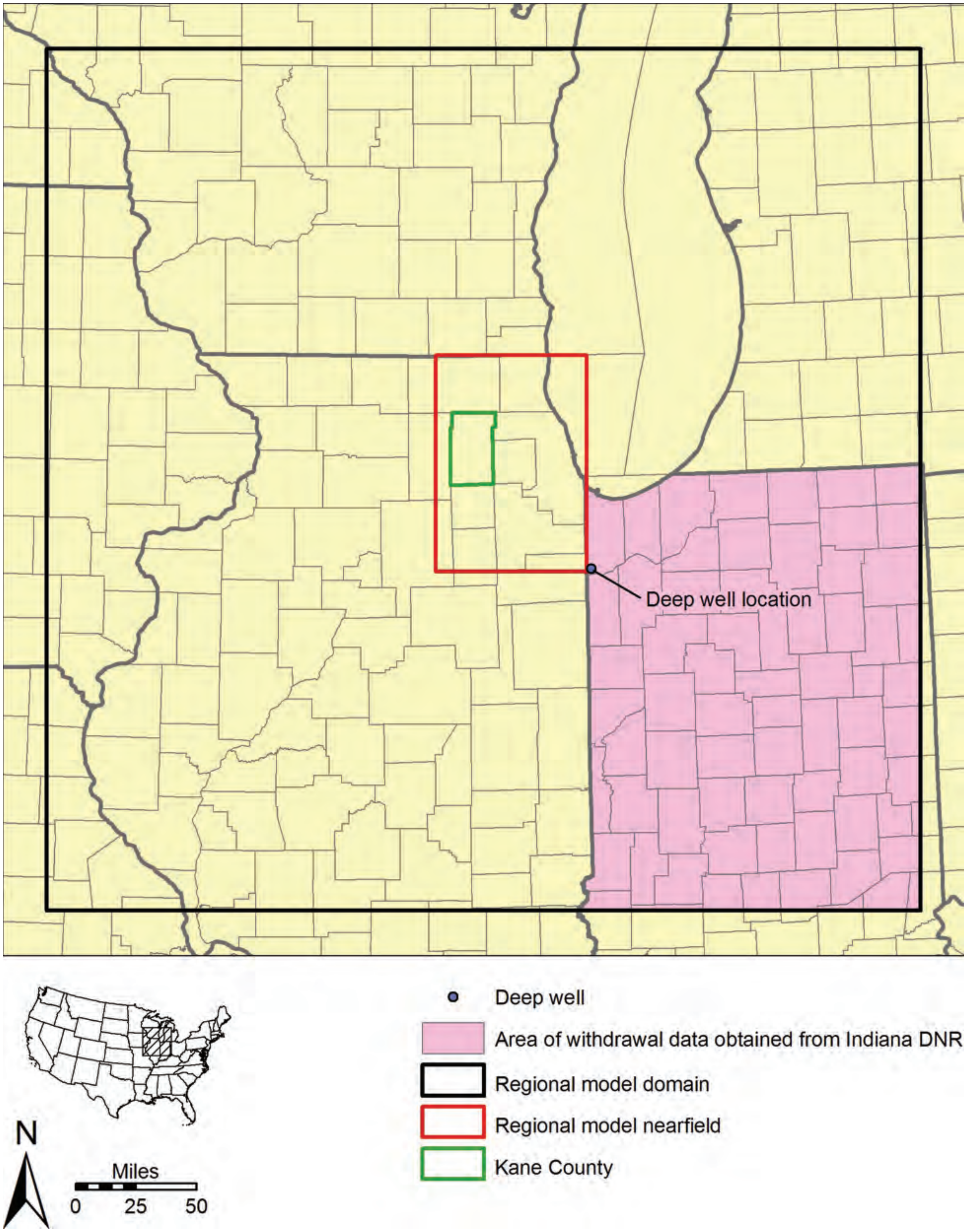

Figure B-13. Deep well in Indiana having 1985-2002 withdrawals documented by Indiana Department of Natural Resources database.

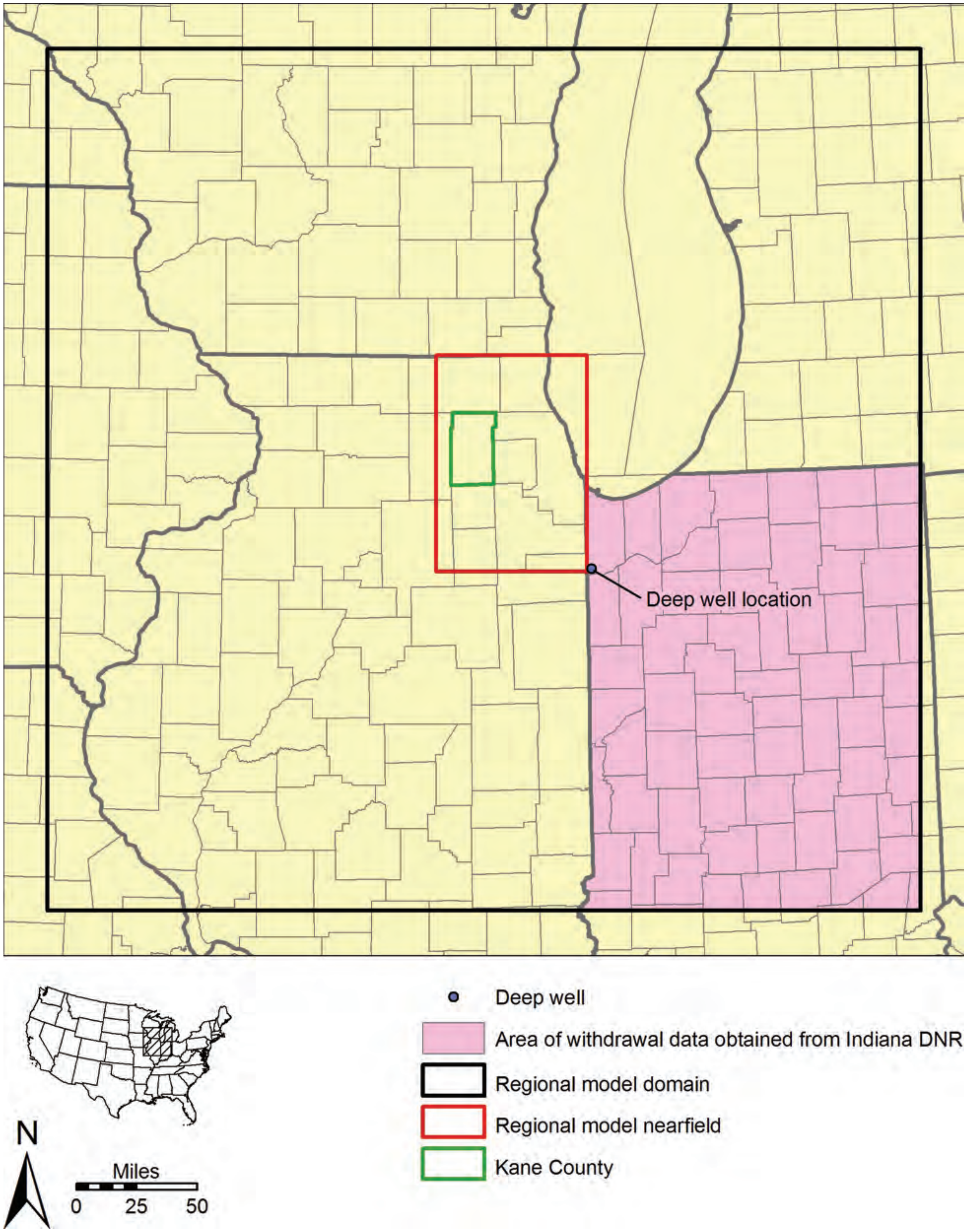

Figure B-14. Shallow wells in Indiana having 1985-2002 withdrawals documented by Indiana Department of Natural Resources database.

B.2.3. Wisconsin

Wisconsin withdrawal data were received from the Wisconsin Geological and Natural History Survey in two separate files, each representing a separate group of wells. In one file, open intervals were characterized using top and bottom elevations of the open interval. In the second file, open intervals were characterized using the uppermost and lowermost model layer to which each well was open, referencing the layer nomenclature employed in the project for which the file was developed (Feinstein et al., 2005a; Feinstein et al., 2005b). The wells in the second file were universally open to the same interval of Cambrian and Ordovician bedrock, an interval corresponding to layers 12 through 20 of the regional groundwater flow model developed for the present study. In both files, withdrawal rates were given as average withdrawal rates for stress periods of 2 to 20 years' duration covering the period 1864 through 2002.

Like the Indiana wells, it was necessary to assign ILLIMAP *x*- and *y*-coordinates to the Wisconsin wells represented in the two files. Coordinates included in the files, as received from the Wisconsin Geological and Natural History Survey, referenced the Wisconsin Transverse Mercator (WTM) projection and coordinate system. The files were saved as an ArcGIS shapefile referenced to the WTM system, and this shapefile was then imported into a data frame referencing the ILLIMAP system. The Wisconsin well locations were then exported as a shapefile referencing the ILLIMAP projection and coordinate system. Fields to contain the ILLIMAP *x*- and *y*-coordinates were then added to the attribute table of the latter shapefile, and these fields were populated using VBA scripts to calculate x- and y-coordinates of the data points.

Stress-period averages were disaggregated and incorporated into the database as the withdrawal rate for each year of the stress period. For example, the pumping rate for a well given by the Wisconsin Geological and Natural History Survey for the stress period 1971 through 1980 was assumed to be the pumping rate for each year of the period 1971 to1980.

The open-interval characterizations provided by the Wisconsin Geological and Natural History Survey as elevations were not altered and were retained in the project database as the basis for input of the wells into the regional groundwater flow model. The open interval characterizations of wells provided as model layers—universally layers 13 through 16 of the Wisconsin modeling effort—were altered to the model layer designations used for the modeling project described in the present study (layers 12 through 20).

The Wisconsin wells represented in the provided dataset include both shallow and deep wells. Since the area covered by the dataset is roughly coincident with the portion of the shallow aquifer withdrawal accounting region (SAWAR) within Wisconsin, no effort was made to remove shallow wells falling outside this region.

Locations of the Wisconsin wells provided by the Wisconsin Geological and Natural History Survey, and included in the modeling database, are shown in Figure B-15 and Figure B-16.

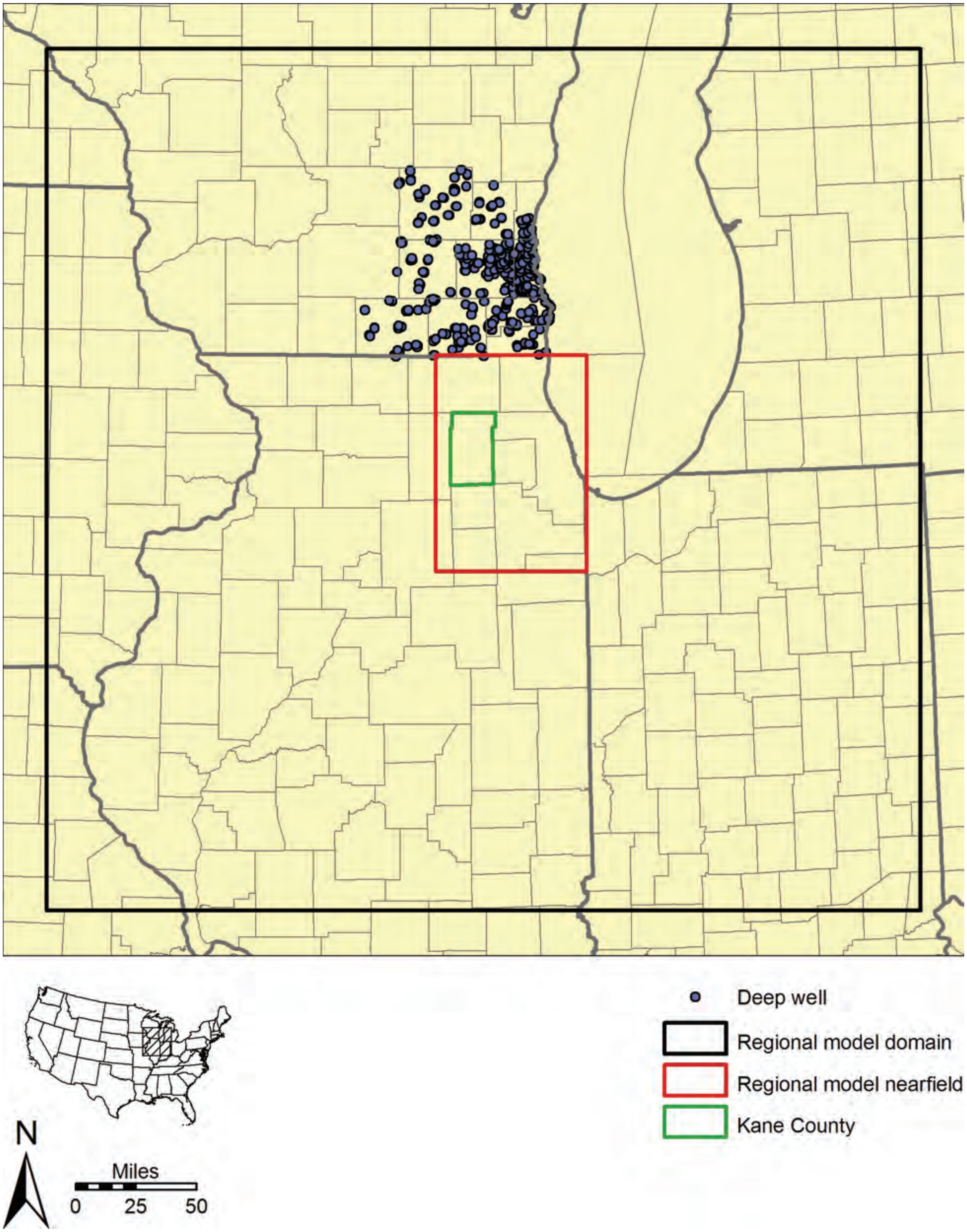

Figure B-15. Deep wells in Wisconsin having 1984-2002 withdrawals documented by records obtained from the Wisconsin Geological and Natural History Survey.

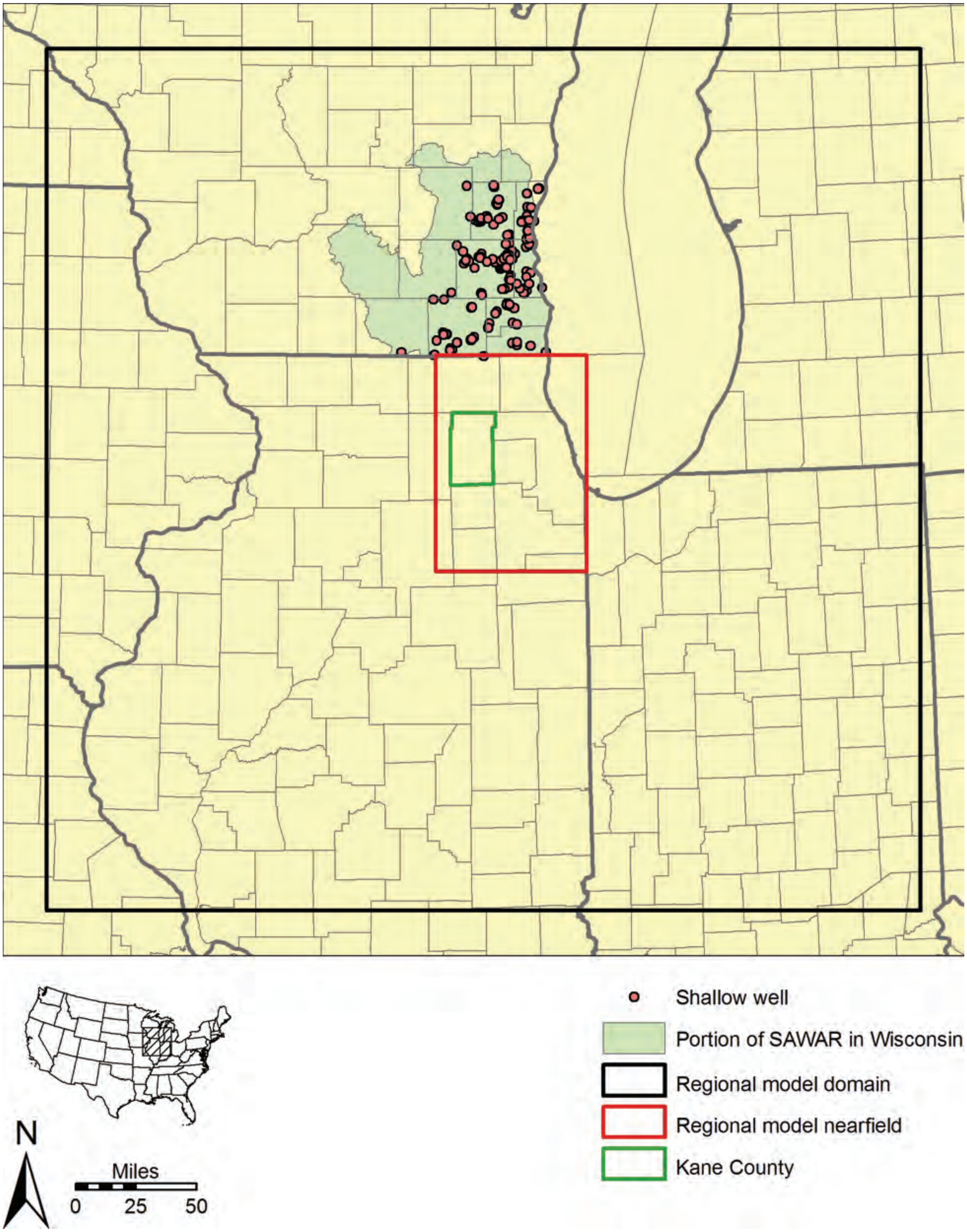

Figure B-16. Shallow wells in Wisconsin having 1984-2002 withdrawals documented by records obtained from the Wisconsin Geological and Natural History Survey.

B.3. Uncertainties

The following section discusses uncertainties associated with the withdrawal data compiled for the modeling effort. Two aspects of uncertainty are discussed below: uncertainty of withdrawal rate data and positional accuracy.

A third aspect—completeness—is commented upon here. The principal withdrawal datasets consulted for this study—pre-1964 Illinois data obtained from previous modeling studies, Illinois data for the period 1964-1979 obtained from hardcopy records, data obtained from the ISWS PICS Database for the period 1980-2003, and withdrawal data obtained from Indiana authorities for the period 1985-2002 and from Wisconsin authorities for the period 1864-2002—are thought by their compilers to represent the majority of withdrawals in these areas during the time periods covered. It is acknowledged that some withdrawals—particularly during years earlier in the history of the groundwater development of the region—have been missed by the compilers of these datasets, but quantification of the completeness of the datasets is beyond the scope of this study. With the exception of withdrawals from domestic wells open to the sub-Platteville interval in the regional model nearfield, withdrawals from domestic wells are not included in the datasets. Withdrawals were not estimated for domestic wells open to shallower units because 85 to 90 percent of the relatively small quantities of groundwater withdrawn from such wells would be returned via on-site wastewater disposal systems to the shallow interval from which they were obtained (Pebbles, 2003; United States Environmental Protection Agency Region V, 1975), with little net effect on groundwater flow.

B.3.1. Illinois

B.3.1.1. Data Obtained from Previous Modeling Studies

Suter et al. (1959) do not estimate the uncertainty of the withdrawal estimates in northeastern Illinois that are employed to represent withdrawals in groundwater flow modeling developed for the present project from 1864 through 1958. Nor do Prickett and Lonnquist (1971), who employed the estimates of Suter et al. (1959) in groundwater flow modeling and whose pumping estimates for the period 1959 through 1963 are employed in the present study. Suter et al. (1959) described a procedure that would seem to imply a high degree of uncertainty, however, indicating that their plots of withdrawals

> *were constructed by piecing together fragments of information on pumpage found in published reports and in the files of the State Water Survey, by making evaluations based on the number of wells, their reported yields, and their time of construction, and by taking into consideration population growth and per capita consumption.*

Furthermore, Suter et al. (1959) indicate that, although records of withdrawals are fairly complete for the period 1942 through 1958, “very few records of pumpage are available for years prior to 1942.” Adding to the uncertainty of the 1864-1963 period is the probability that withdrawal data employed for the present study—received in the form of digital files—were estimated from small plots appearing in the 1959 report of Suter et al. Finally, for the present study, these estimates were revised upward using a rough approximation to reflect contributions to pumping from deep wells by units overlying the Ancell Group and underlying the Ironton-Galesville Sandstone.

With the lack of source documentation of the 1864-1963 withdrawal estimates and the procedures used to generate them, estimation of uncertainty is problematic. A component of uncertainty exists that is associated with the measurement of withdrawals during this time period, and this component of uncertainty—as opposed to those associated with documentation and reporting procedures and with estimation of withdrawals based on population growth, per-capita consumption, and numbers of wells—is quantified in the literature. The United States Department of the Interior Bureau of Reclamation (1997) estimates that most flow-measurement devices produce accuracies of ±5 percent, but accuracy declines to ±10 percent when instruments are not maintained, when they are inappropriate for site conditions, and when they are deployed in nonstandard installations. It is probable, owing to improvements in flow-measurement technology, that accuracies of measured withdrawals are poorer with increasing age. Solely on the basis of the accuracy of flow-measurement devices, it is probable that the pre-1964 withdrawal data employed in the present study are only accurate to ±10 percent.

Burch (1991), who also relied on the early Illinois withdrawal data ultimately derived from the plots of Suter et al. (1959), evaluated the accuracy of published estimates of early withdrawals by comparing published estimates of withdrawals in ISWS reports covering the period 1964-1980 with estimates developed from tabulations of detailed hardcopy withdrawal data covering the same time period. Burch (1991) found that the difference between the published estimates and the tabulations increased from 2 percent in 1980 to 22 percent in 1964. This analysis suggests an uncertainty in excess of ±20 percent for the pre-1964 withdrawal estimates employed for the present study.

Withdrawals for the period 1864-1963 are not assigned to actual well locations but are rather aggregated at seven northeastern Illinois pumping centers. The locations of six of these pumping centers were selected by Suter et al. (1959), with a seventh added by Prickett and Lonnquist (1971), to best represent actual pumping in northeastern Illinois. The *x*- and *y*-coordinates selected by Burch (1991) are employed to represent these pumping centers. Since the coordinates do not represent actual well locations, the positional accuracy of these coordinates is not discussed further. Detailed withdrawal data, representing reported withdrawals at actual well locations, are employed for the post-1963 period, allowing the groundwater flow models nearly 40 years to adjust to detailed pumping conditions. It is acknowledged that model accuracy for the period ending 1963 is limited owing to the simplified representation of pumping conditions for that period.

B.3.1.2. Hardcopy Data

The uncertainty of withdrawals documented in hardcopy form by the ISWS for the period 1964-1979 varies with year, facility, and well. These withdrawal data consist of measurements from water meters or estimates by water managers, reported to the ISWS, as well as estimates by ISWS researchers themselves. Withdrawals from public water system wells are nearly always metered in cities, but many smaller villages operate without meters, and withdrawals from wells operated by self-supplied industrial and commercial facilities and from irrigation wells are not typically metered. The United States Department of the Interior Bureau of Reclamation (1997) estimates that most water measurement devices have an accuracy of ±5 percent, but this accuracy declines to ±10 percent when instruments are not maintained, when they are inappropriate for site conditions, and when they are deployed in nonstandard installations. Metering devices, installations, and procedures are not documented, and undoubtedly vary between facilities and wells, so it is not possible to quantify the uncertainty of these measurements. Accuracies of estimated withdrawals are not known. Based on the accuracy estimates of the Bureau of

Reclamation and the likelihood that estimated withdrawals are less accurate than measurements using water meters, it is probably safe to assume that the hardcopy withdrawal data are accurate only to within ±10 percent.

For the vast majority of wells documented by hardcopy withdrawal records, locational coordinates are largely accurate to the 10-acre plot within which the well is reported to be located (Appendix I). Still, the locations of some wells are not known to the 10-acre plot, but rather only to the section or, in a few cases, the township. For the majority of wells, wherein the locational coordinates are accurate to within a reported 10-acre plot, the *x*- and *y*-coordinates have an accuracy of about ±500 ft. In the worst cases, wherein the coordinates are accurate only to within a reported township, the accuracy of the *x*- and *y*-coordinates declines to about ±22,500 ft. It is acknowledged that the reported locations of these wells may be erroneous, but this source of uncertainty is not evaluated. In other, comparatively rare, cases, well locations are known by surveying and are more accurate, typically within ±100 ft, but possibly within ±20 ft (Locke and Meyer, 2005).

B.3.1.3. ISWS Public-Industrial-Commercial Survey (PICS) Database

Like that of the withdrawal data derived from hardcopy data discussed in the preceding section, the uncertainty of the withdrawal data obtained from the ISWS PICS Database varies with year, facility, and well. This is because the data consist of measurements obtained using a variety of undocumented devices, installations, and procedures, together with estimates by reporting water managers and former ISWS staff. Thus, as for the hardcopy withdrawal data, it is probably safe to assume that the PICS withdrawal data are accurate only to within ±10 percent (United States Department of the Interior Bureau of Reclamation, 1997). Cross-validation analysis against reported rates of a sample of 94 withdrawal estimates, developed for this study using the procedure illustrated in Figure B-7, shows that the median error of the estimates to be about -2 percent.

Positional accuracy of the wells documented in the ISWS PICS Database is also similar to that of the wells documented by hardcopy records. Most of the locational coordinates are accurate to the 10-acre plot within which the well is reported to be located, and the *x*- and *y*-coordinates of such wells have an accuracy of about ±500 ft. This accuracy declines in instances wherein the 10-acre plot location is not known and is at its worst when even the section is unknown, so that the well is arbitrarily located at the center of a township; in the latter case, the accuracy of the *x*- and *y*-coordinates declines to about ±22,500 ft. The accuracy of surveyed coordinates is better, typically within ±100 ft, but possibly within ±20 ft (Locke and Meyer, 2005).

B.3.1.4. Assumed Withdrawals from Deep Domestic Wells in Northeastern Illinois

Withdrawals from deep domestic wells are based on a single estimate of 3.4 people served by each well (Illinois Department of Energy and Natural Resources, 1998), an estimate of per capita withdrawals based on interpolation of USGS estimates of self-supplied domestic per capita withdrawals from 1960 through 2000 [as reported by Dziegielewski et al. (2005)] (Figure B-12), and an assumed pumping period extending from the year of drilling to the year of sealing as shown by records in the ISWS Private Well Database. The uncertainty in these withdrawal estimates is considerable. The year of sealing of most wells listed in the ISWS Private Well Database is often not recorded, and the well has, consequently, been assumed to be active through the year 2003. It is likely that many such wells have actually been sealed, however, and the pumping rate is zero rather than the assumed rate. Countering this uncertainty in the pumping period is the likelihood that the records of the Private Well Database are incomplete, and that there are more deep domestic wells present than are actually recorded.

For purposes of illustrating the considerable uncertainty associated with the estimates of withdrawals from deep domestic wells, one can examine some simple, but likely, possibilities. First, it is very likely, as mentioned in the preceding paragraph, that withdrawals from many wells are zero—100 percent less than the assumed per-well rate—because they have been sealed. On the other hand, if one assumes (1) the highest USGS estimate of self-supplied domestic water use (15.3 ft^3/d per capita) rather than the per-capita rate estimated through interpolation (Figure B-12) and (2) that a well supplies a moderately large family of six rather than the assumed 3.4. It is demonstrable that the assumed per-well rate might be 100 percent more than the assumed rate and—for years prior to 1961 for which a low per-capita water usage of about 5.2 ft^3/d was assumed (Figure B-12)—the actual per-well withdrawal rate might be over 400 percent more than the assumed rate.

Locational coordinates are accurate to the 10-acre plot within which the well is reported to be located, so the *x*- and *y*-coordinates of such wells have an accuracy of about ±500 ft.

B.3.2. Indiana

Indiana groundwater withdrawal data are submitted by water managers to the Indiana Department of Natural Resources. It is probable that these submitted withdrawal data consist of measurements obtained through a wide range of procedures, using a variety of measurement devices and installations, as well as estimates. It is likely that these data are accurate only to within ±10 percent (United States Department of the Interior Bureau of Reclamation, 1997). Positional accuracy is not documented.

B.3.3. Wisconsin

Withdrawal data received from the Wisconsin Geological and Natural History Survey include estimates and measurements obtained using a wide range of procedures, devices, and installations, and accuracy probably varies considerably with facility, well, and year. Like the Illinois data obtained from pervious modeling studies, these estimates cover a long period beginning in 1864. The early estimates, in particular, are probably quite uncertain, possibly in excess of ±20 percent, as discussed in the section on Illinois data obtained from previous modeling studies. The accuracy of later estimates is probably better, possibly within ±10 percent (United States Department of the Interior Bureau of Reclamation, 1997). Positional accuracy is not documented.

B.4. References

Burch, S.L. 1991. *The New Chicago Model: A Reassessment of the Impacts of Lake Michigan Allocations on the Cambrian-Ordovician Aquifer System in Northeastern Illinois*. Illinois State Water Survey Research Report 119, Champaign, IL.

Dziegielewski, B., X. Yang, T. Bik, H. Margono, and M. Richey. 2005. *County-Level Forecasts of Water Use in Illinois: 2005-2025*. Department of Geography, Southern Illinois University, Carbondale, IL.

Feinstein, D.T., T.T. Eaton, D.J. Hart, J.T. Krohelski, and K.R. Bradbury. 2005a. *Regional Aquifer Model for Southeastern Wisconsin; Report 1: Data Collection, Conceptual Model Development, Numerical Model Construction, and Model Calibration*. Wisconsin Geological and Natural History Survey administrative report prepared for Southeastern Wisconsin Regional Planning Commission.

Feinstein, D.T., T.T. Eaton, D.J. Hart, J.T. Krohelski, and K.R. Bradbury. 2005b. *Regional Aquifer Model for Southeastern Wisconsin; Report 2: Model Results and Interpretation*. Wisconsin Geological and Natural History Survey administrative report prepared for Southeastern Wisconsin Regional Planning Commission.

Illinois Department of Energy and Natural Resources. 1998. *Fox River Area Assessment. Volume 2: Water Resources. Illinois Department of Natural Resources Critical Trends Assessment Program Document*. Springfield, IL.

Illinois State Water Survey and Hittman Associates. 1973. *Feasibility Study on Desalting Brackish Water from the Mt. Simon Aquifer in Northeastern Illinois*. Illinois State Water Survey Contract Report 153, Champaign, IL.

Locke, R.A., II and S.C. Meyer. 2005. *Kane County Water Resources Investigations: Interim Report on Shallow Aquifer Potentiometric Surface Mapping*. Illinois State Water Survey Contract Report 2005-04, Champaign, IL.

Pebbles, V. 2003. *Measuring and Estimating Consumptive Use of the Great Lakes Water*. Great Lakes Commission, Ann Arbor, MI.

Prickett, T.A. and C.G. Lonnquist. 1971. *Selected Digital Computer Techniques for Groundwater Resource Evaluation*. Illinois State Water Survey Bulletin 55, Champaign, IL.

Sasman, R.T. and W.H. Baker, Jr. 1966. *Ground-Water Pumpage in Northeastern Illinois through 1963*. Illinois State Water Survey Report of Investigation 52, Champaign, IL.

Sasman, R.T., W.H. Baker, Jr., and W.P. Patzer. 1962a. *Water-Level Decline and Pumpage During 1961 in Deep Wells in the Chicago Region, Illinois*. Illinois State Water Survey Circular 85, Champaign, IL.

Sasman, R.T., C.R. Benson, and G.L. Dzursin. 1974. *Groundwater Pumpage in Northern Illinois, 1960-1970*. Illinois State Water Survey Report of Investigation 73, Champaign, IL.

Sasman, R.T., C.R. Benson, G.L. Dzursin, and N.E. Risk. 1973. *Water-Level Decline and Pumpage in Deep Wells in Northern Illinois, 1966- 1971*. Illinois State Water Survey Circular 113, Champaign, IL.

Sasman, R.T., C.R. Benson, R.S. Ludwigs, and T.L. Williams. 1982. *Water-Level Trends, Pumpage, and Chemical Quality in the Cambrian-Ordovician Aquifer in Illinois, 1971-1980*. Illinois State Water Survey Circular 154, Champaign, IL.

Sasman, R.T., C.R. Benson, J.S. Mende, N.F. Gangler, and V.M. Colvin. 1977. *Water-Level Decline and Pumpage in Deep Wells in the Chicago Region, 1971- 1975*. Illinois State Water Survey Circular 125, Champaign, IL.

Sasman, R.T., C.K. McDonald, and W.R. Randall. 1967. *Water-Level Decline and Pumpage in Deep Wells in Northeastern Illinois, 1962-1966*. Illinois State Water Survey Circular 94, Champaign, IL.

Sasman, R.T., T.A. Prickett, and R.R. Russell. 1961. *Water-Level Decline and Pumpage During 1960 in Deep Wells in the Chicago Region, Illinois*. Illinois State Water Survey Circular 83, Champaign, IL.

Sasman, R.T., W.H. Baker, Jr., and W.P. Patzer. 1962b. *Water-Level Decline and Pumpage During 1961 in Deep Wells in the Chicago Region, Illinois*. Illinois State Water Survey Circular 85, Champaign, IL.

Schicht, R.J., J.R. Adams, and J.B. Stall. 1976. *Water Resources Availability, Quality, and Cost in Northeastern Illinois*. Illinois State Water Survey Report of Investigation 83, Champaign, IL.

Seaber, P.R., F.P. Kapinos, and G.L. Knapp. 1987. *Hydrologic Unit Maps*. United States Geological Survey Water-Supply Paper 2294, Reston, VA.

Suter, M., R.E. Bergstrom, H.F. Smith, G.H. Emrich, W.C. Walton, and T.E. Larson. 1959. *Preliminary Report on the Ground-Water Resources of the Chicago Region, Illinois*. Illinois State Water Survey and Illinois State Geological Survey Cooperative Ground-Water Report 1, Urbana, IL.

United States Department of the Interior Bureau of Reclamation. 1997. *Water Measurement Manual*. U.S. Government Printing Office, Washington, DC.

United States Environmental Protection Agency Region V. 1975. *Great Lakes Basin Framework Study Appendix 6: Water Supply–Municipal, Industrial, Rural*. Great Lakes Basin Commission, Ann Arbor, MI.