An Analysis of Groundwater Use to Aquifer Potential Yield in Illinois

by

H. Allen Wehrmann, Sean V. Sinclair, and Timothy P. Bryant
Groundwater Section
Illinois State Water Survey

December 24, 2003

Contents

Page

List of Tables

List of Figures

Page

An Analysis of Groundwater Use to Aquifer Potential Yield in Illinois

by
H. Allen Wehrmann, Sean V. Sinclair, and Timothy P. Bryant
Groundwater Section
Illinois State Water Survey

Abstract

Proper water resource planning and management requires a firm understanding of water use and water resource availability. This report summarizes a comparison of Year 2000 groundwater withdrawals against estimated aquifer potential yields. The comparison is presented as a ratio of groundwater use (withdrawals) to groundwater yield (i.e., potential aquifer yield) on a township basis. Geographical Information System (GIS) technology was used to determine township use-to-yield ratios for three aquifer types (sand-and-gravel, shallow bedrock, and deep bedrock).

A high use-to-yield ratio (e.g., >0.9) suggests an area where groundwater availability problems exist or could be impending. The area of influence of a well or well field often may extend beyond the township boundaries in which the pumpage is occurring. In such cases, township aquifer potential yields may appear to be approached or exceeded even though the withdrawal does not exceed total aquifer potential yield. Therefore, the delineation of high groundwater use-to-yield areas by this method should be considered simply as a means for calling attention to areas to prioritize on a statewide basis for water resources planning and management.

Comparing groundwater withdrawals to potential aquifer yields in a GIS format is a useful technique for drawing attention to areas where stresses may occur (or are occurring). However, such analysis can not be substituted for local-scale investigations, particularly those that incorporate detailed information into groundwater flow models that can accurately assess local conditions. Areas may be unduly highlighted where large, relatively isolated, withdrawals occur within an extensive aquifer, such as occurs in the Mahomet aquifer near Champaign in east-central Illinois. The effects of such pumpage will be spread across a larger area than the townships where the wells are located, smoothing the use-to-yield ratio over a larger area. In at least one other area near East St. Louis, the withdrawal in one township is intentionally greater than the potential yield for purposes of dewatering to protect below-grade highway roadbeds.

However, areas where the aquifer may be confined to a narrow valley, where multiple pumping wells are located within a small area, or where withdrawals do indeed exceed the estimated recharge rate can be identified (e.g., Fox River valley, Peoria, Lewiston, Normal). Certainly, areas where multiple townships exhibiting high use-to-yield ratios are clustered together (e.g., the deep bedrock of northeastern Illinois) should signify locations where additional research, data collection, and water resource planning may be warranted.

An Analysis of Groundwater Use to Aquifer Potential Yield in Illinois

Introduction

Proper water resource planning and management requires a firm understanding of water use and water resource availability. This report summarizes a comparison of Year 2000 groundwater withdrawals against estimated aquifer potential yields. The comparison is presented as a ratio of groundwater use (withdrawals) to groundwater yield (i.e., potential aquifer yield) on a township basis. Geographical Information System (GIS) technology was used to determine township use-to-yield ratios for three aquifer types (sand-and-gravel, shallow bedrock, and deep bedrock) following the methodology originally used by Collins (Illinois State Water Plan Task Force, ISWPTF, 1984).

A high use-to-yield ratio (e.g., >0.9) suggests an area where groundwater availability problems exist or could be impending. The area of influence of a well or well field often may extend beyond the township boundaries in which the pumpage is occurring. In such cases, township aquifer potential yields may appear to be approached or exceeded even though the withdrawal does not exceed total aquifer potential yield. Therefore, the delineation of high groundwater use-to-yield areas by this method should be considered simply as a means for calling attention to areas to prioritize on a statewide basis for water resources planning and management.

As mentioned, a similar analysis was first conducted in1984 for the ISWPTF. Bowman and Collins (1987) also used this approach to examine the impacts of irrigation on Illinois groundwater resources. Much has changed in terms of groundwater withdrawals since these studies were conducted. Perhaps the largest change has occurred in northeastern Illinois. With the allocation of Lake Michigan water to many Chicago suburbs in the early 1980s, groundwater withdrawals from both the deep bedrock (the Cambrian-Ordovician aquifers, figure 1) and shallow bedrock (Silurian dolomite aquifers) fell dramatically. Therefore, a reanalysis of groundwater use-to-yield, using the most up to date aquifer withdrawals is warranted. A similar analysis, using projected groundwater use, to reflect the growth in groundwater withdrawals that will be needed to accommodate population increases, particularly in the rapidly growing northeast, is contemplated once water demand projections for the state are completed in 2004.

Groundwater Use

The Illinois State Water Survey (ISWS) has been collecting water use and water availability data for Illinois since at least the early 1940s, primarily in regions where water resources were being extensively developed such as the northeastern Illinois, Peoria-Pekin and East St. Louis areas (Schicht and Jones, 1962; Sasman, 1965; Sasman and Baker, 1966; Marino and Schicht, 1969) or for particular water uses (Roberts, 1951; Evans and Schnepper, 1966; Roberts, 1960). Documentation of annual water withdrawals (water use) for all of Illinois began in 1978 under a cooperative agreement with the U.S. Geological Survey (USGS). Fiscal support by the USGS ended in 1991 but the Illinois Water Inventory Program (IWIP) continues under the general oversight of the Groundwater Section of the ISWS. The Illinois Water Inventory Program (IWIP) database of water-using facilities was originally created by compiling responses to a letter of inquiry sent to Illinois industries listed in the Illinois Manufacturer's Directory as well as through review of public water supply records of the Illinois Environmental Protection Agency (IEPA) and the historical files and reports of the ISWS. The list of facilities is continually updated through reviews of IEPA records and reports of high-capacity wells submitted to the ISWS by drillers and county health departments.

Withdrawal data are collected annually by voluntary submission of a form tailored to each (known) major water user in the state. For the Year 2000, for example, IWIP received a 70 percent return on inquiries sent to 2,832 facilities. Those water use data are supplemented by water use data from previous year's responses to "fill-in" for non-respondents, so that a fairly complete water use picture for any one year can be compiled. Large changes in water use (> 10 percent) from one year to the next from any one respondent automatically invokes a follow-up call back to the facility operator to make sure the response is accurate and to inquire about reasons for growth or decline.

Information on the quantity of water withdrawn (both surface water and groundwater) are generally categorized as: Public Water Supply; Self-Supplied Industry - such as thermoelectric power generation, manufacturing, mineral extraction, and hydroelectric power generation; and Other which includes withdrawals for fish and wildlife management areas and irrigation. However, IWIP documentation of irrigation withdrawals for row crop farming is not comprehensive. Further, withdrawals for rural domestic and livestock uses are not collected. Water use data can be broken down into geographical regions such as by county, hydrologic unit, major aquifer system, Standard Metropolitan Statistical Area (SMSA), or, as in the case of this study, by political township.

When the term "water use" appears in this report, withdrawal use (the amount of water withdrawn from its source) is implied. The principal requisite for withdrawal use is that water must be taken from a groundwater or surface water source and conveyed to the place of use. If the water is used more than once by recycling, it will be counted as another withdrawal; that is, if withdrawn water is returned to a stream, lake, aquifer, or other source and then withdrawn anew, the summation of successive withdrawals is counted. Return flows are not subtracted from the withdrawal to determine water use.

"Public water supplies" are defined as systems for the provision to the public of water for human consumption through pipes or other constructed conveyances, if the system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days per year. A public water system is either a community water system (CWS) or a non-community water system (non-CWS). The term public water system applies to both surface water and groundwater supplies. Public water systems often supply water for nondrinking purposes, for example for manufacturing purposes; however, the water supplied will meet quality standards for human consumption.

If a public supply is either not available or not used, the water is "self-supplied." Individual families and small communities not served by a public water supply are categorized as "rural". Industries and commercial establishments using their own water source facilities are categorized as "self-supplied industry." Commercial establishments include businesses such as motels, lake access areas, campgrounds, country clubs, etc. that have been identified as self-supplied.

Water used to generate hydroelectric power is also included as a withdrawal use because of its diversion through power plants. The term "non-withdrawal uses" encompasses all uses taking place within a surface source itself. Non-withdrawal uses are not included in this analysis.

Further, irrigation use is not a principal component of the groundwater use-to-yield analysis contained in this report. Irrigation withdrawals, particularly withdrawals for row-crop production, are largely unreported to the IWIP. The principal reason for the lack of irrigation withdrawal reporting is the severe lack of water meters on irrigation pumps. However, irrigation withdrawals were the object of previous analysis (Bowman and Collins, 1987). Because irrigation in Illinois is concentrated over high-yielding aquifers in rural areas with little other principal uses, the effects of irrigation were found to be "almost identical to those of a non-irrigated situation" when spread out over a year with normal or near-normal precipitation. The impact of drought and potential climate change on irrigation withdrawals are worthy of investigation but are beyond the scope of this study.

Groundwater Availability

Groundwater is developed from three principal aquifer types in Illinois. These are generally categorized as sand-and-gravel aquifers within the unconsolidated geologic materials overlying the bedrock (figure 2); shallow bedrock aquifers lying within approximately 300 feet of land surface (figure 3); and deep bedrock aquifers lying at depths greater than 300 feet of land surface (figure 4).

Water resource availability can be expressed in a number of ways. In the groundwater field, the term "potential yield" or "safe yield" is often used. Potential aquifer yield is the maximum amount of groundwater that can be continuously withdrawn from a reasonable number of wells and well fields without creating critically low water levels or exceeding recharge. Statewide estimates of groundwater availability, based on aquifer potential yield estimates, were developed in the late 1960s (Illinois Technical Advisory Committee on Water Resources, ITACWR, 1967). The ITACWR report presented maps of the estimated potential yields, expressed as recharge rates in gallons per day per square mile (gpd/mi^2), of the principal sand-and-gravel and shallow bedrock aquifers of Illinois (figures 5 and 6, respectively). {For reference, a recharge rate of 100,000 gpd/mi^2 is equal to 2.1 inches/year.} Although the concept of potential, or safe, yield has met some criticism in recent years (Sophocleous, 1997; Wood, 2001; Walker *et al.*, 2003), these maps remain as the best statewide estimates of groundwater availability for Illinois.

> *"The potential yield of principal sand-and-gravel and bedrock aquifers in Illinois are estimated to be 4.8 and 2.5 billion gallons per day (bgd), respectively. The total groundwater potential in Illinois, based on full development of either sand-and-gravel or bedrock aquifers, whichever has the higher recharge rate, is estimated to be 7.0 bgd. Principal sand-and-gravel aquifers underlie only about 25 percent of the total land area in Illinois. About 3.1 bgd, or about 65 percent of the total potential yield of the principal sand-and-gravel aquifers in the state, is concentrated in less than 6 percent of the total land area in Illinois and is located in alluvial deposits that lie directly adjacent to major rivers such as the Mississippi, Illinois, Ohio, and Wabash. About 0.5 bgd, or about 10 percent of the total potential sand-and-gravel yield is from the principal sand-and-gravel aquifers in the major bedrock valleys of the buried Mahomet valley in east-central Illinois and in the river valleys of the Kaskaskia, Little Wabash, and Embarras Rivers in southern Illinois.*

> *Of the total estimated yield of bedrock aquifers in the State, 1.7 bgd, or 68 percent, is available from the shallow bedrock aquifers, mainly dolomites in the northern third of the State. The potential yield of the shallow dolomite varies. In areas where the more permeable shallow dolomites lie directly beneath the glacial drift, the potential yield ranges from 100,000 to 200,000 gpd/mi*^{2}*. In areas where less permeable dolomites lie directly beneath the drift or are overlain by thin beds of less permeable rocks of Pennsylvanian age, the potential yield ranges from 50,000 to 100,000 gpd/mi*^{2}*. Where the overlying Pennsylvanian rocks are thick, the potential yield is less than 50,000 gpd/mi*^{2}*."* (ITACWR, 1967)

The "deep bedrock" aquifers of Illinois generally consist of rocks of Cambrian and Ordovician age and are largely confined to the northern third of Illinois. The southward dip of these bedrock aquifers into the Illinois Basin causes water contained in them to become non-potable (containing ≥2,500 milligrams per liter total dissolved solids) south of a line roughly parallel to and 10 to 100 miles south of the Illinois River. *"Development of the Cambrian-Ordovician aquifers in northeastern Illinois has been possible because sufficient drawdown is available for pumpage to create large cones of depression to divert water from recharge areas in north-central Illinois, where the upper layers of the Cambrian-Ordovician aquifer lie directly beneath the glacial drift."* (ITACWR, 1967) The most widely quoted estimate of the potential yield of the deep bedrock aquifer system is 65 million gallons per day (Walton, 1964).

Potential aquifer yields were based on estimates of groundwater recharge. Recharge to the sand-and-gravel aquifers is from direct infiltration of precipitation to shallow aquifers, leakage of confining beds to deeper aquifers, and induced infiltration to aquifers adjacent to major streams and rivers. Recharge to bedrock aquifers is primarily from vertical leakage occurring through the glacial drift or overlying bedrock formations. Because recharge is not a process that can be measured directly, it was deduced through streamflow measurements (i.e., base flow separation), groundwater level measurements coupled with groundwater withdrawal data (flow net analysis, estimation of diversion areas created from groundwater pumpage), or use of idealized aquifer models (e.g., analytical models, image-well theory). Publications providing background on how these methods were used to estimate recharge include Schicht and Walton (1961), Walton (1962, 1965), Prickett *et al.* (1964), and Zeizel *et al.* (1962). Each method contains inherent measurement uncertainties and it follows that the mapped recharge rates typically cover ranges that vary by 50 to 100 percent or more (e.g., 100,000-150,000 gpd/mi^2; 1,000,000-3,000,000 gpd/mi^2).

A number of studies involving recharge estimation have been conducted since the time of these studies (Schicht *et al.*, 1976; O'Hearn and Gibb, 1980; Roadcap *et al.*, 1993), and while each provides some differences in approach and result, they all tend to reasonably agree within the ranges provided on the statewide maps. Roadcap *et al.* (1993) provided perhaps the best comparison of recharge rate estimation method results for the shallow bedrock of southern Cook and Will Counties. The median of 11 recharge values estimated by diversion area analysis was 65,900 gpd/mi^2 and the median of 12 recharge values estimated by flow channel analysis was 110,000 gpd/mi^2, although the individual analyses covered slightly different areas within south Cook and Will Counties. These areas are more generally mapped in the 50,000-100,000 gpd/mi^2 and 100,000-200,000 gpd/mi^2 ranges on the shallow bedrock yield map (figure 6). Given the uncertainties in the measurement of heterogenous aquifer hydraulic properties such as transmissivity; in the preparation of potentiometric surface maps from which hydraulic gradients and diversion areas are determined; and in the determination of time-variant withdrawal rates and streamflow, the potential yield ranges shown on figures 5 and 6 are reasonable and encompass the range of uncertainty that went into the estimate.

The calculations used to prepare the sand-and-gravel yield map (figure 5) assumed full development of the sand-and-gravel aquifers, reducing potential recharge to underlying bedrock aquifers as well as potential base flow to streams. Thus, full development of the sand-and-gravel aquifers may have undesirable effects that are not intuitively obvious. Similarly, the potential yield estimates of the shallow bedrock aquifers (figure 6) assumed full development of the bedrock. Therefore, caution is warranted where additional groundwater resource development is being considered where productive shallow bedrock aquifers are overlain by sand-and-gravel aquifers, such as in the northern third of the state.

The potential yield of the deep bedrock aquifer recharge area of north-central and northwestern Illinois is estimated to be approximately 20,000 gpd/mi^2 (Visocky *et al.*, 1985); whereas, in the rest of the state, the deep aquifers are overlain by shales of the Maquoketa Group, limiting the potential yield to the maximum amount of water that can move vertically downward through the Maquoketa, or only about 2,100 gpd/mi^2 (Visocky *et al.*, 1985). These areas are presented in figure 7.

Methodology

Groundwater Use

Groundwater use was aggregated for each aquifer (sand-and-gravel, shallow bedrock, deep bedrock) by township for the Year 2000 through the IWIP database. Total annual groundwater use consisted of the sum of public, self-supplied industry, and wildlife management withdrawals. Database queries were formulated in Access® and output was formatted into Excel® for additional manipulation. Annual groundwater withdrawals (gallons) were converted to daily withdrawals by dividing by 365. The database query returns only townships where a withdrawal occurred or a zero withdrawal where large-capacity wells that are the subject of the annual IWIP survey are known to exist. All other townships, where no IWIP database wells occur, were added to the Excel® spreadsheet and coded with a zero withdrawal. This, then, provided a compilation of all townships in Illinois and their associated aquifer withdrawals. Maps of the aggregated township withdrawals, excluding irrigation, for each aquifer system are shown in figures 8, 9, and 10.

Major withdrawals from sand-and-gravel aquifers (figure 8) can be seen in the Metro-East area of St. Louis and in Quincy along the Mississippi River; in the Peoria-Pekin area along the Illinois River, in the Fox River corridor in northeastern Illinois, and in the Champaign area of east-central Illinois. Major withdrawals from the shallow bedrock aquifers (figure 9) can be clearly seen almost solely in northeastern Illinois in southern Cook, Kankakee and Will Counties for communities such as Crest Hill, Lockport, Manteno, New Lenox, Park Forest, and Romeoville. A large shallow bedrock industrial withdrawal also can be seen in the extreme southern tip of Illinois near Joppa. Major withdrawals from the deep bedrock (figure 10) are found spread across northern Illinois, particularly in the Rockford area of north-central Illinois, the Fox River corridor, and farther south in the area of Joliet and the I-55 industrial corridor near Channahon.

Groundwater Availability

The maps of estimated potential yields for the sand-and-gravel and shallow bedrock aquifers were originally created in the 1960s as hard copy paper maps and published in ITACWR (1967). Collins digitized these maps for his analysis in 1984, but the digital versions of the maps could not be found, pointing out the need for consistent file archival and updating as technology advances to make old file formats and hardware obsolete. Therefore, the maps were redigitized using ArcIMS® 3.1. Hard copy versions of the yield maps were scanned, enlarged on-screen, rectified to real-world coordinates, then digitized on-screen, resulting in the maps presented in figures 5 and 6. It should be noted that the original sand-and-gravel aquifer potential yield map (figure 5) does not contain a yield in the range from 50,000 to 100,000 gpd/mi^2.

Once the potential yield maps were in digital format in GIS, they were overlain and intersected with the political township boundaries of Illinois. Then, a total potential aquifer yield for each political township was computed in GIS, based on a sum of the areas of the individual potential yield polygons within each township:

$$Y_T = a_1y_1 + a_2y_2 + ... + a_ny_n$$

where,

Y_T = Area-weighted total township potential aquifer yield, gallons per day (gpd)
a_n = Area within the township containing a particular potential aquifer yield, square miles (mi^2)
y_n = Potential aquifer yield of selected polygon, gallons per day per square mile (gpd/mi^2)

The resulting maps, figures 11 and 12, show estimated potential aquifer yields, composited by township. Collins (ISWPTF, 1984) chose to use the lowest yield value within each mapped potential yield range for the sand-and-gravel and shallow bedrock aquifers and presented them as "worst-case" maps. We chose to use three potential aquifer yield values for each mapped potential aquifer yield range to represent the low, average, and high range of potential aquifer yields shown on the map legends as a means to examine the possible variability/uncertainty in use-to-yield ratios (Table 1). Areas originally mapped as "Other sources preferred" on both the sand-and-gravel and shallow bedrock potential aquifer yield maps were assigned a relatively low potential aquifer yield value of 4,000 gpd/mi^2 for all simulations.

Figure 7 presents the deep bedrock potential yield in two zones, areas underlying the confining Maquoketa shale and areas where the Maquoketa shale is absent. The township-based potential deep aquifer yield was assigned one of two values for use-to-yield calculations (figure 13). For those areas overlain by the Maquoketa Group, a yield of 2,100 gpd/mi^2 was used. For the recharge area of north-central Illinois, including major portions of the counties of Boone, Carroll, DeKalb, Grundy, Jo Daviess, La Salle, Ogle, Stephenson, and Winnebago, a yield of 20,000 gpd/mi^2 was used (Walton, 1965); the same value as used by Collins (ISWPTF, 1984) for the entire aquifer area.

Table 1. Original Map Potential Aquifer Yield Ranges and GIS Model Potential Yields

Aquifer System	Original Map Potential Yield Range*, gpd/mi^2	GIS Model Aquifer Potential Yields, gpd/mi^2		
		Low Yield**	Average Yield	High Yield
Sand and Gravel	Other sources preferred	4,000	4,000	4,000
	< 50,000	20,000	25,000	50,000
	100,000 - 150,000	100,000	125,000	150,000
	150,000 - 200,000	150,000	175,000	200,000
	200,000 - 300,000	200,000	250,000	300,000
	300,000 - 400,000	300,000	350,000	400,000
	1,000,000 - 3,000,000	1,000,000	2,000,000	3,000,000
	3,000,000 - 5,000,000	3,000,000	4,000,000	5,000,000
Shallow Bedrock	Other sources preferred	4,000	4,000	4,000
	< 50,000	20,000	25,000	50,000
	50,000 - 100,000	50,000	75,000	100,000
	100,000 - 200,000	100,000	150,000	200,000
Deep Sandstone	All areas beneath the Maquoketa Group	2,100	2,100	2,100
	Recharge areas directly beneath the glacial drift	20,000	20,000	20,000

* Values of potential aquifer yield as they appear on the original potential yield maps (ITACWR, 1967).

** Values used by Collins (ISWPTF, 1984) for the sand-and-gravel and shallow bedrock aquifers; a single value of 20,000 gpd/mi^2 was used for the deep bedrock.

Comparison of Groundwater Use to Aquifer Yield

Use-to-yield (UTY) ratios were computed and mapped using each of the three estimated aquifer yields for the sand-and-gravel and shallow bedrock aquifers as described in Table 1. Sand-and-gravel UTY maps for average, minimum, and maximum potential yields are presented in figure 11 and figure 12 (a, b). Also shown on those maps is an outline of the principal sand-and-gravel aquifers of Illinois. Townships with a UTY ratio >0.9 are highlighted in red; UTY ratios between 0.5 and 0.9 are shown in orange.

UTY ratios >0.9 using an average aquifer potential yield (figure 11) include the East Dubuque area in extreme northwest Illinois and the Fox River corridor of St. Charles, Batavia, and Geneva in northeast Illinois. In central Illinois, townships representing LaSalle, Peoria, and South Pekin along the Illinois River, Lewiston to the southwest of Peoria, and Normal to the east of Peoria are highlighted. The Champaign and Danville areas in east-central Illinois and townships for wells operated by the E.J Water District, Newton Lake Conservation Area, and Mt. Carmel in southeast Illinois contain UTY ratios >0.9. Several townships surrounding the MetroEast area representing Alton, East Alton, Troy, and the Illinois Department of Transportation dewatering withdrawals at the junction of I-64 and I-55/70 in southwest Illinois; and Grand Tower and the Anna-Jonesboro Public Water District along the Mississippi River farther south are also highlighted. Most of these townships remain highlighted when a higher potential yield is used to compute the UTY ratio (figure 12b) but several more townships fall into the >0.9 category when the minimum yield is used (figure 12a). Additional townships include those representing Fairbury, Mt. Auburn, Red Bud, Algonquin/Carpentersville, Quincy, and Aurora/Montgomery.

Similar UTY maps for the shallow bedrock aquifers are presented in figure 13 using the average potential yield and figure 14a, b using the minimum and maximum potential yields as shown in Table 1. UTY ratios >0.9 using the average potential yield (figure 13) occurred in only four townships: in the Lemont/Romeoville/Bolingbrook area in northeast Illinois; in Villa Grove in east-central Illinois; and in the Joppa area in extreme southern Illinois along the Ohio River. A few additional areas appear when the minimum potential yield is used (figure 14a) including Huntley/Crystal Lake/Lake-in-the-Hills, Richton Park/Park Forest, and Mokena areas all located in northeastern Illinois.

Only one UTY map for the deep bedrock aquifers was prepared, using the potential yields described in Table 1 (figure 15). As might be expected when the potential yield of the aquifer is so low, nearly any withdrawal will create a UTY >0.9 and such is the case with the deep bedrock aquifer in northeastern Illinois. Areas where communities are not served by Lake Michigan, largely the collar communities along the Fox River and to the southwest (e.g., Joliet), are clearly identifiable. Additional communities to the west and south, such as Rockford in north-central Illinois, are visible.

Discussion

A comparison of the current groundwater withdrawals to aquifer yields and the earlier work of Collins (ISWPTF, 1984) or Bowman and Collins (1987) reveals some interesting, if not unexpected, changes in UTY patterns. Generally, the UTY pattern for the sand-and-gravel aquifers is very similar. The area surrounding Rockford has seen a decrease in UTY ratio, probably as a result of a shift to deeper bedrock aquifers for water as a result of shallow aquifer contamination in that area.

Most striking are the changes in northeastern Illinois as a result of Lake Michigan allocations. Both earlier studies presented UTY ratios >0.9 throughout DuPage County in the shallow bedrock and across most of northeast Illinois, including DuPage and Cook Counties, in the deep bedrock. With the allocation of Lake Michigan water, UTY ratios have decreased substantially in the shallow and deep bedrock aquifers in DuPage and Cook Counties. High deep bedrock UTY ratios continue to occur farther west and south in Kane and Will Counties where lake water is not available.

Comparing groundwater withdrawals to potential aquifer yields in a GIS format is a useful technique for drawing attention to areas where stresses may occur (or are occurring). However, such analysis can not be substituted for local-scale investigations, particularly those that incorporate detailed information into groundwater flow models that can accurately assess local conditions. Areas may be unduly highlighted where large, relatively isolated, withdrawals occur within an extensive aquifer, such as occurs in the Mahomet aquifer near Champaign in east-central Illinois. Potential yield estimates and the calculation of UTY ratios consider only the township in which the withdrawal is occurring, when in reality, groundwater capture does not recognize political boundaries. The effects of such pumpage will be spread across a larger area than the townships where the wells are located, smoothing the UTY ratio over a larger area.

For great parts of Illinois, the groundwater resources of the state are underutilized. Only a comparatively few townships appear to be approaching or exceeding aquifer yield capabilities. These areas appear where the aquifer may be confined to a narrow valley, where multiple pumping wells are located within a small area, and where identified withdrawals do indeed exceed the estimated recharge rate (e.g., Fox River valley, Peoria, Lewiston, Normal). Further analysis is warranted to project future demands for comparison to aquifer potential yields. Additional analysis also could be performed to examine the combination of aquifer yields to meet demand in areas where multiple aquifers overlie one another; however, consideration must be given to the effects of shallow aquifer development on recharge (and hence yields) to underlying aquifers. Certainly, areas where multiple townships exhibiting high UTY ratios are clustered together (e.g., the deep bedrock of northeastern Illinois) should signify locations where additional research, data collection, and water resource planning may be warranted.

Acknowledgments

This project was partially funded by the Illinois Board of Higher Education through a cooperative agreement with the Illinois Department of Natural Resources. Partial funding was also provided through General Revenue Fund resources of the Illinois State Water Survey under the supervision of Derek Winstanley, Chief. Digitization of the original potential yield maps for the sand-and-gravel and shallow bedrock aquifers was conducted by Douglas Splitt. Manipulation of water withdrawal data for GIS display was done with the assistance of Stephen Burch. Their help in this endeavor is greatly appreciated.

References

Bowman, J.A., and M.A. Collins. 1987. *Impacts of irrigation and drought on Illinois ground-water resources*. Illinois State Water Survey Report of Investigation 109.

Evans, R.L., and D.H. Schnepper. 1966. *Industrial use of surface waters in Illinois.* Proceedings of the 21st Industrial Waste Conference, May 3-5, 1966, Part I. Purdue University, Engineering Extension Service No. 121.

Illinois State Water Plan Task Force. 1984. *Strategy for the protection of underground water in Illinois*, Special Report No. 8. Illinois Environmental Protection Agency, Springfield.

Illinois Technical Advisory Committee on Water Resources. 1967. *Water for Illinois, a plan for action.* Illinois Department of Business and Economic Development, Springfield.

Marino, M.A., and R.J. Schicht. 1969. *Groundwater levels and pumpage in the Peoria-Pekin area, Illinois, 1890-1966.* Illinois State Water Survey Report of Investigation 61.

O'Hearn, M., and J.P. Gibb. 1980. *Ground-water discharge to Illinois streams.* Illinois State Water Survey Contract Report 246.

Prickett, T.A., L.R. Hoover, W.H. Baker, and R.T. Sasman. 1964. *Ground-water development in several areas of northeastern Illinois.* Illinois State Water Survey Report of Investigation 47.

Roadcap, G.S., S.J. Cravens, and E.C. Smith. 1993. *Meeting the growing demand for water: an evaluation of the shallow ground-water resources in Will and southern Cook Counties, Illinois.* Illinois State Water Survey Research Report 123.

Roberts, W.J. 1951. *Irrigation in Illinois.* Illinois State Water Survey Report of Investigation 11.

Roberts, W.J. 1960. *Industrial water use in Illinois.* Illinois State Water Survey Reprint 4.

Sasman, R.T. 1965. *Groundwater pumpage in northeastern Illinois through 1962.* Illinois State Water Survey Report of Investigation 50.

Sasman, R.T., and W.H. Baker, Jr. 1966. *Groundwater pumpage in northeastern Illinois through 1963.* Illinois State Water Survey Report of Investigation 52.

Schicht, R.J., and W.C. Walton. 1961. *Hydrologic budget for three small watersheds in Illinois.* Illinois State Water Survey Report of Investigation 40.

Schicht, R.J., and E.G. Jones. 1962. *Groundwater levels and pumpage in the East St. Louis area, Illinois, 1890-1961.* Illinois State Water Survey Report of Investigation 44.

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.

Sophocleous, M. 1997. *Managing water resource systems: why "safe yield" is not sustainable.* **Ground Water**, 35 (4): 561.

Walker, D.D., S.C. Meyer, and D. Winstanley. 2003. *Uncertainty of estimates of groundwater yield for the Cambrian-Ordovician aquifer in northeastern Illinois.* Proceedings of Probabilistic Approaches and Groundwater Modeling, American Society of Civil Engineers, Environmental and Water Resources Institute Symposium, Philadelphia.

Walton, W.C. 1962. *Selected analytical methods for well and aquifer evaluation.* Illinois State Water Survey Bulletin 49.

Walton, W.C. 1964. *Future water-level declines in deep sandstone wells in Chicago region.* **Ground Water**, 2 (1): 13-20.

Walton, W.C. 1965. *Ground-water recharge and runoff in Illinois*. Illinois State Water Survey Report of Investigation 48.

Wood, W.W. 2001. *Water sustainability - science or management?* **Ground Water** 39(5): 641.

Zeizel, A.J., W.C. Walton, R.T. Sasman, and T.A. Prickett. 1962. *Ground-water resources of DuPage County, Illinois.* Illinois State Water Survey and Illinois State Geological Survey Cooperative Report 2.

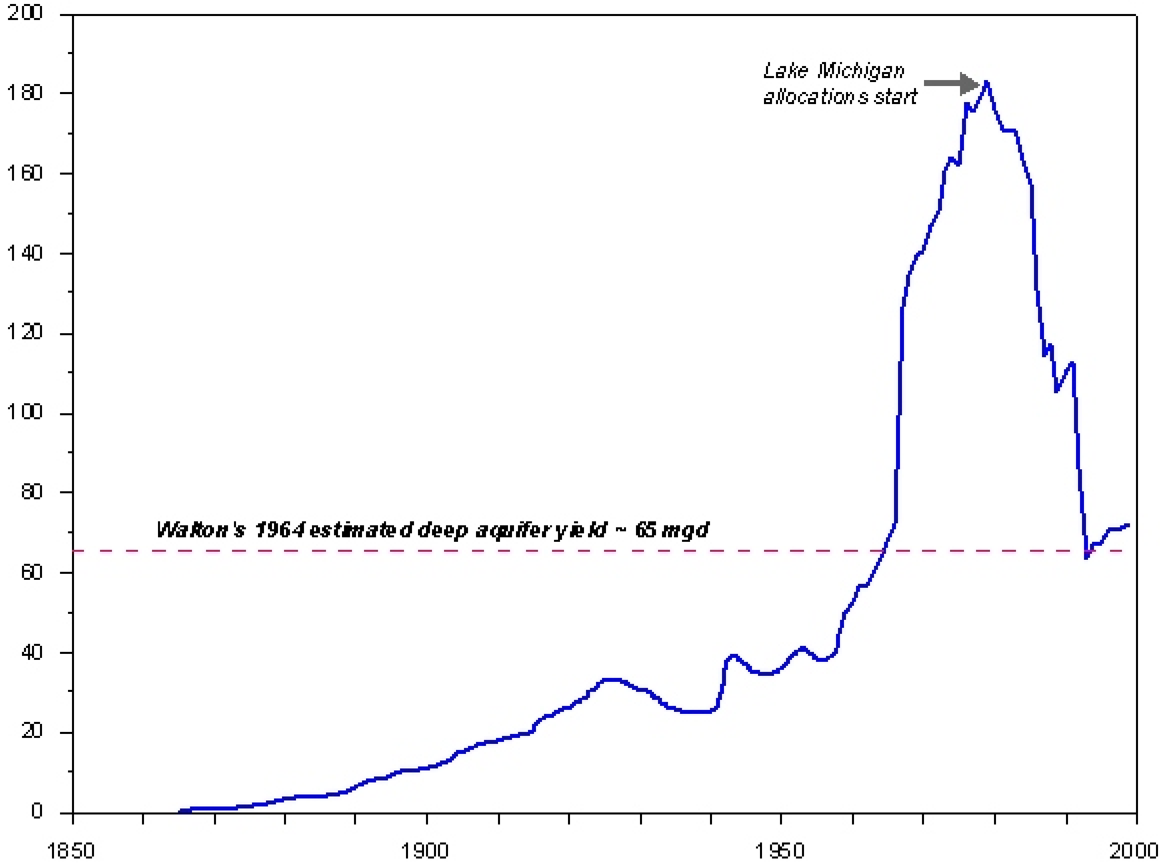

Figure 1. Estimated withdrawals from deep bedrock aquifers in northeast Illinois.

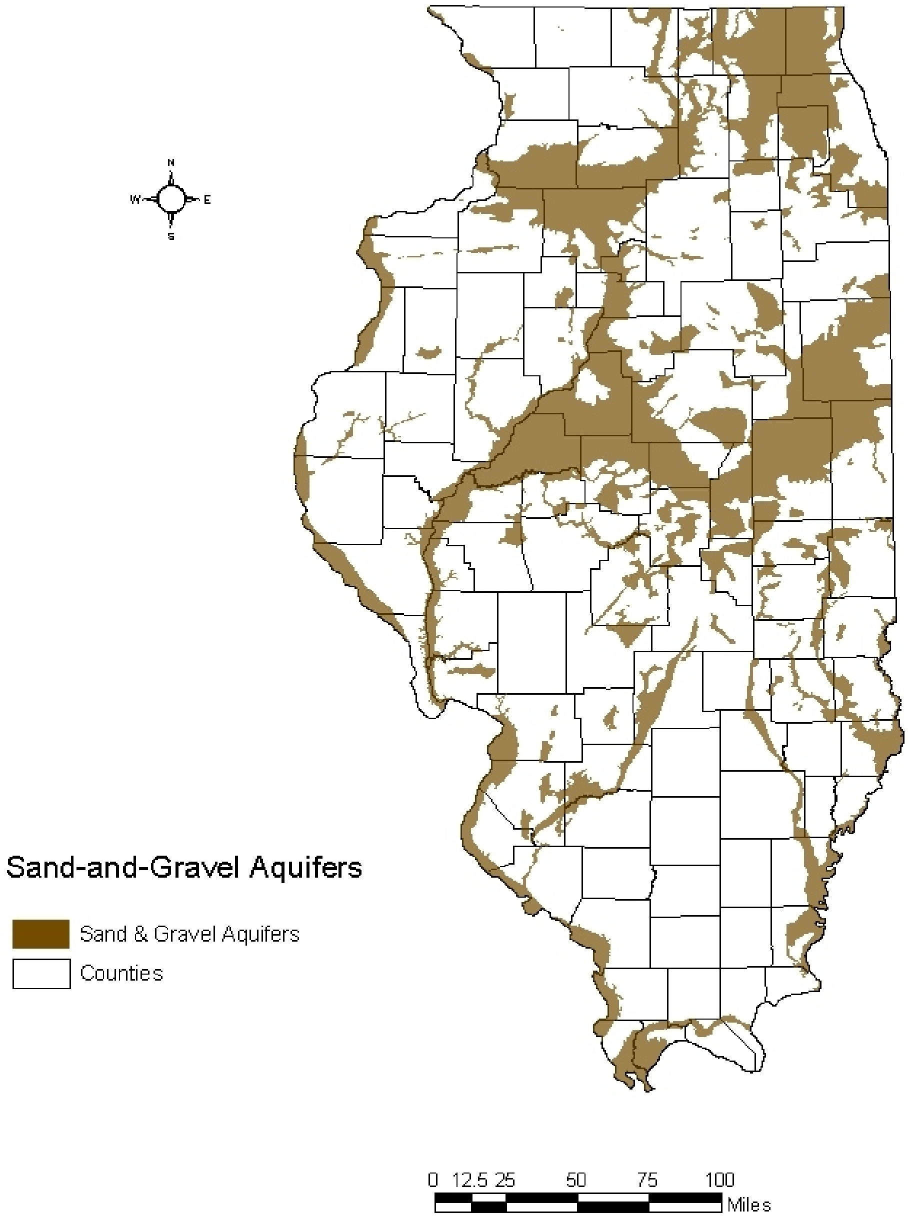

Figure 2. Principal sand-and-gravel aquifers in Illinois.

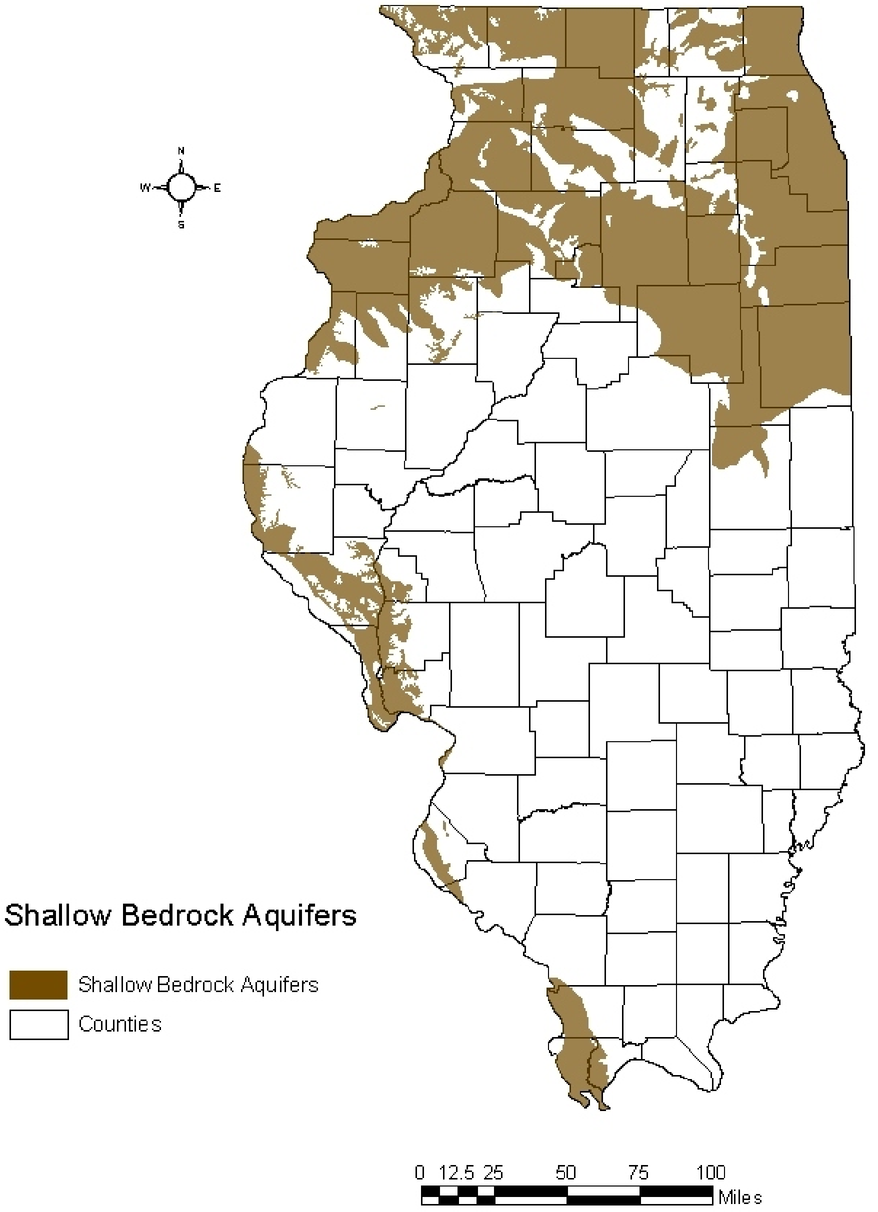

Figure 3. Principal shallow bedrock aquifers in Illinois

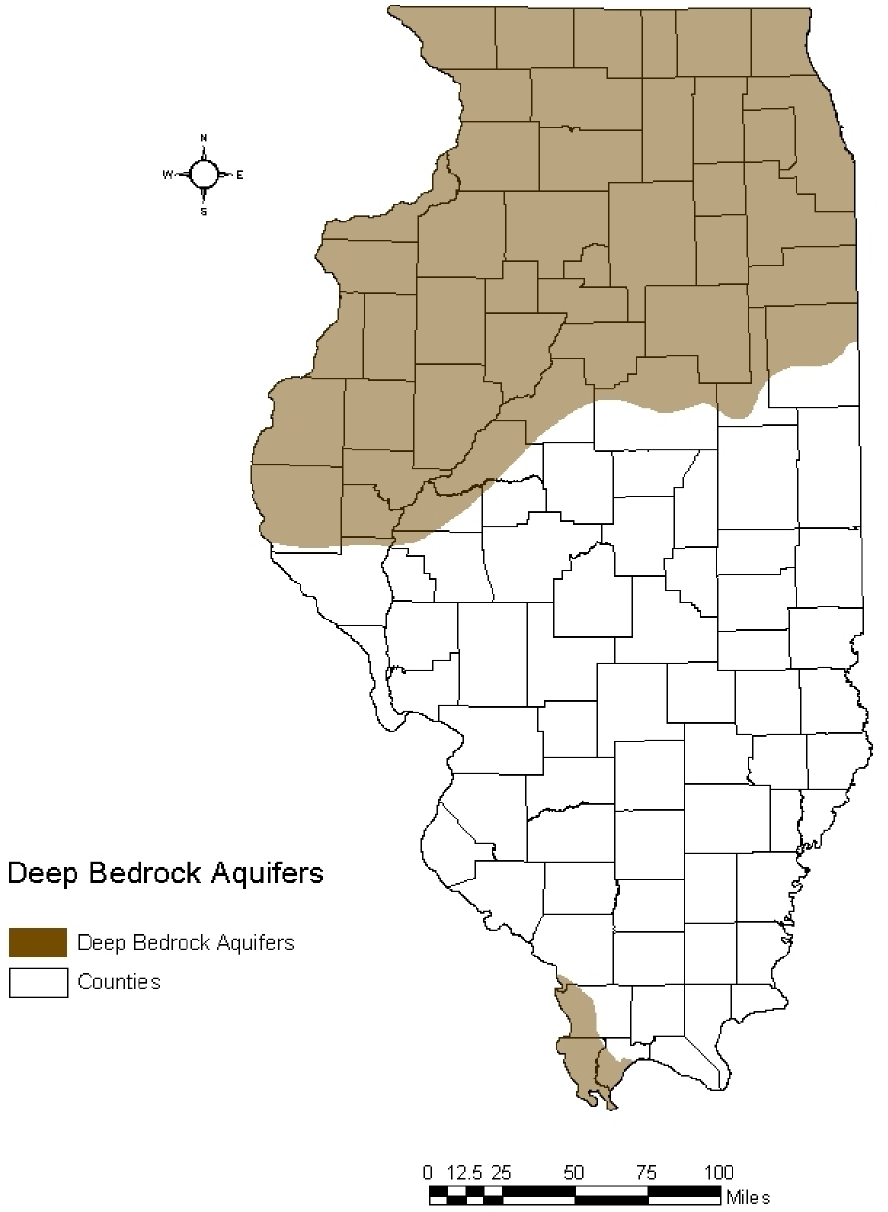

Figure 4. Principal deep bedrock aquifers in Illinois.

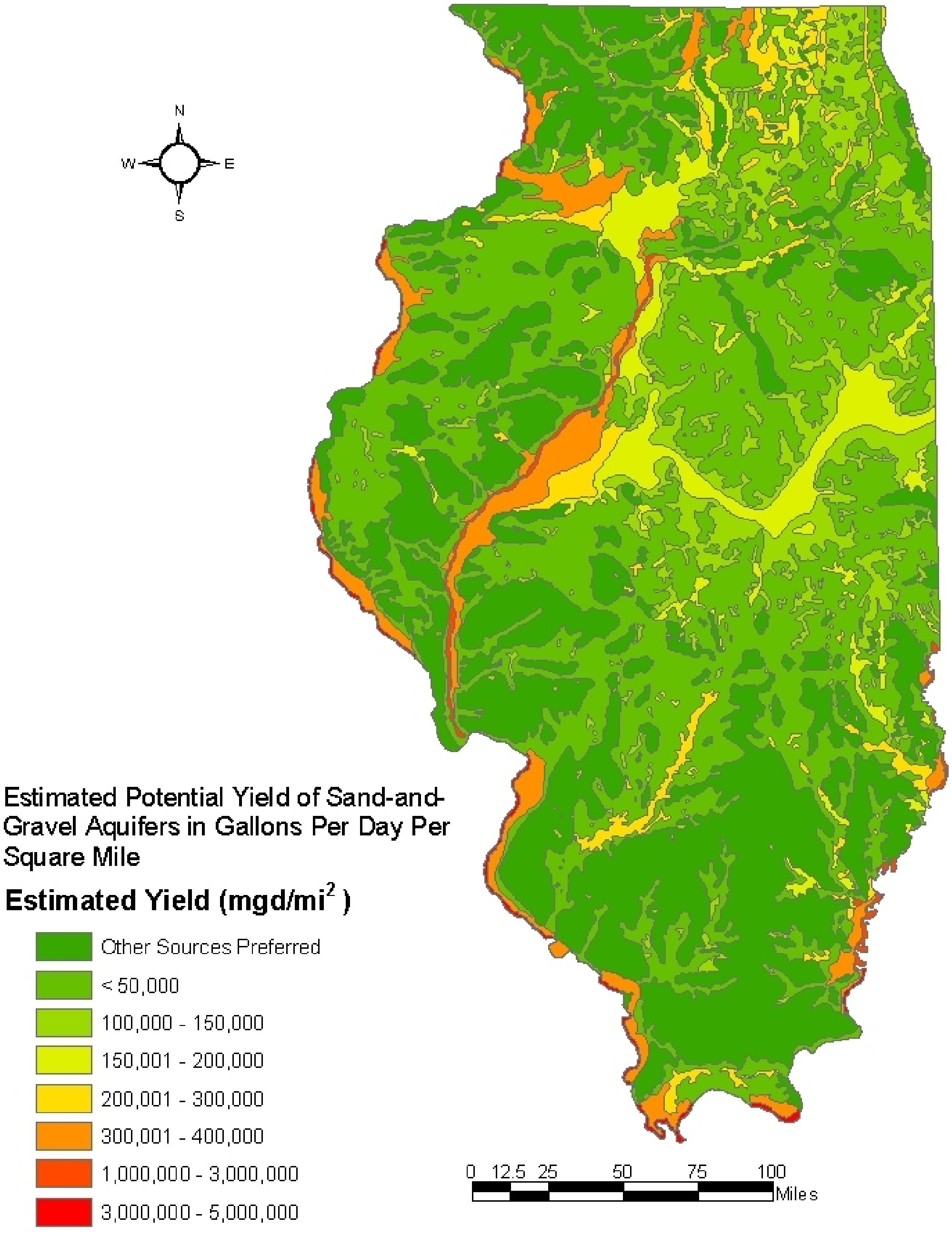

Figure 5. Estimated potential yields of sand-and-gravel aquifers in Illinois.

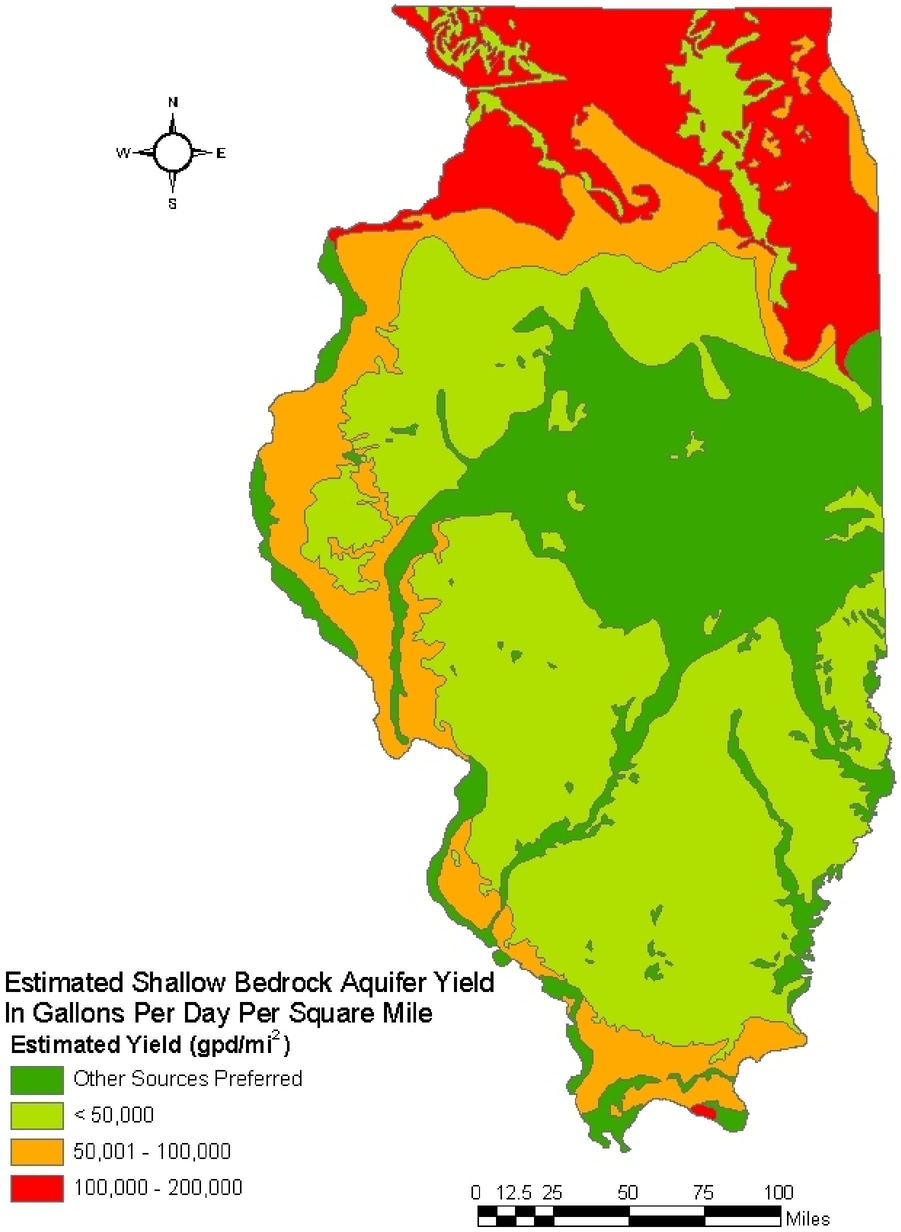

Figure 6. Estimated potential yields of shallow bedrock aquifers in Illinois.

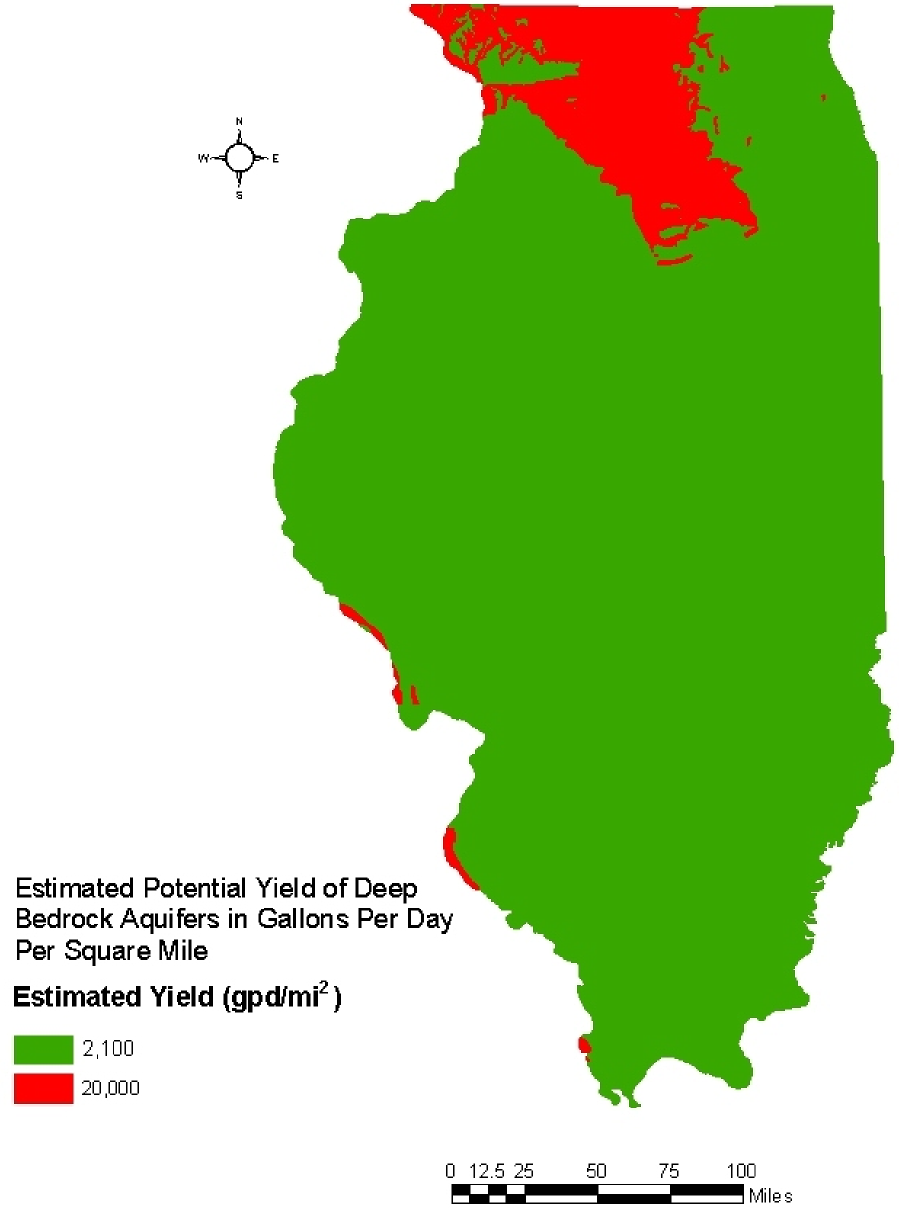

Figure 7. Estimated potential yield of the deep bedrock aquifers in Illinois.

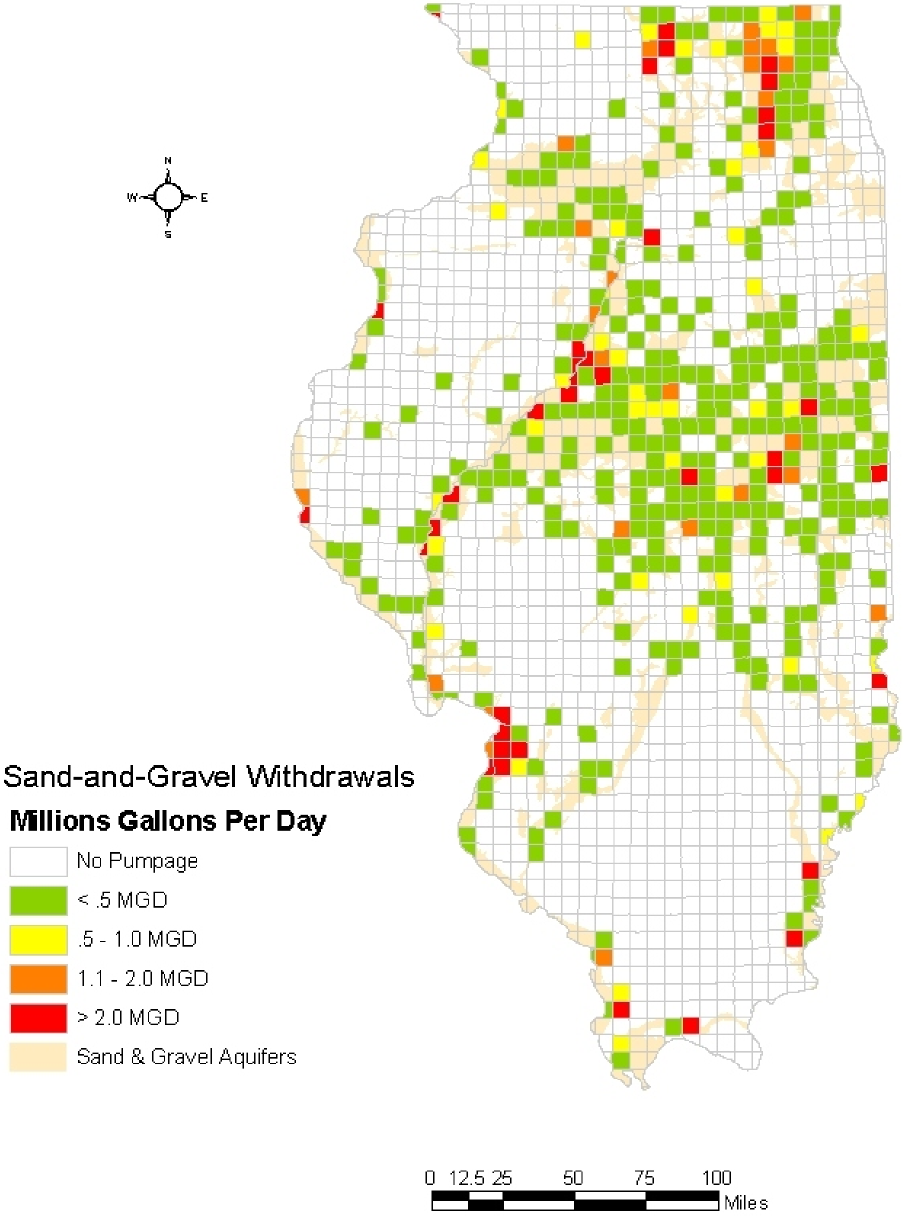

Figure 8. Withdrawals from sand-and-gravel aquifers, by township, mgd.

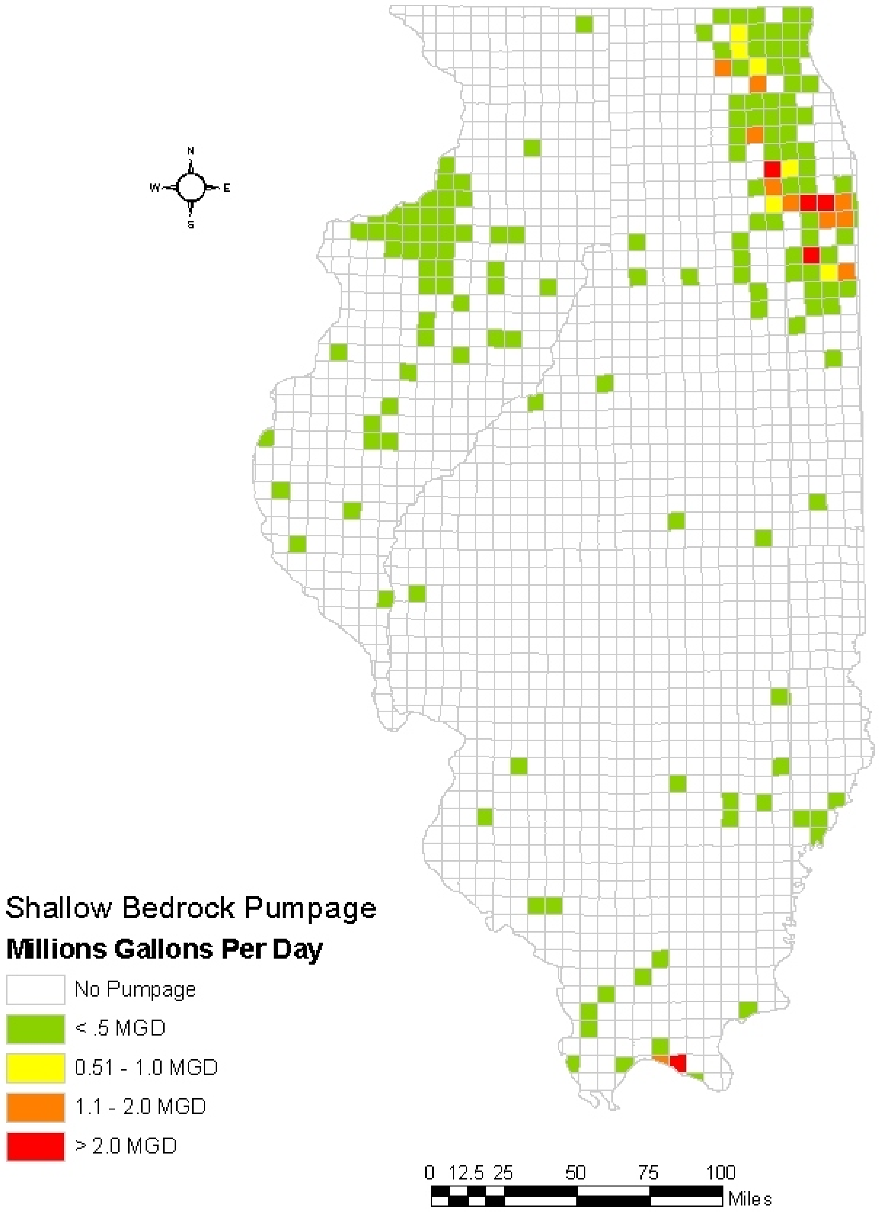

Figure 9. Withdrawals from shallow bedrock aquifers, by township, mgd.

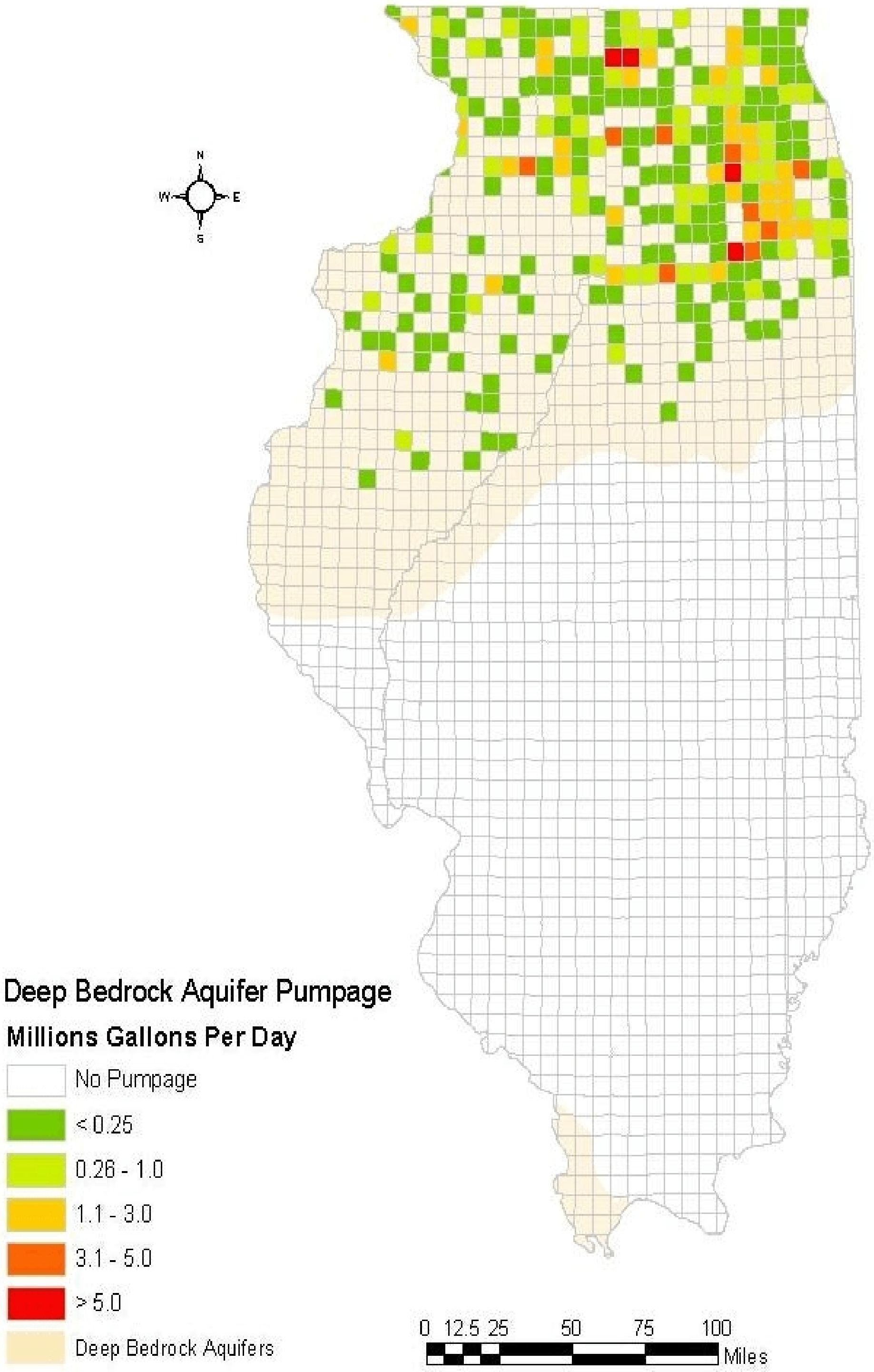

Figure 10. Withdrawals from deep bedrock aquifers, by township, mgd.

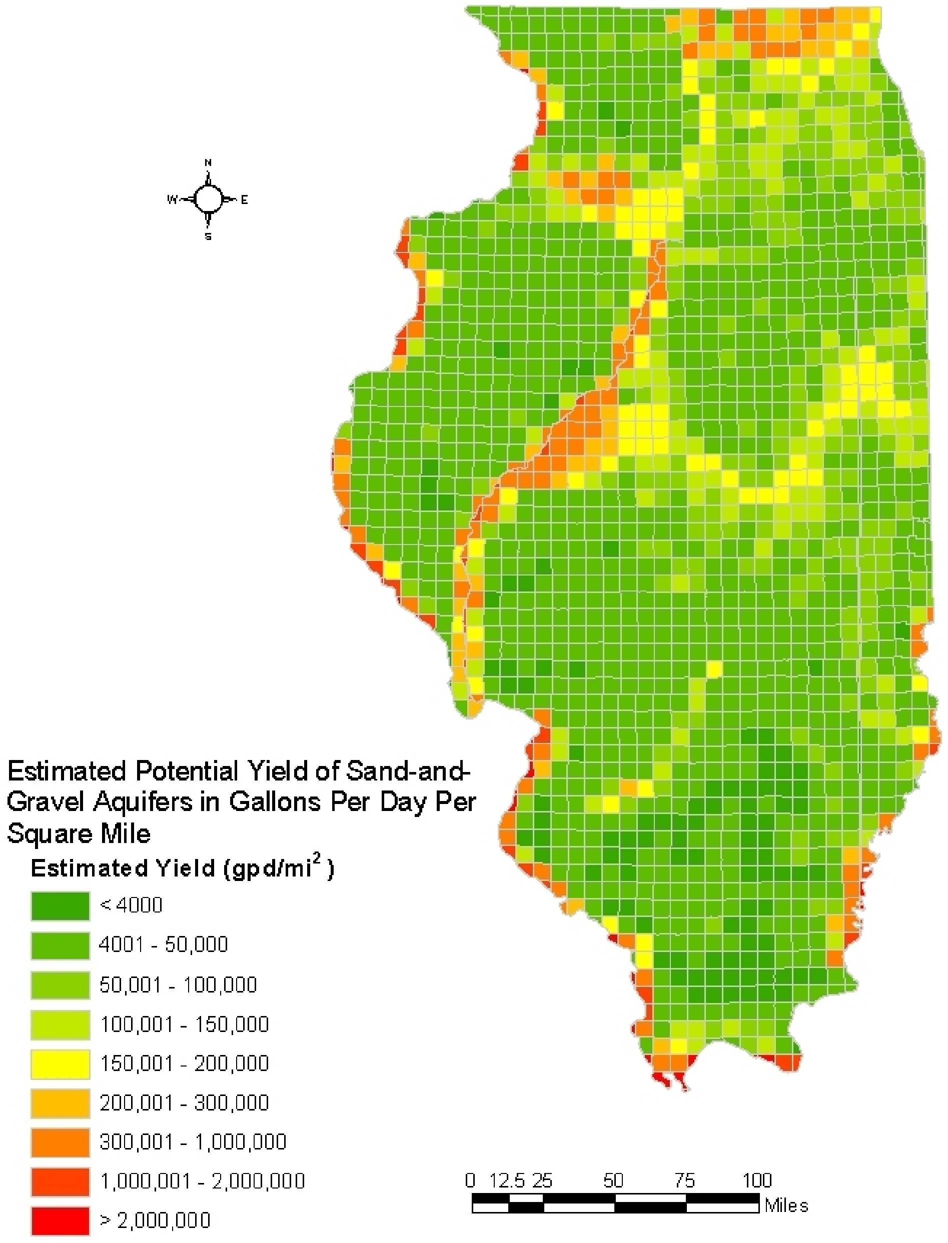

Figure 11. Composited township sand-and-gravel aquifer yields.

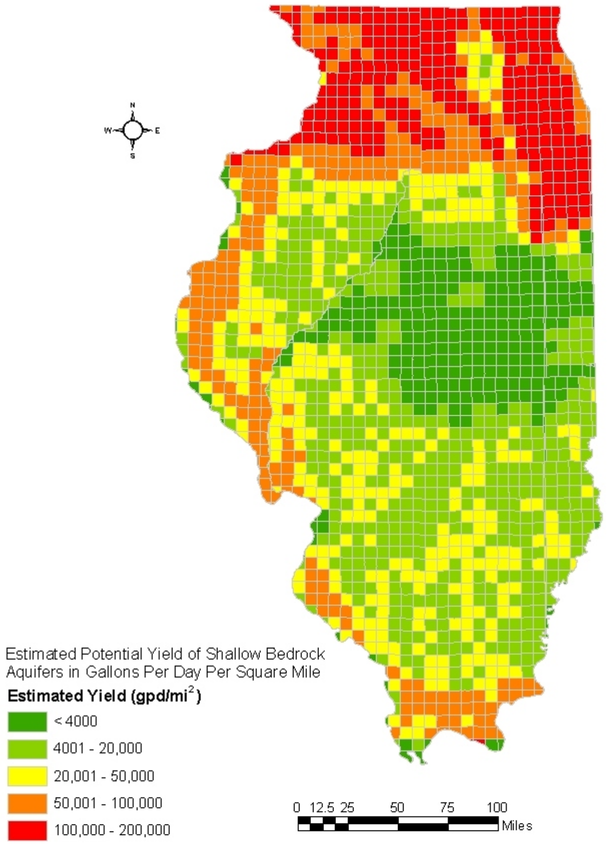

Figure 12. Composited township shallow bedrock yields.

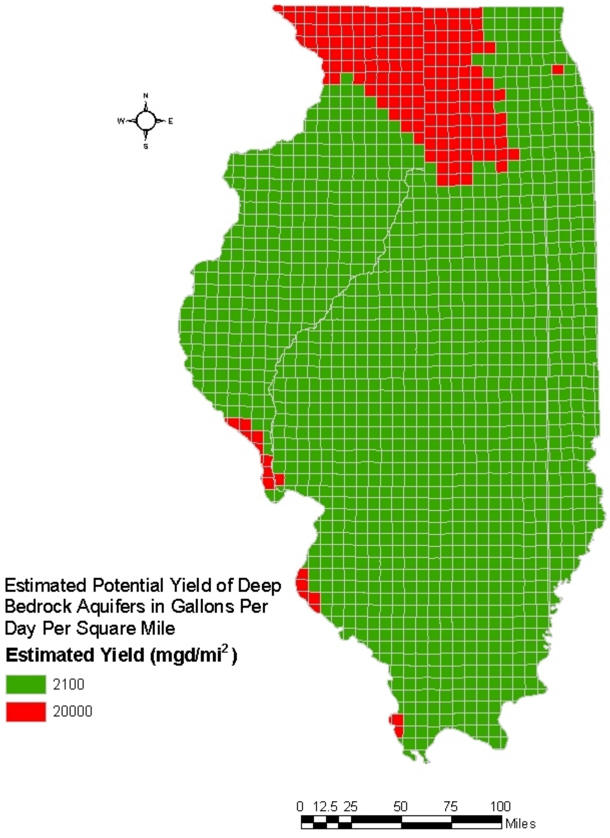

Figure 13. Composited township deep bedrock yields.

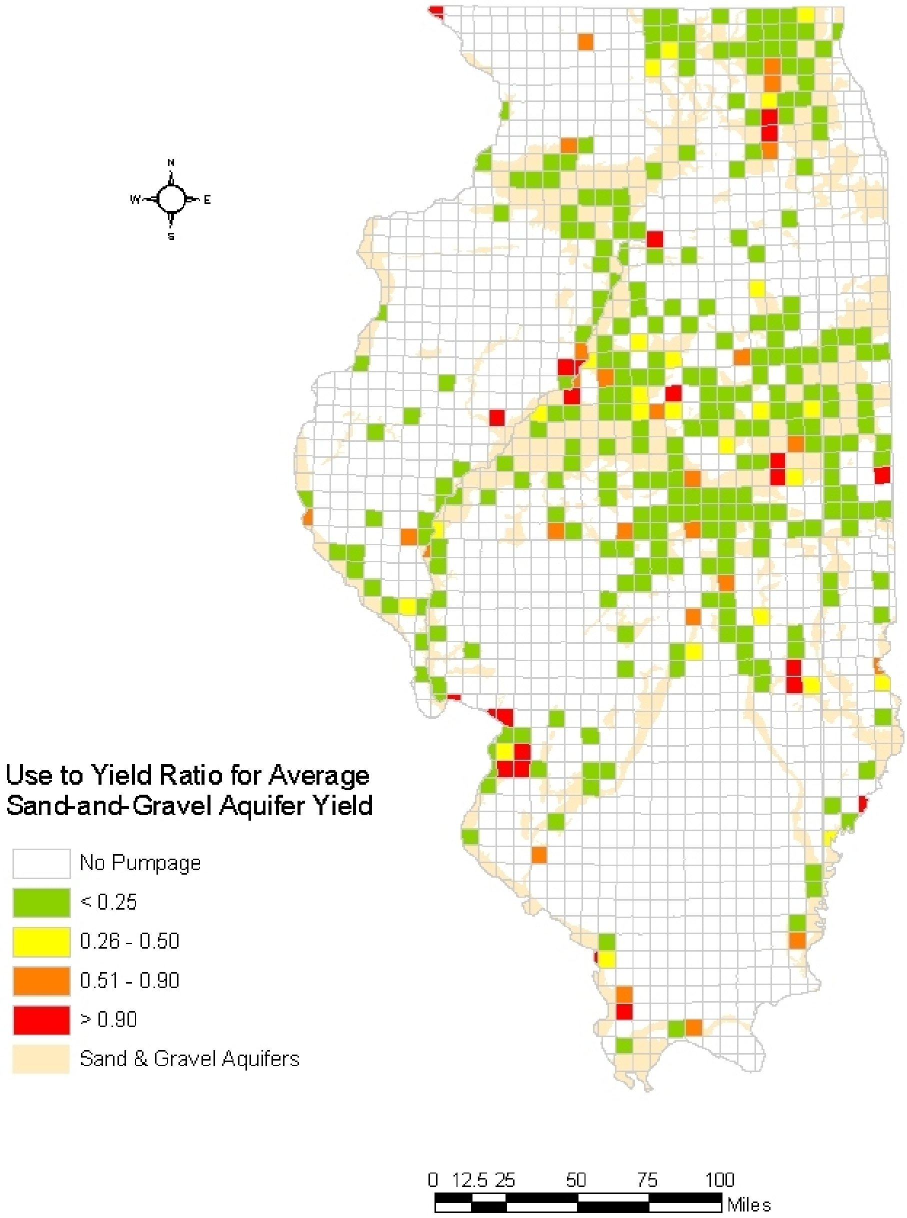

Figure 14. Sand-and-gravel use-to-yield ratios using the average potential yields presented in Table 1.

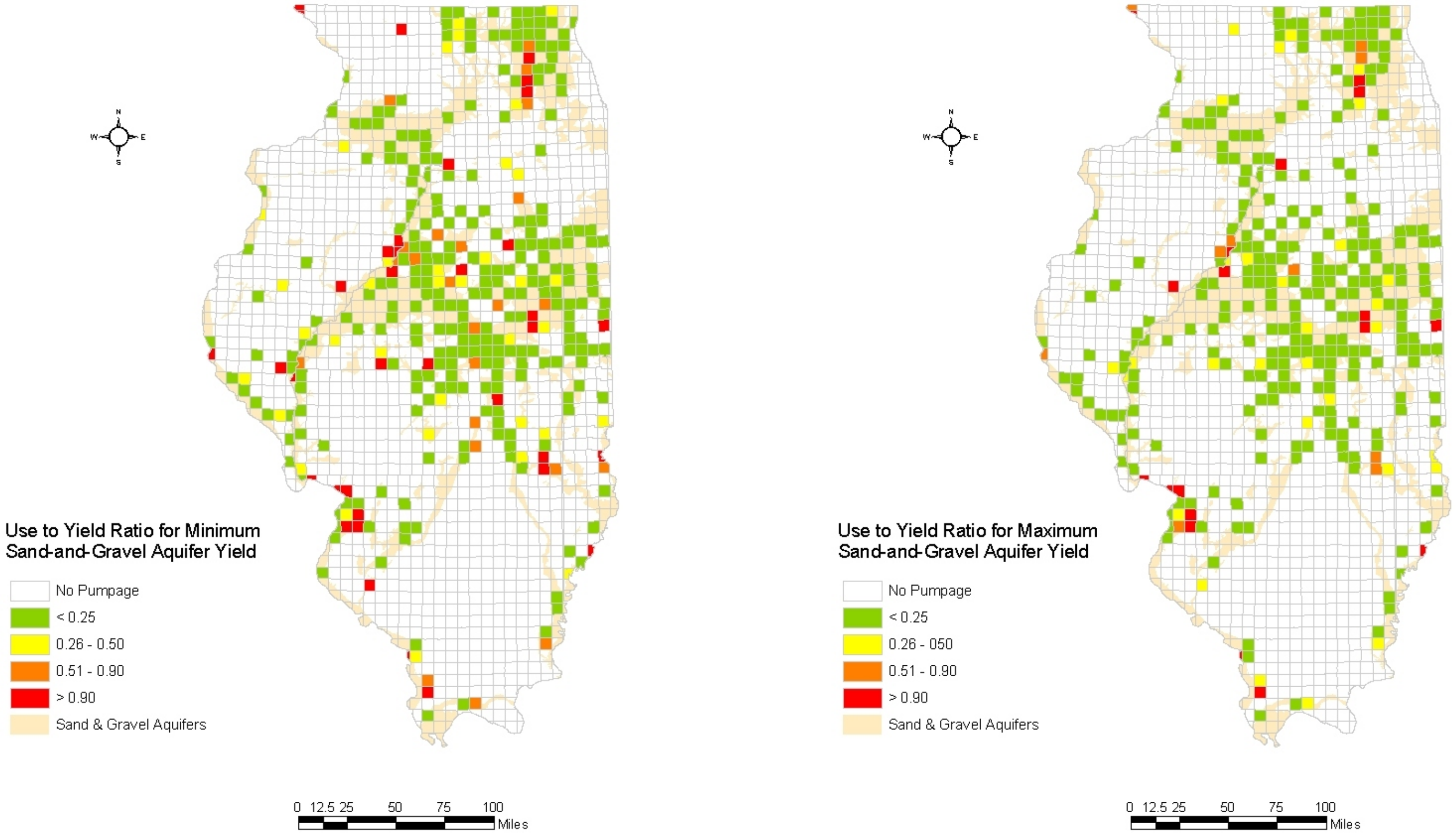

Figure 15. Sand-and-gravel use-to-yield ratios using the a) minimum and b) maximum yields presented in Table 1.

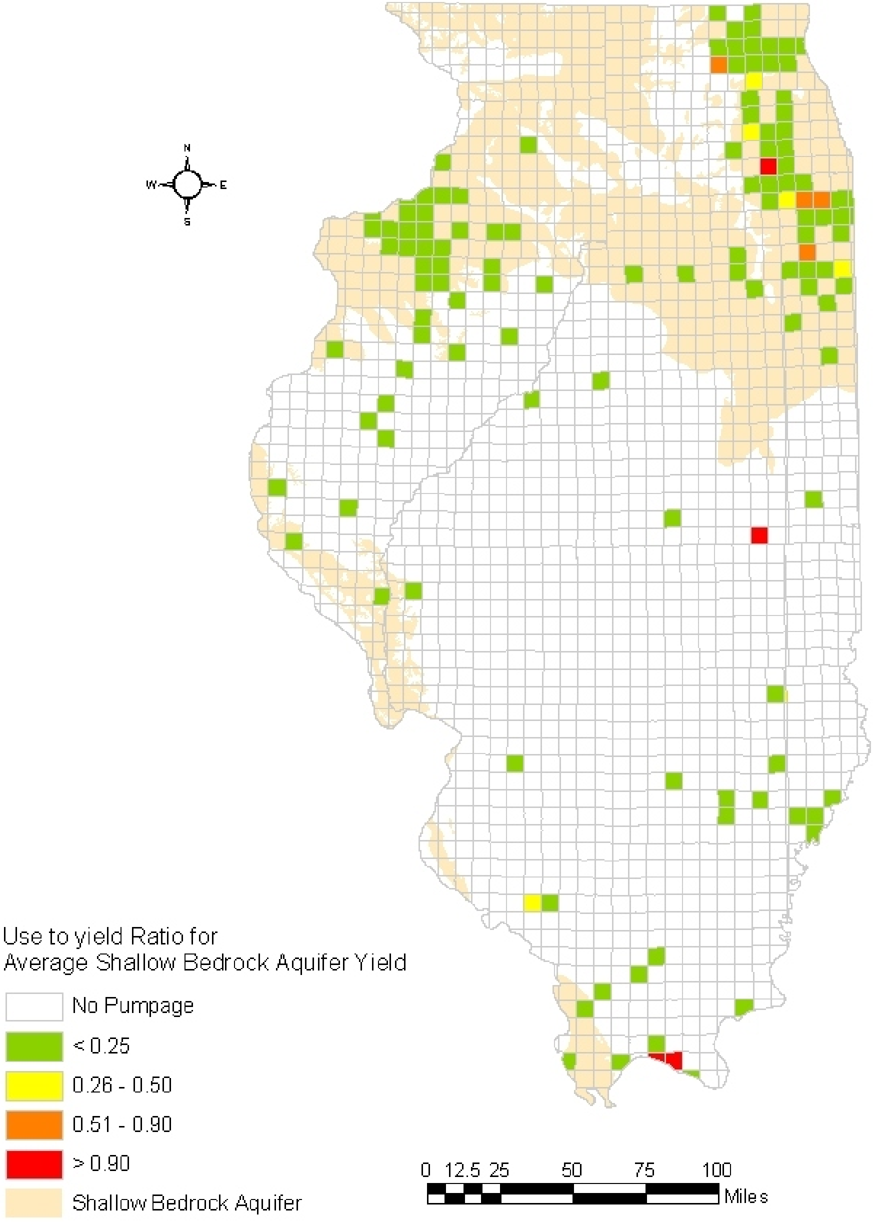

Figure 16. Shallow bedrock use-to-yield ratios using the average yields presented in Table 1.

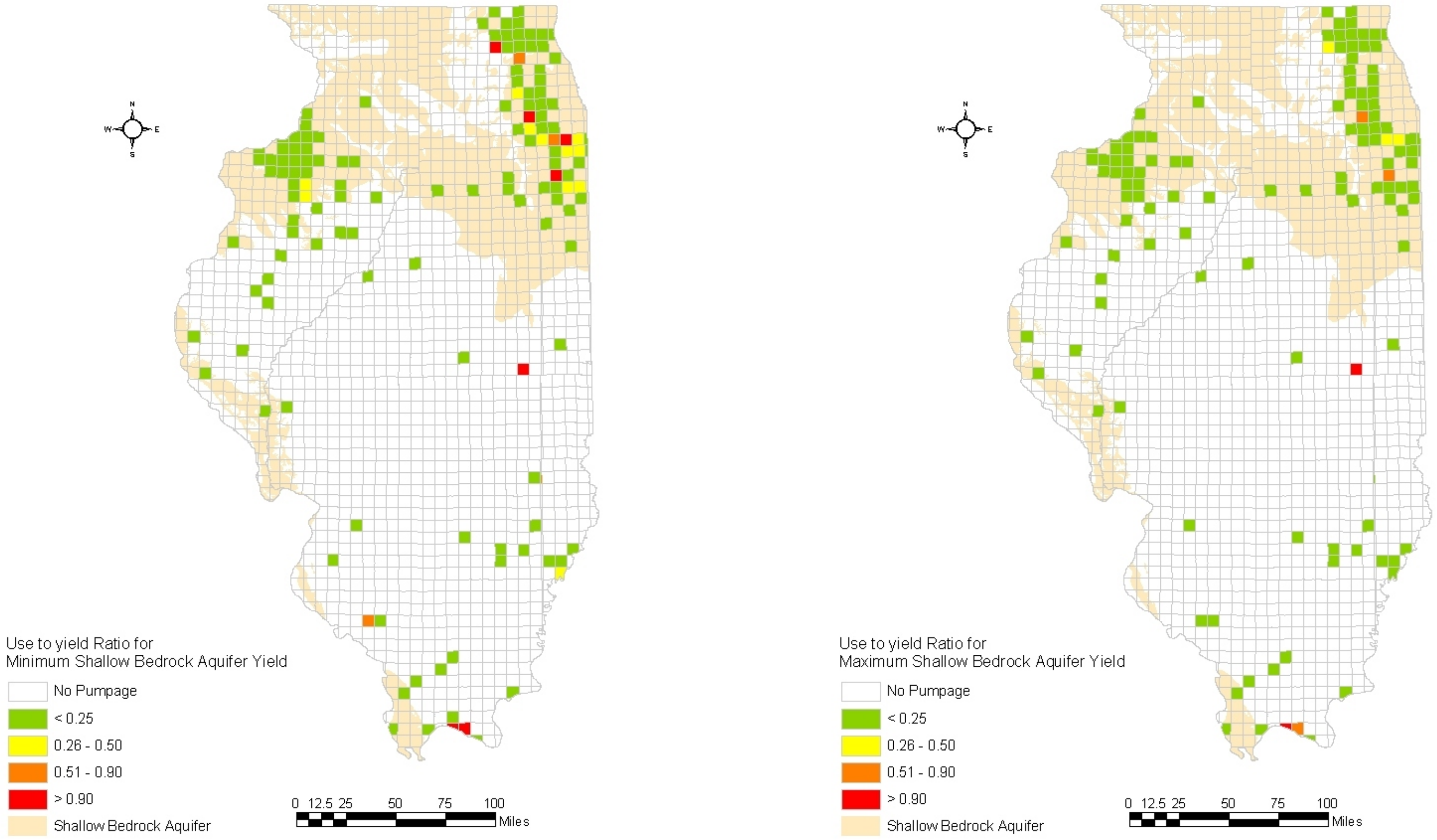

Figure 17. Shallow bedrock use-to-yield ratios using the a) minimum and b) maximum yields presented in Table 1.

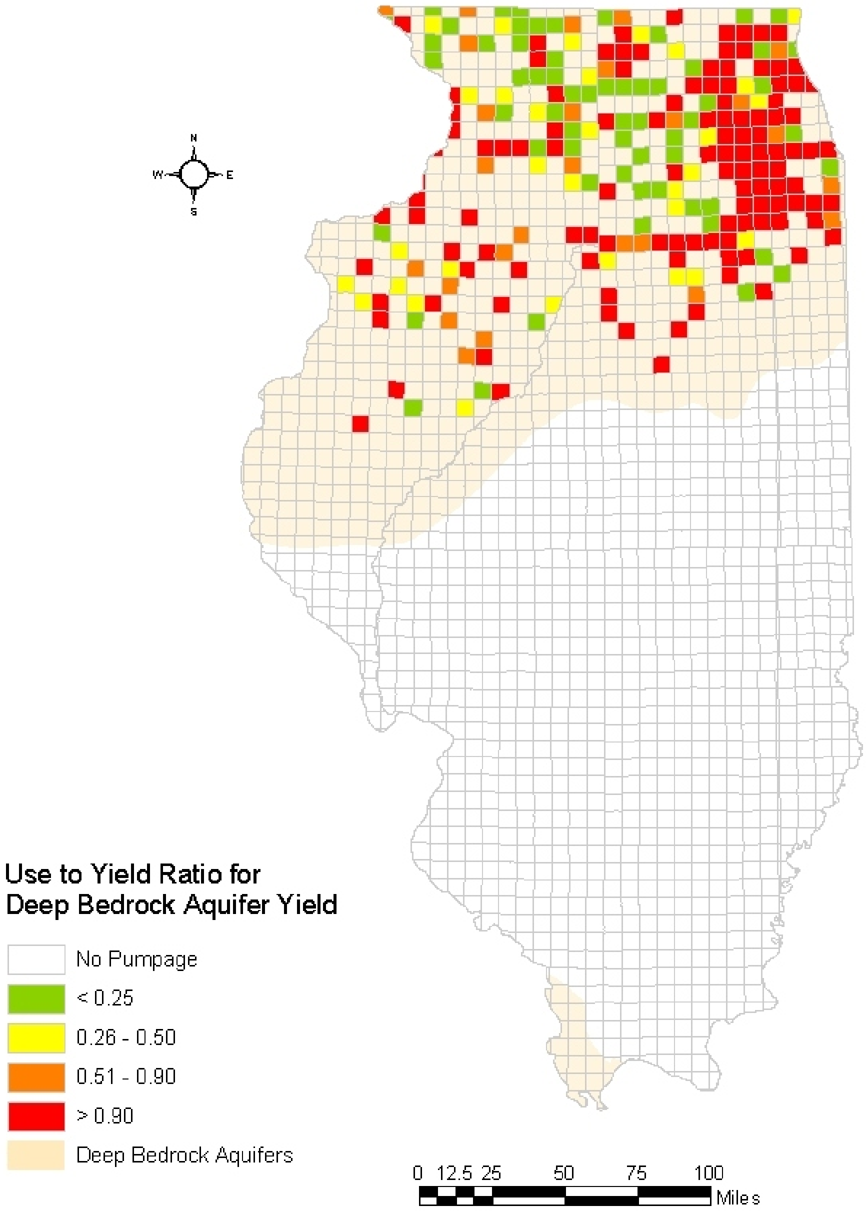

Figure 18. Deep bedrock use-to-yield ratios using the potential yields presented in Table 1.