Modeling a New Well Field for Champaign-Urbana

prepared for

Illinois American Water – Champaign, IL

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1 Introduction

Champaign/Urbana, Illinois lies in a region where major surface waters are scarce. As a result, the community's water supply depends on high-capacity wells that extract water from the Mahomet Aquifer (Figure 1), a deep sand-and-gravel aquifer that is the major source of water for many communities, farmers, and industries in central Illinois. The overlying Glasford Aquifers are used primarily for domestic water use. Currently, the local water utility, owned and operated by Illinois American Water (ILAW) operates two wellfields, located within and just outside the city. In response to increasing demand, ILAW has expanded capacity by constructing additional wells. This report describes an analysis that was done to evaluate the sustainable yield of the Mahomet Aquifer and consider the long-term impacts of a new wellfield located several miles west of the municipality. The new well field needs to provide additional capacity to the system while limiting impact on existing wells.

Because the Mahomet Aquifer is the primary water supply in this part of the state, groundwater availability will ultimately be determined by the balance of regional groundwater demand and recharge into the system. A sustainable water supply can be achieved by balancing supply and demand, so one part of our contract required an analysis of the character of regional demand for drinking water, irrigation, and industrial supply. This report also describes the degree to which a new well field could lower water levels in the aquifer and affect neighboring well owners.

The Illinois State Geological Survey (ISGS) and the Illinois State Water Survey (ISWS) have invested substantial time and resources characterizing the hydrogeology of the Mahomet aquifer system. Their work includes several long-term aquifer tests, groundwater monitoring, and geologic mapping. The ISWS effort has been synthesized in a recently developed, but still evolving, regional groundwater flow model. The purpose of the model is to consider the regional consequences of increased water use on water levels and water quality. Their investigation may be used by the state and the Mahomet Aquifer Consortium (MAC) - a group of local stakeholders interested in characterizing the resource, planning for future growth, and managing groundwater in the region. A recent Executive Order by the Governor of Illinois initiated a pilot program for water supply planning. As the Mahomet Aquifer is one of the two priority water quantity planning areas, this report should be useful to the community in considering the general problem of sustainability of withdrawals from this important resource.

In late 2005, ILAW hired WHPA Inc. (WHPA) to investigate the status, future, and potential of groundwater resources near the Champaign Operation, as an early planning step in the development of a new wellfield. The focus of this investigation is the Mahomet Aquifer in and around Champaign County. While this investigation takes a broad look at the consequences of pumping the regional Mahomet Aquifer on the overlying Glasford Aquifer system, the data and the tools used to model future conditions were limited. Consequently, our conclusions about hydrologic impact are approximate and generally limited to an average conditions and known variation in aquifer properties.

In particular, WHPA has been asked to:

- perform a regional groundwater demand analysis;
- describe what is known about the hydrogeology of the aquifer using existing data and reports;
- implement a groundwater model that is capable of predicting regional and local consequences of new pumping at candidate wellfield sites;
- report on the potential yields of the new wellfield and propose an arrangement of wells that would optimally make use of the resource.

WHPA has proceeded with this investigation, with cooperation, data support, and extensive and ongoing discussions with the ISGS and the ISWS. This report describes the findings of WHPA. It includes an evaluation of geologic logs and aquifer testing done in the area, and a comparison of the relative impacts of alternative designs for the wellfield.

Two related but distinct topics are discussed in this report: a regional groundwater demand analysis for the entire Mahomet aquifer system, and a groundwater modeling investigation for the siting and design of a new wellfield west of Champaign. To the extent possible, we have made use of the demand analysis in our modeling investigation. Wise management and development in the Mahomet Aquifer will require a thorough understanding of regional hydrogeology, groundwater flow, and increasing water demand.

1.1 Cautionary Notes

Readers should understand that the conclusions in this report reflect the considered judgement of a team of scientists that had substantial access to an imperfect data set. This investigation was designed to answer specific questions in order to begin the process of site development. This report is not meant to be a comprehensive description of all that is known about the aquifer(s) in the study area.

1.1.1 Context

Since this work was completed additional funds have been committed by ILAW to continue the exploration and research to understand the aquifers in the area. The goal of this and future scientific work is to map and predict the sustainable groundwater supply so that the community of water users can manage this important regional resource.

1.1.2 Scale

In this case the purpose of using a groundwater flow model is to consider the range of potential impacts of a new well field. The community water utility is interested in the possible regional effects of a new pumping center west of the existing West Well Field. However, water use data is incomplete and only available as annual withdrawal when it is available. The conclusions of this work are based on a relatively coarse representation of the aquifer.

1.1.3 Data Quality

The goal of this work was not to predict the actual drawdowns that may be generated at any point in the aquifer. The conclusions reached in this report are more valid near the proposed well field and are meant to represent annual average conditions.

This investigation builds upon internal water use and water planning reports that have been prepared by ILAW. Consequently, some of the data used in the water demand projections may not be in the public domain.

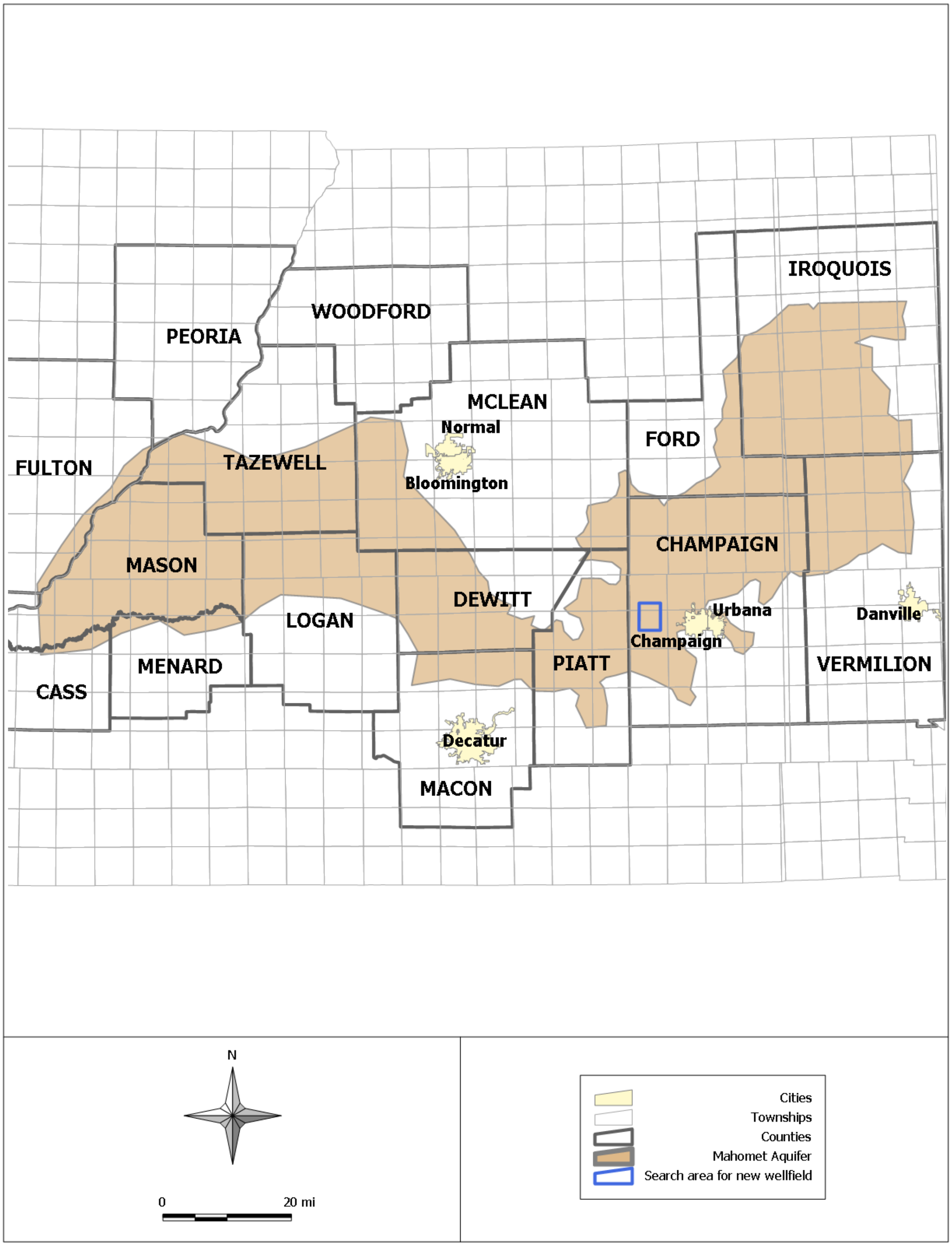


Figure 1: Location of project and extent of the Mahomet Aquifer in east-central Illinois.

2 Regional groundwater demand analysis

Central Illinois has two important sources of supply, the Mahomet Aquifer and the Glasford Aquifers. The Glasford Aquifers are used primarily for domestic use, so the Mahomet Aquifer is the main water-supply source for the cities, towns, and agricultural areas located in central Illinois. As in many parts of the country, water supply in the region overlying the Mahomet Aquifer is changing as cities and counties grow and increase their water supply needs. In order to ensure a sustainable water supply, water suppliers typically forecast water demand for local need, but regional demand studies are often not performed. Regional demand forecasts look at how and where water demand is growing to determine if the configuration of growth in the region is sustainable by available supplies. The first step in assessing whether growth can be accommodated is to put planned growth in the context of a regional water demand projection.

The following section of this report describes work WHPA did for ILAW to predict the regional water demand in the Mahomet Aquifer. This comprehensive assessment utilizes state and local public data to estimate the annual and seasonal groundwater withdrawal. This information is critical as ILAW prepares to site new wells that will provide the water necessary to meet demand while minimizing interference with other users of the aquifer. The new wells in the Champaign Operation will be directly affected by the groundwater demand of neighboring cities and counties, and vice versa. WHPA estimated the current water withdrawals from the Mahomet Aquifer and predicted the likely future withdrawals during the next twenty years. WHPA's knowledge of the location, timing, and amount of groundwater withdrawal informed the modeling effort.

The sub-sections that follow describe:

- the water-use projections that ILAW did for the Champaign Operation (Section 2.1);
- the regional water demand forecast that WHPA created for the Mahomet Aquifer (Section 2.2);
- synthesis of the regional demand forecast results and the Champaign Operation water-use projections (Section 2.3).

2.1 Water-use projections for the Champaign Operation

Recently, Illinois American Water developed projections of future water demand as a part of its ongoing assessment of water supply needs for the community. The historical record of pumping data used in the analysis began in 1992 and includes draft estimates of water use for 2005 (Figure 2). While the older water use records have been finalized, the most recent three years were derived from raw data extracted from the records kept by the production team at the Champaign Operation.

The water supply for the Champaign Operation is currently provided by 21 active wells that extract water from the Mahomet Aquifer and transfer water to two treatment plants (Table 1). The

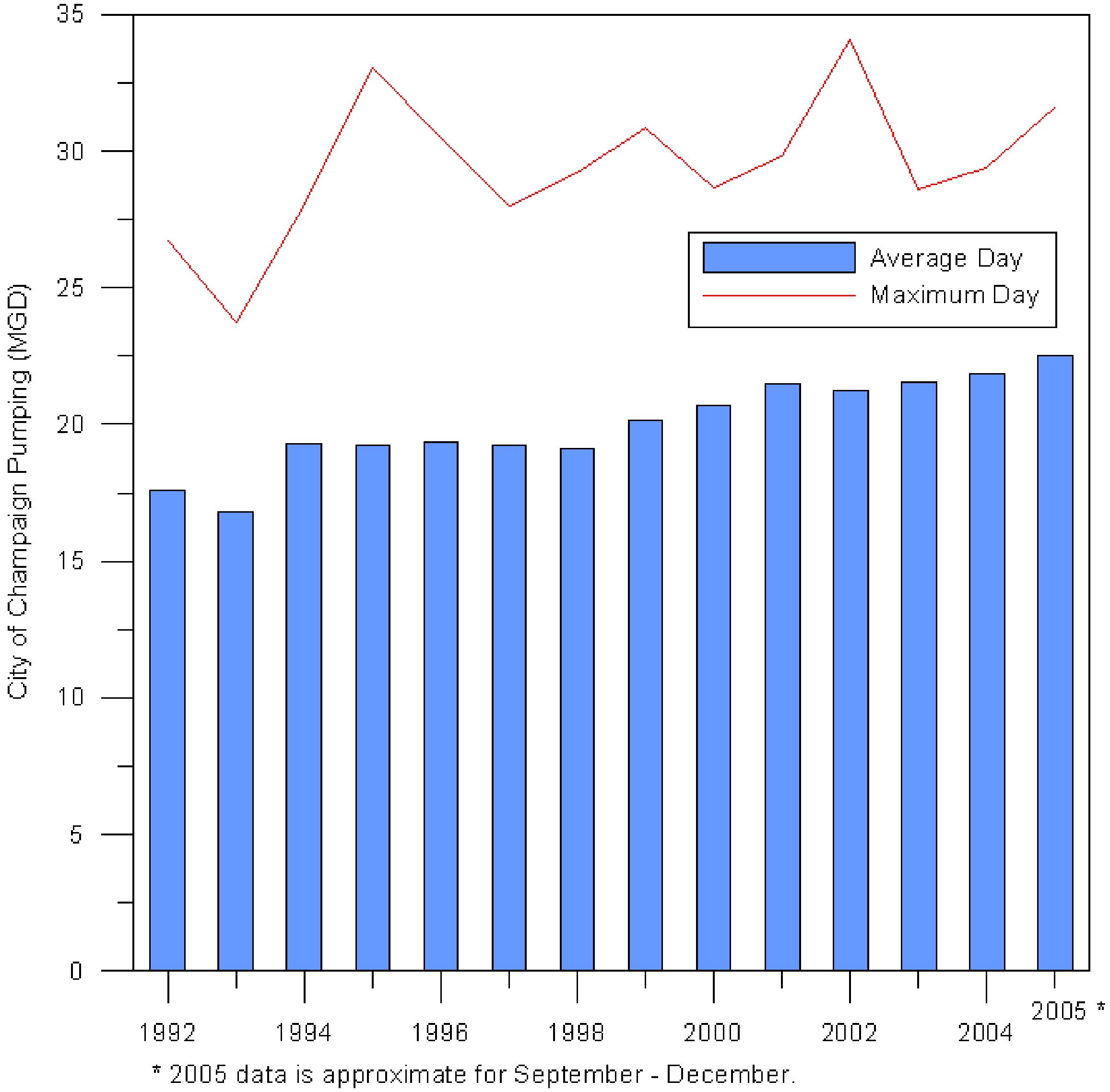


Figure 2: Historical average and maximum day pumping for the Champaign Operation [ILAW, 2005].

East Treatment Plant, on average, treats about 28 percent of the total raw water delivered and has a capacity of 10 million gallons per day (MGD). The West Plant treats about 72 percent of the total raw water delivered with a capacity of approximately 30 MGD. The ILAW wells range in capacity from 275 *gpm* to 3,000 *gpm*.

Over the period of record, the wellfields have produced an average of approximately 20 *MGD* (Figure 2). Like other public water supplies in the Midwest, ILAW experiences higher demands in the summer. On average, the maximum day demand for the utility is approximately 1.5 times the average rate. This means that most wells run continuously when demand is high (Figure 2).

2.1.1 Groundwater pumping by use category

The analysis conducted by Illinois American Water identifies five different water use categories:

residential standard retail domestic water for home-owners

commercial water used by businesses for commercial operations

industrial water used in manufacturing processes as well as any other industrial applications

non-revenue water provided to the community without a fee such as fire suppression, street cleaning, and flushing. Also includes water that is unaccounted for (e.g. leaks in the system)

other water delivered to wholesale customers who deliver to their own array of retail customers. Includes University of Illinois Champaign/Urbana.

The growth in overall demand is a function of both the percentage of the total pumpage in each of these categories and their individual growth rates. For example, the data show steady growth in the number of residential water users over the past decade, but also a concurrent *decrease* in per capita water use for residential customers. A rough estimate of the water consumed by each different water use category (as a percentage of the total pumpage) for the most recent years (1992 - 2002) is indicated below:

- residential: 40% of the total use, average growth rate of 0.11 MGD per year
- commercial: 16% of the total use, average growth rate of 0.05 MGD per year
- industrial: 7% of the total use, average growth rate of -0.06 MGD per year
- non-revenue: 12% of the total use, average growth rate of 0.07 MGD per year
- other: 25% of the total use, average growth rate of 0.17 MGD per year

Table 1: Summary of Illinois American Wells in the Champaign Operation, Illinois.

Well Number	**Depth below ground (feet)**	**Treatment Plant**	**Capacity (gpm)***
35	208	East	500
36	Not in use		
40	212	East	275
41	224	East	600
42	217.5	East	700
43	Well abandoned 2004		
45	199	East	375
46	208.9	East	350
47	215	East	375
52	Used for water level measurements only		
53	290	East / West	2100
54	330.5	East	3000
55	302	East	1000
56	315	East / West	2100
57	304	West	2100
58	326	West	2800
59	338.3	East	2100
60	343.5	West	2400
61	297	West	2100
62	343	East	1060
63	305	West	2430
64	314	West	1400
65	366	West	1700
66	351	West	2100

*Not firm capacity for wells

2.1.2 Method for predicting future water demand

To estimate future average water demand, ILAW projected three different growth rates (low, most-likely, and high) based on a range of economic assumptions. These rates were applied to each use category using base data from 1992 - 2002 (Figure 3). The range of estimates for the “most likely” projected demand indicates a 2006 average daily water use of 23.3 MGD. By comparing the ILAW prediction for water use in 2006 to the actual 2003-2005 pumping averages, we see that the projected growth rate labeled “most likely” is the most accurate forecast so far (Figure 3). The 2006 pumping estimate of 23.3 is just above the estimated 2005 average of 22.5 MGD.

The “most likely” growth rate predicts that the average pumping rate will increase to approximately 26.8 MGD by the year 2016, a 15% increase in the next ten years. Based on a 95% confidence interval, the maximum day demand is projected to increase to 44.6 MGD by the year 2016. This means that the Champaign Operation needs to be able to pump on average of 27 MGD and have a peak capacity of 45 MGD.

2.2 Mahomet Aquifer water demand forecast

WHPA created a regional water demand forecast for the Mahomet Aquifer, based largely on a report produced in 2005 by Southern Illinois University - Carbondale [Dzielgielewski et al., 2005]. A description of how the groundwater withdrawal was estimated for each water-use category follows a brief introduction to water forecasting.

2.2.1 Background

Three basic methods are used to predict water use: basic extrapolation, multiple regression, and disaggregated forecasting. The appropriate method is determined by the amount of available data, the goal of the study, and the characteristics of the particular area.

Extrapolation enables examination of the relationship between one independent variable (*e.g.* time) and one dependent variable (*e.g.* water use). Typically, trends tend to be linear, exponential, or logarithmic. Extrapolation is a good screening tool and is useful for predicting short-term demands. For example, if a utility needs to know whether or not it will be able to meet demands within the next ten years, an extrapolation of historical water use data may be all that is necessary. Extrapolation can be performed with historical water use, population, customer numbers, or any other data that is significantly linked to water use.

Whereas extrapolation analyzes one independent variable in relation to water use, **multiple regression** analyzes the relationship between several independent variables and a dependent variable. Multiple-regression models for water use often involve a combination of variables such as temperature, precipitation, economic factors, population, or employment. The relationship between water use and all of the relevant variables is developed using historical data for a given area. Then that

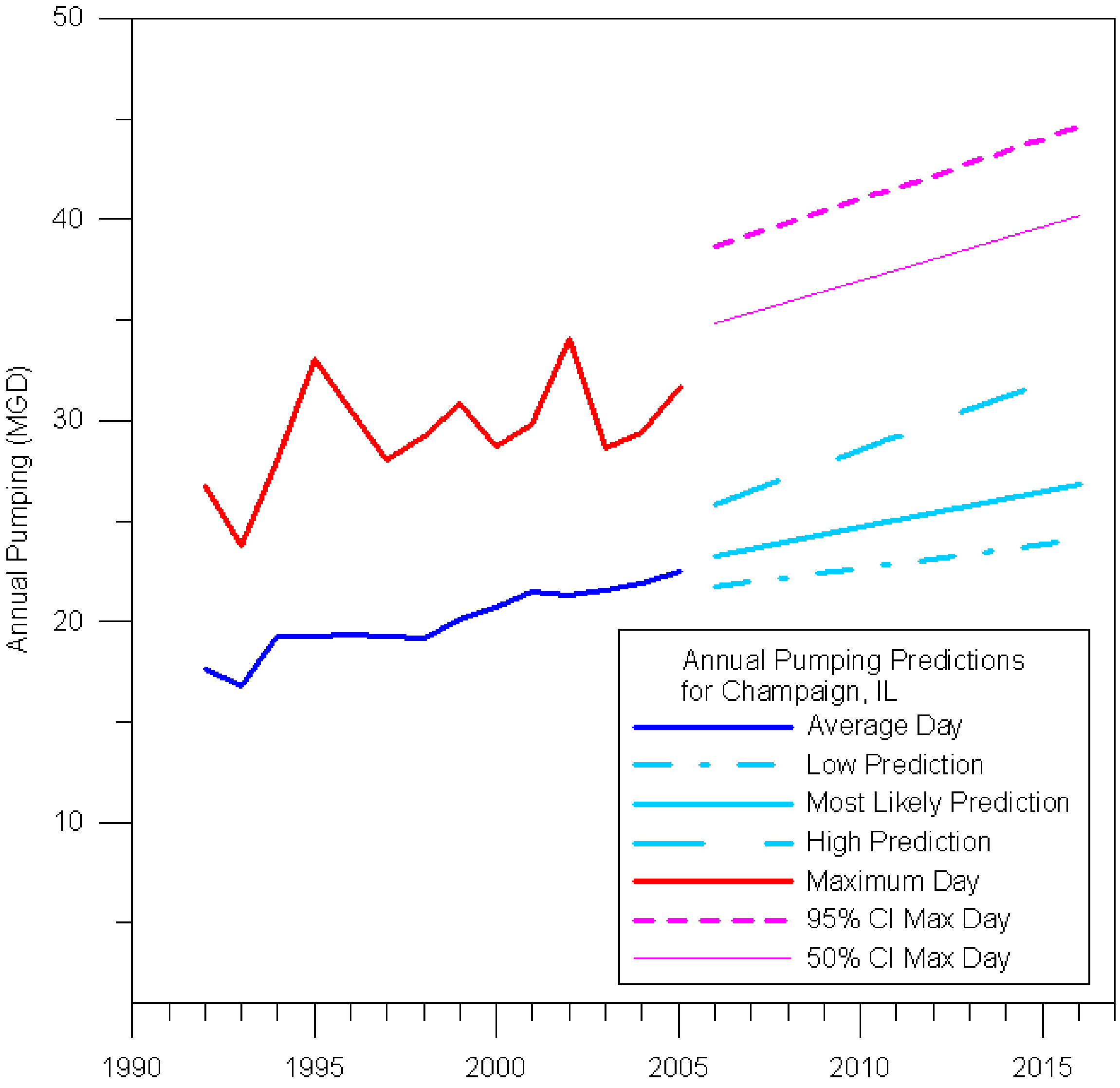


Figure 3: American Water Company Projections for the Champaign Operation [Simpson and Naumick, 2005].

mathematical relationship can be used to calculate future water use by predicting how the independent variables might change in the future.

The **disaggregated forecasting** method separates out demand sectors in a region. The scale of the demand sectors may vary depending upon the size of the area. For example, a city utility may divide its region into sectors such as hospitals, universities, single-family homes, multiple-family homes, and golf courses. A multiple county region, such as the Mahomet Aquifer Region, may separate sectors such as public water supply, industrial, irrigation, and livestock supply. A predictive model is constructed for each sector, either by extrapolation or multiple regression. Then all of the models are added together to predict the regional demand and cumulative change.

For an area as large as the Mahomet Aquifer where each category of water use is affected by different conditions, the disaggregate model is ideal. For example, public water supply trends depend upon employment opportunities whereas agricultural use is affected by precipitation and changing land use. The disaggregate method was chosen for the Mahomet Aquifer regional demand study because it predicts water withdrawal for each sector while including the effects of different variables for different sectors.

2.2.2 Approach

The boundary of the Mahomet Aquifer includes portions of 16 counties (Figure 1). Because the areas overlying the aquifer in Peoria and Fulton Counties are on the opposite side of the Illinois River, they have been left out of the predictive model. It is assumed that the aquifer in these areas is connected to the river, and therefore does not remove a significant amount of groundwater from the eastern side of the river.

The main source of data used in the demand forecasting study was a report produced in 2005 by Southern Illinois University - Carbondale (SIUC) [Dzielgielewski et al., 2005]. The report presents models of county-level water use for the entire state of Illinois and forecasts of the amount of water, both surface water and groundwater, that each county will use from 2005 - 2025 (in five year intervals). SIUC used the best available data for each type of use: public water supply, commercial and industrial use, self-supplied domestic use, livestock, irrigation, mining, and thermoelectric-power generation. For each sector, historical data was used to create a model to predict future water use. Because the water forecasting model created by SIUC used the best available data and a multivariate approach, the model coefficients and other information gleaned from this statewide report were used in our demand study. Our study used information from the report for the fourteen counties but scaled down the numbers to reflect the portions of each county that overlie the Mahomet Aquifer.

Our study first examined the amount of water both historically and currently being pumped from the aquifer in each county for each water-use category in Equation 1. Then, using sector models from the SIUC report, the amount of water used in each area above the Mahomet Aquifer was

Table 2: Water-use sectors used by the SIUC and WHPA groundwater demand forecasts.

Sector	**SIUC**	**WHPA**
Public Water Supply	✓	✓
Commercial and Industrial	✓	
Self-supplied Domestic	✓	✓
Livestock	✓	✓
Irrigation	✓	✓
Mining	✓	
Thermoelectric-power Generation	✓	
Commercial and Industrial, Mining, Power Generation		✓

predicted. The following sub-sections describe how the quantity of water from each water-use type was calculated and forecasted. After each water-use type was predicted, the total water pumped from the aquifer was calculated using Equation 1.

$$TW_t = \sum_i (PS_{it} + DM_{it} + CI_{it} + IR_{it} + LS_{it}) \tag{1}$$

where

TW is total water withdrawal in the fourteen county region for a certain year (*t*)

PS is the public water supply withdrawal in county *i* during year *t*

DM is self-supplied domestic withdrawal

CI is the self-supplied commercial and industrial withdrawal

IR is the irrigation withdrawal

LS is the livestock withdrawal

The mining sector and thermoelectric power generation sector were not differentiated in our model as in the SIUC model because groundwater pumped from these sectors are incorporated into the commercial and industrial water use sector and is reported to the Illinois State Water Survey (ISWS). Furthermore, the most recent USGS water use information reports no groundwater withdrawals for mining in the state of Illinois.

2.2.3 Public water supply

A public water supply, as defined by the EPA, is a public or privately-owned system that serves at least 25 people or 15 service connections for at least 60 days per year [EPA, 2004]. The USGS has been collecting public water supply data since 1950 and these data are used each year to calculate county-level totals reported in national water use summaries. These summaries are the main data used by SIUC to estimate withdrawals in each county. WHPA's forecasts used annual pumping data which is reported to the ISWS by public water suppliers.

SIUC model development SIUC developed a multivariate public-water supply model based upon factors previously determined to influence water use. The study found that water withdrawal at the county level highly correlates with population (R^2=0.98). For this reason, per capita withdrawal was used as the dependent variable. After testing a large number of independent variables, the SIUC researchers found a number of variables that significantly influence water use. These variables are:

- Average Summer Temp - summer temperature data for normal weather patterns were used to calculate projections.
- Percent Multi-Family Housing - single family houses are generally expected to be correlated with higher levels of water use than either multi-family housing or mobile homes. Because county-level projections were not available, the Energy Information Administration rates of housing change for the state of Illinois were applied uniformly to all counties. These estimates predict an increase in the percent of multi-family homes and a decrease in single family homes.
- Percent Employed - population projections and employment changes for each county were combined to forecast the percent of employed persons. The population projections were published by The State of Illinois and the employment projections were reported by the Illinois Department of Employment Security.
- Population served - the future population of each county served by public water supply was assumed to be a constant *percent*. The percent served by public water supply in 2000 was used to calculate future years by multiplying that percent times the projected county population.
- Residential Marginal Price - In 2003, a survey of water prices was performed in each county. Using the survey, a population weighted price variable was calculated for each county.
- Trend - the trend variable accounts for changes in general water use behavior. Examples include decreases in water use due to increased awareness, conservation laws, and rising drinking-water costs.

The variables were regressed against the dependent variable, average annual per capita withdrawal. Both logarithmic and linear models were tested using a stepwise regression procedure. A double-log model was selected that expresses per capita water use as a function of the variables chosen. WHPA forecasted water withdrawal for each county in five year increments through 2025 with this model (Table 3).

Mahomet Aquifer public water supply forecasts using the SIUC model Three scenarios were modeled for public water supply demand:

1. Baseline forecast - the probable water demand with continued growth in the current public water supplies using the Mahomet Aquifer
2. Conservation - the predicted demand from public water supplies with continued implementation of conservation measures
3. Addition of new public water supplies - the baseline water forecast for the current public water supplies plus additional demand from *new* public water suppliers expected to construct wellfields in the Mahomet Aquifer.

The SIUC model predicts total water withdrawal for the years 2005, 2010, 2015, 2020, and 2025 for each of the counties in Illinois. We calculated the percent change over each increment of five years and assumed that the calculated percent increase or decrease was distributed evenly for all public water suppliers in each county (Table 3). For each public water supplier using the Mahomet Aquifer, we forecasted water withdrawal by applying the percent change calculated for their county to their annual pumping rates obtained from the ISWS.

The ISWS maintains annual groundwater pumping records for public water suppliers through the Illinois Water Inventory Program (Figure 4). The program is voluntary and, therefore, lacks data from some public water suppliers for some years. This is apparent in years 1999 and 2003 (Figure 4). Because the historical pumping records can be misleading, we used “revised” 2004 data as a baseline for our projections. The 2004 pumping data were edited by the ISWS using local and historical knowledge to estimate values for the missing data. The 2004 pumping data shown in Figure 4 depicts the edited values used for the projections.

The percent increase in water withdrawal by public water suppliers was calculated using the results of the SIUC model (Table 3). Using these rates of increase, we forecasted future withdrawals by the public water suppliers that overlie the Mahomet Aquifer. The public water supply forecasts are shown in Table 4 and Figure 5. The values for 2005 were calculated by multiplying pumping rates for 2004 with one fifth of the growth rate for 2005-2010 since the projection was not for five years in the future but one year.

Table 3: Percent change in public water supply groundwater withdrawal per county based on [Dzielgielewski et al., 2005].

County	**Year**			
	2010	**2015**	**2020**	**2025**
Cass	0	0	0.85	0.85
Champaign	4.38	3.65	3.52	3.55
DeWitt	0	-0.71	0.71	0
Ford	0.65	0.64	0.64	0.63
Iroquois	-0.9	0.45	0	0.45
Logan	1.06	0.35	0.35	0.7
Macon	1.91	2.08	2.1	2.14
Mason	-2.13	-1.09	0	1.1
McLean	4.26	4.15	4.17	4.25
Menard	7.37	6.86	8.26	7.63
Piatt	1.02	1.52	1.99	2.44
Tazewell	1.64	1.79	2.11	2.13
Vermilion	1.19	1.39	1.48	1.56
Woodford	3.46	4.4	5.06	4.98

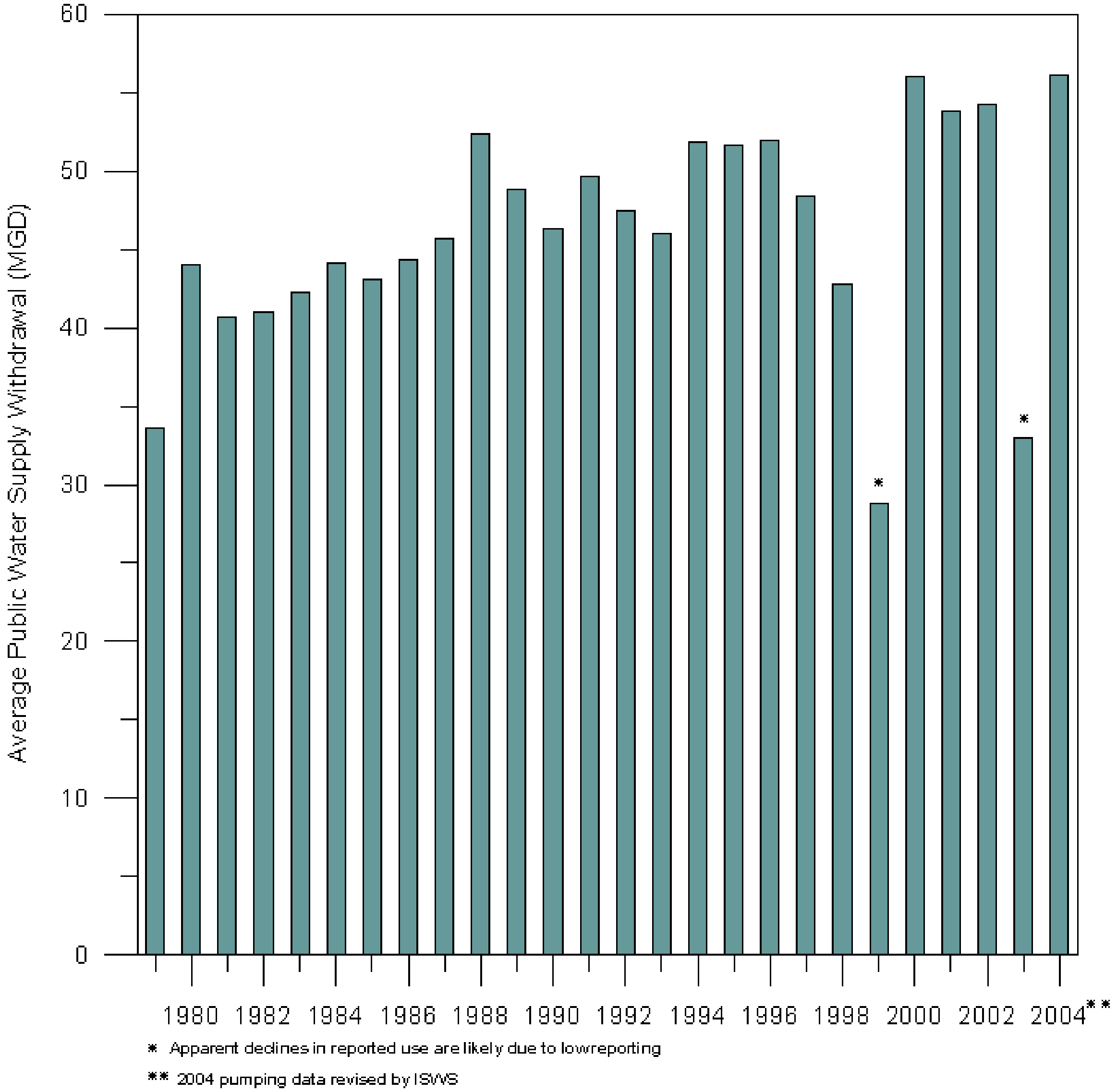


Figure 4: Historic pumping records from the Illinois Water Inventory Program for the public water suppliers using the Mahomet Aquifer.

The conservation scenario used the ’trend’ variable in the SIUC predictive model which captured the conservation trends in water use from 1985-2000. The reduction in per-capita water use during 1985-2000 was mainly due to increased conservation awareness, new laws requiring conservation technologies and appliances, and an increase in the adoption of full-cost pricing of water [Dzielgielewski et al., 2005]. The conservation predictive scenario assumes that the reductions from conservation measures continue to follow along the same trend through 2025 (Figure 5). The likelihood of this trend continuing depends on local efforts. Increased use of water saving appliances such as low-flow toilets, water-saving washing machines, water efficient dishwasher, and low-flow shower-heads help the decrease per-capita water use. But, conservation can “die off” in an area do to inundation with water-saving appliances or loss of interest. Local, continuous monitoring of per-capita water use can inform utilities if conservation trends are continuing or need to be revived with additional efforts.

In addition to the increase predicted by the SIUC model, there are other communities overlying and near the Mahomet Aquifer that have looked at possibly developing additional supply from the Mahomet Aquifer. These communities include Bloomington-Normal, Springfield, Decatur, and Danville. The actual liklihood of these communities adding supply from the Mahomet Aquifer is not currently known, but Decatur has an emergency wellfield already developmed into the Mahomet Aquifer that is capable of pumping over 15 MGD, that has been used as recently as 2005 [ISWS, 2006]. In addition, Bloomington-Normal funded a study in the late 1990s to help identify the potential of developing a 15 MGD wellfield in the Mahomet Aquifer in Eastern Tazewell or Western McLean Counties. Basedon these potential additional users, 15 MGD was added to the model incrementally (5, 10, 15 MGD) to the projections for the years 2015, 2020, and 2025 (Figure 5). Should all of these communities decide to expand into the Mahomet Aquifer, the additional long-term demand scenario could be as high as 80 MGD [ISWS,].

The ILAW water-use projection for the Champaign Operation was performed at a finer scale so we feel it more accurately reflects the growth in the city. For this reason, the results of ILAW projections for the Champaign Operation were incorporated into the Champaign County projections by replacing the WHPA projections for the city with the ILAW projections.

The public water supply baseline projections for each county are shown in Table 4. Baseline, conservation, and additional pumping results are summarized in Table 5.

2.2.4 Self-supplied domestic withdrawals

The self-supplied domestic water use in each county was calculated by multiplying the self-supplied population by the per capita water use coefficient estimated by USGS (Table 6). For the purpose of these projections, the per capita estimate of self-supplied domestic water use was kept at 90 gallons per capita per day (gpcd).

As in the SIUC forecasts, the projections of the self-supplied population in each county were

Table 4: Projections of public water supply pumping from the Mahomet Aquifer in million gallons per day per county based on [Dzielgielewski et al., 2005] and [ISWS, 2005].

County	**Year**					
	2004	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	1.57	1.57	1.57	1.57	1.59	1.60
Champaign*	25.1	25.7	28.0	29.9	31.9	33.8
DeWitt	1.19	1.19	1.19	1.18	1.19	1.19
Ford	0.68	0.68	0.69	0.69	0.7	0.7
Iroquois	1.92	1.92	1.9	1.91	1.91	1.92
Logan	0.98	0.98	0.99	0.99	1.00	1.00
Macon	1.24	1.24	1.27	1.3	1.32	1.35
Mason	0.95	0.95	0.93	0.92	0.92	0.93
McLean	2.08	2.10	2.19	2.28	2.38	2.48
Menard	0.49	0.50	0.54	0.57	0.62	0.67
Piatt	1.31	1.31	1.33	1.35	1.37	1.41
Tazewell	16.4	16.5	16.8	17.1	17.4	17.8
Vermilion	0.88	0.89	0.89	0.9	0.91	0.93
Woodford	1.29	1.30	1.34	1.40	1.47	1.54
TOTAL	**56.1**	**56.8**	**59.6**	**62.1**	**64.7**	**67.3**

*ILAW projections for Champaign Operation included

Table 5: Summary of public water supply pumping from the Mahomet Aquifer in million gallons per day based on [Dzielgielewski et al., 2005] and [ISWS, 2005].

Projection	**Year**				
	2005	**2010**	**2015**	**2020**	**2025**
Baseline	56.8	59.6	62.1	64.7	67.3
Conservation	56.8	56.0	55.3	54.3	53.5
Possible additional PWS	59.8	59.6	67.1	74.7	82.3

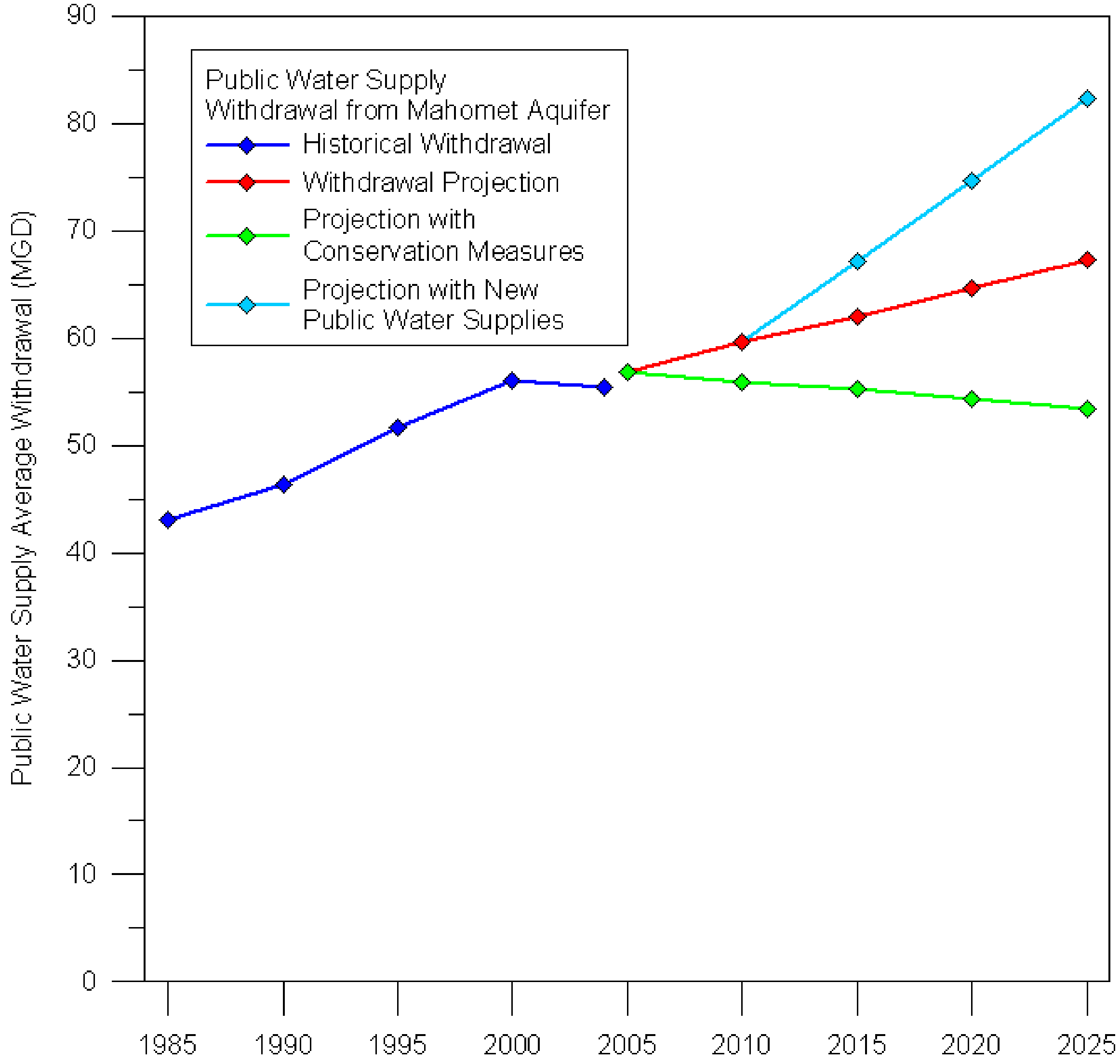


Figure 5: Public water supply withdrawal projections for the Mahomet Aquifer based on [Dzielgielewski et al., 2005] and [ISWS, 2005].

Table 6: USGS domestic self-supplied per capita water use estimates from 1985 - 2000 [Dzielgielewski et al., 2005].

Year	Per Capita Water Use
1985	74.4
1990	84.1
1995	90
2000	90

estimated by subtracting the projections for the public water supply population from the projected total county population. Because only a portion of each county overlies the Mahomet Aquifer, we further multiplied each county-wide self-supplied population by the percent of the county overlying the Mahomet Aquifer (Table 7). For example, 65% of DeWitt County overlies the aquifer, so the county's self-supplied population (5,768 people) was multiplied by 0.65.

Not all domestic wells are drilled into the Mahomet. Some are screened in the overlying Glasford or Mason Formations. There are no precise data available that indicates the number of wells drilled into the Mahomet versus the Glasford. One indication of the percentage of wells drilled into the Mahomet versus the Glasford/Mason Formations is a study performed by the ISGS that examined about 3500 well logs and found that approximately one third of the wells were drilled in the Mahomet Aquifer [Larson et al., 2003a]. Other evidence, from our own investigation of local well logs, revealed that approximately 60% of wells near Champaign are drilled into the Mahomet Aquifer. For the purposes of our withdrawal estimation and forecast, we used a conservative estimate of 50%. (Figure 6). The results of the self-supplied domestic water use forecast are summarized in Table 8.

Self-supplied domestic water withdrawal accounts for approximately 2% of the total withdrawal from the Mahomet Aquifer. This category has an average growth rate of approximately 0.01 MGD per year.

2.2.5 Irrigation

Projections for irrigation water withdrawals were developed by SIUC based on historical trends in Illinois agriculture. The historical trends were based upon USGS estimations of historical irrigation withdrawals. SIUC used the same approach for its projections as the USGS did for its historical estimates of withdrawal. The total amount of cropland acres and the average rainfall deficit was projected for each county [Dzielgielewski et al., 2005]. Then the percent of irrigated cropland was calculated using these trends and a linear model was developed to project the amount of water used in each county for the months of May through August. We used the SIUC total county irrigation

Table 7: Percent of county overlying the Mahomet Aquifer based on [ISWS, 2005].

County	**Percent of County Overlying the Mahomet Aquifer**
Cass	45
Champaign	66
DeWitt	65
Ford	36
Iroquois	68
Logan	60
Macon	36
Mason	100
McLean	36
Menard	28
Piatt	70
Tazewell	86
Vermilion	35
Woodford	26

Table 8: Self-supplied domestic water use projections per county in the Mahomet Aquifer in million gallons per day based on [Dzielgielewski et al., 2005].

County	**Year**					
	2000	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	0.11	0.11	0.11	0.11	0.11	0.11
Champaign	0.41	0.42	0.44	0.46	0.47	0.48
DeWitt	0.17	0.17	0.16	0.16	0.16	0.16
Ford	0.06	0.06	0.06	0.06	0.06	0.06
Iroquois	0.23	0.23	0.22	0.22	0.22	0.22
Logan	0.27	0.27	0.28	0.28	0.28	0.28
Macon	0.08	0.08	0.08	0.08	0.08	0.08
Mason	0.36	0.35	0.33	0.33	0.32	0.32
McLean	0.34	0.35	0.36	0.38	0.38	0.39
Menard	0.04	0.05	0.05	0.06	0.06	0.07
Piatt	0.18	0.18	0.18	0.19	0.19	0.19
Tazewell	0.66	0.66	0.66	0.67	0.68	0.68
Vermilion	0.30	0.31	0.31	0.31	0.31	0.31
Woodford	0.26	0.27	0.28	0.29	0.31	0.33
TOTAL	**3.47**	**3.50**	**3.54**	**3.58**	**3.63**	**3.69**

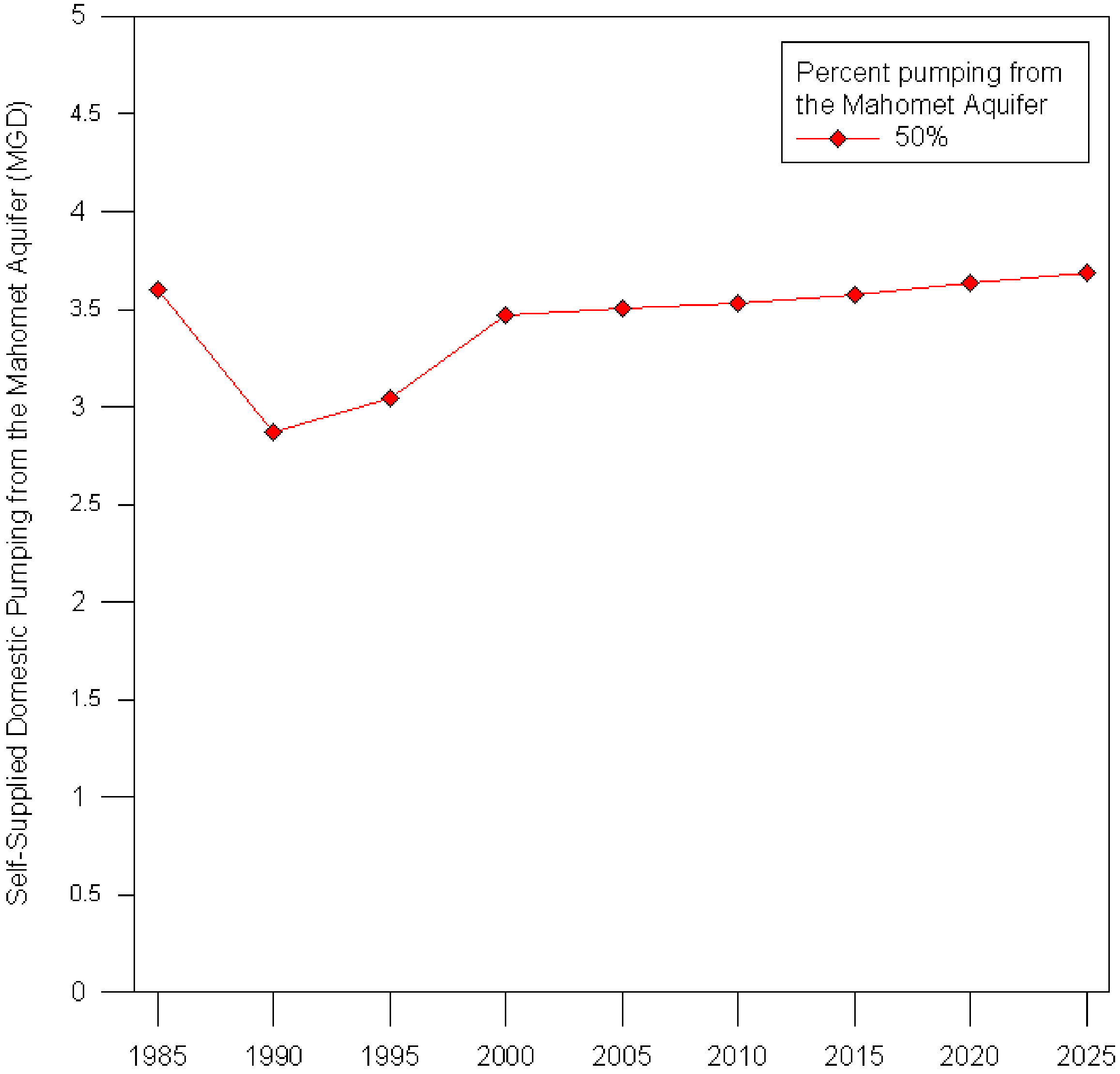


Figure 6: Projection of self-supplied domestic water use in the areas overlying the Mahomet Aquifer based on [Dzielgielewski et al., 2005].

Table 9: Normal rainfall deficit per county [NOAA, 2003].

County	**Normal Rainfall Deficit (inches per year)**
Cass	7.23
Champaign	5.06
DeWitt	6.36
Ford	6.99
Iroquois	5.97
Logan	5.99
Macon	5.45
Mason	7.02
McLean	7.03
Menard	7.10
Piatt	5.40
Tazewell	6.54
Vermilion	5.87
Woodford	7.51

projections and scaled them down by the percent of the county overlying the Mahomet Aquifer.

The average rainfall deficit during the growing season was determined by the weekly precipitation in each county. If more than 1.25 inches of rain fell during one week of the growing season, one-half the amount of rain exceeding 1.25 inches was added to the rain amount during the following week. If less than 1.25 inches of rain falls during a week, then the difference was the rainfall deficit for that week. This is the method used by the USGS in preparation of their estimations of historical irrigation withdrawals.

Although the number of acres of cropland in the region is declining, the amount of irrigation is increasing (Figure 7). This may be due to changes in the tax depreciation laws making installation of irrigation systems more cost effective [Dzielgielewski et al., 2005]. Also, there has been an increase in irrigation of silt and clay loam and clay pan soils because the practice seems to stabilize yields and maintain higher grain quality [Dzielgielewski et al., 2005]. The increase in irrigation may also be due to a growing awareness of the benefits of irrigation, particularly the protection it provides against drought. In the future, more cropland will likely be irrigated and water withdrawal for that purpose will increase.

Based upon the well logs we examined our withdrawal estimates assume 75% of the irrigation wells are completed in the Mahomet Aquifer (Figure 7).

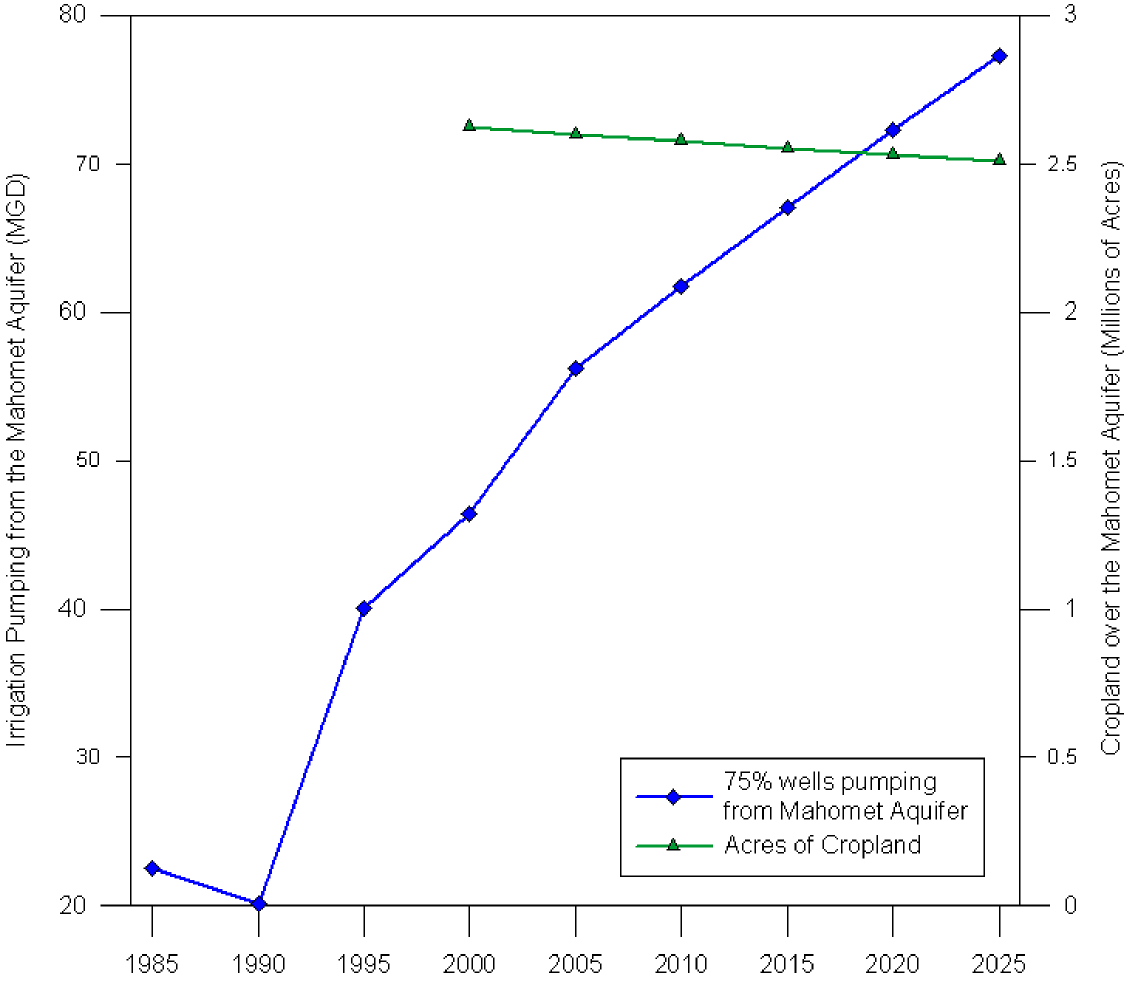


Figure 7: Projection of irrigation water use with projected acres of cropland in the counties overlying the Mahomet Aquifer based on [Dzielgielewski et al., 2005].

Table 10: Irrigation water use projections per county in the Mahomet Aquifer in million gallons per day based on [Dzielgielewski et al., 2005].

County	**Year**					
	2000	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	1.54	1.80	1.89	1.96	2.00	2.03
Champaign	2.23	0.91	0.90	0.88	0.87	0.85
DeWitt	0.25	0.20	0.20	0.20	0.19	0.19
Ford	0.13	0.09	0.10	0.10	0.10	0.11
Iroquois	1.25	1.48	1.84	2.19	2.55	2.90
Logan	0.29	0.11	0.11	0.11	0.11	0.12
Macon	0.05	0.05	0.05	0.05	0.05	0.05
Mason	27.9	37.9	40.9	43.8	46.8	49.7
McLean	0.20	0.13	0.13	0.13	0.12	0.12
Menard	0.11	0.11	0.11	0.11	0.10	0.10
Piatt	0.06	0.07	0.08	0.08	0.09	0.09
Tazewell	12.3	13.23	15.34	17.3	19.2	21.0
Vermilion	0.05	0.02	0.02	0.02	0.02	0.02
Woodford	0.05	0.05	0.05	0.05	0.05	0.04
TOTAL	**46.4**	**56.2**	**61.7**	**67.1**	**72.2**	**77.3**

Irrigation accounts for approximately 42% of the total withdrawal from the Mahomet Aquifer. Even though the number of acres of cropland is expected to decrease in the next twenty years, the amount of irrigation is projected to increase from an annual average of 56 MGD to 77 MGD (Table 10).

2.2.6 Self-supplied commercial and industrial withdrawals

Groundwater withdrawals for commercial and industrial use were calculated from data obtained from the ISWS. Because of confidentiality agreements with industrial/commercial cooperators, the ISWS can not tell us the exact locations of industries nor how much they pumped individually, but they can tell us the aggregate amount of pumping for each township [ISWS, 2005]. To calculate the amount of pumping for commercial and industrial purposes, we subtracted the public water supply pumping from the aggregate township pumping.

To forecast the withdrawals for the future, the SIUC group created a multivariate model that took into account county employment, employment type, and general water use trends. To calculate the amount in each of our sub-county regions, we assumed that our sub-county area would change at the same rate as the county-wide data. With this assumption, we calculated the percent change in the county-wide forecasts and applied them to the corresponding county regions (Figure 8). The SIUC model also included forecasts that take into account conservation measures implemented in the future. These are also shown in Figure 8. The conservation scenario captures the conservation trends in water use from 1985-2000. The conservation predictive scenario assumes that the reductions from continue to follow along the same trend through 2025.

Commercial and industrial groundwater withdrawal is expected to increase 4 MGD from 2005 to 2025, from 24 MGD to 28 MGD (Table 11). If conservation measures are implemented, withdrawal could decrease by 25% (Figure 8).

2.2.7 Livestock

The USGS estimates livestock water use in each county for hogs, beef cattle, dairy cows, horses, and sheep, using a unit-use method. This method uses estimates of the amount of water used daily by each type of animal and multiplies that by the predicted number of animals in each county. The year 2000 was the most recent year the USGS estimates were made. Livestock withdrawals in Illinois accounted for less than one percent of the state's total water use [SIUC, 2005].

To project livestock water use, a unit-use method incorporating the USGS livestock coefficients was used. The USGS coefficients from 2000 were assumed to remain constant for all years as they have historically been relatively constant (Table 12).

Livestock number projections for counties in Illinois could not be located, so national-level projections of the number of hogs, cattle, and dairy cows were prorated to the county level. No

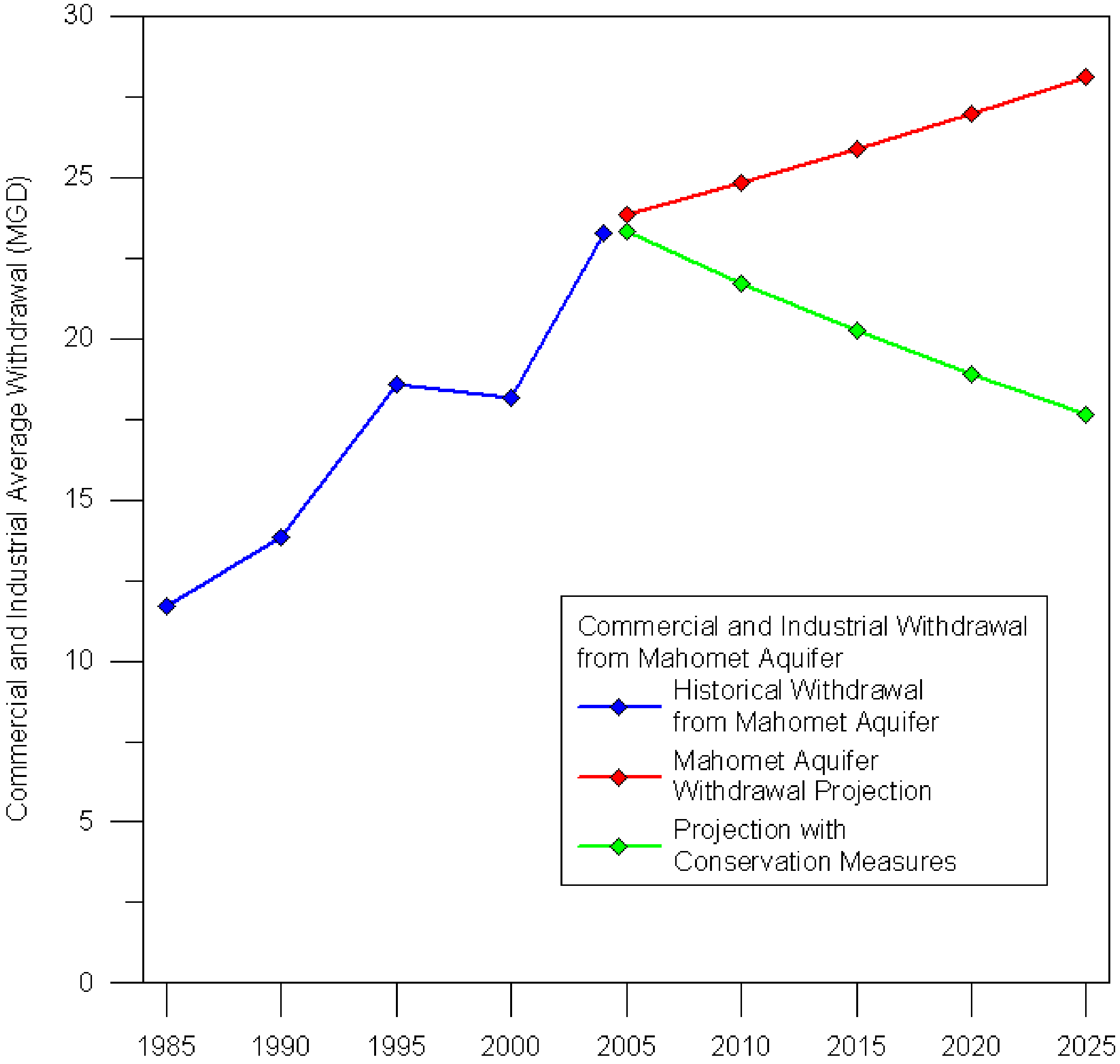


Figure 8: Commercial and Industrial groundwater withdrawal projections for the Mahomet Aquifer based on [Dzielgielewski et al., 2005] and [ISWS, 2005] data.

Table 11: Self-supplied commercial and industrial water use projections per county in the Mahomet Aquifer in million gallons per day based on [Dzielgielewski et al., 2005].

County	**Year**				
	2005	**2010**	**2015**	**2020**	**2025**
Cass	2.13	2.19	2.26	2.32	2.39
Champaign	3.89	4.09	4.29	4.51	4.74
DeWitt	0.020	0.020	0.020	0.020	0.020
Mason	1.20	1.24	1.27	1.31	1.34
McLean	0.01	0.01	0.01	0.01	0.01
Piatt	1.04	1.06	1.09	1.12	1.15
Tazewell	15.6	16.3	17.0	17.7	18.5
Woodford	0.002	0.002	0.002	0.002	0.002
TOTAL	**23.9**	**24.9**	**25.9**	**27.0**	**28.1**

Table 12: Estimated amount of unit water use by animal type used in livestock water use projections [Dzielgielewski et al., 2005].

Animal Type	**Water Use (Gallons per day per Animal)**
Dairy Cows	35
Beef Cattle	12
Horses / Mules	12
Hogs	4
Sheep	2

Table 13: Livestock water use projections per county in the Mahomet Aquifer in millions of gallons per day based on [Dzielgielewski et al., 2005].

County	**Year**					
	2000	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	0.15	0.15	0.16	0.17	0.18	0.18
Champaign	0.07	0.07	0.07	0.07	0.07	0.08
DeWitt	0.02	0.20	0.20	0.20	0.20	0.20
Ford	0.03	0.03	0.04	0.04	0.04	0.04
Iroquois	0.14	0.14	0.15	0.15	0.15	0.15
Logan	0.14	0.14	0.15	0.16	0.17	0.17
Macon	0.03	0.03	0.03	0.03	0.03	0.03
Mason	0.13	0.13	0.13	0.14	0.14	0.15
McLean	0.10	0.10	0.11	0.11	0.12	0.12
Menard	0.04	0.04	0.04	0.04	0.04	0.04
Piatt	0.04	0.04	0.04	0.04	0.04	0.04
Tazewell	0.18	0.18	0.19	0.20	0.20	0.21
Vermilion	0.04	0.04	0.04	0.04	0.04	0.04
Woodford	0.07	0.07	0.07	0.08	0.08	0.08
TOTAL	**1.15**	**1.34**	**1.4**	**1.45**	**1.48**	**1.52**

national or state-level projections for horses, mules, or sheep were located, so the number of these animals was fixed at their 2000 levels. The relatively high withdrawal reported in 1990 may be explained by a national increase in livestock that particular year and may not be accurate for Illinois.

The SIUC-report forecasts the amount of water used for livestock for the years 2005, 2010, 2020, and 2025 in each county in the state of Illinois. We assumed that the livestock in each county was distributed evenly and prorated each county-level estimate with the percentage of the county that overlies the Mahomet Aquifer (Figure 9 and Table 13). The withdrawal estimates and forecasts assume 50% of the livestock wells are drilled in the Mahomet Aquifer, similar to the self-supplied domestic wells.

Livestock accounts for approximately 1% of the total withdrawal from the Mahomet Aquifer. Withdrawal is expected to increase by 14% from 1.3 to 1.5 MGD (Figure 9).

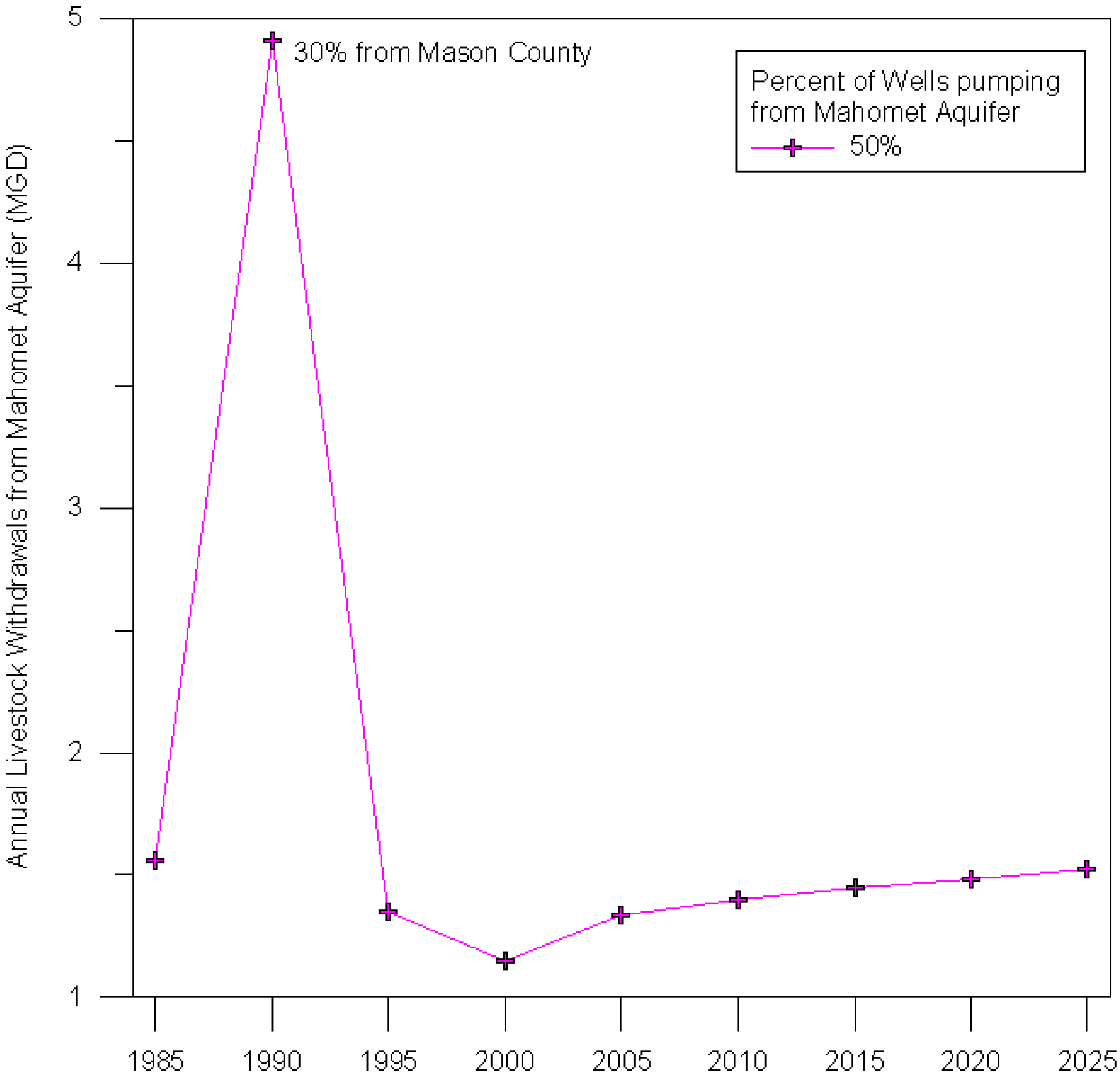


Figure 9: Groundwater withdrawal projections for livestock water use in the Mahomet Aquifer based on [Dzielgielewski et al., 2005].

Table 14: Total groundwater withdrawal in million gallons per day (MGD) from the Mahomet Aquifer per water-use sector.

Water Use Sector	**Year**								
	1985	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Public water supply	43.1	46.3	51.7	56.1	56.8	59.6	62.1	64.7	67.3
Irrigation	22.9	20.1	40.0	46.4	56.2	61.7	67.1	72.2	77.3
Livestock	1.56	4.91	1.35	1.15	1.34	1.40	1.45	1.48	1.52
Domestic	3.60	2.87	3.05	3.47	3.50	3.54	3.58	3.63	3.69
Comm & Industrial	11.7	13.8	18.6	18.2	23.9	24.9	25.9	27.0	28.1
TOTAL	**82.5**	**88.1**	**115**	**125**	**142**	**151**	**160**	**169**	**178**

Table 15: Summary of pumping from the Mahomet Aquifer in million gallons per day.

Projection	**Year**				
	2005	**2010**	**2015**	**2020**	**2025**
Baseline	142	151	160	169	178
Conservation	142	144	148	151	154
Additional PWS	142	151	165	179	193

2.3 Mahomet Aquifer water demand results

The regional water demand analysis for the Mahomet Aquifer provides estimates of when, where, and how much water will be withdrawn from the aquifer within the next twenty years. A summary of the results of the Mahomet Aquifer demand analysis is presented in the following sections and in Tables 14 & 15 and Figures 10 & 11.

2.3.1 Water quantity

The baseline projection predicts the total water withdrawal from the Mahomet Aquifer to increase by 25% over the next twenty years, from 142 MGD to 178 MGD (Table 15). Public water supply withdrawal and irrigation, the largest water users in the Mahomet Aquifer, are predicted to increase by 18% and 38%, respectively (Figure 10). If new public water supplies for Springfield, Bloomington, Decatur, and Danville are added, water withdrawal will increase by 51 MGD from 2005 to 2025 (Figure 11 and Table 15).

The following summarizes the baseline water forecast for each sector in the demand analysis.

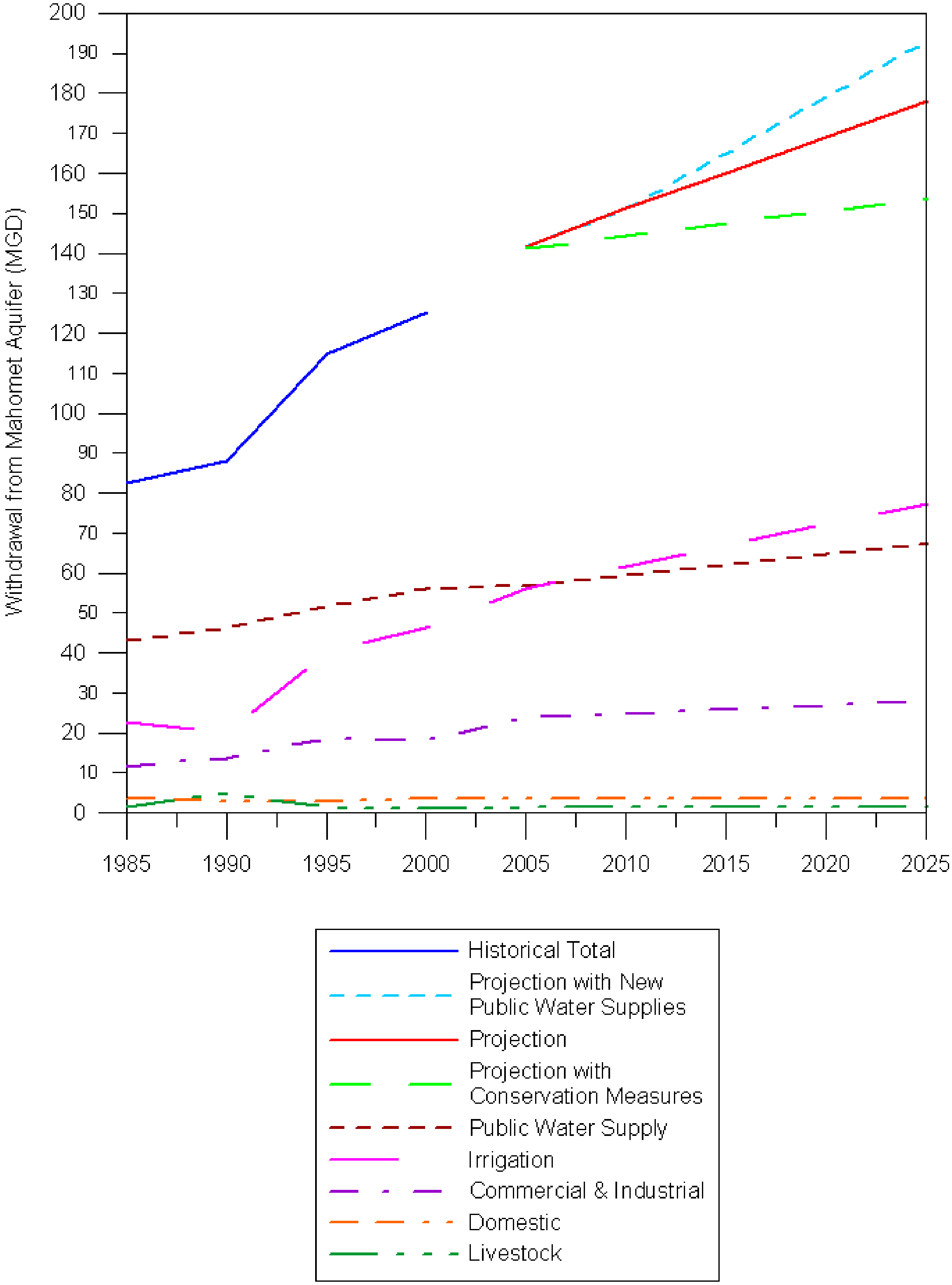


Figure 10: Groundwater withdrawal projections for the Mahomet Aquifer by sector.

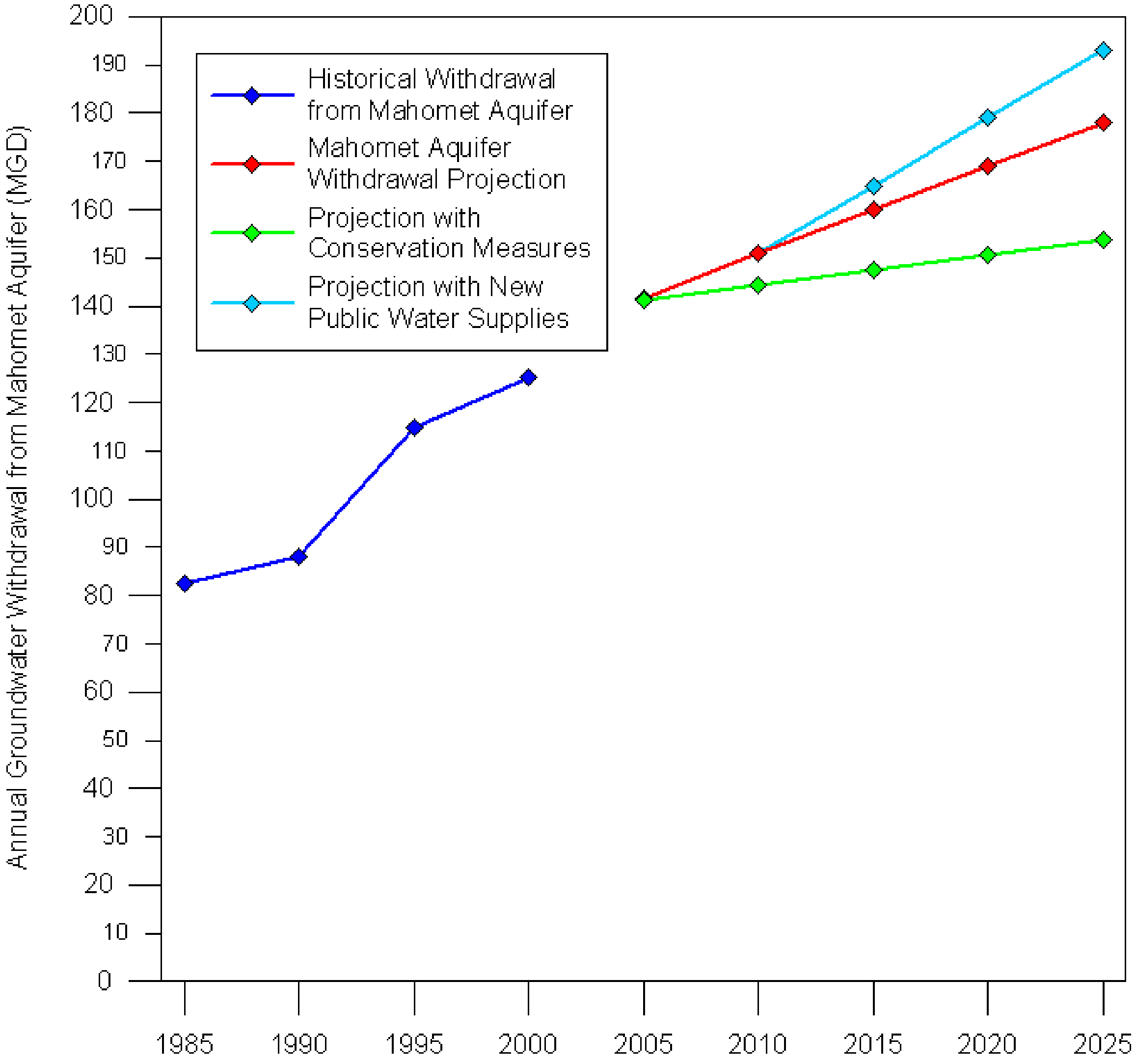


Figure 11: Groundwater withdrawal projections for the Mahomet Aquifer.

Public water supply - Accounts for approximately 40% of pumping in the Mahomet Aquifer. Projections indicate that public water supply pumping from the aquifer will increase 18% over the next twenty years. With the addition of the new public water supplies in the Mahomet Aquifer, the withdrawal is predicted to increase from 60 MGD in 2005 to 82 MGD in 2025.

Irrigation - Accounts for approximately 40% of pumping in the Mahomet Aquifer. Although the acres of cropland will decrease over the next twenty years, water withdrawal projections indicate that irrigation will increase 38% over the next twenty years.

Commercial and Industrial - Accounts for approximately 17% of pumping in the Mahomet Aquifer. Projections indicate that commercial and industrial water withdrawal will increase 18% over the next twenty years.

Self-supplied Domestic - Accounts for approximately 2% of pumping in the Mahomet Aquifer. Projections indicate that self-supplied domestic water withdrawal will increase 5% over the next twenty years.

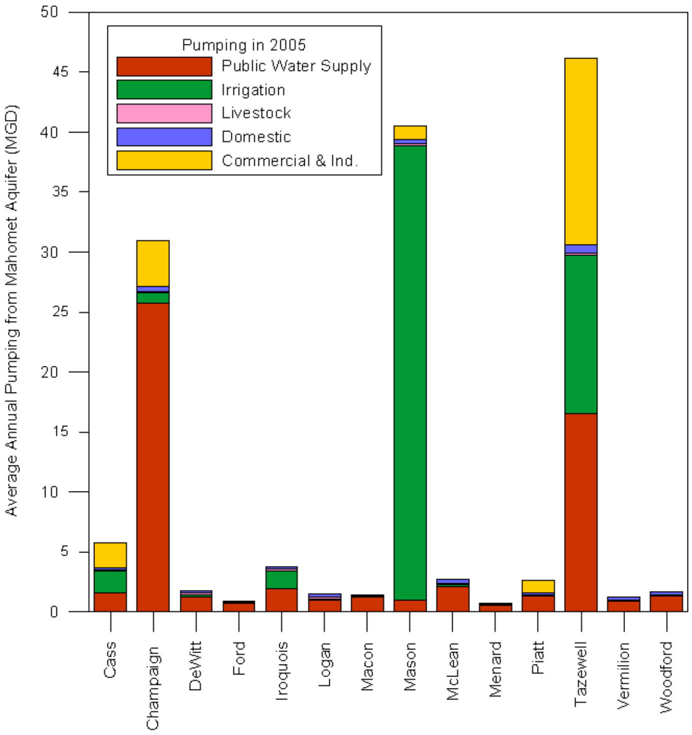
Livestock - Accounts for approximately 1% of pumping in the Mahomet Aquifer. Projections indicate that livestock water withdrawal will increase 14% over the next twenty years.

2.3.2 Geographic distribution of water demand

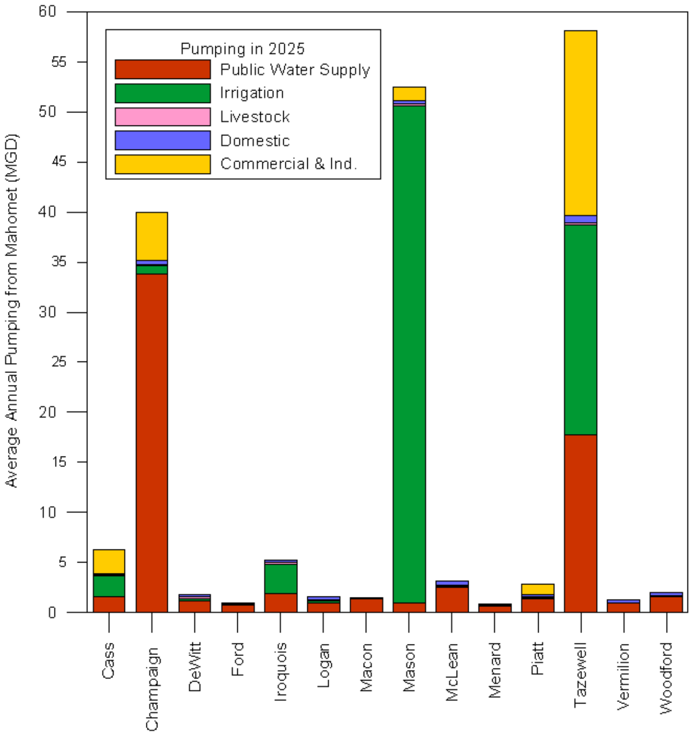
The distribution of pumping affects how the aquifer responds. An aquifer may be able to support a certain amount of withdrawal if it is evenly distributed within the aquifer boundaries, but may not be able to support the same amount if the pumping is geographically concentrated. In the Mahomet Aquifer, groundwater withdrawals are not equally distributed throughout the aquifer. Three counties (Mason, Tazewell, and Champaign) comprise approximately 83% of the total pumping in the Mahomet Aquifer (Figure 12). Groundwater withdrawals in Mason County are predominately for irrigation, approximately 94% of the total pumping in that county. In Champaign County, 83% of groundwater use is for public water supplies. In Tazewell County, groundwater use by sector is more evenly distributed; 36% for public water supply, 29% for irrigation, and 34% for commercial and industrial use. The majority of water use by the remaining counties is public water supply (Figure 13).

2.3.3 Seasonal distribution of water demand

The seasonal distribution of water withdrawal also affects the aquifer response. During the summer months, when temperatures and evapotranspiration are relatively high, more water is used. Public water supply use, self-supplied domestic, and irrigation are all affected by the seasons. Irrigation demand is concentrated within the agricultural growing season, so the annual amount of water used



(a) 2005 Pumping



(b) 2025 Pumping

Figure 12: Estimated groundwater withdrawal for the Mahomet Aquifer by county for a) 2005 and b) 2025.

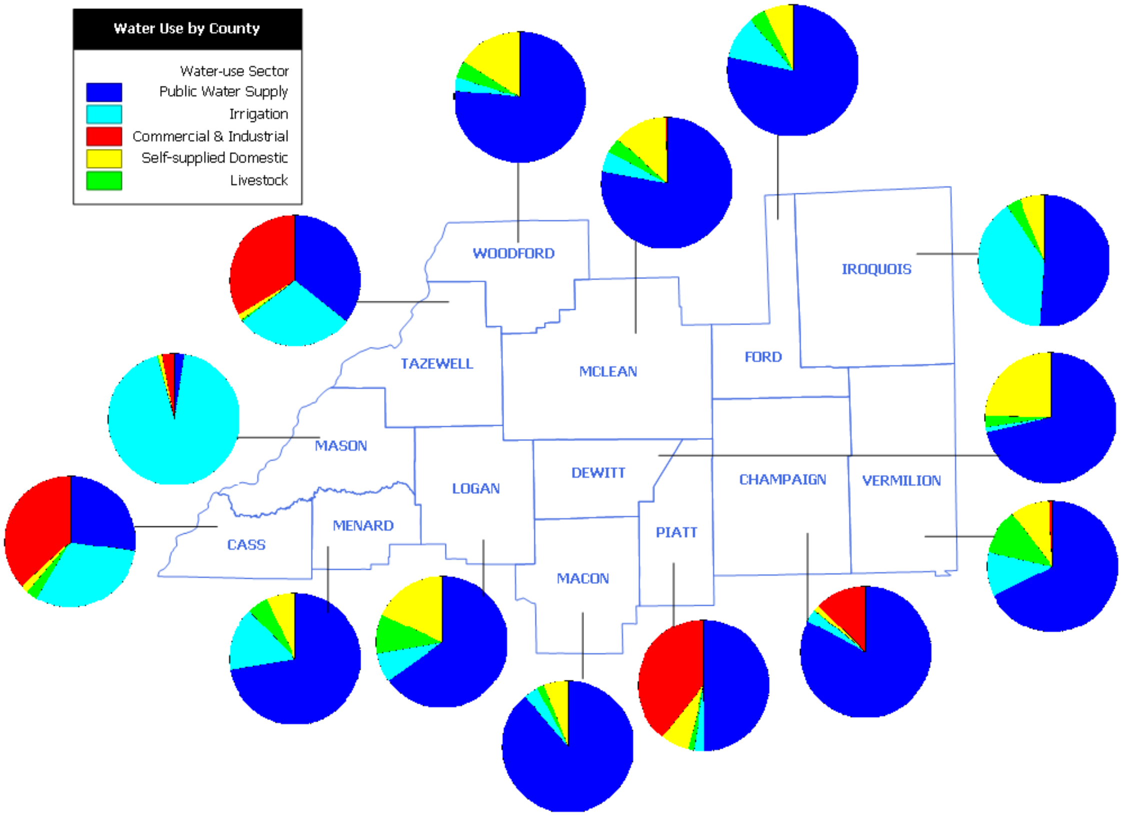
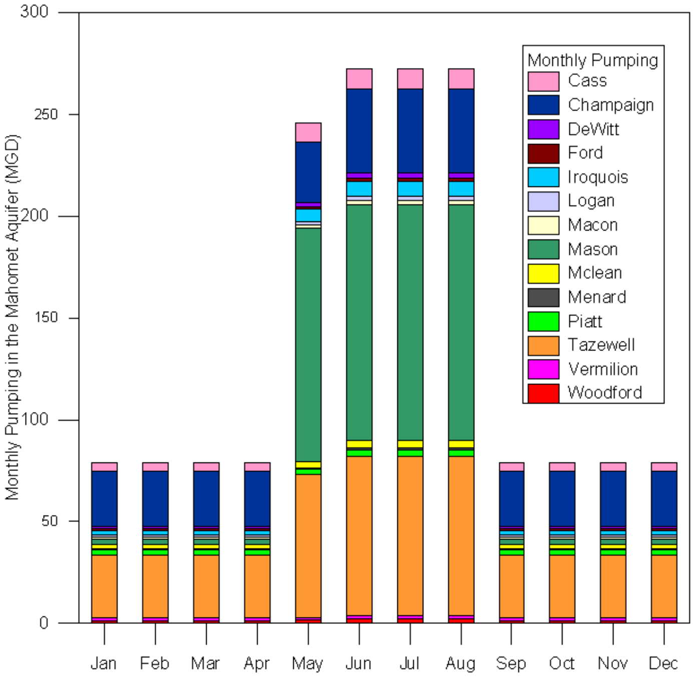
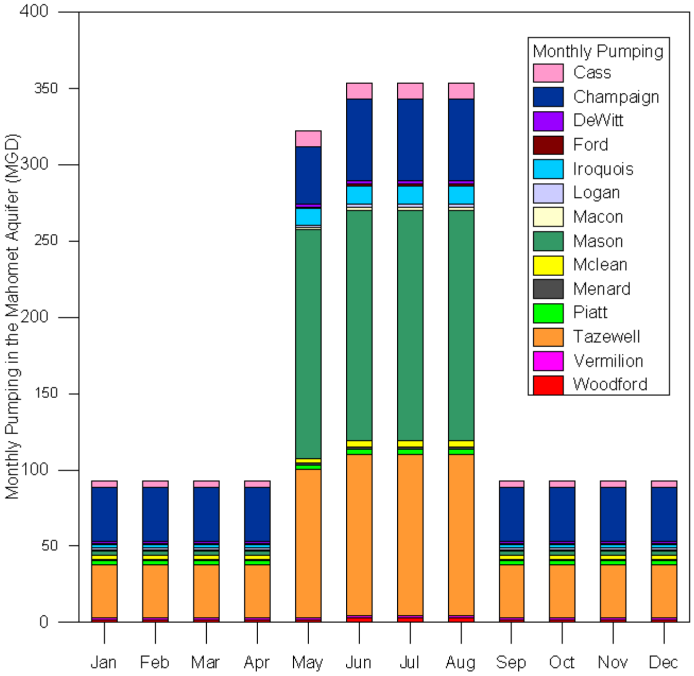


Figure 13: Estimated Mahomet Aquifer water use by sector for each county in 2005.

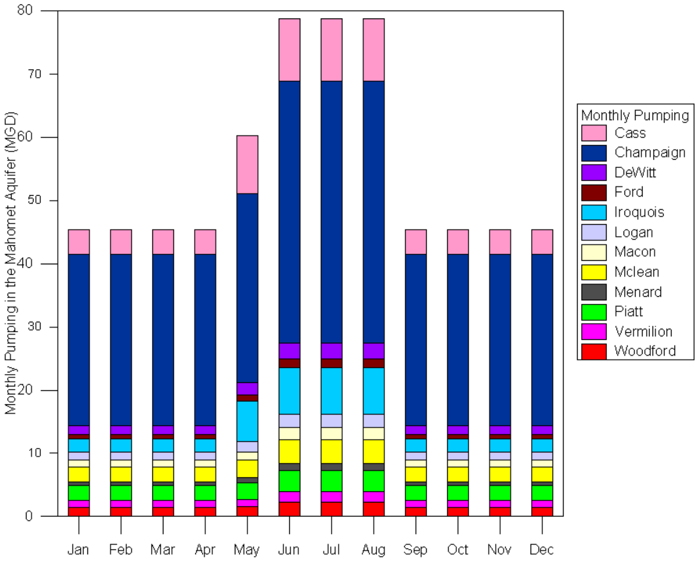


(a) 2005

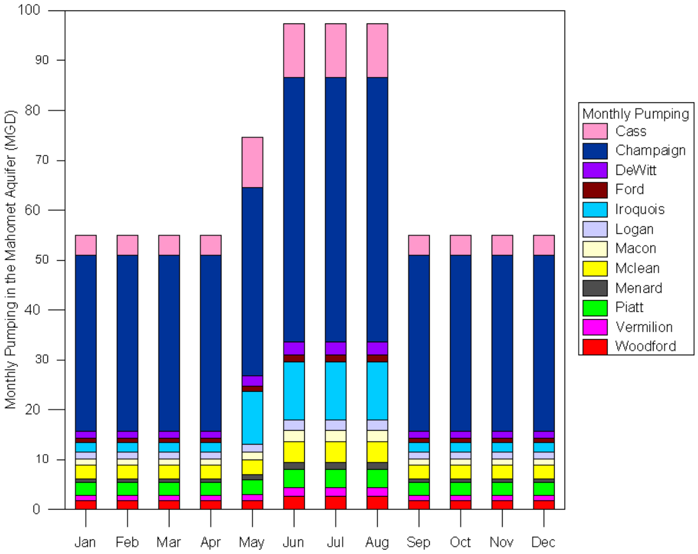


(b) 2025

Figure 14: Estimated monthly groundwater withdrawal for the Mahomet Aquifer in a) 2005 and b) 2025.



(a) 2005



(b) 2025

Figure 15: Estimated monthly groundwater withdrawal for the Mahomet Aquifer in a) 2005 and b) 2025 excluding Tazewell and Mason Counties.

for irrigation is distributed over four months of the year; May, June, July, and August. Public water supply and domestic use also increases in the summer months. In the Midwest, the increase in demand in June, July, and August is usually 1.5 times the normal monthly water use. In order to get a clear sense of the seasonal distribution for groundwater use in each county, annual irrigation withdrawal was evenly distributed throughout the growing season and residential use was increased by 1.5 times in the summer months (Figure 14). In 2005 during June, July, and August, the estimated total withdrawal from the aquifer was 272 MGD whereas the other months of the year pumping is 29% the summer rate (approximately 79 MGD). The withdrawal for 2025 is predicted to be 353 MGD during the summer months and approximately 93 MGD the rest of the year. Much of this pumping is concentrated in Champaign, Mason, and Tazewell Counties.

Over 60% of the total groundwater withdrawal is from Mason and Tazewell Counties most of which is withdrawn in the growing season for irrigation. These counties are on the western edge of the aquifer, near the Illinois River. Geologic data indicate that in this region the Mahomet Aquifer may be hydraulically connected to the river. If wells are connected to the river then the river supplies a large portion of their water, not the aquifer. If we take out the withdrawal from the Mason and Tazewell Counties, the seasonal withdrawal from the Mahomet Aquifer changes (Figure 15). In 2025 without Mason and Tazewell, the withdrawal is predicted to be 97 MGD during the summer months and approximately 55 MGD the rest of the year.

3 Aquifer characterization and available data

The buried Mahomet Aquifer is regionally important in part because there is a lack of significant surface water in east-central Illinois between the Illinois River and Wabash River. The regional geologic setting and hydrogeology of the Aquifer are summarized in this section, with a particular emphasis on the function of the water–bearing formations near Champaign/Urbana.

3.1 Geologic setting

The Mahomet Aquifer is composed of sand and gravel of glacial origin that was deposited in a valley developed on bedrock units ranging in age from Silurian to Pennsylvanian [Soller et al., 1999, Larson et al., 2003b]. The bedrock valley extends eastward outside of Illinois, where the aquifer is known as the Teays Aquifer, an important regional aquifer of central Indiana.

A generalized stratigraphic cross–section from Soller et al. [1999] is shown in Figure 16. This cross–section shows the Mahomet Sand Member of the Banner Formation (referred to in this report as the Mahomet Aquifer) as the deepest and thickest water–bearing unit in the glacial sediments of eastern Illinois. At least one early–Quaternary glaciation is recorded in sediments below the Mahomet Sand [Kempton et al., 1991]. Two thinner and less extensive water–bearing units were deposited above the Banner Formation. In ascending order, these are the Basal Vandalia Sand Member of the Glasford Formation (Vandalia Sand) and the Basal Radnor Sand Member of the Glasford Formation (Radnor Sand). Together the Radnor Sand and Vandalia Sand comprise the Glasford Aquifer. Above the Glasford Aquifer is the Mason Formation which contain only minor surficial aquifers. The extents of the three main aquifer layers in the Champaign/Urbana area are shown in Figure 17.

The till layers that separate the Mahomet Aquifer from the Vandalia Sand and Radnor Sand act as confining units between the aquifer layers. The confining units vary in thickness across the region. In the Champaign/Urbana area, the Upper Banner Formation confining unit ranges from being thin or absent to $60\,ft$.

Well logs in the vicinity of the proposed wellfield were reviewed during the well inventory described in Section 5. The following trends and conditions were noted (see Figure 17 for town locations):

- southwest of the town of Mahomet, the top 30 to 40 ft of the Mahomet Sand is fine–grained and reportedly cemented to some degree.
- near Bondville and Seymour, the Radnor Sand is thicker than indicated by Soller et al.
- in the region between Seymour and White Heath, several wells are screened in a 20 to 30 $foot$ thick sand unit in the Glasford Formation – this unit is not mapped as either the Radnor Sand or the Vandalia Sand.

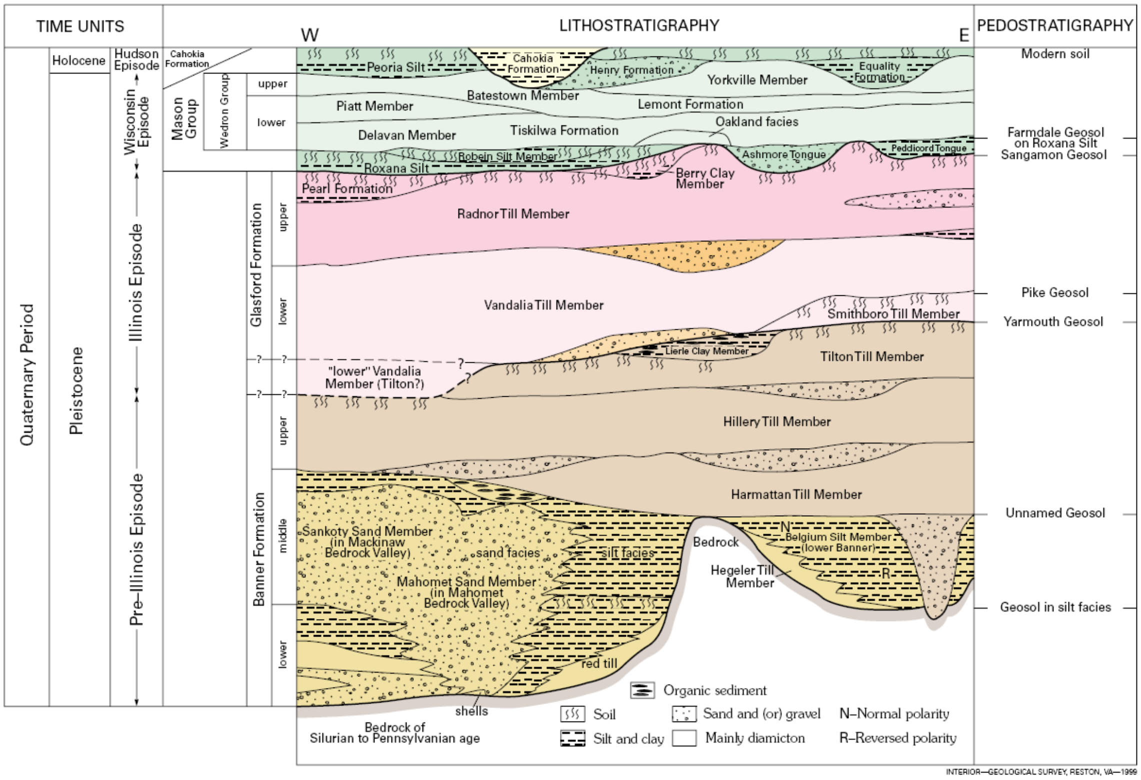


Figure 16: Quaternary stratigraphic column for Champaign/Urbana area [Soller et al., 1999].

3.2 Hydrogeologic setting

Flow in the Mahomet Aquifer is confined or leaky–confined except near its western limit in Mason, Menard, and Tazewell Counties where it is exposed at the land surface and is unconfined [Larson et al., 2003b]. Sandy units in the overlying Glasford Formation form locally important aquifers for small community and domestic wells [Larson et al., 2003b]. In areas in which significant vertical leakage in the Mahomet Aquifer was measured, the source of this leakage was determined to be the Glasford Formation [Visocky and Schicht, 1969]. Aquifers in the Glasford Formation (referred to as the Illinoisan aquifers in Visocky and Schicht, 1969) are also leaky–confined.

The capacity of the Mahomet Aquifer to provide groundwater was assessed as follows by Soller et al. [1999]:

> "Ground water within sand and gravel of the buried Mahomet Bedrock Valley aquifer system has been estimated by the Illinois State Water Survey (Visocky and Schicht, 1969) to be able to provide about 445 million gallons per day (*MGD*) to large municipalities, industry, and private residences. ... Even during the drought of 1988,

> however, only about 85 mgd were used, which was the maximum yearly usage (Illinois State Water Plan Task Force [ISWPTF], 1997)."

Use of the Mahomet Aquifer continues to increase. As described in Section 2, an average of 142 *MGD* was pumped from the Mahomet in 2005.

3.2.1 Aquifer recharge

Water reaches the Mahomet Aquifer via leakage from the overlying Glasford Formation. Similarly, aquifers in the Glasford Formation are recharged via leakage from shallower, water–table aquifers that receive infiltration from precipitation and extended periods of surface saturation. An estimated rate of infiltration to the water table aquifers for Illinois is approximately 200,000 $gal/day/mi^2$ or about 4.2 in/yr [Visocky and Schicht, 1969]. Walton (in Visocky and Schicht, 1969, p. 40) estimated the rate of recharge of the Glasford Aquifer to be 115,000 $gal/day/mi^2$ or about 2.4 in/yr. Visocky and Schicht (1969, p. 41) estimated the average annual recharge to the Mahomet Aquifer west of Champaign for 1953 to 1965 to be 107,000 $gal/day/mi^2$ or about 2.2 in/yr. Areas of known or inferred recharge from streams include the Sangamon River southwest of Monticello [Roadcap and Wilson, 2004] and the Vermilion River northwest of Danville. (See Section 4 for a discussion of the interaction of specific river reaches with the Glasford and Mahomet Aquifers.)

While the modeling work described in this report required a conceptual model of aquifer recharge, there is little data to use in determining the geographic distribution of leakage in the study area. Because there is such uncertainty about recharge rates into the system, recharge rate research is expected to be an element of a recently funded regional Mahomet Aquifer investigation.

3.2.2 Aquifer discharge

East and northeast of Champaign/Urbana, we conclude that the Mahomet Aquifer discharges by upward leakage through the Glasford Member, and eventually to shallow aquifers or streams. This was inferred from potentiometric head information and geochemical trends (see Section 3.3 and Figure 18A). Streams that may receive discharge from the Mahomet Aquifer toward the northeast include the Iroquois River and its tributaries.

Toward the west, discharge occurs from the Mahomet Aquifer to the Illinois River and possibly the lower reaches of the Sangamon River. In this area, the aquifer is unconfined.

3.3 Regional geochemistry

Relative to other portions of the Mahomet Aquifer, the region around Champaign/Urbana contains the least mineralized water. This suggests that rapid infiltration may be taking place, particularly near the Sangamon River. Similarity in water chemistry between the Glasford Aquifer and Mahomet

Aquifer and relatively young radiocarbon ages for water from the Mahomet Aquifer in this area also indicate rapid recharge [Panno et al., 1994]. Groundwater flow paths inferred from geochemical trends are shown on Figure 19A.

Upward leakage from bedrock units can affect water quality in the Mahomet Aquifer [Soller et al., 1999]. This has been observed primarily in areas west and northeast of Champaign/Urbana (Figure 19A) [Panno et al., 1994]. This leakage is likely controlled by the local permeability of the upper bedrock units and the basal Quaternary units.

3.4 Conceptual hydrogeologic model

As described above, the hydrogeologic setting of the aquifers in the Champaign/Urbana area is very complex. For the purpose of our investigation, we have simplified the setting as three distinct aquifers, described in order of increasing elevation:

Mahomet Aquifer is the most important water–resource aquifer for public water supply. It is a deep, relatively geographically continuous buried sand–and–gravel formation. Near Champaign/Urbana, direct communication between the Mahomet Aquifer and the few surface streams is not well understood, but is expected to be generally weak.

Glasford Aquifer is a sandy aquifer that overlies the Mahomet aquifer's confining unit. In some locations, the Glasford Aquifer is an important source for homeowner wells and irrigation wells. The hydrogeology of the Glasford is itself complex, including several different units; the interconnection of these units is poorly understood, but taken as a whole, the Glasford Aquifer is present in most of the Champaign/Urbana area. Near Champaign/Urbana, the direct communication between the Glasford Aquifer and the few surface streams is poorly understood.

Surficial Aquifer is most likely not a single aquifer, but a collection of localized sandy aquifers. It receives infiltration from rainfall, and much of its inflow eventually discharges into surface waters. Leakage from the surficial aquifer is the source of water into the Glasford Aquifer, and by extension, the Mahomet Aquifer.

A conceptual hydrogeologic model for the Mahomet Aquifer and overlying units is shown on Figure 19. A groundwater flow divide exists in the east–central part of the Mahomet Aquifer. Water flows away from this area toward the northeast and toward the southwest. In cross–section, water infiltrates from the land surface and from surface water bodies to the shallow aquifer layers such as the Radnor Sand and Vandalia Sand. These units have limited lateral extent, so lateral flow is limited to the aquifer layers in this elevation of the section. Vertical leakage downward to the Mahomet Aquifer is caused by hydraulic gradients established naturally by regional connection within the Mahomet Aquifer to discharge zones such as the Illinois River shown at the left of Figure 19B.

The hydraulic gradient between the Mahomet Aquifer and shallower layers is affected by the large withdrawals from wells throughout the region. It is likely that in some areas, pumping has reversed the direction of vertical flow, locally creating downward flow where flow was upward in pre–development times. In fact, water levels throughout the aquifer are so highly influenced by pumping from wells that knowledge of the distribution and pumping rates of wells in the aquifer is of critical importance in understanding flow in the aquifer system.

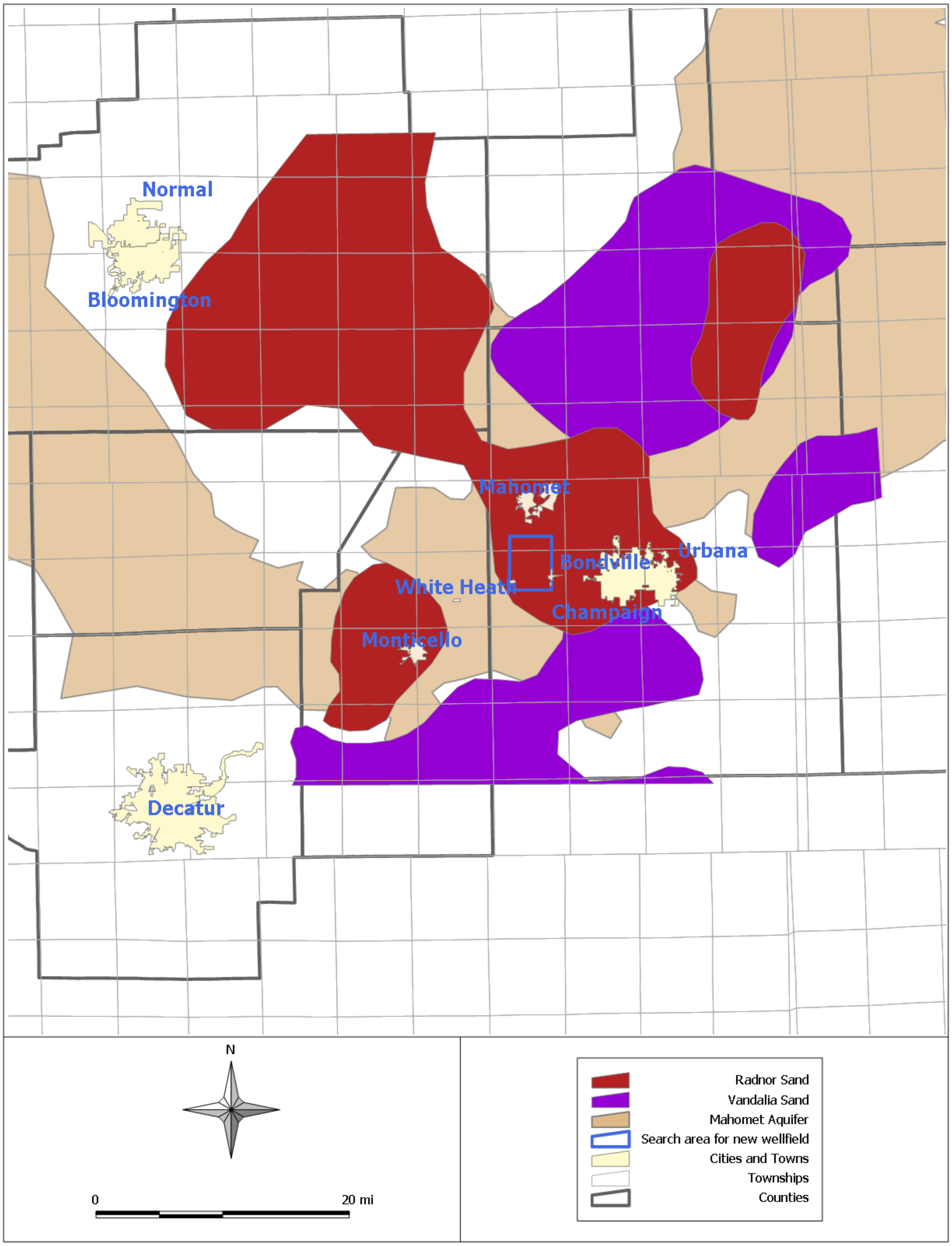


Figure 17: Location of sand units in the Glasford Formation as mapped by Soller et al. [1999].

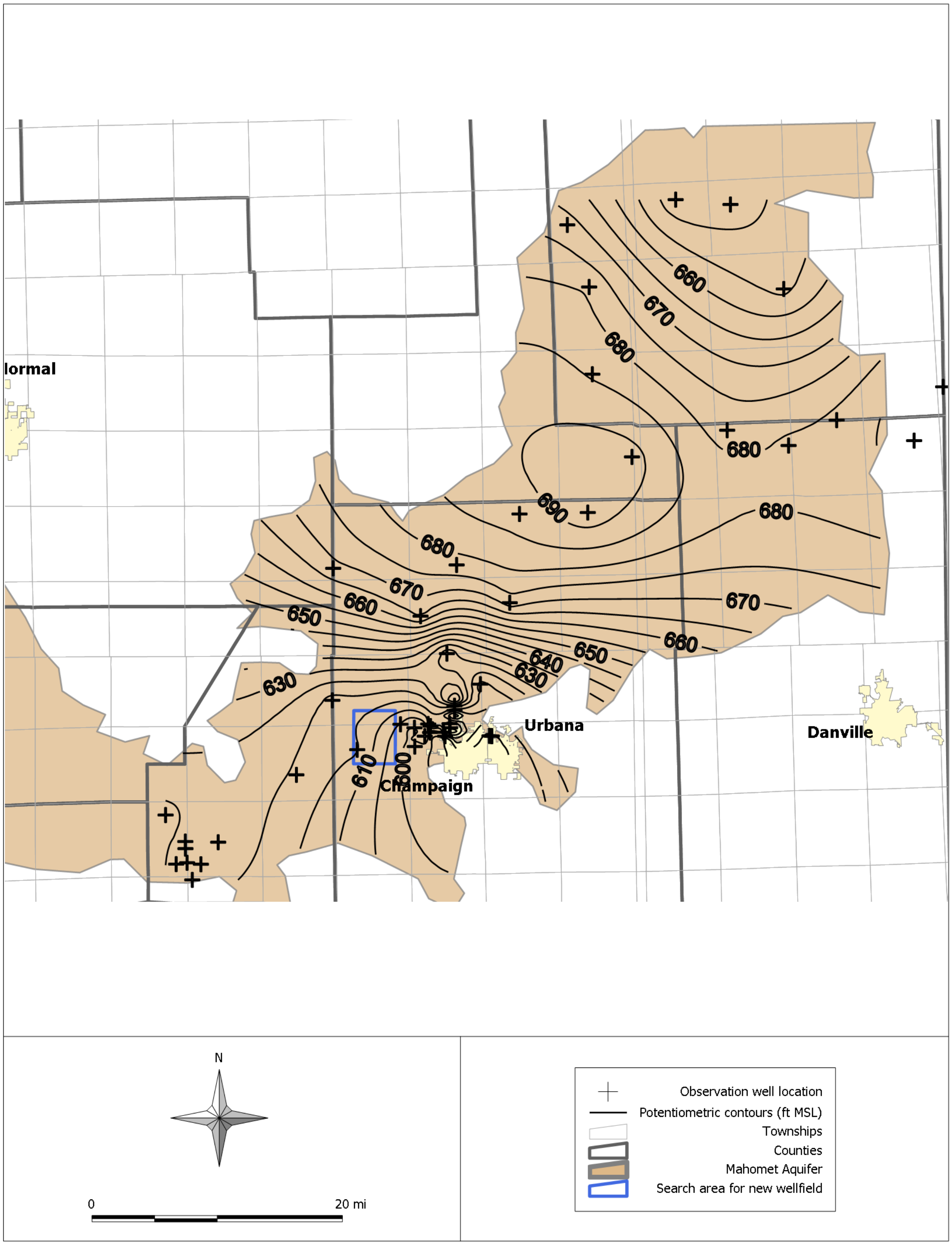


Figure 18: Measured water levels in the Mahomet Aquifer in 2004 (source ISWS).

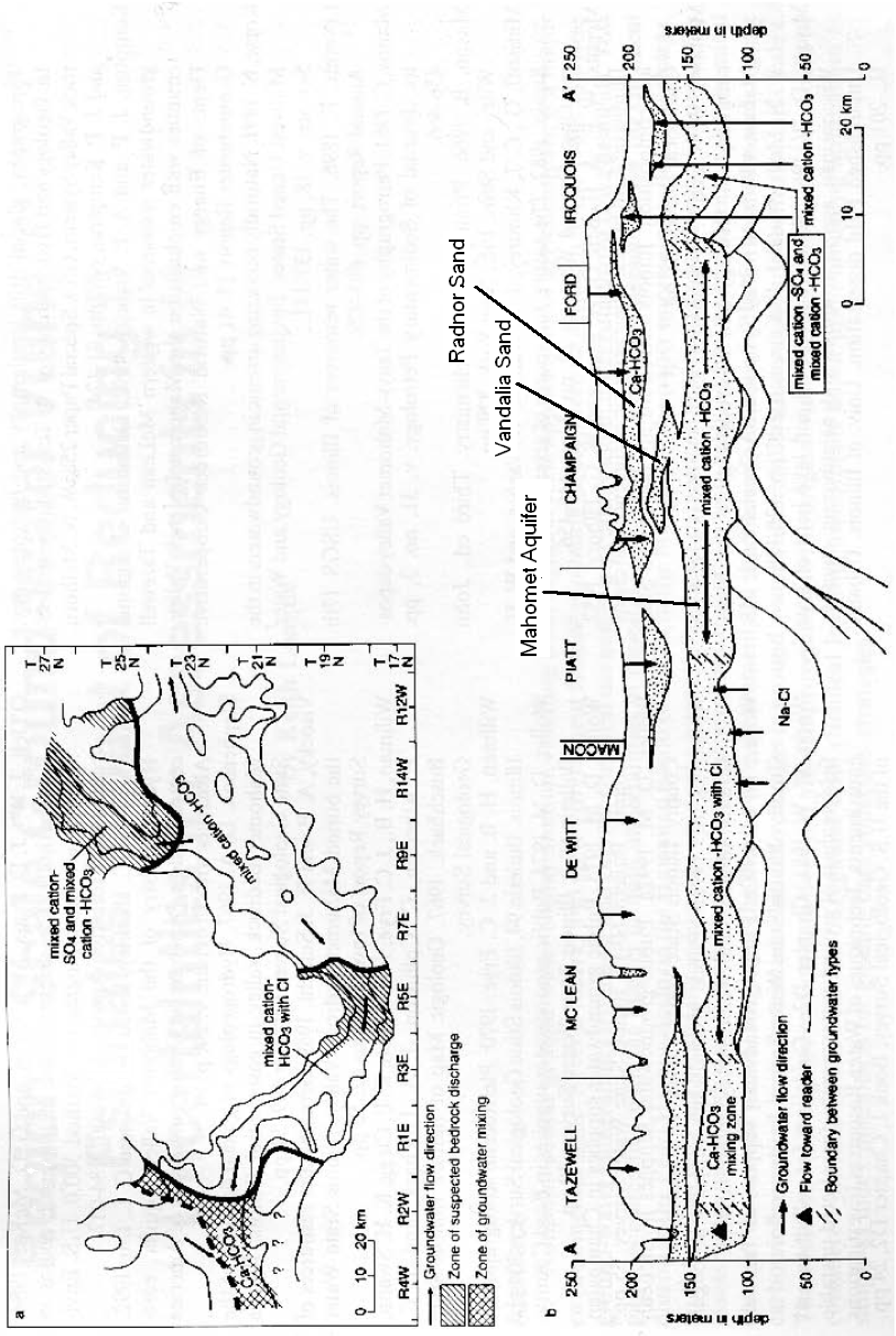


Figure 19: Conceptual hydrogeologic model for the Mahomet Aquifer (a - plan view, b - cross-section), from [Panno et al., 1994].

4 Groundwater flow modeling

Modeling any natural system requires simplification. The work reported on here is a reflection of choices we made to find a balance between what has been published about the aquifers in the area and the level of detail needed to answer the questions related to well field siting.

The approach used to model this aquifer system reflect our goal to describe the essential characteristics of the aquifer so that we might be able to anticipate the character of response to pumping. This section describes the conceptual design, implementation, and calibration of a regional groundwater model for flow in the Mahomet Aquifer. Work by the ISWS and ISGS has demonstrated that the Mahomet Aquifer and overlying aquifers have substantial 3–dimensional complexity. The effect of this 3–dimensional complexity on development of a new wellfield can not be known *a priori*. Simpler tools could have been used to answer the question, but such tools may not reflect the actual conditions sufficiently. For example, the Hantush–Jacob solution [Hantush and Jacob, 1955] could have been used to estimate drawdown due to pumping in the Mahomet Aquifer. This would have reflected the leaky–confined conditions of the aquifer but would not have reflected the influence of lateral limits of the aquifer, spatial variability of the hydraulic connection with the shallower aquifer layers, or the influence of drawdown in the shallower aquifer layers on drawdown in the Mahomet. For these reasons, we chose to develop a tool that could capture the complexity directly.

A MODFLOW [McDonald and Harbaugh, 1988, Harbaugh et al., 2000] model was designed and calibrated to regional water level information in the Mahomet Aquifer and published data from an aquifer test performed west of Champaign. This section describes how the model compares with regional head, drawdown, and water budget information using parameter values that are consistent with published values. Section 5 describes how the groundwater flow model was used to evaluate the effects of development of a new wellfield west of Champaign.

4.1 Groundwater model description

A regional MODFLOW–2000 model was created using the GMS preprocessor [Environmental Modeling Systems, 2005]. Our goal was to use sophisticated methods and analysis along with a simple model of groundwater flow in the aquifer system to determine the changes that would result from a new wellfield. A more detailed model could have been constructed, but given the available published information, the question at hand, and the time available in which to answer that question, we built an appropriate model: one that does not ignore complexity or uncertainty.

4.1.1 Model layers

Commonly, modelers will use general head boundaries to represent influences of flow features outside the model domain. We have instead chosen to explicitly model flow in the Glasford and Mahomet Aquifers. In our model, the active portion of Layer 1 encompasses the sand layers in the

Glasford Formation as mapped by Soller et al. [1999] in the vicinity of Champaign/Urbana (Figure 21). We assume that lateral inflow into the area represented by the active cells in Layer 1 is negligible due to the discontinuous nature of the sand lenses in the Glasford Aquifer. Likewise, the active portion of Layer 3 of the model encompasses the entire footprint of the Mahomet Aquifer within Illinois. The active portion of Layer 2 of the model represents the intersection of the active portions of Layers 1 and 3 and models vertical leakage between these layers (Figures 22 and 23).

Layer elevation data were obtained from the USGS [Soller et al., 1999]. These data were supplied in UTM (metric) units. The grids were converted to the datum indicated in Table 16.

Table 16: Parameters used for the model datum

Parameter description	Value
Projection	Lambert conformal conic
Datum	Clarke 1866
Center latitude	33.0
Center longitude	−89.5
1st standard latitude	33.0
2nd standard latitude	45.0
Distance unit	foot
False easting	3,000,000
False northing	0

The USGS data [Soller et al., 1999] do not cover the entire extent of the Mahomet Aquifer (Figure 20). Beyond the limits of the USGS coverages, the average thickness or top elevation of a given unit was used. The average elevations for the model layers are listed on Table 17.

The Mahomet Aquifer was modeled as a single layer with the base defined as the top of the bedrock from Soller et al. [1999] and the top defined as the top of the Mahomet Sand from Soller et al. [1999] (Figure 16 for stratigraphic unit names and positions). The extent of the top of the Mahomet Sand also defined the active portion of the MODFLOW grid within the range of these data.

The upper Banner Formation was modeled as a single layer with the bottom defined as the top of the Mahomet Sand from Soller et al. [1999] and the top defined as the top of the Banner Formation from Soller et al. [1999]. In areas where the top of the Banner is not defined, a thickness of 1 foot was used for this layer. These are areas in which the Vandalia Sand is in contact with the Mahomet Aquifer.

The Glasford Formation was modeled as a single layer defined as follows:

- the bottom of the layer was defined as the bottom of the Vandalia Sand where this unit is mapped and as the top of Banner Formation where the Vandalia is not mapped by Soller.

- the top of the layer was defined as the top of the Radnor Sand where this unit is mapped and as the top of the Vandalia Till Member where the Radnor Sand is not mapped by Soller et al. [1999].

The following issues arose in making the layer assignments.

- In some areas, the top of the bedrock was above the top of the Mahomet in the USGS data – these areas occur outside the active area of the current model and beyond the defined limits of the Mahomet Aquifer.
- In areas west of Champaign/Urbana, the top of the Mahomet Sand is above the top of the Banner Formation. In these areas, the top of the Banner Formation was defined as the top of the Mahomet Sand plus a nominal thickness of 1 ft. In these areas, the till layers of the Banner Formation are apparently absent. In essence, Layer 2 of the model was assigned a thickness of 1 ft in these areas.

Table 17: Information regarding the model layers

Surface	Average elevation	Grid name
Top of Layer 1	642 $ft\ MSL$	RAD.GRD
Top of Layer 2	552 $ft\ MSL$	BAN.GRD
Top of Layer 3	515 $ft\ MSL$	MAH.GRD
Bottom of Layer 3	478 $ft\ MSL$	BED.GRD

4.1.2 Model grid

An irregular grid was used in order to limit the computational size of the model. The maximum cell size for the far field area was limited to 10,560 ft, a value less than the characteristic leakage length (λ) quantifying the interaction between the Glasford Aquifer and Mahomet Aquifer in order to minimize the introduction of error caused by coarse model cells [Haitjema et al., 2001]. This parameter is also called the leakage factor ([Kruseman and de Ridder, 1991], p. 25). Estimated values for λ range from 5300 ft from aquifer test data to 44,900 ft from wellfield analyses (Table 18). The cell size used in the near field (the area under consideration for a new wellfield and the area around the West Wellfield) is approximately 330 ft.

As a result, the model is probably not accurate enough to use outside the area of fine discretization and is not intended to answer questions outside this area.

4.1.3 Boundary conditions

Boundary conditions for the groundwater flow model include river cells, recharge, and wells. The default no–flow boundary condition was used for the edges of all model layers and the bottom of Layer 3. Two conceptual models regarding the flow of water into and out of Layer 1 were tried. The model boundary conditions are described in more detail in the following subsections.

Recharge Recharge to the Glasford Aquifer passes through the overlying Radnor Till Member, Mason Group, and other surficial deposits (Figure 16). Insufficient detail was available with which to model these layers explicitly. Instead, two different conceptual models of recharge to the Glasford were considered in the investigation:

1. A set of zoned recharge domains were defined based on the hydraulic conductivity zones described in Section 5. This amounts to an assumption that recharge to the Glasford Aquifer is limited by the vertical rate of percolation and does not increase if heads in the Glasford Aquifer drop. This is a conservative assumption in terms of the Glasford Aquifer's ability to yield water to the Mahomet Aquifer. This assumption should also be conservative in terms of modeled drawdowns in the Glasford Aquifer. Because no pumping wells were included in Layer 1 in this conceptual model, recharge rates much lower than regional water budget estimates had to be used or modeled water levels in the Glasford became too high. In fact, there is very little data to constrain estimates of aquifer recharge rates in this part of the state. Total groundwater recharge to the Glasford includes whatever subsequently leaks further downward into the Mahomet and, given the fact that our modeled recharge distribution used rates that were lower than what had been found in earlier investigations, we decided to abandon this conceptual model. What we did not learn from this exercise was the distribution of recharge. What we do know, whoever, is that the saturated zone in the shallow water table aquifer overlying the Glasford is generally between 5 and 15 feet below the land surface.
2. The alternate (and conceptually more honest) approach to recharge distribution was to impose the water table above the Glasford and then adjust leakance using hydraulic properties of the soils. This technique, while requiring adjustments in cell effects near surface water cells, accurately describes what know in the field. In order to model this, each cell in Layer 1 was assigned a river cell with a stage defined as $10\,ft$ below ground surface and conductance proportional to the cell area. This conceptual model creates a water table that is below ground surface everywhere. In this conceptual model, local flow cells can be established in which infiltration in areas of higher elevation discharge to adjacent areas of lower elevation that are not necessarily part of regional drainages. We essentially mapped the water table onto the top of the model and then evaluated the flows that resulted. This model captured the effects of agricultural drainage systems and wetlands. Net infiltration rates were, while lower that most

published estimates, much closer to the water budget estimates than found using the specified recharge domain approach attempted in the first model (Section 4.2.5).

Recharge was applied to the active parts of Layer 3 outside the active portion of Layer 1 in both models. This boundary condition was intended to model percolation to the water table and vertical leakage through all of the overlying units to the Mahomet Aquifer beyond the area in which the Glasford Formation was explicitly modeled.

River boundaries In the first model, all of the rivers shown in Figure 24 were explicitly modeled. These are the rivers that are known or inferred to discharge to or receive discharge from the Mahomet Aquifer. In the second model, each cell in Layer 1 has a river boundary condition that is intended to capture the effects of both areal recharge to the aquifer and discharge to and from rivers. Consequently, the Sangamon River and the Vermilion River were explicitly modeled as the lowest reaches in the water table aquifer. The effect of this approach to modeling recharge is that the upper aquifer will be a sink at the streams and rivers (where heads were lowest) and it will allow more water into the Glasford as heads in the Glasford decline.

Only the rivers beyond the limits of the active area of Layer 1 were explicitly modeled as connected to Layer 3 in both models.

Wells The wells shown in Figure 25 are from the ISWS public water supply database. These wells were included in the groundwater flow model. Those wells outside the limits of the Mahomet Aquifer were not included in the model. Locations of other categories of withdrawal described in the Demand Analysis (industrial, commercial, agricultural, etc.) were not available so these withdrawal were not modeled explicitly. The vast majority of agricultural withdrawal occurs in the western Mahomet Aquifer region; and much of this withdrawal is near the Illinois River and the lower Sangamon River in Mason and Tazewell Counties (Figure 12). For the purposes of our modeling, the recharge and river boundary conditions in the western Mahomet Aquifer adequately capture the effects of agricultural pumping in this area. In order to account for the uncertainty in total withdrawal from the aquifer in other areas, a scale factor was applied to the rate of each known well (Section 4.2.1).

4.1.4 Other model control variables

Layer 1 of the MODFLOW model was defined as a convertible model layer – confined if the computed head is above the top of the layer and unconfined otherwise. Layers 2 and 3 were defined as confined model layers.

Cell drying was not allowed for Layer 1. When the head in a model cell falls below the bottom of the layer, the head is fixed at the elevation of the base of the cell. In this way, the transmissivity of the model layer becomes 0 and the instability caused by cells re–wetting and drying in successive iterations is avoided.

The head convergence criteria used was typically $1 \times 10^{-5}\ ft$; such a low value is required when using PEST as described in the following section. For simulations of the new wellfield, the model was set to converge even if this low tolerance was not met. Even in cases where the tight convergence tolerance was not met, the percent discrepancy on the overall flow budget for steady–state models was less than 0.1 percent.

For transient simulations, the head convergence criteria used was set to $1 \times 10^{-6}\ ft$ and the flow residual convergence tolerance was placed as low as $1 \times 10^{-8}\ ft^3/day$. Biased time–stepping was used and the initial time step was set lower than the critical value described by Anderson and Woessner [1992, p. 205]. For the simulation of the Visocky pumping test, the percent discrepancy on the overall model budget exceeded 1 percent for the first few time steps, but later in the simulation these discrepancies dropped well below 0.1 percent.

4.2 Model calibration

The software package PEST [Doherty, 2004] was used in model calibration. PEST uses a modified Gauss–Marquardt–Levenberg method of non–linear least squares to determine a parameter set that minimizes the sum of squared, weighted residuals. Residuals are the difference between observed and simulated values for the data described above. These differences are summarized as the objective function (Φ) which is a scalar value that PEST seeks to minimize during a typical parameter estimation run; Φ is defined in Equation 2.

$$\Phi = \sum_{i=1}^{m} [(o_i - c_i)w_i]^2 \tag{2}$$

where:

m is the number of observations used in the calibration

o_i is an observation consisting of a measured or estimated value the model is being used to simulate

c_i is the corresponding modeled value

$o_i - c_i$ is the residual associated with observation i

w_i is the weight associated with observation i.

This process did not operate on auto pilot. Calibration of the groundwater flow model was done using a combination of manual and automated methods. A series of water level observations were identified from the ISWS data along with published aquifer test data that were matched by optimizing parameter values used in the model. Details are presented in the following subsections.

Anthropogenic changes on the system are so pervasive that calibration of the system is highly dependent on the accuracy of the groundwater withdrawal information. Withdrawal for irrigation is unreported. Industrial withdrawal information is generalized to the township. Water level data from pumping wells that are temporarily idle are suspect because the water level may not have fully recovered to a representative value. Water level data from widely distributed wells are not likely to have been collected at the same time.

Water levels in the Mahomet Aquifer have declined over time due to increased rates of withdrawal and reduction of storage of water in the aquifer system. Sufficient data to differentiate between these causes is not currently available. Despite these shortcomings, the calibrated model was the best tool available for our evaluation of the new wellfield.

4.2.1 Parameters

Parameters varied during the model calibration are described in this section. The calibrated values for the second conceptual model described in Section 4.1.3 are listed in Table 20. These values are consistent with regional information summarized in Section 3.2 and Tables 18 and 19.

Hydraulic conductivity Zones of uniform hydraulic conductivity were defined within the model layer representing the Glasford Aquifer as follows:

1. a zone representing areas in which neither sand unit was mapped – this is inferred to be a low–conductivity zone that tends to limit the lateral flow of water in the Glasford Aquifer (see Figure 17);
2. a zone representing areas in which only the Vandalia Sand was mapped;
3. a zone representing areas in which only the Radnor Sand was mapped;
4. a zone representing areas in which both the Vandalia Sand and the Radnor Sand were mapped. This zone was set equal to the zone representing the Vandalia Sand in order to reduce the number of model parameters varied during the calibration.

Representative hydraulic conductivity values for the zones in the Glasford Aquifer was estimated using the Equation 3 which is from Anderson and Woessner (1992, p. 69). This assumes each zone is a two–layered system – one layer being the sand layer mapped by Soller et al. [1999] and the other layer being lower hydraulic conductivity material (glacial till).

$$K_{eff} = \frac{K_{sand} \cdot b_{sand} + K_{till} \cdot b_{till}}{b_{sand} + b_{till}} \tag{3}$$

where:

K_{eff} is the effective horizontal hydraulic conductivity of the layered system

K_{sand} is the horizontal hydraulic conductivity of the sand layer

K_{till} is the horizontal hydraulic conductivity of the till layer

b_{sand} is the saturated thickness of the sand layer

b_{till} is the saturated thickness of the till layer

Layers 2 and 3 have uniform hydraulic conductivity with the exception of a zone of lower hydraulic conductivity in Layer 3 north of Champaign/Urbana (Figure 23). This zone was established based on information presented by the ISWS.

Storage parameters MODFLOW-2000 uses specific storage rather than storage coefficient for confined and convertible aquifer layers [Harbaugh et al., 2000]. Specific storage was calculated by dividing the storage coefficient value of 3.1×10^{-4} from the aquifer test of the Petro Well reported by Visocky and Schicht [1969] by the layer thicknesses. Layer 1 was assigned a specific yield value of 0.1. The storage parameters were not adjusted during the model calibration.

Riverbed conductance for linear features Riverbed conductance and resistance are related parameters that both describe flow between a river and a underlying aquifer. For linear features, GMS expresses this parameter in terms of conductance per unit length for linear features ($ft^2/day \cdot ft$). Conductance of a river bed deposit (C) is defined as $C \equiv KA/L$, where K is the vertical hydraulic conductivity, A is the area under consideration, and L is the vertical thickness of the deposit. GMS calculates the length of an arc representing a river within a given model cell. This length is multiplied by a parameter representing the width of the river and the thickness of the vertical hydraulic conductivity of the riverbed deposits. In our model, the conductance multiplier is also intended to represent the effects of the material between the river of interest and the aquifer layer to which the river is assumed to be connected.

Five riverbed conductance parameters were defined for the first conceptual model. The distribution is described in the following list and shown on Figure 24. The second conceptual model included only those rivers assumed to be connected to Layer 3.

- A conductance multiplier for the Sangamon River upstream of the town of Mahomet – applied to model Layer 1.
- A conductance multiplier for the Sangamon River downstream of the town of Mahomet – applied to model Layer 1.
- A conductance multiplier for the Vermilion River – applied to model Layer 1.

- A conductance multiplier for the Iroquois River and tributary – applied to model Layer 3.
- A conductance multiplier for the Illinois River – applied to model Layer 3.

Riverbed conductance for entire model cells As described in Section 4.1.3, the second conceptual model used the MODFLOW river package to model recharge in each active cell in Layer 1. In this case, the riverbed conductance parameter for Layer 1 represented the effective hydraulic conductivity for the material above the Glasford Aquifer divided by the thickness of this material ($ft/day \cdot ft$). This parameter was applied uniformly over the model layer by multiplying by the cell area to produce the conductance value used by MODFLOW.

Recharge In the first conceptual model, recharge zones were defined on both Layers 1 and 3 of the model. In the area in which Layer 1 is active, three zones were defined: one that is underlain by the Vandalia Sand, one that is underlain by the Radnor Sand, and one that is underlain by neither sand. In the second conceptual model, the recharge package was not used to introduce water into Layer 1. In both conceptual models, recharge is applied directly to Layer 3 in the active areas of Layer 3 beyond the limits of the active area of Layer 1.

Pumping rates Due to the uncertainty regarding the pumping database (see the Demand Analysis report for additional information), a scaling factor was applied to the known public water supply pumping from the Mahomet Aquifer. In this way, the effects of unaccounted withdrawal and the possible bias between the average annual rates and the water level measurements (which may occur during periods of high withdrawal) could be addressed. The scale factor was allowed to range between 1 and 2.5. The scale factor caused the modeled discharge values for the ILAW wellfields to be closer to the maximum daily rates than the annual average rates described in Section 2.1.

4.2.2 Observations

Water level data supplied by the ISWS were used as observations in the model calibration (see Figure 18), along with information from an aquifer test data from a test west of Champaign [see Figure 13 of Visocky and Schicht, 1969]. This test was located approximately 1.5 miles east of Bondville and showed a strong leaky–confined signature. The aquifer parameters determined from this test were used to calculate a time–drawdown data set for an observation well located exactly 6 model cells from the pumping well (1980 ft). In this way, the accuracy of the MODFLOW solution is not compromised by interpolating between adjacent cells. A plot of modeled and observed time–drawdown is shown in Figure 26.

It should be noted that although the drawdown at the end of the 24–hour test was approximately 2.5 ft, the steady–state solution has a drawdown of 10.4 ft at the position of the observation well.

This is a reflection of the 3–dimensional complexity of the problem and is consistent with ISWS observations of an aquifer test near the town of Monticello [Roadcap and Wilson, 2004]. Dewatering of shallow water–bearing zones will affect some local wells and will ultimately reduce the capacity of the Mahomet Aquifer due to decreased vertical leakage.

Contour maps of measured and modeled water levels in the Mahomet Aquifer are shown in Figures 27A and B, respectively. A scatter plot of measured and observed water levels from the steady–state model calibration is shown in Figure 28.

4.2.3 Prior information

Prior information in model calibration consists of independent estimates of model parameter values. Articles of prior information were included regarding the effective hydraulic conductivity of the zones in Layer 1 representing the Radnor and Vandalia Sands and the hydraulic conductivity of the Mahomet Aquifer. The hydraulic conductivity values for the Radnor and Vandalia Sands were calculated using Equation 3 with a value of 220 ft/day for the hydraulic conductivity of the sand layers, 10 ft/day for the hydraulic conductivity of the till, a typical saturated thickness of 20 ft for the sand layers, and a typical saturated thickness of 100 ft for the till. The value for the Mahomet Aquifer hydraulic conductivity was determined by dividing the transmissivity reported by Visocky and Schicht [1969, Figure 13] by a model layer thickness in that cell of 130 ft.

4.2.4 Independent model prediction

We included an independent model prediction in the model calibration run. This prediction was the average drawdown in the Mahomet Aquifer beneath all known Glasford Aquifer wells caused by new wells west of the West Wellfield pumping at a combined rate of 20 *MGD*. This approach is the basis for predictive analysis as described in Section 4.3. This prediction was treated as an observation during the model calibration and a value provided to PEST that would push the calibration toward maximizing this drawdown in order to make the analysis conservative. This method is called dual calibration by Doherty [2004, Section 6.1.5].

4.2.5 Budget summary

A summary of the water budgets for the calibrated model representing 2004 conditions and a simulation representing the proposed wellfield pumping is presented in Table 21. The model of the new wellfield includes eight wells pumping at a combined rate of 20 *MGD* with the existing wells in the West Wellfield scaled back a total of 4 *MGD*.

The net inflow to Layer 1 of the calibrated model is roughly $1/4$ of regional estimates for the Glasford Aquifer (see Section 3.2.1) but the model does not incorporate mechanisms such as localized zone of higher infiltration described by Roadcap and Wilson [2004] that would tend to increase the amount of recharge to the Glasford. In addition, no withdrawal from the Glasford is modeled. Such withdrawal would have to be offset by additional recharge to the aquifer.

Layer 2 contains no sources or sinks. Excess water from Layer 1 passes through Layer 2 to Layer 3. In a few model cells, water passed from Layer 3, through Layer 2 and discharged to river cells connected to Layer 1. The net flow direction was downward through Layer 2.

Like Layer 1, the net inflow to Layer 3 of the model is lower than regional estimates with 0.17 to 0.38 in/yr reaching the Mahomet Aquifer compared to an estimated value of 2.2 in/yr (see Section 3.2.1). Unaccounted withdrawal from the Mahomet Aquifer would have to be offset by additional recharge to the aquifer. Groundwater discharge to the Illinois River and Iroquois River divided by the modeled area of the aquifer is 0.16 in/yr.

4.3 Predictive analysis

The method of predictive analysis described by Doherty [2004, Section 6] was applied manually to estimate a worst–case well interference for the new wellfield based on a preliminary layout. Predictive analysis follows model calibration and uses information from the calibration to determine a likely range of values for an independent prediction. In this case, the independent prediction was the average steady–state drawdown in the Mahomet Aquifer beneath wells completed in the Glasford Aquifer due to pumping a new wellfield west of Champaign at 20 MGD. As described in Section 5, these are the wells that are most vulnerable to being rendered unusable. This independent prediction is maximized while keeping the model essentially calibrated.

In predictive analysis, the user specifies an increment to the objective function δ, which is a statistically–derived number based on Equation 4[Doherty, 2004].

$$\delta = \frac{\Phi_{min}}{m-n} F_{\alpha}(n, m-n) \tag{4}$$

where:

Φ_{min} is the minimum value of the objective function obtained during the model calibration

m is the number of observations used in the calibration

n is the number of parameters being calibrated

$F()$ is the critical value for the $F-test$

α is the level of certainty specified for the analysis.

The purpose of the increment δ is to define a value for the objective function $\Phi_{min}+\delta$ that represents a specific uncertainty associated with the model calibration. For the first conceptual model, the average drawdown in the Mahomet Aquifer is most sensitive to the conductance parameter for the reach of the Sangamon River below the town of Mahomet. This is consistent with information from the ISWS regarding vertical leakage to the Mahomet Aquifer in this area [Roadcap and Wilson, 2004]. For the second conceptual model, the average drawdown in the Mahomet Aquifer is most sensitive to the conductance multiplier for the river cells on Layer 1. This parameter was lowered until the objective function rose to approximately $\Phi_{min} + \delta$. The influence of this change on the model prediction is described in Section 5.2.1.

4.4 Discussion

Our experience in calibrating the flow model based on the first conceptual model was that we could not put as much recharge on the Glasford Aquifer as regional information would suggest we should. This is due in large part to the lack of a mechanism for simulated localized discharge in subdrainages or agricultural drains as described in Section 4.1.3. In addition, the hydraulic conductivity of the zones in Layer 1 tended to converge on high values in order to lower heads in this layer. This is why the second conceptual model was adopted.

Any future modeling should include a hybrid between these approaches in which zones of river cell conductance and or hydraulic conductivity in Layer 2 are established that reflect the variability of the hydraulic connection between the rivers and the Glasford and Mahomet Aquifers.

Modeled gradients in the Mahomet Aquifer were much steeper than observed in the narrow “throat” to the West of Champaign County. In general, far–field aquifer properties are less important than in the near–field but in this case the high transmissivity in this part of the aquifer could alter local findings. Conditions that exist may limit regional drawdown from the proposed wellfield to the West. This high–transmissivity area should be explicitly evaluated in future regional groundwater modeling to better understand regional flow through this narrow reach of the buried valley aquifer.

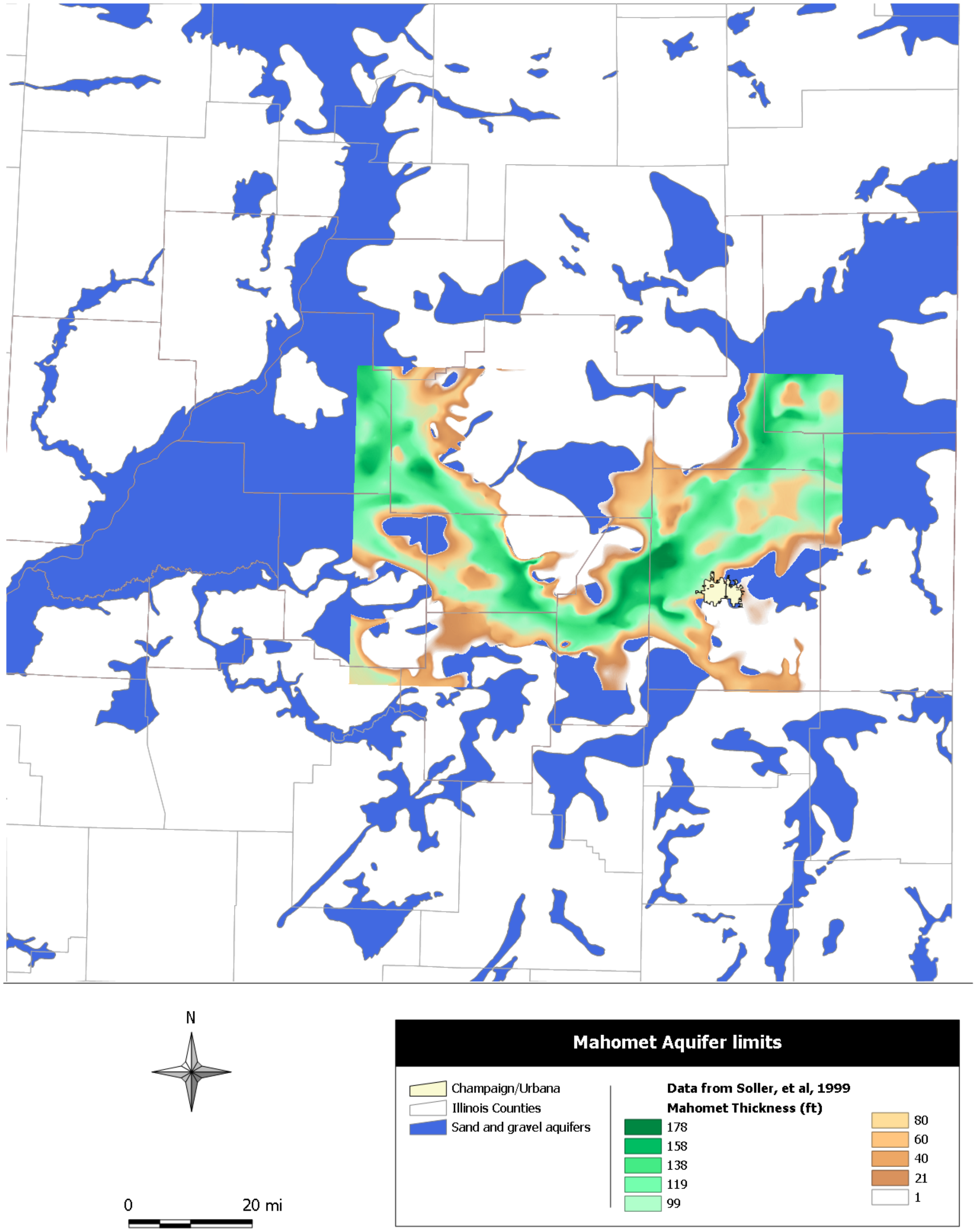


Figure 20: Location of project, limits of data from [Soller et al., 1999], and extent of Quaternary aquifers east-central Illinois.

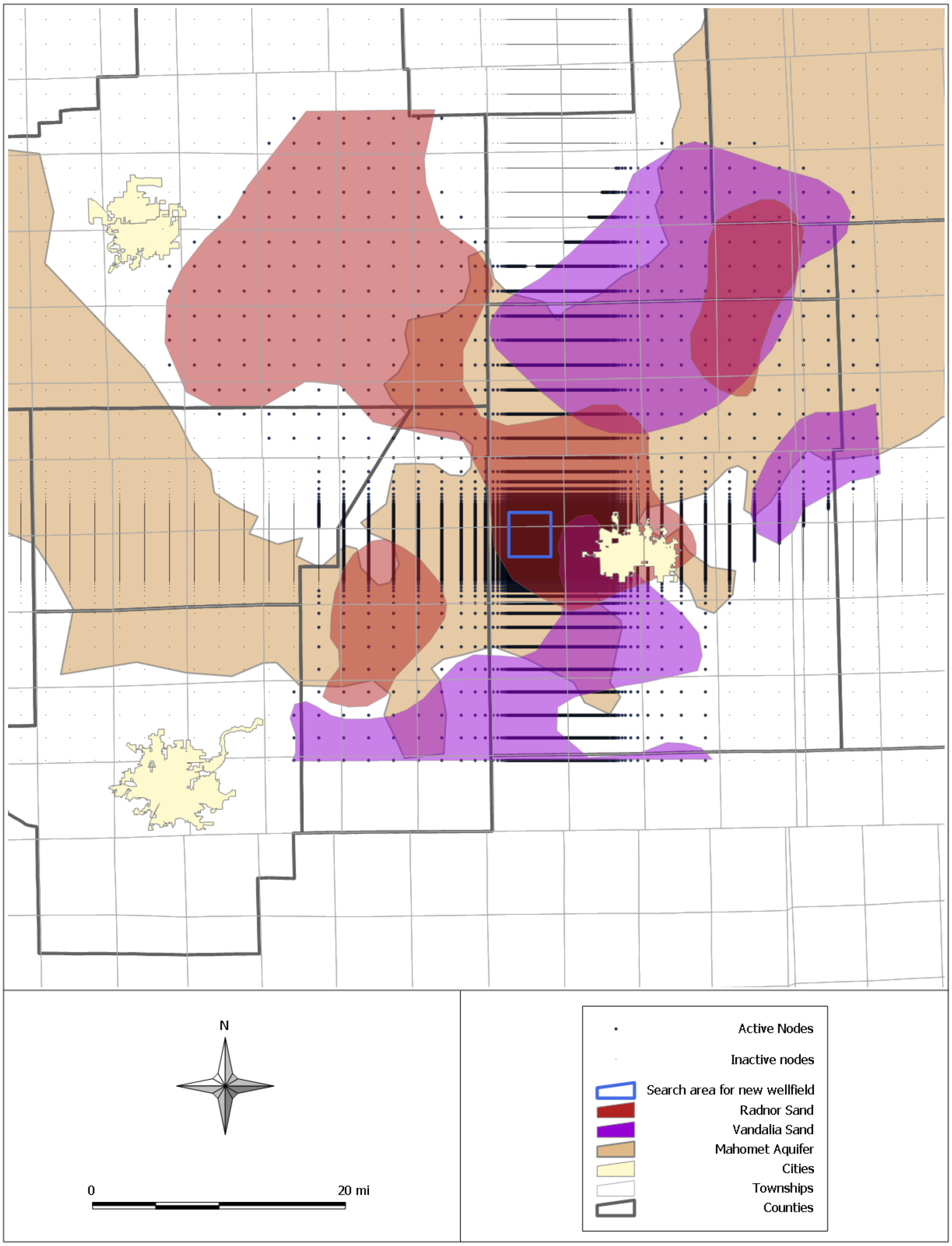


Figure 21: Model grid for Layer 1 with hydraulic conductivity zones in Layers 1 and 3.

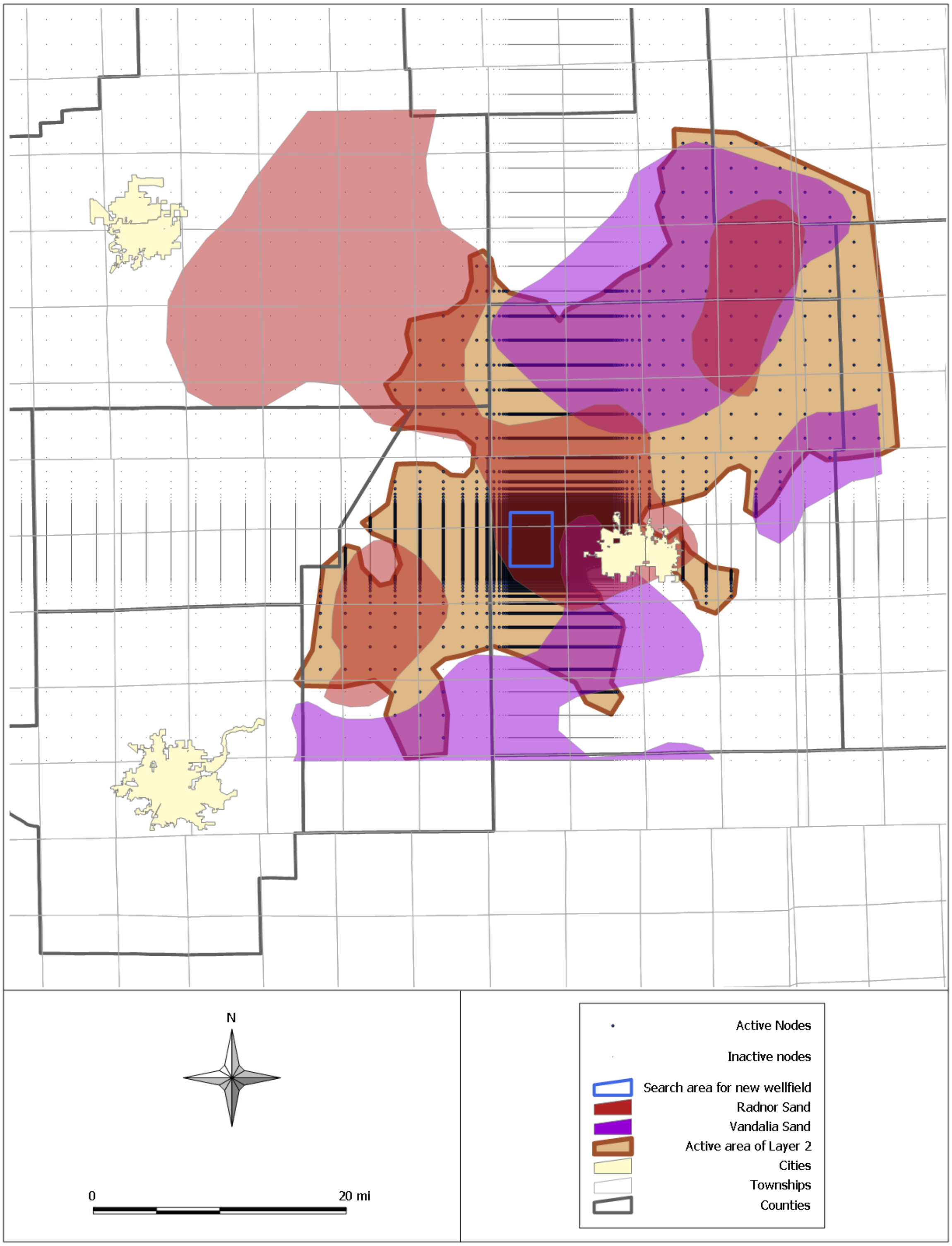


Figure 22: Model grid for Layer 2 with hydraulic conductivity zones in Layers 1 and 3.

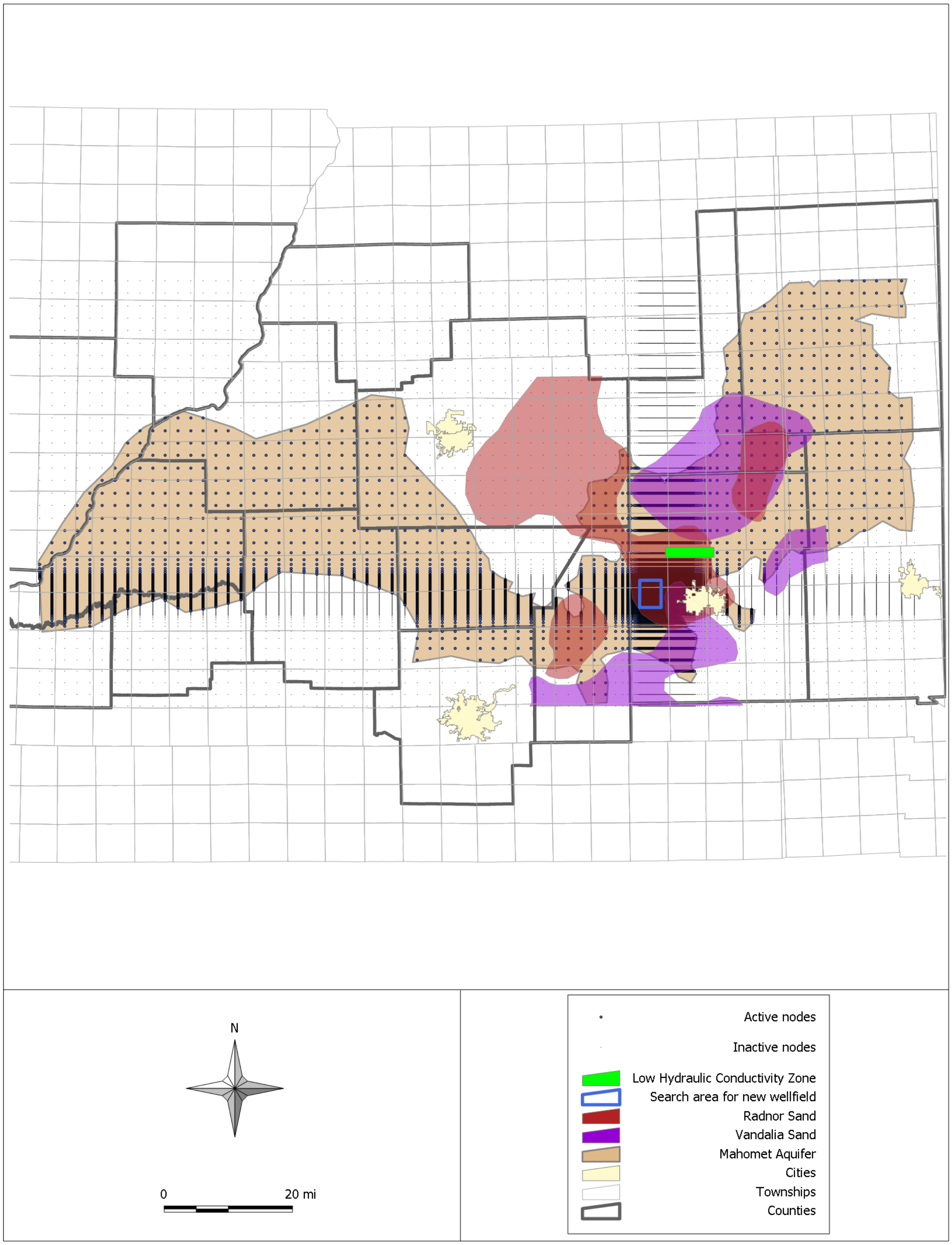


Figure 23: Model grid for Layer 3 with hydraulic conductivity zones in Layers 1 and 3.

Table 18: Aquifer parameter estimates from Visocky and Schicht, 1969

Location	Saturated thickness (ft)	Transmissivity (ft^2/day)	Horizontal hydraulic conductivity (ft/day)	Storage coefficient ($unitless$)	Confining bed thickness (ft)	Vertical hydraulic conductivity (ft/day)	Characteristic leakage length (λ) (ft)
Glasford Aquifer							
Selected aquifer test results from Champaign County							
Tolono	40	1890	47	1.7E-4			
Swift&Co.	38	8480	223	1.0E-5			
St. Joseph	16	1740	109	1.0E-4	34	4.7E-3	
State of Ill.	8	450	56	2.2E-4			
Clifford Jacobs Forging	21	3060	146	3.5E-3	24	4.2E+0	
Results of wellfield case history analyses							
Arcola	20	1340	67	NA	70	5.3E-3	
Hoopeston	52	19000	370	NA	60	5.2E-3	
Rantoul	50	9600	190	NA	80	3.5E-4	
Mahomet Aquifer							
Selected aquifer test results from Champaign County							
No. Ill. Water Corp.	100	43450	435	4.1E-4	35	2.4E-2	8,000
Petro Chemicals Corp.	75	33690	449	3.1E-4	35	2.9E-2	6,400
Petro Chemicals Corp.	83	31550	380	3.1E-4	50	5.6E-2	5,300
No. Ill. Water Corp.	90	43450	483	4.1E-4	35	2.4E-2	8,000
Results of wellfield case history analyses							
Fisher	90	10200	110	NA	87	5.3E-3	12,900
Monticello	94	26700	280	NA	60	3.1E-3	22,800
Rantoul	55	18000	330	NA	75	6.7E-4	44,900
Watseka	45	27000	600	NA	100	1.3E-3	44,900

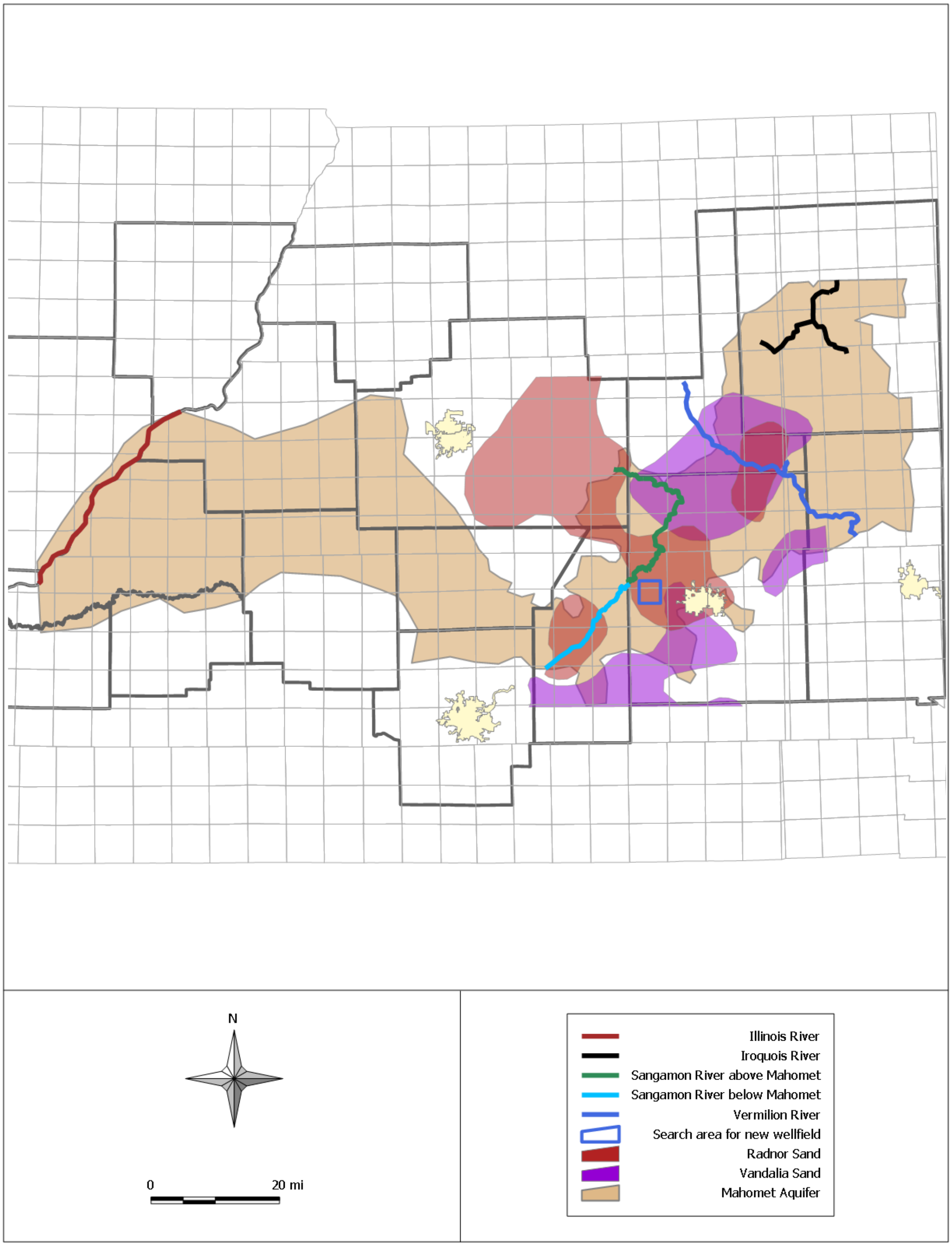


Figure 24: Location of rivers included in the groundwater flow model.

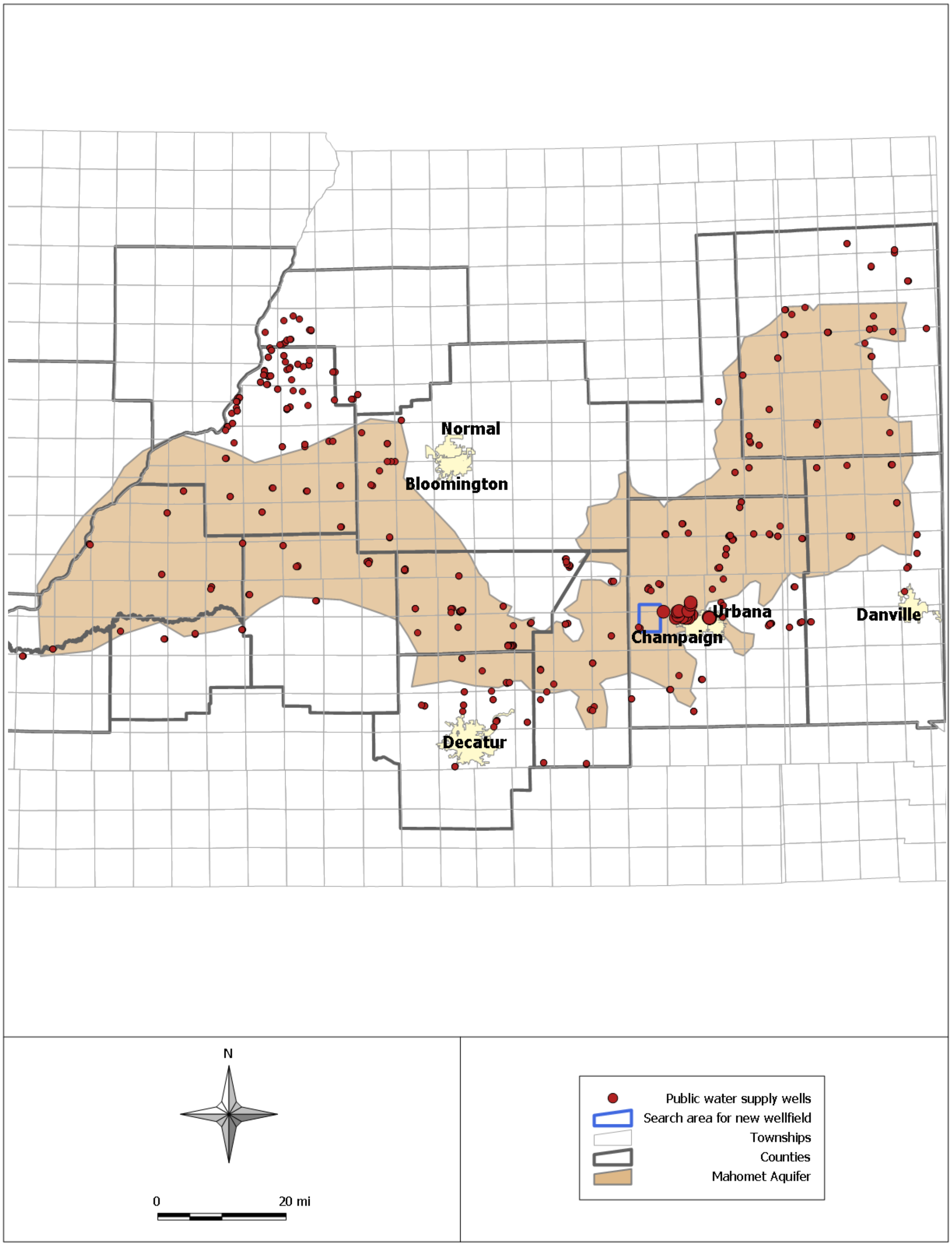


Figure 25: Public water supply wells included in the groundwater flow model.

Table 19: Aquifer parameter estimates from Kempton et al., 1991

Description	Transmissivity (ft^2/day)	Horizontal hydraulic conductivity (ft/day)	Storage coefficient ($unitless$)	Vertical hydraulic conductivity (ft/day)
Glasford Aquifer/confining layers				
minimum			1.5E-5	2.8E-4
maximum	31,100	620	8.0E-2	5.3E-2
Mahomet Aquifer				
minimum			2.0E-5	
maximum	68,200	570	2.0E-3	

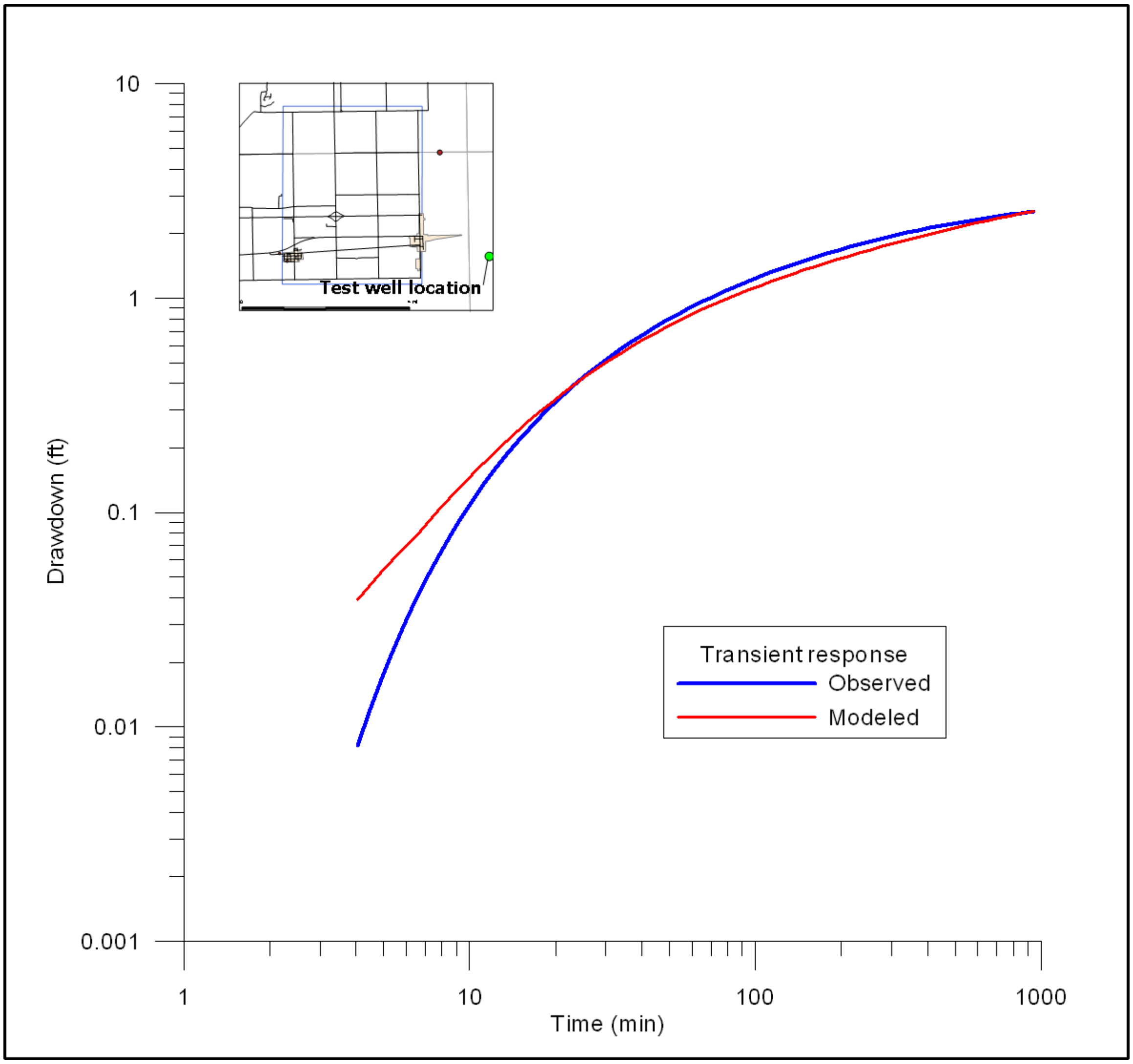


Figure 26: Plot of measured and observed drawdown in response to an aquifer test in the Mahomet Aquifer.

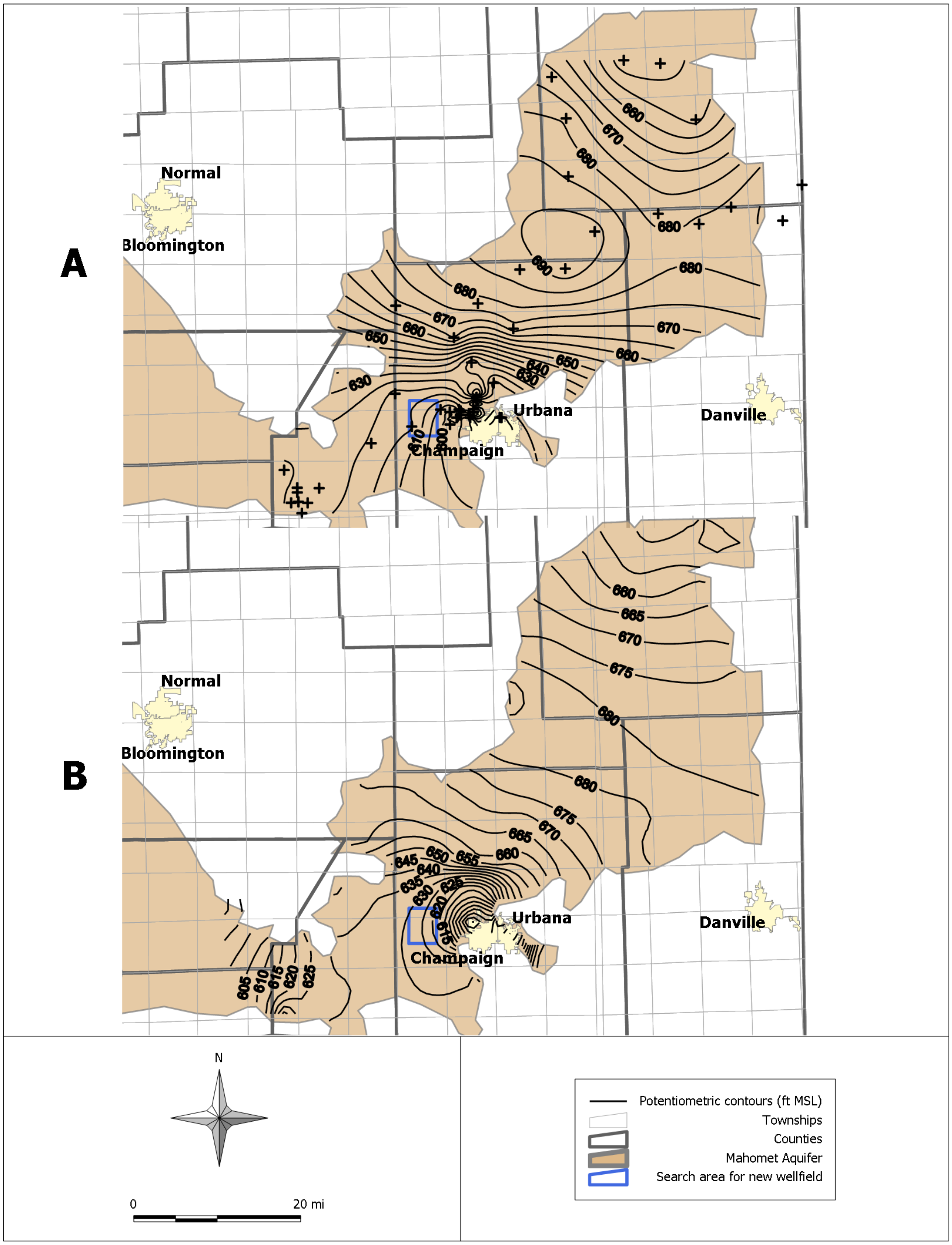


Figure 27: Comparison of measured (A) and modeled (B) water levels in the Mahomet Aquifer.

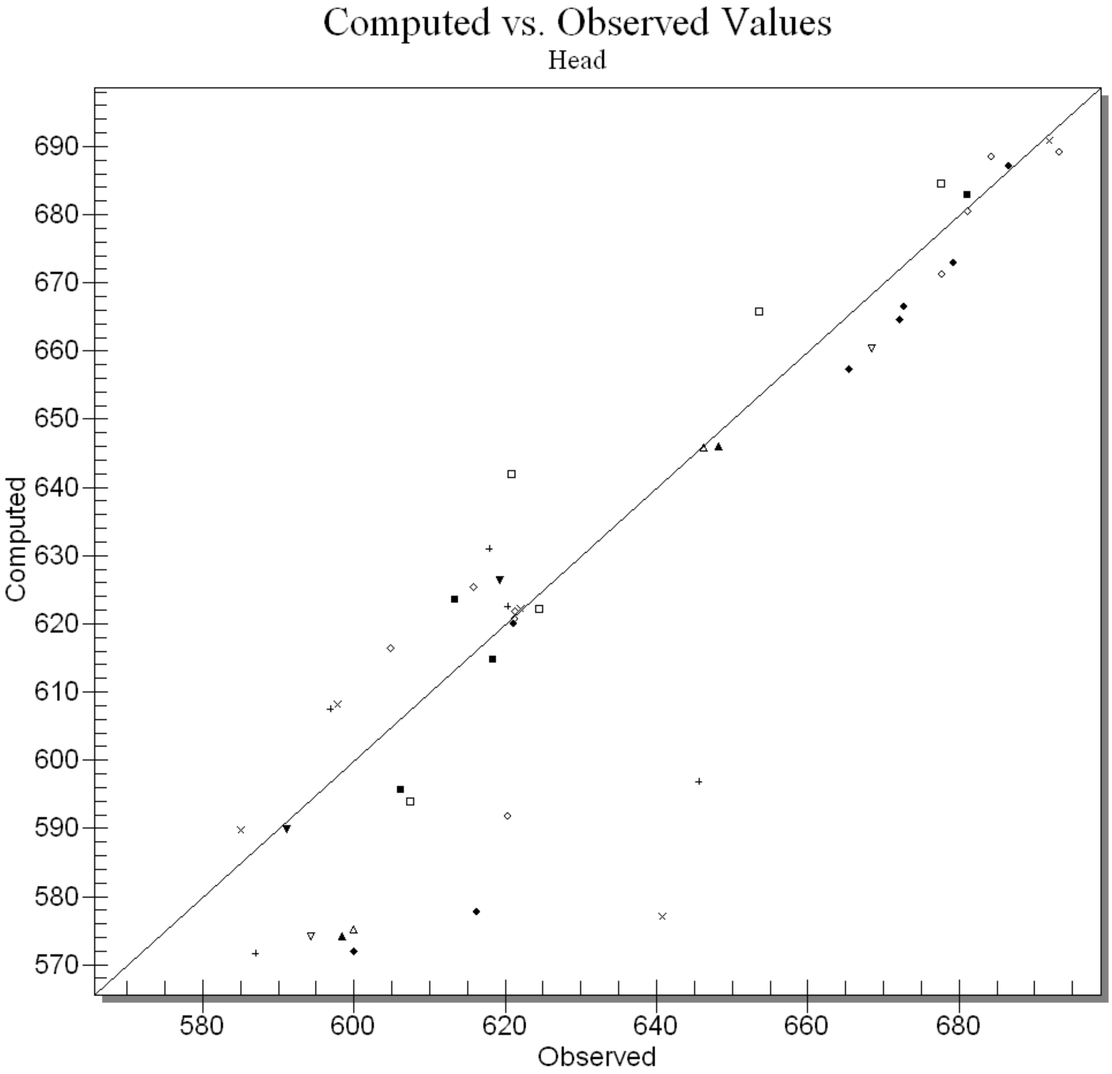


Figure 28: Measured versus modeled heads from the model calibration.

Table 20: Parameter values from the second conceptual model calibration

Parameter description	Calibrated value
Hydraulic conductivity	
Radnor Sand	10.0 ft/day
Vandalia Sand	41.5 ft/day
Non-aquifer in Layer 1	2.0 ft/day
Mahomet Aquifer	372 ft/day
Confining layer (Layer 2)	0.000227 ft/day
Low K zone in Mahomet Aquifer north of Champaign	11.0 ft/day
Recharge	
Recharge on Vandalia Sand	NA[1]
Recharge on non-aquifer material	NA
Recharge on Mahomet (Layer 3)	5.7E-5 ft/day
Recharge on Radnor Sand	NA
River cell conductance	
River conductance multiplier on Layer 1	2.83E-5 $ft/day \cdot ft$
Iroquois River (on Layer 3)	0.266 $ft^2/day \cdot ft$
Illinois River (on Layer 3)	596 $ft^2/day \cdot ft$
Other parameters	
Specific yield of Layer 1 (not varied)	0.1
Scale factor on Mahomet Aquifer pumpage	1.65

[1] Not applicable to this conceptual model - see Section 4.1.3

K - hydraulic conductivity. All layers were assumed to be isotropic ($K_x = K_y = K_z$).

Table 21: Summary of the net flow budget from the calibrated model.

	River cells	Recharge	Net to/from Layer 2	Wells
	Calibrated model of 2004 conditions			
Layer 1	0.53 in/yr	NA	-0.53 in/yr	0
Layer 3	-0.18 in/yr	0.25 in/yr	1.02 in/yr	53.7 MGD
	Calibrated parameters, net increase of 16 MGD in proposed wellfield			
Layer 1	0.66 in/yr	NA	-0.66 in/yr	0
Layer 3	-0.16 in/yr	0.25 in/yr	1.26 in/yr	69.7 MGD

Sign convention: + indicates net flow into the specified layer, - indicates net flow out of specified layer

5 New wellfield evaluation

We classified wells in the vicinity of the proposed wellfield based on the aquifer in which they are screened and defined an amount of drawdown due to pumping in the new wellfield that would likely necessitate lowering pumps in low–capacity wells. This was defined as two times the annual variation in water level measured in area wells, or approximately 12 ft. We also identified wells in which water levels may be drawn so low that they become dry due to limited depth. A series of wellfield configurations were compared in terms of these criteria.

5.1 Well interference assessment

The database of wells for Champaign and Piatt Counties was obtained from the ISGS. We reviewed logs of wells that are within 2–3 miles of the search area for the new wellfield (Figure 29). Of these wells, approximately 540 had enough information to determine which aquifer the well screen penetrates. Of the 540 wells, 220 are screened in the Glasford Aquifer and 320 are screened in the Mahomet Aquifer. The logs were classified according to the hydrogeologic units that could be identified.

Wells that are completed in the Glasford Formation are considered more vulnerable than those completed in the Mahomet Aquifer because water levels in the Glasford Formation could be lowered beneath the bottoms of wells completed in this formation. Figure 30 illustrates this point. The blue water levels represent conditions with none of the wells in the cross-section pumping. Recharge occurs both directly and diffusely to the Radnor Sand, so this unit has the highest water level. Pumping from the Mahomet Aquifer beyond the limits of the cross-section causes this unit to have the lowest water levels. The Vandalia Sand layer has an intermediate water level. The red water levels represent conditions when Well D is pumping from the Mahomet Aquifer. Drawdown is greatest in the pumped well and nearly as great in Well C, another Mahomet Aquifer well. Drawdown decreases vertically due the resistance to vertical flow from the Vandalia Sand to the Mahomet Aquifer and from the Radnor Sand to the Vandalia Sand. Although Well A has the smallest drawdown, it can be dried out because it is so shallow.

Water levels in the Mahomet Aquifer are anticipated to remain above the top of the aquifer, so water levels in wells completed in this formation will remain above the top of the screen. Pumps will likely have to be lowered in many of the Mahomet Aquifer wells to accommodate the lower water levels, but the wells are not anticipated to be rendered unusable.

For wells screened in layers above the Mahomet Aquifer, the available drawdown was estimated. Available drawdown was defined as the difference between the static water level in the well and a point 10 ft above the top of the well screen. Available drawdown was compared with the modeled drawdown in the layer representing the Mahomet Aquifer to determine if the well might be rendered unusable in a given scenario. It is an inherent assumption in our work that the drawdown in Glasford

Aquifer cannot exceed that in the Mahomet Aquifer. The forgoing analysis does not account for additional pumping from Decatur's Dewitt well field that may occur in drought conditions.

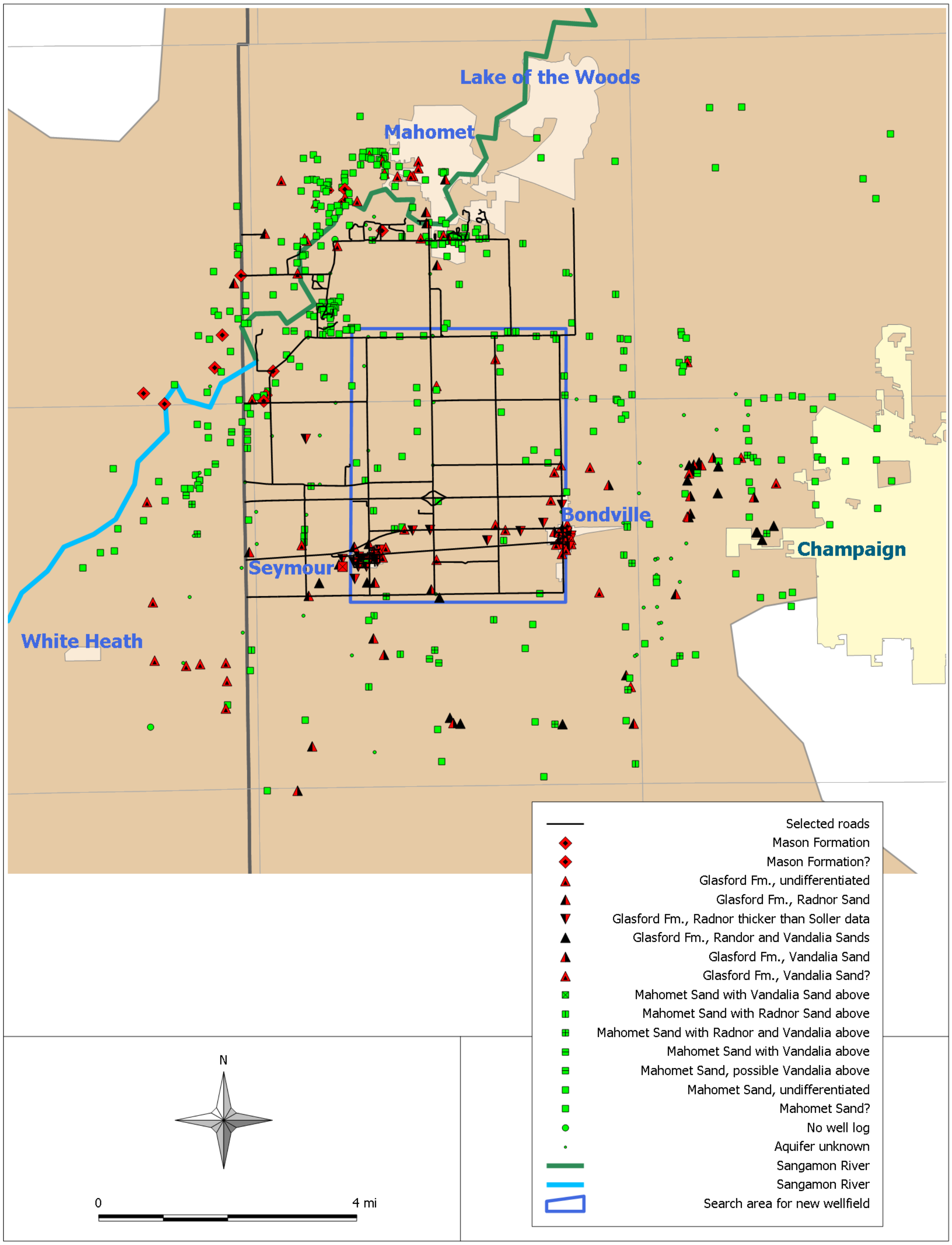


Figure 29: Location of wells from the ISGS database in the vicinity of the proposed wellfield.

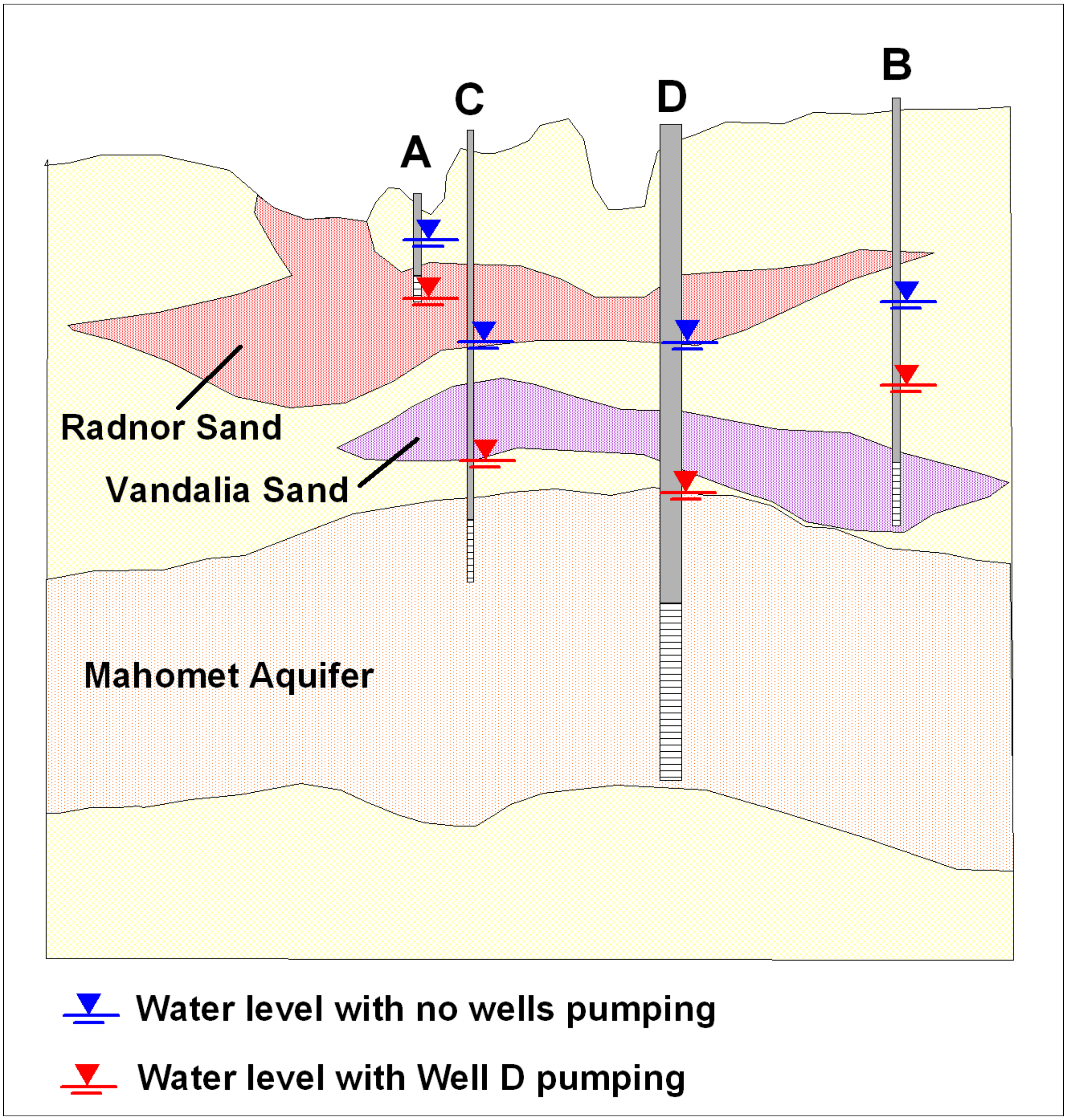


Figure 30: Well interference in various aquifers.

5.2 Wellfield design

The calibrated groundwater flow model described in Section 4 was used to compare candidate well locations within the search area (Figure 31). Based on reported capacities for Mahomet Aquifer wells in the area, a nominal capacity of 2.5 MGD (~1740 gpm) per well should be readily achievable. At that rate, the new wellfield would consist of a minimum of eight wells to produce 20 MGD. The new wellfield may include ILAW's Well 52, which has not yet been connected to the water supply.

5.2.1 Layout comparisons

Seven possible wellfield configurations were considered. Layouts were designed using the following rules:

- wells are to be located along existing roads,
- wells are to be located as far from existing wells as possible, and
- the center of the conceptual wellfield is to be located as close to the West Wellfield as is practical without causing excessive well interference, in order to minimize the cost associated with installing water mains.

Figure 32 shows a comparison of possible well locations within the search area. The drawdown due to a well pumping at each of the locations shown as black dots at a rate of 2.5 MGD was calculated. The information was summarized as the average drawdown in the Mahomet Aquifer beneath all known wells screened in the Glasford Formation (Figure 32A) and the the average drawdown in all known wells screened in the Mahomet Aquifer (Figure 32B).

Due to the concentration of Glasford wells near Bondville and Seymour (Figure 29), less interference with Glasford wells will result if a new well is located toward the northern limit of the search area. It should be noted that ILAW now provides water to these communities so many of these wells are likely no longer in use. Conversely, the southwestern corner of the search area is favored if interference with Mahomet wells is considered.

The configurations are described in the following list and shown schematically in Figure 33. Table 22 contains a comparison of the seven wellfield configurations in terms of the criteria described in Section 5.2.2.

1 nominal layout $\frac{3}{4} - mile$ spacing between wells, utilizing Well 52

2 denser layout $\frac{1}{2} - mile$ spacing, utilizing Well 52

3 #2 moved south $\frac{1}{2} - mile$ spacing, utilizing Well 52, along Bradley Avenue

4 #3 but denser $\frac{3}{8} - mile$ spacing utilizing Well 52, along Bradley Avenue

5 #4 without Well 52

6 very dense $\frac{3}{8} - mile$ spacing, shortest linear distance between wells

7 if pipe were free widest spacing in the search area

5.2.2 Evaluation criteria

Objective criteria identified that could be compared to differentiate the candidate wellfield layouts are listed below. Results of the comparisons are summarized in Table 22 and discussed in Section 5.2.4.

- the average drawdown in Mahomet Aquifer beneath Glasford Aquifer wells,
- average drawdown in Mahomet Aquifer wells,
- maximum drawdown in the Mahomet Aquifer beneath any Glasford Well,
- maximum drawdown in any Mahomet Aquifer Well, and
- the number of Glasford Aquifer wells in which the estimated drawdown will exceed the available drawdown estimated for the well.

5.2.3 Interference within the new wellfield

Pumping of each of the new wells will also reduce the available drawdown in the other new wells. This interference within the new wellfield was evaluated for Layouts 1, 6 and 7. For each simulation, the well with the most drawdown was turned off and the drawdown due to pumping of the other seven wells on this idle well was estimated. This is the total interference due to the other new wells pumping, which was 63.4 ft, 67.0 ft, and 59.5 ft, respectively. Moving from the minimum to maximum spacing is estimated to save 7.5 ft of available drawdown.

5.2.4 Discussion

Due to the high transmissivity of the Mahomet Aquifer, the modeled cone of depression associated with the proposed wellfield is broad and relatively shallow. In other words, drawdown due to pumping the well at steady–state rates is widespread (Figure 37). As a result, the average drawdowns beneath the wells considered in the well search are not strongly influenced by the layout of the wellfield. In fact, because the search area has relatively few Mahomet Aquifer wells near its center, the denser well configurations along Bradley Avenue (cases 3–5) have lower average drawdowns in Mahomet Wells than the other configurations. Conversely, impacts on Glasford Wells slightly favor cases 1,2, and 6. As noted above, ILAW now provides water to Seymour and Bondville so many of the wells in these communities are likely no longer in use.

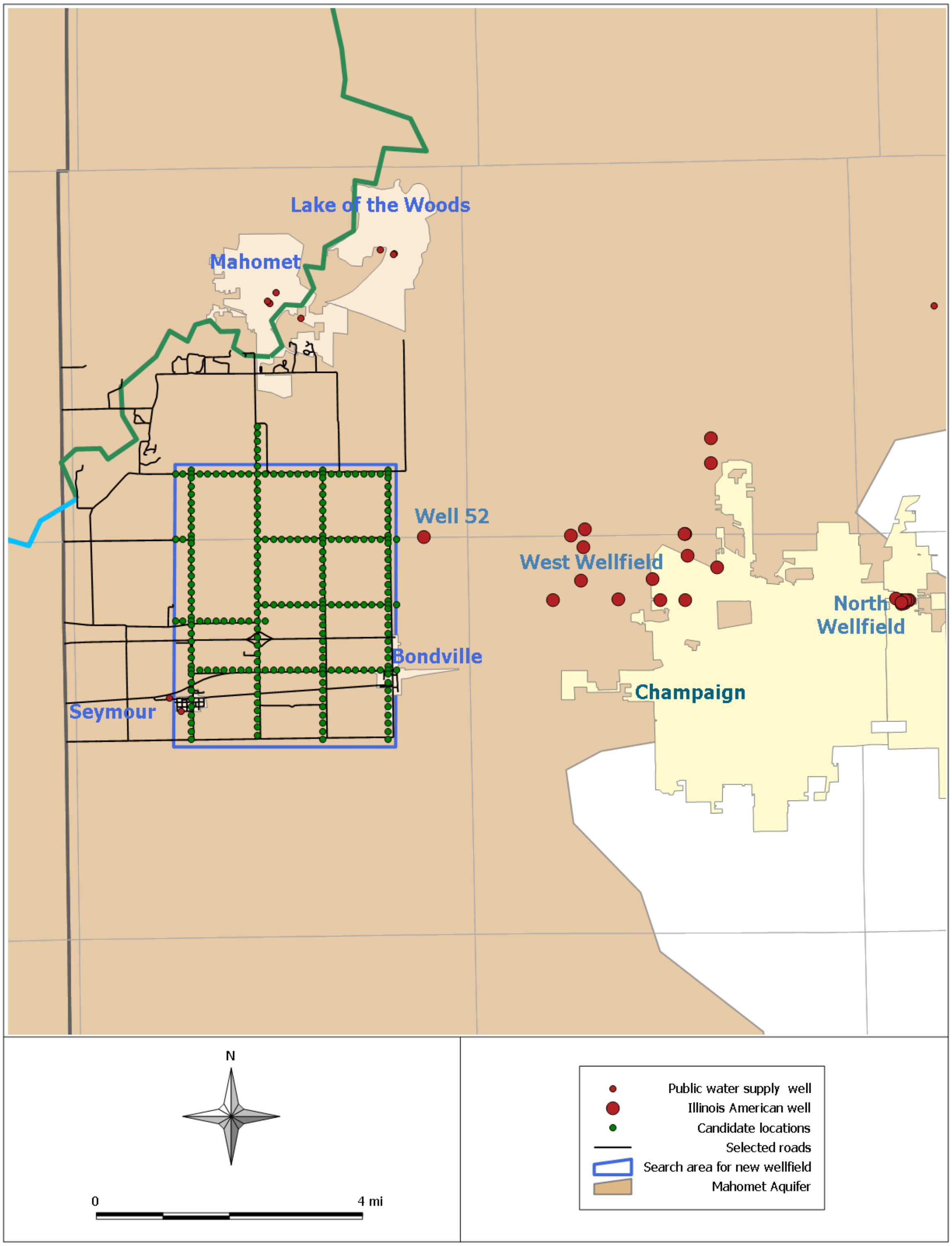


Figure 31: Locations considered for possible new wells in the search area.

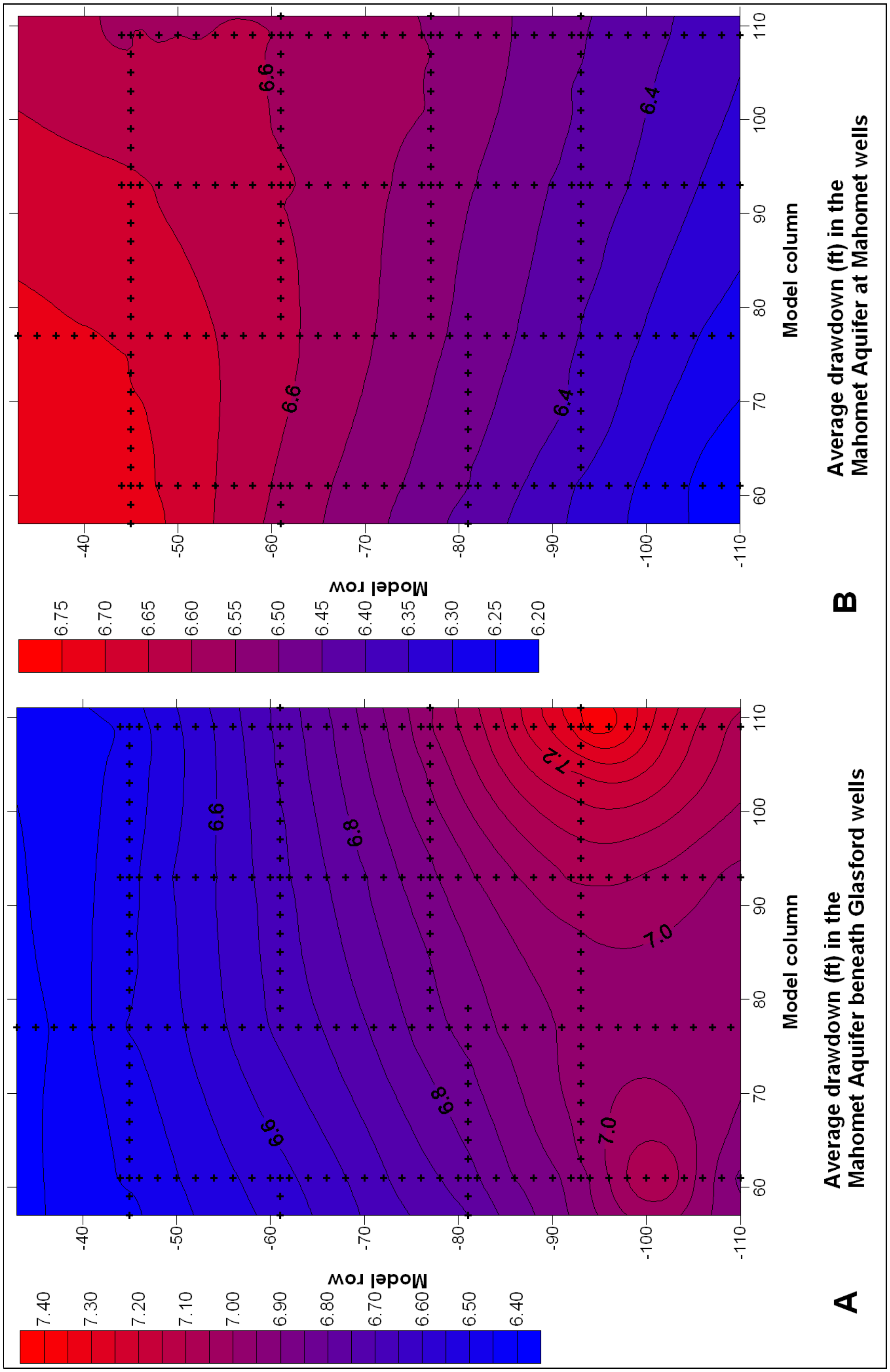


Figure 32: Evaluation of possible well locations in the search area.

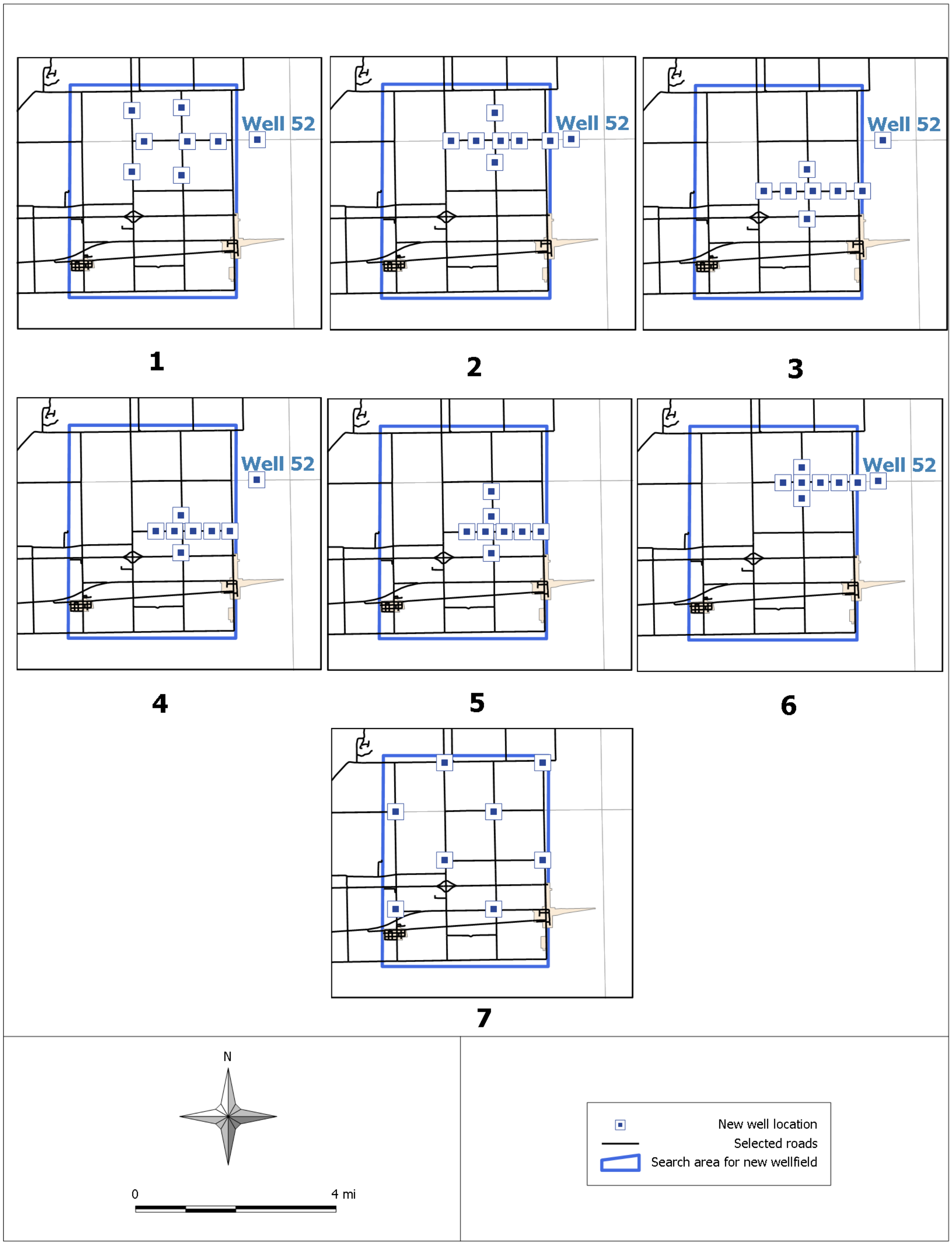


Figure 33: Wellfield configurations used for comparison.

Table 22: Comparison of the effects of wellfield layouts

case	$\bar{s}$ under Glasford wells	$\bar{s}$ in Mahomet wells	s_{max} under Glasford wells	s_{max} in Mahomet wells	Threatened Glasford wells
	Calibrated parameters, net 16 *MGD*				
1	50	49.3	61.5	61.5	65
2	50.1	49.3	61.1	63.7	65
3	51.7	48.9	63.5	64.6	66
4	51.8	48.9	65	66.1	67
5	51.9	48.9	64.9	66.6	69
6	50.1	49.2	62.7	65.1	65
7	50.8	49	59.9	57.2	66
	Worst-case parameters, net 16 *MGD*				
1	73.8	73	85.4	85.5	136
2	73.9	73	85	87.7	135
3	75.5	72.6	87.6	88.7	136
4	75.6	72.6	89.1	90.2	136
5	75.7	72.6	89	90.7	136
6	73.9	73	86.7	89.1	135
7	74.6	72.6	83.8	81.2	135

$\bar{s}$ - average drawdown

s_{max} - maximum drawdown

6 Estimates of wellfield impact

We estimated historical pumping rates from the Mahomet Aquifer and used the groundwater flow model to estimate water levels in the aquifer over time. Based on the results of the wellfield comparisons described in Section 5.2, Layout 1 was then used in a series of simulations of development of the new wellfield over the next 30+ years. These scenarios are simulated at steady-state. We then evaluated the influence of the seasonal nature of the the withdrawal to see if the steady-state models may over-predict the amount of drawdown caused by a given scenario. Using this layout and the proposed pumping rates, the a new well field West of Champaign would provide the needed water and would be sustainable for the next 25 years of pumping. This conclusion is based on assumptions we made about growth in groundwater use in the area. These growth scenarios do not include additional high capacity wells pumping from the Mahomet Aquifer near the proposed well field.

6.1 Water levels over time

In order to put additional groundwater development at the Champaign Operation into perspective, we estimated historical annual average pumping rates from the Mahomet Aquifer and used the model to estimate water levels in the aquifer over time. Table 23 summarizes the simulated discharge rates for Mahomet Aquifer wells. Assumptions and sources for the data in Table 23 are listed below.

- Prior to development in the area (some time before 1890 based on Figure 16 of Visocky and Schicht [1969]), no withdrawal occurred from the Mahomet Aquifer.
- As of 1945, estimated withdrawal from the Mahomet Aquifer was about 4 *MGD* based on Figure 16 of Visocky and Schicht [1969]. None of this withdrawal was in the Champaign/Urbana area based on Figure 20 of Visocky and Schicht [1969].
- As of 1965, estimated withdrawal from the Mahomet Aquifer was about 20 *MGD* based on Figure 16 of Visocky and Schicht [1969]. Approximately 13 *MGD* of this withdrawal was in the Champaign/Urbana area based on Figure 20 of Visocky and Schicht [1969].
- The total withdrawal from the Mahomet Aquifer in 1985 was estimated as the average of the value discussed above for 1965 and the calibrated model value of 53.7 *MGD*. The value reported for ILAW's withdrawal in the Champaign Operation for 1992 was used as representative of 1985.
- Withdrawal for 2004 was taken from the calibrated model described in Section 4.2.5.
- Withdrawal representing conditions in the year 2025 is described in Section 6.2.

Modeled water levels in the Mahomet Aquifer through the search area for the new wellfield and West Wellfield are shown in Figure 34. Pre-development water levels in this area were modeled to be slightly above land surface on the western end of the cross-section to 40 to 70 ft below ground surface on the eastern end. Water level declines in this cross-section are caused by the overall increase in withdrawal from the aquifer and, to a greater extent, by development of ILAW's Mahomet Aquifer wells. For comparison, the last line in Table 23 is the modeled decline in water level (drawdown) at the eastern end of the cross-section. For the calibrated parameter set, the decline from 2004 to 2025 was estimated to be less than that from 1985 to 2004 and about the same magnitude as the decline from pre-development to 1965.

Water levels were predicted to remain above the top of the Mahomet Aquifer except in the simulation using the worst-case parameter set. In other words, the Mahomet Aquifer remains saturated in all of the scenarios except the worst case.

Table 23: Average annual pumping rates (in *MGD*) used in the historical simulations

Year	Predevelopment	1945	1965	1985	2004	2040
Well group						
North Wellfield	0.0	0.0	2.2	2.2	2.2	2.2
West Wellfield	0.0	0.0	10.8	15.8	32.9	28.9
New Wellfield	0.0	0.0	0.0	0.0	0.0	20.0
Other wells[1]	0.0	4.0	7.0	12.8	18.6	18.6
Total	0.0	4.0	20.0	30.8	53.7	69.7
Incremental increase		4.0	16.0	10.8	22.9	16.0
ILAW increase		0.0	13.0	5.0	17.1	16.0
Total drawdown (ft)[2]		1.4	41	59	120	160/180

[1] Other wells are all other wells in the model besides ILAW wells.

[2] Drawdown calculated at the eastern end of the cross-section shown in Figure 34

6.2 Development scenarios

Development of the new wellfield is anticipated to take place gradually. ILAW estimates the rate of growth in demand to be 1.7 percent per year. Four simulations were run with the calibrated parameter set to estimate the changes in water level (drawdown) in response to this development. Table 24 summarizes the distribution of pumping among groups of wells in the model. Predicted effects of this development are illustrated as drawdown relative to modeled conditions for 2004. The following list describes the scenarios.

1. Redistribution of current rates of pumping in the Champaign Operation. Five *MGD* is shifted from the West Wellfield to the new wellfield. This scenario represents conditions from 2006

to about 2011 (see Figure 35). During this period, at the expected rate of growth, ILAW's demand will increase by less than 2 *MGD*. Note that the modeled drawdowns around the West Wellfield are negative because no net increase was modeled but some withdrawal was shifted away from the West Wellfield.

2. An increase of 5 *MGD* in total withdrawal occurs from the year 2006 to 2019. This increased withdrawal is added to the new wellfield (see Figure 36A).
3. An additional increase of 5 *MGD* in total withdrawal occurs from the year 2019 to 2029. This increased withdrawal is added to the new wellfield (see Figure 36B).
4. An additional increase of 6 *MGD* in total withdrawal occurs from the year 2029 to 2040. This increased withdrawal was divided between the West Wellfield (1 *MGD* increase) and the new wellfield (5 *MGD*). Drawdowns were estimated using the calibrated model parameters (Figure 37A) and the worst-case model parameters (Figure 37B).

Table 24: Pumping rates (in *MGD*) used in the forward simulations

Scenario	Calibrated model	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ending year	2004	2011	2019	2029	2040
Well group					
North Wellfield	2.2	2.2	2.2	2.2	2.2
West Wellfield	32.9	27.9	27.9	27.9	28.9
New Wellfield	0.0	5.0	10.0	15.0	20.0
Other wells	18.6	18.6	18.6	18.6	18.6
Total	53.7	53.7	58.7	63.7	69.7

6.3 Steady-state versus transient effects

A comparison was made between modeled steady–state drawdowns and transient drawdowns based on the seasonal variation in withdrawal described in Section 2.3.3. The growing season was assigned to the period May through August. It was assumed that over the eight months between growing seasons, water levels would reach a steady–state. As described in Section 4.2.5 and shown in Table 24, the maximum total pumping in the steady–state model of the proposed wellfield is 69.7 *MGD*. This represents an annual average rate. Assuming a ratio for growing season to off–season pumping of 2:1 results in seasonal average rates of 104.2 *MGD* and 52.1 *MGD*, respectively. Table 25 lists the assumed distribution of this seasonal pumping among groups of wells in the model. The discharge values used for the ILAW wellfields in the steady–state model were higher than the annual average rates described in Section 2.1 because the pumping in these and other wells was scaled up to account for pumpage from unknown wells (see Section 4.2.1).

A steady–state model of the pumping rates representing off–season conditions set the starting heads for a transient simulation of the growing season. Water levels drop throughout the transient simulation, but in general do not drop to the levels indicated by the steady–state simulation. This is illustrated in Figure 38, which is a contour map of the difference between modeled heads at the end of the transient simulation and those from the steady–state simulation. Positive values indicate higher heads (less drawdown) at the end of the transient model. In the near–field, the heads at the end of the transient simulation were approximately 2 ft to 6 ft higher than the steady–state simulation. This difference is sensitive to the value used for the specific yield of Layer 1. In order to be conservative, the specific yield value was decreased from that used in the model calibration (0.10) to a value much lower than would be expected for an unconfined aquifer (5×10^{-4}). In the far–field, scaled–up pumping of wells resulted in more drawdown locally in the transient model than the steady–state model. These results suggest that the steady–state model is a reasonable approximation of conditions near the Champaign Operation, but tends to over–predict drawdowns in the far field.

Table 25: Well discharges used in the comparison of steady-state and transient drawdowns

Well group	Combined discharge MGD		
	Steady-state model	Off-season	Growing Season
ILAW West wellfield	28.9	14.7	29.4
ILAW North wellfield	2.2	1.6	1.6
Proposed ILAW wellfield	20.0	10.0	20.0
Irrigation wells	0	0	11.2
Other wells	18.6	25.8	42.0
Total	69.7	52.1	104.2

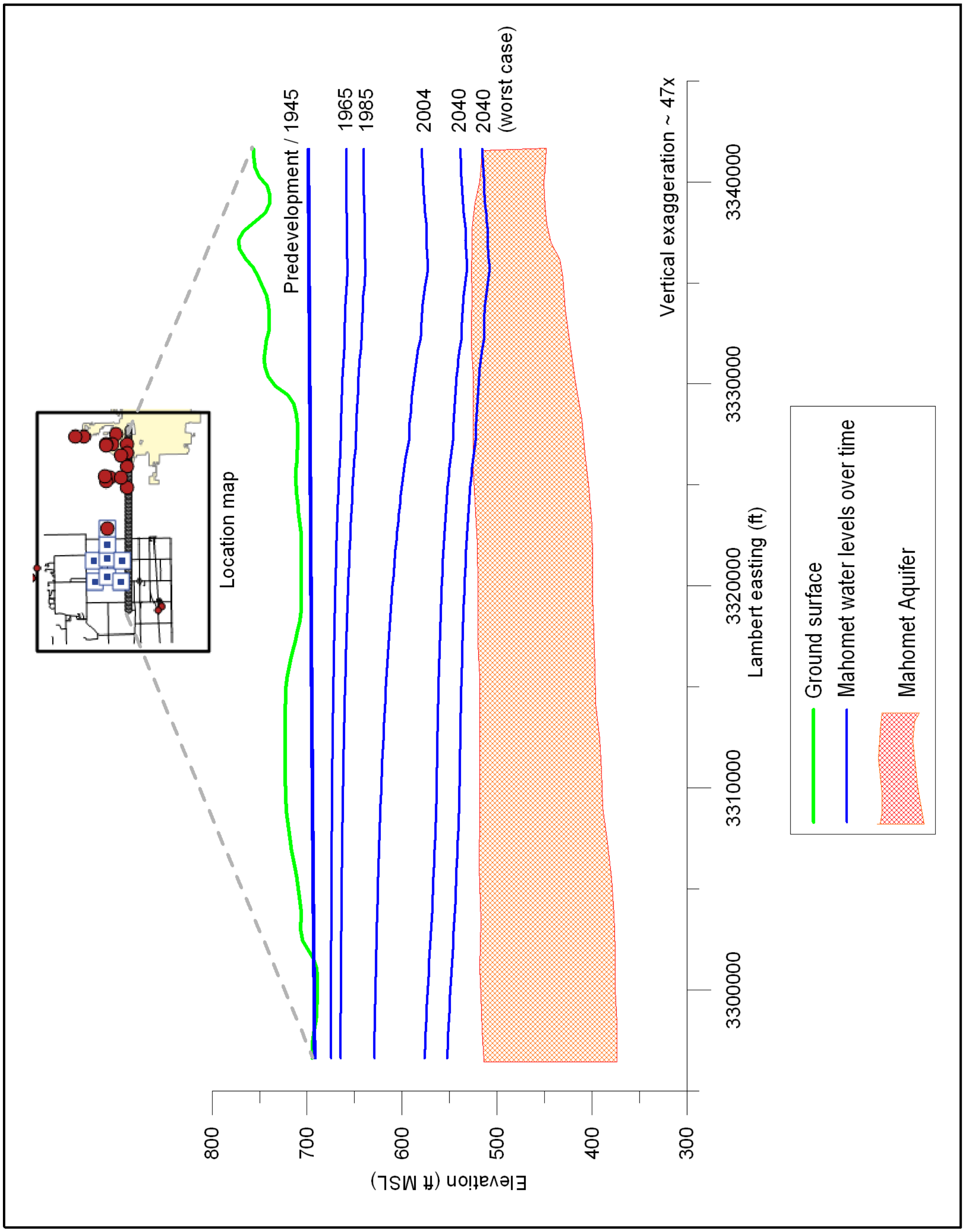


Figure 34: Cross-section of simulated historical water levels and projected levels for the year 2025.

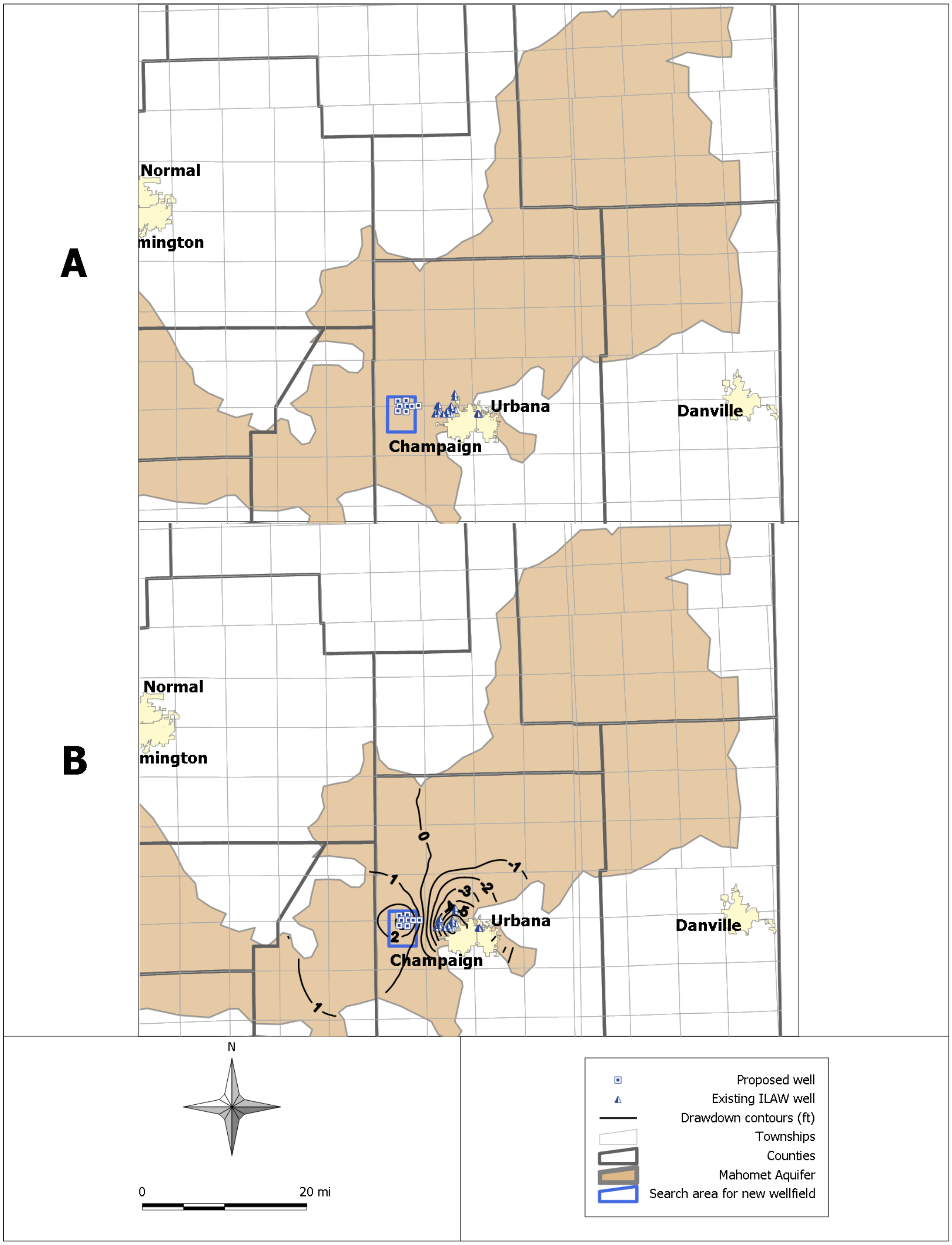


Figure 35: Base map (A) and modeled drawdowns for the year 2011 (B).

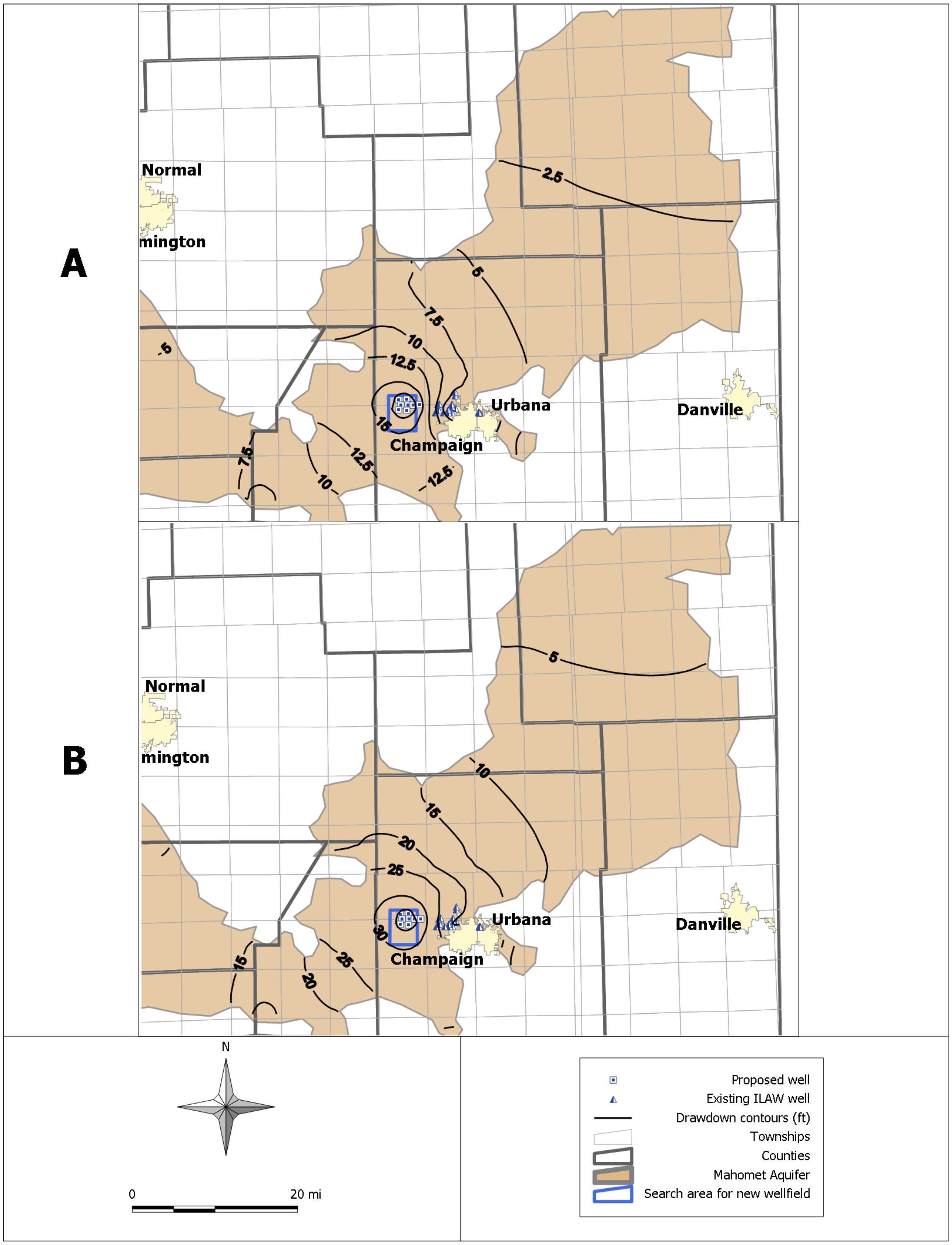


Figure 36: Modeled drawdowns with the calibrated parameters for the years 2019 (A) and 2029 (B).

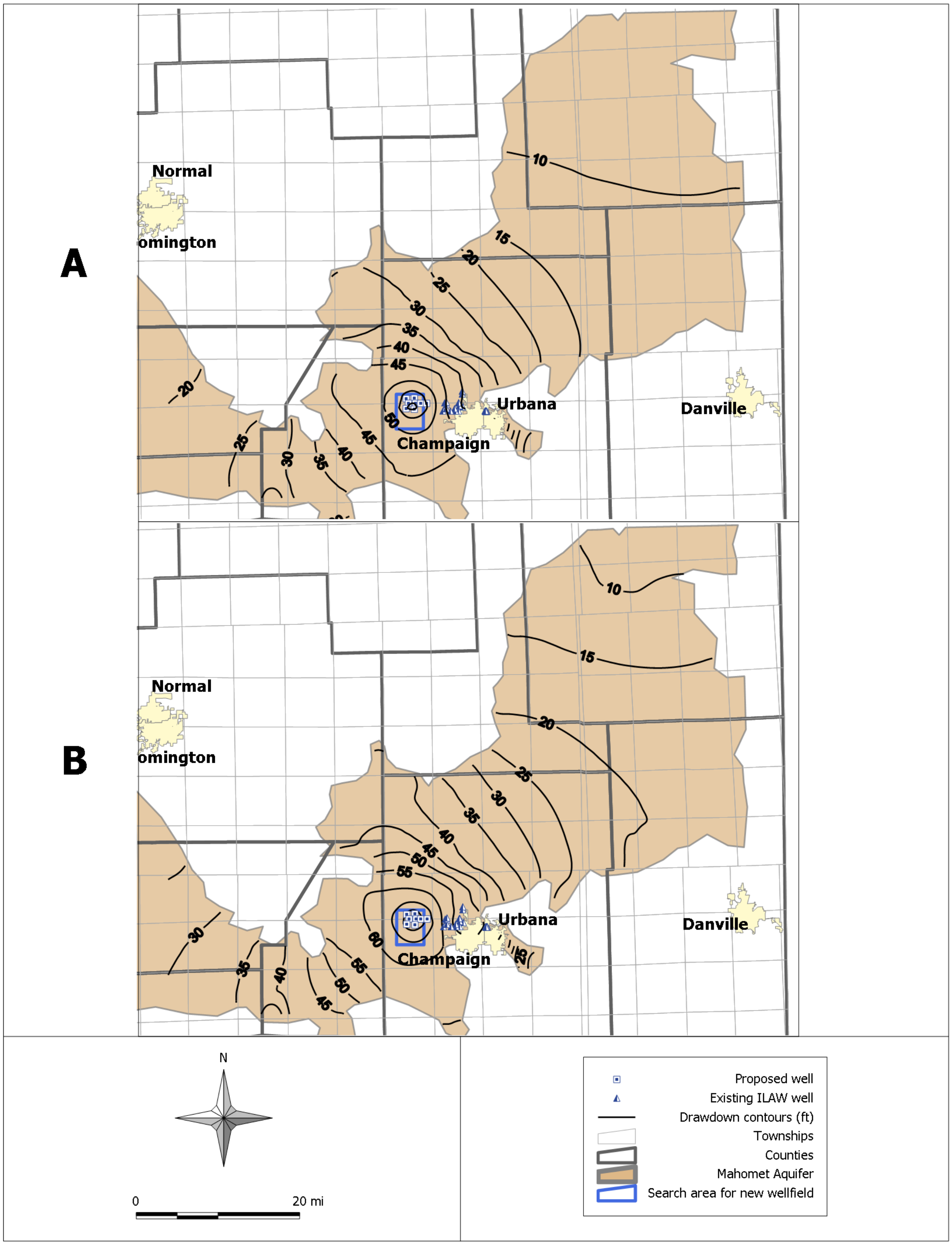


Figure 37: Modeled drawdowns with the calibrated (A) and worst-case parameters (B) for the year 2040.

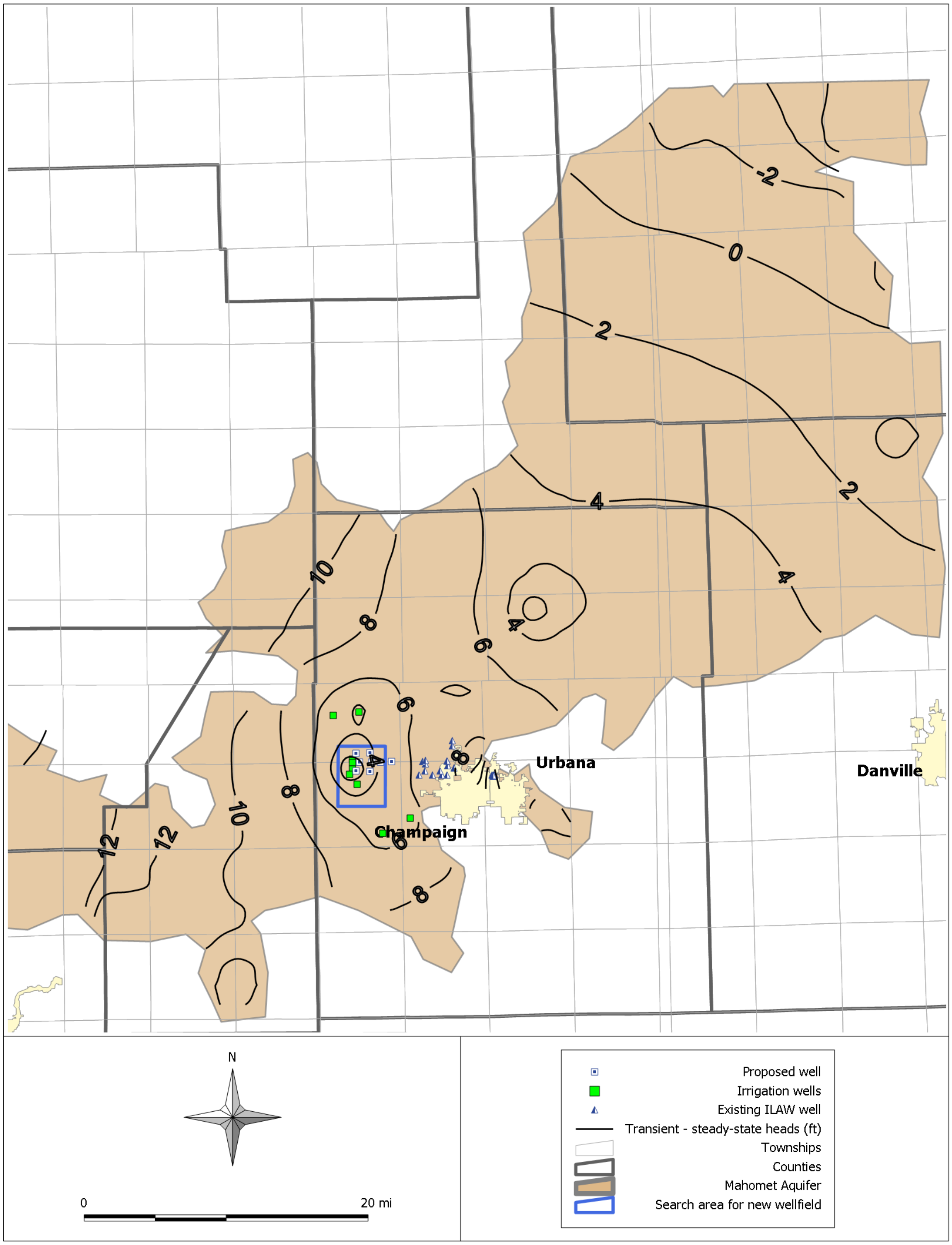


Figure 38: Comparison between steady-state heads and heads from the end of a transient model of the growing season.

7 Conclusion and recommendations

The modeling analysis, supported by the local data, suggests that the new wellfield can be a sustainable supply at its planned future pumping rate. The regional water demand analysis described in this report shows that other users' withdrawal from the Mahomet Aquifer will increase over time, perhaps dramatically if municipalities not located above the aquifer shift their sources of supply to the aquifer. This increase in withdrawal will reduce the capacity of the aquifer system to yield water in the Champaign/Urbana area and will exacerbate the effects of expansion of the ILAW source of supply. In other words, the sustainability of Champaign/Urbana public water supply will be determined by the combined water use in the region. Conservation measures should be implemented by all users of the resource.

Dewatering of water–bearing zones above the Mahomet Aquifer will affect local wells and will likely reduce the capacity of the Mahomet Aquifer due to decreased vertical leakage. A system of monitoring wells in the Glasford Aquifer will allow ILAW to understand this trend. Results of the ISWS's Glasford Well survey should be incorporated as they become available. Water level data from this survey will be useful in further calibrating the model.

Groundwater flow modeling described in this report suggests that the impact of development of a new wellfield west of Champaign will be widespread and not extremely sensitive to the layout of the wellfield. It has been observed elsewhere in the Mahomet Aquifer that the 3–dimensional complexity of the aquifer dictates how water flows through the system. A prototype wellfield should be constructed and monitored to determine the actual impact and ultimate design of the wellfield. The groundwater flow model developed for this report should then be updated with information from the prototype wellfield and used to determine whether additional wells are required and if so, determine if they can be placed between existing wells or must be located further out to avoid excessive interference.

The recommended wellfield design is shown in Figure 39. This design utilizes Well 52 and calls for initial installation of five new wells. We recognize that logistical considerations may alter this layout. A long–term test should be performed using these wells (or long–term monitoring of their actual operation). Data from the actual operation of these initial wells and actual decline in water levels in the Mahomet and Glasford aquifers should be utilized to determine whether the wellfield can be completed by filling in between the initial wells or if the wellfield must be expanded to limit its impact on existing wells.

Monitoring data from operation of the wellfield should also be used to determine the effective specific yield of the Glasford Formation so transient simulations can be made with more certainty. Transient models could be used to develop wellfield operation plans with respect to maximizing infiltration from the Sangamon River during periods of excess river discharge or other criteria.

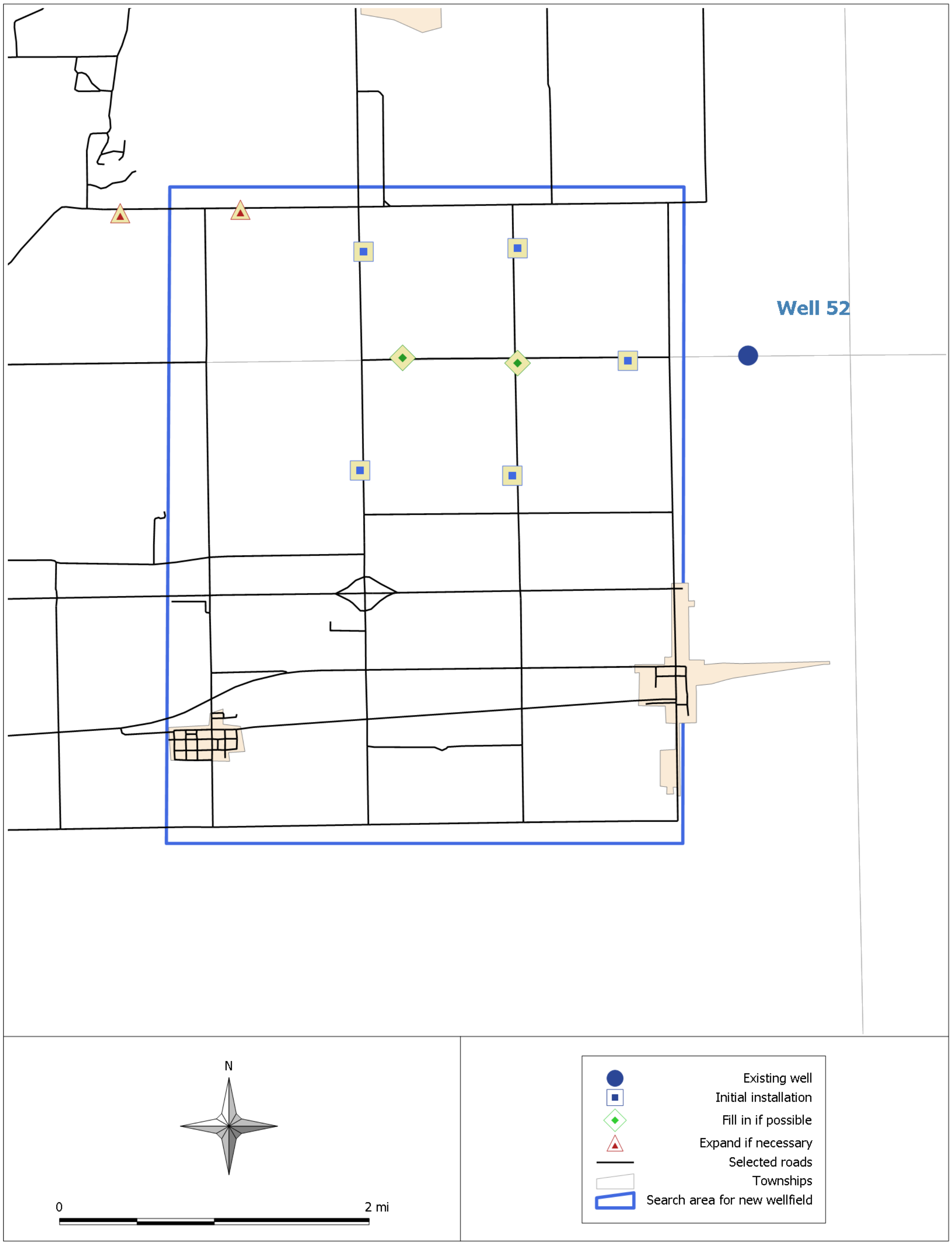


Figure 39: Recommended layout for the new wellfield.

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A Additional water demand results tables

Additional data tables are provided from the water demand section. The tables show the raw data used in the graphs and/or calculations of the water demand projections presented in Section 2.

Table 26: Population projections per county [ISU, date, Dzielgielewski et al., 2005].

County	2000	2005	2010	2015	2020	2025
Cass	13695	13374	12967	12793	12718	12644
Champaign	179669	186234	195752	201810	207331	213002
DeWitt	16798	16546	16253	16033	15874	15717
Ford	14241	14177	14075	13940	13804	13671
Iroquois	31334	30757	30075	29795	29611	29428
Logan	31183	31763	32166	32473	32669	32866
Macon	114706	114516	114242	114597	114845	115093
Mason	16038	15443	14911	14568	14469	14370
McLean	150433	156861	162357	167370	171641	176021
Menard	12486	13772	14879	16082	17522	19091
Piatt	16365	16555	16699	16946	17347	17757
Tazewell	128485	129922	130233	130857	132465	134093
Vermilion	83919	84324	84471	84872	85640	86414
Woodford	35469	36869	38226	40238	42756	45431

Table 27: Percent population growth projections in each county. Calculated from [ISU, date, Dzielgielewski et al., 2005]

County	**Percent change**				
	2005	**2010**	**2015**	**2020**	**2025**
Cass	-2.34	-3.05	-1.34	-0.59	-0.58
Champaign	3.66	5.11	3.09	2.74	2.73
DeWitt	-1.49	-1.78	-1.34	-1.00	-0.99
Ford	-0.44	-0.71	-0.95	-1.02	-0.95
Iroquois	-1.84	-2.21	-0.94	-0.62	-0.61
Logan	1.86	1.27	0.96	0.61	0.60
Macon	-0.16	-0.24	0.30	0.22	0.22
Mason	-3.71	-3.44	-2.30	-0.67	-0.69
McLean	4.28	3.50	3.09	2.55	2.56
Menard	10.30	8.04	8.09	8.95	8.97
Piatt	1.16	0.87	1.48	2.36	2.37
Tazewell	1.12	0.23	0.48	1.23	1.23
Vermilion	0.48	0.18	0.47	0.91	0.90
Woodford	3.95	3.68	5.26	6.26	6.26

B Model input files

A compact disc containing the model input files for the MODFLOW model runs described in this report was provided to the Illinois State Water Survey. See the file read_me_ISWS.txt for a description of the disc contents and other information about the model files.

Table 28: Self-supplied domestic population per county.

County	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	5605	5474	5307	5236	5205	5175
Champaign	13649	14148	14871	15331	15751	16181
DeWitt	5768	5682	5581	5506	5451	5397
Ford	3821	3804	3777	3741	3703	3668
Iroquois	7504	7366	7203	7135	7091	7048
Logan	9913	10097	10225	10323	10386	10448
Macon	5096	5088	5076	5091	5102	5113
Mason	7998	7701	7436	7265	7216	7166
McLean	20813	21703	22463	23156	23747	24354
Menard	3496	3856	4166	4503	4906	5346
Piatt	5685	5751	5801	5887	6026	6169
Tazewell	16945	17135	17175	17258	17470	17685
Vermilion	19299	19392	19426	19518	19695	19873
Woodford	22099	22971	23817	25070	26639	28306

Table 29: Acres of cropland projections per county.

County	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	152744	141011	130180	120180	110949	102426
Champaign	543427	534414	525550	516834	508231	499831
DeWitt	194712	190770	186907	183122	179414	175781
Ford	306557	317264	328345	339812	351681	363964
Iroquois	632924	630909	628899	626896	624900	622909
Logan	363588	368778	374042	379382	384797	390290
Macon	301783	299907	298043	296190	294349	292520
Mason	264143	263688	263233	262779	262326	261874
McLean	655885	639537	623596	608052	592896	578118
Menard	151766	149955	148164	146396	144648	142921
Piatt	243438	240521	237639	234792	231979	229200
Tazewell	300357	292159	284185	276428	268883	261544
Vermilion	456220	453399	450594	447807	445037	442285
Woodford	276597	278846	281114	283400	285705	288028

Table 30: Acres of irrigated cropland projections per county [Dzielgielewski et al., 2005].

County	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	9914	10416	10783	11032	11179
Champaign	4889	4810	4733	4657	4582
DeWitt	856	848	840	832	824
Ford	668	690	713	736	761
Iroquois	6536	8119	9692	11255	12808
Logan	549	557	564	572	579
Macon	467	471	476	480	485
Mason	96890	104457	111996	119510	126997
McLean	936	918	901	884	868
Menard	966	955	944	934	924
Piatt	334	362	390	416	442
Tazewell	42256	48963	55273	61203	66767
Vermilion	144	144	144	144	143
Woodford	504	478	451	424	397

Table 31: Acres of irrigated cropland projections overlying the Mahomet Aquifer.

County	**2005**	**2010**	**2015**	**2020**	**2025**
Cass	4461	4687	4852	4964	5031
Champaign	3227	3175	3124	3074	3024
DeWitt	556	551	546	541	536
Ford	240	248	257	265	274
Iroquois	4444	5521	6591	7653	8709
Logan	329	334	338	343	347
Macon	168	170	171	173	175
Mason	96890	104457	111996	119510	126997
McLean	337	330	324	318	312
Menard	270	267	264	262	259
Piatt	234	253	273	291	309
Tazewell	36340	42108	47535	52635	57420
Vermilion	50	50	50	50	50
Woodford	131	124	117	110	103