

ISWS CONTRACT REPORT 2020-01

JUNE 2020

ANALYSIS OF GROUNDWATER LEVEL CHANGES, SURFACE WATER CONDITIONS, AND WATER USE IN THE GREATER BARRINGTON REGION, 2014–2019

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Illinois State Water Survey

PRAIRIE RESEARCH INSTITUTE

Analysis of Groundwater Level Changes, Surface Water Conditions, and Water Use in the Greater Barrington Region, 2014–2019

A Report to the Barrington Area Council of Governments (BACOG),
May 2020

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Abstract

The Barrington area is dependent on shallow groundwater resources for water supply and is unusual in that much of the water demand required by its residents is met by private wells as opposed to centralized community water systems. The Barrington Area Council of Governments (BACOG) supports a groundwater and surface water monitoring program consisting of continuous and periodic water level measurements in local streams and in the shallow sand and gravel aquifer system (Henry Formation). BACOG also leads a yearly mass measurement of water levels at municipal wells within and surrounding the BACOG study area. We developed potentiometric surfaces (maps that represent aquifer water level elevations) for the sand and gravel aquifer system for the years 2014–2019 using geographic information system (GIS) interpolation tools, and from those developed potentiometric change maps. We also analyzed trends in baseflow conditions using United States Geological Survey (USGS) streamgauge data and water use from the sand and gravel and shallow bedrock aquifers using Illinois Water Inventory Program (IWIP) data.

The potentiometric surfaces show a consistent groundwater high in the western half of the BACOG study area due to the Henry Formation being at or near the land surface. Results from this study indicate that water levels in the sand and gravel aquifer within the BACOG study area have generally increased over the five-year study period. Water levels increased on average: 1) by around 5 feet at the continuously monitored USGS sites, 2) by 5.8 feet at the Illinois State Geological Survey monitoring wells, and 3) by over 5 feet at municipal wells. Baseflow also trended upward at the Fox River and Poplar Creek streamgaging sites. Regional municipal water use from the sand and gravel aquifer decreased from 16 million gallons per day in 2005 to around 13 million gallons per day in 2018. The increase in water levels may be due to a combination of less municipal water use, above average precipitation, and improved household water use efficiency.

Because of the projected increases in precipitation intensity, flooding events, and climate variability, we recommend the continuation of BACOG's groundwater monitoring program to understand long-term (decadal) trends in groundwater levels to support long-term regional planning of water supplies. Because of the predominance of private wells in the region and that a significant portion of the aquifer is susceptible to contamination, we also recommend that groundwater quality sampling be a focus of future BACOG studies.

Acknowledgments

This project was funded by the Barrington Area Council of Governments (BACOG), led by Janet Agnoletti, Executive Director of BACOG, who initiated this project. We thank Janet for her continued support of the ISWS and her dedication to understanding groundwater resources in the Barrington area. We also thank Tomasz Szczuka, GIS Analyst at BACOG, Riley Balikian at the Illinois State Geological Survey (ISGS), David Raynes at the Illinois State Water Survey (ISWS), and others for data collection and management. BACOG wishes to acknowledge Kurt O. Thomsen, who developed the initial methodology for the monitoring program in 2014. Without BACOG's data collection and monitoring efforts, this project would not have been possible. Special thanks to all the municipalities that have participated in the yearly measurements of their wells.

We also thank Daniel Abrams and Cecilia Cullen (both at ISWS) for their constructive peer reviews of this report. Lisa Sheppard (ISWS) edited the text. The views expressed in this report are those of the authors and do not necessarily reflect the views of the sponsor, the ISWS, or the Prairie Research Institute.

Introduction

Residents in the Barrington area are dependent on groundwater from the shallow sand and gravel aquifer system for water supply. The Barrington area, defined as the Villages of Barrington, Barrington Hills, Deer Park, Lake Barrington, North Barrington, South Barrington, and Tower Lakes, as well as Cuba and Barrington Townships, is unusual in that most water use is from domestic wells, whereas centralized municipal water supplies serve the majority of residents in most surrounding communities. Understanding groundwater conditions is vital for long-term planning of Barrington area water supplies for both domestic and municipal use.

The Barrington Area Council of Governments (BACOG) is a regional planning organization composed of local governments that funds and maintains a groundwater monitoring network and supports surface water monitoring efforts in the Barrington area. BACOG's monitoring initiative is informed through the goals of BACOG's Regional Comprehensive Land Use Plan. Monitoring consists of periodic and continuous measurements in the shallow sand and gravel aquifers and in local streams. BACOG also enacts a protocol for measurements of static water levels in surrounding municipal sand and gravel wells in early July of each year. The 2015 report by KOT Environmental Consulting, Inc., *Development of a Groundwater Monitoring System Protocol and Determination of Baseline Surface and Groundwater-Level Conditions*, synthesized this data to: 1) construct a potentiometric surface of the sand and gravel aquifer system for July 2014, 2) analyze trends in groundwater levels, and 3) determine baseflows from USGS streamgage data. The report established a baseline potentiometric surface for the sand and gravel aquifer system for comparison with data from subsequent years and gave recommendations for future monitoring and data analyses (Thomsen, 2015).

This report aims to: 1) provide an update to BACOG about groundwater and surface water levels in the Barrington area, 2) describe the changes that have occurred since the 2014 potentiometric surface was developed, and 3) discuss trends in water use from the sand and gravel and shallow bedrock aquifers by municipalities within and surrounding the Barrington area.

Background

Geologic and Hydrogeologic Setting

The surficial geology of the BACOG area is a complex sequence of glacial deposits consisting of clays, silts, sand and gravels, and tills (formations with a range of clast sizes within a matrix of silts and clays) (Thomason and Barnhardt, 2007). The most productive sand and gravel deposit, the Henry Formation, serves as an important aquifer and is used by private and municipal wells in the region. The Henry Formation is present at the land surface in portions of the western BACOG area and along the Fox River (Figure 1). In much of the western BACOG area, the Henry Formation is overlain by the Lemont Formation (Figure 2), which is a sandy till deposit with lenses of sand and gravel. Thus, both areas where the Henry Formation is at the land surface and where the Lemont Formation overlies the Henry Formation are important recharge areas and are classified as highly sensitive to contamination (Figure 3). The Henry Formation dips toward the east where it is overlain by the less permeable Equality and Wadsworth

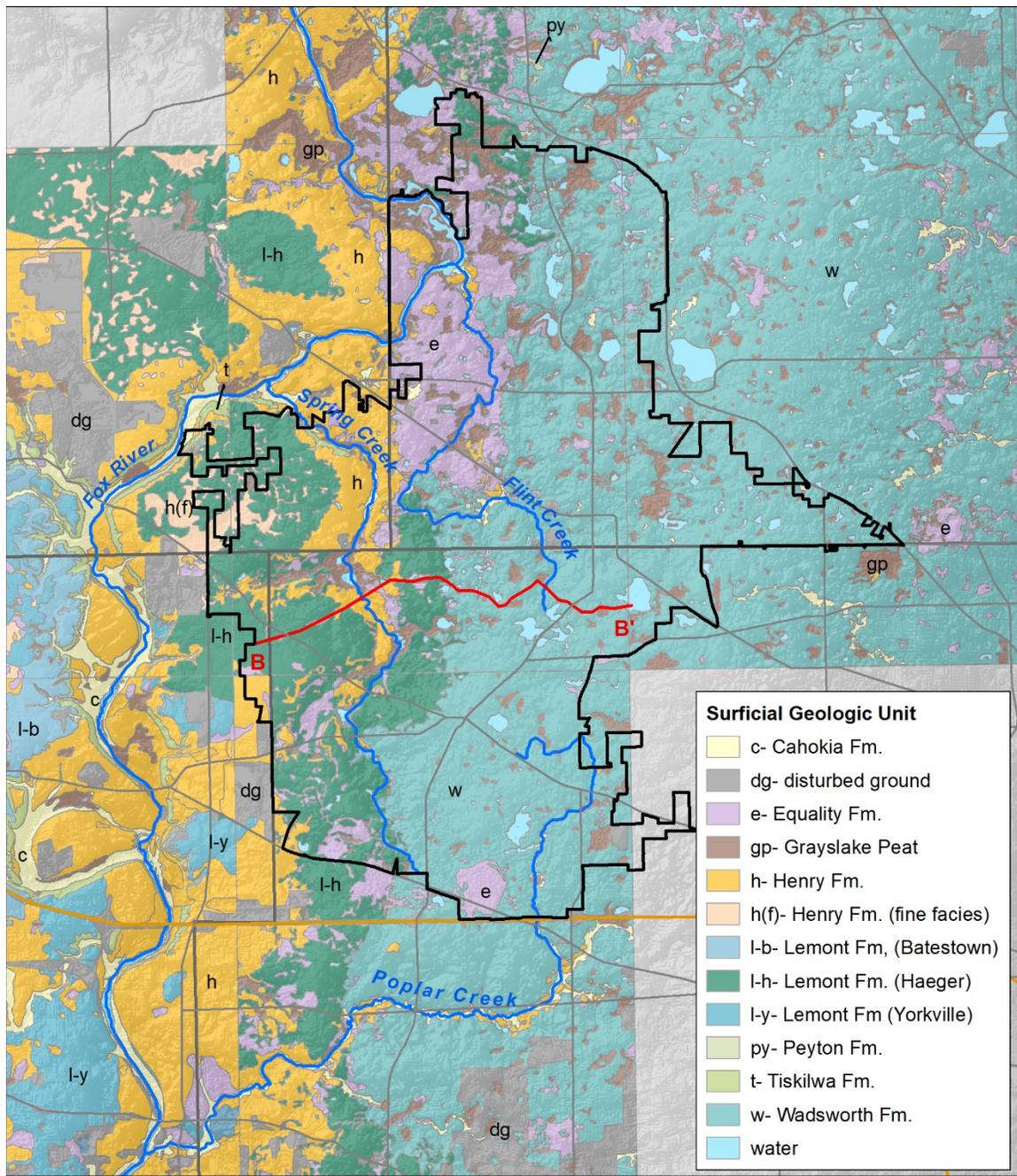
Formations (Figure 2). The Equality and Wadsworth Formations consist of clays and silts deposited in glacial lake environments and tills deposited in subglacial environments, respectively. Both formations are major aquitards that limit recharge to the underlying sands and gravels, although there are isolated lenses of sand and gravel in the Wadsworth Formation. Thus, in the eastern BACOG area, the Henry Formation is confined and is much less sensitive to contamination.

The Henry Formation is not laterally continuous and has variations in permeability. This formation is actually composed of several glacial tongues (a part of a geological unit that extends past its main body) that may be separated by lenses of the Tiskilwa Formation (Figure 2). The Tiskilwa Formation is predominantly composed of till but may have isolated pockets of sand and gravel. Wells open to the Henry Formation have varying well screen lengths and may be open only to specific lenses of the formation; therefore, private and public wells may have a range of productivity.

The bedrock units underlying the surficial glacial deposits consist of Silurian dolomite and the Maquoketa shale (Figure 4). The Silurian dolomite is fractured and weathered near the bedrock surface, and thus serves as an important aquifer for domestic and municipal use. Where the Silurian dolomite is eroded, the Maquoketa shale is present at the bedrock surface. However, the Maquoketa shale is an aquitard and is rarely used for water supply. In the BACOG study area, the Barrington 1, Barrington 2, and Tower Lake 5 wells are open to the Silurian dolomite. Most municipal wells in the surrounding BACOG area withdraw from either the Silurian dolomite or are open to the Galena-Platteville dolomite that underlies the Maquoketa shale.

Water Use in the BACOG Region

Municipalities and private homeowners within and around the BACOG region are highly dependent on groundwater for water supply. Outside of the BACOG region, communities also use water from Lake Michigan, the Fox River, and deeper sandstone aquifers (Figure 5). The BACOG region is unusual in that North Barrington, Barrington Hills, South Barrington, Lake Barrington, and Deer Park do not have central municipal water systems. Instead, the population of those communities is reliant upon individual private wells that use the shallow sand and gravel aquifer and the shallow bedrock systems. Only the communities of Barrington and Tower Lakes have central municipal systems that use the sand and gravel and shallow bedrock systems. An inventory of wells conducted by BACOG in 2015 indicated that there were more than 7,480 wells in the BACOG study area, of which only a few were municipal or community subdivision wells. The population of the BACOG area is around 38,000 people, and only around 11,300 of them are served by municipal water supplies. This indicates that more than 70 percent of BACOG residents rely on private wells.



Explanation

BACOG Boundary — Geologic Cross Section
 County Boundary Quadrangle Data Unavailable
— Major Stream/River

Figure 1: Surficial geologic map of the BACOG study area and surrounding region representing type of glacial material at the land surface. Map was compiled by the Illinois State Geological Survey (ISGS) by merging several quadrangle maps. Refer to Thomason and Barnhardt (2007) for more detailed surficial unit descriptions. Cross section B-B' is depicted in Figure 2. Note where the Henry Formation (sand and gravel aquifer) is at land surface and exposed along the major streams and the Fox River. Detailed geologic maps are unavailable for the Palatine quadrangle (to the southeast of the study area) and the McHenry quadrangle (to the northwest of the study area).

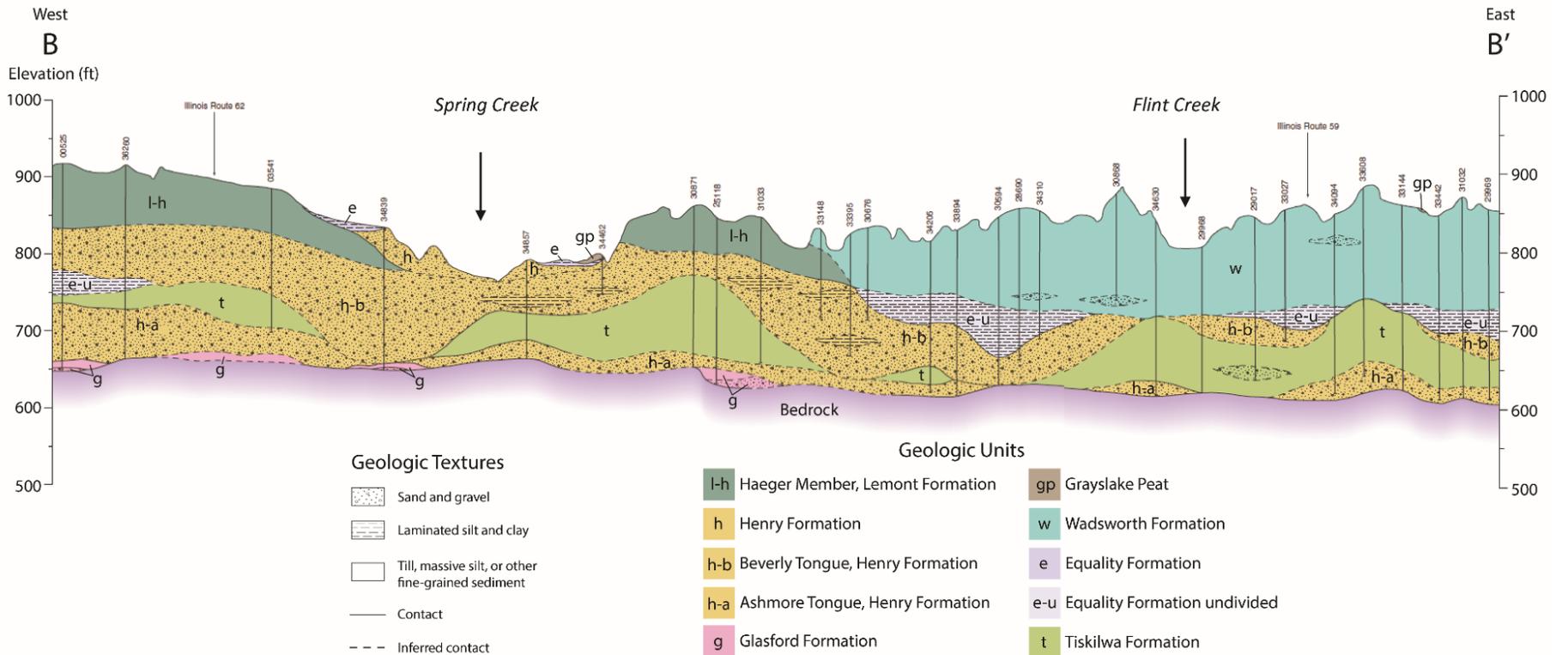
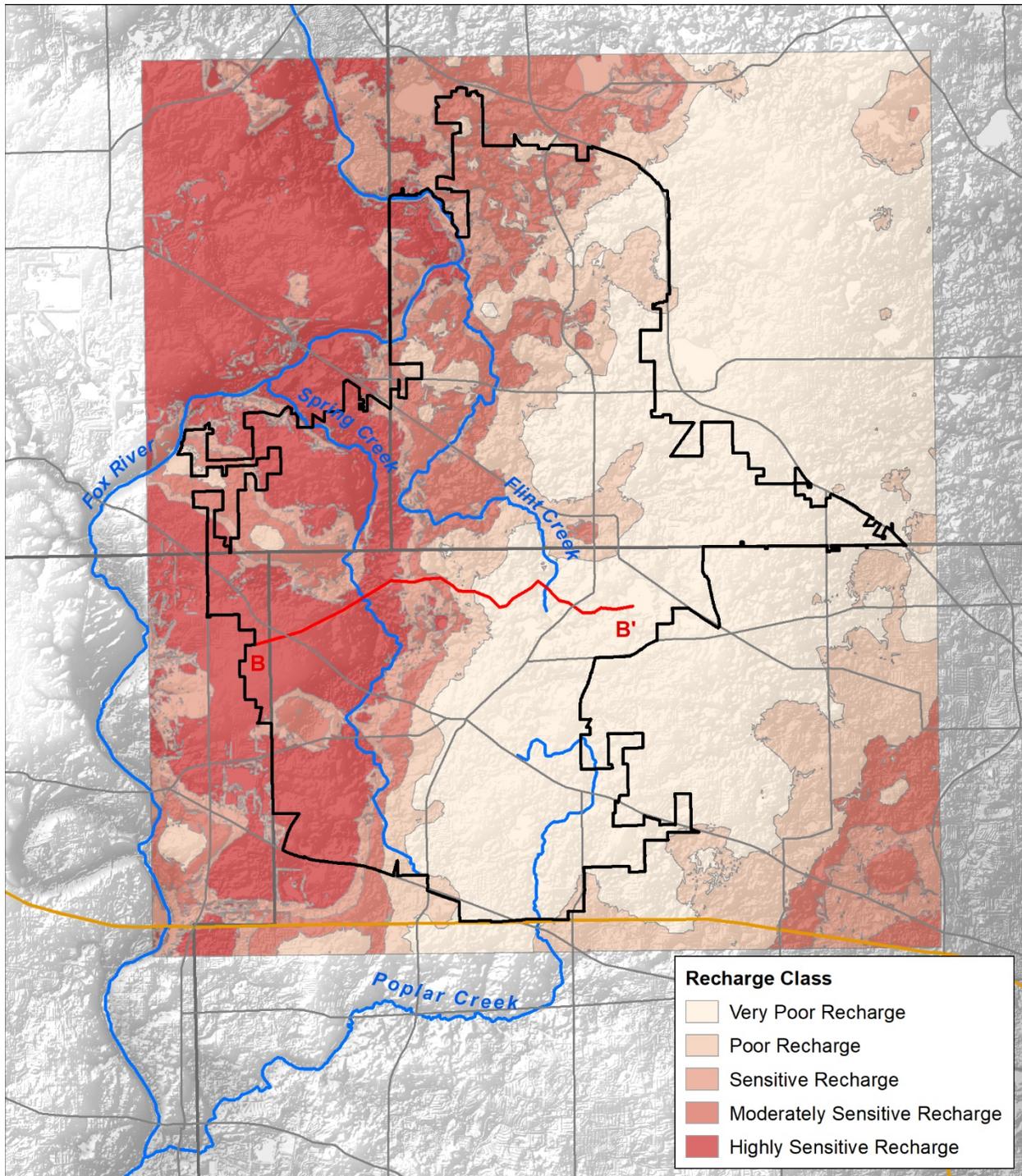


Figure 2: Generalized cross section of surficial (glacial) deposits in the BACOG study area from west to east. Cross section modified from Thomason and Barnhardt (2007). Refer to Figure 1 for location of cross-section.



Explanation

- BACOG Boundary
- County Boundary
- Major Stream/River
- Geologic Cross Section

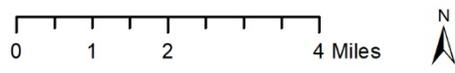
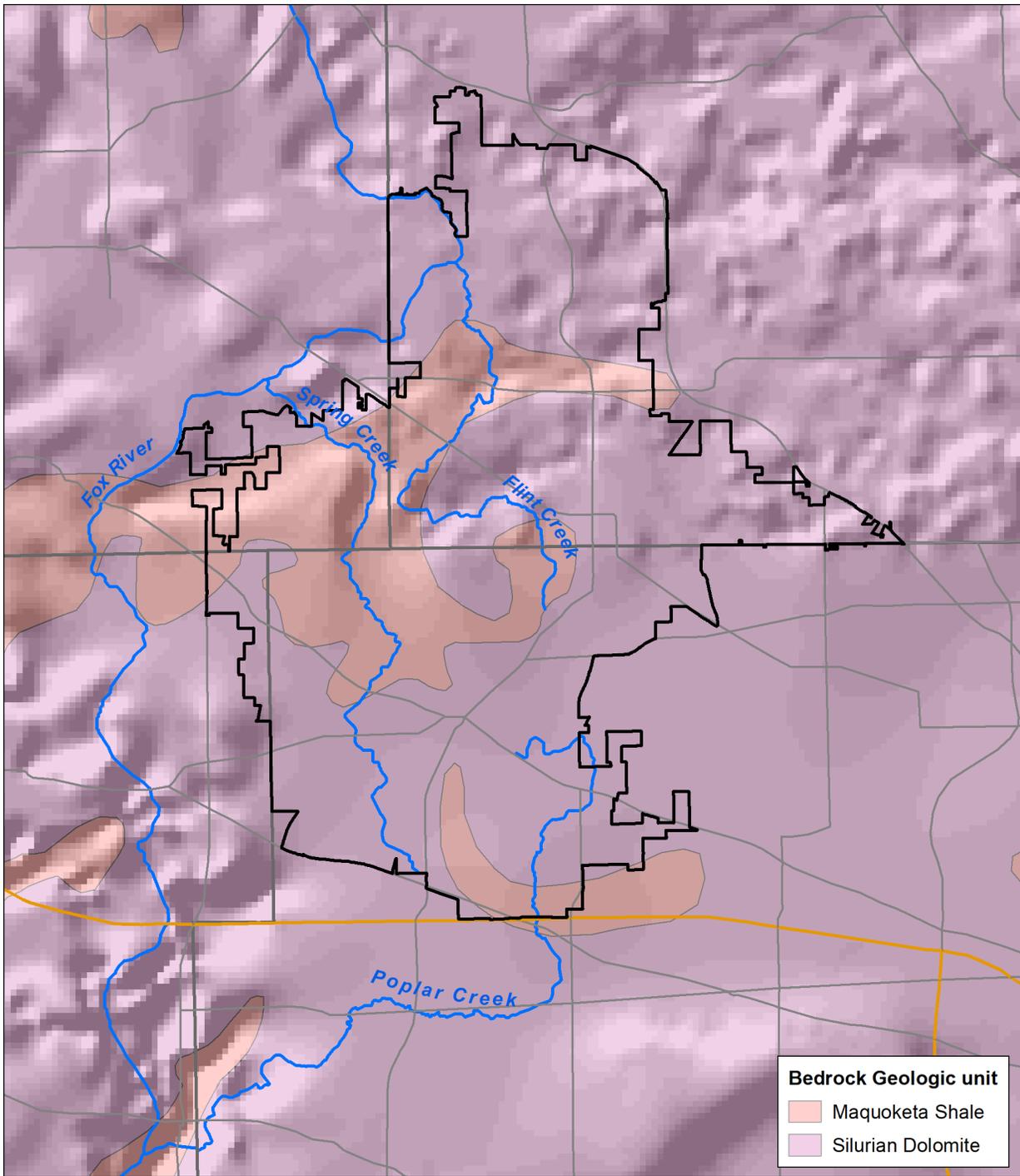


Figure 3: Aquifer sensitivity map modified from Thomsen (2015). Note that high sensitivity (high recharge) in the western BACOG study area corresponds to where the Henry Formation and Haeger Member of the Lemont Formation are at the land surface (refer to Figure 1).



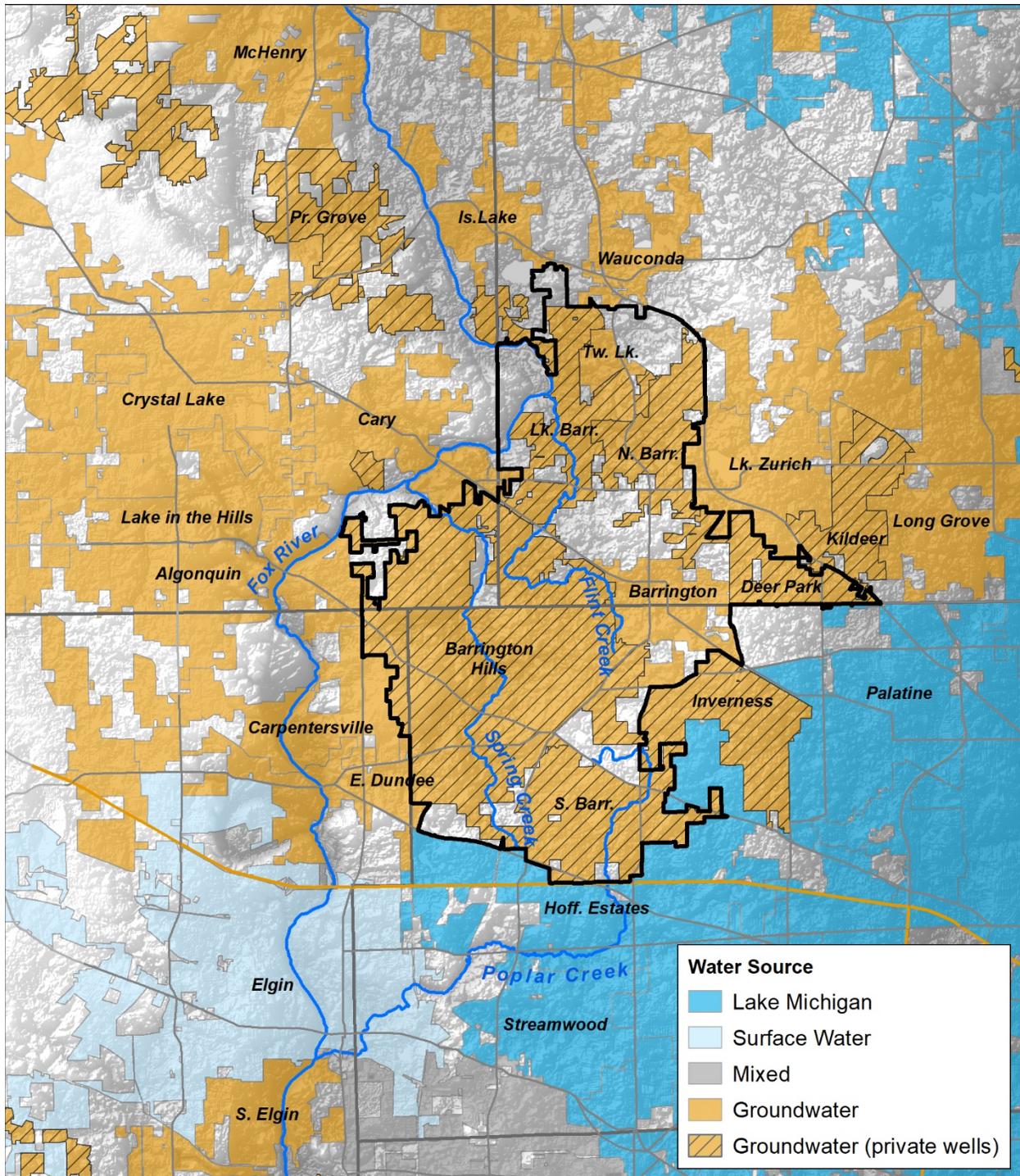
Explanation

- BACOG Boundary
- Major Stream/River
- County Boundary

Figure 4: Bedrock geologic map of the BACOG study region, modified from Kolata (2005). Background shading represents the topography of the underlying bedrock surface, not land surface. Rivers and streams depicted are meant to serve as a locational reference, not to indicate stream connections with the underlying bedrock.

BACOG Monitoring Program

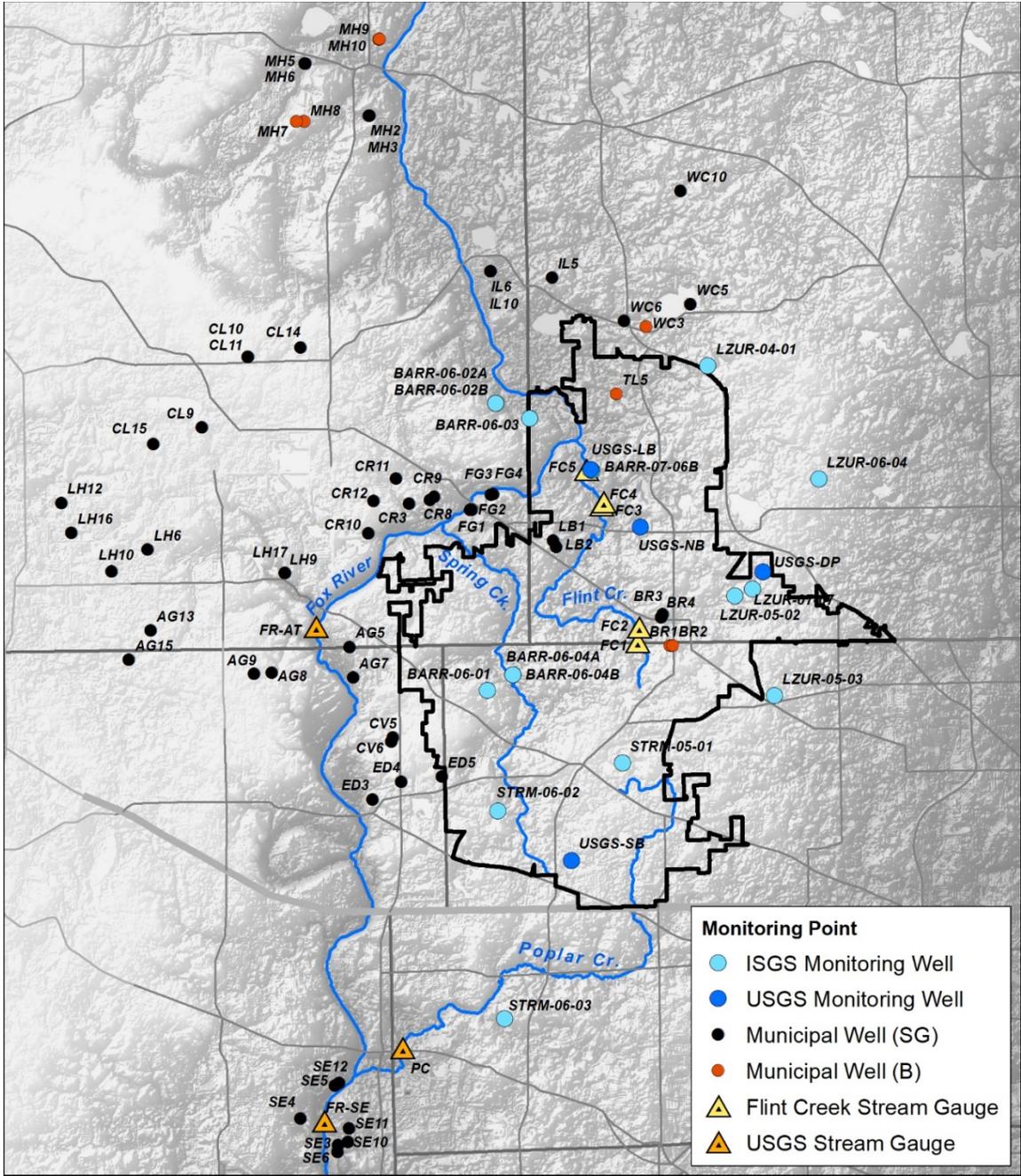
Since 2014, BACOG has funded and maintained a groundwater monitoring program that consists of continuously monitored wells (operated by the United States Geological Survey [USGS]), and Illinois State Geological Survey (ISGS) monitoring wells that are measured periodically by various agencies (Table 1, Figure 6). BACOG also supports a surface water monitoring program that consists of five streamgages owned by the Flint Creek Watershed Partnership on Flint Creek that measure stage (Table 1, Figure 6). In addition to the groundwater and surface water monitoring programs, BACOG also initiates and manages a mass measurement of water levels in municipal wells within and surrounding the BACOG region (Table 2, Figure 6). This mass measurement occurs in early to mid-July of each year and consists of water operators reporting water levels to BACOG for inclusion in a database. From 2014 to 2016, water operators at these facilities measured water levels under pumping conditions. However, water operators did not record pumping rates of the measured wells nor the length of time that the well was on prior to the measurement. This makes it difficult to compare water levels between years since pumping rates and duration can vary greatly at the time of measurement. To reduce uncertainty and to have a protocol in which a standard can be adhered to year after year, BACOG requested that water operators take static water level measurements instead of pumping levels during the measurement period on the advice of the Illinois State Water Survey (ISWS). This new protocol was enacted in 2017. During these municipal mass measurements, all ISGS monitoring wells are visited and measured with an electric dropline. Water levels in the USGS monitoring wells are also recorded from the USGS website at noon during the day that most municipal water levels are measured, and measurements from the Flint Creek streamgages are also recorded at noon on that day.



Explanation

- BACOG Boundary
- Major Stream/River
- County Boundary

Figure 5: Map of water use in the BACOG area and surrounding region, indicating the dominant source of water used by each municipality. Areas outside of municipal boundaries (not colored) are unincorporated areas and are assumed to have a private well (groundwater) source. Figure modified from Hadley (2017).



Explanation

- BACOG Boundary
- County Boundary
- Major Stream/River

- Monitoring Point**
- ISGS Monitoring Well
 - USGS Monitoring Well
 - Municipal Well (SG)
 - Municipal Well (B)
 - ▲ Flint Creek Stream Gauge
 - ▲ USGS Stream Gauge

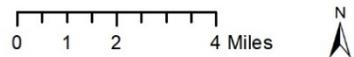


Figure 6: Map of monitoring wells, streamgages, and municipal wells used for July mass measurements in the BACOG study area and surrounding region. Municipal Wells: AG-Algonquin, BR-Barrington, CL-Crystal Lake, CR-Cary, CV-Carpentersville, ED-East Dundee, FG-Fox River Grove, IL-Island Lake, LB-Lake Barrington, LH-Lake in the Hills, MC-McHenry, SE-South Elgin, TL-Tower Lakes, WC-Wauconda. Streamgages: PC-Poplar Creek, FR-SE- Fox River at South Elgin, FR-AT- Fox River at Algonquin Tailwater, FC-Flint Creek. Black dots (SG) refer to wells that withdraw from “sand and gravel,” while red dots (B) refer to wells open to the “shallow bedrock” (similar to nomenclature in Table 2).

Table 1: List of monitoring wells within and surrounding the BACOG study area and July water level measurements during the study period (2014–2019).

Owner	Monitoring Well Name	Water Level Elevation (ft AMSL)						Change 2014-2019
		2014	2015	2016	2017	2018	2019	
ISGS	BARR-06-01	770.79	772.59	776.31	775.76	778.51	783.47	12.68
ISGS	BARR-06-02A	735.54	734.94	734.58	736.7	735.99	736.58	1.04
ISGS	BARR-06-02B	750.85	750.18	750.53	752.21	753.43	752.64	1.79
ISGS	BARR-06-03 ¹	-	775.81	-	741.3	742.60	743.27	-
ISGS	BARR-06-04A	774.03	775.81	773.13	778.14	779.20	779.20	5.17
ISGS	BARR-06-04B	-	770.55	-	771.34	771.66	771.79	-
ISGS	BARR-07-06B	743.67	743.71	745.27	744.69	-	745.57	1.90
ISGS	LZUR-04-01	746.17	746.44	749.59	748.31	748.81	750.52	4.35
ISGS	LZUR-05-02 ²	788.67	782.06	779.30	771.85	767.69	763.98	-
ISGS	LZUR-05-03	729.33	-	-	728.71	732.23	738.56	9.23
ISGS	LZUR-06-04	717.05	716.83	-	718.24	718.59	723.37	6.32
ISGS	LZUR-07-07	727.23	729.16	732.72	729.89	731.75	737.51	10.28
ISGS	STRM-05-01 ³	748.33	749.17	747.94	747.89	-	-	-
ISGS	STRM-06-02	808.45	808.84	-	811.03	813.56	814.44	5.99
ISGS	STRM-06-03	765.86	766.11	765.78	767.06	767.31	768.53	2.67
USGS	Lake Barrington	743.98	743.96	743.49	746.82	746.5	746.83	2.85
USGS	North Barrington	738.34	739.85	741.47	741.87	743.19	746.45	8.11
USGS	Deer Park ⁴	723.16	725.48	726.82	-	-	-	-
USGS	South Barrington ⁵	-	-	770.33	769.08	771.63	774.7	-
Average water level change								5.57

1. Anomalous 2015 water level elevation not used in generating 2015 potentiometric surface

2. No data included in generating potentiometric surfaces due to potential casing failure and anomalous water levels

3. Well sealed in 2018

4. Period of record ends in 2016

5. Period of record starts in 2016

Table 2: List of municipal wells within and surrounding the BACOG study area and water level measurements taken in July of each year during the study period (2014–2019). Table 2 continues on the next page.

Municipal Well Name	Well Type ¹	Water Level Elevation (ft AMSL)						Change 2014-2016	Change 2017-2019	Change 2014-2019
		Pumping			Static					
		2014	2015	2016	2017	2018	2019			
ALGONQUIN 5	SG	762	759	767	753	751	745	5	-8	-17
ALGONQUIN 7	SG	700	699	702	696	690	690	2	-6	-10
ALGONQUIN 8	SG	818	832	832	824	824	824	14	0	6
ALGONQUIN 9	SG	837	844	850	837	835	835	13	-2	-2
ALGONQUIN 13	SG	835	818	817	819	801	805	-18	-14	-30
ALGONQUIN 15	SG	842	NA	854	830	834	832	12	2	-10
BARRINGTON 1	B	702	726	726	744	749	742	-	-	-
BARRINGTON 2	B	-	-	-	-	-	-	-	-	-
BARRINGTON 3	SG	-	-	-	-	-	-	-	-	-
BARRINGTON 4	SG	-	714	716	736	737	739	-	3	-
CARPENTERSVILLE 5	SG	767	767	762	768	768	772	-5	4	5
CARPENTERSVILLE 6	SG	752	765	752	765	765	769	0	4	17
CARY 3	SG	781	791	778	803	804	804	-3	1	23
CARY 8	SG	713	714	715	741	740	736	2	-5	23
CARY 9	SG	700	701	693	745	753	749	-7	4	49
CARY 10	SG	787	789	789	821	821	821	2	0	34
CARY 11	SG	804	805	804	818	820	819	0	1	15
CARY 12	SG	811	810	809	822	822	823	-2	1	12
CRYSTAL LAKE 9	SG	755	743	747	787	781	790	-8	3	35
CRYSTAL LAKE 10	SG	792	794	801	822	819	826	9	4	34
CRYSTAL LAKE 11	SG	804	805	815	826	815	822	11	-4	18
CRYSTAL LAKE 14	SG	795	778	783	822	818	829	-12	7	34
CRYSTAL LAKE 15	SG	875	862	861	886	881	882	-14	-4	7
EAST DUNDEE 3	SG	-	-	-	792	761	773	-	-19	-
EAST DUNDEE 4	SG	-	-	-	826	763	771	-	-55	-
EAST DUNDEE 5	SG	-	-	-	769	743	736	-	-33	-
FOX RIVER GROVE 1	SG	721	-	724	-	741	732	3	-	11
FOX RIVER GROVE 2	SG	723	723	-	732	733	733	-	1	10
FOX RIVER GROVE 3	SG	-	-	701	-	-	-	-	-	-
FOX RIVER GROVE 4	SG	-	675	-	736	738	738	-	2	-
ISLAND LAKE 4-6*	SG	650	641	642	636	637	636	-	-	-
ISLAND LAKE 4-10*	SG	648	642	658	629	625	623	-	-	-
ISLAND LAKE 5	SG	720	716	720	761	761	753	0	-8	33
LAKE BARRINGTON 1	SG	741	725	764	768	776	776	23	8	35
LAKE BARRINGTON 2	SG	-	744	744	769	768	768	-	-1	-

1. SG- sand and gravel well, B- shallow bedrock well

* Well not included in calculations or generating potentiometric surfaces due to anomalous water levels

Table 2 (cont.): List of municipal wells within and surrounding the BACOG study area and water level measurements taken in July of each year during the study period (2014–2019).

Municipal Well Name	Well Type ¹	Water Level Elevation (ft AMSL)						Change 2014-2016	Change 2017-2019	Change 2014-2019
		Pumping			Static					
		2014	2015	2016	2017	2018	2019			
LAKE IN THE HILLS 6	SG	843	846		841	888	888	-	47	45
LAKE IN THE HILLS 9	SG	767	767	767	727	756	756	0	29	-11
LAKE IN THE HILLS 10	SG	855	851	855	828	869	864	0	36	9
LAKE IN THE HILLS 12	SG	809	814	816	804	865	863	7	59	54
LAKE IN THE HILLS 16	SG	822	826	824	812	866	866	2	54	44
LAKE IN THE HILLS 17	SG	727	729	729	713	776	777	2	64	50
MCHENRY 2	SG	735	735	733	747	748	747	-2	0	12
MCHENRY 3	SG	669	668	666	743	744	735	-3	-8	66
MCHENRY 5	SG	711	713	711	750	754	750	0	0	39
MCHENRY 6	SG	704	704	700	749		757	-4	8	53
MCHENRY 7	B	711	704	705	783	777	784	-	-	-
MCHENRY 8	B	787	719	746	777	784	786	-	-	-
MCHENRY 9	B	647	658	635	722	716	723	-	-	-
MCHENRY 10	B	611	612	609	669	664	670	-	-	-
SOUTH ELGIN 3	SG	677	686	686	686	690	688	9	2	11
SOUTH ELGIN 4	SG	735	762	764	705	706	708	29	3	-27
SOUTH ELGIN 5	SG	698	695	699	702	702	700	1	-2	2
SOUTH ELGIN 6	SG	687	-	689	687	693	686	2	-1	-1
SOUTH ELGIN 10	SG	683	684	694	675	683	681	11	6	-2
SOUTH ELGIN 11	SG	705	704	701	698	684	671	-4	-27	-34
SOUTH ELGIN 12	SG	649	641	651	704	702	695	2	-9	46
TOWER LAKES 5	B	693	693	693	693	690	689	0	-	-
WAUCONDA 3	B	650	650	653	748	749	750	3	-	-
WAUCONDA 5	SG	751	752	753	782	782	782	2	0	31
WAUCONDA 6	SG	717	716	717	746	747	748	0	2	31
WAUCONDA 10	SG	707	706	718	744	-	-	11	-	-
Average water level change in SG wells								2.2	3.2	17.9

1. SG- sand and gravel well, B- shallow bedrock well

* Well not included in calculations or generating potentiometric surfaces due to anomalous water levels

Methods (Data Analysis)

Municipal Water Use (IWIP)

The ISWS oversees an annual water use and withdrawals collection program called the Illinois Water Inventory Program (IWIP). IWIP reporting is mandatory for all facilities that are classified as Public Water Supply facilities (providing water for human consumption to at least 15 service connections or regularly serving an average of at least 25 people at least 60 days per year) or any facilities that own or operate “high-capacity” water wells or intakes. “High-capacity” is defined as a well or intake located on a parcel of property where the rate or capacity of water withdrawal of all wells and intakes on the property is equal to or in excess of 100,000 gallons during any 24-hour period (Water Use Act, 1983).

IWIP collects annual reports from qualified facilities after the close of the calendar year both via an online reporting system and paper reports submitted by mail. The IWIP database contains water use and withdrawals information by individual well or intake and facility beginning in 1979. The data are checked for quality by IWIP staff; however, it takes several years to finalize annual datasets due to incomplete reporting, lack of communication from facilities, or lack of IWIP funding. Thus, the IWIP data contained in this report have undergone quality control/quality assurance by IWIP staff up to the year 2015, but are “as reported” past 2015 as there has been limited post-processing of values submitted by facilities to correct outliers. It should also be noted that some communities simply have not submitted water use data for certain years or do not have those records in which to provide to the IWIP program.

Potentiometric Surface Development

We developed potentiometric surfaces of the shallow sand and gravel aquifer system (Henry Formation) for the years 2014–2019 using mass measurement data from municipal wells, ISGS and USGS monitoring wells, and stream elevation data. The potentiometric surfaces thus represent groundwater conditions in the shallow sand and gravel aquifer for early July of each year and should be considered a snapshot of groundwater conditions in the area at the time of measurement. Water levels change seasonally in response to precipitation events and climate patterns, and for municipal wells water levels may change significantly on an hourly basis in response to withdrawals at those wells. However, the potentiometric surface can give a general sense of groundwater conditions and flow directions.

As described earlier, the sand and gravel aquifer (Henry Formation) is at the land surface in certain areas in the study region. Where streams cut through the Henry Formation, we assume that there is a strong hydraulic connection between those streams and the aquifer. This hydraulic connection is present along the Fox River, the lower reach of Poplar Creek, the lower half of Spring Creek, and a small segment of Flint Creek (Figure 1). This assumption is supported by the fact that: 1) the hydrograph at USGS-Lake Barrington closely mimics the hydrograph at the FC-5 streamgage (Figure 7), and 2) there are very shallow or even artesian (flowing) water levels at BARR-06-04A & B (Supplemental Workbook 1) that are both around 500 feet from Spring Creek (Figure 1). We therefore included stream elevations in generating the potentiometric surfaces where this hydraulic connection is present by extracting elevation data along the stream segments that overlie the Henry Formation. Elevations from the National Hydrography Dataset

(NHD) were extracted using a suite of packages in Python (programming language) and then converted to point elevations in ArcGIS (USGS, 2020a). We used the same stream elevations for each of the yearly potentiometric surfaces because we found there to be minimal deviations between recorded stages at Flint Creek, Poplar Creek, and the Fox River during July compared to our extracted NHD elevations (Supplemental Figure 1).

Several municipal wells that have been measured over the study period are shallow bedrock wells (Table 2) and were not included as data points for the potentiometric surface, since the goal of this project was to develop surfaces only for the sand and gravel system. Two of the Island Lake wells (4-6 and 4-10) had unusually low water levels compared to Island Lake 5 and other municipal wells (Wauconda 5, Wauconda 6) that could be attributed to operator error or wells nearby running at the time of measurements. We did not include these data in our analyses. At Barrington 4, no measurement was taken in 2014, but this is one of the few municipal sand and gravel wells within the BACOG boundary and is important in controlling groundwater elevations. We therefore assigned the same value recorded in 2015 to the 2014 surface. We also noted the following anomalous water levels at the ISGS monitoring wells:

- LZUR-05-02 increased over 120 feet between 2006 and 2007 and has declined towards 2006 levels since the anomalous increase (Supplemental Workbook 1). This is likely due to a casing failure and may no longer represent a water level in the sand and gravel aquifer. We did not include any of these water levels in generating the potentiometric surfaces.
- A water level elevation of 775.61 was recorded by BACOG at BARR-06-03 for the year 2015, which is approximately 30 feet higher than any previous or subsequent measurements (Table 1 and Supplemental Workbook 1). We did not include this point to generate the 2015 potentiometric surface.
- A water level was not taken at STRM-06-02 for the year 2016. However, this point is within a recharge area and is important in controlling elevations when generating the potentiometric surfaces. Water levels have also remained relatively the same throughout the study period (Table 1), and its location in a sparsely populated area surrounded by forest preserves ensures little outside influence of withdrawals. We therefore averaged the 2015 and 2017 elevations and included this value to generate the 2016 potentiometric surface.

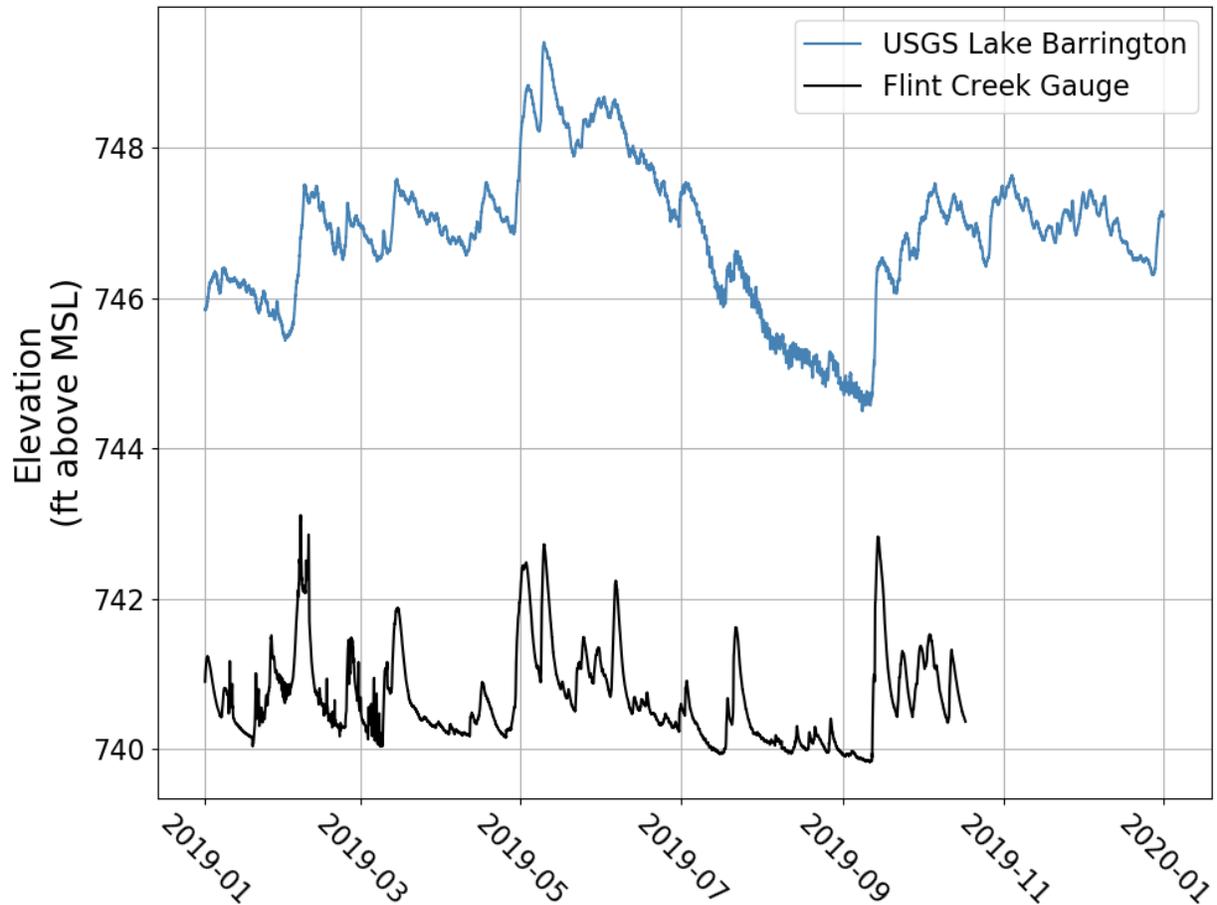


Figure 7: Hydrograph illustrating the connection between Flint Creek (black line) and the surficial aquifer monitored at the USGS Lake Barrington groundwater monitoring well (blue line).

Once groundwater and surface water elevation data were compiled and corrected for any anomalies, we used the *Topo to Raster* interpolation technique in ArcGIS to develop the July potentiometric surfaces. We used this particular interpolation technique because it is specifically designed to create hydrologically correct digital elevation models that adhere to drainage networks (Hutchinson, 1989), can be used effectively with variable densities of data points, and overall creates a surface that mimics realistic topography. Water levels in the shallow sand and gravel system are topographically controlled to some degree where the aquifer is at the land surface and where there is a direct hydraulic connection to streams. This interpolation technique also creates a surface that passes through the measured water level elevations, as opposed to a kriging interpolation technique that may pass above or below a measured point. Because the generated surface passes through the data points, high and low water levels become very apparent, whereas a kriging technique may smooth these out.

We used the *Minus* tool in ArcGIS’s spatial analyst toolbox to create surfaces that represent water level changes from year to year. We should note that the previous BACOG report (Thomsen, 2015) produced a potentiometric surface for 2014; however, we did not use this surface in generating change maps because we do not have the complete raster surface and the footprint is different from the surfaces generated for this report. Instead, we re-created the 2014 surface using the same *Topo to Raster* interpolation technique and subtracted that from

subsequent years. Because the measurement protocol for municipal wells changed from pumping levels to static levels, we report on changes in the potentiometric surface from 2014 to 2016 (when municipalities reported pumping levels) and from 2017 to 2019 (when municipalities reported static levels). We also report on an overall change from 2014 to 2019 but note where this change in protocol influences the results.

USGS Groundwater Hydrographs

Three USGS groundwater monitoring wells are currently active in the BACOG area: North Barrington, Lake Barrington, and South Barrington (Table 1). A monitoring well was previously installed at Deer Park, and there is a period of record from June 2014 to July 2016. The equipment was transferred to the South Barrington site in July 2016. Several months of data are missing after the relocation because of an equipment malfunction until it was serviced in December 2016. The South Barrington period of record is from Dec. 2016 to the present. Both North and Lake Barrington sites have observational records of June 2014 until the present. All available data (June 2014 to January 2020) were downloaded via the USGS National Water Information System (NWIS) for these groundwater monitoring stations (USGS, 2020b).

Daily records of precipitation were obtained from a National Oceanic and Atmospheric Administration (NOAA) climate station in the BACOG area (NOAA, 2020). The observations obtained from NOAA spanned from July 8, 2009 to January 1, 2020. This precipitation gage was assumed to best represent precipitation conditions in the BACOG area.

The precipitation time series and groundwater hydrographs were trimmed to the same length of time and graphically compared with one another to discern the relative impact of precipitation on groundwater in the BACOG area.

Analysis of Baseflow at USGS Gaging Stations

We employed the USGS PART method (Rutledge, 1998) to analyze the baseflow contributions at USGS streamgaging stations on the Fox River (Tailwater) at Algonquin, IL (site ID: 05550001), the Fox River at South Elgin, IL (site ID: 05551000), and on Poplar Creek at Elgin, IL (site ID: 05550500). For each site, daily average streamflow discharges from January 2010 to January 2020 were obtained from the USGS NWIS online database (USGS, 2020c).

The PART method estimates average baseflow discharge from a long record of daily streamflow data (ideally a year or longer). The PART method estimates baseflow by establishing periods of streamflow recession (i.e., no major runoff), setting those equal to baseflow, and interpolating them together through/beneath storm periods (Rutledge, 1998). Although the PART method estimates baseflow on a daily timescale, “results should be reported at a larger time scale (at least a month but preferably longer)” and daily results are “provided for generating graphics but should not be used quantitatively” (Rutledge, 2007). Thus, our analysis reports quarterly (i.e., every three-month) estimates of baseflow calculated using the PART method.

Furthermore, to determine whether baseflow conditions were increasing, decreasing, or remaining constant throughout the period of record, we performed a Seasonal Mann-Kendall (SMK) analysis on each site’s baseflow estimates (Hirsch et al., 1982). The SMK analysis removes the impact of seasonal cycles on the data to examine the underlying trends within the data (Hirsch et al., 1982).

Results/Discussion

Municipal Water Use in the Sand and Gravel and Shallow Bedrock Aquifers

We compiled the total annual withdrawals reported by each IWIP facility and separated the reported values by aquifer classification for the years 2005–2018. Figure 8 shows annual withdrawals summed over the region of study and classified by withdrawals from sand and gravel aquifers or shallow bedrock aquifers. Total annual reported withdrawals from the sand and gravel aquifers steadily declined from 16 million gallons per day (mgd) in 2005 to around 13 mgd in 2018. Reported total withdrawals from the shallow bedrock aquifer were generally a quarter less than sand and gravel withdrawals and did not change significantly from year to year. For individual plots depicting total annual withdrawals reported from each facility separated by aquifer class, refer to Appendix B.

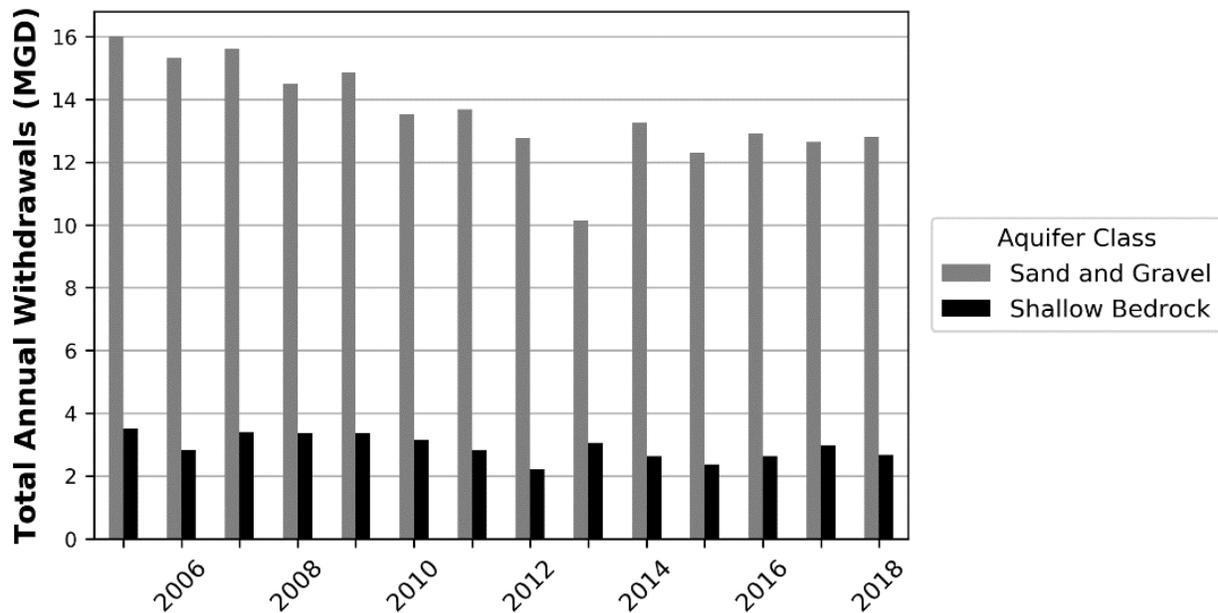


Figure 8: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at municipalities within and surrounding the BACOG study area. Values are the reported values from each municipality received through IWIP. For a complete list of included communities, refer to Appendix B.

Potentiometric Surfaces of the Sand and Gravel Aquifer

Figure 9 shows the potentiometric surface for July 2019 (see Appendix A for the 2014, 2015, 2016, 2017, and 2018 surfaces). There is a potentiometric high in the southwestern BACOG area that extends south towards Poplar Creek and STRM-06-03. From this potentiometric high, groundwater flows either west towards the Fox River where it discharges, north towards Spring Creek where it discharges, or east towards the towns of Barrington, Lake Zurich, and Deer Park. The potentiometric high is most apparent at STRM-06-02. As noted in the previous BACOG report (Thomsen, 2015) and described earlier in this report, the western portion of the BACOG area is underlain by sandy material that allows for high recharge rates to

the sand and gravel aquifer. The numerous lakes in the Spring Creek watershed (Penny Road Pond, Galvin's Lake, and Mud/Spring Lake) were also reported to have similar elevations to nearby wells, thus indicating hydraulic connections and possible additional sources of recharge (Thomsen, 2015). Water levels are lower in the eastern half of the BACOG area, most notably at LZUR-06-05, LZUR-05-03, LZUR-07-07, and the USGS Deer Park well. These lower water levels likely occur because the sand and gravel aquifer is deeper in this region and overlain by a thick glacial till unit (Wadsworth Formation) that limits recharge to the system and creates confined conditions. In the northern portion of the region, water levels become higher (but to a lesser degree than the western BACOG area) near Wauconda and Island Lake, which is likely because the Wadsworth Formation is becoming thinner or absent [see Thomason and Barnhardt (2007), Cross-Section A], allowing higher rates of recharge to the sand and gravel aquifer.

West of the Fox River, water levels are high and follow a steep gradient down to the Fox River. The highest water levels are at Crystal Lake and Lake in the Hills. These high water levels (in comparison to the BACOG study area) simply reflect higher topographic elevations and higher stratigraphic elevations of the Henry Formation. The potentiometric surface also becomes more variable outside of the BACOG study area because of the influence of municipal wells. This variability is most apparent at Algonquin, Cary, Crystal Lake, and East Dundee where there are large head differences between wells. These differences could be attributed to wells not fully recovering after pumps are turned off prior to taking static measurements or wells nearby running while static water levels were being measured. We should note that data are sparse southeast and southwest of the BACOG area; therefore, we have less confidence in the accuracy of the potentiometric surfaces in those areas.

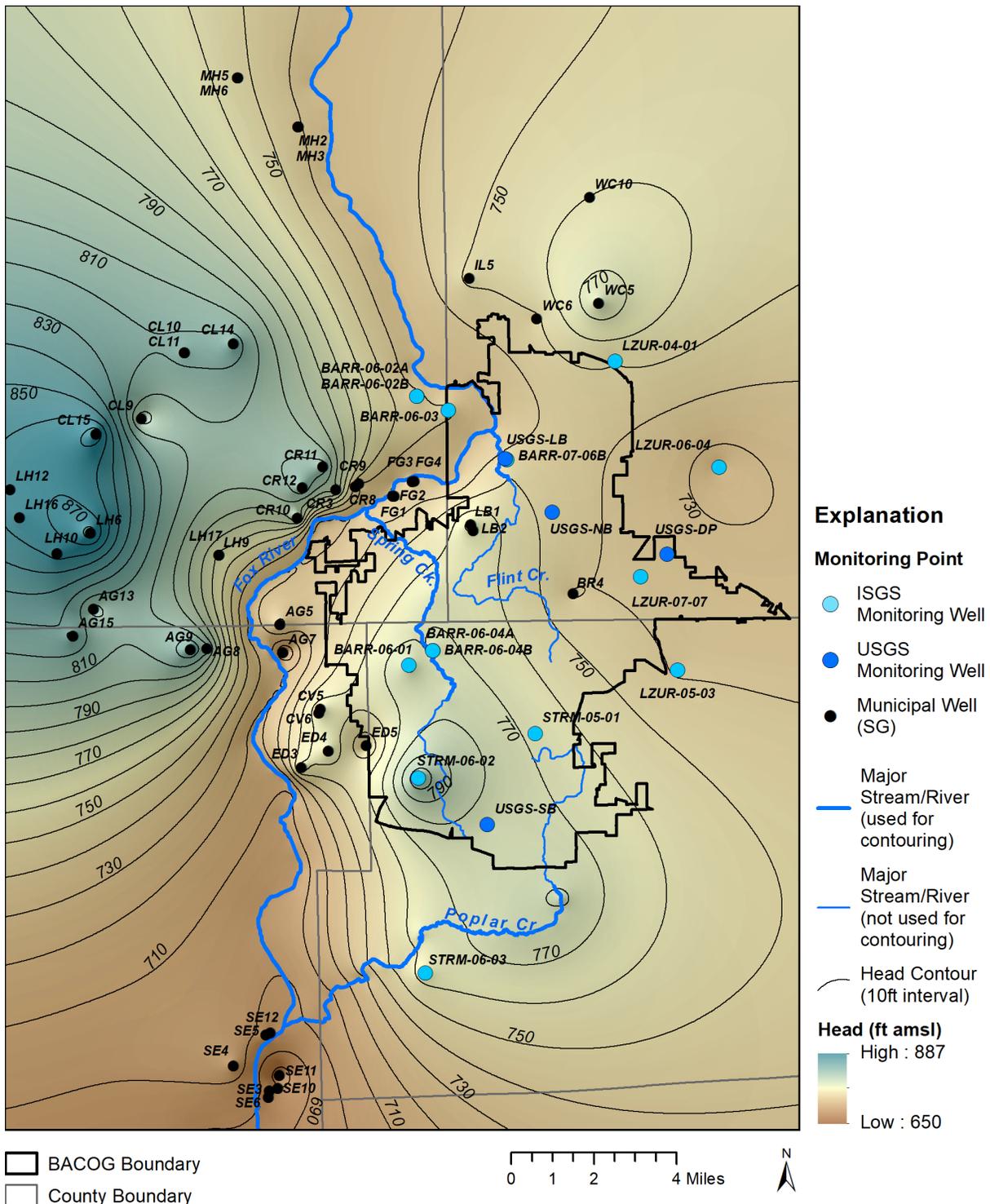


Figure 9: Potentiometric surface of the sand and gravel aquifer for the BACOG study area and surrounding region for July 2019. Note that stream elevations were used to generate the potentiometric surface where the streams are in direct hydraulic connection with the aquifer (bold blue lines).

Changing Water Levels at Monitoring Wells

Hydrographs at the USGS monitoring wells (North Barrington, South Barrington, Lake Barrington, and Deer Park) all show that groundwater levels are generally lowest during the late fall months and gradually increase during the winter and spring. Groundwater levels are typically highest in May and June (except at Lake Barrington, which is typically in July and August) and decline throughout the late summer and early fall months (Figure 10). All four hydrographs show increasing trends in groundwater elevations since 2014 when comparing seasonal lows and highs from year to year.

The hydrograph of the USGS Lake Barrington monitoring well indicates that the aquifer responds rapidly to precipitation events. For most large rainfall events there is almost a simultaneous increase in aquifer levels, indicating that there is rapid recharge at this location. This is unsurprising given that the sand and gravel is at the land surface and generally mirrors the streamflow hydrograph at Flint Creek (Figure 7). The hydrograph of the USGS North Barrington well is more subdued and responds seasonally to rainfall. This well has a deeper screened interval and is in a part of the aquifer that is overlain by the Wadsworth till and is thus confined. The hydrograph of the USGS South Barrington well shows a similar seasonal pattern as the North Barrington monitoring well, but there is an obvious influence of pumping nearby that causes steep drops in July with subsequent recovery in October. This pumping influence is likely caused by a high-capacity well(s) in the nearby area of which the ISWS is unaware. Hoffman Estates has two sand and gravel wells (Hoffman Estates 21 and 22) that are less than a mile to the southwest, but these are designated as emergency use and periodically withdraw very little water. The hydrograph of the USGS Deer Park well also showed a seasonal response in aquifer levels and arguably was the least responsive to rainfall events. The USGS Deer Park monitoring well was on the eastern edge of the BACOG study area where the Wadsworth till is thickest and thus has the weakest hydraulic connection to the land surface and the slowest recharge rates.

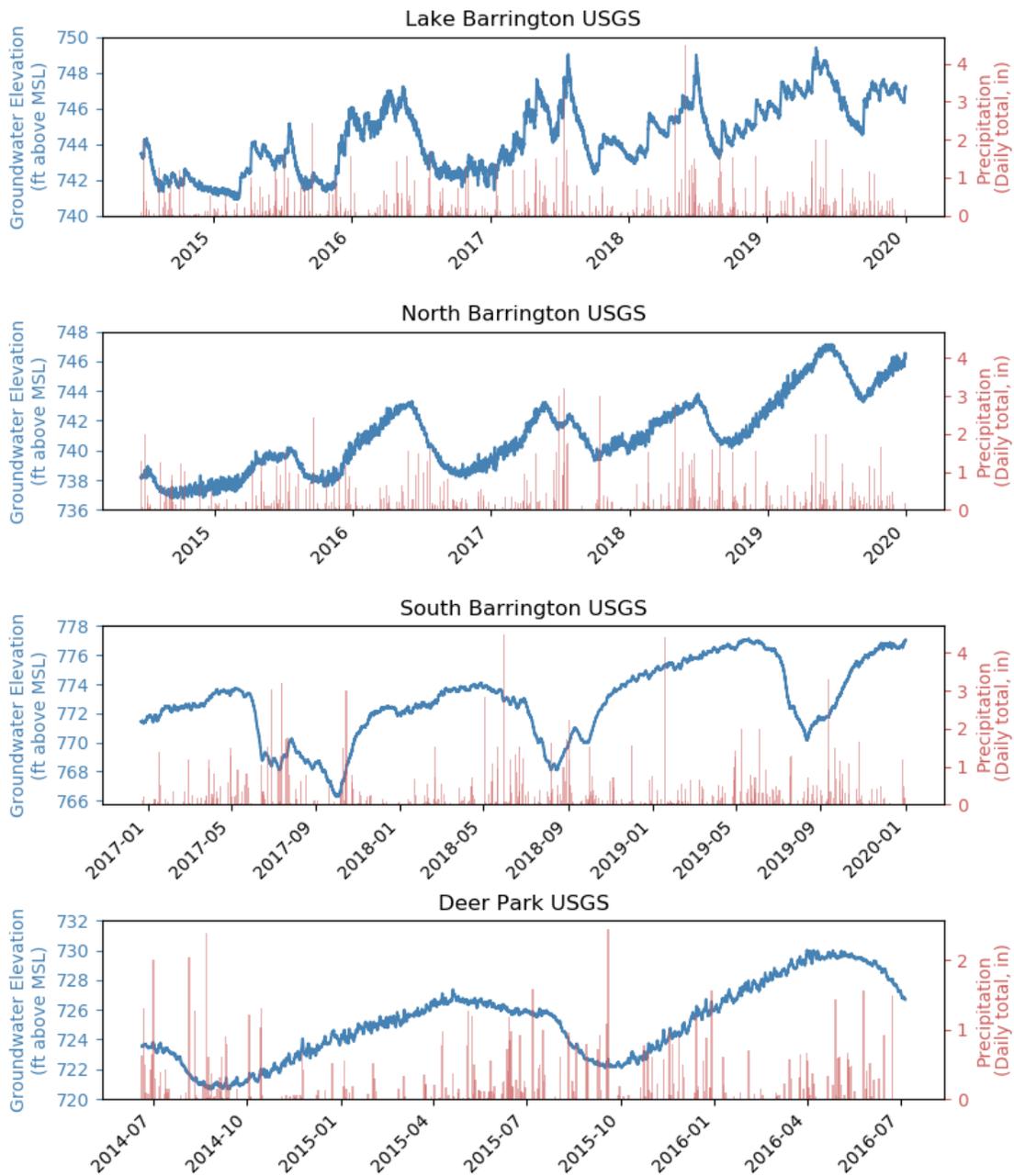


Figure 10: Groundwater hydrographs at the USGS monitoring wells in the BACOG study area and the influence of precipitation on groundwater levels. NOAA precipitation records are red vertical lines (right axis), while groundwater hydrographs are in blue (left axis). Note the variable date ranges on the horizontal axes.

Potentiometric Surface Changes

Water levels in the sand and gravel aquifer increased by several feet in the BACOG study region from 2014 to 2016, particularly in the eastern half of the study area (Figure 11). Water levels in the western half of the BACOG study area changed minimally from 2014 to 2016. There were no substantial changes at East Dundee, Carpentersville, or Algonquin. West of the Fox River, water level decreases were observed in many of the Lake in the Hills and Crystal Lake wells (Table 2). However, this may simply reflect variable pumping rates at the time of measurements in 2014 and 2016 (e.g., pumping rates may have been larger in 2016 compared to 2014). We should note that the largest increase shown in the potentiometric surface, at LZUR-06-04, is the result of insufficient data (there was no measurement in 2016) and interpolation at the edge of the study area. Minimal change was likely from 2014 to 2016 at that location.

Water levels continued to increase by several feet in the eastern BACOG study area from 2017 to 2019 (Figure 12). The potentiometric surface shows a large head increase at STRM-05-01, but this was another location that had missing data (in 2018 the well was abandoned), resulting in an interpolated surface that overrepresents the increase. There was likely a minimal head increase in this location. There were notable head decreases at East Dundee (particularly at East Dundee 4) and at the Algonquin wells east of the Fox River (Algonquin 5 and 7). These head declines could be due to increased usage (over an annual basis) to meet demands. However, East Dundee did not report to the IWIP program past 2011 (Appendix B, Figure B.6) so this can't be verified. West of the Fox River, head increases (under static conditions) were observed at all the Lake in the Hills wells.

Figure 13 represents the overall change in the potentiometric surface from 2014 to 2019; however, it should be noted that at municipal wells, the comparison is being made from pumping levels in 2014 to static levels in 2019. Thus, the magnitude of head increases observed at many of the Crystal Lake, Cary, Lake in the Hills, McHenry, and Wauconda wells are much larger than if the wells were measured consistently under static conditions since 2014. However, heads declined at many of the Algonquin and South Elgin wells from 2014 to 2019, despite wells being measured under pumping conditions in 2014 (Table 2). This could be attributed to operator error. In a large portion of the eastern BACOG study area, water levels increased by 10 to 20 feet (particularly around Barrington) and by several to 10 feet at many of the ISGS monitoring wells (LZUR-05-02, LZUR-06-04, LZUR-04-01, STRM-05-01) (Table 1). In the western portion of the study region, water levels increased at BARR-06-01 and STRM-06-02 by around 12 feet and 6 feet, respectively. On average, July water levels increased by 5.6 feet from 2014 to 2019 at the ISGS and USGS monitoring wells (Table 1), which is similar to increases at the North and South Barrington USGS monitoring wells in non-summer months (Figure 10). Lake Barrington also had a large water level increase, particularly at the Lake Barrington 1 well (Table 2).

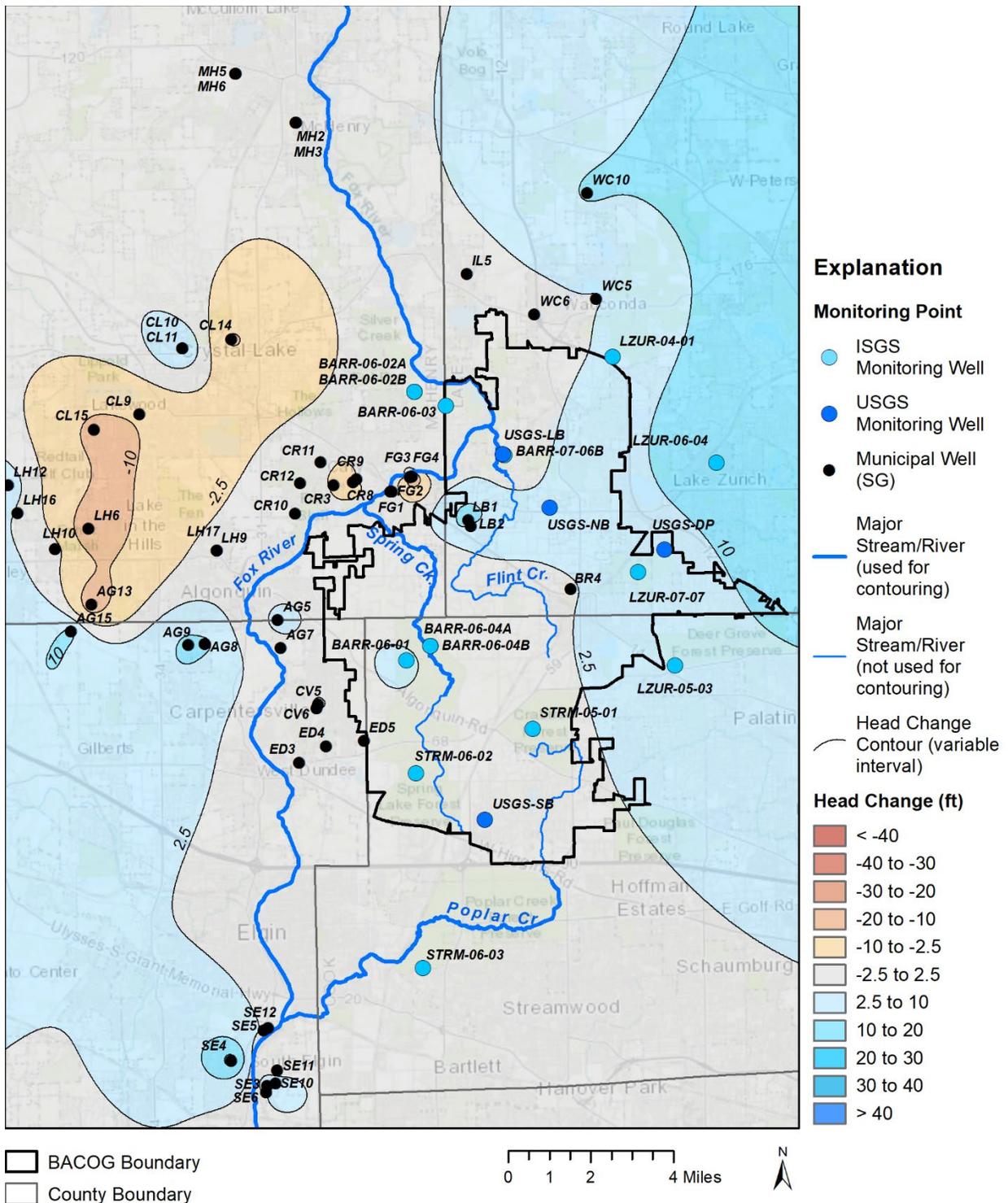


Figure 11: Map of water level change from July 2014 to July 2016 for the sand and gravel aquifer system in the BACOG study area and surrounding region.

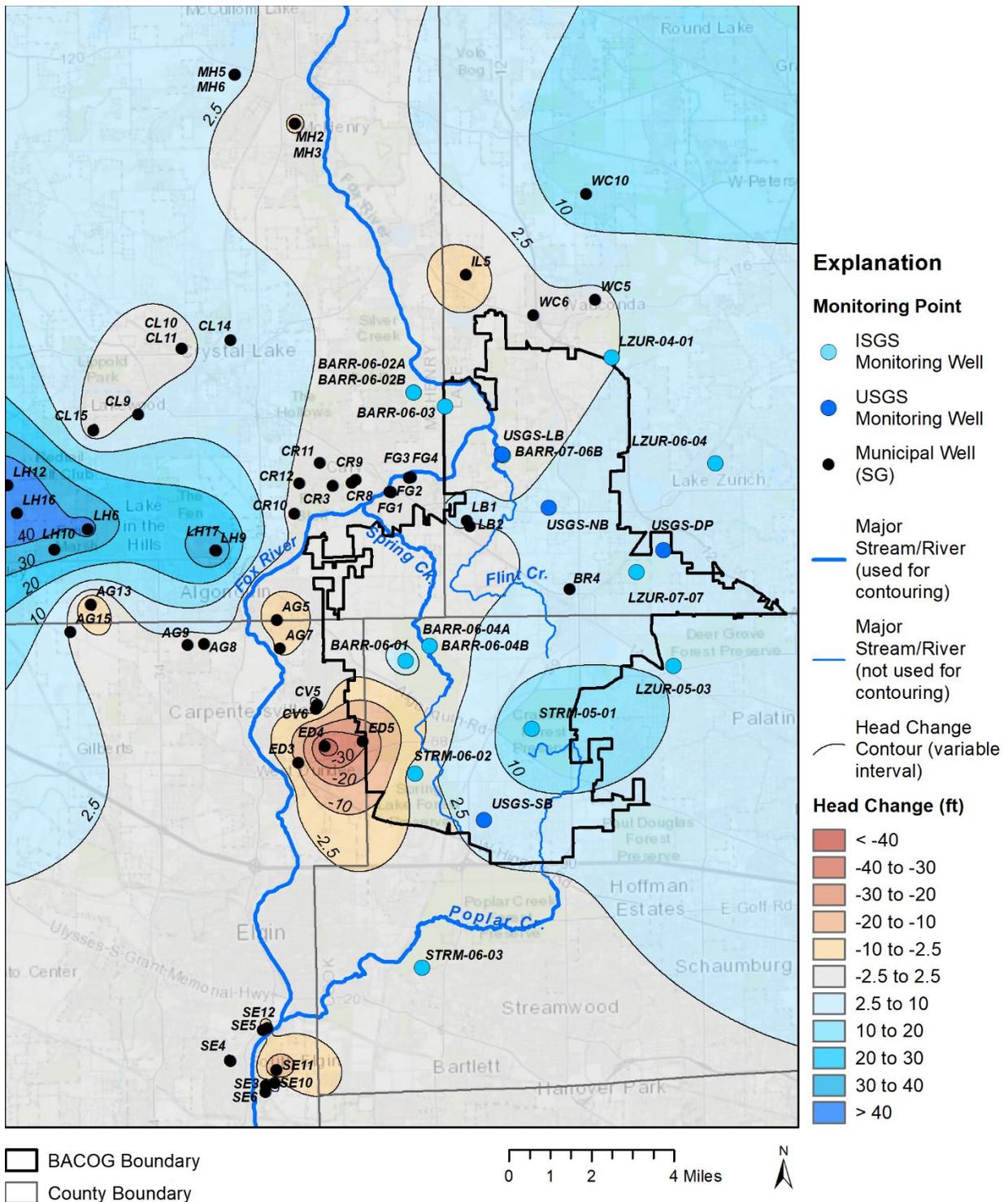


Figure 12: Map of water level change from July 2017 to July 2019 for the sand and gravel aquifer system in the BACOG study area and surrounding region.

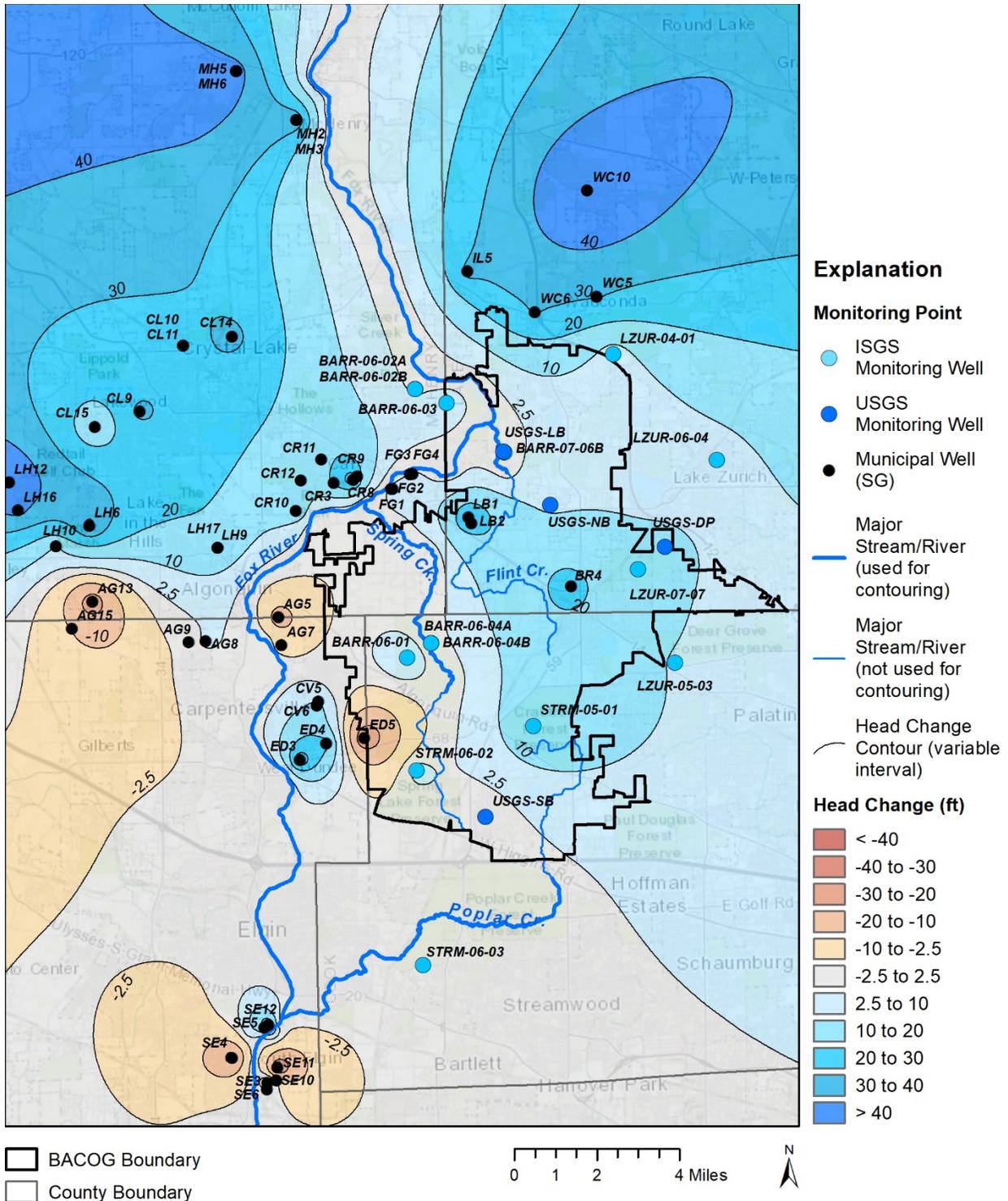


Figure 13: Map of water level change from July 2014 to July 2019 for the sand and gravel aquifer system in the BACOG study area and surrounding region. Note that at municipal wells, the comparison is being made from pumping levels in 2014 to static levels in 2019, and thus changes are likely much larger than if the wells were measured consistently under static conditions since 2014.

Streamflow and Baseflow Conditions

Quarterly estimates of baseflow from 2010 to 2020 calculated via the PART method are presented in Figure 14. The SMK analysis on these baseflow estimates resulted in a statistically significant increasing trend at all sites (Figure 14). Note, the SMK slope does not act as a predictor of baseflow changes over time like a linear regression; instead, it enables a relative comparison of trends between gaging stations (Hirsch et al., 1982).

There are several explanations for the observed increasing trend in baseflow. Rising groundwater levels in the BACOG region may have led to increased baseflow to the Fox River and Poplar Creek over the past decade. Alternatively, anthropogenic discharges (e.g., effluent) into surface waters could be increasing, and the PART algorithm may be unable to accurately distinguish baseflow from these anthropogenic discharges. Inaccurate partitioning of streamflow likely leads to overestimation of baseflow by the PART method. Thus, as streamflow increases over time on account of an increasing anthropogenic discharge, baseflow overestimation also likely increases and creates an apparent increasing trend in baseflow.

Analysis of the baseflow for the Fox River using the PART method has several limitations that should be noted. The drainage area for the Fox River sites are larger than the recommended drainage area size for the PART method. The discharge of the Fox River has also been heavily modified, whether by dams, lock and pool systems, or effluent discharge, all of which make accurate baseflow separation more difficult, if not impossible. Furthermore, the PART method is designed to estimate baseflow at gaging stations at the “downstream end of the basin, [which] measures all or most outflow” (Rutledge, 2007). Although this application may not have been the perfect fit for the PART method, we used this method because the previous study for BACOG did so (Thomsen, 2015). Our goal was to properly re-present the results of the PART analysis and explain its caveats to prevent misinterpretation of results from any regional baseflow analyses.

Shallow Bedrock Aquifer Water Levels

Only a few shallow bedrock water levels are measured at municipalities during the July mass measurements (Table 2). Therefore, it is difficult to make any definitive statements on the differences between shallow bedrock and sand and gravel water levels for the July months. At McHenry, water levels are about 40 feet higher in the McHenry 2 and 3 sand and gravel wells compared to the nearby shallow bedrock wells (McHenry 7 and 8) for 2017–2019. However, the Barrington 1 well (a shallow bedrock well) has water levels up to 10 feet higher than Barrington 4 (a sand and gravel well) (Table 2). Abrams et al. (2015) reported on a shallow bedrock potentiometric surface for Northeastern Illinois that was generated by combining water levels from 1990 to 2016. To give a general idea of how heads differ between aquifers in the BACOG study area, we subtracted the shallow bedrock potentiometric surface developed by Abrams et al. (2015) from the 2019 sand and gravel potentiometric surface (Figure 15). In general, water levels are higher in the sand and gravel aquifer in the BACOG region, near Crystal Lake and Lake in the Hills, and near Wauconda. Heads are calculated to be higher in the shallow bedrock aquifer northwest of McHenry, west of South Elgin, and south of Streamwood. However, there are no data points for the sand and gravel system in these areas, which creates a high degree of uncertainty in the sand and gravel potentiometric surface. We therefore hesitate to make any

definitive conclusions about head differences between the sand and gravel and shallow bedrock aquifers in these areas.

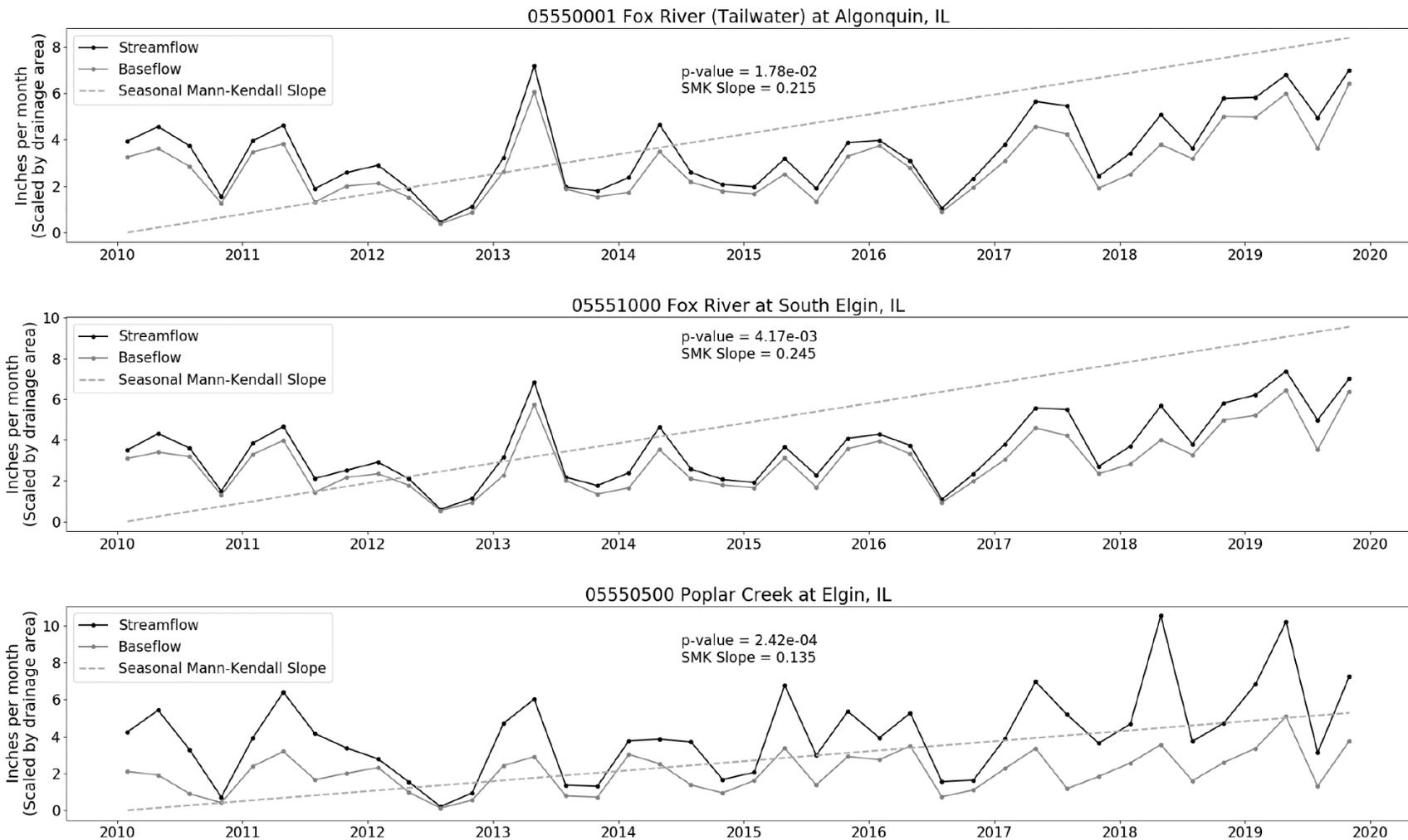


Figure 14: Quarterly estimates of baseflow for the Fox River and Poplar Creek between 2010 and 2020 calculated by the PART method. Baseflow estimates are scaled using the drainage area of the USGS streamgaging sites: 1,429.0 mi² at Fox River (Tailwater) at Algonquin, IL; 1,556.0 mi² at Fox River at South Elgin, IL; and 35.20 mi² at Poplar Creek at Elgin, IL (USGS, 2020c). All sites exhibit a statistically significant (i.e., p-value < 0.05) increasing (i.e., positive) Seasonal Mann-Kendall (SMK) trendline slope when their baseflow is analyzed over time. Note, SMK slope does not act as a predictor of baseflow changes over time like a linear regression, but rather enables a relative comparison of trends between gaging stations (Hirsch et al., 1982).

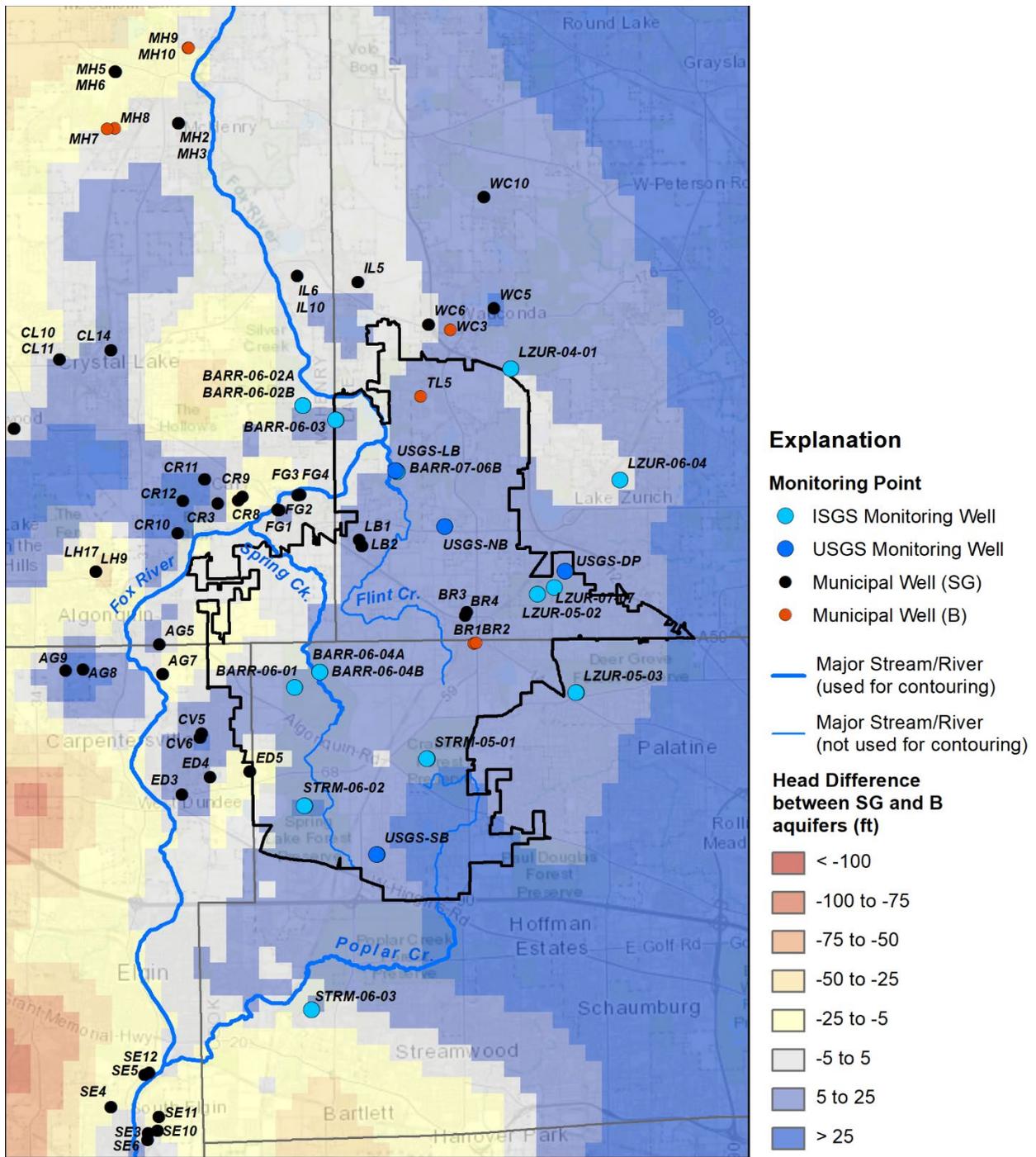


Figure 15: Map of head differences between the shallow bedrock potentiometric surface for northeastern Illinois (Abrams et al., 2015) and the 2019 sand and gravel potentiometric surface. A positive value (cool shades) indicates that water levels in the sand and gravel (SG) aquifer are higher than in the shallow bedrock (B) aquifer. Conversely, a negative value (warm shades) indicated where water levels in the sand and gravel aquifer are lower than water levels in the shallow bedrock aquifer. There is a large degree of uncertainty where data points are sparse, particularly in the northwest and southwest corners of the figure; therefore, results in these areas may be very inaccurate.

Conclusions and Recommendations

The Henry Formation serves as an important sand and gravel aquifer to the BACOG region and surrounding area for both municipal and domestic use. Water levels measured from 2014 to 2019 by BACOG, the ISWS, the ISGS, the USGS, and municipalities show that water levels in the sand and gravel aquifer system have increased over a five-year period. This conclusion is supported by the following:

- Hydrographs at the continuously monitored USGS wells show that water levels trended upward. All four hydrographs show a seasonal response in the aquifer in which water levels are lowest in the fall/early winter months and highest in the spring/early summer months. These seasonal peaks and lows from year to year can be compared. At the USGS North Barrington and Lake Barrington sites, water levels generally increased by around 5 feet over the five-year study period. At the USGS Deer Park and South Barrington sites, both of which have a shorter period of record, water levels increased by 2 to 3 feet.
- Measurements taken in July of each year at the ISGS monitoring wells also indicate that water levels in the sand and gravel aquifer are increasing. On average, water levels increased by 5.6 feet when comparing sites that were measured in both 2014 and 2019.
- The July mass measurements at municipal wells within and surrounding the BACOG region also show increasing water levels. From 2014 to 2016, when municipalities measured water levels under pumping conditions, water levels increased on average by 2.2 feet. From 2017 to 2019, when municipalities measured water levels under static (non-pumping) conditions, water levels increased on average by another 3.2 feet.

The potentiometric surfaces and the maps of potentiometric surface changes reflect these increasing trends seen at monitoring and municipal wells. The potentiometric surfaces provide a valuable tool to discern flow paths and areas of recharge and discharge. Based on the surfaces generated for this report and analysis of stream baseflow, the following can be stated:

- A potentiometric high in the western half of the BACOG study area is consistent year after year. This mounding of water levels is the result of high recharge rates since the Henry Formation is at or near the land surface. Because there is no overlying aquitard of significant thickness, precipitation can readily enter the aquifer. Thus, this area may exhibit increased susceptibility to aquifer contamination.
- In the eastern half of the BACOG study area, the Henry Formation becomes confined as it dips towards the east. This results in lower water level elevations compared to the recharge area. The eastern BACOG study area has a thicker glacial till aquitard and is likely less prone to aquifer contamination.
- The sand and gravel aquifer is hydraulically connected to the Fox River, the lower reach of Poplar Creek, the lower half of Spring Creek, and a small segment of Flint Creek. These are areas where the sand and gravel aquifer discharges to the streams as baseflow.

- Our analysis of baseflow using the USGS PART method indicates that baseflow is increasing along the Fox River and at Poplar Creek. At Poplar Creek, this increase is likely due to more discharge from the sand and gravel aquifer as aquifer levels rise. At the Fox River, baseflow may be increasing on account of higher aquifer levels or may simply reflect increases in upstream effluent inputs.

Water levels in the sand and gravel aquifer may be increasing from a combination of the following:

- Municipalities are withdrawing less water out of this aquifer over time. Overall withdrawals decreased from 16 mgd in 2005 to around 13 mgd in 2018.
- This five-year period may have received more rainfall than normal and did not experience any significant droughts, resulting in more recharge to the system
- Domestic water use may be declining because of improved household appliance efficiency. Households may have also reduced lawn watering due to the absence of any significant drought.

Given these trends, we feel that the available water supply in the sand and gravel aquifer should be sufficient over the short-term (i.e., next 5 years or so). However, the precipitation regime of northeast Illinois has changed over the past several decades and will continue to change in the future, potentially with increased precipitation, precipitation intensity (i.e., large storm events), and flood recurrence (Angel and Markus, 2019). This potential change in precipitation patterns and increased runoff events could affect the timing and amount of recharge entering the groundwater system and thus affect groundwater availability. Also, more frequent flooding and runoff events do not necessarily mean there will be an absence of droughts. Long-term groundwater level data will be essential for addressing future drought concerns and assessing whether recharge rates have changed. We therefore strongly recommend the continuation of real-time groundwater data collection at USGS monitoring wells, as these data will be vital for understanding seasonal changes and long-term trends (years to decades) in the sand and gravel aquifer and supporting long-term regional planning of water supplies.

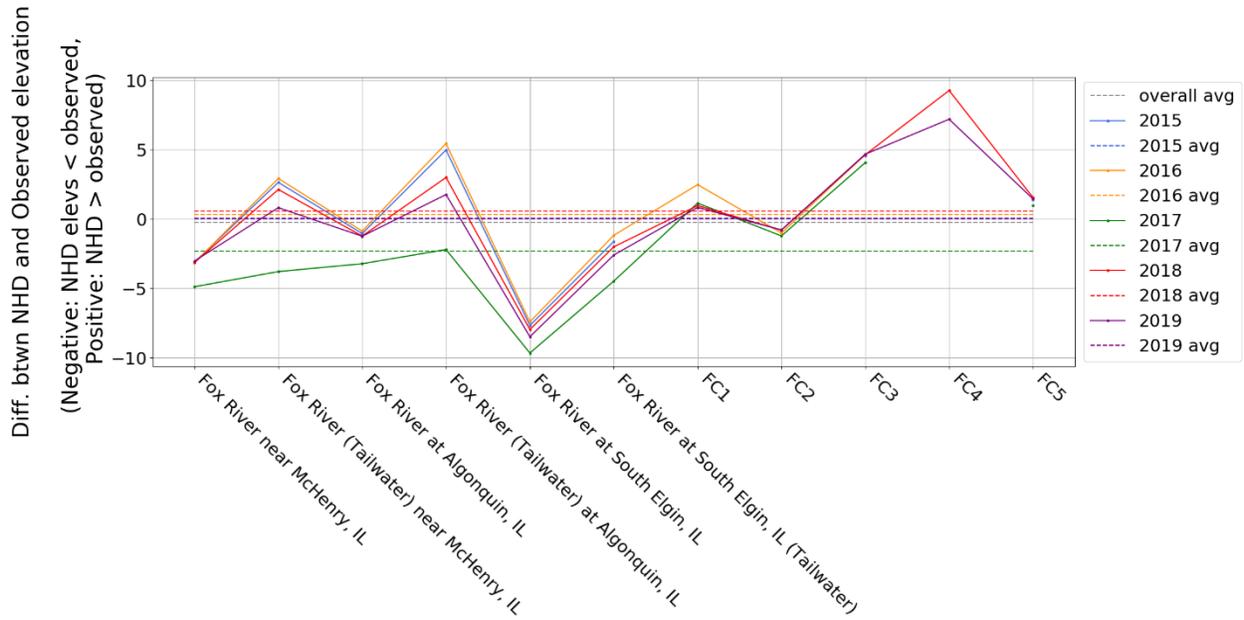
In the immediate short-term, potential water quality issues present the greatest concern to the BACOG area's groundwater supply. Since a large portion of the sand and gravel aquifer is susceptible to contamination, we recommend that water quality sampling be a primary emphasis of future BACOG studies. Particular attention should be given to understanding if chloride levels are increasing as a result of road salt use as this is a growing concern in northeastern Illinois (Kelly et al., 2016; Kelly, 2008). We also recommend measuring additional municipal sand and gravel wells such as Hoffman Estates and/or Palatine during the yearly mass measurements to better constrain the potentiometric surface in the area surrounding BACOG where data are limited.

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Supplemental Material



Supplemental Figure 1: Comparison of NHD and observed elevations at USGS and BACOG streamgaging sites. Solid lines exhibit the difference between NHD and observed elevations at each gaging station from 2015 to 2019. Negative values depict years when the NHD elevation is less than the observed elevation, while positive values display the opposite. Dashed lines display the average difference across all sites for a given year with most annual averages hovering near zero.

Supplemental Workbook 1: Separate Excel workbook file containing water levels taken by ISGS and ISWS staff at the BACOG ISGS monitoring wells.

Appendix A

Potentiometric surfaces of sand and gravel aquifer, 2014–2018

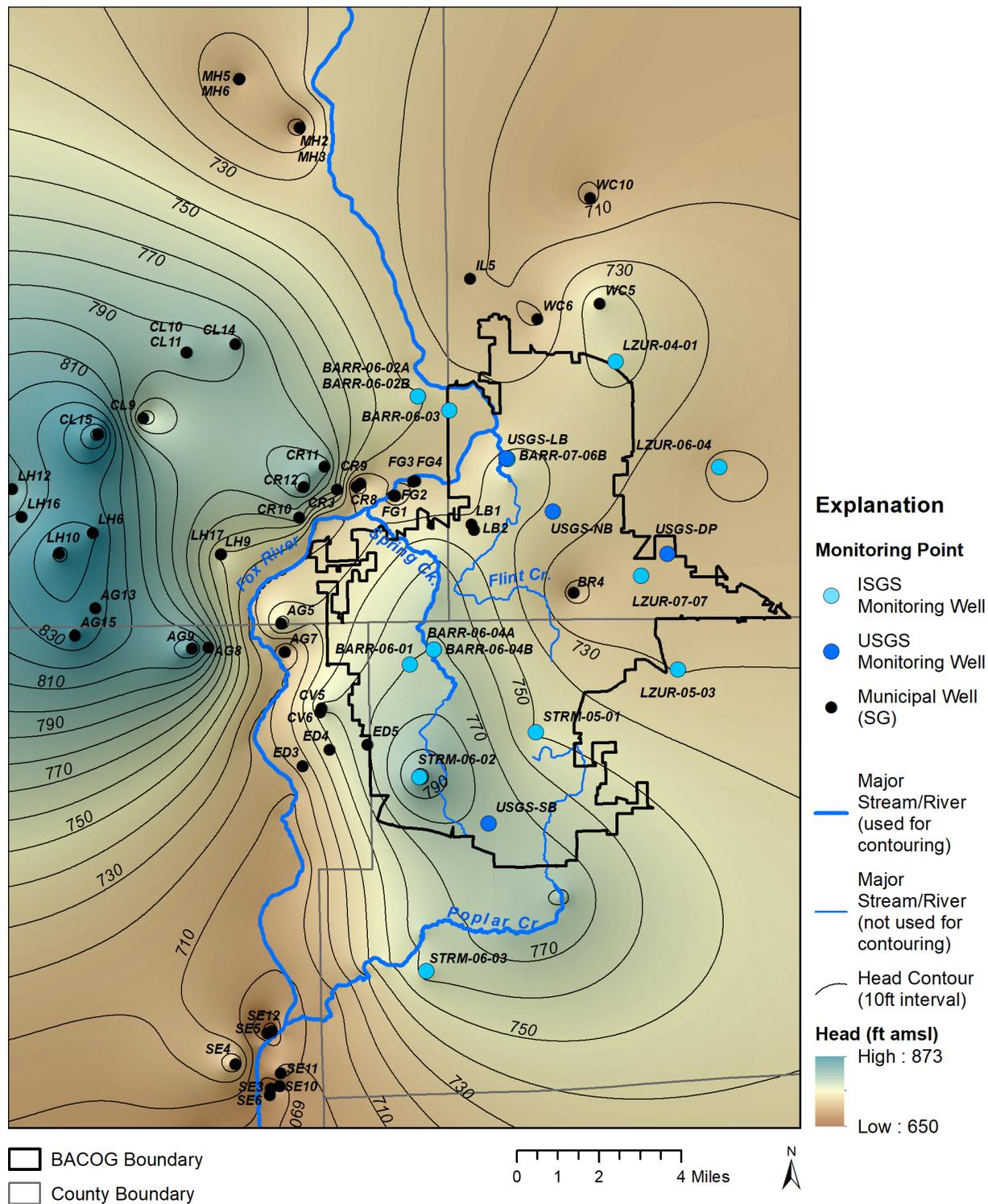
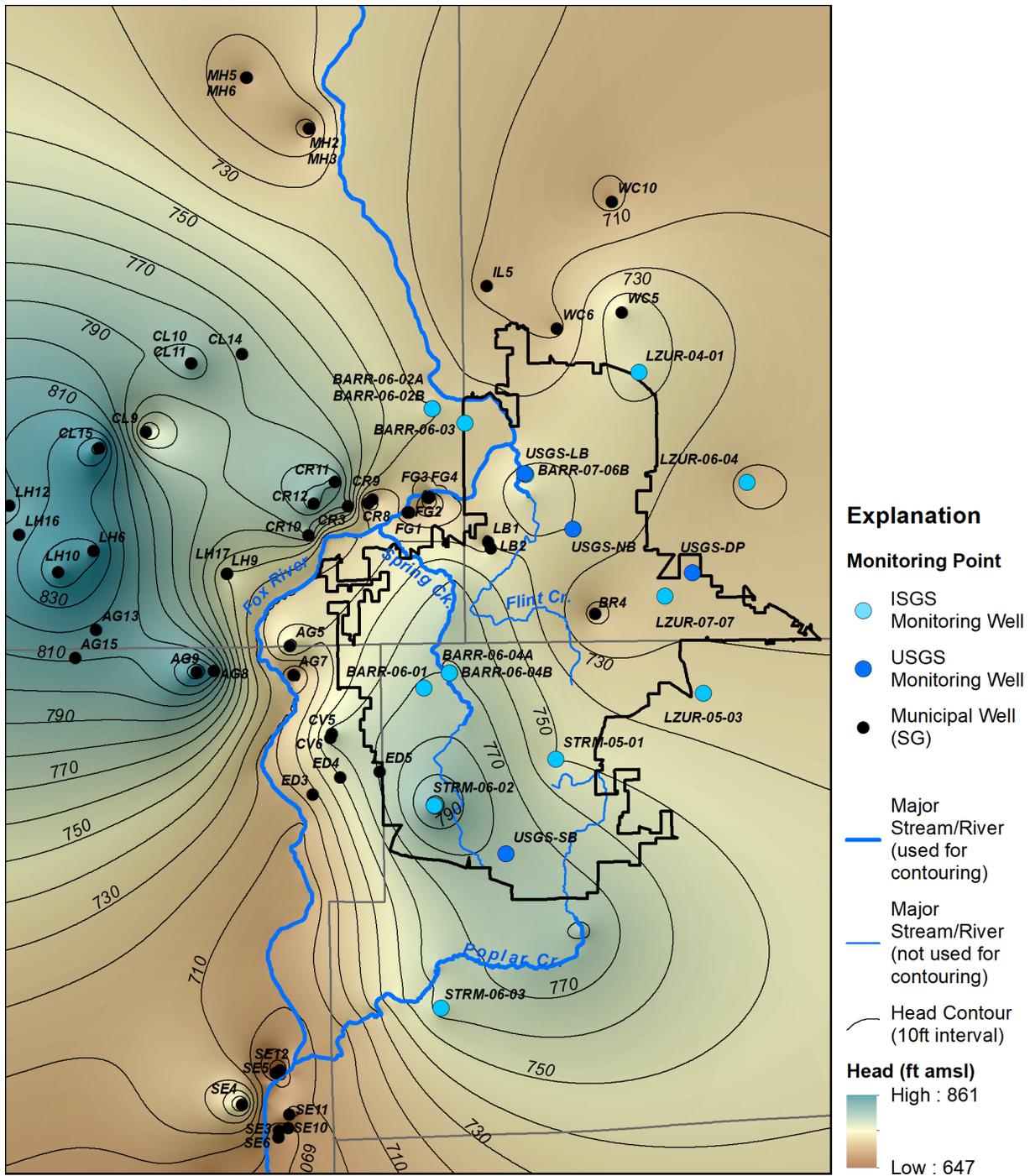


Figure A.1: Potentiometric surface of the sand and gravel aquifer in the BACOG study area and surrounding region for July 2014.



□ BACOG Boundary

□ County Boundary

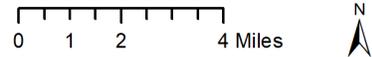
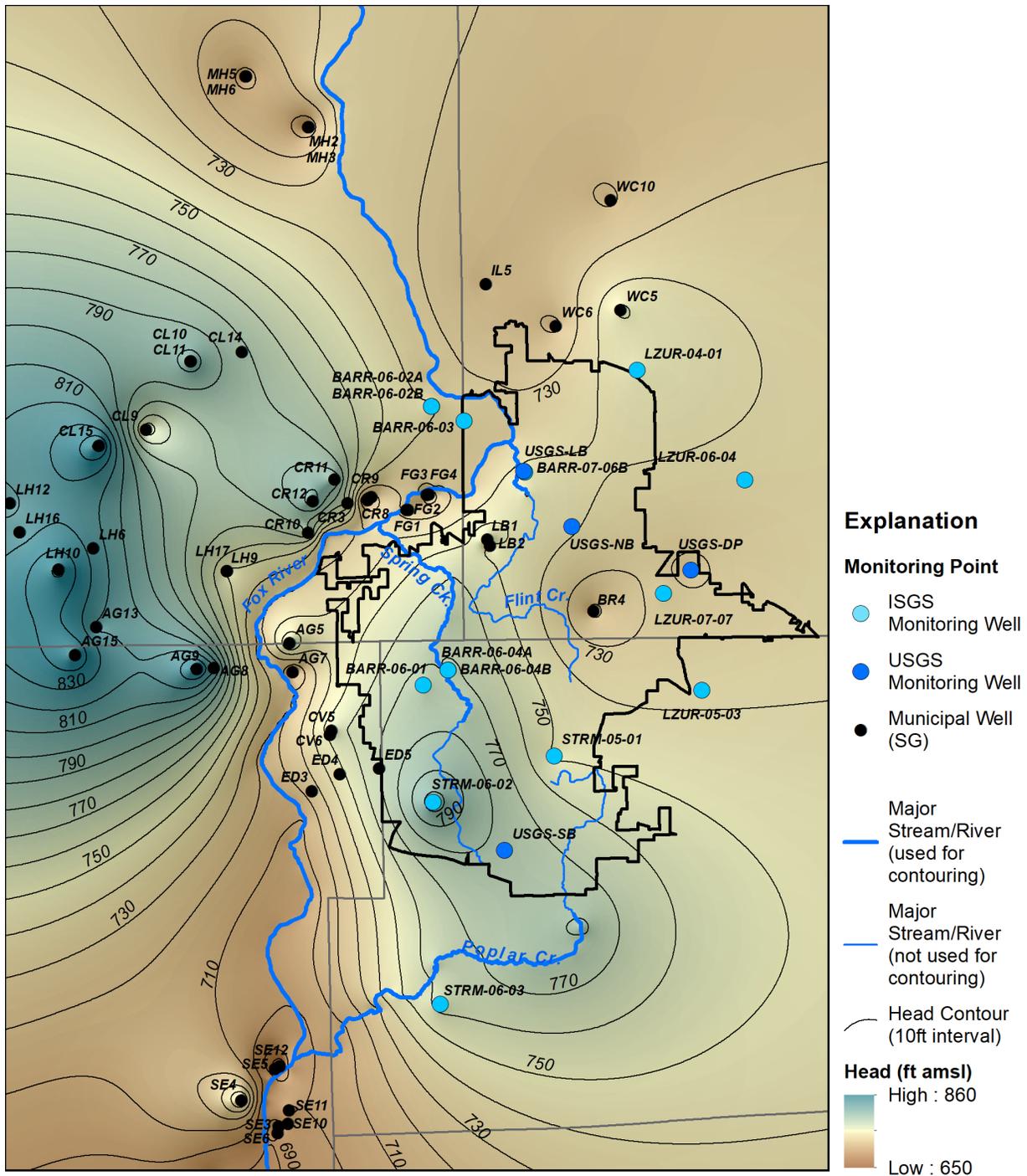


Figure A.2: Potentiometric surface of the sand and gravel aquifer in the BACOG study area and surrounding region for July 2015.



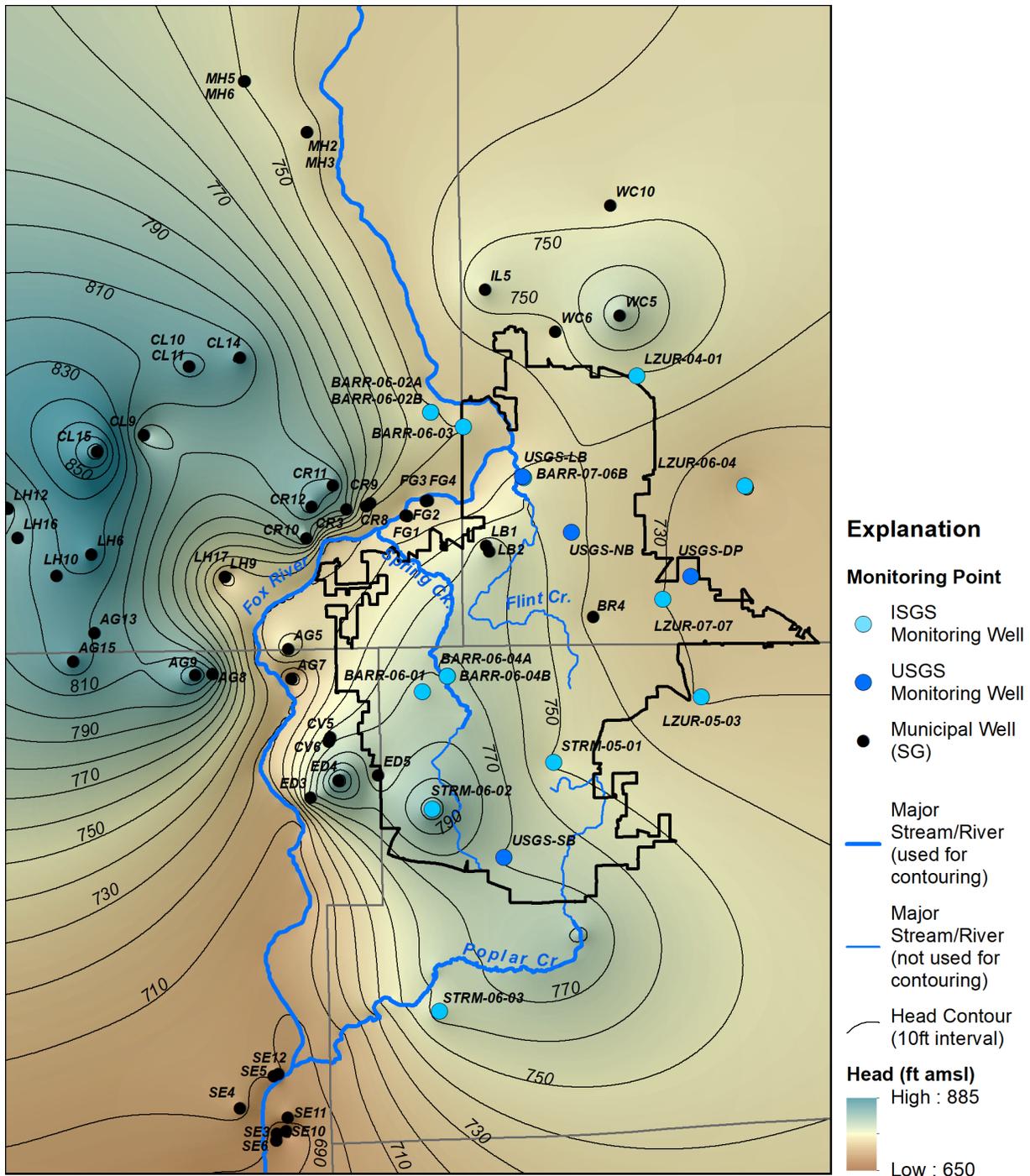
□ BACOG Boundary

□ County Boundary

0 1 2 4 Miles

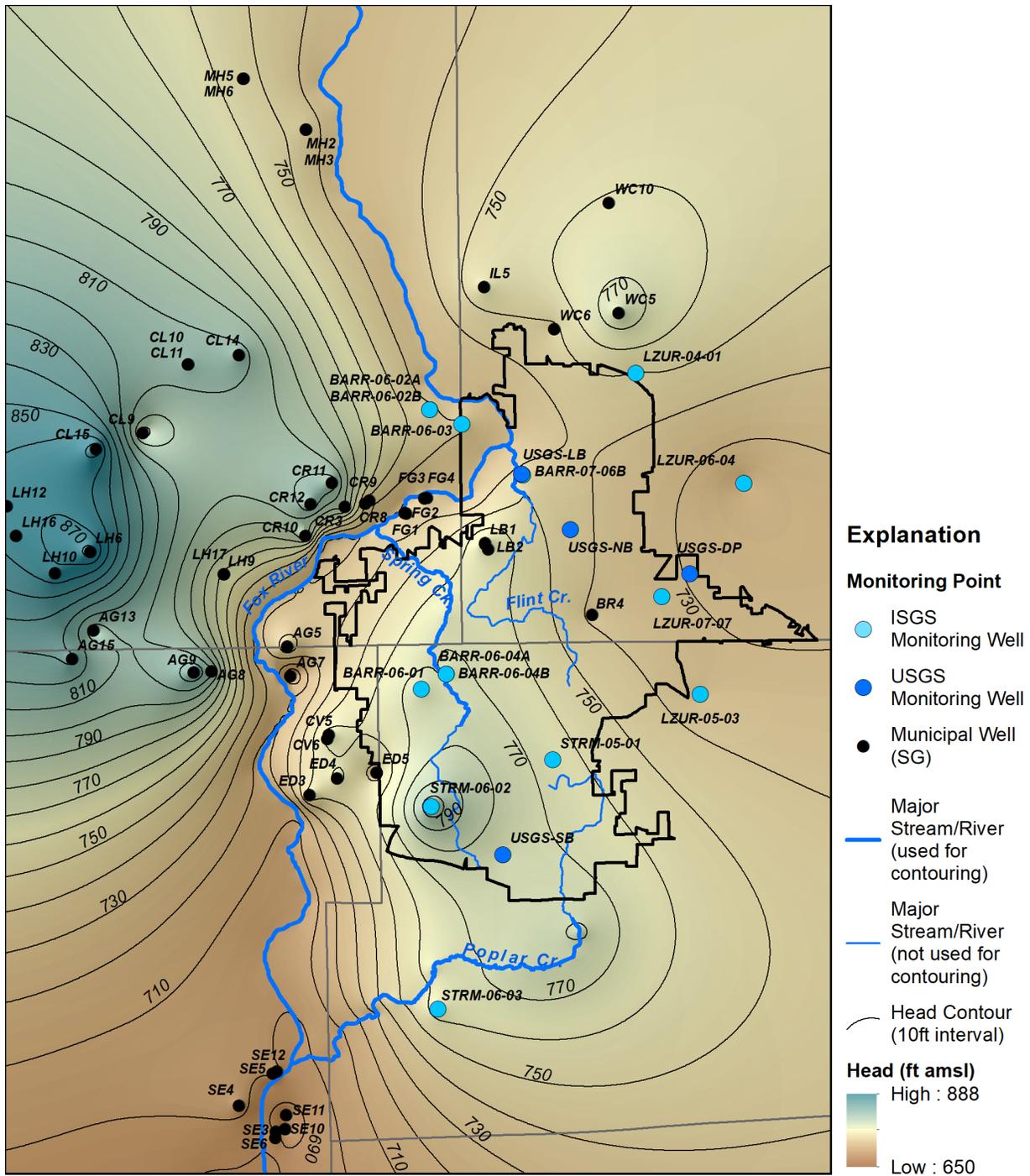


Figure A.3: Potentiometric surface of the sand and gravel aquifer in the BACOG study area and surrounding region for July 2016.



BACOG Boundary
 County Boundary

Figure A.4: Potentiometric surface of the sand and gravel aquifer in the BACOG study area and surrounding region for July 2017.



BACOG Boundary
 County Boundary

Figure A.5: Potentiometric surface of the sand and gravel aquifer in the BACOG study area and surrounding region for July 2018.

Appendix B

Graphs of reported municipal water use in the BACOG study area and surrounding region from 2005 to 2018.

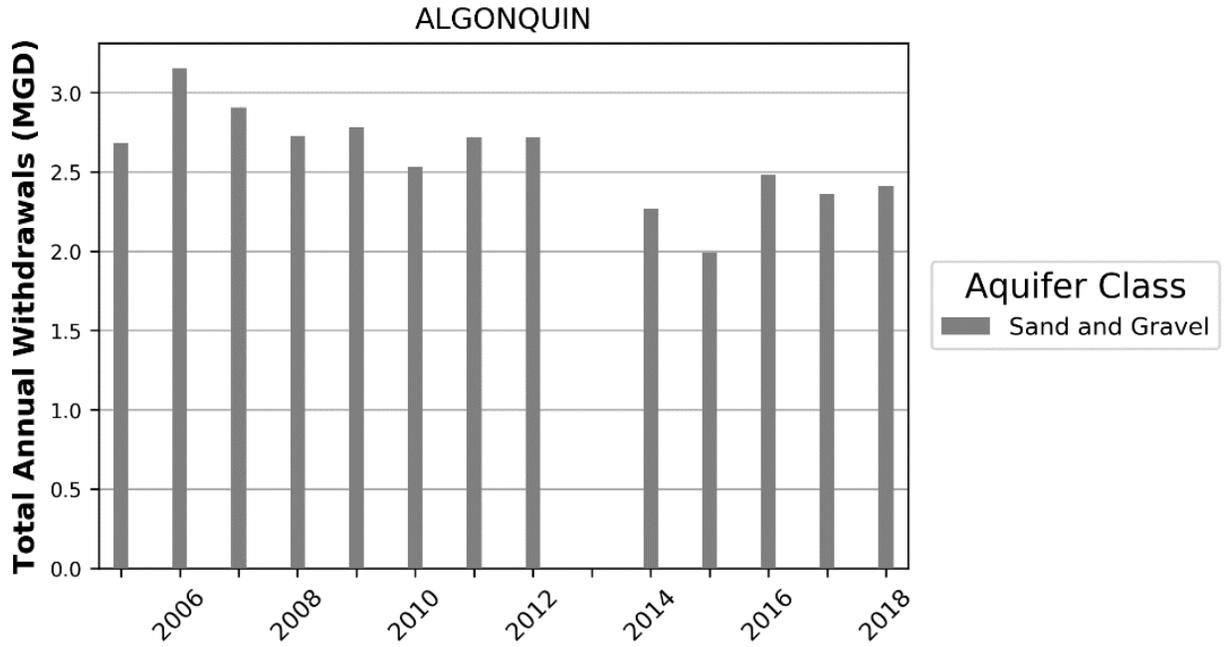


Figure B.1: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Algonquin. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

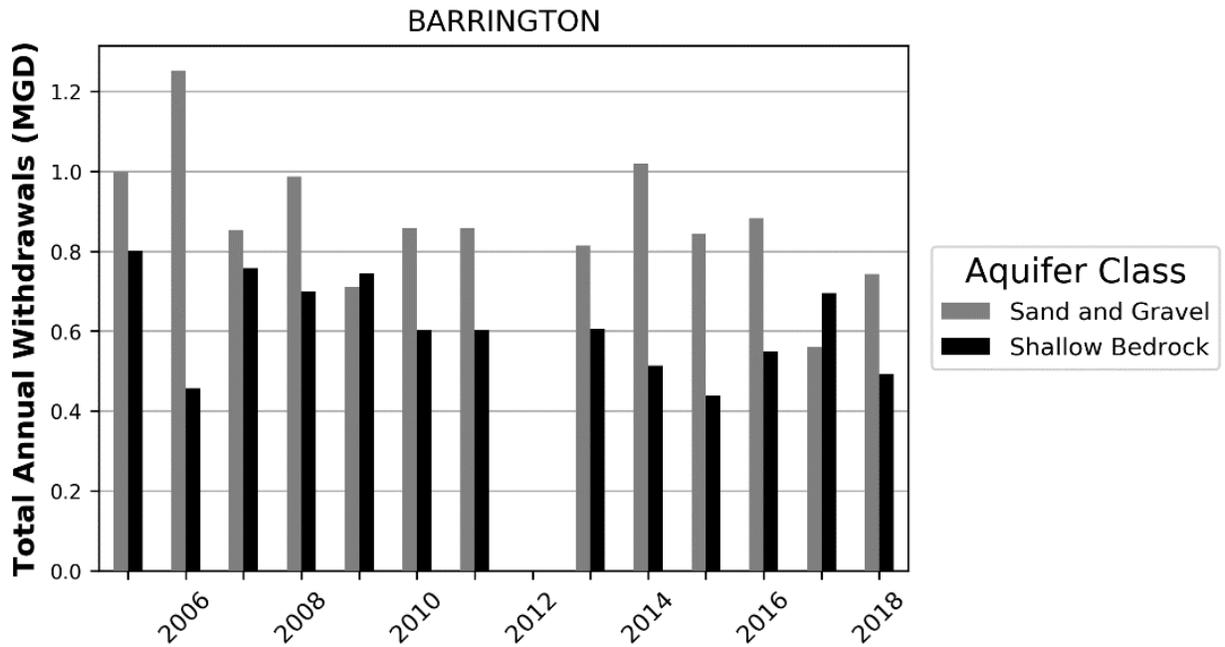


Figure B.2: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Barrington. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

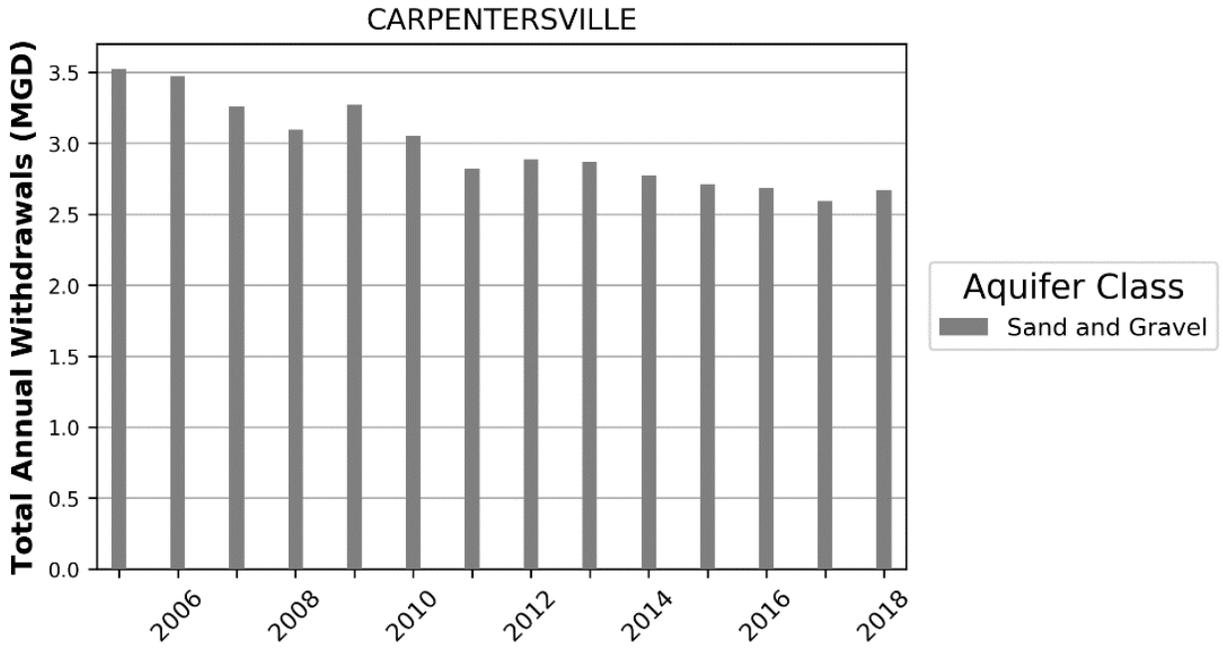


Figure B.3: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Carpentersville. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

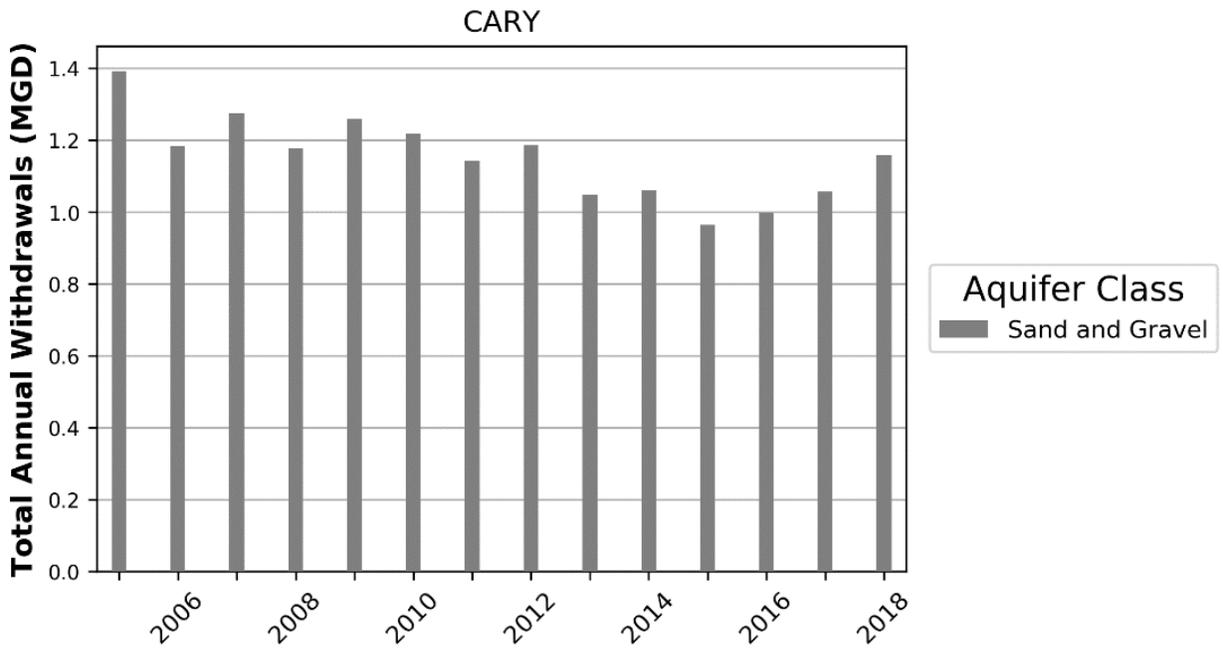


Figure B.4: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Cary. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

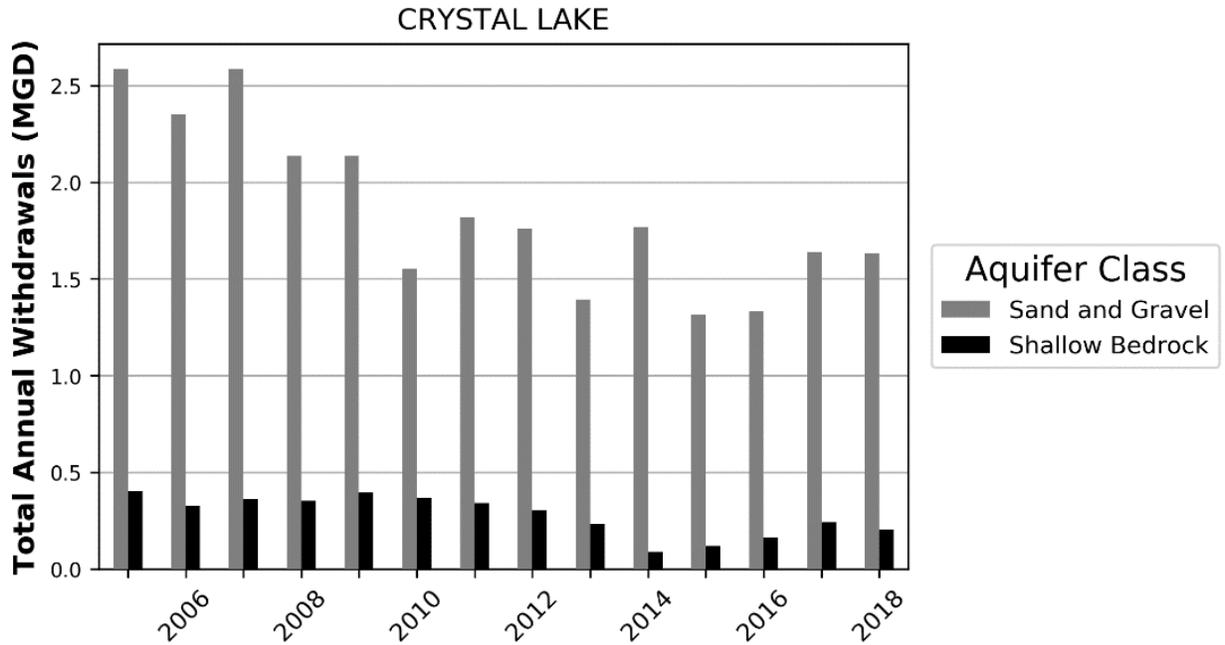


Figure B.5: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Crystal Lake. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

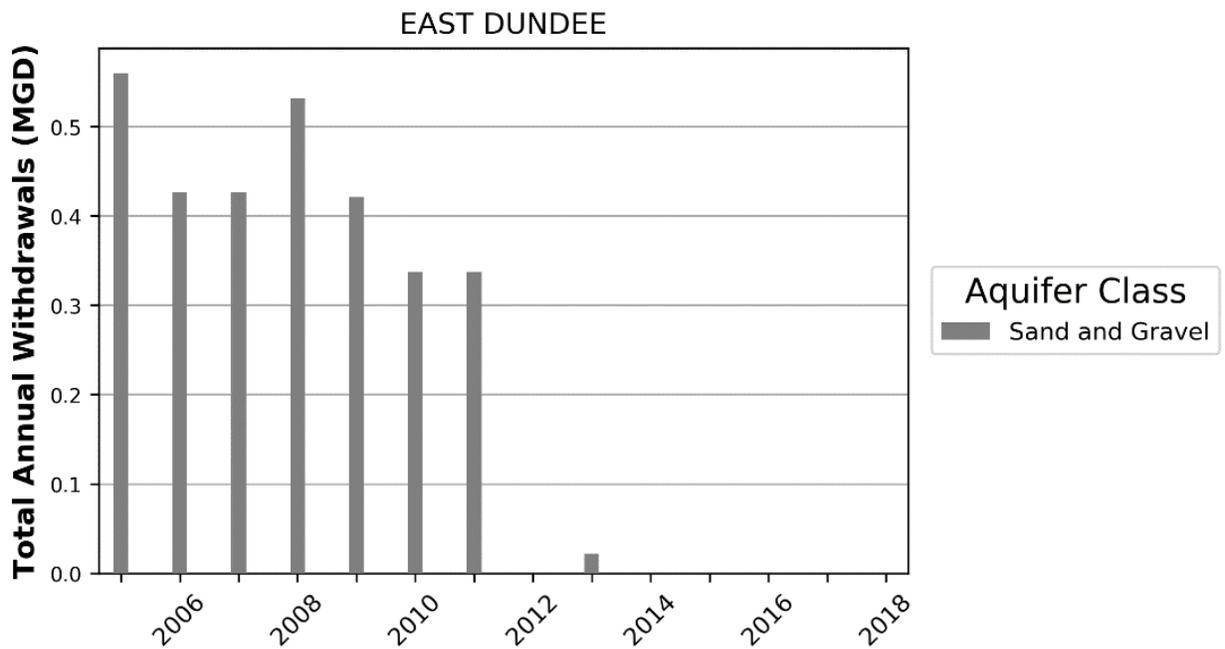


Figure B.6: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at East Dundee. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

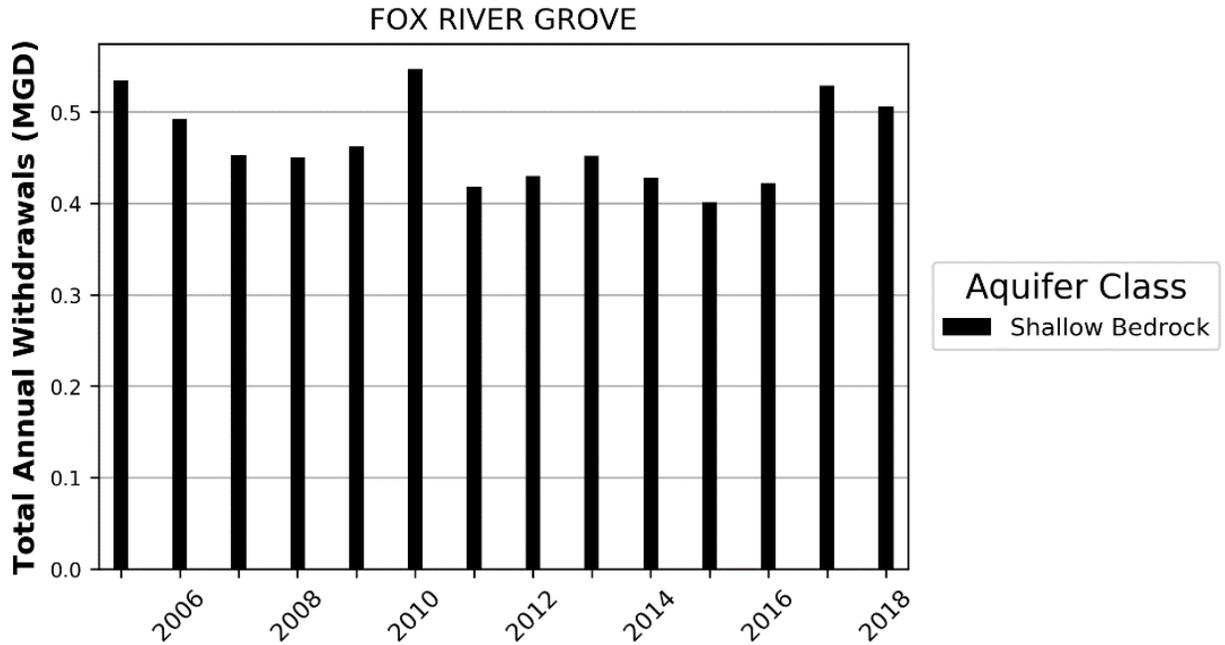


Figure B.7: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Fox River Grove. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

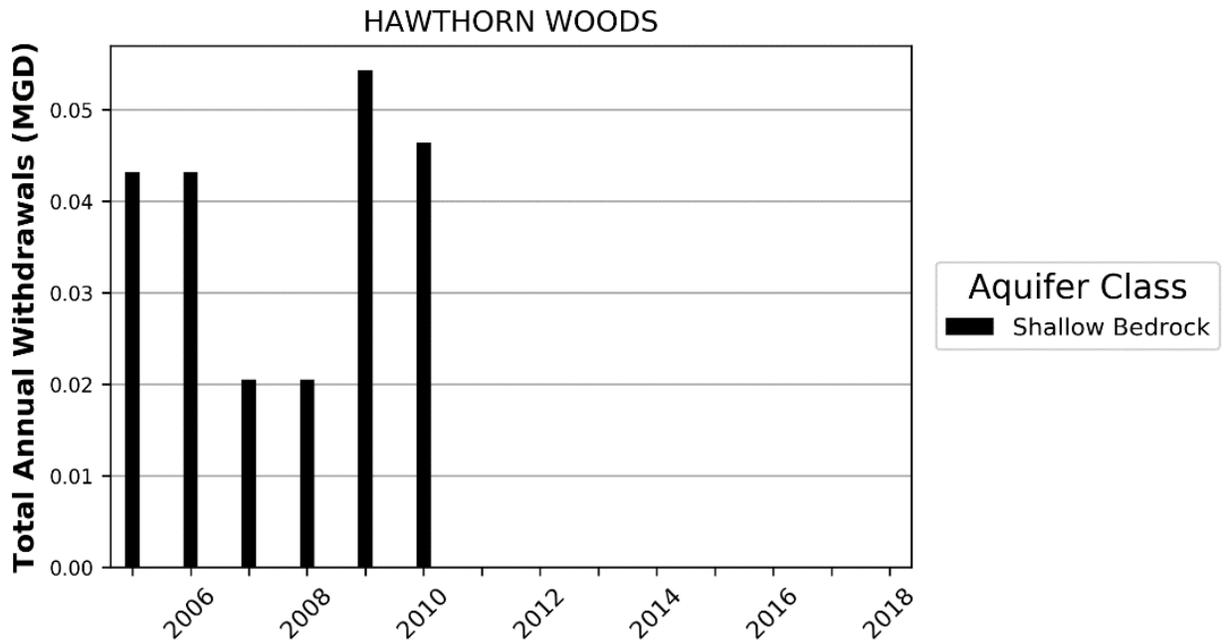


Figure B.8: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Hawthorn Woods. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

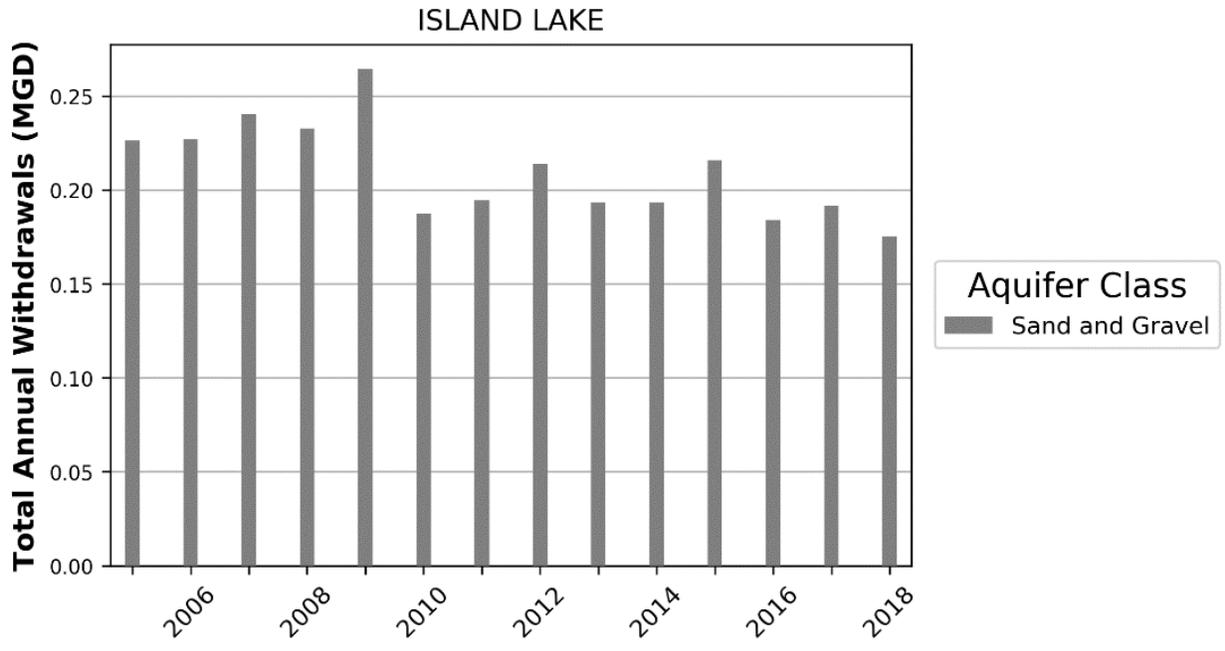


Figure B.9: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Island Lake. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

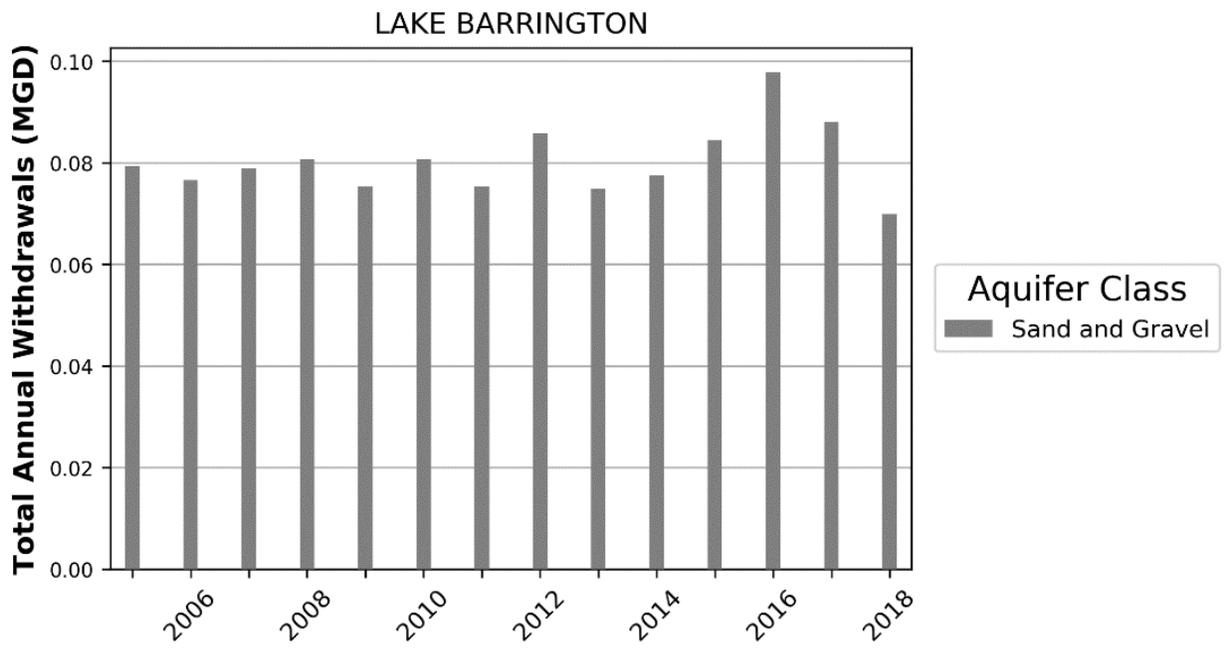


Figure B.10: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Lake Barrington. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

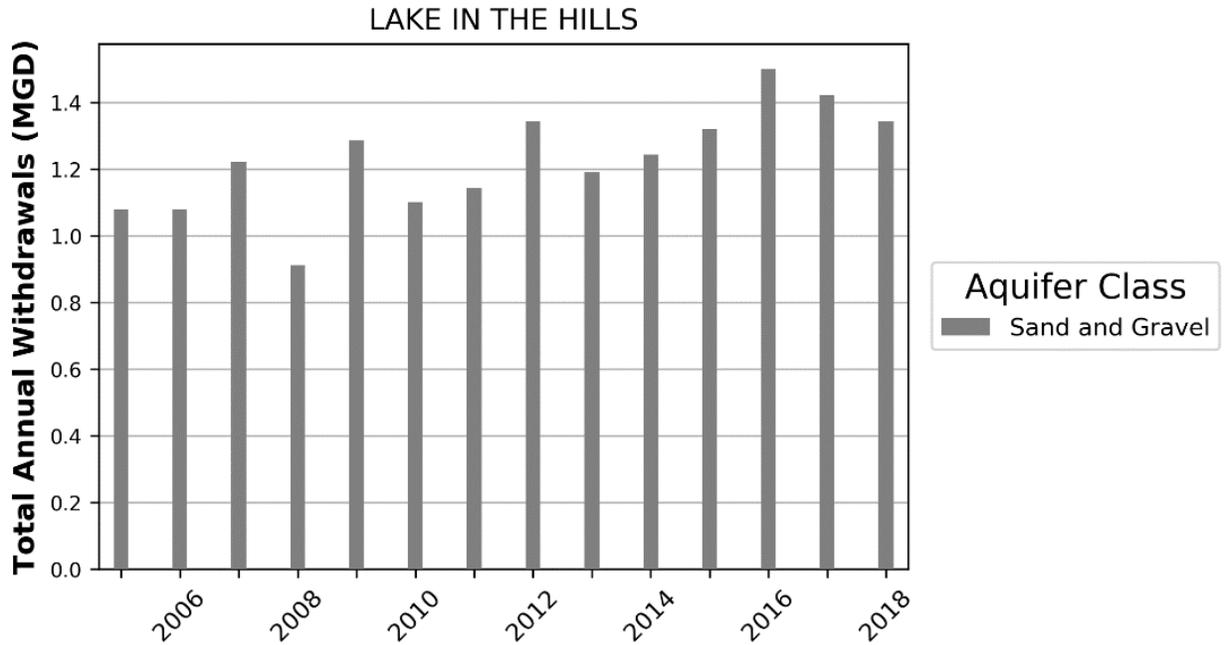


Figure B.11: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Lake in the Hills. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

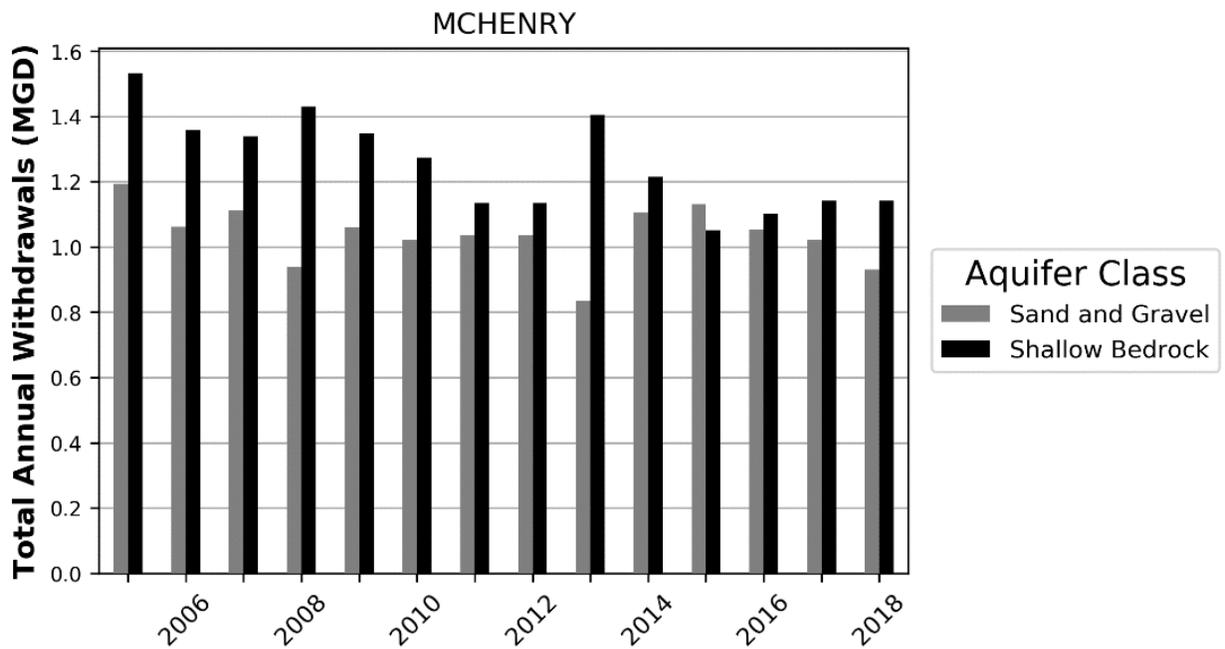


Figure B.12: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at McHenry. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

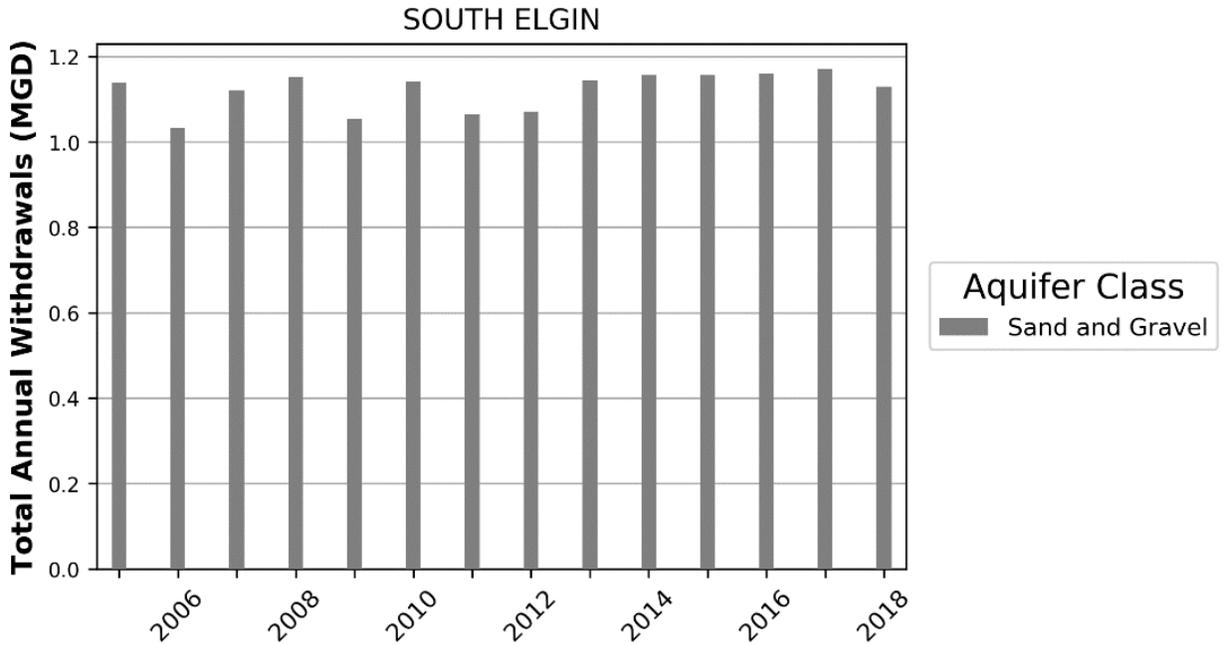


Figure B.13: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at South Elgin. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

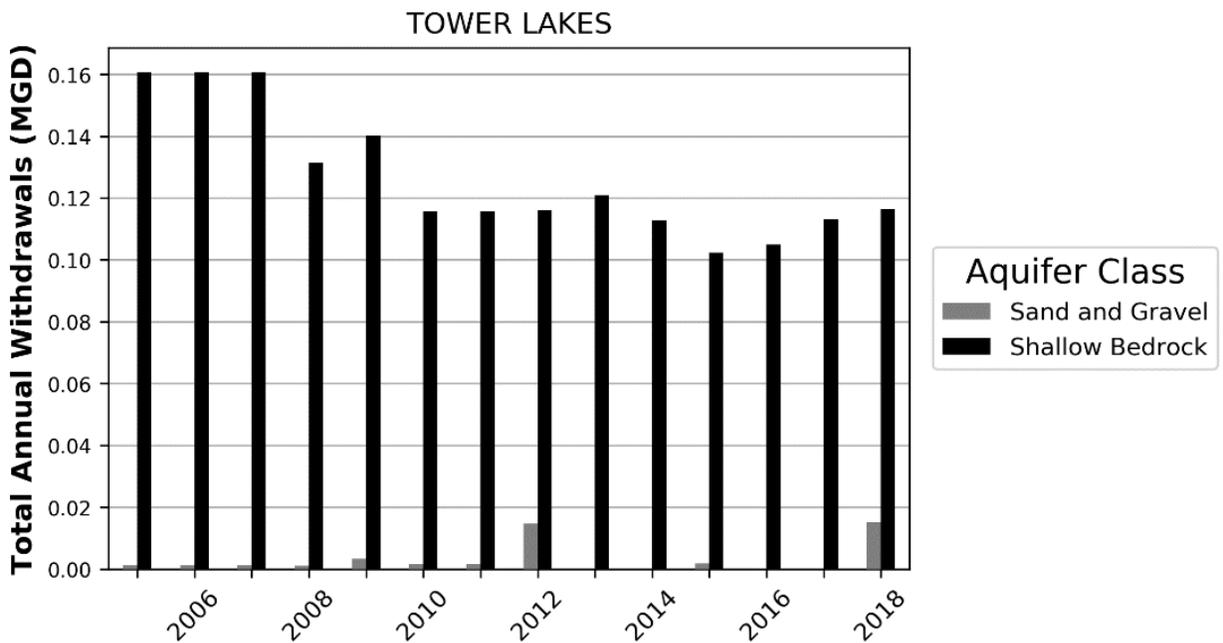


Figure B.14: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Tower Lakes. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.

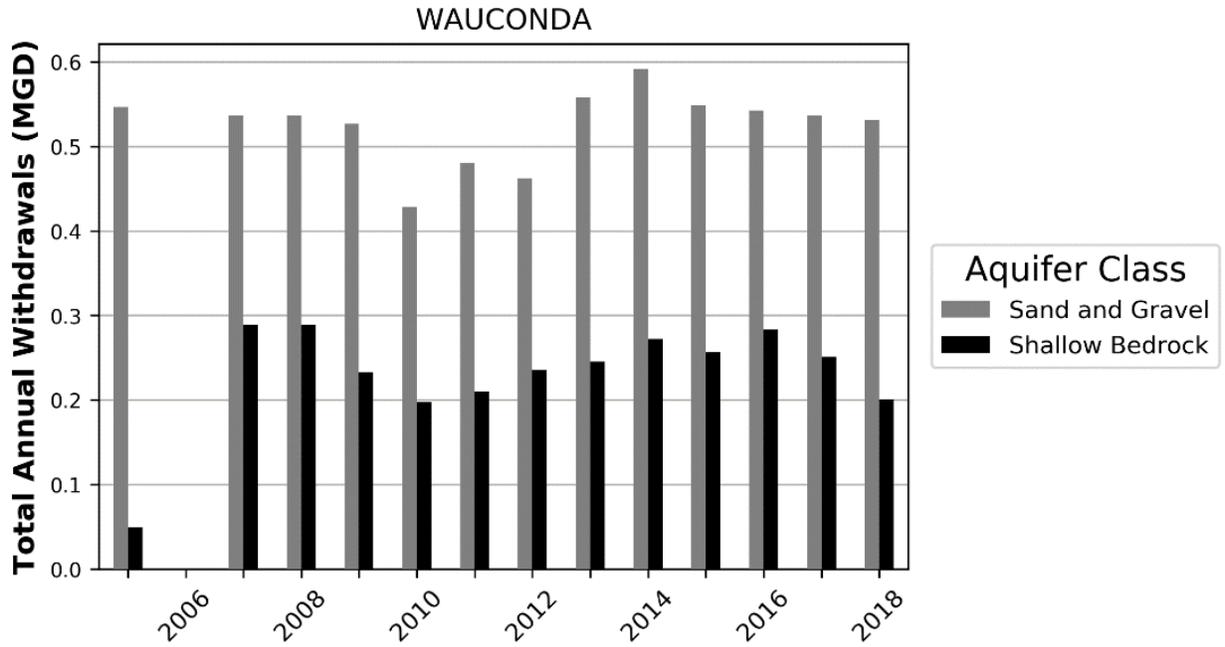


Figure B.15: Total annual withdrawals from the sand and gravel and shallow bedrock aquifer systems at Wauconda. Values are “as reported” to IWIP and may have years where non-reporting results in an apparent lack of withdrawals.