Water Supply Planning:
Assessment of Water Resources for Water Supply in the Rock River Region

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Abstract

The Rock River water supply planning region is comprised of eleven counties: Jo Daviess, Stephenson, Winnebago, Boone, Ogle, Carroll, Whiteside, Lee, Rock Island, Henry, and Bureau Counties. This report focuses on the important drivers affecting the availability and sustainability of the water supply in the region. The results of these scientific analyses are intended to highlight the opportunities and challenges ahead for meeting future water demand in the region.

While total surface water usage is far greater than groundwater usage, the number of point withdrawals of groundwater are far greater. This is because the few surface water intakes are generally associated with thermoelectric power generation. Present (2010) water demand for thermoelectric power generation totals 1,160 mgd, which is 87 percent of the total reported demand of 1,332 mgd. This water, which is surface water that used for cooling, is largely returned to its source after use. Future demand for thermoelectric power generation will depend strongly on cooling system design and gross generation capacity of operating power plants in the region.

There are three major aquifer systems in the region, the shallow unconsolidated (sand and gravel) aquifers, shallow bedrock (often karst) aquifers, and deep sandstone aquifers. Although the type of usage is mixed for each aquifer, the largest agricultural demands are sourced from the shallower aquifers and the largest public supply demands are sourced from the Cambrian-Ordovician sandstone aquifer.

The sand and gravel aquifers are heavily utilized for irrigation, particularly in the Green River Lowlands where agricultural demands have increased since the last study in the region 25 years ago. As a result, the water levels during the peak of irrigation in the Green River Lowlands are lower than when first studied. This can result in reductions in natural groundwater discharge, which has possible ecological impacts, and the potential for summertime supply disruptions, particularly during the next drought in the region.

Demands in Winnebago County, and in particularly Rockford, are generally sourced from the Cambrian-Ordovician sandstone aquifer and might also be unsustainable, particularly when considering the impact of reductions in natural groundwater discharge on streams. However, another concern in the Rockford region is the potential for contamination—legacy, acute, or otherwise—to make its way into public and private water supplies.

The shallow aquifers of the region are vulnerable to a variety of contaminants, including nitrate from agricultural contamination, chloride from road salt applications, agricultural runoff and/or septic/sewage discharge, and arsenic from natural sources. Deep aquifers are also subject to a variety of natural contaminants, such as radium and barium. The karst aquifers of Jo Daviess County are particularly vulnerable to contamination due to their rapid travel times and limited ability to remove contaminants traveling through the subsurface. While wells sampled in the region had limited contamination, springs did indicate signatures of septic system discharge.

Despite the larger demands, streamflows in the region have generally seen increasing trends since the 1970s, which is promising for surface water supply. Increasing streamflow will provide

more available water but may result in greater minimum flow requirement for surface water withdrawals. Thus, an environmental flow assessment will be needed in the future to determine aquatic ecosystem water demand, which can be used to assist determinations of minimum flow requirements. Ideally, this analysis would also consider the ecological impacts of reductions in natural groundwater discharge. The power generation industry is overwhelmingly the largest surface water user. Better understanding of power generation trends in the region and close collaboration with local stakeholders is critical for surface water supply planning in the future.

With all sources combined, demands exceed sustainable supply in two counties, Winnebago and Whiteside. This follows from the comparatively large demands in the two counties, predominantly municipal in Winnebago and agricultural in Whiteside. In both cases, sustainability is defined as the reductions in natural groundwater discharge exceeding 10% of predevelopment baseflow conditions in streams. This metric was assigned based on a study in Michigan. An analogous study in Illinois is needed, particularly focused on possible ecological impacts of different order streams. This could be coupled with the environmental assessment recommended as a result of the low-flow assessment recommended for the surface water portion of this study.

The metric used to assess shallow groundwater supply is limiting. Further investigations of vulnerability to contamination and potential for drawdown from demands, particularly for confined aquifers, should be considered in a local analysis of supply. The ISWS continues to refine the methodology for defining supply, so readers of this report are recommended to visit the Rock River Planning website to see any updates to these numbers.

1 Introduction

The availability and sustainability of an adequate and dependable water supply is essential for our public, environmental, and economic health. This important understanding led to the initiation, under direction of Executive Order 2006-01 from the Governor of Illinois, of a program for comprehensive regional water supply planning and management. Under the framework of the order, the Illinois Department of Natural Resources' Office of Water Resources (IDNR-OWR) directs this effort. The Illinois State Water Survey (ISWS) and Illinois State Geological Survey (ISGS), both within the University of Illinois' Prairie Research Institute (PRI), are responsible for quantifying the available water supply. These responsibilities include collecting and interpreting scientific data and developing predictive water supply models. The state is divided up into ten water supply planning areas (Figure 1), and regional water supply planning has so far been completed in four: (1) Northeastern Illinois (CMAP, 2010; Meyer, 2012), (2) East Central Illinois (Roadcap et al., 2011; Uken et al., 2009, 2015), (3) the Kaskaskia River Region (Kaskaskia Basin Water Supply Planning Committee, 2012; Knapp et al., 2012), and (4) the Middle Illinois Region (Kelly et al., 2018).

This report focuses on the technical aspects of water supply assessment for the Rock River Water Supply Planning Region (WSPR) in northwestern Illinois, an area comprising Jo Daviess, Stephenson, Winnebago, Boone, Carroll, Ogle, Whiteside, Lee, Rock Island, Henry, and Bureau counties (Figure 1). The results of our scientific analyses are intended to highlight the opportunities and challenges ahead for meeting future water demand in the Rock River WSPR.

Stakeholder water supply planning committees have been created in each priority planning area, and each planning committee is tasked with developing regional water supply planning and management recommendations in accordance with existing laws, regulations, and property rights. For this region, the Rock River Regional Water Supply Planning Committee (RWSPG) formed under guidance from the Blackhawk Hills Regional Council. The ISWS and ISGS, along with the IDNR-OWR, are responsible for providing technical support to the Rock River RWSPG and updating and expanding regional water resource information. The RWSPG is charged with developing a regional water supply plan that clearly describes water supply and demand issues of the region under study. IDNR-OWR suggested that the regional plans address at least the following principal components:

- Descriptions of the sources of water available to the region;
- Plausible estimates of how much water may be needed to the year 2060;
- Estimates of the impacts of withdrawing sufficient water to meet demand; and
- Descriptions of options for providing additional sources of water and/or decreasing demand.

The ISWS and ISGS were assigned the responsibility of developing initial water demand scenarios to 2060, with the Rock River RWSPG reviewing and adjusting the scenarios using local knowledge. The final water demand report has been completed (Meyer et al., 2019), although the group continues to provide feedback for the demand scenarios.

This report presents a summary of 1) the technical information assembled to describe existing water availability and sources of supply within the Rock River Water Supply Planning Region

(Rock River WSPR) and 2) the results of analyses used to estimate impacts to water availability resulting from future water development in the region to the year 2060. The report focuses on the two primary sources of water supply within the Rock River WSPR: (1) direct withdrawals from the Rock River; and (2) groundwater withdrawals from within the Rock River Watershed.

1.1 Study Area

Eleven counties are in the Rock River WSPR: Jo Daviess, Stephenson, Winnebago, Boone, Ogle, Carroll, Whiteside, Lee, Rock Island, Henry, and Bureau Counties (Figure 1). The Rock River watershed extends into southern Wisconsin, which is an important consideration for the surface water analyses in this report. The Mississippi River borders the Rock River Region to the west.

Rockford is the largest city in the region, with a population of about 148,000. Other cities with populations greater than 5,000 include, Rock Island, Sterling, Galena, and Moline. There are three major aquifer systems in the region, the shallow unconsolidated (sand and gravel) aquifers, shallow bedrock (often karst) aquifers, and deep sandstone aquifers. The shallow sand and gravel aquifers were deposited by glaciers or rivers. Bedrock aquifers are found throughout the region, although their productivity is highly variable depending on several geologic factors.

Demands in the Rock River region are generally satisfied from local sources; a large central entity that distributes water over a large portion of the region does not exist. Almost all municipalities rely on groundwater. Self-supplied industrial and commercial entities in the region rely solely on groundwater. Most of the water used for agricultural irrigation is also from groundwater sources. The city of Rockford pumps water from the bedrock aquifers. Two major cities in the Rock River WSPR, Moline and Rock Island, use water from the Mississippi River to meet public supply demands. Surface water from the Rock River and Mississippi river is also used to supply water for thermoelectric power generation.

1.2 Report Structure

The next section of this report, Section 2, provides a general discussion on water supply and demand and presents a brief presentation of the three scenarios describing future water demands to 2060.

The focus of Section 3 is groundwater availability. The section begins with a description of the aquifers in the region and overviews of the regional geology and hydrogeology. Two of the largest demands, agricultural demands in the Green River Lowlands and municipal demands in Rockford, are highlighted in more detail. Finally, an overview of water quality in the different aquifers of the region is provided.

Section 4 focuses on surface water availability, emphasizing the analytical methods used to determine river yields, uncertainties in data inputs, and the use of statistical methods to estimate the 90 percent confidence yields. A set of scenarios is modeled to project potential future water demands are their impacts on streamflows. Impacts of severe droughts and climate change are also considered.

Section 5 reports on several screening analyses to quantify and evaluate the water supply in the region. Supply and demand are assessed at a county level, with values originating from a regional groundwater flow model under several simplifying assumptions. Risk to aquifer supply is also assessed at a municipal level by evaluating the transmissivity of the combined aquifer and water levels in the deeper Cambrian-Ordovician sandstone aquifers and local risk areas in the agricultural areas of Bureau, Lee, Whiteside, and Henry Counties.

Section 6 presents a general summary of water resource availability and recommendations for further study.

1.3 Caveats

The primary focus of the water supply planning initiative is on water quantity. Although water quality is not emphasized in this planning effort, water quality issues are reported where existing relevant information is known to the ISWS. Given the expertise available in the state surveys and the resources and time available to conduct the necessary studies, the following is a list of topics that are important in regional water supply planning and management, but are not addressed comprehensively in this report:

- Economics
- Legal matters
- Societal and ethical issues and values
- Water infrastructure
- Water treatment
- Water losses
- Storm water and floods
- Utility operations
- Conservation and water reuse
- In-stream water uses (ecosystems, recreation, navigation, etc.)
- Governance and management
- Ecological implications of withdrawals

Surface and groundwater models were developed using the most accurate available knowledge of regional hydrologic conditions. Although the results represent a range of important impacts of the withdrawals simulated in the study, new information and more powerful tools could produce different results from those expressed in this report.

It should be noted that a new approach to water supply planning was adopted in the middle of planning for the Rock River WSPR. Preliminary results are presented in Section 5. All of these analyses attempt to quantify supply, which as mentioned above is by its nature highly uncertain and transient. Discussions with the Rock River RWSPG remain ongoing and will either be updated in this report before the final version is available or will be updated on the corresponding online web material associated with this project.

1.4 How Much Water is Available in the Rock River WSPR?

The amount of water that the streams and aquifers of the Rock River WSPR can supply depends on where the demand is, how much money users are willing to spend, and what societal and environmental consequences are acceptable. The amount of water available fluctuates. Many water development projects act to increase water availability by capturing water that would otherwise be lost to flooding or evaporation. Other projects and hydrologic processes act to decrease water availability, such as reservoir siltation or aquifer desaturation. Future increases in water demand and water development projects will take place on a landscape where water is already heavily influenced by drainage networks, dredged streams, reservoirs, water withdrawals, and wastewater discharges.

Unlike other natural resources that humans consume, such as petroleum, only a tiny amount of the mass of water used is permanently removed from the environment. Most of the water we consume is returned to the hydrologic cycle through wastewater discharge or evaporation. However, impacts to available supply may occur where water is removed from one source and returned elsewhere (such as removing groundwater via pumping and returning to a stream). Where do scientists, and more importantly the public, draw the line as to what is or is not an acceptable impact? If impacts suggested by the models are considered by stakeholders (in this case, represented by the RWSPG) to be unacceptable or too uncertain, they may recommend to adopt policies and target monitoring and water management efforts to track and mitigate impacts regionally or in specific affected areas, or to conduct additional studies to reduce uncertainty. The analyses and models developed for this project are intended to be used for future analysis of other scenarios to test the effects of alternative management strategies. **Most analyses in this report investigate the "sustainability" of water supplies, which is a leading priority of the funding agency of this work, IDNR OWR.**

In this study, we examine the impact of current and future water demands on the streams and aquifers in the Rock River WSPR through the use of computer-based models and other analyses. Current water demands were estimated from annual surveys of large water users conducted by the Illinois Water Inventory Program (IWIP) at the ISWS. Future water demands were estimated by the ISWS (Meyer et al., 2019). The modeling and analysis of groundwater and surface water in this study were conducted separately because of the fundamental difference in their hydrologic behavior and the analytical tools used to evaluate each. Surface water supplies are strongly influenced by the timing and magnitude of precipitation events and thus we chose to model them with transient simulations and statistical analyses of past streamflow records. Groundwater supplies exhibit more steady hydraulic behavior but vast variability in the spatial geometry of the aquifer materials, so we chose to model the aquifers with a deterministic numerical groundwater flow model, MODFLOW (McDonald & Harbaugh, 1988).

1.5 Acknowledgments

The report was prepared under the general supervision of ISWS Director Kevin O'Brien. The views expressed in this report are those of the authors and do not necessarily reflect the views of the Illinois State Water Survey, the Illinois State Geological Survey, the Prairie Research Institute, and the University of Illinois Board of Trustees.

This project was funded, in part, by the IDNR-OWR and by General Revenue Funds of the State of Illinois. Several staff members of the Illinois State Water and Geological Surveys assisted with the project. Kevin Rennels collected groundwater-level data. Greg Rogers and Brad Larson assisted with the model preparation, ISGS geologic data, and interpretations. Jennifer Marten processed USDA flyover images to determine the number of irrigated acres in the study region in 2017. Technical reviews were provided by Dan Hadley and Laura Keefer. Lisa Sheppard provided technical editing.

A special acknowledgement to Whiteside County resident and citizen scientist, Arlyn Bush, whose tireless efforts in measuring water levels in ISWS monitoring wells located throughout the Green River Lowlands have greatly impacted our understanding of the region's hydrology.

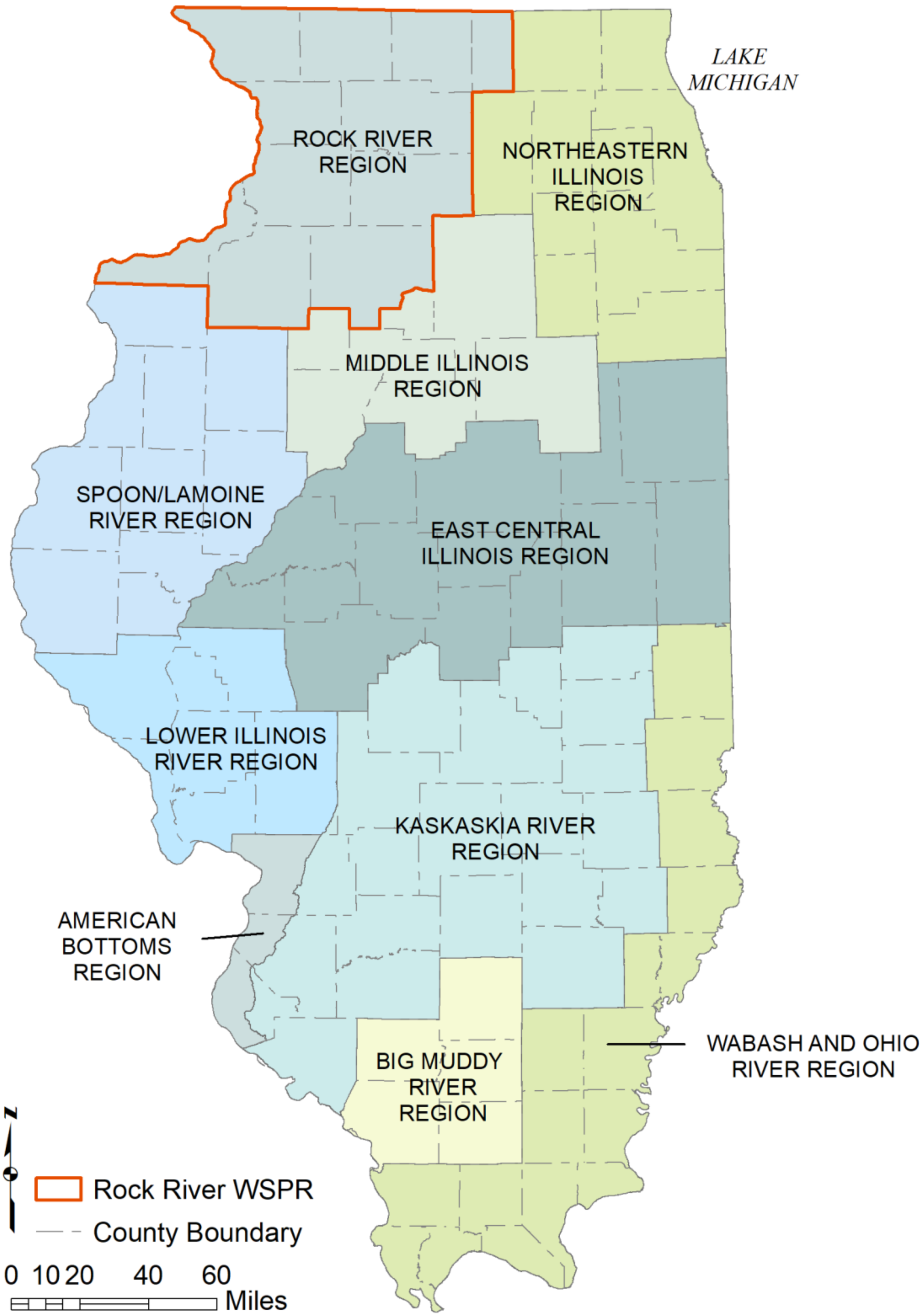

Figure 1. Water supply planning regions (WSPRs) in Illinois and location of the Rock River Region.

2 Water Use and Demand Projections for the Rock River WSPR

2.1 Current Demand in the Rock River WSPR

ISWS has maintained the IWIP database that collects water use data in Illinois since 1978. The surface water and groundwater withdrawals for 2018 in the Rock River Region are shown in Table 1 and Figure 2. Note that instream water demand by hydroelectric facilities is not included as the hydroelectric facilities in the region do not divert water off the channel and water consumption is minimal. Demands outside of the region that fall within the Rock River watershed are also shown.

The total surface water withdrawals in the Illinois region is 1,147.3 million gallons per day (mgd) in 2018. The overwhelming portion (98% of the total surface water withdrawal) is used by power generation for cooling purposes. Exelon – Quad Cities Station and Exelon – Byron Station are the two largest users. Public water supply is the second largest surface water user with three cities (Rock Island, Moline, and East Moline) relying on surface water for public water supply. Due to their proximity to the Mississippi River, there is no concern on water quantity to meet the future water demand by these cities. Exelon – Quad Cities Station and the three public water supply systems are all withdrawing water from the Mississippi River. The only major user relying on the Rock River is Exelon – Byron Station. In addition, most of the Mississippi River withdrawals are returned to the river as wastewater or sewage. Considering the amount of streamflow in the Mississippi and Rock Rivers in the Rock River Region, surface water supply is sufficient to meet the demand. **If the two nuclear power plants retire in the future, surface water demand will be decreased dramatically.** Recent news reports indicate that the Exelon – Byron Station will likely retire in 2021.

The total groundwater withdrawals in the region reported to IWIP in 2018 was 72.2 mgd with 60.0 mgd of withdrawals being within in the Rock River watershed. The largest groundwater use in the Rock River Region is assumed to be irrigation, although this is was the smallest groundwater use reported to the IWIP program in 2018. This discrepancy is in large part due to the program being in the early stages of formally collecting and compiling water use reports from the agricultural irrigation sector. Irrigation in 2010 was estimated to be 90 mgd in a normal climate year (Meyer et al., 2019). For groundwater, the largest reported use sector, public water supply, reported 56.1 mgd withdrawal in 2018, followed by industry, power generation, and irrigation.

Table 1. Water withdrawals by water use sector reported to IWIP in the Rock River Region in 2018

Water use sector	*Surface water withdrawal (mgd)*	*Groundwater withdrawal (mgd)*
Public	13.6	56.1
Power	1126.3	4.7
Industry	7.2	6.8
Irrigation	--	--
Total	1147.3	72.2

* Prior to 2015, agricultural irrigation water use reporting to IWIP, was done on a voluntary basis. Actual data in the region appears to be under-reported. The ISWS is currently working to use reported data to estimate irrigation in the region, but this data is not ready to release.

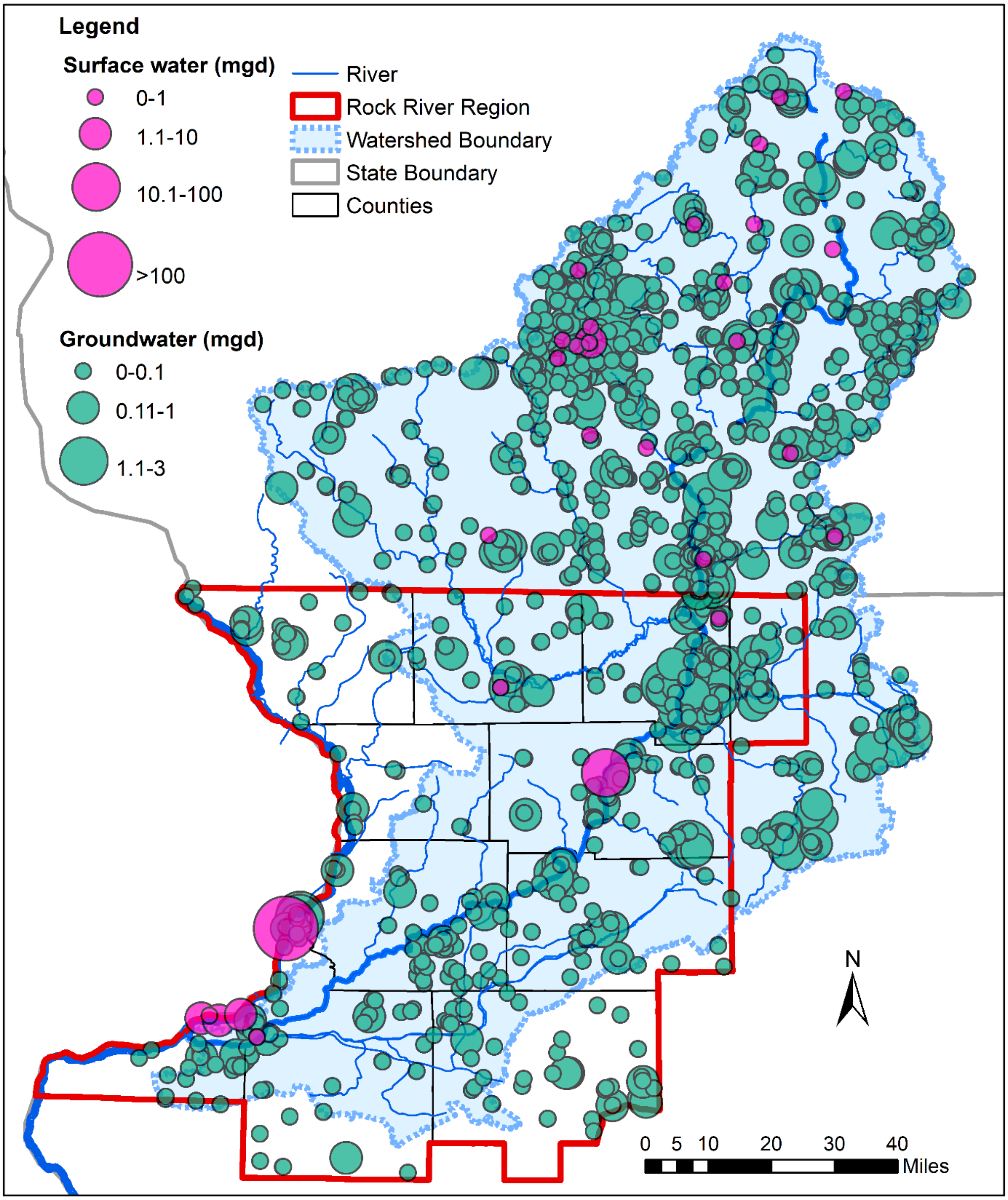

Figure 2. Surface water and groundwater withdrawals for 2018 in the Rock River region and, outside of the region, Rock River Watershed. Image does not include center pivot irrigation demands.

2.2 Demand Projections for the Rock River WSPR

We have developed estimates of water demand in the Rock River WSPR from 2015 to 2060; this analysis was conducted using a historic data record ending in the year 2010. The estimates are developed separately for five major water-demand sectors: (1) public supply; (2) self-supplied domestic; (3) self-supplied thermoelectric power generation; (4) self-supplied industrial and commercial; and (5) self-supplied irrigation, livestock, and environmental. The estimates are developed for all sectors on a county level, but estimates of demand for public supply are also developed at a facility level for 42 dominant public systems, including the largest two systems in each county.

Our demand estimates are provided and discussed in a separate report (Meyer et al., 2019). This report was completed in anticipation of a local water-supply planning committee providing review and local knowledge to improve and make more relevant the estimates.

2.2.1 Methodology

The techniques used to develop the water usage estimates differ across the five sectors. In these estimates, future water use is a function of demand drivers and, for many sectors and subsectors, explanatory variables. Explanatory variables are variables influencing unit rates of water demand, such as summer-season temperature and precipitation, median household income, marginal price of water, employment-to-population ratio, labor productivity, and precipitation deficit during the irrigation season. For most sectors and subsectors, we estimate total demand by multiplying unit rates of water demand by demand drivers. Demand drivers include such measures as population served by public systems, population served by domestic wells, number of employees, gross thermoelectric power generation, irrigated cropland acreage, irrigated golf course acreage, and head counts of various livestock types.

We employ available data and analyses to estimate plausible future values of demand drivers, explanatory variables, and unit rates of water demand. For each sector, we have developed three scenarios of future water demand that reflect three different sets of plausible socioeconomic and weather conditions. These include a less resource intensive (LRI) scenario, a current trend (CT) (or baseline) scenario, and a more resource intensive (MRI) scenario. To estimate water demand under each scenario, we use differing sets of justifiable assumptions regarding future values of explanatory variables, unit rates of water demand, and/or demand drivers. A “normal” climate, based on 1981-2010 climate means, is assumed in all scenarios. **Although our estimates suggest a plausible range of future demand, they do not represent forecasts or predictions, and they do not indicate upper and lower bounds of future water demand. Different assumptions or future conditions could result in predicted or actual water demand that is outside of this range.** For areas that show up as unsustainable or at-risk, we strongly recommend that the methodology used to assess these projections and perhaps additional model analyses be considered.

2.2.2 Data sources

We employ data from a diversity of sources to estimate future values of demand drivers, explanatory variables, unit rates of water demand, and—ultimately—total water demand.

Facility-level historical water withdrawal data were obtained from the IWIP database. We also made use of county-level demand data developed by the United States Geological Survey (USGS), which in turn bases its estimates for many sectors on IWIP data. Counts of domestic wells were obtained from a database maintained by the ISWS. We obtained data on historical and future values of demand drivers and explanatory variables from a variety of state and federal agencies including the Illinois Commerce Commission; Illinois Department of Employment Security; Illinois Department of Public Health; Illinois Environmental Protection Agency; Midwestern Regional Climate Center, Center for Atmospheric Science, ISWS; United States Census Bureau; United States Department of Agriculture; United States Department of Labor Bureau of Labor Statistics; and the United States Energy Information Administration.

2.2.3 Self-Supplied Water for Thermoelectric Power Generation

Demand for self-supplied water for thermoelectric power generation--i.e., for power plants fueled by nuclear fission or fossil fuels—dominates water demand in the region (Figure 3). These power plants are located along the Rock and Mississippi Rivers (Figure 2). We discuss this sector in greater detail than other sectors, partially because of its dominance of regional water demand, but also because the fate of the water used in thermoelectric power generation is critically important in understanding its impacts, and because future demand for self-supplied water for thermoelectric power generation is particularly challenging to quantify.

Water for thermoelectric power generation is used almost entirely for cooling, and because the demand for cooling water at power plants is great, most plants are sited adjacent to rivers or large surface water bodies. Cooling system design, as well as gross generation capacity, strongly influence water demand. Demand by plants using *once-through* cooling is typically greater per unit of generated electricity than by plants using *closed-loop* cooling, in which the cooling water is recirculated through heat exchangers, cooling lakes, or cooling towers at the plant. The proportion of the withdrawn water lost to evaporation, or consumed, is greater from plants using closed-loop systems, however. Less than 3 percent of the withdrawn water at plants using once-through cooling is typically consumed, mainly through evaporation (Solley et al., 1998). In plants using cooling towers in a closed-loop system, however, losses range from 30 percent in nuclear facilities to 70 percent in plants using fossil fuels (Dziegielewski et al., 2006). In both once-though and closed-loop cooling, cooling water is typically discharged to its source a short distance downstream of its point of withdrawal.

In the Rock River WSPR, demand for self-supplied water for thermoelectric power plants totaled 1,160 mgd in 2010, or 87 percent of total regional water demand of 1,332 mgd (Figure 3). The United States Energy Information Administration reports that gross electricity generation at the responsible power plants totaled 35,575,009 megawatt-hours (MWh) in 2010. Assuming an approximation of 1.05 gallons of evaporation per kilowatt-hour (KWh) of generated energy (Torcellini et al., 2003), this total suggests that consumptive loss from the 1,160-mgd demand totaled about 102 mgd in 2010, or about 9 percent of the total.

Exelon – Quad Cities Station uses a once-through cooling system, most of its withdrawal is returned to the Mississippi River, though at a higher temperature. Exelon – Byron Station uses a recirculating cooling system and thus consumes much of its withdrawal by evaporation. Exelon –

Quad Cities Station was commissioned in 1973 and Exelon – Byron Station was commissioned in 1985. Both power plants are close to their life expectancy and the long-term futures of these plants are not clear yet. The future surface water demand in the region will be greatly impacted by how long these two power plants will keep operating in the future. Working with these power plants to understand their long-term plan is critical for water demand projection and water supply planning.

Future demand for self-supplied water for thermoelectric power generation in the Rock River WSPR depends heavily on the gross generating capacity and the cooling system design of active power plants in the region. Estimation of this demand cannot be based on local demand for electricity, because electricity that is generated in the region may be sold outside the region. In fact, assuming an Illinois Commerce Commission estimate of per-capita electricity demand of 10.14 MWh/capita-year, we estimate that regional electricity demand in 2010 was only about 23 percent of gross generation in the Rock River WSPR. Figure 4 shows aggregate projected demand in the Rock River WSPR to 2060 for all sectors. From 2010 to 2060, total demand in the region decreases from 2010's usage of 1,370 mgd to 1,361 mgd under the LRI scenario, increases to 1,421 mgd under the CT scenario, and increases to 1,522 mgd under the MRI scenario The CT and LRI scenarios therefore assume, preliminarily, that regional gross thermoelectric power generation remains constant from 2010 to 2060, and that water demand continues at the 2010 level of 1,160 mgd. The MRI scenario assumes that one new gas-fired combined-cycle thermoelectric plant having a gross capacity of 1,200 MW begins operation in Lee County in 2030. This addition increases regional water demand for thermoelectric power generation to 1,171 mgd.

As mentioned previously, our scenario definitions are flexible, and we seek review and guidance from local authorities regarding them. Specifically, we ask for local knowledge of the county location, gross generation capacity, likely operation start date, and cooling system design of proposed thermoelectric power generation facilities. We also seek information on plans to retire power plants or individual generators.

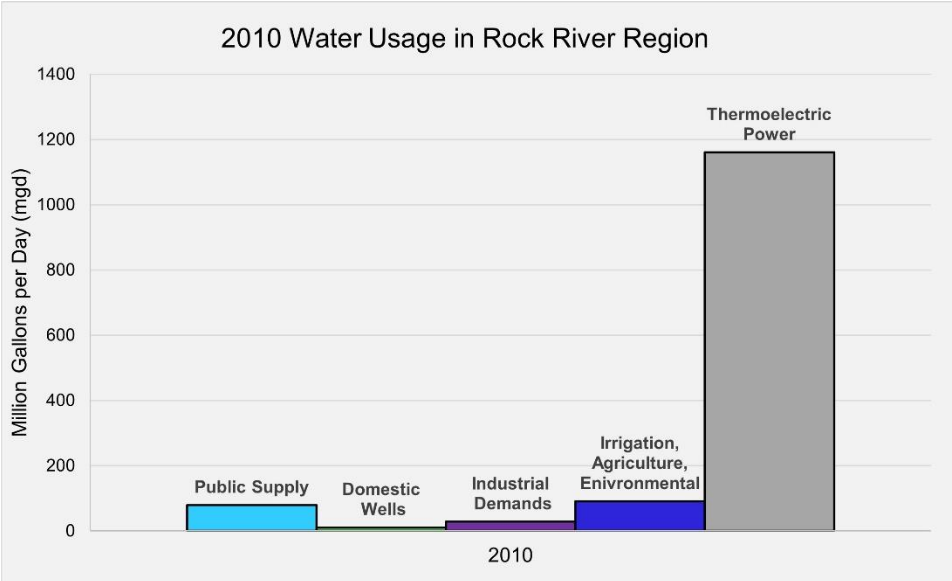

Figure 3. 2010 water usage in the Rock River WSPR, with a weather normalized demands to account for unreported usage in the irrigation, agriculture, and environmental sector.

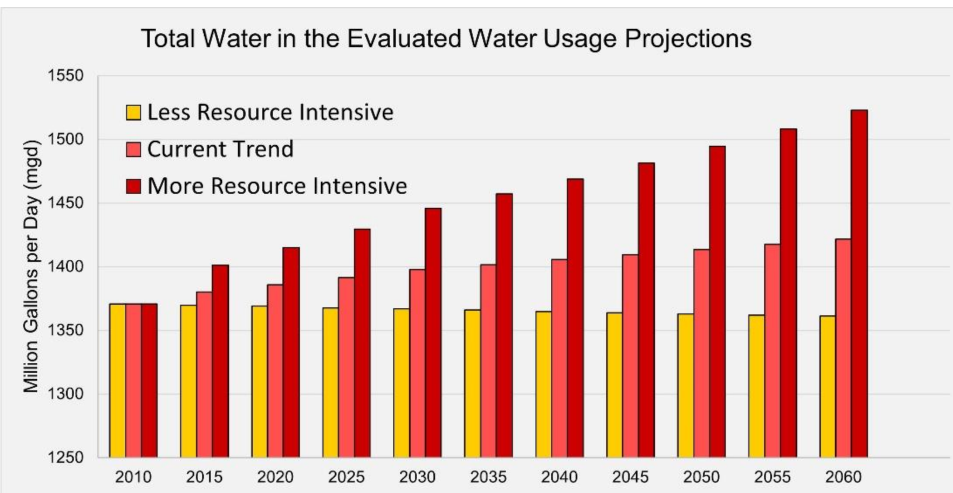

Figure 4. Climate normalized historical (2010) and projected (2015-2060) water demand in Rock River WSPR for all demand sectors.

2.2.4 Other Water-Demand Sectors

The remainder of this section discusses demand in the other four water-demand sectors considered in our analysis. These include public supply; self-supplied domestic; self-supplied industrial and commercial (IC); and self-supplied irrigation, livestock, and environmental (ILE). The environmental subsector included within ILE sector includes water used to support environmental amenities such as wetlands, forest and prairie preserves, park districts, and game farms.

Figure 5 shows demand in 2010 based on published USGS estimates (Maupin et al., 2014) and withdrawal data reported to IWIP. The demand in Figure 6 is climate-normalized, corrected for unreported values in the ILE sector. We estimate 2010 climate-normalized Rock River WSPR demand at 210 mgd, higher than the reported total of 171 mgd. Demand by public water systems in 2010 totaled 79 mgd, or 6 percent of total demand, with Winnebago County accounting for the largest share, 39 percent, of total public system demand. Reported self-supplied ILE demand totaled 52 mgd, or 4 percent of regional demand, with a climate-normalized value increased to 91 mgd. Whiteside County accounted for the greatest share, 40 percent, of regional self-supplied ILE demand. Most of the ILE usage supplies water for irrigation via center pivots. Demand by self-supplied IC establishments in the Rock River WSPR totaled 28 mgd, or 2 percent of the total demand of 1,332 mgd, with Rock Island County accounting for about 50 percent of self-supplied IC demand. Self-supplied domestic demand totaled 11 mgd, about 1 percent of regional demand. Regional water demand in 2010, not including the self-supplied demand for thermoelectric power generation, totaled 171 mgd.

Figure 6 shows the projected demand with the exclusion of water for self-supplied thermoelectric power generation. From 2010 to 2060, demand in the region decreases from 2010's usage of 210 mgd to 201 mgd under the LRI scenario, increases to 261 mgd under the CT scenario, and increases to 351 mgd under the MRI scenario. Use of a climate-normalized estimate of 2010 demand—one in which we use the methods of this study to estimate public supply and ILE demand in 2010 under 1981-2010 normal climate—permits meaningful comparison of estimates of future demand with present demand as represented by 2010 socioeconomic conditions. Our 2060 LRI total is 4 percent less than the 2010 climate-normalized total, whereas the CT and MRI totals are, respectively, 24 percent and 67 percent greater than the 2010 climate-normalized total. Figures 7, 8, and 9 show climate-normalized demand for each sector (omitting thermoelectric power generation) under each scenario. They show that the greatest proportion of water demand in the region will, under 1981-2010 normal climate, be within the self-supplied ILE sector, which is dominated by irrigation demand. Under the CT and MRI scenarios, most of the increase in total demand is accounted for by increases in self-supplied ILE demand.

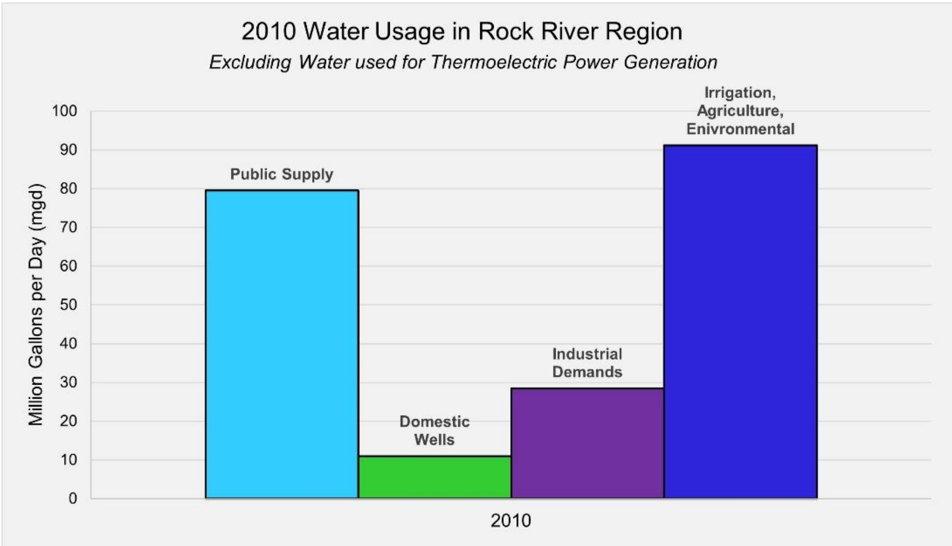

Figure 5. 2010 water usage (normalized) in the Rock River WSPR excluding demands for thermoelectric power generation.

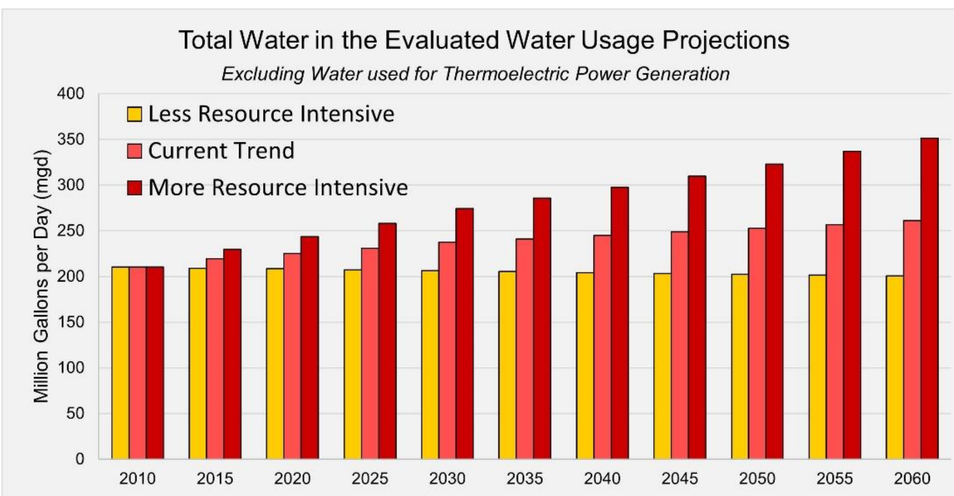

Figure 6. Climate normalized historical (2010) and projected (2015-2060) water demand in Rock River WSPR excluding demands for thermoelectric power generation.

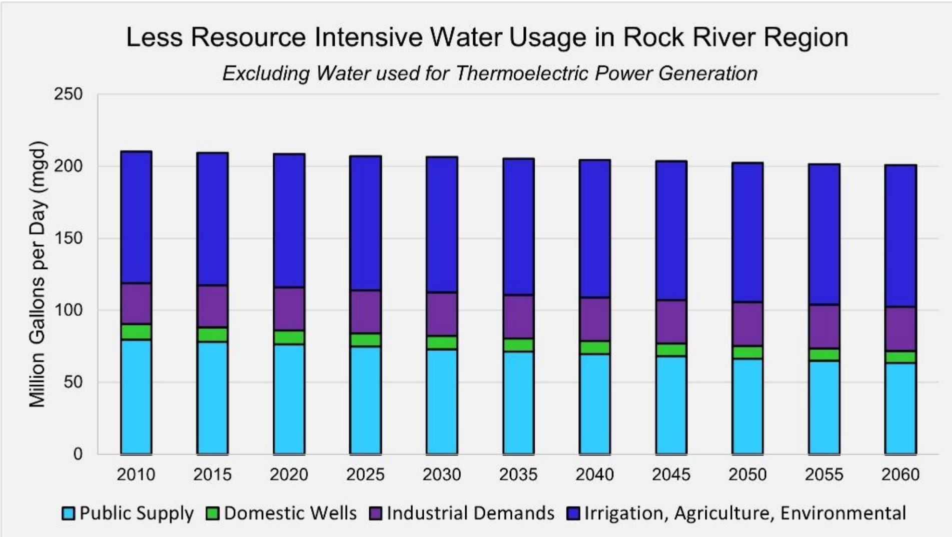

Figure 7. Climate-normalized historical (2010) and projected (2015-2060) water demand in Rock River WSPR for all demand sectors except self-supplied thermoelectric power generation, LRI scenario.

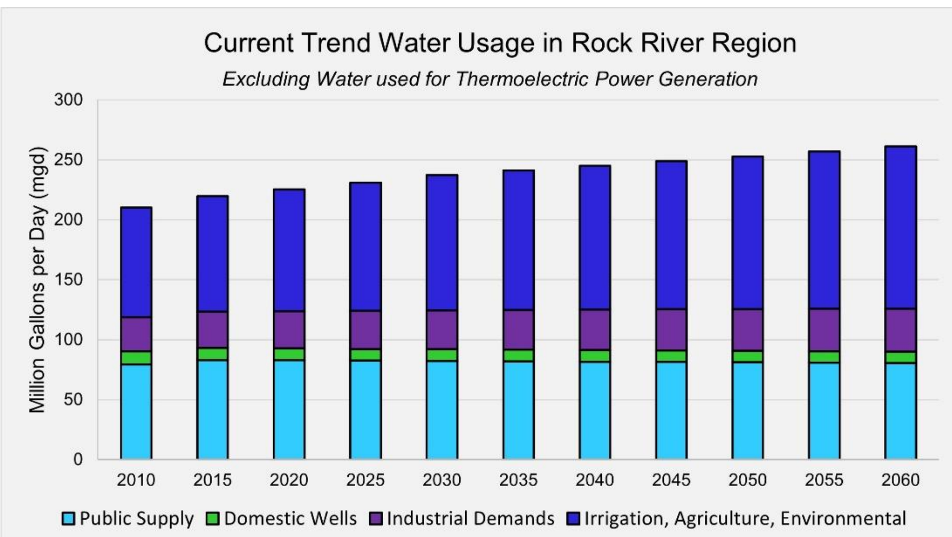

Figure 8. Climate-normalized historical (2010) and projected (2015-2060) water demand in Rock River WSPR for all demand sectors except self-supplied thermoelectric power generation, CT scenario.

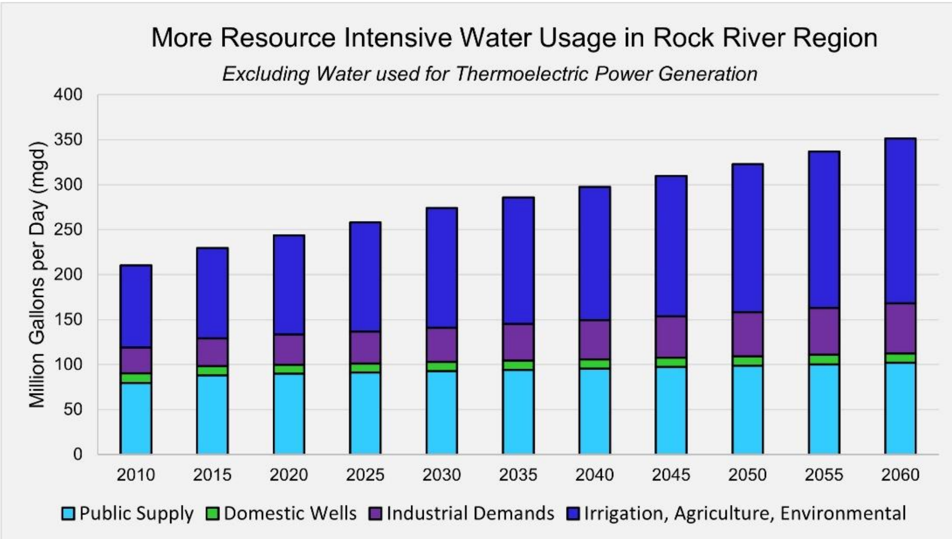

Figure 9. Climate-normalized historical (2010) and projected (2015-2060) water demand in Rock River WSPR for all demand sectors except self-supplied thermoelectric power generation, MRI scenario.

3 Groundwater Studies in the Rock River Region

3.1 Geology

The geology of the Rock River region is diverse, but three classes of aquifers are most important for purposes of major water supply:

1) The deep Cambrian-Ordovician sandstone aquifer system
2) Shallow bedrock aquifers, either weathered carbonate or sandstone at the bedrock surface
3) Unconsolidated sand and gravel aquifers

3.1.1 Cambrian-Ordovician Sandstone Aquifer System

Deep sandstone aquifers are an important source of water in the northern half of Illinois (Abrams et al., 2015). Sandstone is a sedimentary rock composed of sand-sized grains with significant primary intergranular porosity. In other words, the pore spaces between grains in the sandstone are comparatively large and generally interconnected. Sandstone can also develop secondary fractures which can further increase permeability, and well treatment often attempts to enhance these fractures to boost local permeability and reduce drawdown when a well is pumping. Since the major sandstone aquifers in northern Illinois are Cambrian or Ordovician in age, they are collectively referred to as the Cambrian-Ordovician sandstone aquifers.

The sandstone aquifers are contained within a sequence of bedrock layers in Illinois. The intervening layers, referred to as aquitards, are generally composed of shale, siltstone, and unweathered carbonates. The aquitards that separate the individual sandstone aquifers generally have lower permeability and impede the vertical flow of groundwater. ISWS studies suggest that some of these layers may provide considerable water from storage, but further investigation is required to confirm (Mannix et al., 2019). A simplified cutaway of the geology is depicted in Figure 10. The cutaway runs through Lee and Whiteside counties near the western edge of the cross-section (near A). Note that this diagram refers to hydrostratigraphic units, each lumping similar geologic material into a single layer. This is primarily done to simplify the geologic framework of groundwater flow models.

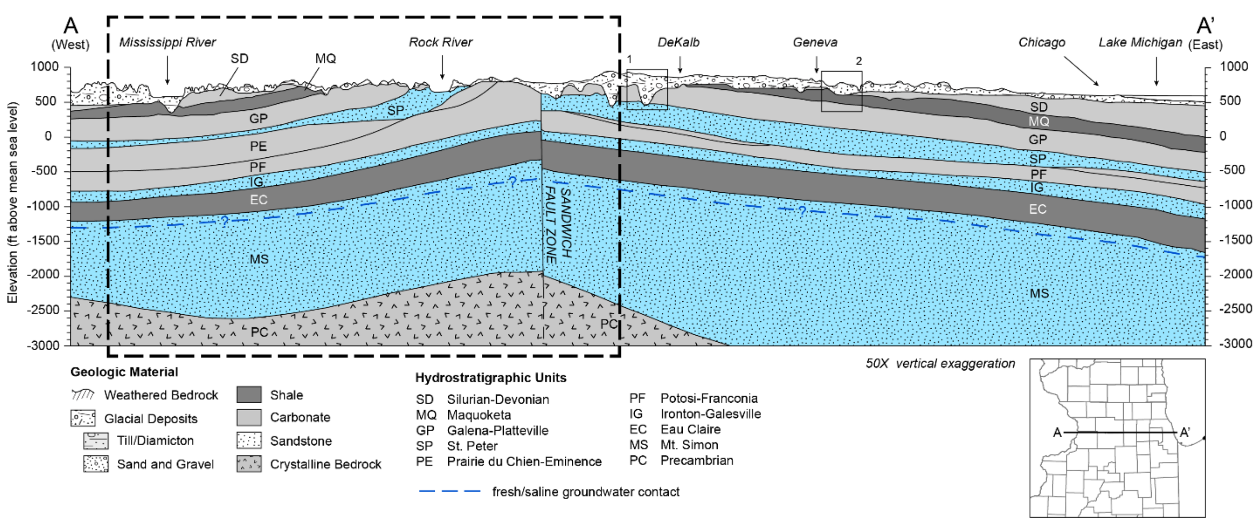

Figure 10. Generalized geologic cross-section of the Cambrian-Ordovician sandstone aquifers (St. Peter-SP, Ironton-Galesville-IG). The Rock River Region is represented by the area enclosed by the dashed line. Modified from (Abrams et al., 2015).

Two sandstone aquifers are of interest in the region, the uppermost St. Peter and the lower Ironton-Galesville. The St. Peter Sandstone consists mostly of well-sorted and well-rounded quartz sand and is at bedrock surface in portions of north-central Illinois (Figure 11). Shale layers (mostly the Maquoketa and Pennsylvanian-Mississippian) overly the sandstone in the southern portion of the Rock River Region (Figure 11), greatly impeding vertical infiltration to the St. Peter Sandstone and deeper.

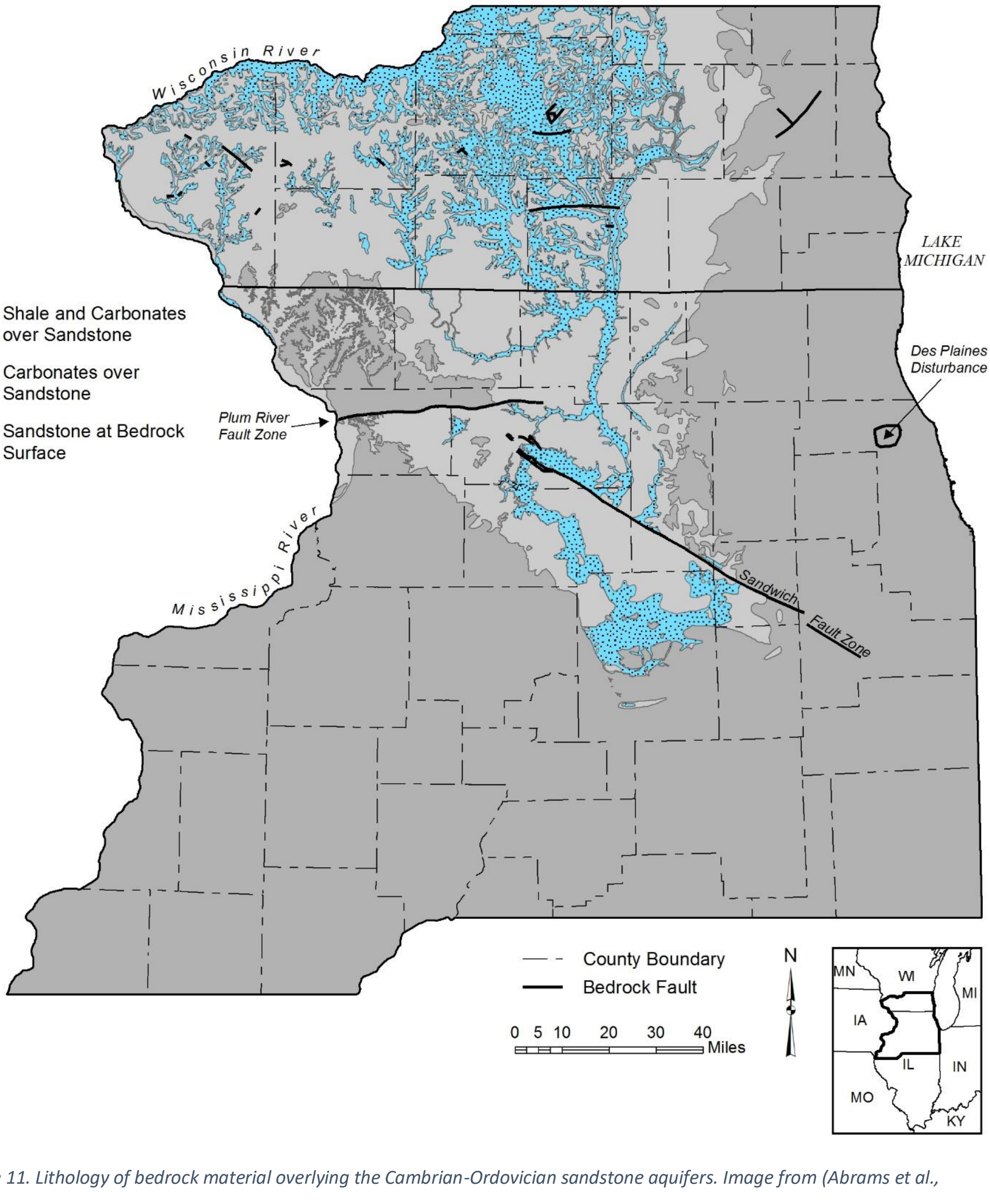

Figure 11. Lithology of bedrock material overlying the Cambrian-Ordovician sandstone aquifers. Image from (Abrams et al., 2015).

The Ironton-Galesville Sandstone consists of well-rounded quartz sand grains similar to the St. Peter. In the study area, the Ironton-Galesville is separated from the St. Peter Sandstone by two predominantly (unweathered) carbonate units, the Prairie du Chien-Eminence and Potosi-Franconia. These units greatly impede flow between the St. Peter and Ironton-Galesville, at least under natural conditions where artificial connections from long-open interval wells are absent. The Ironton-Galesville does not approach the bedrock surface in Illinois. As a result, vertical leakage is limited everywhere in the state, so high-capacity wells open to only the Ironton-Galesville generally pump in excess of sustainable yield, regardless of location.

A third, even deeper sandstone, the Mt. Simon, is present in the region. While it is more saline, several wells in the region are drilled into the Mt. Simon. In fact, Winnebago County withdraws 21 mgd from wells open to the Mt. Simon, although water being withdrawn is also sourced from the Ironton-Galesville in most cases. Also, four other counties (Ogle, Boone, Lee, and Whiteside) have 1-3 mgd of withdrawals from wells open to the Mt. Simon.

3.1.2 Shallow Aquifers (Sand and Gravel, Shallow Bedrock)

The unconsolidated strata of the Rock River Water Supply Planning Region comprise five distinct geomorphic regions of the State: the Wisconsin Driftless Section, Rock River Hill Country, Galesburg Plain, Bloomington Ridged Plain, and the Green River Lowland (Figure 12). Each region contains important insights into Illinois's geologic history during the Quaternary period and present unique water supply opportunities and challenges.

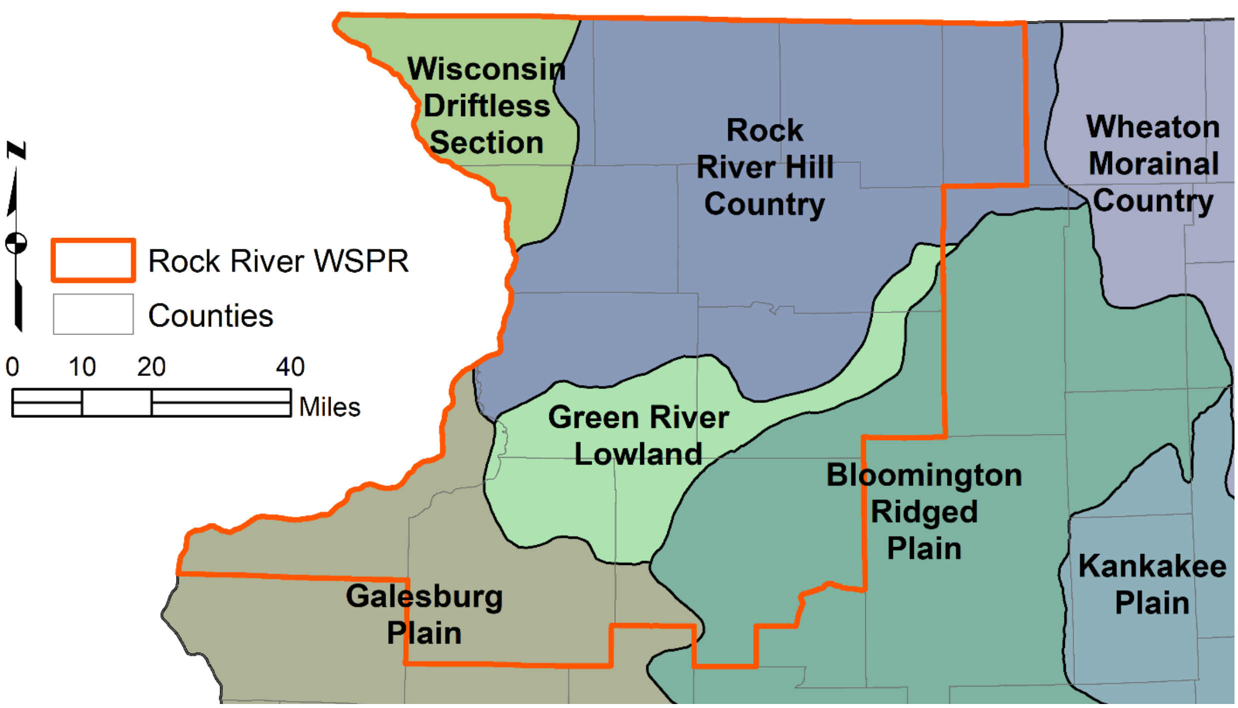

Figure 12. Geomorphic regions of the Rock River Water Supply Planning Region (Leighton et al., 1948).

The *Wisconsin Driftless Section* encompasses almost the entirety of Jo Daviess County and the northwest corner of Carroll County and is characterized by deeply carved river valleys. While there are substantive loess deposits (>50 feet thick) along the western margin of this region, most of the section's geology is characterized by hilly exposures of Ordovician- and Silurian-age bedrock. Extensive analyses of slow forming erosional clays and streambed alluvium deposits strongly support the notion that this isolated region never experienced deposition of continental glacial material during the Quaternary period (Willman et al., 1989). Existing Quaternary deposits formed as a result of outwash and eolian deposition. These deposits are too thin to provide adequate aquifer material for municipal, industrial, or irrigation use. Groundwater demand is met exclusively by shallow Ordovician carbonates or deep Cambrian sandstones.

The neighboring *Rock River Hill Country* is composed of the remainders of Jo Daviess and Carroll counties, the entireties of Stephenson, Winnebago, and Boone counties, the majority of Ogle County, and the portions of Whiteside and Lee counties that are north of the Rock River. The hilly topography of the Driftless Section is still present throughout this region. While the underlying bedrock and pre-Quaternary erosional mechanisms are similar, regional topography is more subdued due to burial by Illinoian-age (~190,000 years before present) drift deposits which are often less than 25 feet west of the Rock River and generally greater than 100 feet east of the Rock River (Knapp & Russell, 2004) and can locally approach 200 feet in thickness (Willman & Frye, 1970). Productive sand and gravel bodies are rare. However, some municipalities may supplement their water supplies from localized aquifers, such as the city of Freeport in Stephenson County. Regionally, water supplies are primarily sourced in deep Cambrian sandstone strata. In addition, localized pockets of sand and gravel in Winnebago County are sufficient to support limited irrigation demand.

Illinoian glacial drift deposits also blanket the *Galesburg Plain*, which is composed of Rock Island County, the southwestern three quarters of Henry County, and a small portion of southwestern Bureau County. The flatter geomorphology of this section compared to the Rock River Hill Country is due to the younger shales and sandstones (less resistant to glacial erosion) that compose the local bedrock, and the relative distance from the glacial source (Willman & Frye, 1970). The generally flat topography of the region is interrupted by incised stream valleys with local relief of 50-75 feet. Except for localized pockets, unconsolidated material is generally less than 50 feet in thickness. The bulk of water demands in this region are met by the Mississippi River and bedrock sources.

The formation of the *Bloomington Ridged Plain* is also the consequence of glacial processes. However, in this case, deposition occurred during the Wisconsin Glaciation. Because this region is geologically younger, and overlies Illinoian deposits, unconsolidated thickness is significantly greater. In the study region, the Bloomington Ridged Plain comprises the southeastern portions of Lee and Bureau Counties and is characterized by nearly flat to gently rolling topography crossed by low and broad end moraines. Although water demand is met primarily by bedrock sources, many communities supplement their water supply from unconsolidated aquifers. Agricultural irrigation that utilizes groundwater is present, but not prevalent.

The remaining geomorphic region, the *Green River Lowlands*, comprises the southeastern corner of Ogle County, a sliver down the center of Lee County, the southern half of Whiteside County and portions of northern Bureau and Henry counties. This region formed from outwash from the Illinois and Wisconsin glaciations, and from the interglacial clays and eolian deposits of both episodes. The geomorphology of the region is comprised of a low lying, poorly drained plain with prominent sand ridges and dunes (Willman & Frye, 1970). The thickness and transmissivity of unconsolidated aquifers in the Green River Lowlands enable the region to meet municipal, industrial, and agricultural water demands almost exclusively with shallow groundwater. While supply is currently adequate and yearly recharge is sufficient to buffer against long-term decline in water levels, continued monitoring is needed to ensure demands due to severe drought do not overwhelm regional recovery. Furthermore, areas with thick, or unusually low conductivity, confining layers and growth in center pivot installation may be susceptible to extreme drawdowns even under “normal” precipitation conditions. These concerns can lead to short-term supply interruptions and long-term economic, water supply, and geologic consequences. The hydrogeology of this region will be explored in greater detail in Section 3.3.

3.1.3 Geologic controls on available water supply: Transmissivity

When developing groundwater analyses, the complex geologic history of the region is quantified as transmissivity. Transmissivity, which has units of square feet per day (or frequently gallons per minute per foot), quantifies the potential for flow of groundwater through an aquifer, all else (such as pumpage and proximity to surface water) being equal. As a rule of thumb, the higher the transmissivity, the more water that can be extracted. For a starting analysis, a transmissivity map provides guidance into understanding of where, on a regional scale, groundwater availability would likely be greater (Abrams et al., 2018).

The shallow unconsolidated geologic material of the Rock River region has localized pockets of very high transmissivity (Figure 13). Blue areas in this map indicate where sand and gravels are present and transmissivity values are greater; red areas indicate where finer grained material are present and transmissivity is limited. Regionally, the shallow bedrock aquifers of the region are more limited in transmissivity (Figure 14), although locally secondary porosity may conduct greater quantities of water than indicated by the map in Figure 14.

Where these two shallower aquifers cannot support water demands, the deep sandstone aquifers are commonly utilized. Regionally, this aquifer has a relatively constant low transmissivity (Figure 15), around 2,000 ft^2/day based on previous modeling exercises (Abrams et al., 2018). However, the deep sandstone under predevelopment conditions had built up considerable pressure resulting in hundreds of feet of available head above the top of the sandstone. In many cases throughout Illinois, the first wells drilled into the deep sandstone had water levels above land surface, resulting in flowing artesian wells. This initial large available head allows for the extraction of groundwater with few immediate implications. Where the sandstone is overlain by shale, water removed is not immediately replaced by precipitation; as a result, withdrawals often exceed sustainable yield. Water supply issues can certainly manifest, as has occurred in northeastern Illinois (Abrams & Cullen, 2020), but it can take decades, centuries, or longer depending on how much sustainable yield is exceeded.

The total transmissivity available to a community can be calculated by summing the transmissivity from the three major aquifer systems (sand and gravel, shallow bedrock, and deep sandstone), and is shown in Figure 16. This map mimics the transmissivity from the sand and gravel aquifers, particularly the high locations, but note that the reds in Figure 16 are lighter than in Figure 13. This is an important distinction, because lighter red areas might be sufficient to support relatively small demands.

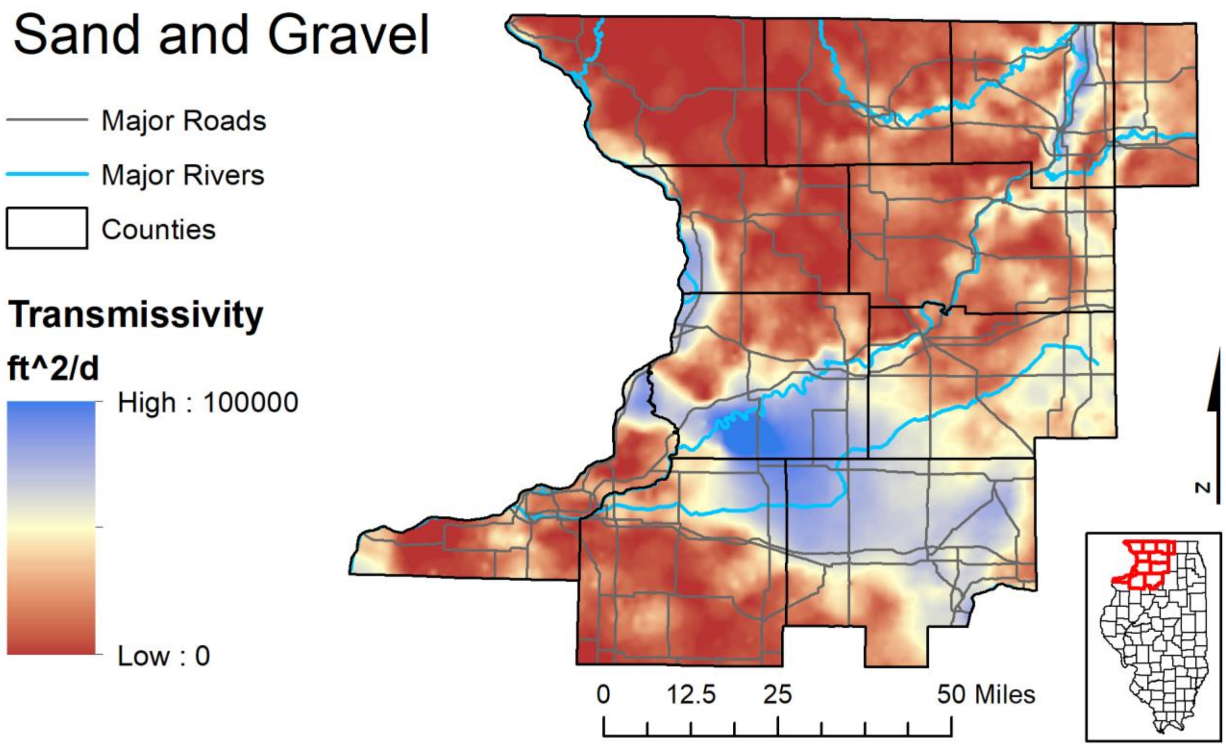

Figure 13. Transmissivity of the shallow sand and gravel aquifers of the Rock River Region.

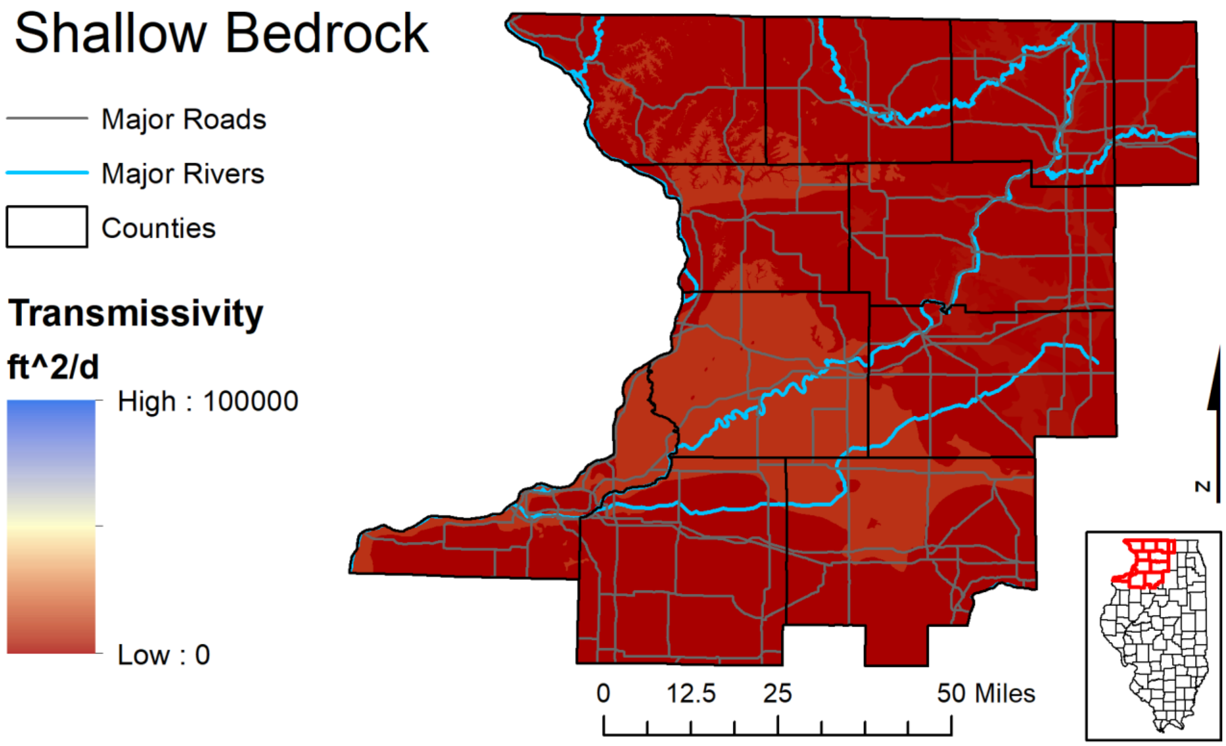

Figure 14. Transmissivity of the shallow bedrock aquifers of the Rock River Region.

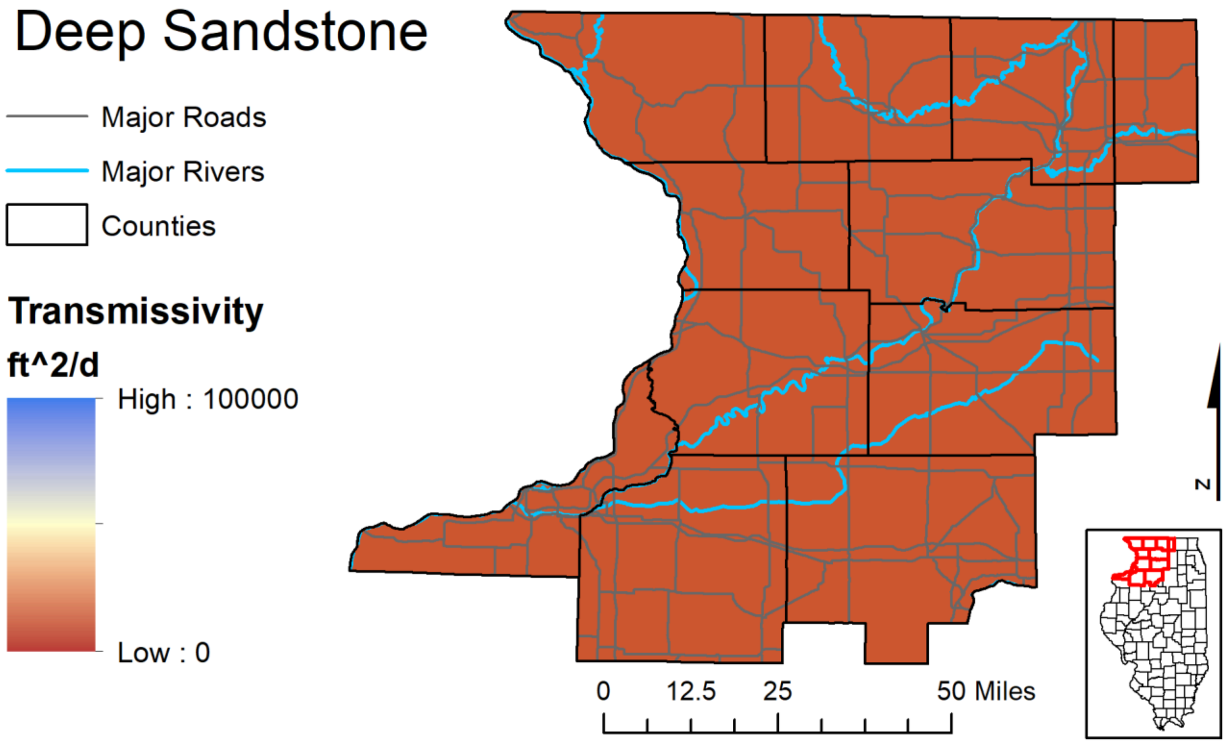

Figure 15. Transmissivity of the deep sandstone aquifers of the Rock River Region. This is assumed to be generally constant, with a transmissivity of 2000 ft^2/day.

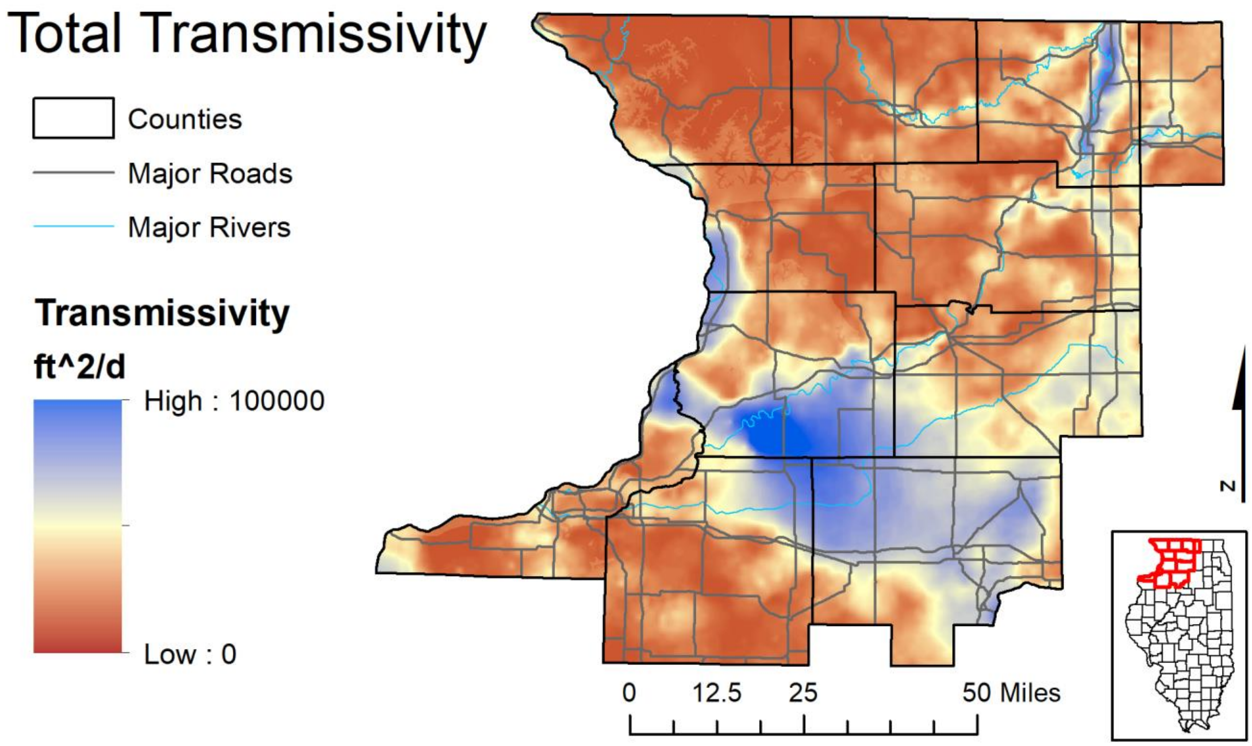

Figure 16. Total transmissivity of the Rock River Region.

3.2 Rockford Supply

The City of Rockford and the surrounding region have plentiful groundwater resources including the shallow alluvial aquifer system that runs through the Rock River valley (labeled "Major Sand and Gravel Aquifer" in Figure 17) and two bedrock aquifers. The bedrock aquifers are the deep Cambrian-Ordovician aquifer system found throughout the region, and the shallow Ordovician-aged Galena-Platteville system found in the highlands surrounding the valley (Figure 17). Due to this abundance of water resources and its unique geology, the Rockford area has long been a region of interest for both the ISWS and ISGS with reports dating back to 1897.

The story of groundwater in Rockford comes in two parts: water quantity and water quality. Groundwater resources in the Rockford area are relatively plentiful and careful planning can help ensure the sustainable use of the aquifers. The area has records of naturally good groundwater quality dating back to 1897 (Palmer, 1897), but with the rise of industry and poor disposal practices throughout the 20th century, there is now contamination at several sites in the Rockford area (Clarke & Cobb, 1988). Water supply planning efforts in the region should be informed on both the quantity and quality of the region's water resources while being conscious of how groundwater use impacts natural systems.

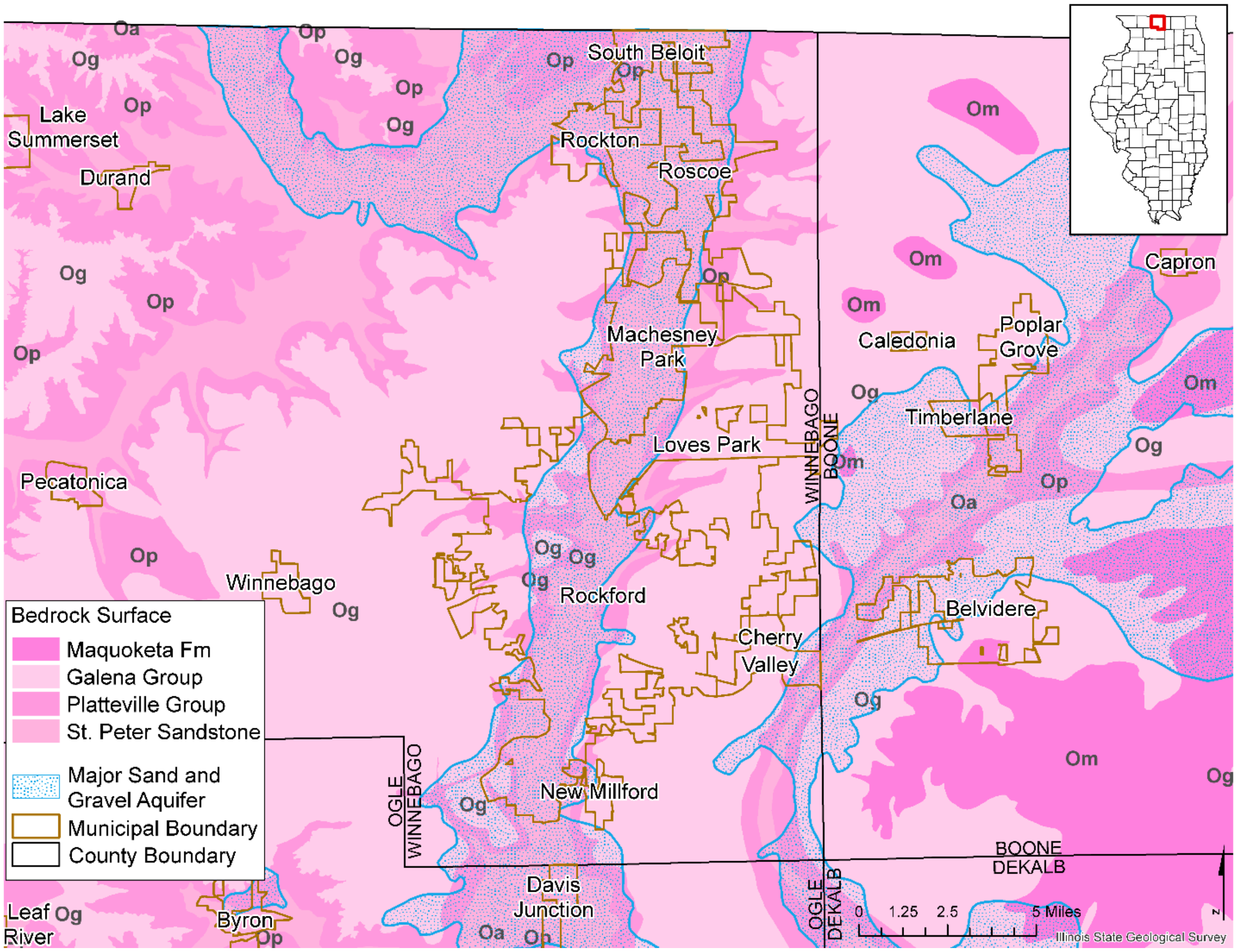

Figure 17. Bedrock surface and the major sand and gravel alluvial aquifer in the Rockford area.

3.2.1 Rockford Water Quantity

Of the aquifers present in the Rockford area, there are two types: the unconsolidated, unconfined aquifer of the Rock River valley (made up of glacial and riverine sands and gravels) and two bedrock aquifers. The bedrock aquifers are (1) the Cambrian-Ordovician system, which is the deeper of the two and is comprised of sandstones and dolomites, and (2) the Galena-Platteville system, which is shallower and is comprised primarily of dolomite. The Cambrian-Ordovician aquifer is present throughout the Rockford area, but is at the bedrock surface and in direct contact with overlying alluvial sand and gravel deposits only in the Rock River Valley where the Galena-Platteville was eroded (Figure 17). The Galena-Platteville aquifer is present in the highlands surrounding the Rock River valley where it overlies the Cambrian-Ordovician system. These relationships play a major role in the interconnectivity of the aquifers and the movement of water and contaminants.

Because the alluvial aquifer is shallow, unconfined, and in direct contact with the Rock River, it has a high degree of interconnectivity with surface processes. On average, groundwater discharges to the Rock River, although under periods of high flow or where nearby extraction wells are present, the Rock River likely loses water to the aquifer. Precipitation infiltrates and directly recharges the alluvial aquifer. Due to this high recharge rate and the transmissive nature of both the alluvial and the Cambrian-Ordovician aquifers, the Cambrian-Ordovician can receive a high degree of leakage from the overlying alluvial aquifer.

The same cannot be said for areas outside of the Rock River valley where the Cambrian-Ordovician is overlain by the Galena-Platteville aquifer. Though the upper Galena-Platteville is highly fractured and consequently more transmissive, the lower portion of the system remains unfractured and therefore functions as an aquitard restricting leakage to the Cambrian-Ordovician. This means pumping of the Cambrian-Ordovician where it is overlain by the Galena-Platteville aquifer will see a higher degree of drawdown over time (i.e., a larger cone of depression) than pumping of either the alluvial aquifer or the Cambrian-Ordovician where it is overlain by the alluvial aquifer.

These conclusions are supported by the historical record of water levels reported by the City of Rockford for wells numbered 1, 6, and 30 analyzed by the ISWS in a 2015 report titled *Changing Groundwater Levels in the Sandstone Aquifers of Northern Illinois and Southern Wisconsin: Impacts on Available Water* (Abrams et al., 2015). Data in this analysis are from regular synoptic water level measurements carried out by the ISWS across the state. In this report, Wells 1 and 6 are finished in the Cambrian-Ordovician aquifer within the Rock River Valley where it is overlain by the alluvial aquifer (Figure 18). Well 30 is also finished in the Cambrian-Ordovician but is located to the east of the Rock River Valley, where the Cambrian-Ordovician is overlain by the Galena-Platteville system. Wells 1 and 6 had little drawdown (< 50 ft) over more than 70 years of pumping (approximately 1941 to 2014), while well 30 had much greater drawdown (>100 feet) in less than 45 years of operation (approximately 1970 to 2014).

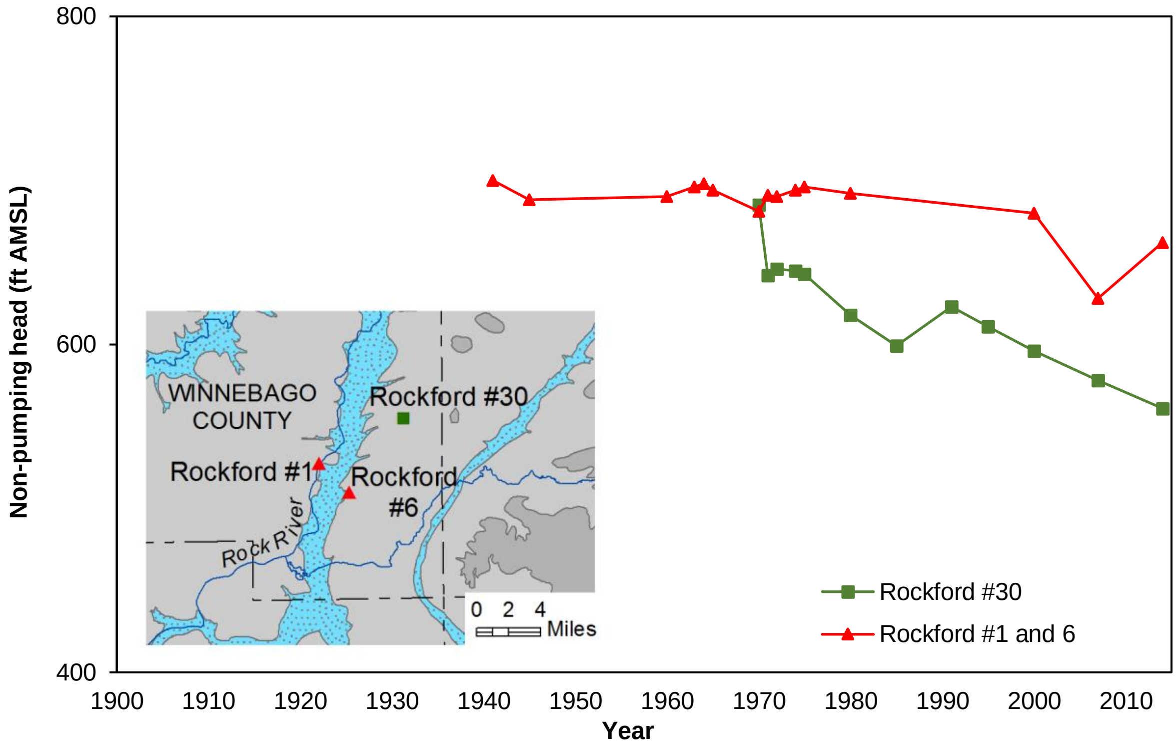

Figure 18. Water levels in Rockford Cambrian-Ordovician wells 1, 6, and 30. Adapted from (Abrams et al., 2015).

Generally, well depth at a given location is dependent on which is the shallowest productive aquifer at that location. The location of the public water supply wells in the Rockford Area reflect this dependency (Figure 19). Sand and gravel wells are the dominant well type in the area of the Rock River valley alluvial aquifer, with some Cambrian-Ordovician wells interspersed. Likewise, the dominant well setting for the area outside of the Rock River valley is in the deeper Cambrian-Ordovician system rather than the less productive shallow bedrock Galena-Platteville aquifer.

The ISWS has analyzed groundwater levels of wells of the Cambrian-Ordovician aquifer system and produced maps of drawdown in the aquifer for northern Illinois (Abrams et al., 2015). As may be expected with the distribution of wells in Figure 19, much of the drawdown in the Cambrian-Ordovician system in the Rockford area is concentrated to the east of the Rock River valley where it is overlain by the Galena-Platteville (Figure 20). Drawdowns in this area reach as much as 100 to 200 feet from estimated pre-development levels (1863) to 2014.

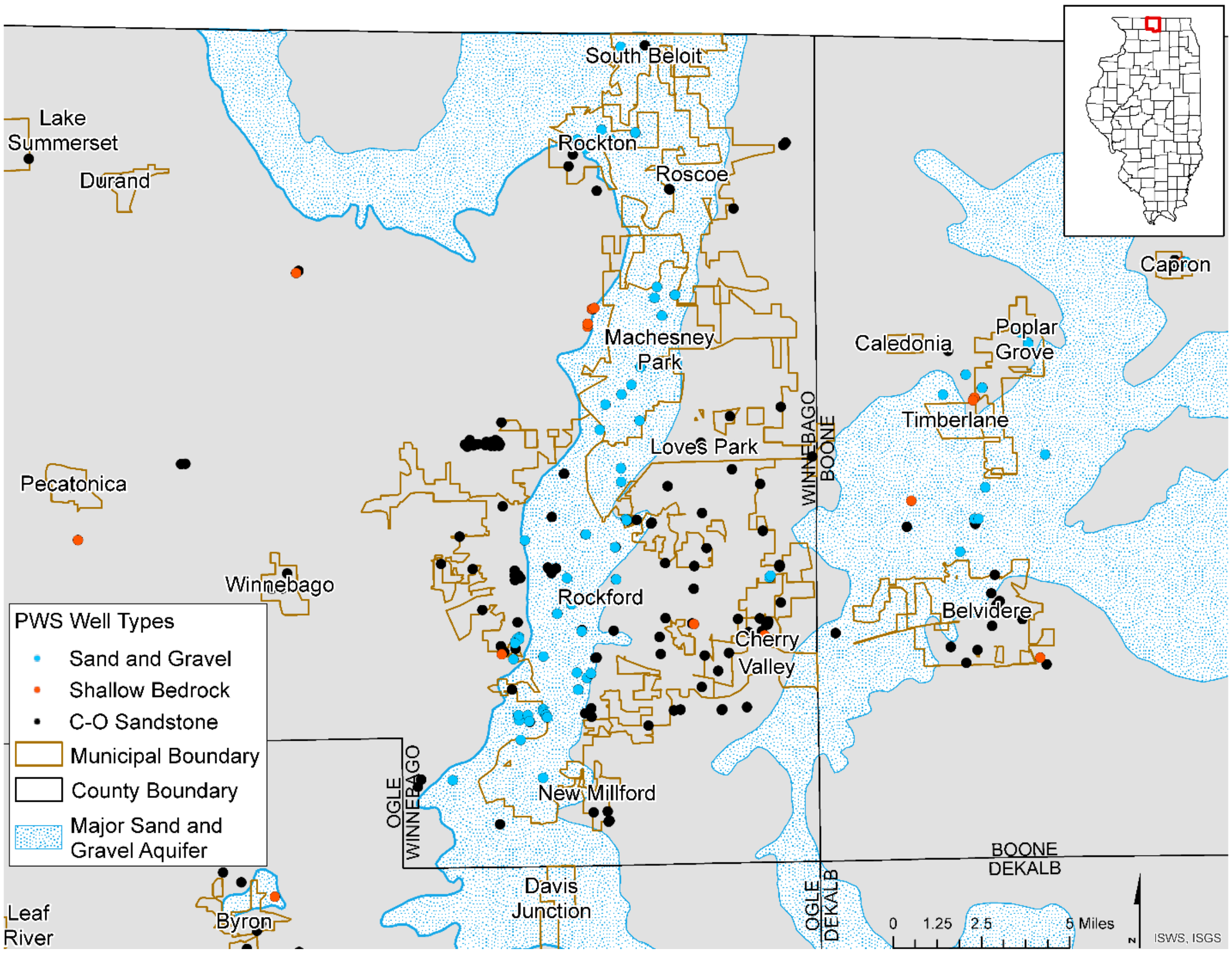

Figure 19. Different types of public water supply wells in the Rockford area.

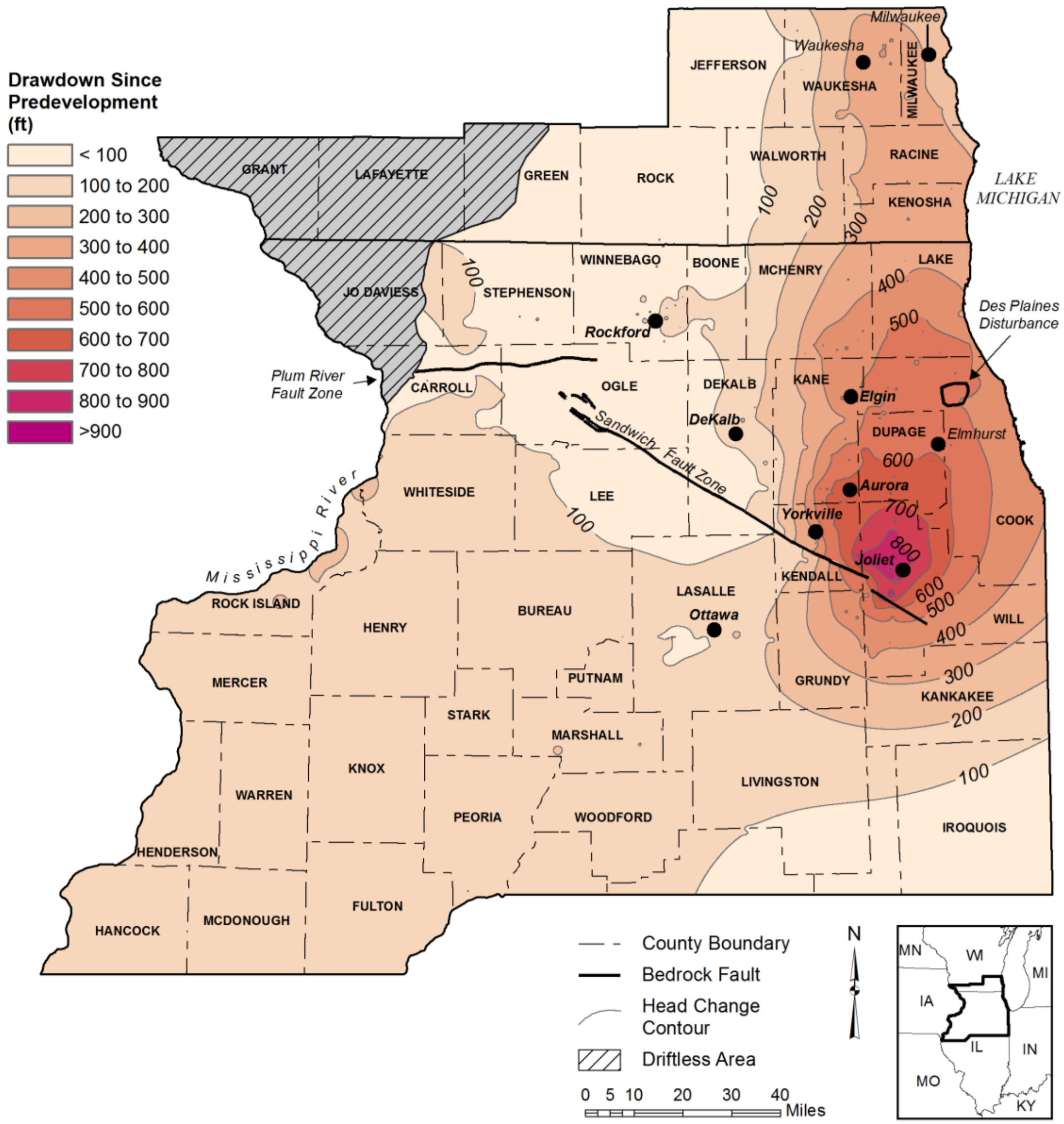

Figure 20. Drawdown in the Cambrian-Ordovician aquifer system across Southern Wisconsin and Northern Illinois. Figure adapted from (Abrams et al., 2015).

Preliminary analyses of historic water level measurements indicate that long-term trends in water levels in the Cambrian-Ordovician system differ based upon their geographic location. To the east of the Rock River, most water levels in Cambrian-Ordovician wells are either stable or decreasing (Figure 21a). To the west of the Rock River water levels in most Cambrian-Ordovician wells are either stable or increasing (Figure 21b). Wells in the shallow alluvial aquifer are more sensitive to surface conditions such as precipitation and the stage of the Rock River, and exhibit increasing trends with greater noise (Figure 22). A preliminary analysis of 23 of the City of Rockford's wells reveals that five have increasing water levels, seven have decreasing levels, eight are stable, and three exhibit no discernible trend (levels vary greatly over the period of record) (Table 2).

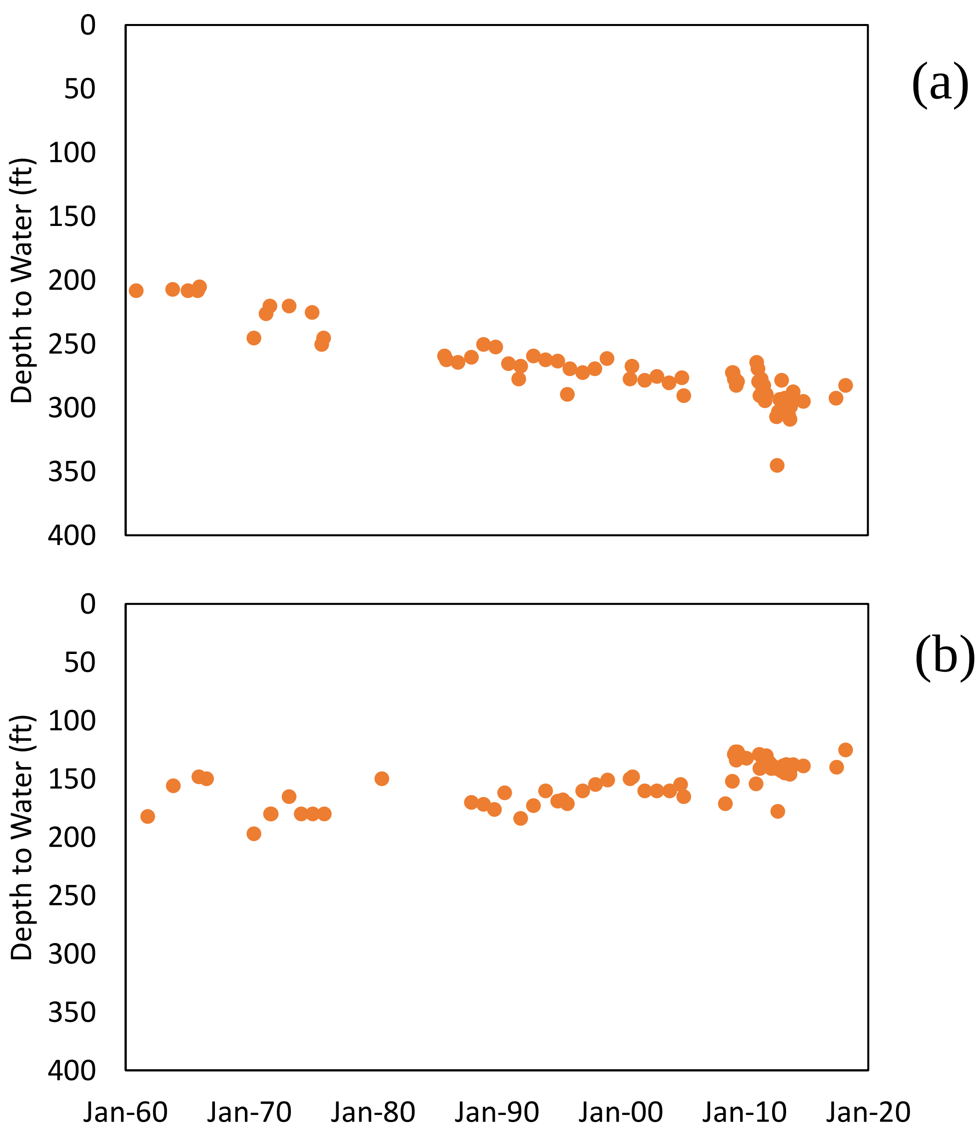

Figure 21. Water levels in the Cambrian-Ordovician system at Rockford. (a) Well #10 east of the Rock River and (b) Rockford Well #18 west of the Rock River.

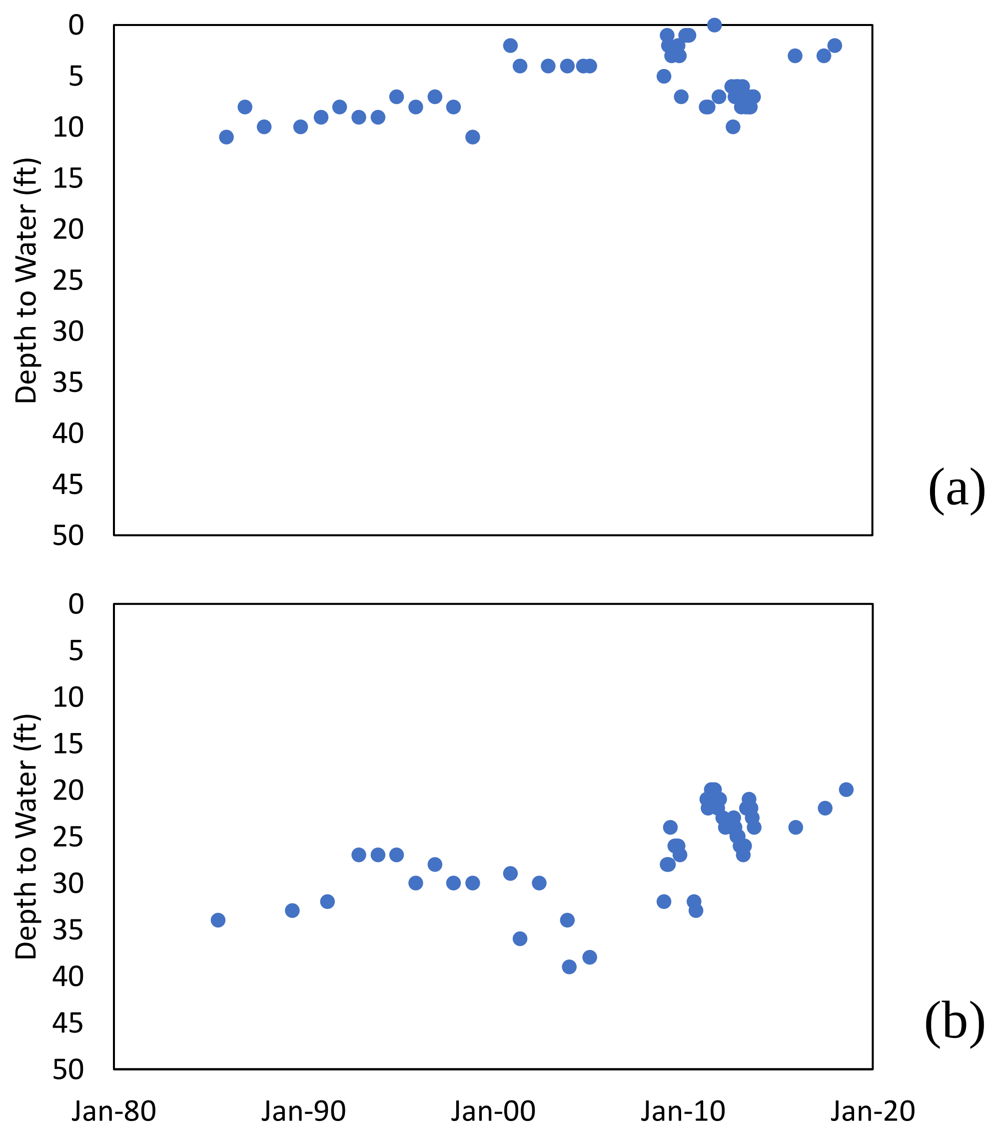

Figure 22. Water levels in the alluvial aquifer at (q) Rockford Well #23 and (b) Rockford Well #35.

Table 2. Water level trends of 23 selected City of Rockford wells. Orange indicates a Cambrian-Ordovician well to the west of the Rock River, blue indicates a Cambrian-Ordovician well to the east, and white indicates an alluvial aquifer well within the Rock River valley. Asterisks denote wells that need further investigation to confirm records.

Well	Increasing	Decreasing	Stable	No Trend
3			X	
18	X			
21	X*			
22		X*		
34	X*			
37			X	
44				X
23	X			
24				X*
35	X			
5		X		
6			X	
10		X		
13			X	
26			X	
29		X		
30		X		
31		X		
36			X	
39				X
40			X	
42			X*	
43		X		

These apparent trends in water levels may be due in part to the observed changes in pumpage for both the City of Rockford and Winnebago County as a whole. Since 1979, the ISWS has collected information on the pumping of groundwater across the state via IWIP. The City of Rockford's pumping has steadily declined from 32 mgd in 1979 to 16 mgd in 2019 (Figure 23). These reductions in pumpage may help explain why water levels in the majority of wells assessed were found to either increase or remain stable despite ongoing pumping.

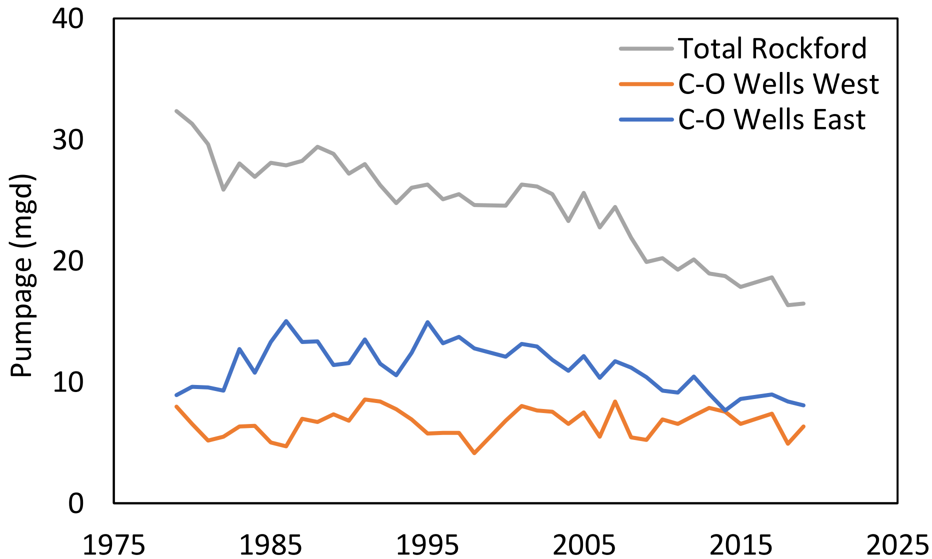

Figure 23. Total pumping (including alluvial aquifer pumping), Cambrian-Ordovician pumping west of the Rock River valley (orange), and Cambrian-Ordovician pumping east of the Rock River valley (blue) reported by the City of Rockford through IWIP from 1979 to 2019.

In a 2019 report from the ISWS, Meyer et al. (2019) examined future water demands out to 2060 for the Rock River WSPR. The Rock River WSPR is comprised of eleven counties including Winnebago County and the Rockford area. Three future water demand scenarios were developed based on different socioeconomic outlooks for the region (Meyer et al., 2019). These scenarios are known as Less Resource Intensive (LRI), Current Trend (CT; based off 2010 water use), and More Resource Intensive (MRI). For Winnebago County, the MRI scenario estimates a 31% increase in water demand (35 mgd in 2010 to 45 mgd in 2060), the CT scenario analyzes a 4% increase (35 mgd in 2010 to 36 mgd in 2060), and the LRI scenario looks at a 16% decrease (35 mgd in 2010 to 29 mgd in 2060). Scenario water demands from 2010-2060 are presented in Figure 24.

Water supply planning in the Rockford area, specifically of water quantity, should consider the geographic location of demand increases and how well depth and location can affect drawdown. If, for example, total water demands remain constant but demands in the Cambrian-Ordovician system increase where it is overlain by the Galena-Platteville system, this might require further study to assess risk to both water quantity and water quality.

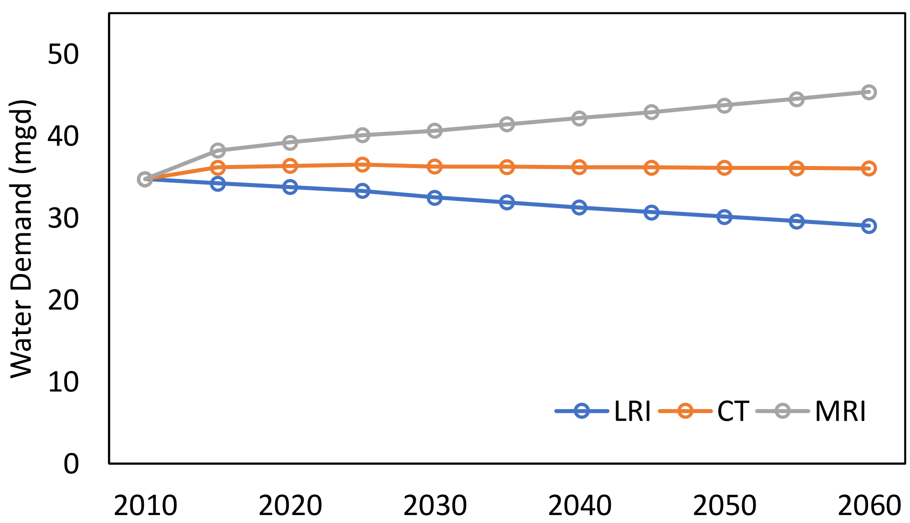

Figure 24. Water Demand for Winnebago County from (Meyer et al., 2019).

3.2.2 Rockford Water Quality

The risk of groundwater contamination is enhanced by the highly transmissive nature of the sand and gravel deposits present within the Rock River valley. This risk has been realized in some parts of the Rockford area. Both state and federal agencies have worked in the past to help document and address contamination in the region. The primary contamination concern is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; commonly known as “Superfund”) site known as the Southeast Rockford Ground Water Contamination (SRGWC).

Though contamination had been ongoing since the late 1950s, the City of Rockford first discovered contaminants in municipal wells in 1981. The City found volatile organic compounds (VOCs) in the groundwater, forcing four municipal wells out of service (USEPA, 2018). VOCs were found in private residential wells soon after in 1982. Testing in the area between 1982 and 1988 found many more contaminated wells and culminated in the declaration of the SRGWC Superfund site on March 31, 1989 (USEPA, 2018). A total of 14 contaminants have been discovered in the groundwater at five different areas within the SRGWC. Much of this contamination was caused by poor industrial disposal practices (USEPA, 2018).

A USGS report described how contamination in the SRGWC was transported not only within and between the alluvial aquifer and Cambrian-Ordovician, but also within and between the less transmissive Galena-Platteville aquifer and Cambrian-Ordovician (Kay et al., 1994). Transport within the Galena-Platteville aquifer occurs via fractures that serve as flow conduits in the otherwise low conductivity substrate. These fractures can be connected between sites as far apart as half a mile (Kay et al., 1994). This is another important pathway for understanding the risks contamination poses and the factors that need to be considered when planning for water supply management in the region.

Along with the major SRGWC Superfund site, there is an additional site that falls under the jurisdiction of Superfund, six sites that fall under the Resource Conservation and Recovery Act (RCRA), and more than 80 Brownfield sites in the Rockford area (Figure 25) (USEPA, 2020a).

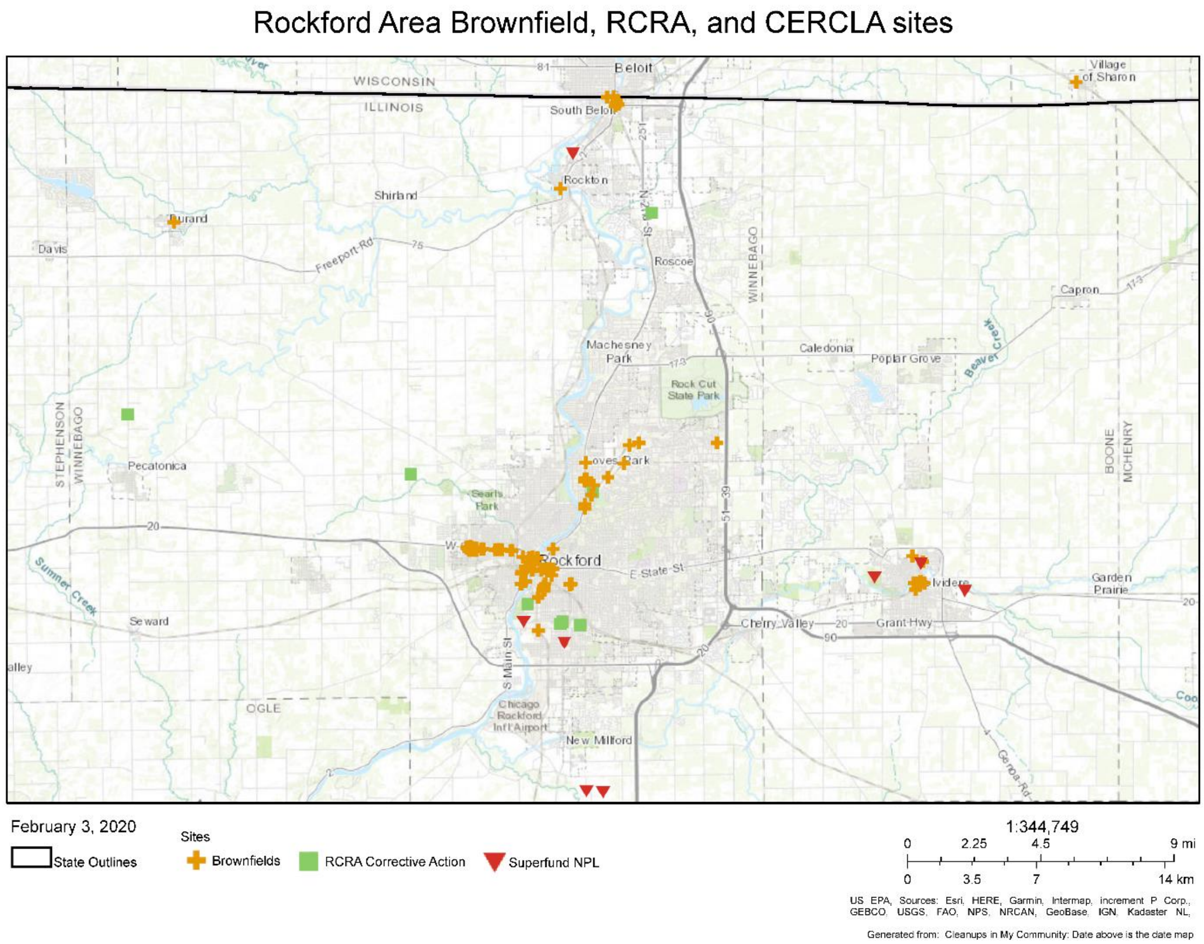

Figure 25. Brownfield; Resource Conservation and Recovery Act (RCRA); and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, Superfund) sites in the Rockford Area. (This figure was made with the USEPA's Cleanups in My Community tool available at https://www.epa.gov/cleanups/cleanups-my-community.

In a 1988 report, the Illinois Environmental Protection Agency noted that many of the contaminated deep wells in Winnebago County are near shallow wells that are also contaminated (Clarke and Cobb, 1988). In fact, at the time of the study, 90 percent of contaminated bedrock wells were adjacent to contaminated sand and gravel wells (Clarke & Cobb, 1988). This indicates there is likely a direct pathway between the shallow and deep aquifers near those sites. These pathways could be the result of direct infiltration and leakage through a hydrologic connection between the alluvial and Cambrian-Ordovician aquifers, or it could be the result of a deep well casing failing and providing a conduit for contaminant transport.

Alongside the relatively acute risks posed by industrial chemical contamination, there is also the risk of contamination of shallow groundwater by runoff from the application of road salt and nitrate contamination from agricultural and residential sources. Chloride and total dissolved solids (TDS) contamination of streams and shallow aquifers in snowy climes have been reported throughout the United States, Canada, and Europe. An ISWS report studied the effect of road salt runoff on groundwater quality in Kane County in the Chicago, Illinois region (Kelly et al., 2016). They found excessive and increasing levels of chloride from road salt runoff that in some cases exceeded the USEPA's secondary maximum contaminant level (MCL) of 250 mg/L (USEPA, 2020b).

Nitrate is a common groundwater pollutant and is typically discussed in relation to agricultural sources—namely fertilizer and manure—but nitrate pollution can also be attributed to residential sources. A 1983 ISWS report investigated water quality issues in Roscoe, IL (approximately 12 miles north of Rockford) and found, along with agricultural sources, a major source of nitrate contamination was residential septic tanks (Wehrmann, 1983). These residential septic systems had been built in soil that was not sufficiently impermeable and was therefore allowing large scale leaching of waste into the ambient groundwater. Due to both the ambient agricultural pollution and leaching from septic systems, sampling and testing found no location in the Roscoe study area to be totally unaffected by nitrate contamination (Wehrmann, 1983). In 1982, average concentrations nitrate-nitrogen (NO_3-N) concentrations measured in Roscoe were approximately 6 mg/L with concentrations at some residences exceeding the drinking water standard of 10 mg/L.

3.2.3 Rockford Area Reductions in Natural Groundwater Discharge to Surface Waters

Established literature has shown that reductions in natural groundwater discharge to rivers and streams can negatively impact aquatic ecosystems. In a collaborative study done by the Michigan Department of Natural Resources and the Marquette Fisheries Research Station, researchers found that there can be a disproportionately large impact on species diversity when there is more than a 10 percent reduction in natural groundwater discharge to rivers and streams (Zorn et al., 2012). At the time of writing, an assessment to establish reductions in the quantity of groundwater discharge to rivers and streams for the Rockford area is ongoing. Quantifying this impact can help protect biota in Rockford area rivers and streams.

3.2.4 Future Studies and Recommendations for Rockford

The primary concern for ensuring a stable water supply for the City of Rockford and the greater area is the potential for contamination—legacy, acute, or otherwise—to make its way into public and private water supplies. Contaminants could become mobilized by existing pumping regimes, but a more pressing risk could be the mobilization of contaminants due to changes in pumping and increases in drawdown. Changes in pumping, such as shifting pumping distribution between existing wells or adding new wells, could alter or steepen groundwater gradients and mobilize contaminants. New sources of contamination should be limited to prevent infiltration into the alluvial and the Cambrian-Ordovician aquifer systems. This is especially important in the Rock River valley where infiltration rates are high. Currently, many wells in the Rockford region may be approaching the end of their lifecycles and, if well casings fail, they may present a conduit through which contamination may spread into otherwise uncontaminated aquifers. Steps should be taken to identify and properly abandon such wells.

In addition, quantifying the reductions in natural groundwater discharge to rivers and streams due to pumping would be a worthwhile step towards ensuring sustainable water withdrawals and the protection of biodiversity in the Rock River and its tributaries. A preliminary goal of ensuring that current pumping does not reduce groundwater flow to rivers and streams by more than 10 percent should be pursued with the ultimate goal of reducing impacts below the 10 percent threshold. An assessment to establish a threshold specific to the region should be done with an additional focus on the relative impacts to large rivers such as the Rock River and smaller streams such as the Kishwaukee River and Keith Creek.

A locally calibrated groundwater model that is able to simulate groundwater flows as well as contaminant transport could also help address existing contamination issues, possible future changes in pumping regimes and their effects on contamination, and the degree to which pumping is reducing natural groundwater discharge to streams and rivers.

3.3 Green River Lowlands

3.3.1 Previous Studies

The first scientific investigation of the Green River Lowlands by a State of Illinois Survey is recorded in volume 5 of the ISGS's first *Geological Survey of Illinois* (Worthen, 1866). The geologist who conducted extensive field surveys of the region and surrounding counties, James Shaw, noted the great value of the region, in terms of mineralogical, agricultural, and industrial potential, to the State. His minutely detailed field observations provide a primary resource that is useful in reconstructing plausible "pre-development" modeling surfaces. While the region has not undergone extensive urbanization in the intervening years from Shaw's initial observations, there have been significant changes to the overall climate, hydrogeologic demand by the agricultural industry, and hydraulic engineering infrastructure to modulate drainage, flooding, and navigation of waterways.

An early attempt to untangle the complex, glacial geologic history of the region provided better geologic context for Shaw's observations and delineated the extent and development of drainage networks within the Green River Lowlands (Anderson, 1968). This study would be helpful in early water supply planning efforts and later scientific investigations by providing a simple conceptual model by which water resources could be identified and preliminarily analyzed in the region.

Later studies integrated well records to formally assess the groundwater resources in the region (Larson et al., 1995). By correlating lithologies between logs, detailed maps and cross sections were generated, including the example shown in Figure 26.

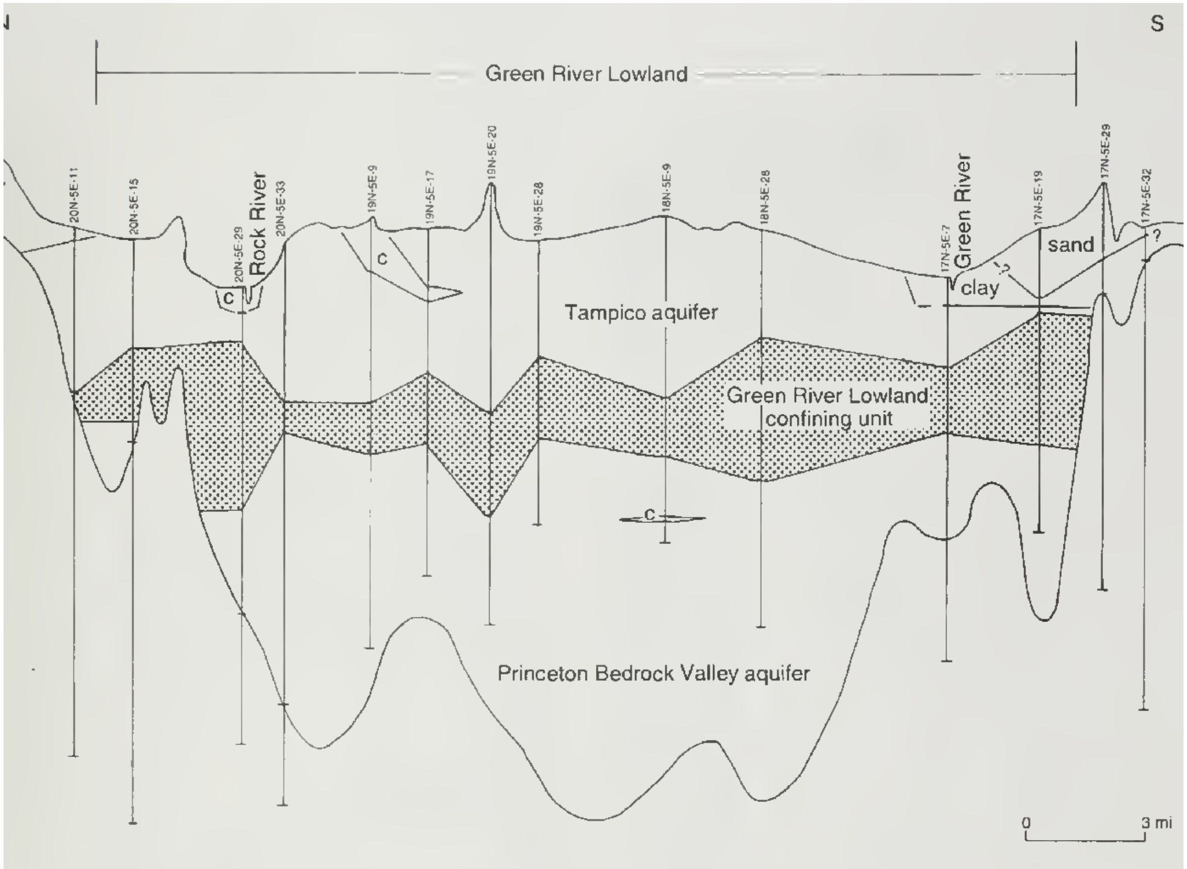

Figure 26. North-South hydrostratigraphic cross section of the Green River Lowlands. (Image from Larson et al., 1995)

The "Larson" model of three hydrostratigraphic units (an unconfined aquifer—Tampico—underlain by a confining unit of variable thickness and lithology, underlain by a confined aquifer—Sankoty/Princeton Bedrock Valley) is broadly accurate and sets the foundation for modeling studies. The uppermost boundary of the Sankoty Aquifer consistently occurs at elevations between 530-540 feet above mean sea level (MSL), and slopes gently from Rock Falls to Hennepin.

A previous study recommended to "define groundwater flow within the aquifers, the movement of groundwater along horizontal and vertical gradients from recharge to discharge areas, the hydraulic relationships between the drift aquifers and the bedrock, and the interactions between groundwater and surface water" (Larson et al., 1995). This resulted in the implementation in the 1990's of a regional monitoring network (Burch, 2004), shown in Figure 27.

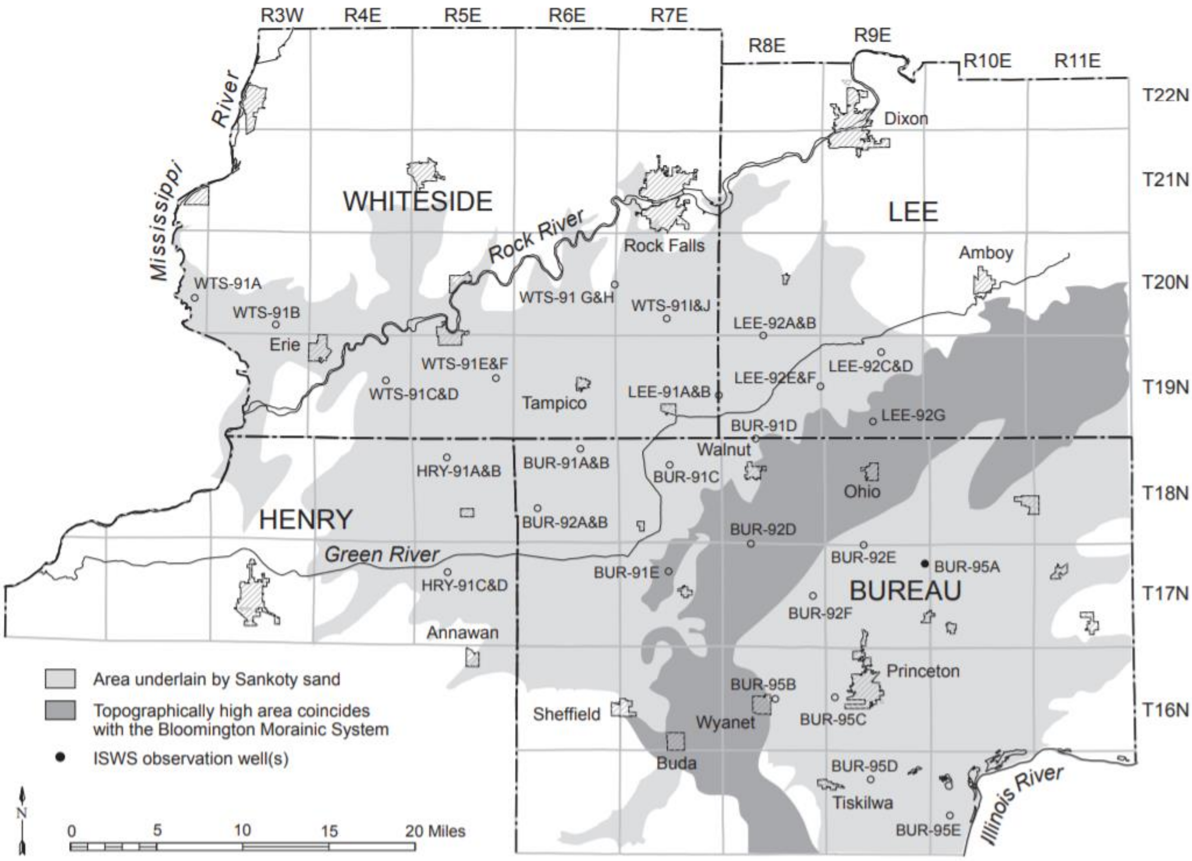

Figure 27. Locations of monitoring wells installed in the Green River Lowlands. (Image from Burch, 2004).

Using data collected during the construction of monitoring wells, observations over several years, and analysis of historical records, ranges of estimates of hydraulic properties of the regional aquifers were obtained (Table 3).

Aquifer	Tampico [upper]	Sankoty [lower]
Hydraulic Conductivity [gpd/ft^2]	176 – 3,860	575 – 2,400
Specific Capacity [gpm/ft]	55.2 - 83	20 - 89
Transmissivity [gpd/ft]	67,000 – 185,200	100,000 – 310,600

Table 3. Ranges of estimates for hydraulic properties of the major aquifers in the Green River Lowlands (Burch, 2004)

Recharge to both aquifers was also assessed by integrating historical precipitation records. For the Tampico Aquifer, recharge only occurs from early October to mid-February (Figure 28) when mean monthly precipitation exceeds mean potential evapotranspiration. During the summer months (May-August), net evaporation of water from the aquifer can exceed 2,000,000 gpd/mi^2, especially during abnormally dry conditions or if vegetation with high evapotranspiration potential dominates the landscape (i.e., corn and soybeans). Average annual recharge was estimated at 333,000 gpd/mi^2.

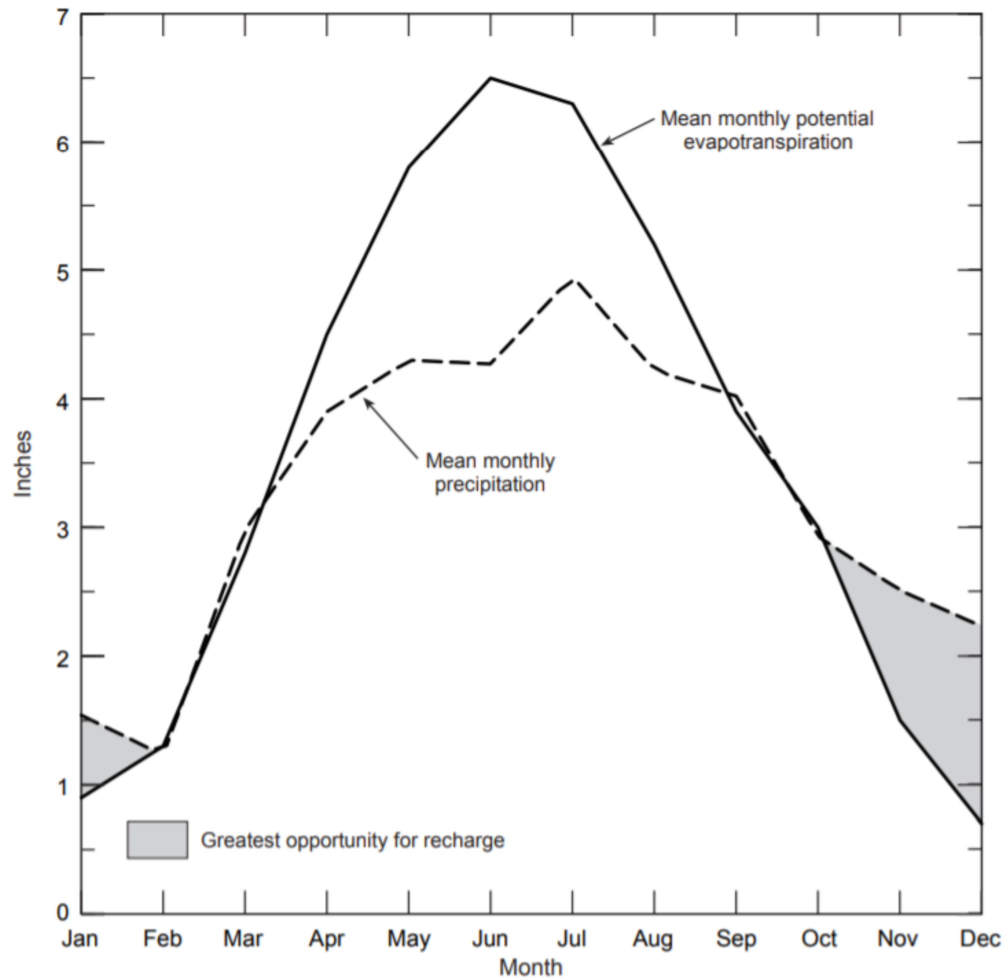

Figure 28. 30-year [1961-1990] mean monthly precipitation and mean monthly potential evapotranspiration (Image from Burch, 2004).

Recharge to the Sankoty Aquifer comes from two sources, lateral inflow into the Paw Paw Bedrock Valley from the surrounding highlands and vertical leakage through the confining layer. Calculated recharge values ranged from 67,000-279,000 gpd/mi^2 based on inferences from studies in regions of similar geology and approximations of inflow geometry (Burch, 2004). The recharge contribution ratio of vertical leakage to lateral inflow is estimated at 3:1. Given that no long-term trend in water levels was observed during the study period, vertical leakage estimates of 0.97 inches from annual recharge balance inflows and outflows.

Figure 29 shows a hypothetical distance-drawdown curve for wells in both aquifers, where pumping is assumed to occur for 80 days at 800 gpm (Burch, 2004). Transmissivity in this aquifer is assumed to be 75,000 gpd/ft, storage in the unconfined aquifer (Tampico) is assumed to be 0.1, and storage in the confined aquifer (Sanktoy) is assumed to be 0.0003. For example, consider a monitoring well that is 1000 ft away from a well pumping 800 gpm. If both are in the Sankoty aquifer, then drawdown at the monitoring well would be approximately 10.6 ft after 80 days of pumping.

The impacts of pumping are additive; as a result, if two wells were pumping at 800 gpm, and both are 1000 ft from the monitoring well, then the monitoring well would be expected to have 21.2 ft of drawdown. Drawdown would be larger at the monitoring well under the following conditions: 1) if the pumping well is closer, 2) if the well ran for more than 80 days, or 3) if transmissivity was smaller. If drawdown increases to the point that it starts to dewater (becomes unconfined), the storage coefficient would be larger and drawdown decrease.

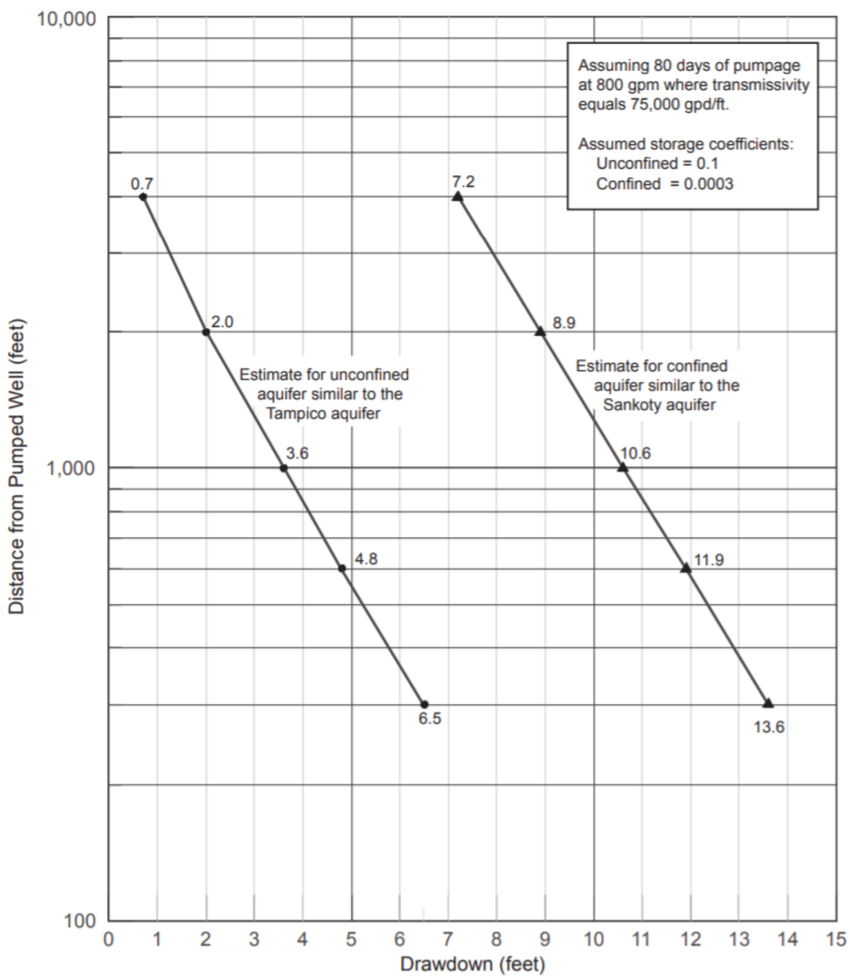

Figure 29. Graphical comparison of distance-drawdown responses for hypothetical confined [Sankoty] and unconfined [Tampico] conditions (image from Burch, 2004).

This relationship applied to the regional monitoring network allows for assessment of demand impacts on aquifer supplies, leading to the following observations and relationships (Burch, 2004):

- Public supply and industrial demands were 3.5 mgd on average and occurred continuously throughout the year.
- Annual irrigation demands were estimated to exceed public and industrial demands by at least a factor of 5, but only occur during the summer months.

- The Tampico and Sankoty aquifers are typically hydraulically independent, and the Sankoty was used more frequently by irrigators.
- Groundwater levels within the Sankoty declined each summer and recovered during the winter months to a level near the maximum of the previous year. Drawdown exceeded 13 feet over several square miles. The regions of greatest drawdown occur south of the Tampico and reach a maximum in late July.
- Artesian pressure within the Sankoty Aquifer causes water levels to rise above the top of the aquifer. The distance above the top of the aquifer, known as artesian head, is indicative of the local hydrostatic pressure. Artesian heads can exceed 120 feet in the eastern part of the study area and are generally 70-80 feet in areas of prime irrigation.
- The regional direction of groundwater flow in both aquifers is away from Lee County, which appears to behave as a recharge area near Amboy/Dixon. In the Tampico aquifer, gradients decrease from 6.5 to 3 ft/mi. Water from the Sankoty outflows to the Illinois and Mississippi Rivers.
- Under normal climate conditions, natural groundwater discharge to rivers exceeds estimated irrigation demand.

A cursory assessment of water quality within the monitoring wells was also conducted. Broadly, water from the Sankoty is less mineralized and less acidic than water from the Tampico. No major inorganic contaminants were observed in either aquifer, although concern was raised over rising chloride and nitrate concentrations in select wells within the Tampico (Burch, 2004).

3.3.2 Water Levels in the Green River Lowlands

The ISWS has continued to visit the Green River Lowlands monitoring network quarterly, when funding and staffing allow, to maintain the monitoring well network and collect water level measurements.

In the 1990s, irrigated land in the Green River Lowlands was estimated to be 36,000 acres, with 32,000 acres concentrated in Whiteside and Lee Counties (Burch, 2004). Based on analysis of USDA flyover images from 2012, 2014, and 2017, as of 2017 there were 150,000 irrigated acres in the region, concentrated in Bureau and Henry Counties (Figure 30). This is a growth rate of approximately 2 percent per year.

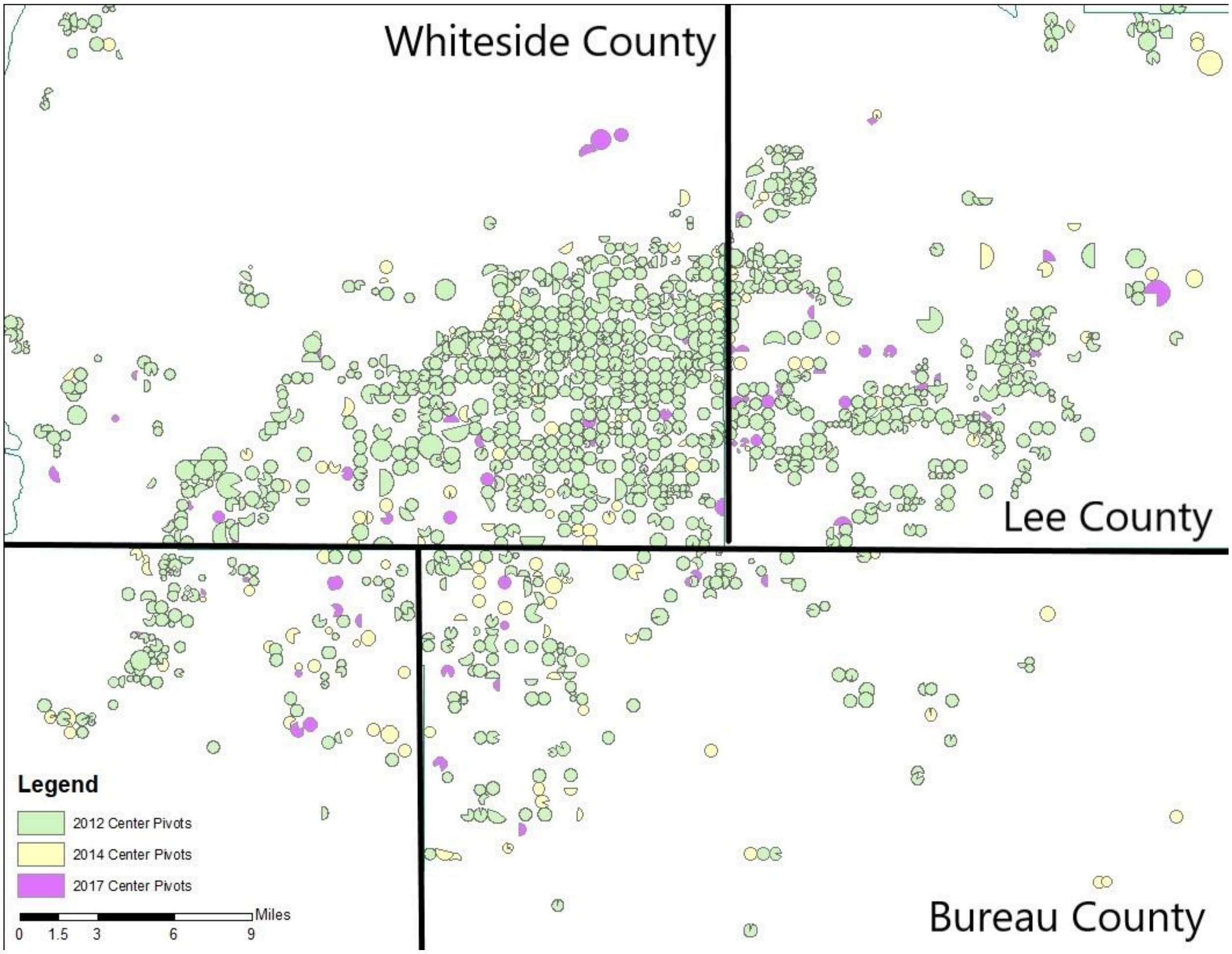

Figure 30. Map of irrigated acres in the Green River Lowlands.

Since 2015, seven of the monitoring stations (five of which are nests) have been equipped with pressure transducers and telemetry stations to improve our understanding of the consequences of this irrigation growth. Further installations and precipitation monitoring apparatuses are planned for the next few years. These installations enable the collection of near real-time data, which, in turn, allow for higher resolution analyses of aquifer response to demand and recharge events, hydraulic connections between the two aquifers, and local aquifer properties.

All records are viewable and available for download from the ISWS website at the following link:

https://www.isws.illinois.edu/groundwater-science/groundwater-monitoring-well-networks/green-river-lowlands-monitoring.

Presented in this section are a selection of hydrographs with the most complete periods of record to aid in a discussion of the hydrologic trends in the representative counties.

Sankoty water levels in Bureau County, particularly in the northwest corner, have shown the greatest change over time and are therefore the most concerning. At BUR-91A (Figure 31), summertime declines of approximately 10 feet were observed during the 1990s. However, there were only 4000 irrigated acres estimated to be driving demands during that period. Subsequent droughts in 2005 and 2012, coupled with growth of the agricultural industry, have greatly increased the number of center pivot installations throughout the Green River Lowlands. The highest rate of growth is in northwest Bureau County, with over 12,000 irrigated acres in 2017. An additional confounding variable is the nature of the confining layer in northwest Bureau County. The confining layer is not exceptionally thicker here than in other parts of the aquifer with similar or greater demands (Larson et al., 1995). However, the aquifer response to pumping clearly indicates a significantly lower vertical conductivity, and therefore reduced recharge, between the Tampico and Sankoty. Thus the lithology of the confining layer likely differs here from the rest of the region. Declines now routinely approach 50 feet regardless of drought conditions. Additionally, water levels are beginning to come within 20 feet of the top of the aquifer surface. Should water levels reach the aquifer surface, serious environmental and economic impacts could occur. These include lost well capacity, precipitation of cements within dewatered aquifer material (decreasing the amount of pore space available for future recharge), and a necessity to deepen existing wells or lower pumps.

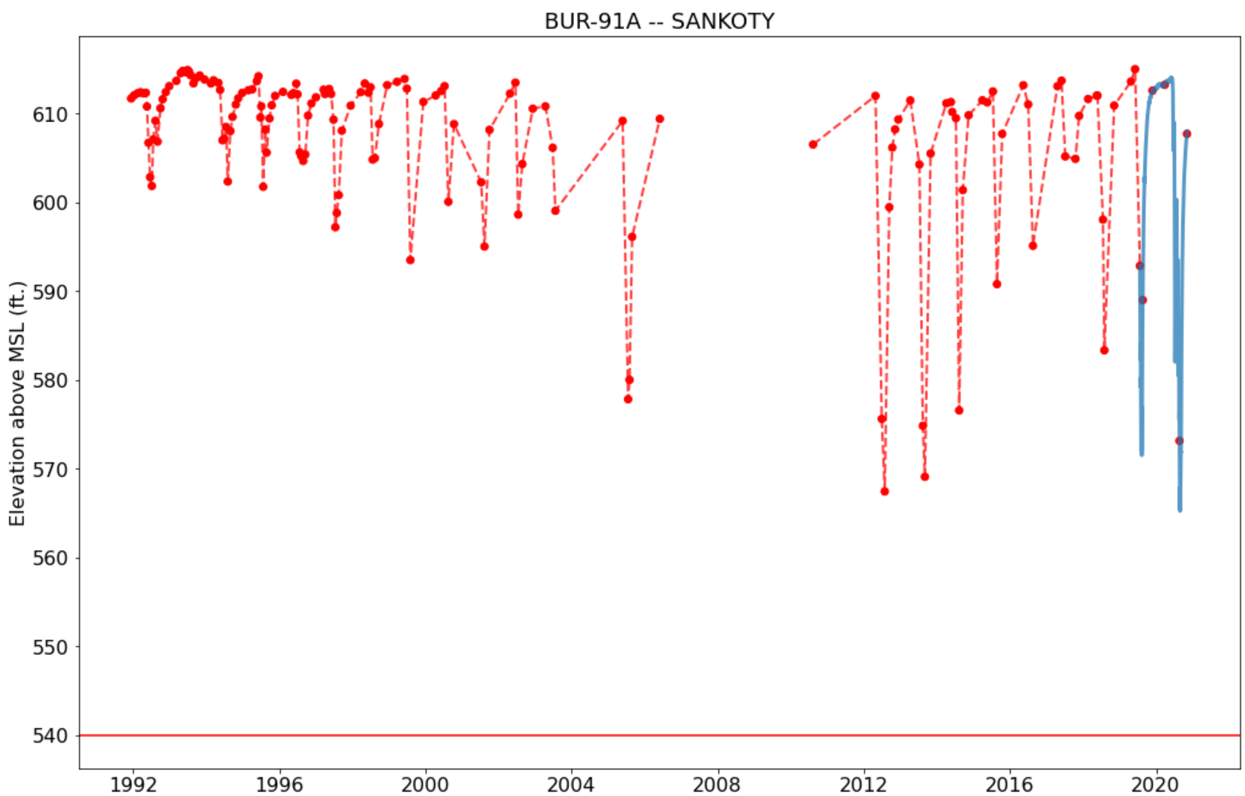

Figure 31. Hydrograph for BUR-91A. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data do not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted. Solid red line at 540 feet above MSL represents an approximate location for the top of the Sankoty Aquifer.

The lowest water levels during summer irrigation do not occur at monitoring wells, but rather nearby pumping wells (Figure 32); as a result, the head above the top of the Sankoty aquifer is likely less in some areas than shown in Figure 31. Additionally, water level extremes may not be adequately recorded with quarterly hand measurements. If only hand measurements were available at this site for 2019, the true low would have been underestimated by over 15 feet. Therefore, it is possible that routine dewatering is already occurring during summer months. We cannot know with certainty without knowledge of withdrawal rates or better estimates of local aquifer transmissivity, storativity, and recharge rates.

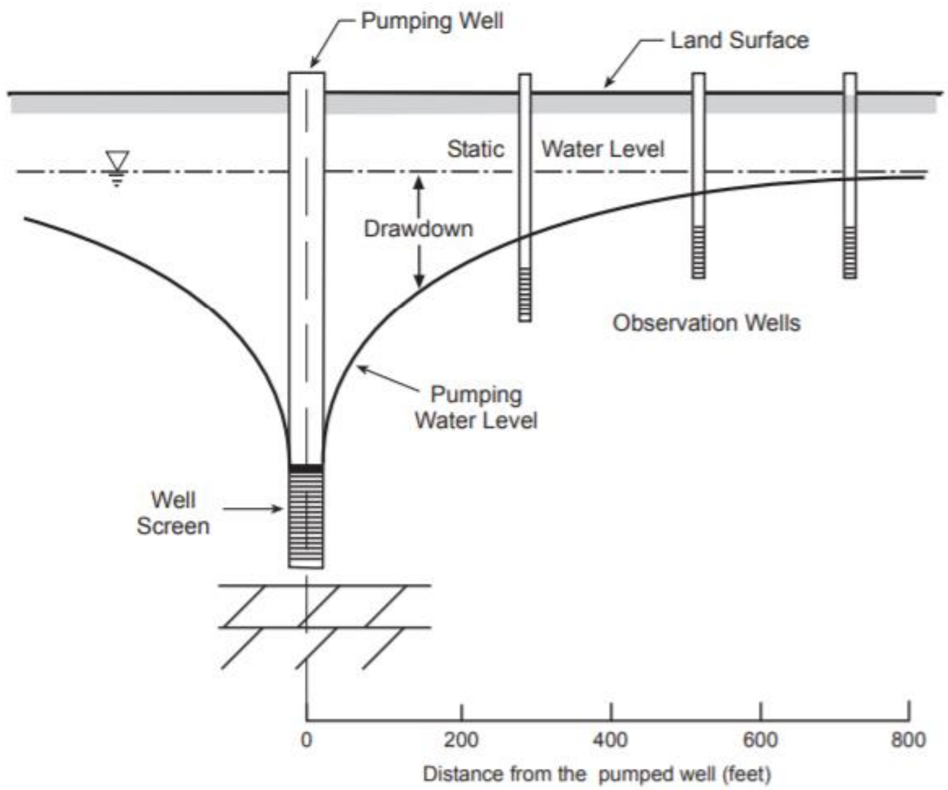

Figure 32. Extension of drawdown beyond the pumping center. (image from Burch, 2004)

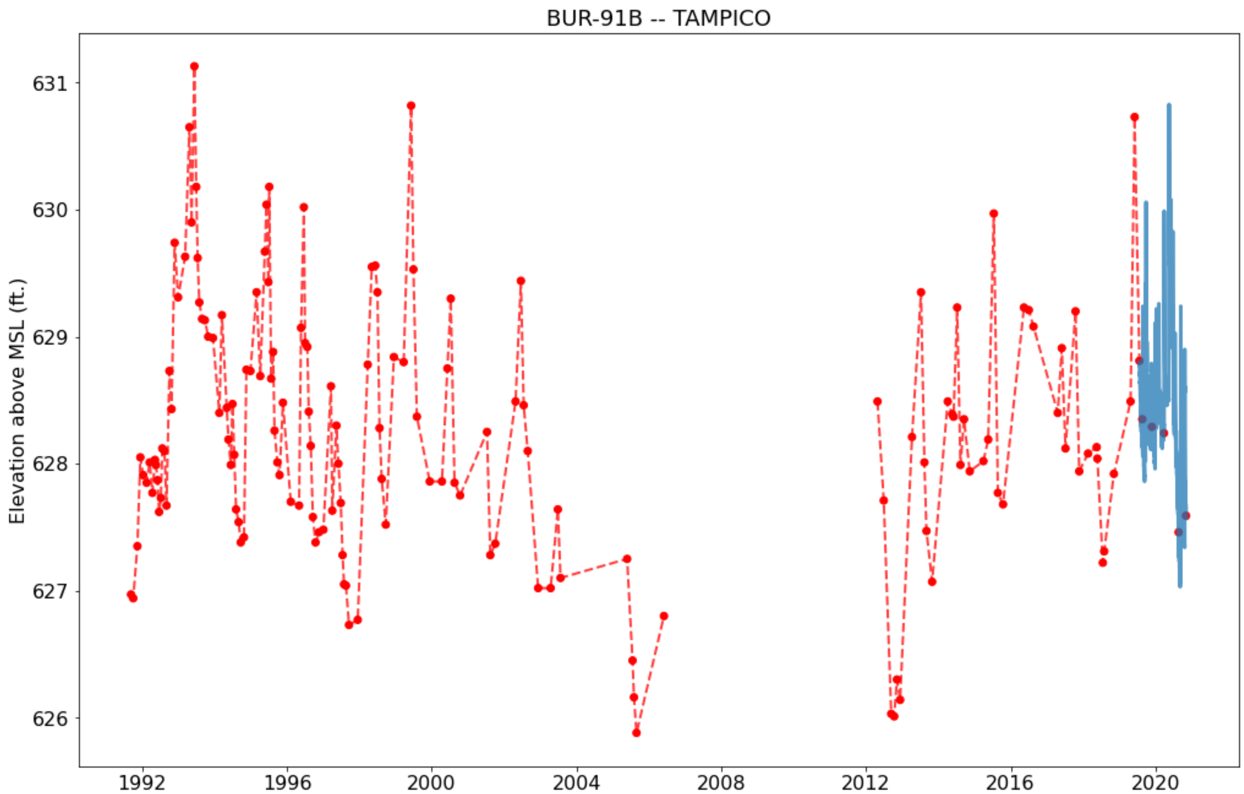

Figure 33. Hydrograph for BUR-91B. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted.

Aquifer response in the Tampico at BUR-91B (Figure 33) is typical of an unconfined aquifer. Rain events cause water levels to rise, while sustained dry periods precede falls. At their maximums, Sankoty and Tampico water levels are within 10 feet of each other.

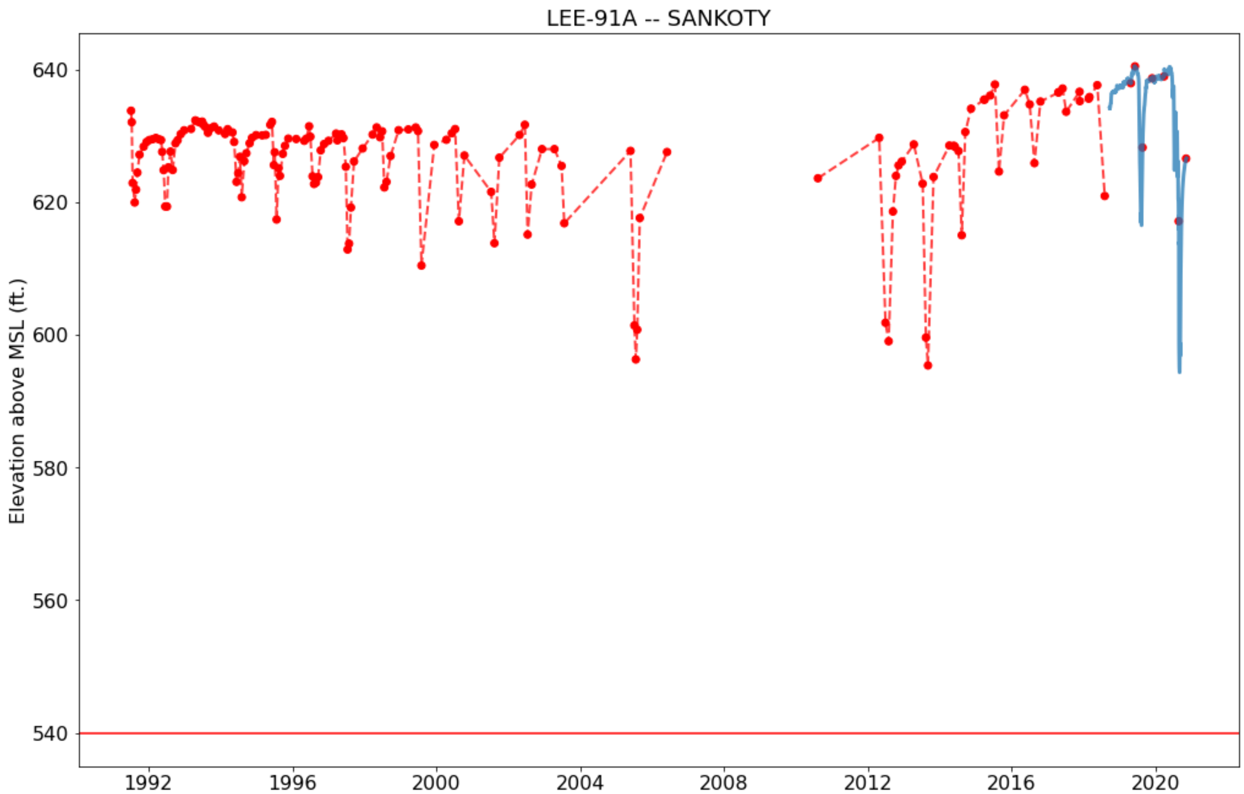

Figure 34. Hydrograph for LEE-91A. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted. Solid red line at 540 feet above MSL represents an approximate location for the top of the Sankoty Aquifer.

Sankoty water levels in Lee County at LEE-91A (Figure 34) also show increasing magnitudes of summertime declines over the past 30 years. A 50-foot drawdown occurred during 2020, which is consistent with observations in Bureau County. However, spring water levels are naturally 10-15 feet higher in this location. In fact, there appears to be a recent increasing (short-term) trend in springtime water levels, more than 10 feet in 30 years. Also, drawdown is significantly subdued during summers with above-average precipitation, likely due to enhanced recharge and decreases in irrigation by farmers in the region, or a combination of these factors. Conversations with farmers in Lee County indicate that some do utilize the Green River as a supplemental irrigation water source, but the prevalence of this practice and the amount of offset demand is unknown.

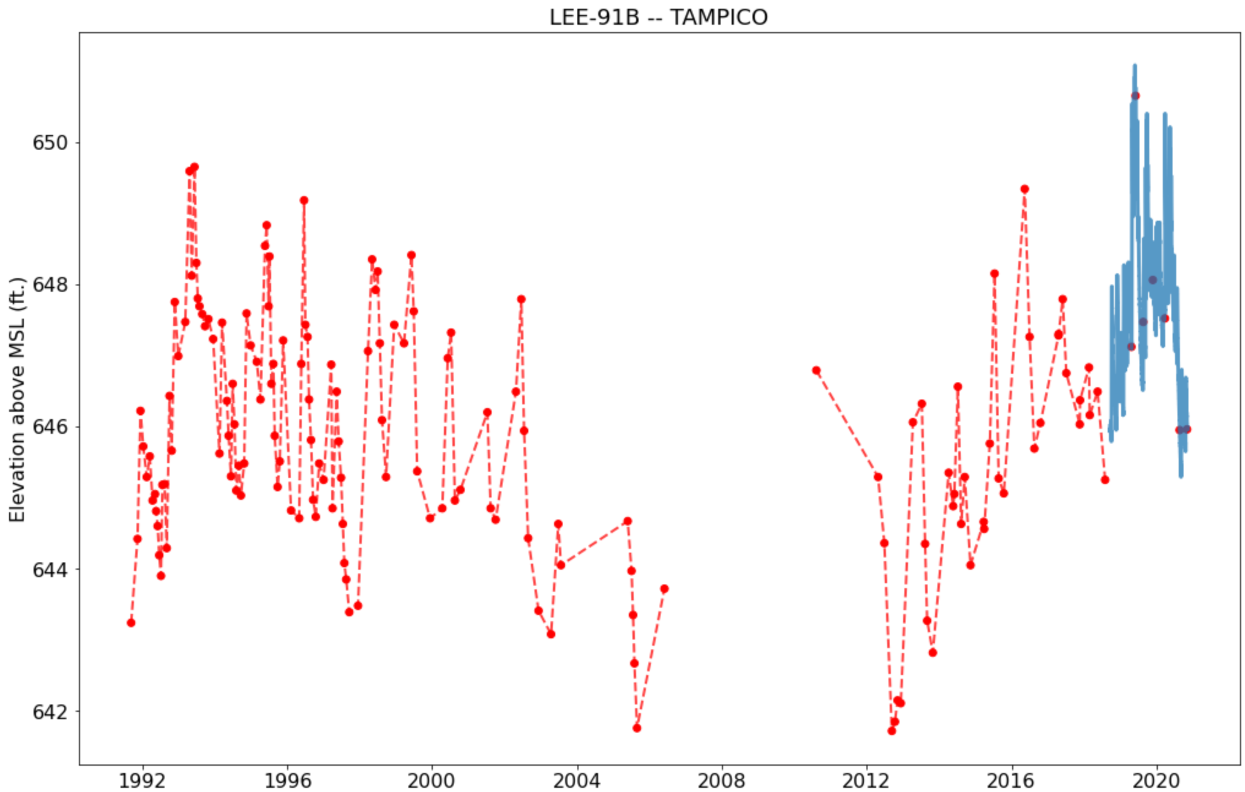

Figure 35. Hydrograph for LEE-91B. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted.

Tampico water levels in Lee County at LEE-91B (Figure 35), show similar behavior to those observed in Bureau County. However, depths to water are on average 2 to 3 feet closer to the surface. This increases the risk of groundwater flooding during intense rain events. Additionally, peat deposits at the surface in this county have lower effective infiltration rates than the rest of the region which is primarily sandy. Significant ponding on cropland was observed during the abnormally rainy spring of 2019, which reduced the arable land available.

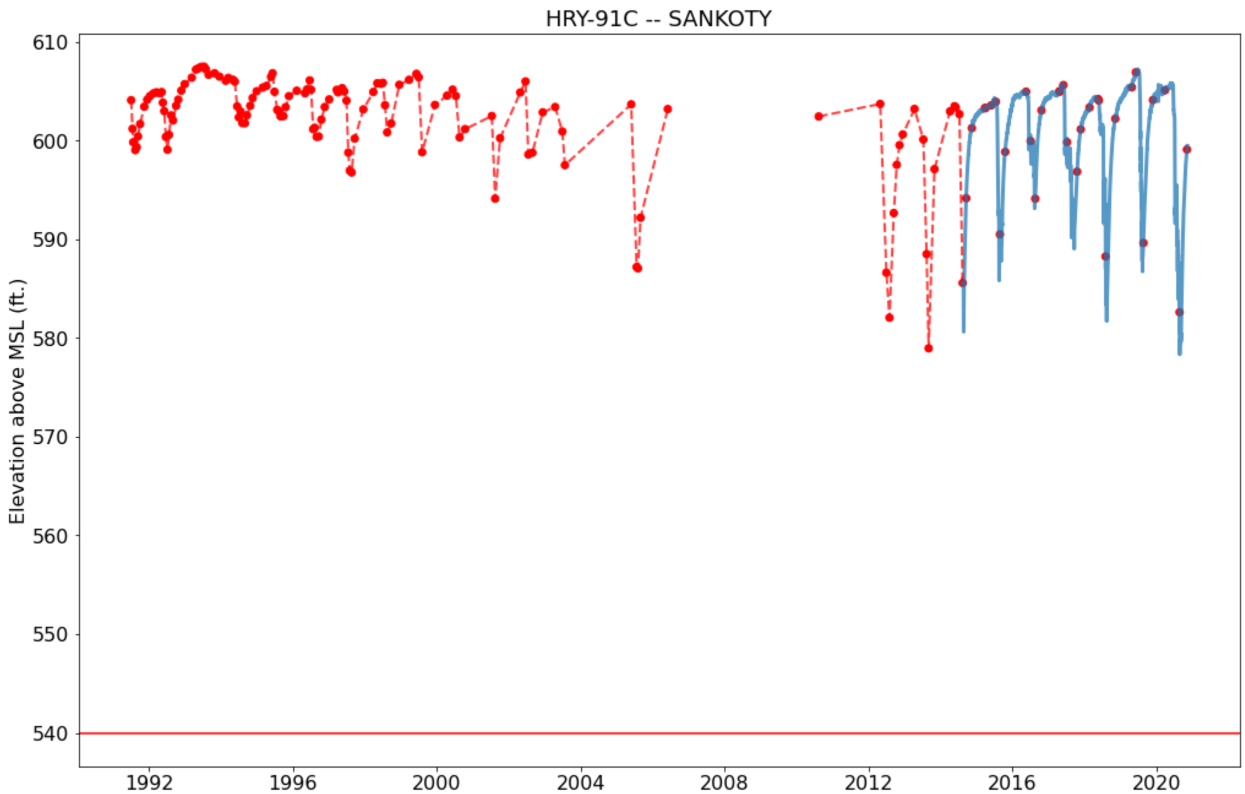

Figure 36. Hydrograph for HRY-91C. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted. Solid red line at 540 feet above MSL represents an approximate location for the top of the Sankoty aquifer.

Summer drawdowns in the Sankoty are less in Henry County at HRY-91C (Figure 36) compared to Lee and Bureau Counties. Maximum observed drawdowns are approximately 25 feet, with greater than 40 feet of head still available before dewatering potential increases. Lower irrigation demand and a thinner, discontinuous confining layer allow for greater communication between the two aquifers. An additional factor is the geometry of the aquifer and lithology of the bedrock. Henry County is near the downgradient edge of the Sankoty and the aquifer abuts the bedrock valley walls which are composed of impermeable Pennsylvanian shales. The combination of these factors causes water to pond and buoy pressure heads (Burch, 2004). Henry County has the lowest density of irrigated land in the Green River Lowlands. Therefore, the distance between monitoring wells and pumping centers is greater.

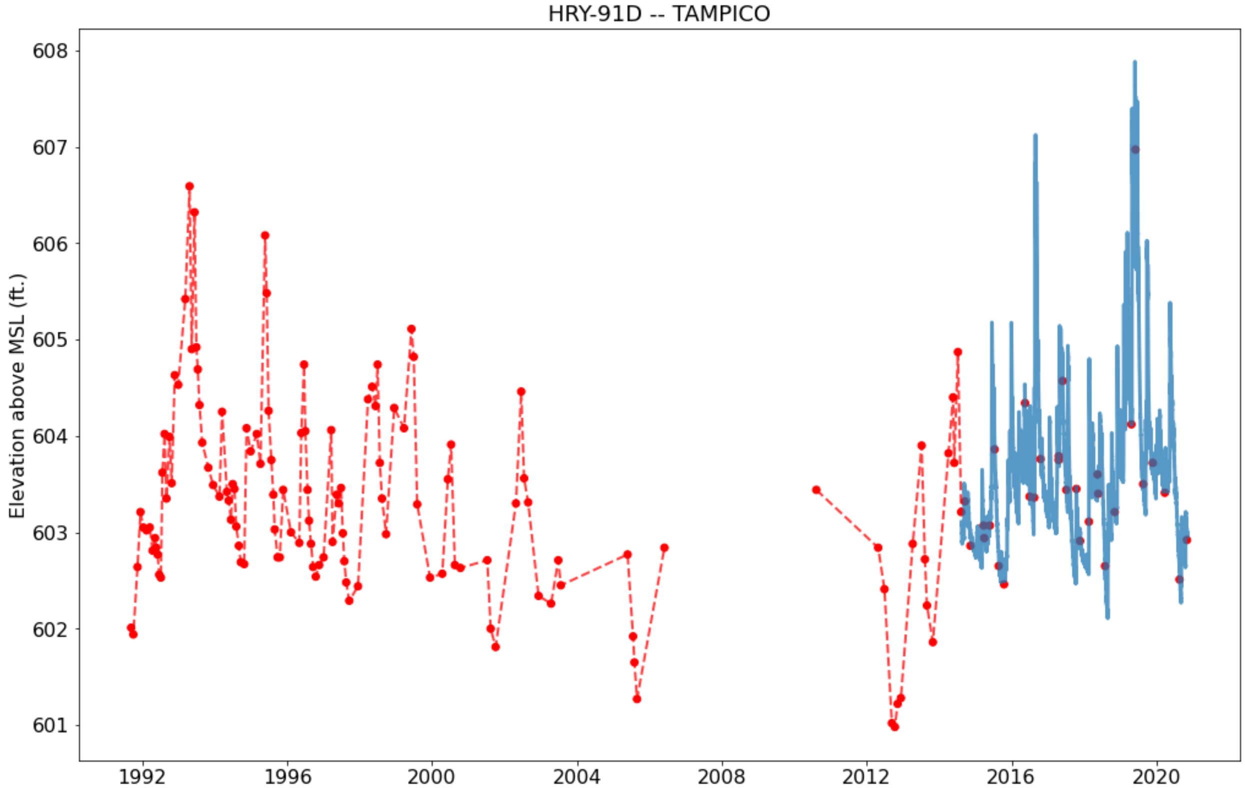

Figure 37. Hydrograph for HRY-91D. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted.

The relationship between the aquifers in Henry County is distinct. Except during the irrigation season, Tampico water levels at HRY-91D (Figure 37), are about a foot lower than Sankoty water levels at the same location. This temporary gradient reversal is due to the aquifer boundary condition discussed previously. The increased pressure in the lower aquifer is sufficient to overcome the gravitational force drawing water downwards. This is unusual and interesting from an academic standpoint, but this ephemeral contribution does not constitute a significant source of water to the Tampico. There may be an increased risk of springtime flooding in Henry County during storm events since the effective infiltration of the Tampico is reduced, but that needs to be assessed with further modeling studies that are outside the scope of this study.

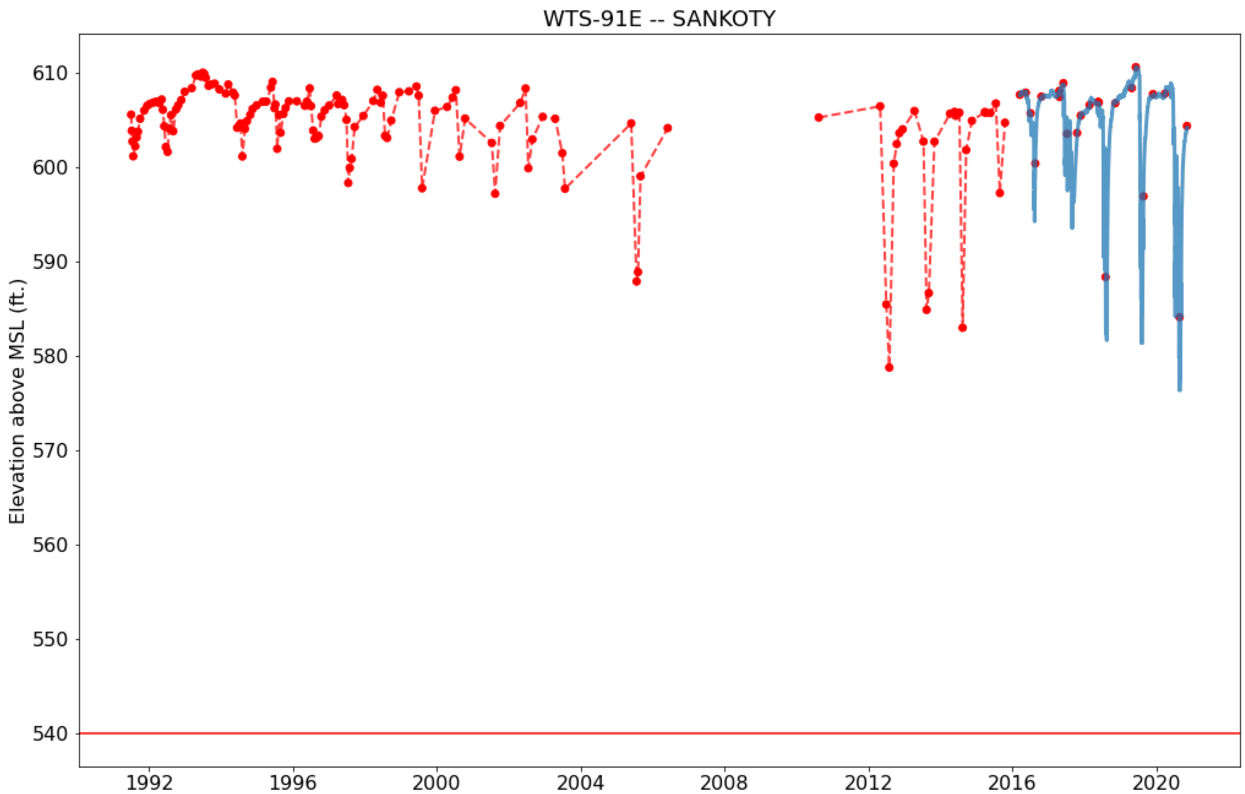

Figure 38. Hydrograph for WTS-91E. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted. Solid red line at 540 feet above MSL represents an approximate location for the top of the Sankoty Aquifer.

Irrigation-induced drawdowns in the Sankoty Aquifer at WTS-91E (Figure 38) in Whiteside County are the same, if not slightly lower, than those observed in Henry County. This is surprising considering the magnitude and density of irrigated land. Of the four counties in the region, Whiteside County contains most of the irrigation water demands, and yet appears to be the least affected hydrologically. This is due to the thin confining layer, which locally disappears, forming pockets of a single continuous, unconfined aquifer. Whiteside County also receives additional recharge from the Rock and Mississippi River valleys.

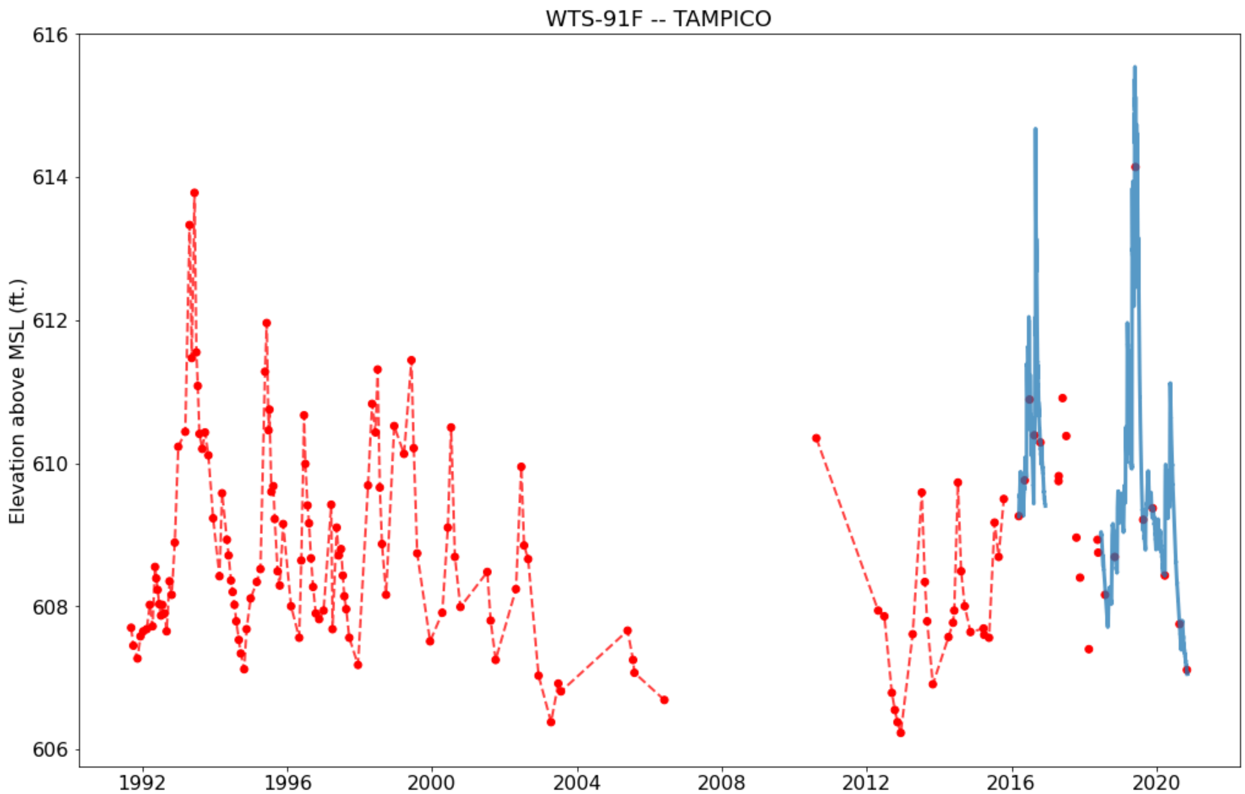

Figure 39. Hydrograph for WTS-91F. Red dots indicate hand measurements, while blue lines indicate hourly data measured via pressure transducer. Hand measurements are connected by a dashed line where transducer data does not exist. No field measurements are available from 2007 to 2010, so the dashed line was omitted.

Water levels in the Tampico at WTS-91F (Figure 39) come within 5 feet of those in the Sankoty when both aquifers are at their maximum. Water levels in both aquifers also appear to increase and decrease in unison. This is a testament to the connectivity between the aquifers present in Whiteside County. Average Tampico water levels are 3 to 4 feet higher than those observed in Henry County due to a combination of their upgradient location and the contribution of water from the Rock and Mississippi Rivers.

The complex, spatially variable hydrogeology of the hydrostratigraphic units within the Green River Lowlands and the correlation of demands to the magnitude and timing of annual precipitation makes it difficult to correlate water level changes between monitoring wells and identify regions with demand-driven risks. To generalize spatiotemporal complexity and qualitatively assess regions at risk of dewatering, maps of the percent change between annual maximum and minimum heads above the Sankoty surface were generated for 1995, 2012, 2018, 2019, and 2020. The Tampico was not considered because there are no appreciable demands in that aquifer. A given value represents the percentage of available hydraulic pressure removed during that year's irrigation season. A value greater than 100 percent would indicate that dewatering has occurred. Fortunately, no such values have so far been observed within the monitoring well network. However, there are some important caveats to consider. Water levels at monitoring wells underestimate conditions at withdrawal points, with the magnitude of underestimation increasing with distance from the withdrawal (Figure 32). During time periods and at monitoring wells where continuous pressure transducer data are not available, it is unlikely that true minimums are captured by quarterly hand measurements. Thus, the location of local minima of water level surfaces will be biased toward locations and times where transducer data are available. Finally, monitoring wells were correlated and contoured using simple Kriging. This produces a surface that best fits the observations but does not consider the geologic and hydraulic variables away from the observation points. The further a region on the map is from a monitoring well, the less likely it represents reality. The following maps should be regarded as qualitative underestimates of local susceptibility to dewatering during irrigation.

Despite summertime irrigation demands, Sankoty water levels were relatively stable in 1995 (Burch, 2004), which is supported by the 1995 percent change map (Figure 40). Most of the regional declines were less than 10 percent. There is a region in southwest Lee County that indicates a decline of greater than 30 percent, but there are no monitoring wells within that region to justify the predicted decline. This region is likely an artifact of the Kriging method rather than a reflection of reality.

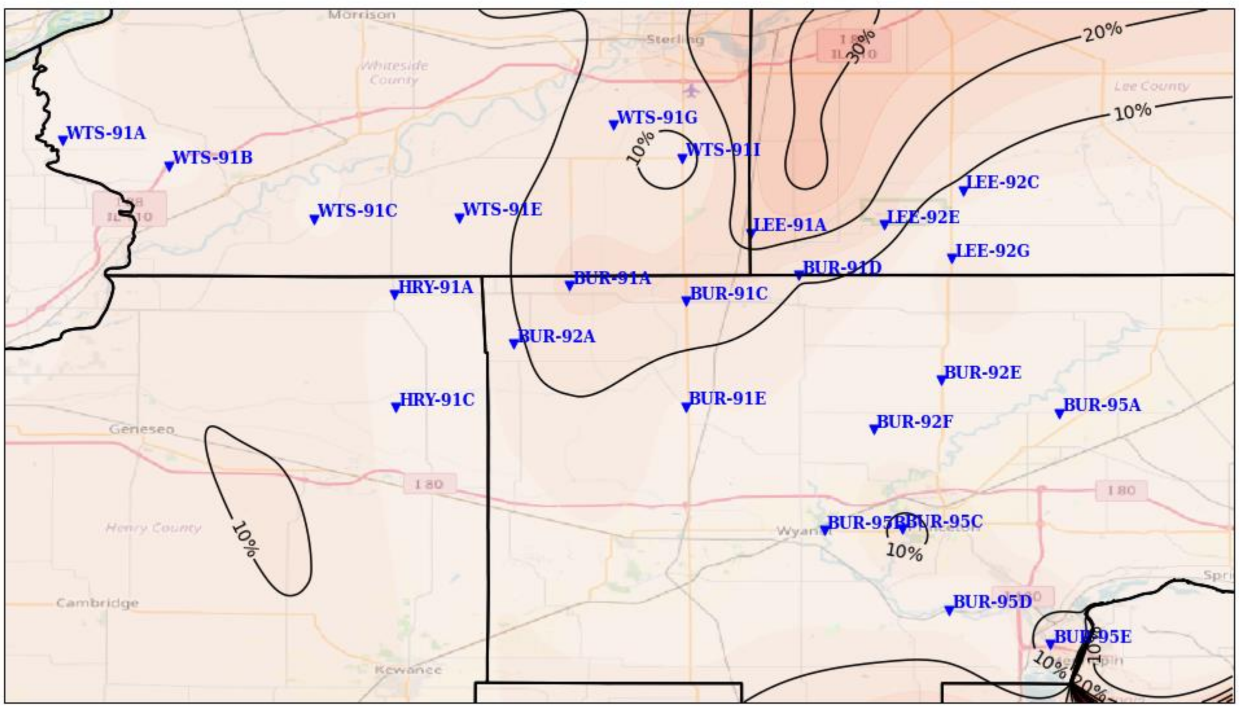

Figure 40. Pressure head above Sankoty percent change map for water year 1995. 50% indicates that half of the water above the aquifer boundary was removed during summer irrigation. 100% indicates that water levels reached the aquifer surface and will behave as an unconfined aquifer if water continues to be removed.

Analysis of data gathered during the 2012 drought (Figure 41) suggest a different conclusion. Regional declines were greater than 20 percent. The most extreme declines exceeded 80 percent and were in the northwest corner of Bureau County. True maximum drawdowns at monitoring wells were likely much lower than measured on 27 July 2012. Without exception, monitoring wells equipped with pressure transducers indicate that annual maximum drawdowns do not occur until August, and excluding the abnormally rainy 2019, late August. In Bureau County, water levels in monitoring wells have been observed to decline an additional 15-20 feet during the month of August. Discussions with local drillers indicate that pumps were lowered and older wells deepened, which strongly suggests that local dewatering did occur in Bureau County in 2012.

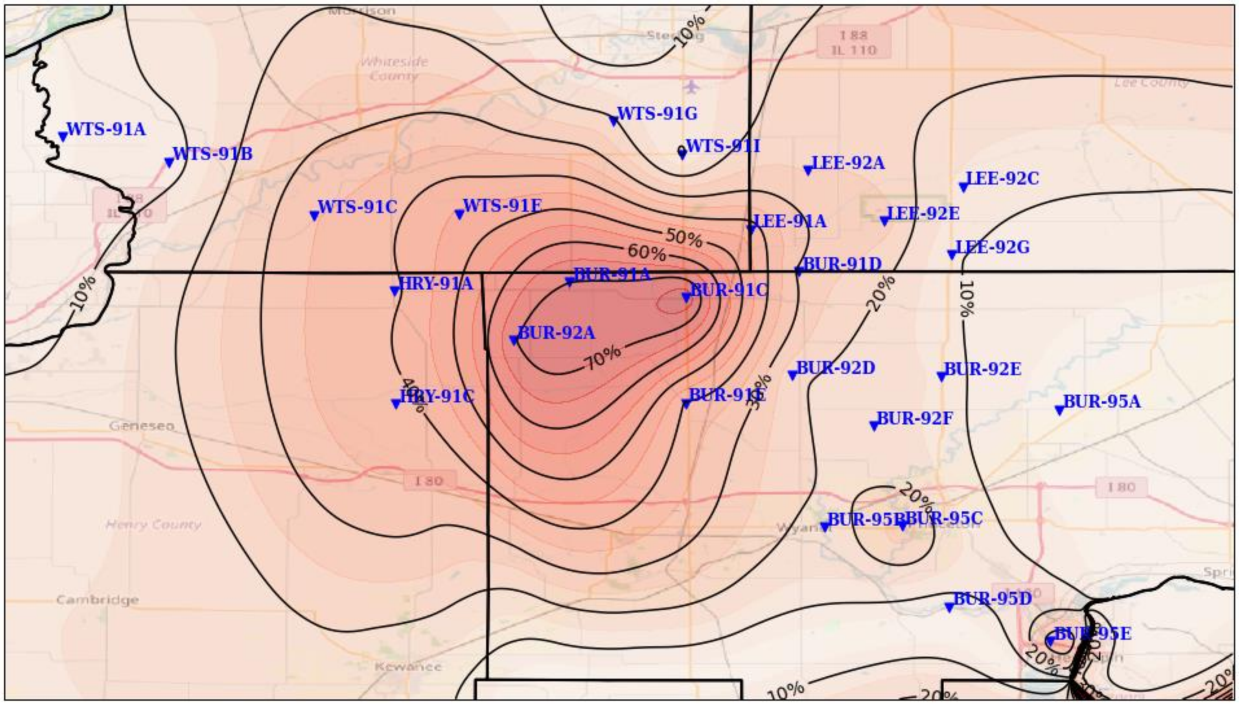

Figure 41. Pressure head above Sankoty percent change map for water year 2012. 50% indicates that half of the water above the aquifer boundary was removed during summer irrigation. 100% indicates that water levels reached the aquifer surface and will behave as an unconfined aquifer if water continues to be removed.

While droughts on the scale of 2012 are rare occurrences, when they do occur, farmers are incentivized to invest in irrigation infrastructure to protect their crop yields. Once installed, this infrastructure is available to generate water demand, even under non-drought conditions. This new demand regime was exemplified in 2018 under average precipitation conditions. An estimated additional 10,000 acres were added to the region after 2012, with approximately 1,000 acres concentrated in the northwest corner of Bureau County. While percent drawdowns in 2018 (Figure 42) were not as great as 2012, the local and regional impacts of increased irrigation are still evident in the percent change map. Loss of 45 percent of available head was observed at monitoring wells in northwest Bureau County, but this could have been much greater since transducer data were not available for this year in this region. Monitoring wells in Whiteside and Henry Counties were equipped with transducers, so there is a high degree of confidence in the >35 percent head loss at HRY-91A and approximately 40 percent head loss at WTS-91E.

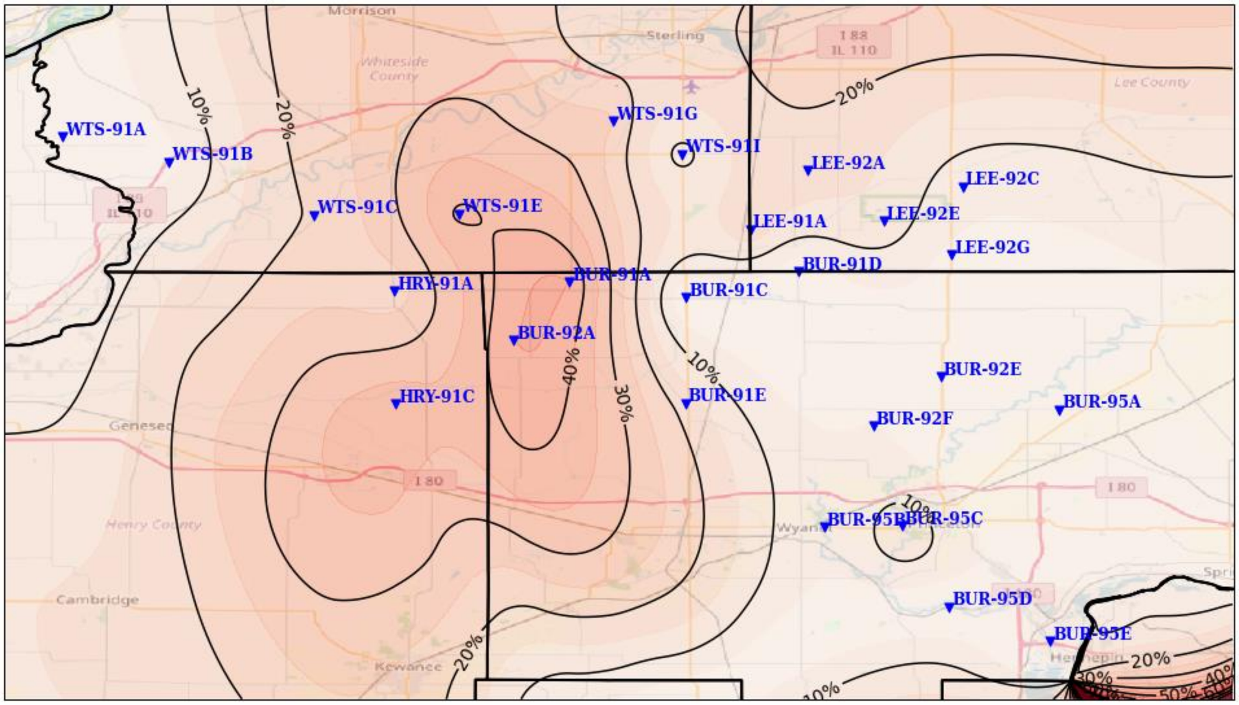

Figure 42. Pressure head above Sankoty percent change map for water year 2018. 50% indicates that half of the water above the aquifer boundary was removed during summer irrigation. 100% indicates that water levels reached the aquifer surface and will behave as an unconfined aquifer if water continues to be removed.

The spring and early summer of 2019 experienced greater than average precipitation. Extensive flooding delayed the onset of planting and therefore shortened the growing season. Some arable acreage was lost because areas of ponded water persisted throughout the summer. Short periods of abnormal dryness occurred during the mid to late summer, but nothing was classified as a drought. Transducer stations were installed in northwest Bureau County to improve insight into the region where the greatest declines have historically been observed. An additional transducer was installed at LEE-91A to gain higher resolution data in the upgradient portion of the aquifer. The percent change map for 2019 (Figure 43) shows that the surplus precipitation and decreased arable acreage did not temper peak demands. Declines greater than 60 percent were observed at monitoring wells in northwest Bureau County. Water demand remained below 10 percent in Lee County.

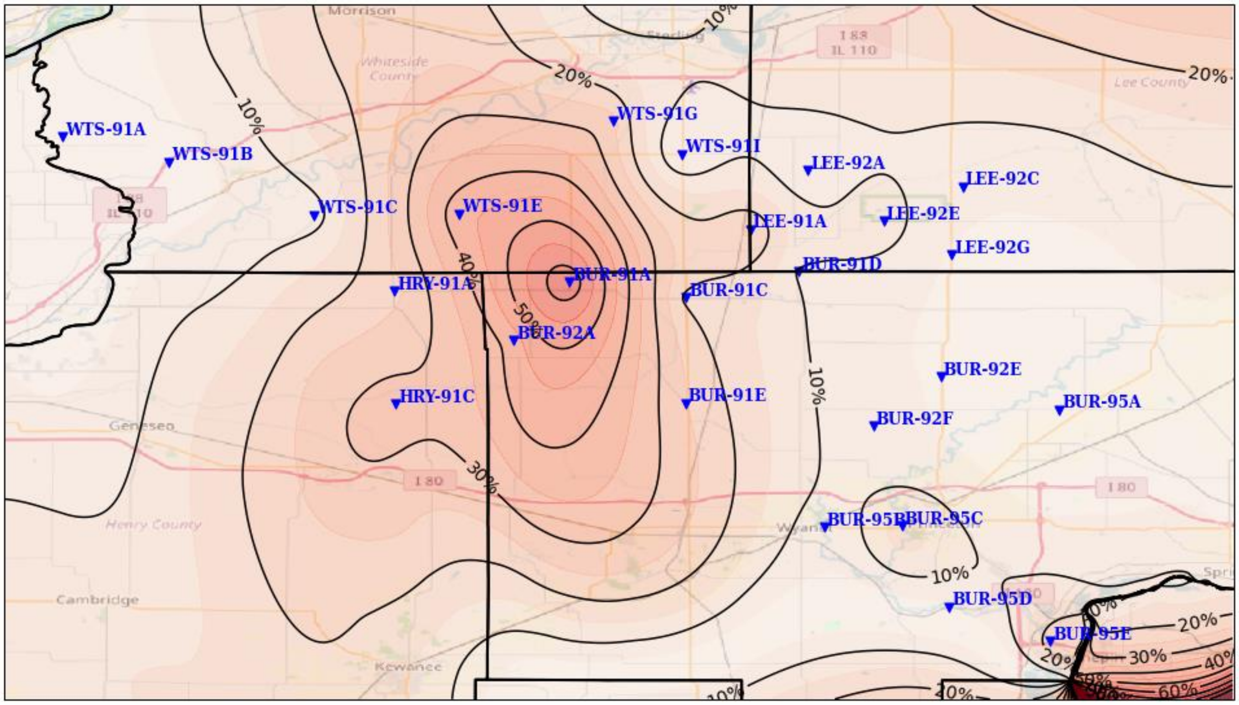

Figure 43. Pressure head above Sankoty percent change map for water year 2019. 50% indicates that half of the water above the aquifer boundary was removed during summer irrigation. 100% indicates that water levels reached the aquifer surface and will behave as an unconfined aquifer if water continues to be removed.

Besides unique insights into agricultural water demand impacts in the face of a sustained global pandemic, 2020 also had an abnormally dry summer. This presented an opportunity to preview how a future drought may appear, now that the monitoring network has better spatial coverage of continuous data. The increasingly concentric shape of the contours (Figure 44) suggests that an organized regional cone of depression centered somewhere near the location of BUR-91A is regularly forming during the summer. In 2020, 75 percent of the available head was lost at that site. If another drought of 2012's magnitude occurs, dewatering will likely occur at this site first and spread outwards as demands continue throughout the summer.

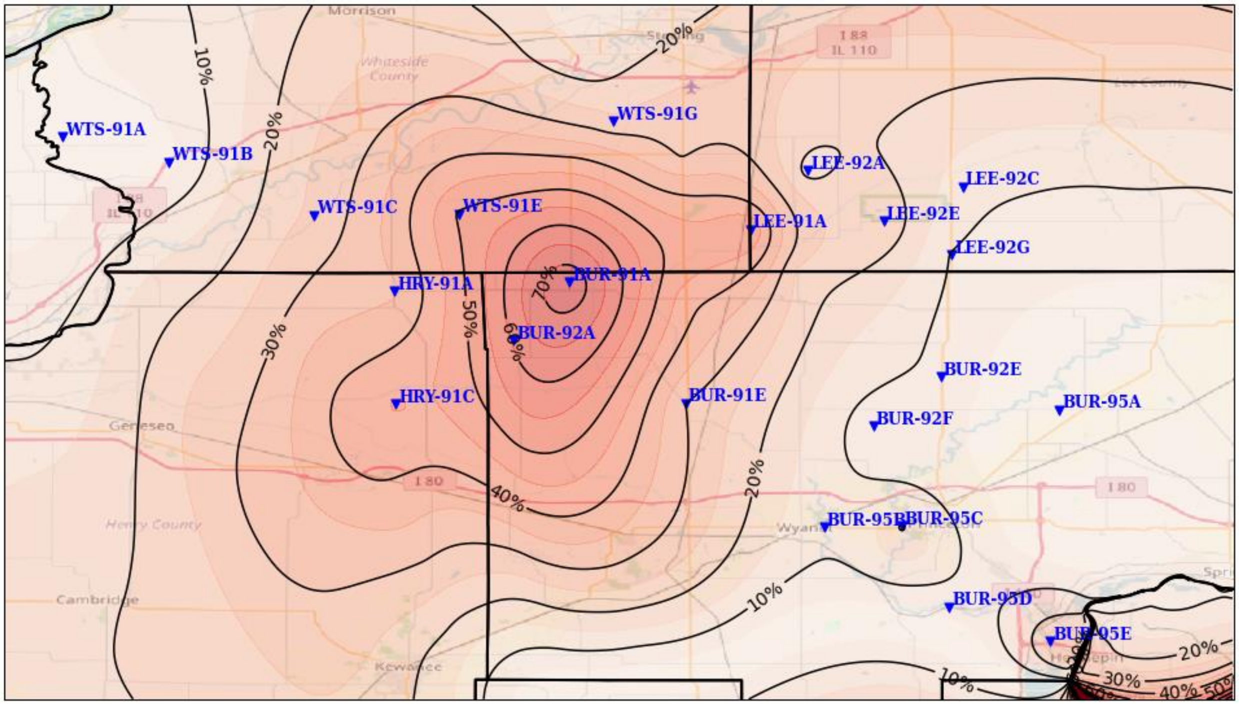

Figure 44. Pressure head above Sankoty percent change map for water year 2020. 50% indicates that half of the water above the aquifer boundary was removed during summer irrigation. 100% indicates that water levels reached the aquifer surface and will behave as an unconfined aquifer if water continues to be removed.

3.3.3 Recommendations

Stakeholders within the Green River Lowlands face a changed hydrodynamic setting since the ISWS last conducted an extensive regional analysis, 25 years ago. Two conclusions of Burch (Burch, 2004) should be reassessed in light of the quadrupling of irrigation demands within the region and the continued ingress of withdrawal points into a portion of the Sankoty Aquifer susceptible to periodic dewatering:

- Natural discharge to rivers may no longer exceed irrigation demands.
- Water levels in the Green River Lowlands can no longer confidently be considered “stable”.

Should irrigation demands exceed natural discharge rates, even locally, surface hydrology may be affected. Less water will contribute to streamflow, lowering the available supply for power generating facilities along the Rock and Mississippi Rivers. Environmental impacts are possible depending on the sensitivity of local plant and animal life.

Although long-term water levels do not yet show evidence of decline, and are perhaps even increasing in Lee County, there are other short- and long-term consequences of periodic dewatering of the Sankoty. New wells will need to be drilled deeper to protect against the risk of summertime supply disruptions. This “race to the bottom” of the aquifer means that average infrastructure installation, maintenance, and renovation costs will increase over time. Relieving hydrostatic pressures, even temporarily, increases the probability of mineralization within pore spaces of the aquifer material. Over time, this has the effect of reducing the amount of storage available for recharge, which in turn will exacerbate future dewatering and precipitate declines in maximum springtime water levels. Increased downward hydraulic gradients can also promote the migration of contaminants into the Sankoty Aquifer through the confining layer (especially where not present), and towards Bureau County.

Mitigating the risk of dewatering is a long-term, cost-effective strategy and is therefore preferred. Possible strategies include:

- Coordination among landowners in northwest Bureau County, and even throughout the region, to spread out demands throughout the day or week. Since irrigation only occurs in a limited window during the year, slowing down the rate of decline may limit the magnitude of decline.
- Selection of drought resistant crops or crops with low water demand in areas identified as being at risk for dewatering.
- Offsetting demand in critical areas of the Sankoty Aquifer with a supplemental source or investment in more efficient irrigation infrastructure.
- Conversion of land in regions with high dewatering risk into protected natural areas that are managed by Local, State, or Federal agencies.

3.3.4 Proposal for Continued Collaboration

The creation of a robust hydrogeologic model developed with stakeholder participation would be a valuable tool for testing various climate and demand growth scenarios as well as the effectiveness of any proposed risk mitigation strategies.

Expansion and continued upkeep of the regional monitoring network is an important component in model development. Increasing the amount of monitoring stations equipped with pressure transducers and other continuous environmental monitoring apparatuses will continue to be a part of that effort. Recruiting members of the community to assist with collection of hand measurements, and potentially increasing measurement frequency to monthly, and even further during active irrigation, can be done to immediately increase the resolution of observation data.

Irrigation well operators should consider engaging with IWIP, either individually or through the creation of a regional water commission, to an extent greater than what is mandated by law. Better understanding of irrigation withdrawal rates, local practices, and scheduling will increase our ability to predict potential dewatering events sooner and make more effective and timely recommendations to stakeholders.

Better estimates of local hydraulic properties and connections are necessary as well. Better knowledge of demands at pumping centers coupled with observations at monitoring wells will improve these constraints. By coordinating with landowners to turn on selected irrigation wells, outside of the irrigation season, and then noting the response over time in a nearby monitoring well, these properties can be directly measured to verify model predictions.

3.4 Groundwater Quality in the Rock River Region

3.4.1 Data Sources

Groundwater quality data discussed in this report come primarily from the ISWS Groundwater Quality Database. This statewide database contains data for more than 60,000 samples collected from wells in Illinois dating back to the 1890s. Data sources include public water supply well data (collected by the IEPA since the 1970s and from other sources before then), ISWS Public Service Laboratory (PSL) data, primarily from private wells, ISWS research project data, and several other sources. Private well samples may be biased towards poorer water quality, in that private well owners are more likely to contact PSL for a sample analysis if they suspect something is wrong with their well water quality. An additional dataset that was used was the Illinois Department of Agriculture's (IDOA) pesticide monitoring network (Illinois Department of Agriculture, 2020). In the late 1990s, approximately 150 shallow monitoring wells were installed throughout the state, including 41 in the Rock River Region. Wells were installed in shallow aquifers where depth to the top of aquifer material was less than 50 feet below land surface in row crop areas. Most of the wells have been sampled on an approximately twice a year since 1998 for four pesticides, three pesticide breakdown products, and nitrate; since 2015, nitrate data are no longer being collected.

For this study, we focused on data from 2000 to the present for human contaminants such as nitrate and chloride, which change temporally based on human activities, and from 1990 to the present for naturally occurring contaminants such as arsenic and radium.

3.4.2 Shallow vs. Deep Aquifers

In water quality assessments, we typically evaluate the data based on aquifer type, specifically unconsolidated (sand and gravel) versus different types of bedrock (sandstone, limestone, dolomite). We are also interested in shallow versus deep, especially as it relates to human-derived contaminants. These distinctions, however, are difficult in a region as large as the Rock River Region. As reported earlier, there are considerable differences in geology and hydrogeology across the region, including what constitutes shallow aquifers. From a water quality perspective, our interest in shallow aquifers is that they are the most vulnerable to human contamination, which primarily occurs at or near the land surface. Depending on where one is in the region, shallow aquifers can be either sand and gravel or bedrock formations, or both. Sand and gravel aquifers are the predominant shallow aquifers in the southern part of the region, including Henry, Bureau, Lee, and Whiteside Counties, which is also the area of most intense irrigation in the region. Most shallow wells in Winnebago and Boone counties are also in sand and gravel aquifers. In the other counties, most shallow wells are drilled into bedrock, including Silurian dolomite, Galena-Platteville limestone, and St. Peter sandstone. This can be confusing because the Galena-Platteville and St. Peter are considered to be "deep bedrock" aquifers to the east and south in Illinois. Sand and gravel aquifers are absent from the Driftless Area, an area in the midwestern U.S. that was not covered by glaciers during the Pleistocene, resulting in no glacial deposits covering the bedrock units (Panno et al., 2016).

3.4.3 Human-Derived Contaminants

In Illinois, the most common human-derived, or anthropogenic, contaminants found in groundwater are nitrate-nitrogen (NO_3-N), chloride (Cl^-), and total dissolved solids (TDS). Chloride and TDS contamination usually result from the same sources and thus are often correlated; in this report we will focus on chloride. Nitrate-N has a primary drinking water standard of 10 milligrams per liter (mg/L), while chloride (250 mg/L) and TDS (500 mg/L) have secondary drinking water standards. Primary standards are health related and enforceable for community water supplies, while secondary standards relate to aesthetic concerns (taste, odor) and are non-enforceable. Drinking water standards are not enforceable for private wells.

Because the sources of nitrate and chloride/TDS contamination are generally the result of human activities at or near the land surface, shallow aquifers are most vulnerable to being contaminated by them. The main factor determining whether surface-derived nitrate and chloride/TDS contamination reach shallow aquifers is how well the aquifers are protected by overlying impermeable units. We used a well depth of 300 feet to distinguish between shallow and deep aquifers with respect to water quality. Sand and gravel aquifers are generally not found beneath this depth in the Rock River region.

Nitrate has numerous sources, including agricultural activities (synthetic fertilizer, livestock manure, soil disruption) and human waste (sewage and septic systems). While the primary drinking water standard for NO_3-N is 10 mg/L, concentrations greater than 2 to 3 mg/L generally indicate contamination from human sources (Panno, Kelly, et al., 2006). Elevated concentrations of NO_3-N were found in much of the region, especially in the northern half, as well as along rivers such as the Rock, Pecatonica, and Mississippi (Figure 45). The majority of wells sampled in sand and gravel aquifers, especially in the Green River Lowlands and the Rockford region, had elevated NO_3-N concentrations (greater than 3 mg/L). Shallow bedrock wells in the northern half of the region (Jo Daviess, Stephenson, Carroll, Ogle Counties) also commonly had elevated NO_3-N levels. Nitrate concentrations tended to be relatively low in the southernmost part of the region, in Bureau and Henry Counties especially. This may be due to several reasons, including: (1) the Bloomington Moraine runs across this area, resulting in thicker overlying impervious sediments and lower recharge rates; (2) there is less irrigation and thus less high capacity pumping; and (3) there is less cropland and more forested land in this area, thus less fertilizer application.

Chloride is a common contaminant in shallow aquifers that generally indicates human activities, although natural sources exist as well. Where there are no significant natural sources, concentrations greater than 10 to 15 mg/L generally indicate human contamination (Hwang et al., 2015; Panno, Hackley, et al., 2006). In the Rock River region, Cl^- concentrations were most likely to be elevated in Rockford (Figure 46), likely due to road salt runoff. Elevated levels in other, more rural parts of the region are probably the result of agricultural runoff and/or septic/sewage discharge, as well as road salt runoff (Kelly et al., 2012).

Well depth is an important variable for NO_3-N and Cl^- (Figure 47). The sources for both NO_3-N and Cl^- contamination are found at or near the land surface, so it is not surprising that shallower wells, especially those less than 100 feet deep, tend to have higher concentrations of these contaminants. Nitrate-N and Cl^- concentrations were not correlated, indicating that the major sources for these two contaminants are different.

In row crop regions, pesticides are a potential contaminant to shallow aquifers. In approximately 31 percent of the samples collected for the IDOA pesticide monitoring program in the Rock River Region, at least one of the seven pesticide compounds analyzed for was detected. None of the samples had concentrations exceeding drinking water standards, although of the compounds analyzed for only atrazine (3 µg/L) and simazine (4 µg/L) have primary standards. The most commonly detected compounds were two atrazine breakdown products, deethylatrazine (DEA) and deethyldeisopropylatrazine (DEDIA). The counties with the highest percentages of pesticide detections were Carroll, Winnebago, Ogle, and Bureau.

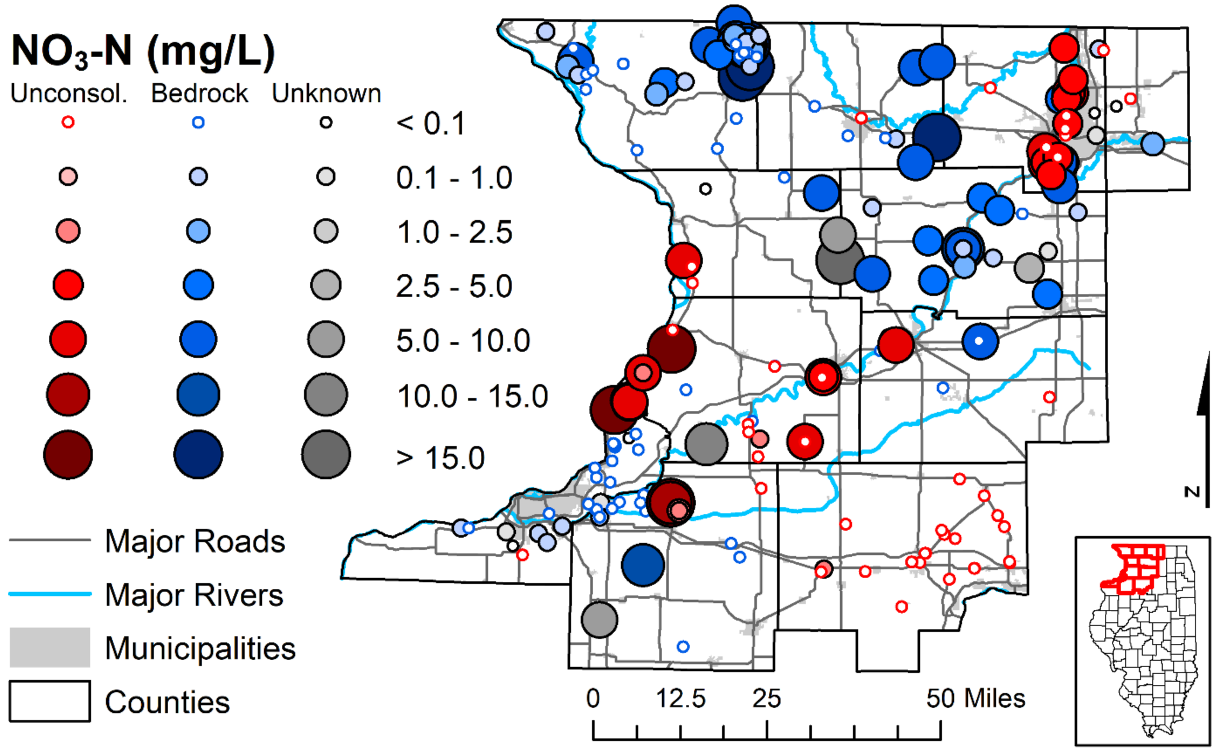

Figure 45. Nitrate-N concentrations in shallow wells (< 300 ft) sampled since 2000. Different colors represent different aquifer types (unconsolidated (sand and gravel), bedrock, or unknown).

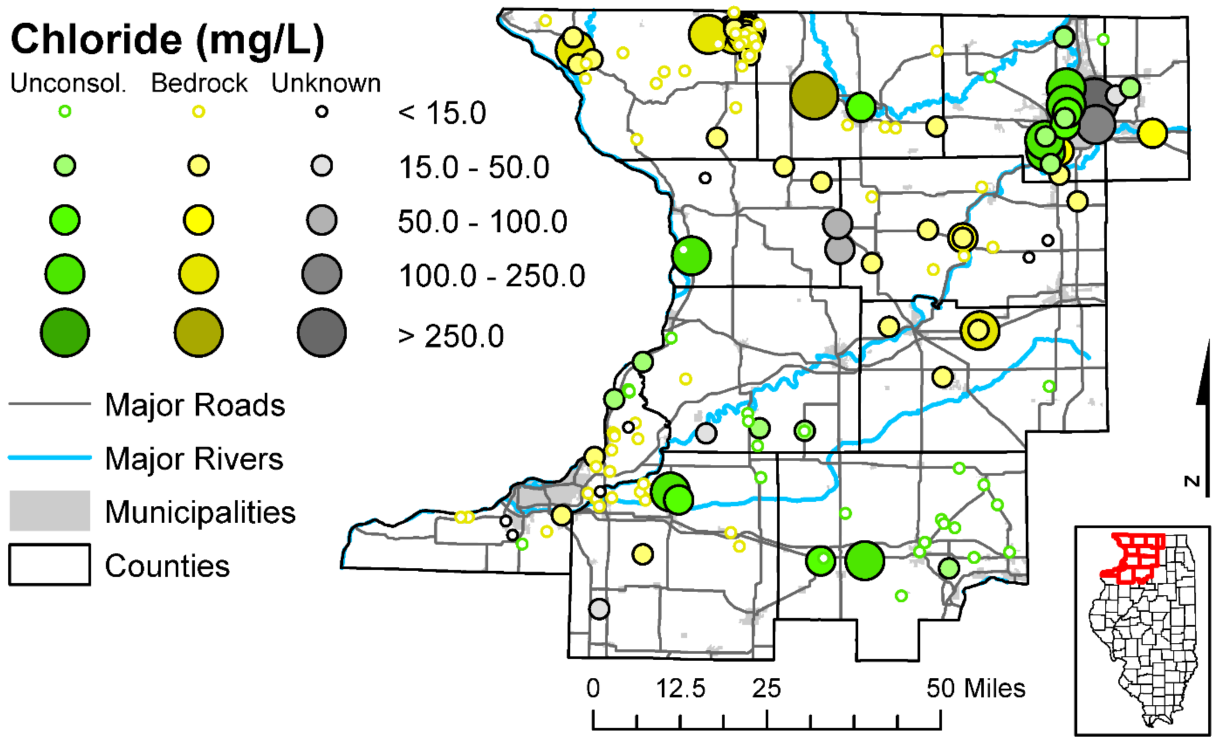

Figure 46. Chloride concentrations in shallow wells (< 300 ft) sampled since 2000.

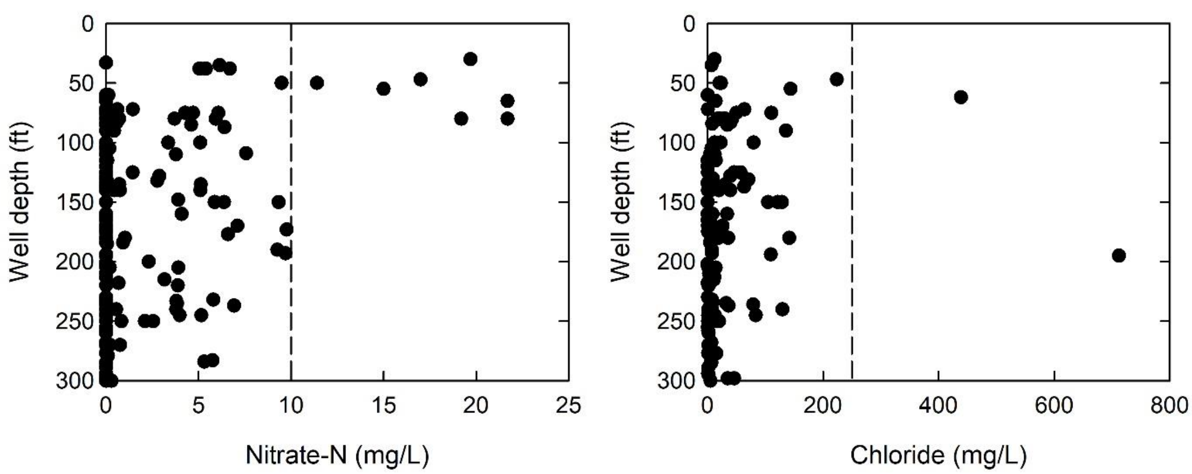

Figure 47. Nitrate-N and chloride concentrations vs. well depth for shallow wells (< 300 ft) sampled since 2000. Dashed lines show the primary (nitrate-N) and secondary (chloride) standard thresholds for each contaminant.

3.4.4 Natural Contaminants

There are many contaminants found in groundwater that can occur naturally, also known as geogenic contaminants. Some of these can be health concerns and have primary drinking water standards. The most notable ones in Illinois are arsenic, fluoride, and radium. Other contaminants are mainly nuisances, including iron, manganese, hardness (calcium + magnesium), and TDS.

Arsenic is a common contaminant in sand and gravel aquifers throughout the state, but is typically not found in bedrock aquifers (Holm & Curtiss, 1988; Kelly et al., 2005). During the Pleistocene, when glaciers moved back and forth across Illinois, large volumes of sediment were deposited on the landscape. Arsenic is a minor constituent of some common minerals that were deposited in many of these sediments. Most of the arsenic in these sediments is thought to be associated with iron-containing minerals such as hematite, and biogeochemical reactions that occur in the subsurface can dissolve the arsenic (Kelly et al., 2005; Kirk et al., 2004). As a result, arsenic is sensitive to minute variations within the geochemical conditions of the aquifer, and it can be difficult to predict where elevated concentrations occur (Holm & Wilson, 2009).

Arsenic concentrations greater than the primary drinking water standard (10 μg/L) are common in sand and gravel aquifers in the southern half of Rock River region, especially in Bureau County (Figure 48). As expected, with a few exceptions, elevated arsenic levels are generally not found in shallow bedrock aquifers. There is widespread geographic variability in arsenic concentrations in the region, which has also been observed in other parts of the state (Holm & Wilson, 2009; Kelly et al., 2005; Kelly & Holm, 2011). Well depth is not an important variable affecting arsenic concentrations.

Community water supplies that rely on the St. Peter and Ironton-Galesville sandstones often have to deal with elevated levels of radium, which is produced naturally within the aquifers (Szabo et al., 2012; Wilson, 2011) (Figure 49). The primary standard for total radium (the sum of the isotopes ^{226}Ra and ^{228}Ra) is 5 picocuries per liter (pCi/L). Of the 59 wells sampled for radium by IEPA that are open to the St. Peter and/or Ironton-Galesville aquifers, 12 (~20 percent) had levels greater than the drinking water standard. The use of these bedrock aquifers as drinking water sources requires treatment in order to meet the drinking water quality regulations. Domestic wells are not routinely sampled for radium analysis, but it is likely that if they are open to the St. Peter sandstone, such as in Ogle County, they may have levels of concern.

In most of Illinois, the bedrock aquifers are part of the Illinois Basin, which deepens from north to south. In the northern part of the Rock River region, the Cambrian-Ordovician aquifers (Galena-Platteville, St. Peter, and Ironton-Galesville) are at or relatively close to land surface. These aquifers deepen to the south of the region, wells must be drilled deeper, and natural TDS levels increase. Illinois was a marine environment when these rocks were deposited, and the fluids that initially saturated them were seawater brines, remnants of which are still evident in these aquifers. A map of chloride concentrations in wells greater than 300 feet deep (Figure 50) shows that, in most of the region, chloride concentrations are fairly low, generally less than 50 mg/L. In the extreme south in Bureau and Henry Counties, however, several wells have chloride concentrations that exceed the secondary drinking water standard of 250 mg/L. Dilute meltwater from Pleistocene glaciation has flushed out the in situ brines in the northern part of the region, but the chemical signature of ancient brines can still be seen in chloride concentrations in the southern part of the region (Figure 50). Less flushing has occurred in this part of the basin because of the greater distance from the recharge zones found further north. These remnant brines can also be seen further south in the Middle Illinois Water Supply Planning Region (Kelly et al., 2018). Elevated chloride and TDS levels found further north are likely primarily the result of surface contamination such as road salt runoff.

Because of the higher TDS levels in the southern part of the region due to remnant brines, many elements and aqueous species also have elevated concentrations. One parameter related to these remnant brines is fluoride, which like TDS and chloride tends to be elevated in Bureau and Henry Counties, and into Rock Island County (Figure 51). Fluoride has both a primary (4 mg/L) and secondary (2 mg/L) drinking water standard.

Regarding nuisance contaminants, shallow groundwater in the Rock River region tends to be hard to very hard (greater than 120 mg/L as CaCO3), and have elevated iron concentrations commonly greater than 1 mg/L. Ammonium levels also tend to be high in the southern part of the region, especially in wells deeper than 300 feet and particularly in Rock Island County. These contaminants can be dealt with using conventional treatment technologies.

3.4.5 Groundwater Quality in the Driftless Area (Jo Daviess County)

The Driftless Area, particularly in Jo Daviess County, is unique in the Rock River region for many reasons, one being the susceptibility of its water resources to contamination. Soils are thin and the dolomite aquifers (Galena and Silurian) can exhibit karst features, such as sinkholes, springs, and conduit flow in the bedrock (Panno et al., 2017). Karst aquifers are susceptible to contamination because water tends to move rapidly from the surface into and through the subsurface, with little chance for biogeochemical reactions that might retard contaminant transport. Scientists from the ISWS and ISGS have sampled wells and springs in Jo Daviess County since 2014 in order to assess the county's shallow groundwater quality (Panno et al., 2019). The wells sampled generally did not show contamination, with some exceptions, but many of the springs, which amalgamate the shallowest groundwater flow in a region, were contaminated. The primary contaminants were nitrate and bacteria, including *E. coli*. The main source of contamination was suspected to be septic system discharge.

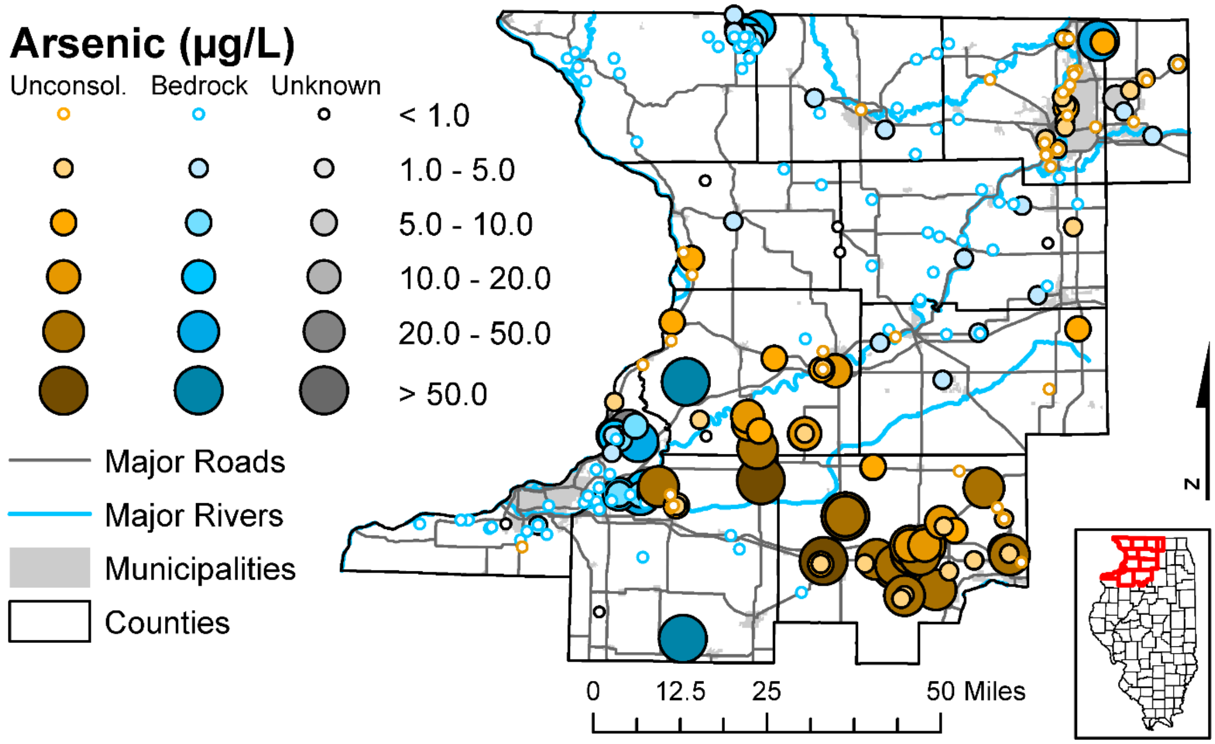

Figure 48. Arsenic concentrations for shallow wells (< 300 ft) sampled since 2000.

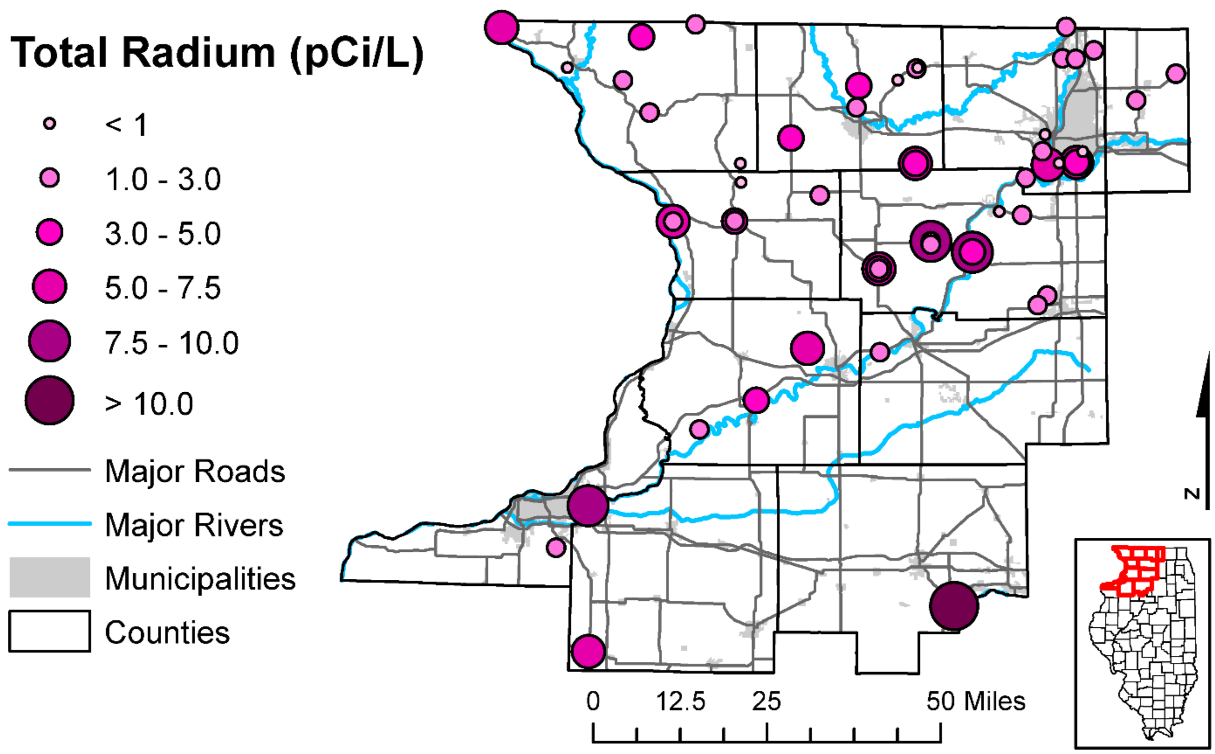

Figure 49. Total radium ($^{226}Ra + ^{228}Ra$) in public supply wells finished in Cambrian-Ordovician bedrock aquifers sampled since 1990.

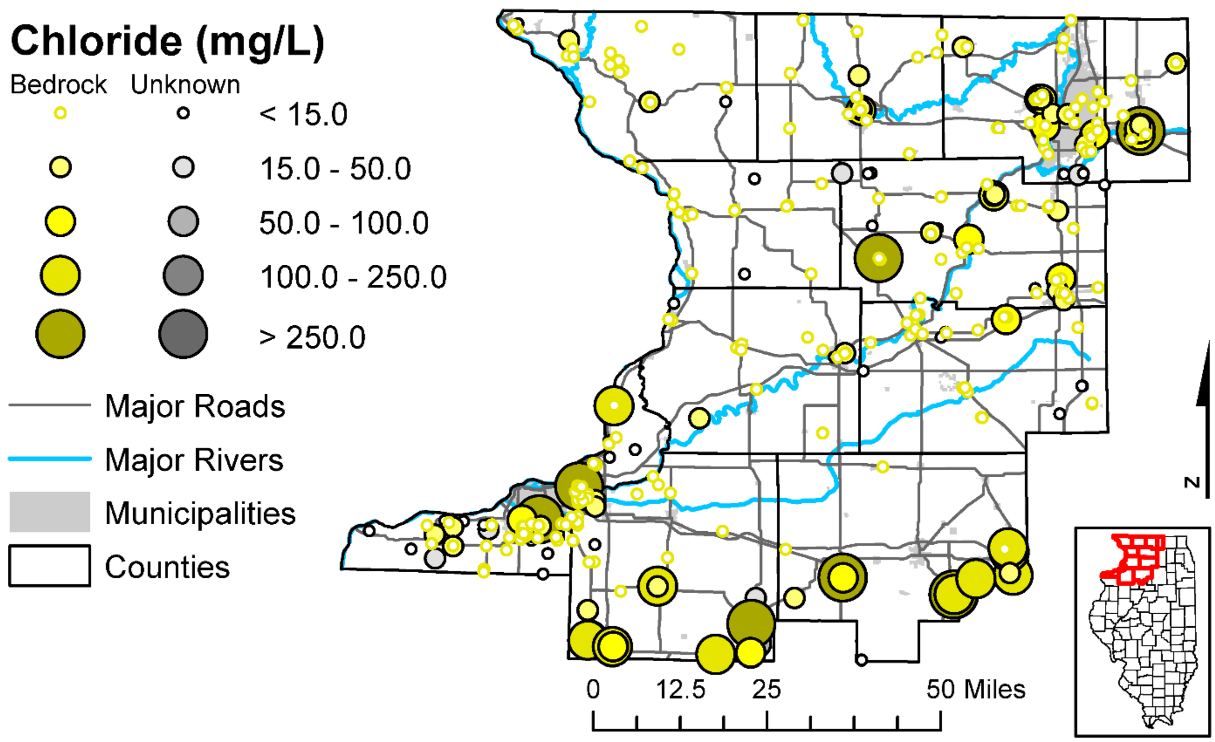

Figure 50. Chloride concentrations in deep wells (> 300 ft) sampled since 1990.

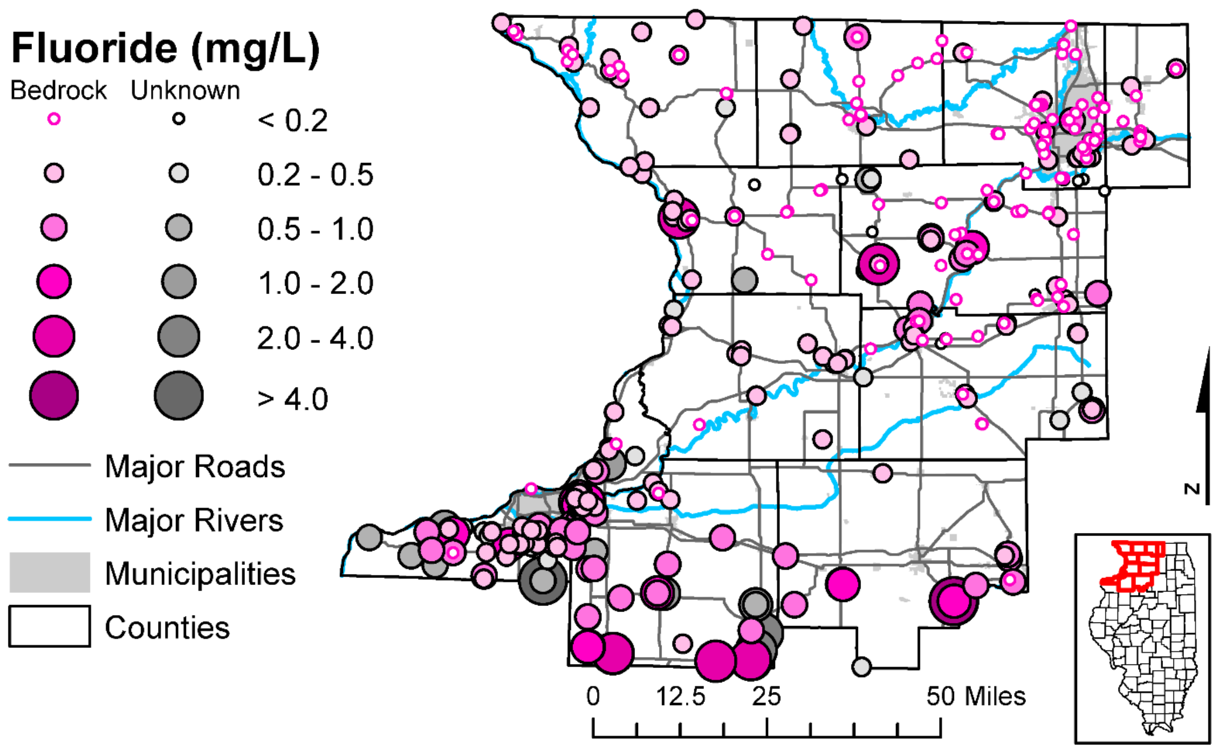

Figure 51. Fluoride concentrations in deep wells (> 300 ft) sampled since 1990.

4 Surface Water Studies in Rock River Region

4.1 Surface Water System

Surface water resources in Illinois primarily include free-flowing streamflow in rivers and streams, stored water in reservoirs or lakes, and water diverted from Lake Michigan. For rivers and streams with limited streamflow during drought conditions, a low-head dam can provide additional storage for a short period. Off-channel reservoirs can augment streamflow and/or low-head impoundment storage. When stored water is needed for an extended period, such as during a multiple month drought, a reservoir impounding the entire river valley may be needed to supply surface water.

The surface water system in the Rock River WSPR primarily consists of the Rock River and its tributaries as well as the Mississippi River and its tributaries in northwestern Illinois upstream of the confluence of the Rock and Mississippi Rivers.

4.1.1 Illinois Public Waters

According to Illinois Administrative Code, a Illinois public waters, also known as Illinois Public Bodies of Water, re generally defined as all lakes, rivers, streams, and waterways that are or were navigable, are open or dedicated to public use and include all bayous, sloughs, backwaters, and submerged lands connected by water to the main channel or body of water during normal flows or stages (Illinois General Assembly, 1984; Meyer, 2012). Figure 52 shows Illinois's major public waters, which include the Mississippi River, the Rock River, the Pecatonica River, and the Hennepin Canal in the Rock River Region.

To provide instream flow for aquatic ecosystem and environment purposes, the State of Illinois typically requires minimum flows for public waters. For withdrawals in the public waters with minimum flow requirement, water users are required to cease water withdrawals whenever the streamflow falls either below the required minimum flow or when the withdrawal would otherwise cause the streamflow to decrease below the required minimum flow. When there is no site-specific data or studies with respect to instream flow needs and other water demands, the 7-day, 10-year low flow (7Q10) is generally adopted as the minimum flow for Illinois public waters (https://www.isws.illinois.edu/watershed-science/water-supply/7-day-10-year-low-flow-maps). 7Q10 is defined as the minimum 7-day average flow that has a 10 percent chance of being equal to or less than annually (Singh & Ramamurthy, 1993; Zhang & Kroll, 2007).

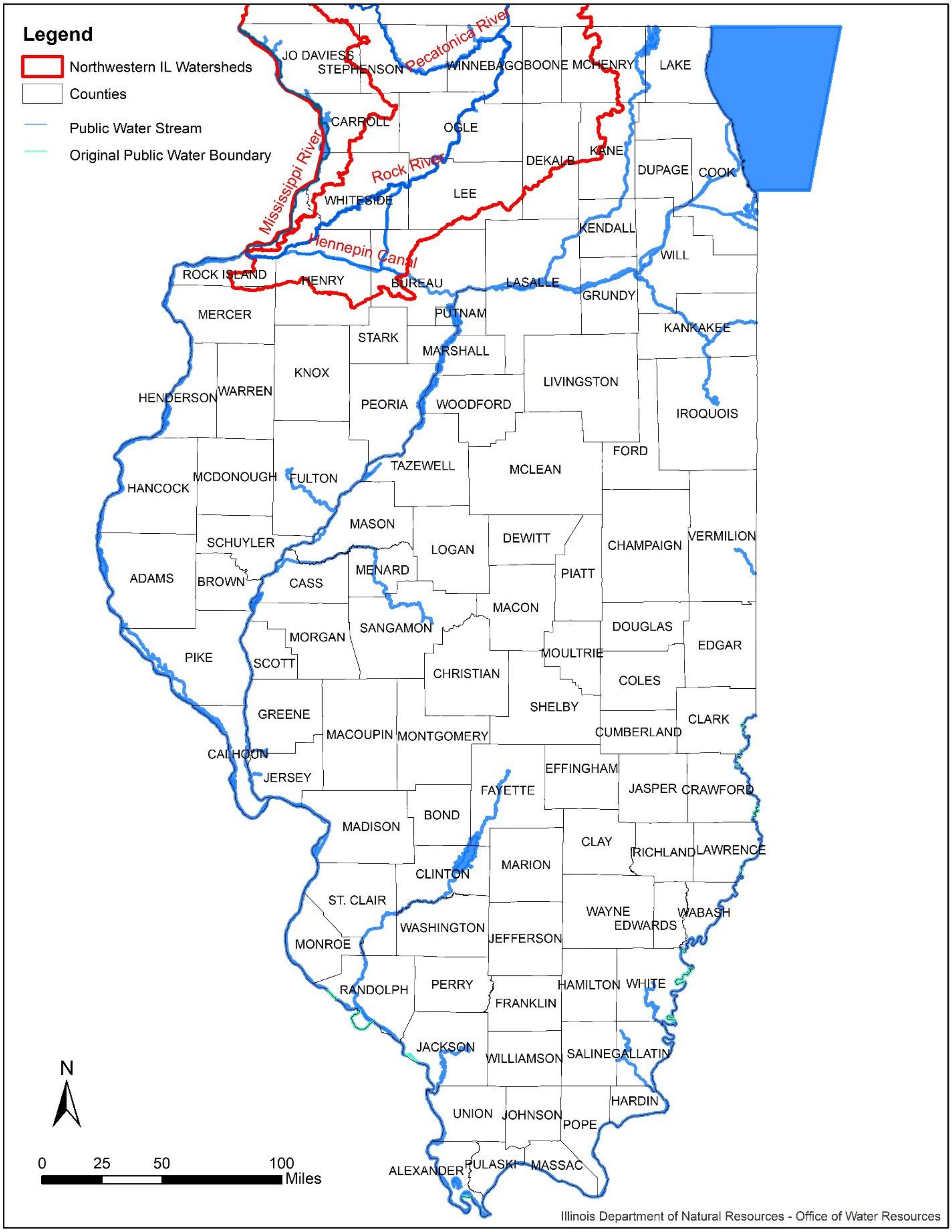

Figure 52. Public waters of Illinois, adapted from (Illinois Department of Natural Resources, 2015).

4.1.2 The Mississippi River, Rock River, and Hennepin Canal

The surface water systems that cover the Rock River Region include the Rock River watershed and the Mississippi River valley from Wisconsin-Illinois state line to the confluence of the Rock River and the Mississippi River as shown in Figure 53.

The Mississippi River is the second-longest river in the United States and the fourth-longest river in the world spanning 2,340 miles from the source at Lake Itasca in Minnesota to the Mississippi River Delta in the Gulf of Mexico. The Mississippi River watershed is the largest watershed by drainage area and drains all or parts of 32 states and two Canadian provinces with a drainage area of 1,150,000 square miles (mi^2) (Kammerer, 1990).

The Mississippi River is about 274 miles long in the Rock River Region and the Mississippi River valley has a drainage area of 1103 mi^2 in Illinois. There are 29 locks and dams (L&D) on the Upper Mississippi River and eight L&Ds on the Illinois River, which consists of the Upper Mississippi River System. The L&Ds, built in the 1930s, covers the Mississippi River between about Cairo, IL to Minneapolis, MN and maintains navigation channel of at least 9 feet deep. Four of these L&Ds are within the Rock River Region, .i.e. L&D 12 at Bellevue, IA (elevation of 592ft), L&D 13 at Fulton, IL (elevation of 583 ft), L&D 14 at LeClaire, IA (elevation of 572 ft), and L&D 15 at Rock Island, IL (elevation of 561 ft). The tributaries in Illinois that drain to the Mississippi River, from north to south, include the Galena River (13.3 mi), Apple River (31.9 mi), Rush Creek (21.6 mi), Plum River (27.2 mi), and Johnson Creek (17.4 mi).

The Rock River watershed is located in south-central Wisconsin and northwestern Illinois with a total drainage area of 10,915 mi^2. The watershed covers 12 counties in Wisconsin and 15 counties in Illinois which include: Jo Daviess, Stephenson, Winnebago, Boone, McHenry, Carroll, Ogle, DeKalb, Kane, Whiteside, Lee, Rock Island, Henry, Bureau, and Mercer. The total length of the Rock River is 285 miles. Within Illinois, the Rock River is 163 miles long with a drainage area of 5281 mi^2. The major tributaries with drainage areas of 1,000 mi^2 or more include the Pecatonica, Kishwaukee, and Green Rivers. The lengths and drainage area of the three rivers are show in Table 4.

Table 4. The lengths and drainage areas of the major Rock River tributaries

River	Length (mile)	Drainage area (mi^2)
Pecatonica River	167	2643
Kishwaukee River	64	1247
Green River	93	1121

The Hennepin Canal connects the Mississippi River at Rock Island, IL and the Illinois River at Hennepin, IL (Knapp & Russell, 2004). The canal is 75.2 miles long and a 30-mile long feeder supplies water from the Sinnissippi Dam on the Rock River to the canal. The canal was abandoned in 1951 and was resurrected in the late 20th century as a recreational waterway (Knapp & Russell, 2004).

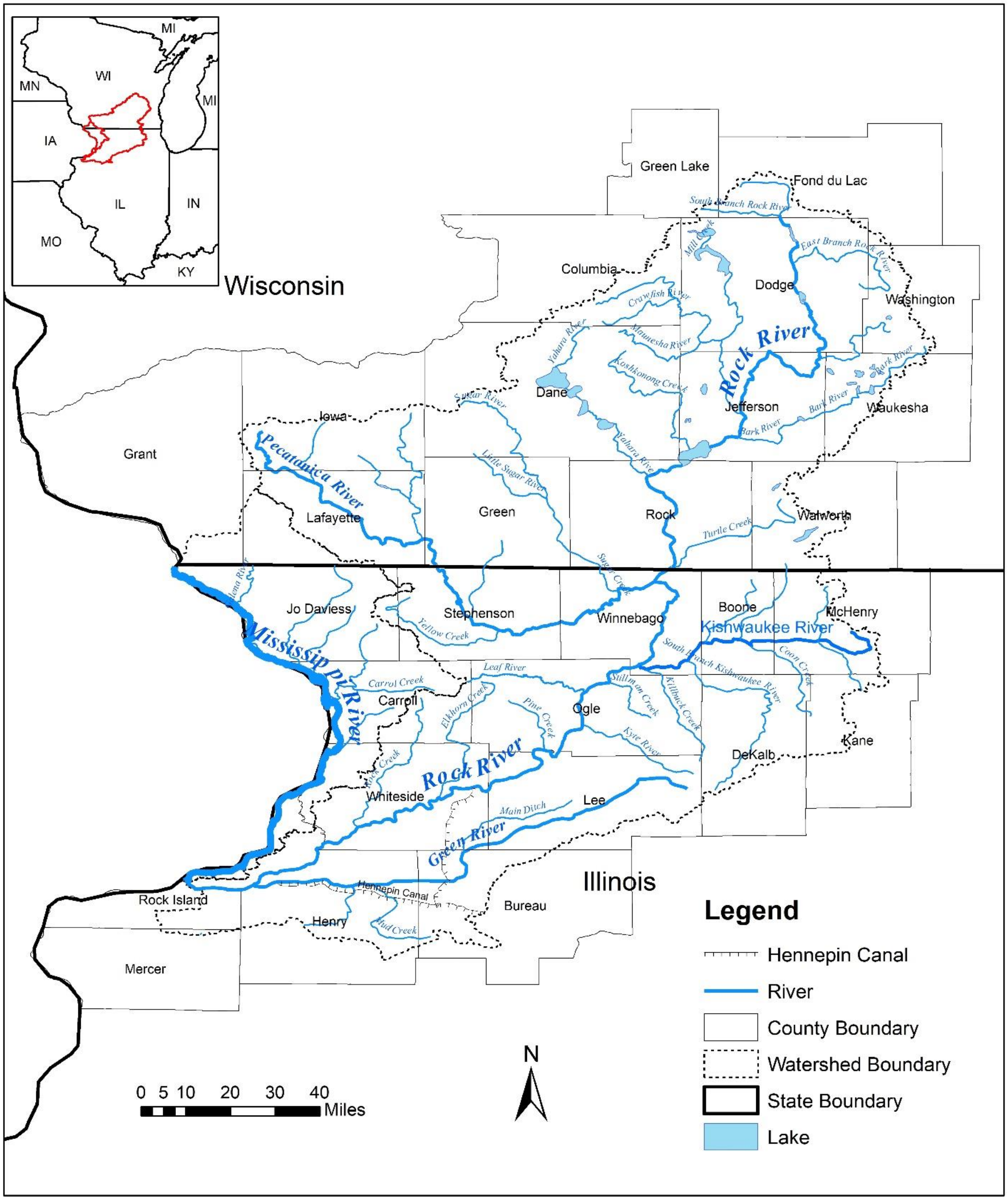

Figure 53. The surface water system including the Rock River watershed and the Mississippi River valley

4.1.3 Watershed Characteristics

Based on the surface watershed boundaries, the Rock River Region consists of two areas: the Rock River watershed and the Mississippi River valley (Figure 54). Compared with the other parts of Illinois, the landscape of the Rock River Region is varied, rugged and complex with six physiographic regions (Leighton et al., 1948). The six physiographic regions are the Wisconsin Driftless Section, Rock River Hill Country, Green River Lowland, Wheaton Morainal Country, Bloomington Ridged Plain, and Galesburg Plain (Figure 54). See Section 3.1.2 for more information on the physiographic regions of the watersheds of the Rock River Region.

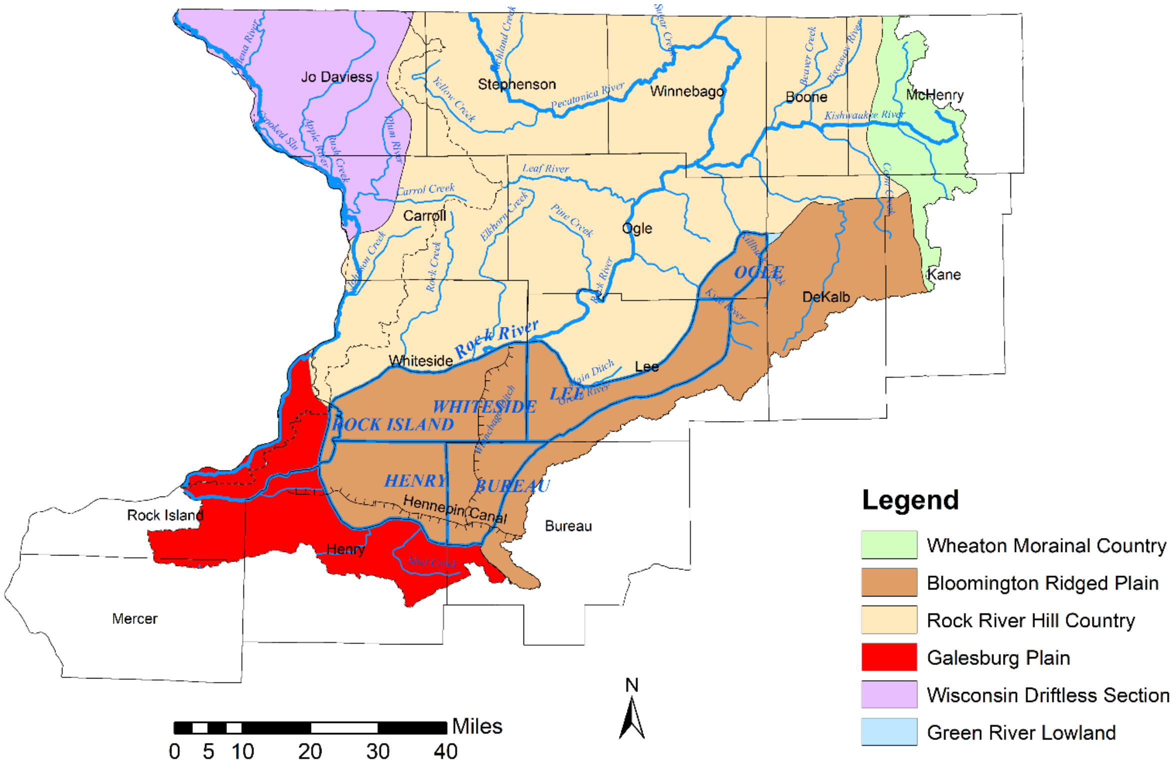

Figure 54. Physiographic regions of the Rock River Region

Figure 55 shows the land cover in the region based on the 2016 National Land Cover Database (NLCD 2016) which was released in 2019 (Homer et al., 2020). The release of NLCD 2016 provides the most recent available land cover information across conterminous United States. It is noted that while herbaceous/hay is separately shown in the map, it is included in the agriculture land in the analysis. It can be seen that agricultural land dominates the region. Major developed land are located in Winnebago and Rock Island counties, centered with Rockford and Rock Island, respectively. The herbaceous/hay primarily is distributed along the Mississippi River valley.

Figure 56 shows the percentages of different land cover in the Rock River watershed. Agriculture is the dominant land use in the watershed and accounts for 81.6% of the total land area. This reflects a decrease from 85.9% in 1990s. The developed land accounts for 10.2% which increased from 5.3% in 1990s. The forest covers about 7.0% of the watershed, increasing from 5.1% in the 1990s. Wetland only accounts for about 1.3% which decreased from 1.8% estimated in 1990s (Knapp & Russell, 2004). The water area (lakes and streams) accounts for 0.8% which decreased from 1.7% in the 1990s. It is noteworthy that algorithms used in NLCD were changed after 2007 and wetland and open water area are highly impacted by the by the timing of the remote sensing images and different approaches used for estimating open water area used in (Knapp & Russell, 2004) and in the NLCD 2016. The total area of wetland and open water kept decreasing in the last 3 decades. Historically, the Rock River watershed has abundant lakes and wetlands with 15 percent of the land in Wisconsin portion Rock River watershed covered by lakes and wetlands. The Illinois portion may have had a similar percentage area of lakes and wetlands. The majority of wetlands in the Illinois portion of the Rock River watershed have been drained for agriculture.

Figure 57 demonstrates the percentages of land cover in the Mississippi River valley. The primary land cover in the Mississippi River watershed is agriculture which accounts for 62.5% (including the herbaceous designation). The Mississippi River has less percentage agricultural land compared with the Rock River watershed but it has much more percent forest which accounts for 21.8%. This is due to topography being hillier in the valley than the Rock River watershed which results in less favorable land for agricultural purposes. The developed land accounts for 7.5%. Water area (lakes and streams) and wetlands account for 4.8% and 3.3%, prospectively. The relatively large wetland fraction and open water area are primarily with the Mississippi River corridor. Outside of the river corridor, the hilly terrain and rugged topography is not favorable for wetlands.

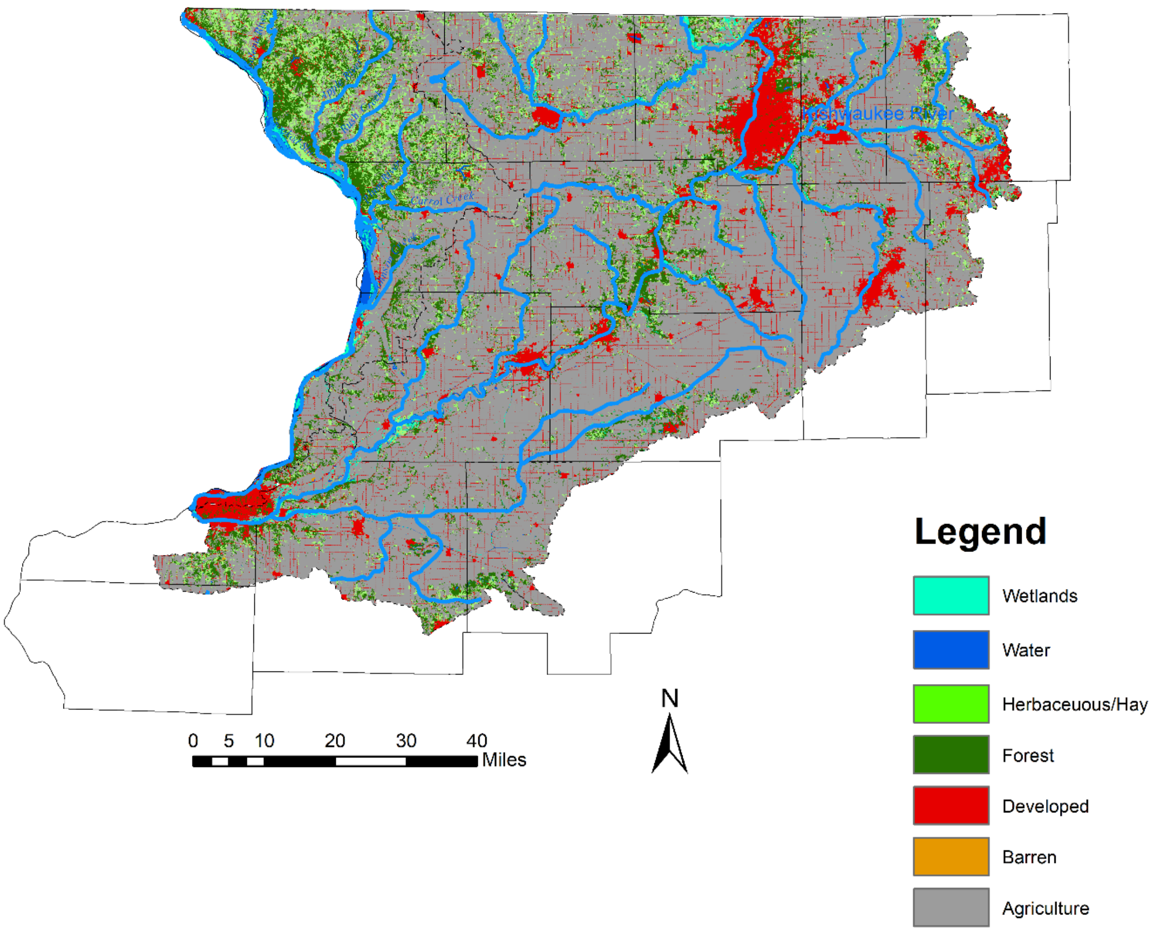

Figure 55. Land cover in the Rock River Region. Data from the 2016 NLCD (Homer et al., 2020).

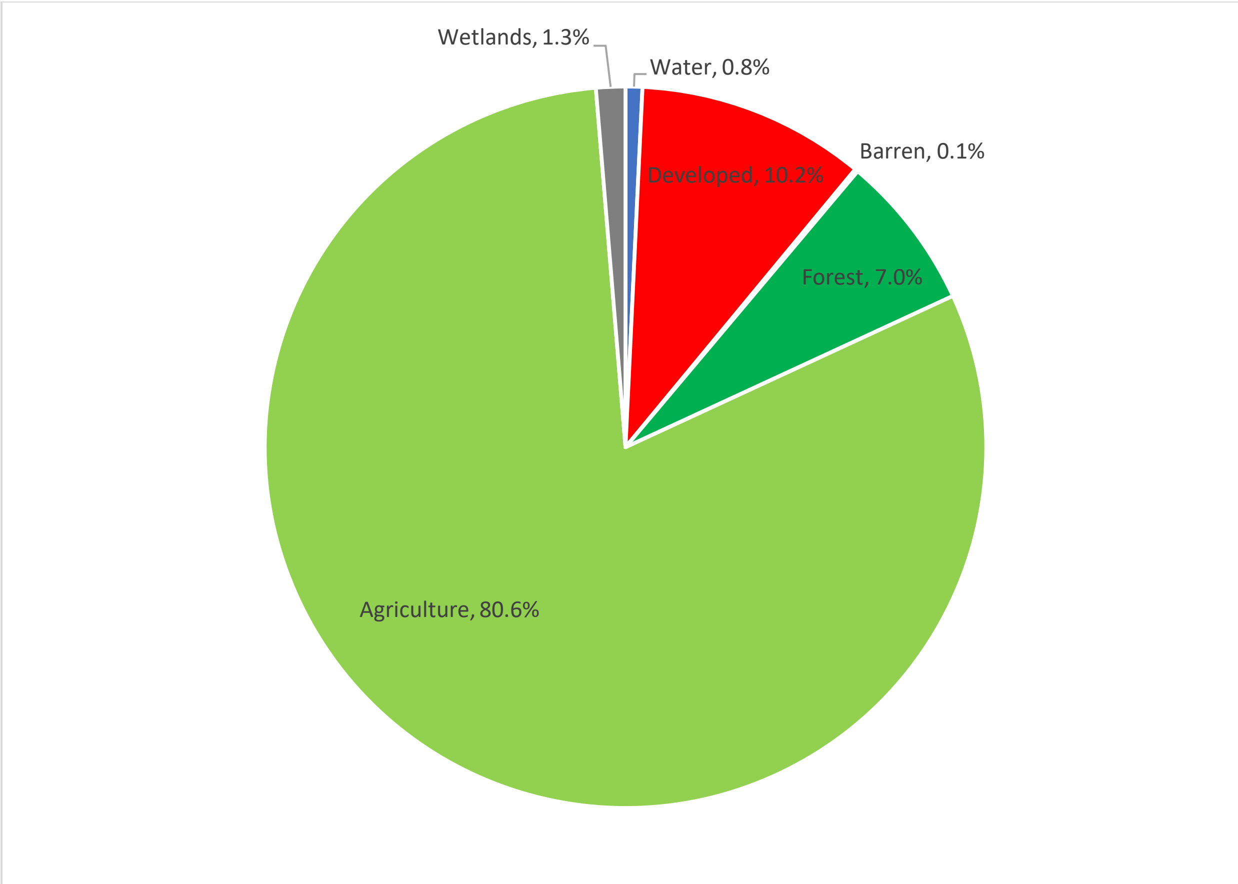

Figure 56. Percentage of land cover in the Rock River watershed. Note: agriculture land includes agriculture and herbaceous/hay in Figure 55. Data from the 2016 NLCD (Homer et al., 2020).

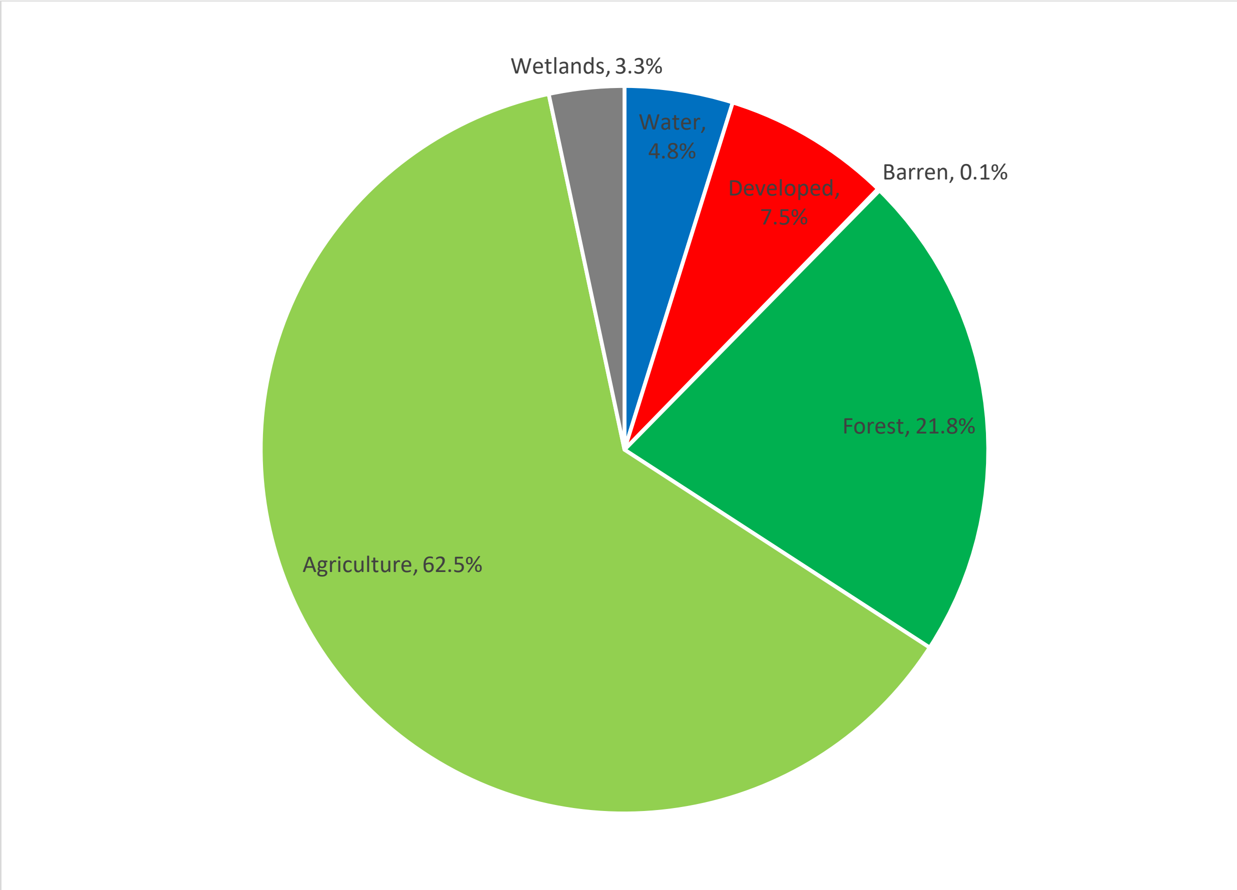

Figure 57. Percentage of land cover in the Mississippi River valley. Note: agriculture land includes agriculture and herbaceous/hay in Figure 55. Data from the 2016 NLCD (Homer et al., 2020).

4.2 Surface Water Demand

4.2.1 Water Demand in Wisconsin Portion of the Rock River Watershed

Section 2 discusses the details of surface water demands in the Illinois portion of the Rock River watershed (see Figure 2). Additionally, water demand in the Wisconsin portion of the Rock River watershed affects water availability in the Illinois portion of the Rock and Pecatonica River. In light of this, understanding water use within the Wisconsin portion of the Rock River watershed can help inform water supply planning within the RRWSPR. The Wisconsin Department of Natural Resources requires water users to report withdrawals for a variety of reasons:

- high capacity wells;
- permitted surface water withdrawals;
- water use permit holders in the Great Lakes basin; and
- anyone withdrawing an average of 100,000 gallons per day (0.1 mgd) or more in any 30-day period.

Water users are required to report water use location, purpose, amount, water source, etc. The groundwater and surface water withdrawals in 2018 are shown in (Meyer et al., 2019) and summarized by water use sectors in Table 5. There are 110.0 mgd total demand (8.5 mgd surface water demand and 105. mgd groundwater demand) in the Wisconsin portion of the Rock River watershed. Surface water is primarily used for power generation and industry purposes. Groundwater use is dominated by public water supply, followed by industry. Many water demands are in Dane, Rock and Waukesha counties, which is expected as major population centers such as Madison and Janesville are located in these counties. For the Pecatonica River watershed, there is limited water demand and only one reported surface water demand.

Although groundwater withdrawals in Wisconsin are believed to have a minimal impact on the aquifers of Illinois, wastewater originated from groundwater increases the streamflow in the Rock River in Illinois. The wastewater originated from surface water will reduce the impact of surface water withdrawal on streamflow downstream of corresponding wastewater discharge points.

Table 5. Water withdrawals by water use sector in the Wisconsin portion of the Rock River watershed in 2018

Water use sector	Surface water withdrawal (mgd)	Groundwater withdrawal (mgd)
Public	0.0	77.9
Power	5.7	2.1
Industry	2.7	18.8
Irrigation	0.0	2.8
Total	8.5	101.5

4.3 Streamflow Characteristics

4.3.1 Hydrologic Records

Continuous streamflow gages monitor the streamflow or water level of rivers and streams at certain locations, providing valuable data to characterize streamflow such as magnitude, frequency, duration, timing and rate of change of surface water resources (Liu et al., 2018). Streamflow records may be used for evaluating water availability and impacts of climate, land use, water use, effluent discharge, etc., on water resources.

There are 43 USGS streamflow gages in and adjacent to the Rock River Region (Figure 58). Among these gages, 23 gages are active and still operated by the USGS presently and 20 are inactive. Table 6 shows the pertinent information of these gages.

It is noted that 6 of these gages are adjacent to the Rock River Region, including 1 gage on the Mississippi River and 5 gages on the Rock River and its tributaries. These 6 gages are located on rivers close to the Iowa-Illinois or Wisconsin-Illinois state boarders and provide streamflow records of relatively long-term periods. It is also noted that the current gage of Pecatonica River *near* Shirland, IL (USGS 05437050) includes all the previous records (1940-1958) of the inactive gage at Pecatonica River *at* Shirland, IL (USGS 05437000). Thus, the gage of the Pecatonica River *at* Shirland, IL is not considered in the later analysis.

For the active gages, the periods of record range from 8 to 145 years with an average of 70 years and 17 having been operating for more than 50 years. These gages with long periods of record are indispensable for monitoring long-term trends and impact of climate variability and change. The drainage areas of the active gages on the rivers and streams except the Mississippi River are between 9.58 and 8,615 mi^2 and the gage at Mississippi River at Clinton, IA (USGS 05420500) monitors a drainage of 85,600 mi^2, most of which is out of the Rock River Region.

For the inactive gages, the gages monitored between 1 and 46 years with the range of drainage area of 1.31 to 10,800 mi^2. Excluding the gages on the Rock River, most of the gages were monitoring headwaters or small streams with a drainage area of 250 mi^2 or less. This indicates that the gages monitoring headwaters or small watersheds are prone to being discontinued when funds for streamflow monitoring is limited. The same phenomenon has been observed in other parts of the state such as the Kankakee River watershed and Middle Illinois region. One obvious reason is that the gages monitoring larger rivers are often used by more users and considered more important. The discontinuation of gages on headwaters not only results in few available long-term streamflow records for headwaters but also make the estimation of streamflow for ungaged locations less reliable as there are limited data to calibrate the estimation process.

For regional water supply studies, representative streamflow records which cover wet, normal, and dry conditions must be used to capture characteristic variability of streamflow. Short-term streamflow records may over- or under-estimate water availability, depending on whether the period covers wet, normal, or dry conditions. For the Rock River Region, 14 gages provide 80 years of records from 1939-2019 and cover a variety of streamflow conditions, and thus this period is selected as the base period.

Table 6. Continuous USGS streamflow gages in and adjacent Rock River Region and pertinent information

Gage No.	Gage Name (active gages are shaded)	Record Start	Record End	Drainage Area (sq mi)
05414820	Sinsinawa River Near Menominee, IL	1967	2020	39.6
05416000	Galena River At Galena, IL	1934	1938	196
05419000	Apple River Near Hanover, IL	1934	2020	247
05419500	Plum River Near Savanna, IL	1934	1941	162
05420000	Plum River Below Carroll Creek Near Savanna, IL	1940	1977	230
05420100	Plum River At Savanna, IL	1994	1997	273
05420500	Mississippi River At Clinton, IA	1873	2020	85600
05430500	Rock River near Afton, WI	1914	2020	3340
05431486	Turtle Creek At Carvers Rock Road Near Clinton, WI	1939	2020	199
05434500	Pecatonica River At Martintown, WI	1939	2020	1034
05435000	Cedar Creek Near Winslow, IL	1951	1971	1.31
05435500	Pecatonica River At Freeport, IL	1914	2020	1326
05436500	Sugar River Near Brodhead, WI	1914	2020	523
05437000	Pecatonica River At Shirland, IL	1939	1958	2550
05437050	Pecatonica River Nr Shirland, IL	1939	2020	2556
05437500	Rock River At Rockton, IL	1903	2020	6363
05437630	Spring Cr At Mcfarland Road Near Rockford, IL	1979	1981	2.44
05437632	Spring Cr At Rock Valley College At Rockford IL	1979	1981	2.81
05437695	Keith Creek At Eighth Street At Rockford, IL	1979	1988	13.4
05438137	Unnamed Tr To Sb Kishwaukee C Nr Huntley, IL	1999	2000	4.46
05438170	Kishwaukee River At Marengo, IL	2010	2020	170
05438250	Coon Creek At Riley, IL	1961	1982	85.1
05438283	Piscasaw Creek Near Walworth, WI	1992	2020	9.58
05438500	Kishwaukee River At Belvidere, IL	1939	2020	538
05439000	South Branch Kishwaukee River At Dekalb, IL	1925	2020	77.7
05439500	South Branch Kishwaukee River Nr Fairdale IL	1939	2020	387
05440000	Kishwaukee River Near Perryville, IL	1939	2020	1099
05440500	Killbuck Creek Near Monroe Center, IL	1939	1971	117
05440700	Rock River At Byron, IL	2000	2020	7990
05441000	Leaf River At Leaf River, IL	1939	1958	103
05441500	Rock River At Oregon, IL	1939	1949	8205
05442000	Kyte River Near Flagg Center, IL	1939	1951	116
05442300	Rock River At Dixon, IL	2010	2020	8615
05443500	Rock River At Como, IL	1914	2020	8753
05444000	Elkhorn Creek Near Penrose, IL	1939	2020	146
05445000	Rock Creek Near Coleta, IL	1939	1942	82.8
05445500	Rock Creek Near Morrison, IL	1942	1958	158
05446000	Rock Creek At Morrison, IL	1940	1986	164
05446500	Rock River Near Joslin, IL	1939	2020	9549
05447000	Green River At Amboy, IL	1939	1958	201
05447500	Green River Near Geneseo, IL	1936	2020	1003
05447800	Rock River Near Moline, IL	1939	1940	10800
05448000	Mill Creek At Milan, IL	1939	2020	62.4

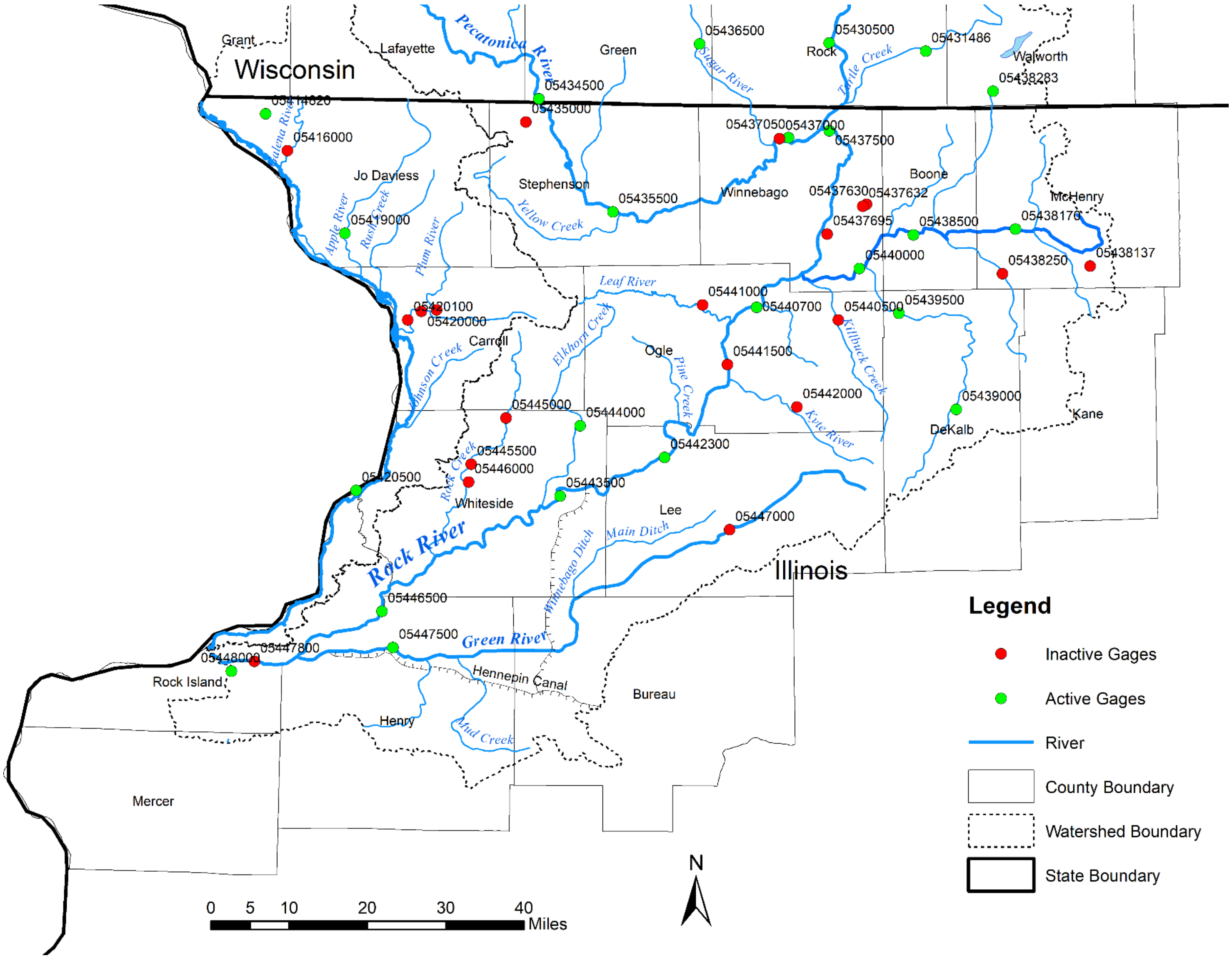

Figure 58. Locations of the continuous streamflow gages in and adjacent to the Rock River Region

4.3.2 Streamflow Variability

Flow duration curves (FDC) are a commonly used graphical tool to characterize streamflow variability in a concise way, demonstrating the relationship between flow magnitude and flow frequency (Zhang, 2017). Variability between watersheds can lead to variation in the shapes and slopes of FDCs. These differences in FDCs are indicative of important differences in the hydrologic processes operating in different watersheds. One of the primary characteristics determining an FDC is the drainage area. Thus, 3 groups of gages have been selected based upon their drainage areas: the Rock and Mississippi Rivers, the major tributaries that have a drainage area of greater than 1,000 square miles, and the small streams with a drainage area of less than 1,000 square miles. The Rock and Mississippi gages include the Rock River near Afton, WI (USGS 05430500), at Rockton, IL (USGS 05437500), and near Joslin, IL (USGS 05446500), as well as the Mississippi River at Clinton, IA (USGS 05420500). The selected major tributary gages are Pecatonica River at Martintown, WI (USGS 05434500) and at Freeport, IL (USGS 05435500), Kishwaukee River near Perryville, IL (USGS 05440000), and Green River near Geneseo, IL (05447500). The Apple River near Hanover, IL (USGS 05419000), South Branch Kishwaukee River at Dekalb, IL (USGS 05439000) and near Fairdale, IL (USGS 05439500), Elkhorn Creek near Penrose, IL (USGS 05444000), and Mill Creek at Milan, IL (USGS 05448000) are selected to represent the small stream gages.

The FDCs for the Rock and Mississippi Rivers, the major tributaries, and the small streams are shown in Figures 59, 60, and 61, respectively. Interestingly, the shapes and slopes of FDCs for the gages at the Rock and Mississippi Rivers are roughly similar though the flow magnitudes are remarkably different. The slopes of the FDCs are stable until they get close to the minimum or maximum values when the slopes change dramatically. This implies the maximum and minimum streamflows could be substantially different from the medium streamflows. For water supply purpose, the FDCs demonstrate that the Mississippi River and the Rock River provide stable water supply for majority of the time. The magnitude of the FDCs implies that both rivers also provide large amount of water supply to meet water demand.

For the major tributaries in the region, the Pecatonica River has a milder slope than the Kishwaukee and Green Rivers, indicating that the streamflow for the Pecatonica River is less variable (Figure 60). The baseflow contribution to the streamflow in the Pecatonica River is higher than other rivers. The glacial outwash in the river valleys in the Pecatonica River watershed provides sustained baseflow contribution to the river, leading the lower variability in streamflow. For water supply purposes, the Pecatonica River provides greater and more reliable water supply than the Kishwaukee and Green Rivers.

For the small streams, the Mill Creek and the South Branch Kishwaukee River at DeKalb show noticeably steeper slope than other streams. This indicates that the streamflow variabilities for the Mill Creek and the South Branch Kishwaukee River are much higher. In fact, both these streams has the observed minimum daily flow of 0 cfs. For the high flow, 5 percent streamflow (P5) of the Mill Creek is about 58% of the P5 of the Elkhorn Creek near Penrose and the median flow (P50) of the Mill Creek is 26% of the P50 of the Elkhorn Creek. However, the low flow (P95) of the Mill Creek is only 3% of that of the Elkhorn Creek. This is because the southern edges of the Rock River watershed are in the Galesburg Till Plain and Bloomington Ridged Plain with less permeable soil and thus the baseflow is not as sustained as other areas in the watershed. Considering streamflow during drought conditions in the small streams could be extremely low, temporary storage may be needed to supplement water supply during drought conditions if the small streams are used for water supply purpose.

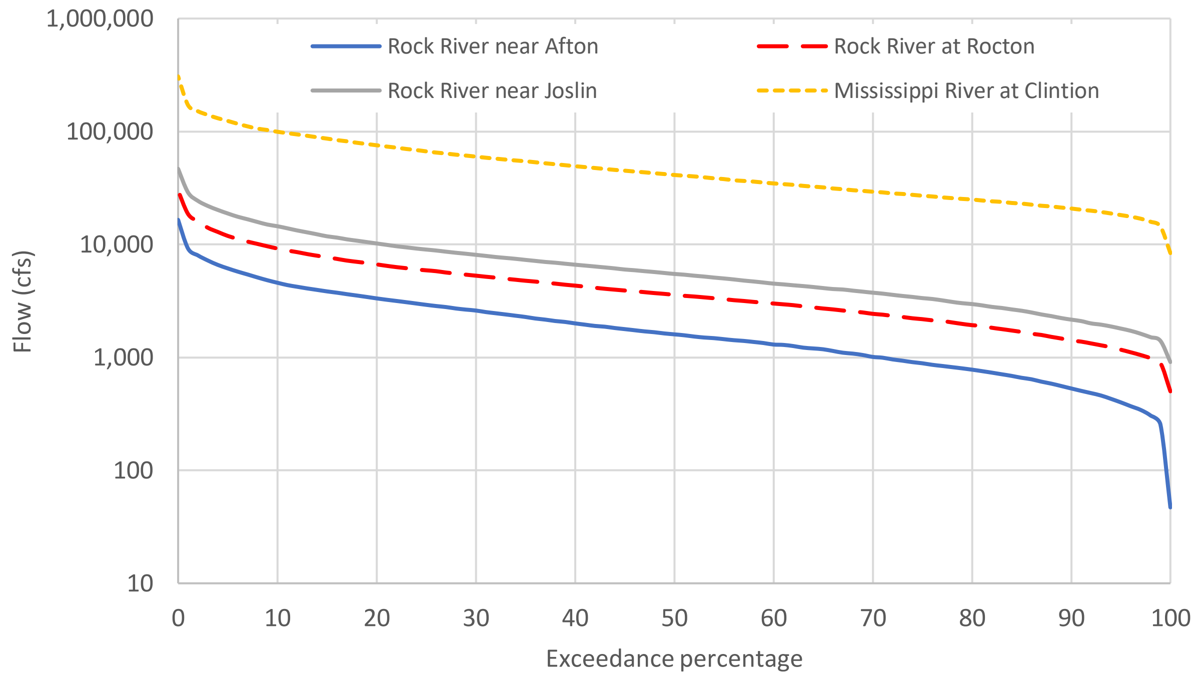

Figure 59. The FDCs for the Rock and Mississippi Rivers in the Rock River Region.

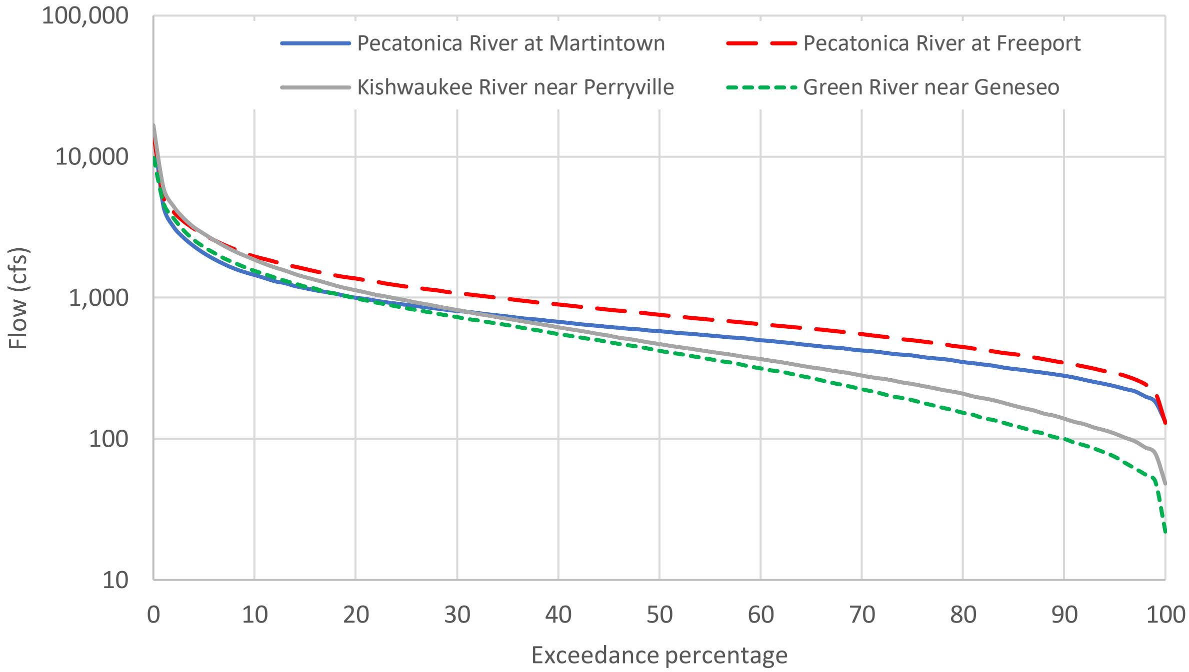

Figure 60. The FDCs for the major streams with a drainage area more than 1000 square mile in the Rock River Region.

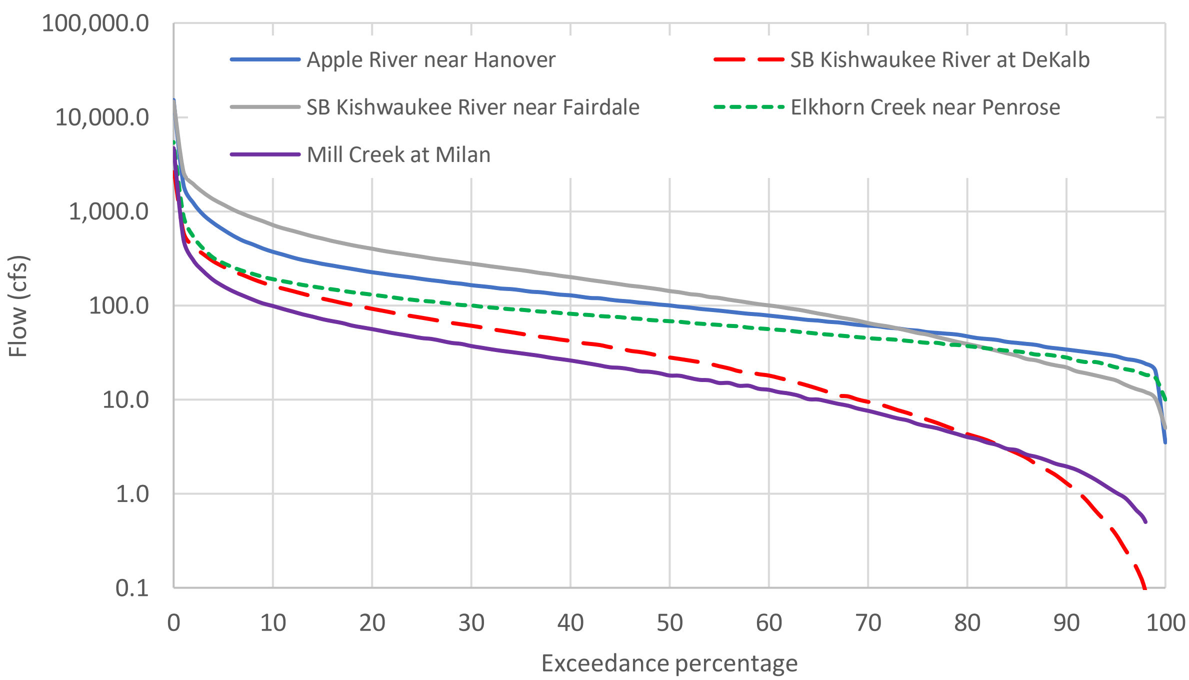

Figure 61. The FDCs for the small streams with a drainage less than 1000 square miles in the Rock River Region.

4.3.3 Streamflow Trend Analysis and Low Flow Fluctuations

Based on the streamflow variability and characteristics, four gages are selected for analyzing the low flow fluctuations. The USGS gage at the Mississippi River near Clinton, IA (USGS 05420500) represents the condition of the Mississippi River watershed upstream of Clinton, IA which covers a much larger area than the Rock River Region but provides surface water supply for the largest users in the region including power generation and public water systems. The USGS gage at the Rock River near Joslin, IL (USGS 05446500) represents the overall condition of the Rock River watershed. The USGS gage at the Pecatonica River at Freeport, IL (USGS 05435500) is indicative of the hydrology features of streams in the watershed with lower streamflow variability and sustained baseflow. The USGS gage at the South Branch Kishwaukee River at DeKalb, IL (USGS 05439000) represents the conditions in the southeastern edge of the Rock River watersheds with higher streamflow variability.

While the spectrum of streamflow is important to characterize the variability of streamflow as shown in the FDCs discussed above, the low flow is often the limiting factor which determines surface water availability. In Illinois, for water supply planning purposes, a suite of low flow statistics have been employed to characterize water availability from free-flowing rivers or rivers with low-head dams. A range of drought statistics, defined as the expected low flow during a long critical duration, 18-54 months, have been explored to analyze extended droughts and water availability from reservoirs and lakes. The low flow and drought flow statistics along with the FDC frequency comprise the backbone of the Illinois Streamflow Assessment Model.

To estimate low flow and drought flow statistics, the annual minimum n-day moving average flow is used. The 1-, 7-, 15-, 30-, and 90-day low flows are often employed to cover a range of periods. Among these, 7-day low flow is most commonly used in Illinois and the U.S.A. for evaluating short-term impact of low streamflow on water supply, waste assimilation, water quality, aquatic habitat, recreation, etc. The 7-day low flows are described here to examine the trends of low flows in the region.

The annual minimum 7-day flows for the four selected gages are shown in Figure 62 through 65. Shown in the figures are also the mean 7-day flow for two periods, pre-1970 and post-1970 as it has been noticed in literature that the low flows in the region and other parts of Illinois have increased abruptly around 1970 (Knapp & Russell, 2004; Zhang, 2017). The obvious common feature of the four figures are the abrupt increasing trend that occurred around 1970 though the four gages have a range of period of records. Table 7 summarizes the change of mean 7-day flow for the four gages. The increase of mean 7-day flow is remarkable with 45% to 106% increases across the four gages.

Table 7. The mean 7-day flow for pre- and post-1970 for the four gages and associated changes

	Pre-1970	Post-1970	Changes (cfs)	Change (%)
Clinton	15,329	22,189	6,860	45
Joslin	1,785	3,083	1,298	73
Freeport	308	518	210	68
Fairdale	16.9	34.8	18	106

For the gage at Mississippi River at Clinton, the streamflow record starts in 1875 which provides rare streamflow records before the 20^{th} century (Figure 62). It is noteworthy that this gage does not reflect the local hydrology conditions within the Rock River Region as the majority of the drainage area is out of the region. However, it is the largest source in the region for suppling water to meet public and power generation water demand. The worst drought observed in this gage is in the 1930s. In addition, extreme low flows were seen in 1890s and 1910s. The low flow before 1890 was relatively higher compared with the period of 1890 to 1940. Two interesting findings are observed for this gage. First, the extreme low flow in the 1950s which was observed in many Illinois rivers are not observed for this gage in the 1950s. Secondly, the low flows appear to have increased since 2010. Due to the limited records since 2010, it is inconclusive to judge if this change is a long-term change or normal variability.

The gage at Rock River near Joslin started in 1940 and monitors almost the entire Rock River watershed (Figure 63). The 7-day flow in the period 1940-1970 is much less than that of post-1970. The lowest 7-day flow are observed for the 1950s. After 1970, the lowest 7-day flow are observed during the droughts of 1976-1977, 1988-1989, 2005 and 2012. Like the 7-day flow at the Clinton gage, the 7-day flow at Rock River near Joslin also appears to increase since 2010 (Figure 63). It is unknown if the increasing trend in 2010 will be sustained or if it is a normal fluctuation as more observation will be needed to reach a decisive conclusion.

The Pecatonica River at Freeport experienced the extreme low 7-day flow in the 1950s as well (Figure 64). However, the drought in the 1930s is more prominent, intensive, and protracted. The abrupt increase around 1970 is observed as well. The 7-day flow also appears to show an increasing trend since 2010. The droughts after 1970 observed in the Rock River was also experienced in the Pecatonica River.

The low flow pattern at the South Branch Kishwaukee River is markedly different from other gages, though it does show the abrupt increase in 7-day flow around the 1970s (Figure 65). First, the annual 7-day flows were consistently low and thus the drought in the 1950s was not as prominent as the other gages. Second, the annual 7-day flow does not appear to increase after 2010 as observed in other gages. Third, the 7-day flow in the droughts of 1976-1977, 1988-1989, 2005 and 2012 for the South Branch Kishwaukee River is only slightly less than the average year 7-day flow. For the other 3 gages, the annual 7-day flow is greatly diminished during the corresponding droughts. This indicates that 7-day flow at South Branch Kishwaukee River is greatly impacted by less severe droughts since this watershed is covered by less permeable soil and thus produces less sustained baseflow.

The observed abrupt increase of low flow around 1970 in the region and the Mississippi River is especially intriguing for water supply purposes. On one hand, it is beneficial as the available water during the driest periods has increased. Water users relying on surface water sources will have access to more water during critical times. On the other hand, it results in a paradox of minimum flow regulation. For water withdrawals from Illinois public waters, the withdrawals would be required to cease whenever the streamflow falls either below the required minimum flow or when the withdrawal would otherwise cause the stream to decrease below the required minimum flow. The required minimum flow is usually based on low flow statistics, especially

7Q10. Low flow statistics such as 7Q10 will be higher when streamflow records of post-1970 are used for estimating low flow statistics than when streamflow records of pre-1970 are used only. The higher low flow statistics in turn will increase the minimum flow requirement as they are used to define the minimum flow requirement. With increased minimum flow requirement, it would diminish available surface water and water users would need backup water sources or storage for a longer period. This is especially troublesome for water supply systems if the drought of record in the 1930s or 1950s occur again in the future. Thus, how to best determine minimum flow requirement with consideration of aquatic ecosystem protection and water supply is critical.

The increased low streamflow is highly related to the increased precipitation in the region since 1970. (Knapp, 2005) found that the precipitation for the period of 1840 to 1870 in the Upper Mississippi River watershed was comparable to that during the post-1970 period. This might imply that increased precipitation since 1970 might be an effect of long-term climate variability instead of permanent climate change. There is no substantial evidence suggesting that precipitation will keep increasing or stay at the increased level. The Mississippi River at Clinton streamflow also shows relatively greater low flow before 1890 (Figure 62). Thus, it is not certain that the streamflow in the region will keep increasing or stay at the increased level permanently. The extreme droughts that occurred in the 1930s and 1950s may occur in the future though it is unknown when they will happen. When surface water sources are needed, the water supply risks need to be assessed assuming the record of drought may occur in the future.

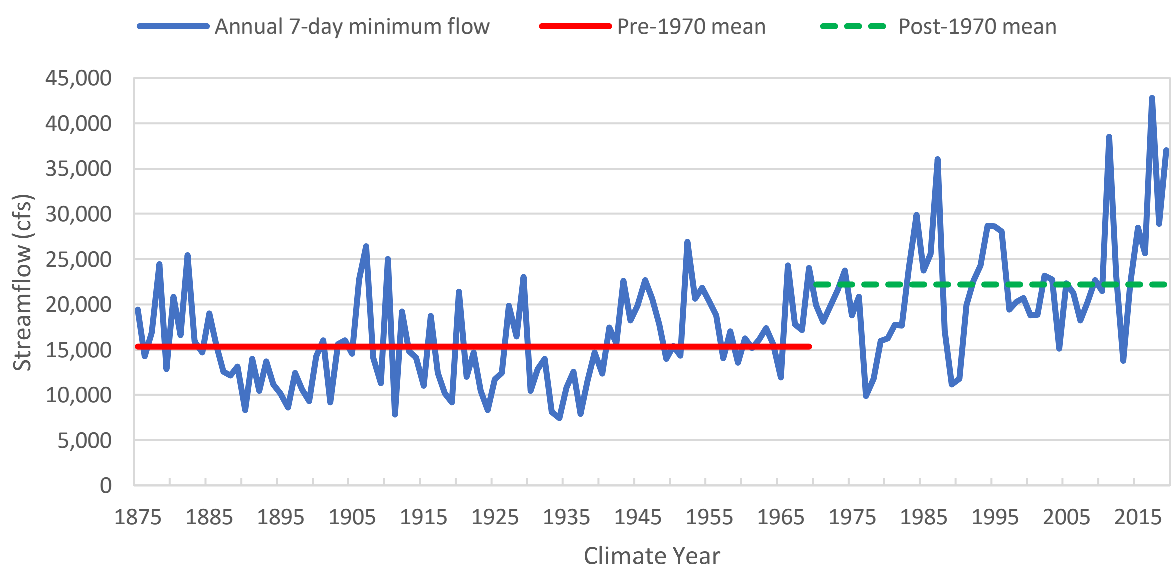

Figure 62. Annual 7-day minimum flows for the Mississippi River at Clinton, IA

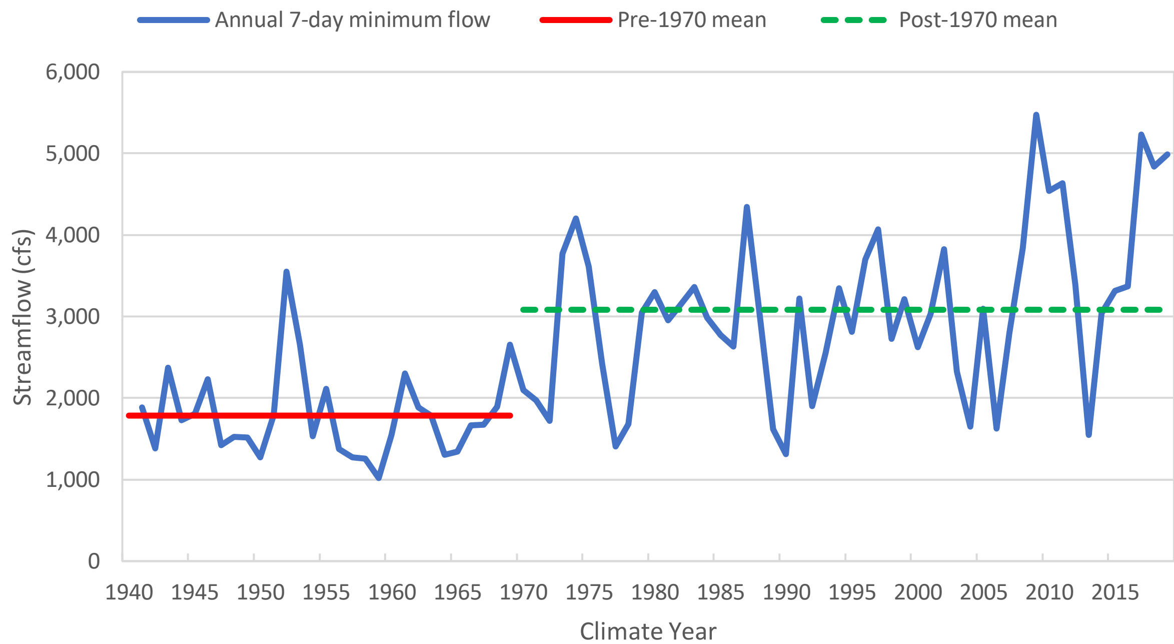

Figure 63. Annual 7-day minimum flows for the Rock River near Joslin, IL

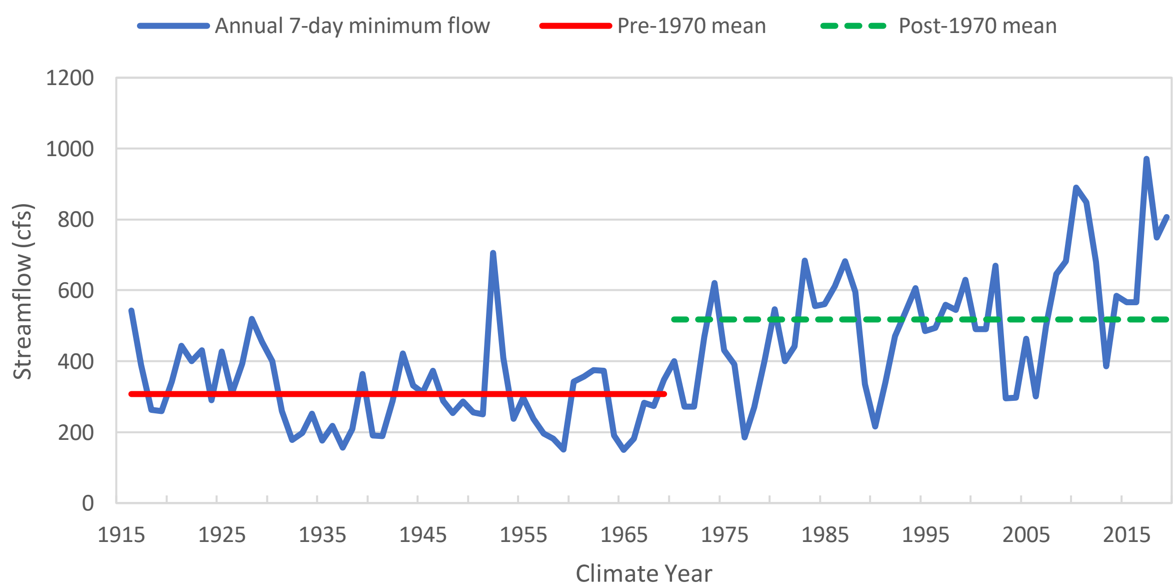

Figure 64. Annual 7-day minimum flows for the Pecatonica River at Freeport, IL

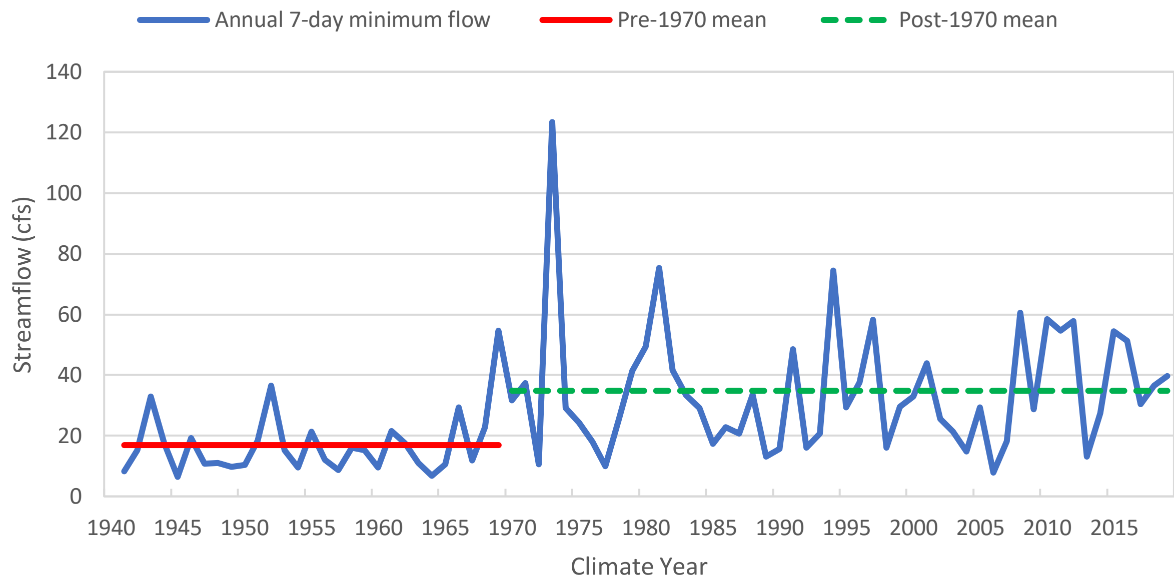

Figure 65. Annual 7-day minimum flows for the South Branch Kishwaukee River near Fairdale, IL

4.3.4 Hydrologic Indices and Streamflow Assessment Tool

Assessing and responding to variation of hydrology with respect to water supply planning requires quantitative measures of hydrologic conditions. A metric that summarizes magnitude, frequency, duration, rate of change, and timing of surface hydrologic conditions, e.g. streamflow, is a hydrologic index. Hydrologic indices have commonly been used in water resources planning and management. For water supply planning, a suite of hydrologic indices are used to characterize water availability for a range of hydrologic conditions, e.g. mean flows, flow duration statistics, n-day T-year low flows (referred to as low flows hereafter) and n-month T-year drought flows (referred to as drought flows hereafter). It is noted that for water supply purposes, hydrologic indices are often computed using daily flow records, directly or indirectly.

The mean flows are the average flows over a period of record. When streamflow records over entire years are used to estimate the mean flow, it is annual mean flow. When streamflow records over a specific month through a period of time are used, it is monthly mean flow. Annual and monthly mean flows are especially informative for characterizing average water availability and analyzing water availability for water supply reservoirs.

The flow duration statistics derived from an FDC are hydrologic indices commonly used in water resources management for a wide range of purposes such as water supply planning, water quality management, flood control, and drought management. The flow duration statistic is often designated as percentile flow that is expected to be exceeded on the selected percentage of time. For example, 90 percent flow (P90) is the daily flow that is expected to be exceeded 90 percent of the time over the period of record. For a specific stream or river, daily flows are above the P90 most of the time and are only below P90 for 10 percent of the time, while P5 is a high flow that flow is rarely seen at 5 percent chance.

The n-day T-year low flow is defined by a duration of consecutive n-day and a recurrence interval of T-year. For example, 1-day low flow is the lowest daily flow experienced in a given year. The 1-day, 10-year (1Q10) is the lowest daily flow expected to occur with a 10 percent chance annually. The n-month T-year drought flows are computed based on monthly flows and is defined by a duration of consecutive n-month and a recurrence interval of T-year and thus are used to characterize relatively long-term drought impacts on streamflow.

To estimate these hydrologic indices for the regional water supply planning, a base period that covers wet, average, or dry climatic and hydrologic conditions is needed. The period of 1939-2019 are selected as the base period for the region based on available records and this period covers the drier period of 1950s and the wetter period of post 1970.

To provide the hydrologic indices for rivers and streams in Illinois, ISWS developed the watershed management information tool named the Illinois Streamflow Assessment Model (ILSAM) since 1985 (Knapp et al., 1985) for many watersheds in the state. The ILSAM is applicable for a watershed with a minimum drainage area of 10 mi^2. In the ILSAM, unaltered flows are estimated by separating flow modifications which are quantifiable with available data. Unaltered flow is the natural flow condition primarily influenced by climate, topography, hydrogeology, land cover, and soils in the watershed. Flow modifications are the alteration of streamflow due to human activities such as water use, effluent discharges, and reservoirs. Land use change and urbanization change streamflow as well.

The Rock River Region is primarily comprised of rural watersheds and the major land use change occurred in the late 1800s when the major marshes in the region were drained for agriculture. Thus, the unaltered flow in the region refers to the hydrologic condition that exited since the 1930s after major the land use change. The gages used for estimating the suite of hydrologic indices are listed in Table 6 and the locations of these gages are shown in Figure 58.

4.4 Summary and Recommendations

4.4.1 Summary

The Mississippi River and the Rock River are the main surface water sources in the Rock River Region. These two rivers have a large amount of available surface water even during severe drought conditions and are close to many major population centers such as Rockford and Rock Island. In addition, the Mississippi River channel in the region has locks and dams and the Rock River has several low-head dams along the channel that maintain water levels during drought conditions. The physiographic features in the region are favorable to groundwater recharge and thus streamflow variability in the region is comparatively lower than many other rivers in Illinois. Therefore, the Mississippi River and the Rock River provide sufficient and reliable surface water supply for public water supply and power generation purposes.

While the number of surface water users in the Rock River Region is limited, the amount of water demand on surface water is high with use approaching 1150 mgd for 2018. The Mississippi River currently provides a large amount of cooling water for Exelon Quad Cities

Station and public water supply for Rock Island, Moline, and East Moline. Most of the cooling water (about 97%) is returned to the Mississippi River as the Exelon Quad Cities Station uses a once-through cooling system. Most water used by the public water supply systems is returned to the Mississippi River as sewage. Thus, impacts of surface water demand on streamflow are limited to the proximity of corresponding intakes. The Rock River provides cooling water for Exelon Byron Station, which uses a recirculating cooling system with natural draft cooling towers and therefore consumes much of the withdrawal.

The Pecatonica River, Kishwaukee River, and Green River are other potential surface water sources that could meet future water demand if needed. Other small tributaries in the region, however, do not provide sufficient water for direct withdrawal during drought conditions and water supply would need be augmented by impoundment or off-channel storage during drought conditions.

Streamflow for many rivers and streams in the region has seen a step increase in a short period around 1970. Some rivers and streams experienced increasing low flow since 2010 but it is inconclusive due to the limited post-2010 streamflow records. This observed increasing low streamflow is highly related with increasing precipitation since 1970. It is unclear though how streamflow will change in the future due to climate change and variability.

The landscape in the Rock River Region is varied and complex with 6 physiographic regions. Therefore, it is difficult to estimate hydrologic indices for ungaged sites in the region. Compounding this issue, long-term continuous streamflow gages in headwaters and small streams are few and are often cut when funds for streamflow gaging are not sufficient.

4.4.2 Recommendations

Streamflows in the region increased in a short period around 1970 and some rivers and streams have seen increasing low flow since 2010, which is promising for surface water supply. Increasing streamflow will provide more available water but may result in greater minimum flow requirement for surface water withdrawals. Thus, an environmental flow assessment will be needed in the future to determine aquatic ecosystem water demand, which can be used to assist determinations of minimum flow requirements.

The paradox of minimum flow regulation for public waters of Illinois resulting from the increasing low flows in the regions since 1970 is an intriguing issue that is worthy of further investigation on its impact and implications to water use policy and water supply. This is an ongoing issue that must consider future climate variability and climate change.

Long-term continuous streamflow records are critical to assess surface water supply and calibrate hydrologic models that may be used to assess surface water under changing conditions. It is also valuable to monitor streamflow for headwaters and small tributaries, especially for Green River Lowland and Wisconsin Driftless Section.

While a few users currently rely on surface water, those that do withdraw a huge amount of water from the Mississippi and the Rock Rivers. It is recommended that IWIP improve the water use reporting from larger surface water users, which is critical to understand surface water demand. For example, if IWIP collects monthly withdrawal and discharge amount for power plants, it will allow characterization of water use seasonality and estimation of water consumption by power generation. For public water supplies, if IWIP requires monthly withdrawal data, it can be used with effluent discharge data reported in NPDES to better understand public water use patterns.

The power generation industry is overwhelmingly the largest surface water user. Better understanding of power generation trends in the region and close collaboration with local stakeholders is critical for surface water supply planning in the future.

5 Available Water Supply and Associated Risk

In this section, we combine the local analyses discussed above with statewide water supply planning exercises to identify available supply versus current demand. The statewide analyses that complement this study were completed concurrent with the development of this report. Moving forward, this information is expected to be presented at the beginning of a water supply planning process, propelling discussion about both the methodologies used to calculate supply and risk to water supplies. As such, this information has not been fully vetted by stakeholders at the time of writing and should be viewed as screening analyses. This may change before final publication of this information or even after publication, in which case the most current information will be available at:

https://www.isws.illinois.edu/groundwater-science/rock-river-region-webmap-version.

The sustainable supply information in this report is highly simplified, so we do not recommend making local planning decisions exclusively based on the information presented here. Instead, please contact the Illinois State Water Survey to discuss the implications of these preliminary analyses. Stakeholder input is critical to improving our understanding of water supply issues potentially facing the local community.

5.1 Sustainable Supply

The second most common question asked of scientists at the ISWS is "How much water is available to me?" (we will deal with the first question later in this section). This question is more difficult to answer than it seems, with the most challenging aspect being the identification of a threshold to define available water. The ISWS has established the following criteria to determine these values for a statewide assessment. Unless stated otherwise, these criteria are established to determine the available ***sustainable*** supply of water resources, per the mission of the Illinois Department of Natural Resources Office of Water Resources.

5.1.1 Defining available shallow groundwater supply

What is the sustainable volume of water that can be withdrawn from a shallow aquifer? There are several methods to potentially address this. For the statewide analysis, we consider the potential ecological impacts of the removal of groundwater. Pumping from an aquifer can capture groundwater that would otherwise flow into streams, which in turn can both reduce low-flow conditions in a stream and impact the temperature of the benthic zone; both important factors for sensitive species (Zorn et al., 2008). In addition to capturing groundwater, pumping near a stream can also induce flow into the aquifer from the stream, with similar adverse consequences.

Zorn et al. 2012 found that approximately 10% of thriving (sensitive) species in warm Michigan streams and rivers were adversely impacted by a 10% reduction in natural groundwater discharge. Thriving species appeared to be more robust in colder streams and rivers, where a 30% reduction in natural groundwater discharge was required to have the same impact. Without an analogous study in Illinois, a 10% reduction was assumed as the (conservative) threshold for sustainable groundwater withdrawals for this investigation.

Ecological impacts are not the only possible metric to define sustainability, and local discussions with communities can consider additional factors. These can include:

1) Comparison of groundwater inflow to withdrawals. Long-term declines in aquifer water levels often indicate unsustainable groundwater usage. Seasonal declines, such as observed in Figure 33, also indicate unsustainable withdrawals during peak pumping conditions, although the return to non-irrigation water levels each year indicates that the annual average withdrawals are balanced by recharge.
2) Contamination levels that impact available supply. To assess this, evaluation of Figures 45 through 51 is necessary to determine if there are water quality issues in your community. You can also contact the Public Service Lab at the ISWS to request a water quality sample.

5.1.2 Defining available Cambrian-Ordovician sandstone aquifer supply

The deep Cambrian-Ordovician Sandstone Aquifer is generally unsustainable where overlying shale is present (Figure 11); there is limited water that can infiltrate vertically to the sandstone to replace the water withdrawn, leading to drawdown even in areas with small demands (Figure 20). The ISWS used a groundwater flow model to evaluate the inflow into the sandstone aquifer, which is used to determine available supply. Where shale is absent, the same metric used for the shallow aquifer system (10% reduction in natural groundwater discharge) was applied. As with the shallow aquifer, water quality (particularly chloride, radium, and barium) should also be considered when evaluating local supply but are not considered in the regional analysis.

One important note is that most counties pumping from areas of the sandstone aquifer that are overlain by shale will show up as unsustainable, and this follows from the long-term observed drawdown. However, the available head before dewatering the sandstone aquifer, at least where shale is present, is several hundred feet, while drawdown is less than 200 ft in scenarios evaluating little appreciable future growth. Modeled declines due to unsustainable withdrawals are only a few feet before 2050. To be clear, unsustainable withdrawals would eventually lead to issues, but those might be centuries away. However, the deep sandstone aquifer is highly responsive to changes in demand, so if growth in water use occurred more rapidly than simulated here, this assessment would have to be re-evaluated.

5.1.3 Defining available river supply

Sustainable water supply from streamflow has not been calculated; this research remains ongoing at the time of publication. As a proxy, the ISWS has assessed available water supply from streamflow by infrastructure capacity. Lacking full information, the supply has been estimated as the maximum withdrawal reported to IWIP over the last five years. For the Rock River Region, the surface water demands are predominantly along the Rock and Mississippi Rivers, which have all had increasing low-flow rates after 1970. Streamflow in these major rivers appear able to meet the present and projected surface water withdrawals.

5.1.4 Sustainable supply vs demand

The following plots compare sustainable supply versus demand aggregated at a county level, broken out in different ways to enable a range of analyses. All analyses are available to explore interactively in this story map: https://arcg.is/1G8v591.

5.1.4.1 Total supply and demand

Based on this screening analysis, two counties have (consumptive) demands that exceed sustainable supply: Whiteside and Winnebago (Figure 66). These counties are two of the three largest water users in the region. The county with the second greatest water demands, Rock Island, uses water from the Mississippi River to meet public supply demands. Due to increasing flow in the Mississippi River since 1970, there is not a quantity concern from that source. Rock Island also has the largest non-consumptive use (Figure 67), but again does not pose any sustainability concerns.

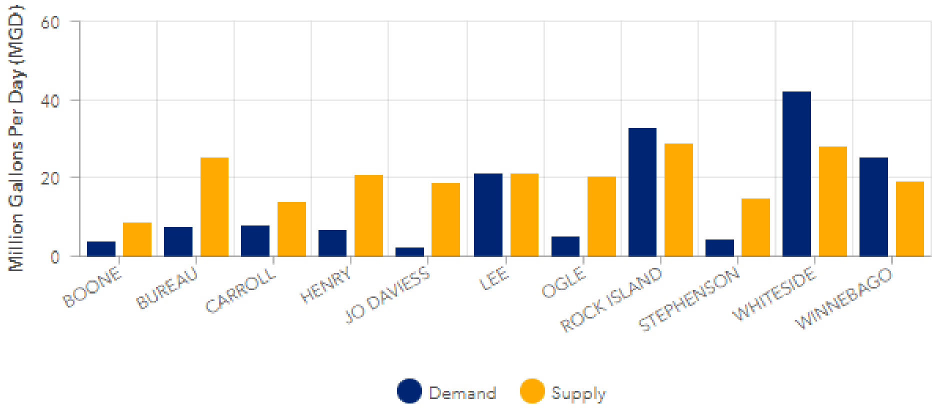

Figure 66. Consumptive supply and demand aggregated by county

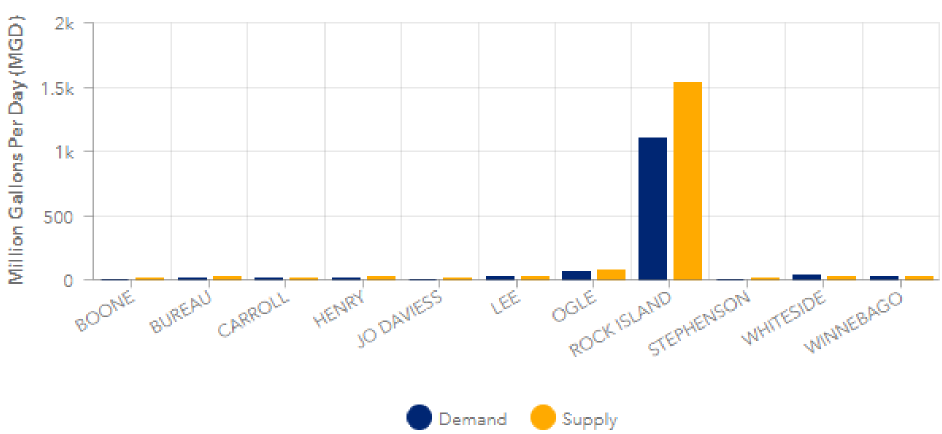

Figure 67. Consumptive plus non-consumptive supply and demand aggregated by county

5.1.4.2 Groundwater and surface water consumptive demands

Groundwater use in Whiteside, Winnebago, and Rock Island Counties exceeds the estimated sustainable supply in this analysis (Figure 68). In addition, groundwater usage is nearly identical to supply in Lee County. A more focused analysis on those two counties is strongly recommended to ensure that local issues are not in danger of manifesting as water supply shortages or other complications. It should be noted that the total supply in Bureau County exceeds demand when totaled over the county and averaged over a year. However, the northwestern corner of Bureau County likely has unsustainable withdrawals during the summer months, as indicated by the continual decline in peak pumping water levels observed in Figure 33, and requires further investigation. The only reported consumptive surface water demand in the Rock River region is in Rock Island County (Figure 69). The unsustainability of the Mississippi River (the source of the demands) is not considered to be an issue due to trends in increasing flow since 1970.

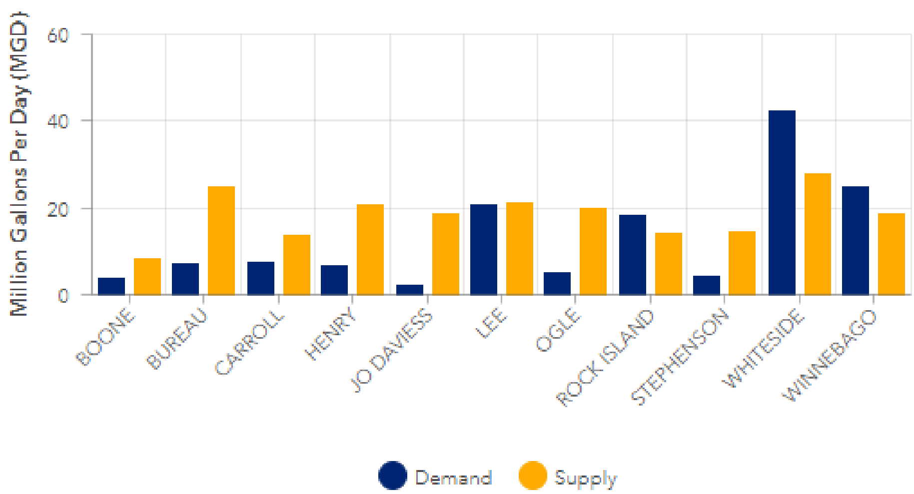

Figure 68. Groundwater supply and demand aggregated by county

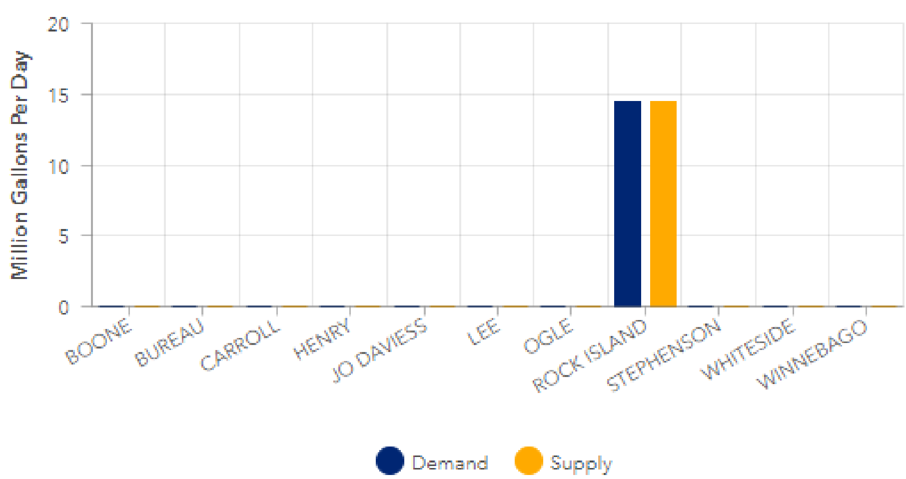

Figure 69. Surface water supply and demand aggregated by county

5.1.4.3 Supply and demand by water use type

To assess supply by water use type (sector), the total supply was subdivided based on the proportion of demands. This disaggregation was necessary because Illinois does not have a water rights system that quantifies usage. Water use type was determined based on the breakdown from the Rock River region demand study (Meyer et al., 2019). The sectors are public supply/municipal (Figure 70), self-supplied commercial and industrial (Figure 71), agricultural (Figure 72), and thermo-electric power generation (Figure 73).

The two counties with the largest municipal demands are Winnebago and Rock Island, but only Winnebago demands exceed available municipal supply (Figure 70). The two counties with the largest industrial demand are Rock Island and Stephenson and both utilize less than their available supply (Figure 71). The largest supply and demand for agriculture are located in Whiteside County. These demands exceed the estimated value for a 10% reduction in natural groundwater discharge (Figure 72). Reductions in low streamflow conditions would most likely be greatest: 1) during the summer in peak pumping conditions and 2) where streams are closer to withdrawals. Water demands for power generation is most prominent in Rock Island County, although Ogle County also uses water for this purpose (Figure 73).

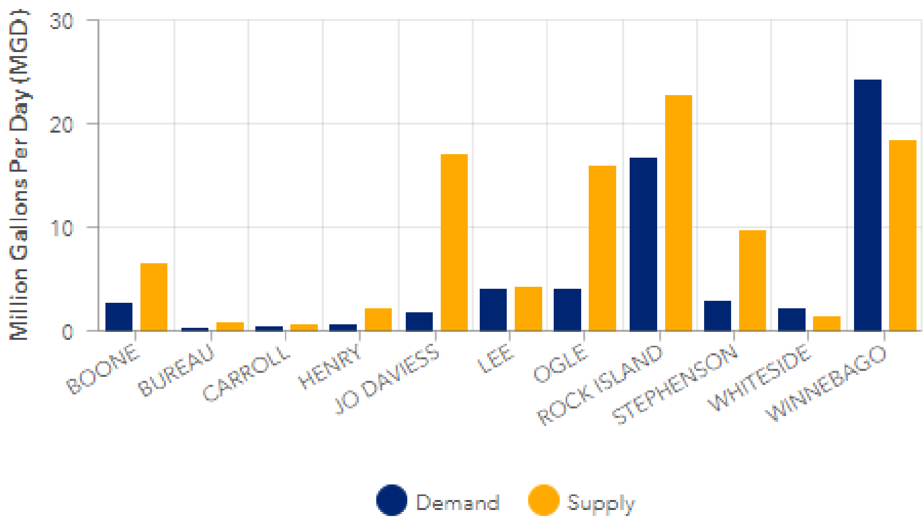

Figure 70. Supply and demand for public supply/municipal water use

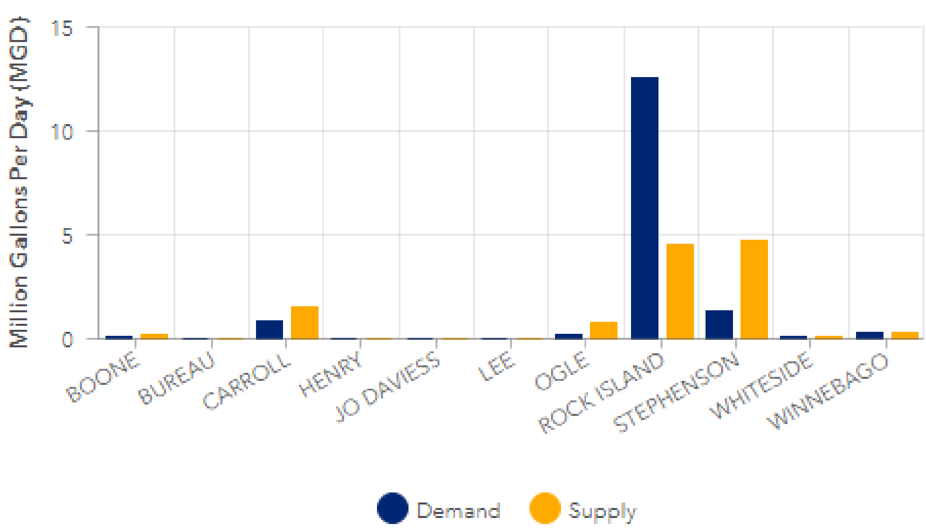

Figure 71. Supply and demand for self-supplied industrial and commercial water use

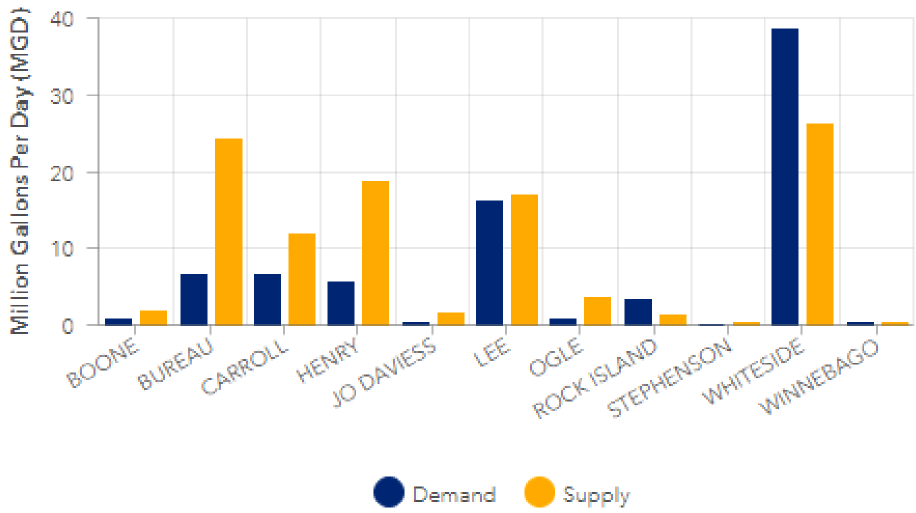

Figure 72. Supply and demand for agricultural use

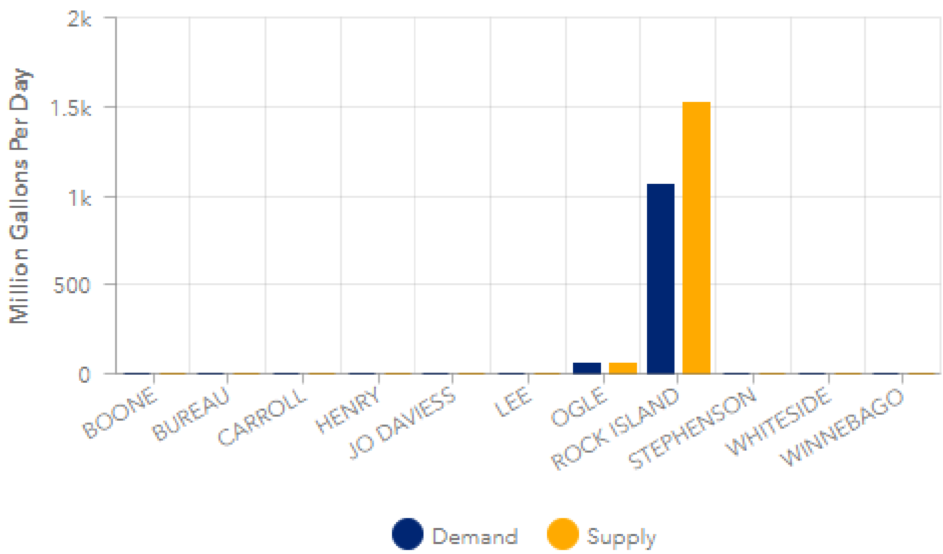

Figure 73. Supply and demand for thermo-electric power generation use

5.2 Longevity of Supply

The most common question that the ISWS receives from owners of high capacity wells is "When will my water supply run out?". This is a highly challenging question because exact estimates do not exist for future water use. Section 2 discusses demand *scenarios* that do not have an associated probability of occurrence. Rather, the scenarios explore water use under different circumstances that could occur in the future. Post-audits at the ISWS have revealed that scenarios often deviate from reality due to a number of unexpected drivers. In the Mahomet Aquifer, the combination of a 2012 drought and high corn prices led to an irrigation increase; by 2014, the estimated irrigation demands exceeded what had been predicted to occur by the year 2050 by the most recent set of projections (Roadcap et al., 2013). In contrast, in Northeastern Illinois, the housing market crash of 2008 stalled rapid growth in water use that had occurred in the earlier portions of the decade; as a result, the increase in water use through the 2010's was far lower than any scenario previously simulated (Meyer et al., 2009).

Because of this variability in demands, the ISWS does not provide a single estimate of the time remaining for water supply in a community. The scenarios presented in this report still have value; they allow for the assessment of how a local community's water supply can respond to different drivers, and this understanding can guide water supply planning. However, three scenarios are occasionally not enough to capture the full range of uncertainty in a system. In this case, ISWS hydrogeologists work with local communities to reach a deeper understanding of the complex impacts of additional perturbations to their water supply, such as the addition of a new industry.

5.3 Risk to Groundwater Supplies

Given the preceding analysis, it is still important to note that this study concludes that the Rock River Region as a whole has ample water available to meet demands. Although there is not enough evidence to state any definitive risk, the ecological impacts of withdrawals do require further consideration in Winnebago County (discussed in more detail in Section 3.2) and Whiteside County (discussed in more detail in Section 3.3). The latter may be surprising to hear, given the record flooding in the Spring of 2019, but this assessment is based on the potential impacts during low flow conditions, which often coincides with peak irrigation where water levels during peak pumping conditions in the Sankoty are continuing to decline (Figure 38). Water levels do not appear to be declining similarly in the Tampico (Figure 39); one possible explanation for this is the loss of water from streams during peak pumping conditions to maintain shallow aquifer levels. More research is needed, and this is the highest priority of investigation recommended by the ISWS.

Risk to the water supply of smaller communities should also be considered. The following analyses identify some areas that could **potentially** be at greater risk of water supply issues. An important caveat must be observed here- the following analyses are based on regional datasets that could be missing important local details. Furthermore, the analyses rely heavily on the use of a statewide transmissivity map, discussed further in Section 3.1.3; this map defines transmissivity for the state of Illinois using a database query and not traditional geologic mapping techniques. **As a result, this should only be used as a provisional screening tool to guide priorities for further investigation and not as criteria to make major water supply decisions.**

5.3.1 Withdrawals from Low Transmissive Aquifers

As a method of screening potential at-risk systems, the ISWS compares the ratio of water demands for a municipality to the average total transmissivity within the municipal boundaries (Figure 16), normalized by the area of the community- referred to as the Q/T ratio for brevity. This ratio is normalized by area to avoid highlighting areas with larger water users with demands distributed over a large area. For example:

- A community pumping 100 gallons per minute per square mile [gpm/mi^2] from an aquifer with an average transmissivity of 100 gallons per minute per foot [gpm/ft] would have a ratio of 1 [ft/mi^2].
- A community pumping 100 gpm/mi^2 from an aquifer with an average transmissivity of 10 gpm/ft would have a ratio of 10 ft/mi^2.

The actual value of this ratio doesn't have a physical meaning, nor are the units meaningful; it is simply used to compare the available supply in communities. The higher the Q/T ratio, *all else equal*, the more likely a community might struggle to meet supply. The Q/T ratios are intended as a tool to screen for communities within the Rock River region that could potentially struggle to extract water from the aquifers within their municipal boundaries; the next recommended step would be further local scale analysis- often beyond the scope of this regional study. **Local hydrogeologic complexities should be considered before making major water supply planning decisions based on this ratio alone.** Some communities might withdraw from aquifers adjacent to a river or that are located in a higher recharge area; other areas, like northwest Bureau County, may be in a high transmissive area but have most of the withdrawals in a deeper confined aquifer.

A few important factors to consider when evaluating the results of this analysis:

1) Only the transmissivity within municipal bounds are considered.

Implication: This analysis should only be viewed as providing insight into the available water within a community. Some communities may have very low transmissive units and elected to build a pipelines that extends outside of municipal bounds to find a productive aquifer to meet their water demands. Indeed, this pipeline would have been the solution to the problem of low transmissivity.

2) Transmissivity is averaged within a municipality.

Implication: Some community officials outside of the Rock River region have been surprised to see that they have a high Q/T ratio, explaining that the community wells are in a very productive aquifer. Commonly, this is because this highly productive aquifer is either outside of the municipal bounds or only over a small portion; the transmissivity for the rest of the region is very low by comparison so the average comes out low. What does this mean? Simply put, the community will likely be able to continue pumping from the highly productive aquifer with no quantity issues. However, if the aquifer were to become contaminated, there would be limited opportunity to drill replacement wells within the municipality.

3) Transmissivity is based on a regional analysis.

Implication: The statewide transmissivity map was developed by interpolating information from well logs at the Illinois State Geological Survey (Abrams et al., 2018). Actual transmissivity values were also inferred from aquifer tests at the Illinois State Water Survey. No additional geologic information or insight was utilized in the development of this transmissivity map. One of the major flaws of this approach is that, as a statewide analysis, all data was used without QA/QC of well location in many areas. Wells are often approximately located in the databases, and while this likely has little impact for a large community like Rockford, the sand and gravels used by small communities could be misplaced outside of municipal boundaries. In other words, communities concerned about a comparatively large Q/T ratio should approach the ISWS to provide local information to help address inaccuracies in the transmissivity map.

The results of the Q/T ratio analysis are provided in Table 8. A commonality is that communities utilizing the shallow bedrock or sandstone aquifers generally have higher Q/T ratios due to the lack of productive sand and gravel aquifers. Freeport is the only community that uses any sand and gravel and has a ratio greater than 1.5, either indicating that the sand and gravel is spatially limited or that the transmissivity map does not capture the full spatial extent of the unconsolidated aquifer. Although most communities with a relatively high Q/T ratio drill into the deep sandstone to meet water supply demands, a number also use the shallow bedrock if enough secondary porosity is available.

Table 8. Community source of water, demands, average transmissivity, area, and Q/T ratio normalized by area.

MUNICIPALITY	GROUNDWATER TYPE	PUMPING (GPM)	TRANSMISSIVITY (GPM/FT)	AREA (SQ. MI)	Q/T RATIO
KEWANEE	c-o sandstone	1378.22	20.37	11.90	5.69
PERU	shallow bedrock	1743.64	21.47	16.11	5.04
STOCKTON	c-o sandstone	272.01	18.69	2.92	4.98
ALPHA	mixed shallow bedrock and c-o sandstone	41.40	15.87	0.57	4.59
SHANNON	c-o sandstone	87.65	22.36	0.87	4.49
SCALES MOUND	mixed shallow bedrock and c-o sandstone	27.80	15.64	0.42	4.23
ROCK CITY	c-o sandstone	23.22	23.08	0.28	3.59
MOUNT MORRIS	c-o sandstone	222.74	23.50	2.72	3.48
FREEPORT	mixed sand and gravel and c-o sandstone	2340.56	37.01	21.55	2.93
DIXON	c-o sandstone	1579.35	38.10	14.18	2.92
WARREN	c-o sandstone	90.33	18.19	1.78	2.79
REYNOLDS	shallow bedrock	48.21	26.97	0.66	2.71
CEDARVILLE	c-o sandstone	56.09	25.63	0.83	2.65
MILLEDGEVILLE	c-o sandstone	60.57	18.21	1.26	2.65
DAVIS	c-o sandstone	36.26	18.90	0.79	2.44
LENA	c-o sandstone	208.39	18.49	4.78	2.36
WOODHULL	mixed shallow bedrock and c-o sandstone	56.64	17.83	1.46	2.18
POLO	c-o sandstone	135.62	25.58	2.45	2.16
DAKOTA	c-o sandstone	29.65	28.18	0.53	2.00
GALVA	mixed shallow bedrock and c-o sandstone	175.39	17.75	5.04	1.96
OREGON	c-o sandstone	284.39	41.11	3.68	1.88
DURAND	c-o sandstone	102.73	32.55	1.72	1.84
SILVIS	mixed shallow bedrock and c-o sandstone	465.78	34.59	7.41	1.82
GALENA	c-o sandstone	268.04	19.68	7.66	1.78
SAVANNA	c-o sandstone	335.92	38.84	4.93	1.75
COAL VALLEY	shallow bedrock	210.12	24.56	4.91	1.74
ROCHELLE	c-o sandstone	1810.67	44.99	23.35	1.72
ORANGEVILLE	c-o sandstone	40.62	21.91	1.15	1.61
ELIZABETH	shallow bedrock	45.55	20.14	1.42	1.59
ORION	shallow bedrock	74.87	30.17	1.62	1.53
PECATONICA	c-o sandstone	192.05	53.85	2.37	1.50
GENESEO	mixed sand and gravel and c-o sandstone	470.00	41.69	7.83	1.44
GERMAN VALLEY	mixed shallow bedrock and c-o sandstone	34.70	27.46	0.88	1.43
WINNEBAGO	c-o sandstone	169.85	34.84	3.56	1.37
WINSLOW	c-o sandstone	24.01	22.13	0.83	1.31
CAPRON	c-o sandstone	74.21	40.57	1.42	1.29
MORRISON	c-o sandstone	348.84	61.94	4.44	1.27
FORRESTON	c-o sandstone	81.23	41.77	1.64	1.18
BELVIDERE	mixed sand and gravel and c-o sandstone	2212.12	84.45	22.48	1.17
BISHOP HILL	shallow bedrock	19.24	17.49	0.95	1.16

HANOVER	c-o sandstone	49.55	22.63	1.92	1.14
ROCKFORD	mixed sand and gravel and c-o sandstone	13987.22	109.90	113.18	1.12
COMPTON	sand and gravel	14.57	45.91	0.30	1.07
SPRING VALLEY	c-o sandstone	552.65	40.12	13.26	1.04
APPLE RIVER	c-o sandstone	27.43	18.19	1.46	1.03
ANDALUSIA	shallow bedrock	60.05	30.03	2.11	0.95
MILAN	mixed shallow bedrock and c-o sandstone	343.59	32.17	11.51	0.93
MOUNT CARROLL	c-o sandstone	83.93	26.70	3.67	0.86
BUDA	sand and gravel	73.34	51.40	1.78	0.80
AMBOY	c-o sandstone	275.14	31.36	11.31	0.78
LOVES PARK	mixed sand and gravel and c-o sandstone	2574.72	115.59	30.12	0.74
LADD	sand and gravel	74.80	50.73	2.11	0.70
ALBANY	mixed sand and gravel and c-o sandstone	51.39	38.40	1.93	0.69
PAW PAW	c-o sandstone	55.89	78.33	1.05	0.68
ROCK FALLS	sand and gravel	629.04	140.96	6.82	0.65
LEAF RIVER	mixed shallow bedrock and c-o sandstone	25.10	26.06	1.52	0.64
CARBON CLIFF	mixed shallow bedrock and c-o sandstone	78.69	33.98	3.65	0.63
EAST DUBUQUE	mixed sand and gravel and c-o sandstone	139.61	42.01	5.32	0.62
ROCKTON	mixed sand and gravel and c-o sandstone	742.15	116.87	10.49	0.61
STILLMAN VALLEY	c-o sandstone	61.37	114.08	0.99	0.55
STEWARD	sand and gravel	17.89	96.04	0.37	0.50
CHERRY VALLEY	c-o sandstone	445.36	60.48	15.87	0.46
HOLLOWAYVILLE	sand and gravel	3.69	96.65	0.08	0.45
WALNUT	sand and gravel	110.90	171.76	1.47	0.44
HARMON	sand and gravel	8.73	76.64	0.26	0.43
PORT BYRON	mixed shallow bedrock and c-o sandstone	54.20	31.29	4.44	0.39
SHEFFIELD	sand and gravel	61.37	126.19	1.26	0.39
HILLCREST	c-o sandstone	54.26	29.05	5.72	0.33
DE PUE	c-o sandstone	161.74	93.67	5.32	0.32
DAVIS JUNCTION	c-o sandstone	139.87	71.39	7.71	0.25
OHIO	sand and gravel	45.16	126.64	1.43	0.25
PRINCETON	sand and gravel	650.57	199.30	13.29	0.25
MANLIUS	sand and gravel	27.55	235.75	0.55	0.21
FULTON	c-o sandstone	193.69	236.66	4.22	0.19
DOVER	sand and gravel	14.11	189.30	0.47	0.16
ANNAWAN	shallow bedrock	55.21	104.54	3.51	0.15
LA MOILLE	sand and gravel	48.16	185.60	2.14	0.12
TAMPICO	sand and gravel	31.41	384.47	0.69	0.12
PROPHETSTOWN	mixed shallow bedrock and c-o sandstone	128.60	526.72	2.50	0.10
THOMSON	mixed sand and gravel and c-o sandstone	63.30	262.95	4.32	0.06

5.3.2 Withdrawals from the Sandstone Aquifers

In areas where pumping is high relative to the transmissivity (Table 8), wells are commonly drilled into the unsustainable Cambrian-Ordovician Sandstone Aquifer System. A major question remains whether the unsustainable demands have manifested in risk to the deep aquifer. This was addressed using the groundwater flow model (Abrams et al., 2018) with the Current Trend future demand scenario discussed in Section 2. Two important observations from the risk map shown in Figure 74 should be made:

1) Currently, risk to the uppermost St. Peter is present, as defined as red areas in Figure 74. This is defined as areas where either the simulated water level (which represents non-pumping conditions) falls within 200 ft of the top of the St. Peter OR the available head above the top of the St. Peter has decreased by over 50% since predevelopment conditions. These red areas represent the most likely locations that, when pumping the St. Peter sandstone could become dewatered. This can have negative quantity implications (in particular caving of the St. Peter sandstone that can render wells ineffective) and introduce oxygen into the deeper sandstone, which can lead to adverse impacts such as degraded well casings or sleeves. In areas with significant contamination such as Rockford, this red area also increases portions of the aquifer with significant hydraulic gradients that could results in the downward migration of contaminants.
2) The future simulation shows very limited growth to the risk areas (limited appearance of orange areas representing future risk in Figure 74). This follows from the relatively minor increase in demands in the region in the Current Trend scenario. Although demands from the deep sandstone are generally unsustainable, particularly where shale overlies the sandstone (Figure 74), the resulting declines in water levels are slow enough to keep the risk area from growing a considerable amount. It is important to note that water use growth beyond the Current Trend scenario could expand the areas that appear at-risk.

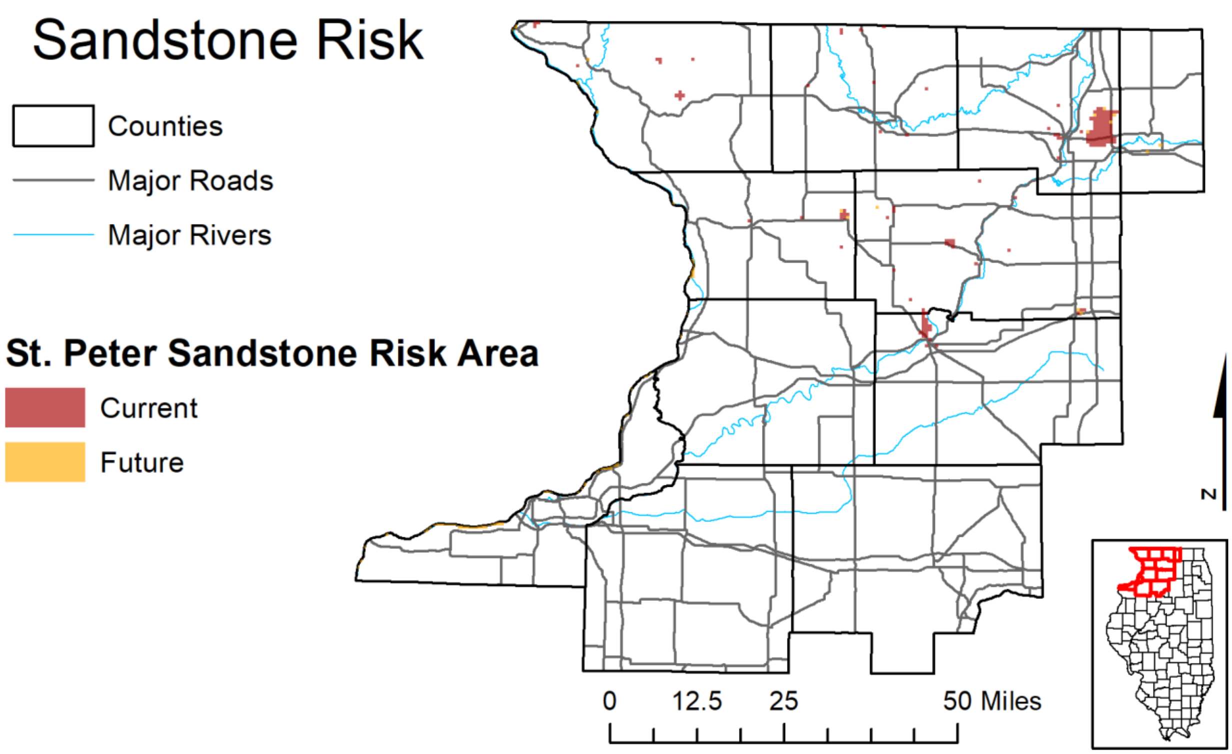

Figure 74. Risk to the sandstone aquifer in the Rock River region.

6 Summary and Recommendations

Demands

1. Water demand for thermoelectric power generation dominates present and future demand in the region. Present (2010) water demand for thermoelectric power generation totals 1,160 mgd, which is 87 percent of the total reported demand of 1,332 mgd. This water, which is surface water that used for cooling, is largely returned to its source after use. We estimate that roughly 102 mgd, or 9 percent, of the total demand 2010 demand of 1,160 mgd was evaporated. Future demand for thermoelectric power generation will depend strongly on cooling system design and gross generation capacity of operating power plants in the region. Our scenario of maximum demand assumes that one additional power plant will be built in the region, and that present power plants will continue to operate at 2010 levels until 2060, resulting in total water demand for thermoelectric power generation increasing to 1,171 mgd.
2. We estimate demand for public supply, self-supplied domestic demand, self-supplied industrial and commercial (IC) demand, and self-supplied irrigation, livestock, and environmental (ILE) demand to 2060. We estimate these demands under three plausible scenarios of socioeconomic, weather conditions, a less resource-intensive (LRI) scenario, a moderate current-trends (CT) scenario, and a more resource-intensive (MRI) scenario. Reported demand for these four water-demand sectors totaled 171 mgd in 2010, with public system demand accounting for 79 mgd of this total. From 2010 to 2060, total demand for these four sectors increases to 201 mgd under the LRI scenario, 261 mgd under the CT scenario, and 351 mgd under the MRI scenario. Most of the increase in total demand under all scenarios, but in particular the CT and MRI scenarios, is accounted for by increases in self-supplied ILE demand.

Groundwater

3. Demands in the Green River Lowlands, predominantly agricultural, have increased since the last study in the region 25 years ago. Although long-term springtime water levels do not yet show evidence of decline, and might actually be increasing in Lee County, the water levels during the peak of irrigation are lower. This can result in reductions in natural groundwater discharge, which has possible ecological impacts, and the potential for summertime supply disruptions, particularly during the next drought in the region. Specific strategies to reduce demands should be considered, especially in areas where irrigation growth may continue to expand. Further, continued monitor is highly recommended to improve the groundwater flow models of the region. Finally, of upmost importance, entities reporting demands in the region to the IWIP program should continue to do so, with an emphasis on expanding reporting from the agricultural sector.
4. Demands in Winnebago County, and in particularly Rockford, might also be unsustainable, particularly when considering the impact of reductions in natural groundwater discharge on streams. However, another concern in the Rockford region is the potential for contamination—legacy, acute, or otherwise—to make its way into public

and private water supplies. Contaminants could become mobilized by existing pumping regimes, but a more pressing risk could be the mobilization of contaminants due to changes in pumping and increases in drawdown. This is especially important in the Rock River valley where infiltration rates are high. Currently, many wells in the Rockford region may be approaching the end of their lifecycles and if well casings fail, they may present a conduit through which contamination may spread into otherwise uncontaminated aquifers. Steps should be taken to identify and properly abandon such wells.

5. The shallow aquifers of the region are vulnerable to a variety of contaminants, including nitrate from agricultural contamination, chloride from road salt applications, agricultural runoff and/or septic/sewage discharge, and arsenic from natural sources. Deep aquifers are also subject to a variety of natural contaminants, such as radium and barium. These water supply issues can impact both high-capacity and domestic wells, although the latter are often not tested for the contaminants of concern. The karst aquifers of Jo Daviess County are particularly vulnerable to contamination due to their rapid travel times and limited ability to remove contaminants traveling through the subsurface. While wells sampled in the region had limited contamination, springs did indicate signatures of septic system discharge.

Surface Water Supply

6. Streamflows in the region increased in a short period around 1970 and some rivers and streams have seen increasing low flow since 2010, which is promising for surface water supply. Increasing streamflow will provide more available water but may result in greater minimum flow requirement for surface water withdrawals. Thus, an environmental flow assessment will be needed in the future to determine aquatic ecosystem water demand, which can be used to assist determinations of minimum flow requirements. Ideally, this analysis would also consider the ecological impacts of reductions in natural groundwater discharge.
7. Long-term continuous streamflow records are critical to assess surface water supply and calibrate hydrologic models that may be used to assess surface water under changing conditions. It is also valuable to monitor streamflow for headwaters and small tributaries, especially for Green River Lowland and Wisconsin Driftless Section.
8. While a few users currently rely on surface water, those that do withdraw a huge amount of water from the Mississippi and the Rock Rivers. Currently, withdrawals are reported as annual totals, limiting the characterization of seasonal water use and estimation of water consumption by power generation. For public water supplies, monthly withdrawal data could be combined with effluent discharge data reported in NPDES to better understand public water use patterns. While the collection of monthly withdrawal and discharge data would allow for more robust analyses, but this effort would require a considerable expansion of the IWIP program beyond its current scope and mission.
9. The power generation industry is overwhelmingly the largest surface water user. Better understanding of power generation trends in the region and close collaboration with local stakeholders is critical for surface water supply planning in the future.

County Level Supply vs Demand and Risk

10. Sustainable supply exceeds demand in two counties, Winnebago and Whiteside. This follows from the comparatively large demands in the two counties, predominantly municipal in Winnebago and agricultural in Whiteside. In both cases, sustainability is defined as the reductions in natural groundwater discharge exceeding 10% of predevelopment baseflow conditions in streams. This metric was assigned based on a study in Michigan. An analogous study in Illinois is needed, particularly focused on possible ecological impacts of different order streams. This could be coupled with the environmental assessment recommended as a result of the low-flow assessment recommended for the surface water portion of this study.
11. The metric used to assess shallow groundwater supply is limiting. Further investigations of vulnerability to contamination and potential for drawdown from demands, particularly for confined aquifers, should be considered in a local analysis of supply. The ISWS continues to refine the methodology for defining supply, so readers of this report are recommended to visit the Rock River Planning website to see any updates to these numbers.
12. Communities are often forced to drill wells into the less transmissive shallow bedrock and sandstone aquifers due to limited or non-existent sand and gravel aquifers. This can become problematic when pumping water levels fall below the top of the sandstone aquifers, which is at-risk of happening now in a few locations throughout the region. Due to the low growth in the modeled scenarios, future sandstone declines are expected to be minimal. However, if certain areas do experience growth, expanding zones of risk to the sandstone water supply should be evaluated closely. This includes municipal or industrial growth, including emerging industries such as ethanol production. Reporting this information to the ISWS, particularly changes of more than 1 million gallons per day, is strongly encouraged.

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