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Drawdown in the northeast groundwater management area (Brown, Outagamie, and Calumet Counties, Wisconsin)

Final report prepared for the Wisconsin Department of Natural Resources
(Submitted June 30, 2009)

J.A. Luczaj
University of Wisconsin–Green Bay
D.J. Hart
Wisconsin Geological and Natural History Survey

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DRAWDOWN IN THE NORTHEAST GROUNDWATER MANAGEMENT AREA (BROWN, OUTAGAMIE, AND CALUMET COUNTIES, WI)

A final report prepared for the Wisconsin Department of Natural Resources

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University of Wisconsin – Green Bay

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Wisconsin Geologic and Natural History Survey
Madison, WI

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PROJECT SUMMARY

Title: Drawdown in the Northeast Groundwater Management Area (Brown, Outagamie, and Calumet Counties, WI)

DNR Project Numbers: PRJ16FE and PRJ16BW

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Period of Contract: *Beginning 7/01/08 through 06/30/09*

Background/Need:

In eastern Wisconsin, water levels over large regions have decreased due to many wells pumping from beneath a confining layer. This combination of geology and cumulative pumping from the wells has resulted in a large regional drawdown cone centered around Brown County, Wisconsin. The region has experienced drawdowns greater than 400 feet with a significant portion of Brown County showing drawdowns greater than 150 feet in the confined aquifer.

Wisconsin groundwater quantity legislation, 2003 Act 310, addresses these large drawdowns by designating areas with drawdowns greater than 150 feet as Groundwater Management Areas (GMAs). These GMAs are to receive special attention. However, there had not been any analysis of the drawdowns or pumping rates in nearly 10 years (Walker and others, 1998) in the northeastern GMA, the region in this study. In this report we remedy this gap in our knowledge with compilations of drawdowns, pumping rates, and an improved hydrostratigraphy of the northeastern GMA in Brown, Outagamie, and Calumet counties, WI. In addition, eight communities in the northeastern GMA switched from groundwater to surface water, providing an opportunity to observe changes in water levels from the decreased pumping rates.

Objectives:

The objective of this study was to improve our understanding of the hydrogeology, flow system, and drawdowns in the northeastern GMA. This will allow the WDNR to assist those communities and parties in the northeastern GMA who still rely on groundwater for their current and future water supply needs.

Methods:

We collected basic data: water levels, pumping rates, and hydrostratigraphy. These data were compiled into a database of water levels and pumping rates (municipal and non-municipal hi-cap) over time. We analyzed those data and developed maps of drawdown cones and created tables with associated pumping rates. We used the switch from groundwater to surface water by the eight municipalities to estimate a vertical conductivity of the confining layer through a Hantush leaky aquifer analysis. We refined the hydrostratigraphy by using results from an ongoing STATEMAP proposal and the Glacial Lake Oshkosh project (Moeller and others, 2007; Hooyer and others, 2009). We tested several boreholes using geophysical logging, flowmeters, and packer testing to improve the geologic interpretation and to derive hydraulic properties of the confining unit and the confined aquifer.

Results and Discussion:
In general, the water levels in the deep sandstone aquifer have increased more than 100 ft around the central portion of the main cone of depression located in central Brown County since the eight communities switched from groundwater to surface water. Although the rate of water level increase has slowed, water levels are still slowly rising. In fact, water levels in the deep sandstone aquifer have the potential to rise above the land surface causing flowing wells; the town of Howard's well #3 has already begun to flow. A smaller portion of the cone of depression in the northeastern GMA, located to the south and centered around the Fox Cities area near the north end of Lake Winnebago has not shown any change. This smaller portion is located too far from the change in pumping to have seen any changes in water levels.

Pumping rates in the northeastern GMA decreased by 12 mgd due to the switch from groundwater to surface water supplies by the eight communities. Current pumping rates in the area in central Brown County are around 4.2 mgd. However pumping rates in the Fox Cities area remain at around 7 mgd.

The hydrostratigraphy of the area has been refined. Analyzing recovery curves from central Brown County wells with the Hantush method using an automated fit approach resulted horizontal conductivity (Kh) values of the deep aquifer that ranged from 2.7 to 19.1 feet per day. Vertical conductivity (Kv) values of the confining unit ranged from $2.8x10^{-7}$ to $2.3x10^{-3}$ feet per day. Geophysical logs, flowmeter logs, and packer testing were collected at several wells. One result of this logging is an increased appreciation for high conductivity zones in the sandstone aquifer, whether it be vertical fractures seen in the Shorewood golf course well, BN-422, or the horizontal high K zones in the McKeefry borehole, BN-424, that received or produced flows greater than 50 gpm over zones less than 1 foot in thickness.

Conclusions and Recommendations:
Pumping rates control water levels in the deep sandstone aquifer in the northeastern GMA. We now have two instances, one from 1957 and one from 2005-2007, where pumping rates have decreased dramatically and the aquifer has been allowed to recover. As a result we know that if the aquifer is overpumped (around 7 mgd in central Brown County), the mineralized zone of the St. Peter Sandstone may become dewatered and might act as a source of arsenic. Also, if the pumping rate is too low, many wells open to the deep sandstone aquifer may begin to flow, creating a need to deal with the excess water.

Related Publications (Abstracts):

1. *Hart, D.J., Luczaj, J.A., and Chase, P.M., 2008, A Large Scale Pumping Test in the Northeastern Wisconsin Groundwater Management Area. American Water Resources Association Conference, Wisconsin Chapter, Brookfield, WI, page 50.*
2. *Maas, J.C., Hart, D.J., and Luczaj, J.A., 2009, Groundwater Recovery and Hydrostratigraphy in the Northeastern Groundwater Management Area of Brown, Outagamie, and Calumet Counties, Wisconsin. American Water Resources Association Conference, Wisconsin Chapter, Stevens Point, WI, page 39.*

Keywords:
Hydrostratigraphy, pumping rates, drawdowns, groundwater management area

Funding: *Wisconsin Department of Natural Resources*

Final Report:
A final report containing more detailed information on this project is available for loan at the Water Resources Institute Library, University of Wisconsin–Madison, 1975 Willow Drive, Madison, Wisconsin 53706; (608) 262-3069.

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INTRODUCTION

Recent groundwater legislation, 2003 Wisconsin Act 310, addresses concerns about groundwater as a resource and provides the Wisconsin Department of Natural Resources (WDNR) with additional groundwater management tools. This project was designed in response to a WDNR request for additional information supporting Act 310 in the northeast Wisconsin Groundwater Management Area (GMA; Figure 1).

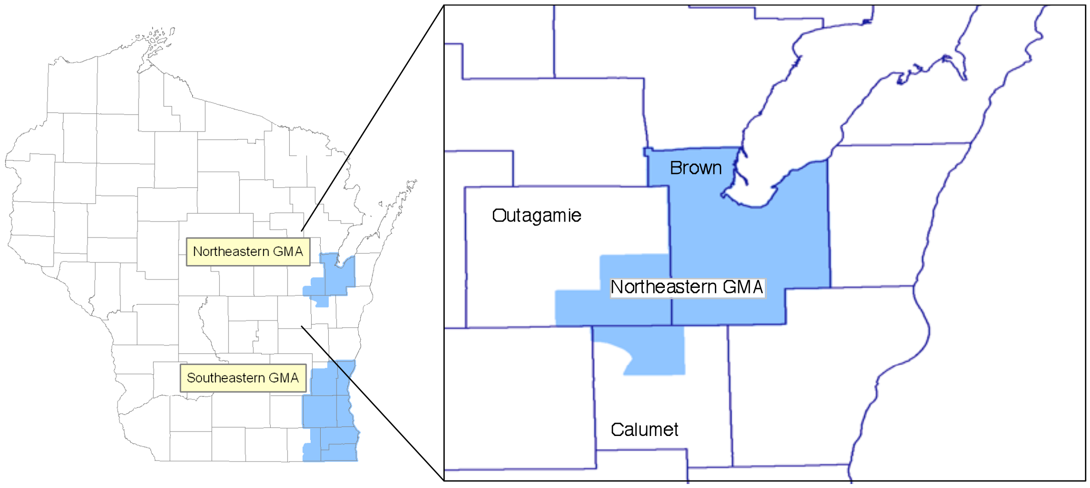


Figure 1. Location of the Northeastern GMA shown in blue.

Objectives

Our objective was to collect basic hydrogeologic data for the northeastern GMA and the surrounding area. These data include water levels and pumping rates for a variety of municipal, industrial, and residential wells, with a focus on the deep aquifer. In addition, a two-year U.S. Geological Survey funded project to map the bedrock geology of Brown County (Luczaj and McLaughlin, 2007, 2008) has provided resources and information to aid in our understanding of the hydrostratigraphy of the region.

This basic study is necessary because of the large data gaps in the water levels and pumping rates in this GMA. In 1998, results of groundwater flow modeling were published for this region (Walker and others, 1998; Conlon, 1998). Since that time, there has been little data collection and less analysis of the hydrogeology in the GMA, even though the drawdowns in the GMA had greatly exceeded 150 feet in 1998. Between 1998 and the beginning of this project, we did not have a full understanding of the variation in pumping rates or water levels and little knowledge of the overall state of the resource. Some data were available in WDNR and Public Service Commission records submitted by municipalities but they had not been compiled or analyzed.

This project contains three principal components, each of which focuses on different aspects of the hydrogeology of the northeastern GMA. Two of these components are pumping rates and water levels over time, and they are included in a Microsoft Access database (Appendix 3). The third component is a refined understanding of the hydrostratigraphy of the northeastern GMA, with a focus on the Green Bay region.

This project has supported graduate student Julie Maas at the University of Wisconsin – Green Bay as a graduate research assistant. She was responsible for compiling most of the water levels and pumping rates, and for serving as a liaison with private and municipal well operators. Julie also participated in onsite investigations, hydrogeologic calculations, and cross section compilations.

Background

The northeastern GMA includes all of Brown County and parts of Outagamie and Calumet counties (Figure 1). It has an area of around 700 square miles that lies completely within the Great Lakes basin and is home to more than 350,000 people (U.S. Census, 2009). As concerns over groundwater quantity and quality have grown within the northeastern GMA, surface water has become the predominant source of municipal water supply for the larger municipalities. However, significant industrial, commercial, municipal, and residential groundwater use continues in the northeastern GMA.

The geology of the area (Figure 2) is generally similar to that of southeastern Wisconsin with a few important stratigraphic differences. The area is underlain by a basement of Precambrian crystalline rocks at depths ranging from around 700 feet in the northwest to as much as 1,700 feet, with depths increasing toward the southeast. These crystalline rocks have little capacity for groundwater production. Above the crystalline bedrock is an aquifer that consists of Cambrian and Ordovician sandstone and dolostone. These rocks go from the Mount Simon Sandstone at the bottom of the section to the St. Peter Sandstone at the top of the section to form a deep aquifer with a thickness of around 600 feet. The Prairie du Chien Group dolostones (up to 200 feet thick) are present within this aquifer, and are sandwiched between the Cambrian and Ordovician sandstones. This aquifer is very productive and was historically the predominant source of water for the region. Above the deep aquifer is a confining unit, the Ordovician Sinnipee Group, containing dolostone and shaly dolostone with a thickness of 200 feet. In the eastern part of the GMA, the Sinnipee Group is overlain by the Maquoketa Shale (an aquitard) and several Silurian dolostone formations. The Silurian dolostone units are part of a regional karst aquifer but do not produce nearly as much water as the deep sandstone aquifer and have water quality problems relating to bacteria and nitrate contamination. A variety of glacial materials ranging in thickness from 0 to 200 feet covers the bedrock.

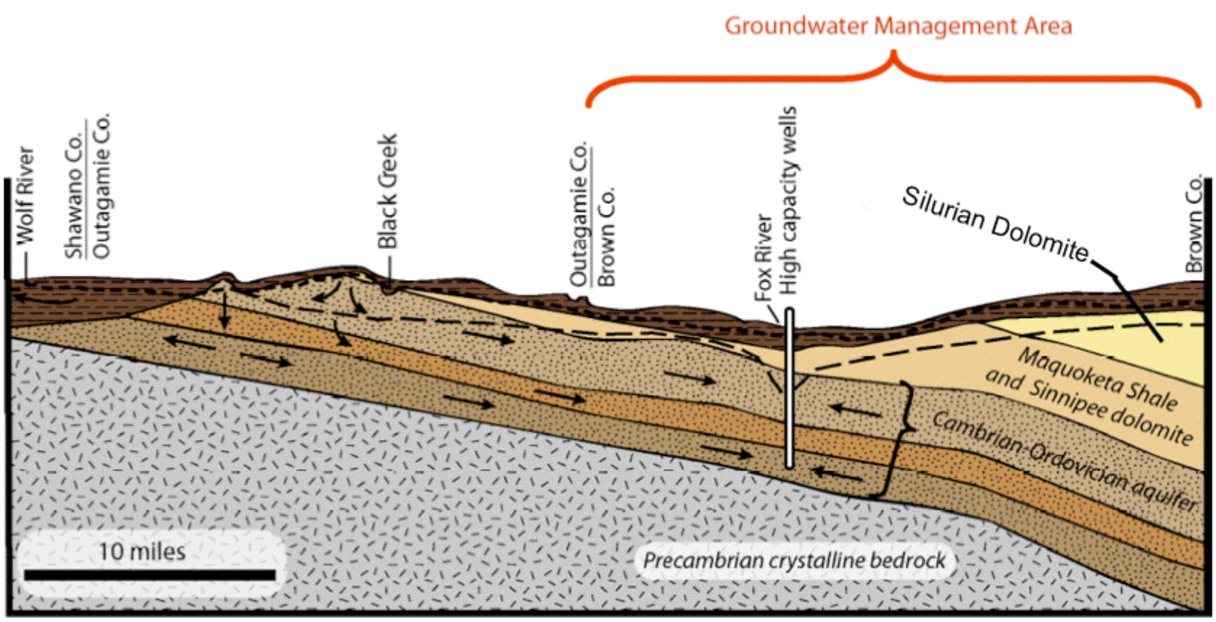


Figure 2. Generalized cross section showing the regional hydrostratigraphy in the northeastern GMA (modified after Conlon, 1998; Bradbury and Batten, 1996).

The northeastern GMA has a history of large drawdowns greater than 150 feet in the deep confined aquifer in two general locations. The largest cone of depression is centered in central Brown County near the Green Bay metropolitan area, and the other is centered in the Fox Cities Area between Kimberly and Kaukauna. The most significant historical changes in the northeastern GMA occurred in central Brown County, near the Green Bay metropolitan area, and are the focus of this report.

The problem of declining water levels in northeastern Wisconsin first impacted the Green Bay area. Before 1957, groundwater was the major source of water for the region with a withdrawal rate of 13 million gallons per day (mgd) in the metropolitan area. Approximately half of the withdrawals were from municipal wells in the City of Green Bay. At that time, the water levels in the deep aquifer wells had been lowered by about 400 feet below pre-development conditions. Initially, the heads in the deep sandstone aquifer were around 100 feet above land surface. However, by 1957 they were 340 feet below land surface due to pumping in the deep aquifer. Because of this drawdown, Green Bay switched from groundwater to surface water in 1957. The switch significantly reduced pumping and the water levels rebounded accordingly from lows of around 340 feet below ground surface to less than 100 feet below ground surface. The rebounds and pumping rates are documented in Knowles (1964).

Over the subsequent 50 years, pumping rates for municipal and industrial wells in the communities surrounding Green Bay had increased significantly. By 1979, 22 years after Green Bay switched to surface water, approximately 8.9 mgd of groundwater were withdrawn from the deep aquifer in Brown County (Krohelski, 1986). At that time, six public supply systems and four industrial users were responsible for 60 percent of that amount. By 2005, our present study estimates that approximately 14-16 mgd of water was being withdrawn from the deep aquifer in central Brown County. In response, the water levels in the deep sandstone aquifer had decreased at a rate of 2-3 feet/year to conditions similar to those present in 1957 (Figure 3). Water levels for well BN-76 are available from the Wisconsin Groundwater Monitoring Network to April 2009.

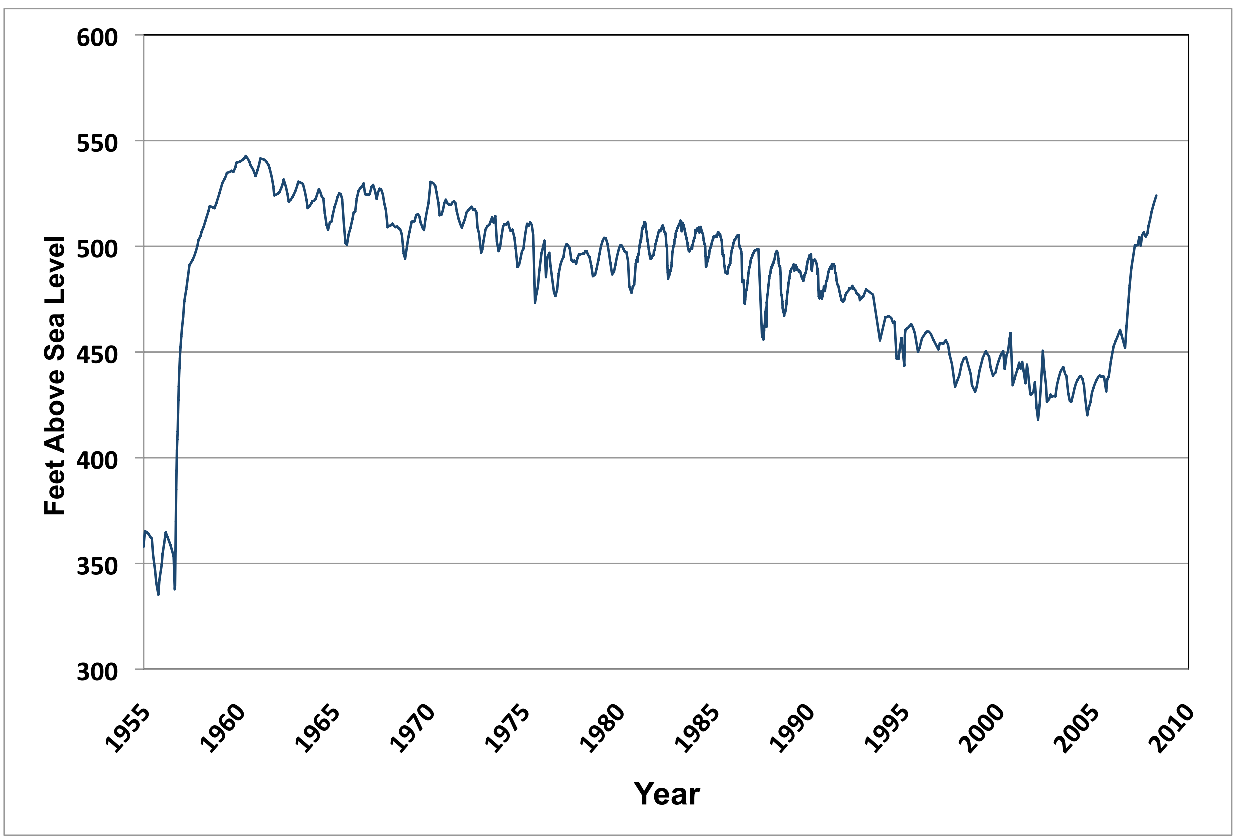


Figure 3. Water levels over a 54-year period in Well BN-76, Green Bay, WI. The water level recovery events of 1957 and 2007 are both illustrated in this hydrograph.

In 1992, eleven communities surrounding Green Bay commissioned an engineering report to study long-term solutions to the declining water levels in the deep aquifer system (Consoer, Townsend &

Associates, Inc., 1992). The report concluded that the deep aquifer system in the Green Bay metropolitan area would not be able to sustain the needs of the community through the subsequent 10 to 20 years. While these regional decreases in deep aquifer water levels were a significant long-term concern, new EPA standards for radium taking effect in December 2006 would have required all Brown County municipal water utilities to treat for high radium levels. These high radium levels were the principal driving force behind the desire to switch to surface water.

These groundwater quantity and quality concerns led municipalities to consider the options available to them. State Legislation passed in 1998 allowed communities to combine efforts to address water problems and in 1999 the Central Brown County Water Authority (CBCWA) was formed. The CBCWA communities (the City of De Pere, the Villages of Allouez, Bellevue, and Howard, and the Towns of Lawrence, and Ledgeview) considered several solutions for their water supply concerns. These options included purchasing water from Green Bay or independently building a pipeline to Lake Michigan. After comparing these options amid much political controversy (e.g., Egan, 2006), the CBCWA signed an agreement to purchase water from the City of Manitowoc's Public Water Utility.

In 2006, construction began on a 65-mile long pipeline that would eventually transport water from Manitowoc's processing facility on the shore of Lake Michigan to each of the CBCWA communities. This project was completed and all member communities were connected and receiving surface water by autumn of 2007. Rather than join the CBCWA, the Village of Ashwaubenon and the Town of Scott addressed their water needs by signing agreements to purchase their municipal water from the City of Green Bay. Scott's well was turned off in October 2005 and Ashwaubenon stopped pumping groundwater in June 2006. The eight communities that stopped pumping groundwater are shown in Figure 4.

The switch from groundwater to surface water by these eight communities has resulted in a substantial reduction in withdrawals from the deep aquifer. Since the switch, water levels in the aquifer have shown dramatic recovery, which is a primary focus of this study.

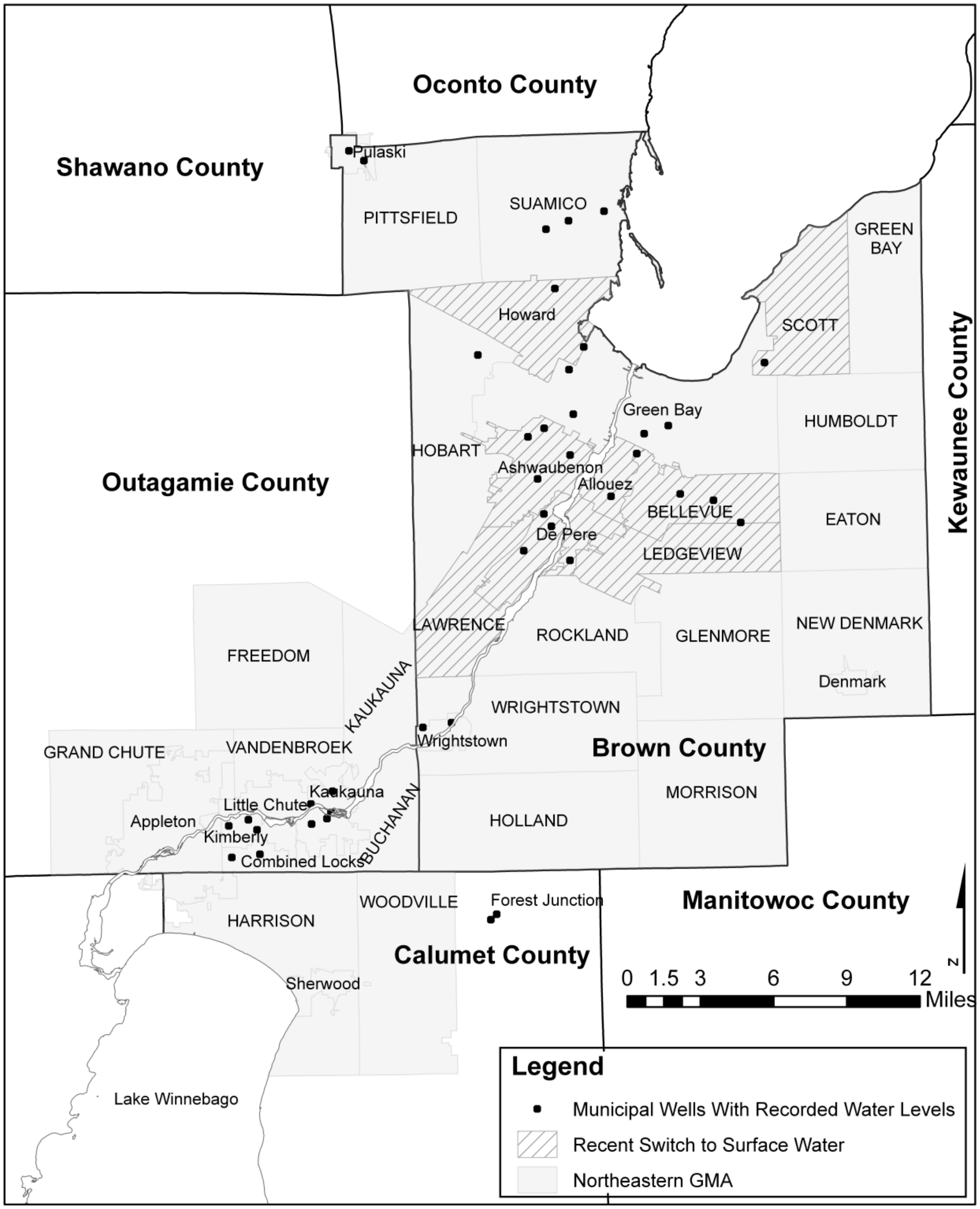


Figure 4. Townships and cities of the Northeastern GMA, with emphasis on municipalities that recently switched from groundwater to surface water. Black dots represent municipal wells for which water levels were recorded after the switch to surface water.

PROCEDURES AND METHODS

Hydrostratigraphy

Our first objective was to gain a better understanding of the hydrostratigraphy in the northeastern GMA. We compiled existing hydraulic conductivity, lithologic, and geophysical data from published and unpublished sources. We performed geophysical logging (gamma and resistivity), spinner and heat pulse flow meter logging, video logging, and caliper logging on two existing wells and a third borehole near Pulaski, Wisconsin that was drilled in conjunction with this project. In this report, wells or boreholes designated by BN-xxx refer to WGNHS well identification numbers, as used in the WiscLITH database.

Pulaski Borehole Investigation

The borehole south of Pulaski, designated BN-424, was drilled as part of a U.S. Geological Survey (STATEMAP) funded project to map the bedrock geology of Brown County (Luczaj and McLaughlin, 2007). In addition to the parameters mentioned above, this borehole was more intensely studied from a hydrostratigraphic perspective. Flowmeter testing was performed under a variety of conditions, including non-pumping, as well as pumping at 40 gpm and 105 gpm with the pump set at 100 feet. Due to equipment malfunction, the quality of the video log for this well was limited, so an acoustic borehole image log was run to gain a better understanding of the stratigraphy and fracture characteristics in the borehole. In addition, packer testing using a U.S. Geological Survey rig was conducted on the borehole at 17 different depth intervals ranging from 60 feet to 719 feet below ground surface to determine heads and horizontal hydraulic conductivities of the aquifer.

Hantush Analysis of Regional Aquifer Properties

Knowles (1964) and Krohelski (1986) analyzed recovery curves from Green Bay's 1957 switch to surface water, which reduced the volume pumped from the deep aquifer in the City of Green Bay by 7.8 mgd. For this project, a similar analysis was performed for the recovery curves from sixteen wells after the recent switch from groundwater to surface water by eight central Brown County communities.

This analysis is really equivalent to a "giant pumping test" because groundwater withdrawals by the eight municipalities in central Brown County ceased over a short period of time, analogous to turning off a single giant pumping well. Aqtesolv™ software was used to apply an "automated-fit" method to the recovery curves, as well as recovery curves for two wells used by Knowles.

Water Levels

Our second objective was to obtain water level data from a variety of sources. Complete or partial static water level records for the period between January 2006 and June 2009 were provided by 17 municipalities (Figure 4). These water levels were entered into the project database. Some records also include water levels measured during pumping conditions and some begin earlier than January 2006. Early in the project four Solinst level loggers were installed in wells open to the deep aquifer in Brown County. Three of these loggers suffered from technical problems, including Well BN-76 (Figure 3), which recorded water levels through April 2009. One level logger continues to record data in a well owned by the Oneida Nation (see Figure 21). Static water levels were also obtained from well construction records accessed through the WDNR Well data disc (WDNR, 2009a). Additional historical water levels were obtained from the U.S. Geological Survey's Active Groundwater Level Network website (USGS, 2009).

Pumping Rates

Our third objective was to assess the volume and nature of groundwater withdrawals from the deep aquifer before and after the recent switch to surface water by eight municipalities in central Brown County. We obtained pumping data from a variety of sources to estimate the volume of withdrawals and to understand who continues to use water from the deep aquifer, how it is used, and how this has changed over time.

Municipal well operators in our study area were requested to supply monthly pumping records for each well in service within their utility. The operators who maintain such records provided them to us. Some utility operators did not provide monthly volumes pumped per well, but municipal well operators in Wisconsin are required to report their monthly groundwater withdrawals to the Wisconsin Public Service Commission (PSC). These values are published in annual reports that are available to the public. These values are reported as the combined total volume pumped from all wells within each public utility. For pumping data acquired from PSC annual reports, we were able to use the combined total because all municipal wells for which we relied on PSC data are open to the deep aquifer. One municipality, the town of Greenleaf, has one well open to the deep aquifer and one open to the shallow aquifer. The well operator for this utility confirmed that the deep well has not been in use during our study period, therefore, no pumping volumes were included for Greenleaf wells (T. Weyenberg, personal communication, 2009).

Non-municipal wells fall into a wide range of categories, including but not limited to industrial, commercial, agricultural, irrigation, and residential. The State of Wisconsin requires permits for all high capacity wells. High capacity wells in Wisconsin are defined as those having a capacity higher than 70 gpm (or a combined capacity of greater than 70 gpm if there is more than one well on a property). We searched the WDNR's well database (WDNR, 2009a) for high capacity wells in our study area and contacted well operators to request pumping records for the period between January 1, 2006 and December 31, 2008. We obtained some pumping records from high capacity well operators by contacting them directly. However, other operators were not locatable or did not keep pumping records.

Since 2007, the WDNR has required permit holders to report withdrawals by each of their high capacity wells annually. For wells in which we were unable to obtain data directly from operators, we searched the annual reported values, available from the WDNR's online high capacity well inventory (WDNR, 2009b). Pumping records for many wells were reported for one or more years, with a noticeable increase in reporting in 2008. Partial records were available for some wells, and we used the values we received to estimate the use in missing time periods. For example, if volumes were available for 2007 and 2008 for a particular well, the average monthly values for these years were applied to 2006. If only one year of volumes was reported, that year's values were applied to the missing years. For wells drilled during the study period, zeroes were applied to all months before that well became operational.

Pumping rates for non-high capacity wells are not collected in an official manner in Wisconsin. Many residents obtain water for their household use from non-high capacity, domestic self-supplied wells. Two methods were used to estimate withdrawals from the deep aquifer in the Northeast GMA.

For the first method, residential water use values reported by the PSC and average household size information from the US Census (US Census, 2009) were used to determine average residential use in gallons per capita per day (gpcpd) throughout our study area. Additional population data from the Program for Agricultural Technology Studies (PATS) (PATS, 2009) and PSC values were used to estimate the number of residents who live in areas not served by municipal water providers, as well as how much water they consume per day. The WDNR's well records database (WDNRa, 2009) provided data to determine the percentage of wells that are open to the deep aquifer in each township. This percentage was applied to the total estimated above to estimate residential withdrawals from the deep aquifer.

A simpler method was also applied to estimate water usage from domestic water supply wells. We used the total number of wells open to the deep aquifer in each township (from our search described above) and multiplied that number by the average household size in that township. We then multiplied that number by the average residential consumption in gpcpd and summed the totals for all townships.

These two methods for estimating residential withdrawals suffer from some limitations. Population data are from the 2000 census and do not account for growth that has taken place in the study are since then. Also, the WDNR well records database contains, with few exceptions, only wells that have been drilled since 1988. These methods also assume that all wells reported in the WDNR database are residential. Commercial non-high capacity wells are not included in our estimates for this report.

Estimation of St. Peter Sandstone Dewatering Point

We attempted to estimate the volume of water that could be pumped in central Brown County without dewatering the St. Peter Sandstone. This is important because the top of the St. Peter typically contains abundant arsenic-bearing sulfide minerals that oxidize when exposed to the air. Krohelski modeled the underflow and vertical leakage of the deep aquifer in Brown County to estimate the volume of water that could be withdrawn from aquifer storage without dewatering the St. Peter Sandstone.

Before eight communities recently switched to surface water, several wells in the northeastern GMA had water levels that were below the top surface of the St. Peter Sandstone, particularly those located in or near the center of the cone of depression. The distance between the water level and the top of the St. Peter Sandstone was determined for these wells both before the switch in 2005-2007 and after the switch in 2008. We used linear interpolation to estimate the regional pumping rate that would keep water levels at or above the top of the St. Peter. While this is obviously a simplistic solution to a four-dimensional problem, it does provide a basic estimate of target pumping.

RESULTS AND DISCUSSION

Hydrostratigraphy

Geologic Framework

The northeastern GMA is underlain by a basement of Precambrian crystalline igneous and metamorphic rocks (Krohelski, 1986; Young, 1992). The Precambrian rocks are overlain by sedimentary rocks that are Cambrian to Silurian in age. Cambrian to Ordovician sedimentary rocks comprise the deep aquifer, which is described in detail later in this section. The deep aquifer is overlain and confined by a sequence of dolostone, shaly dolostone, and some shale. Silurian dolostone overlies the confining layer in the eastern portion of the study area and is generally an aquifer, although it does not typically produce as much water as the deep aquifer. Pleistocene lacustrine clays, tills, and other glacial sediments overlie the entire sequence. The clays and tills generally act as aquitards, while other sediments could act as either aquifers or aquitards. Tables 1 and 2 and Figure 2 summarize regional geology and hydrostratigraphy. Figures 5 and 6 are cross sections illustrating the stratigraphy of the northeastern GMA.

<u>Precambrian</u>

The study area is underlain by a basement of Precambrian igneous and metamorphic rock that slopes eastward at about 31 feet per mile in the western half of the county and increases to about 35 feet per mile between Scott and Luxemburg, Wisconsin. These rocks are predominantly red granite, but also contain some schist and other crystalline rocks. The depth of the Precambrian rock surface ranges from 700 to 1,700 feet, increasing towards the east (Krohelski, 1986; this study).

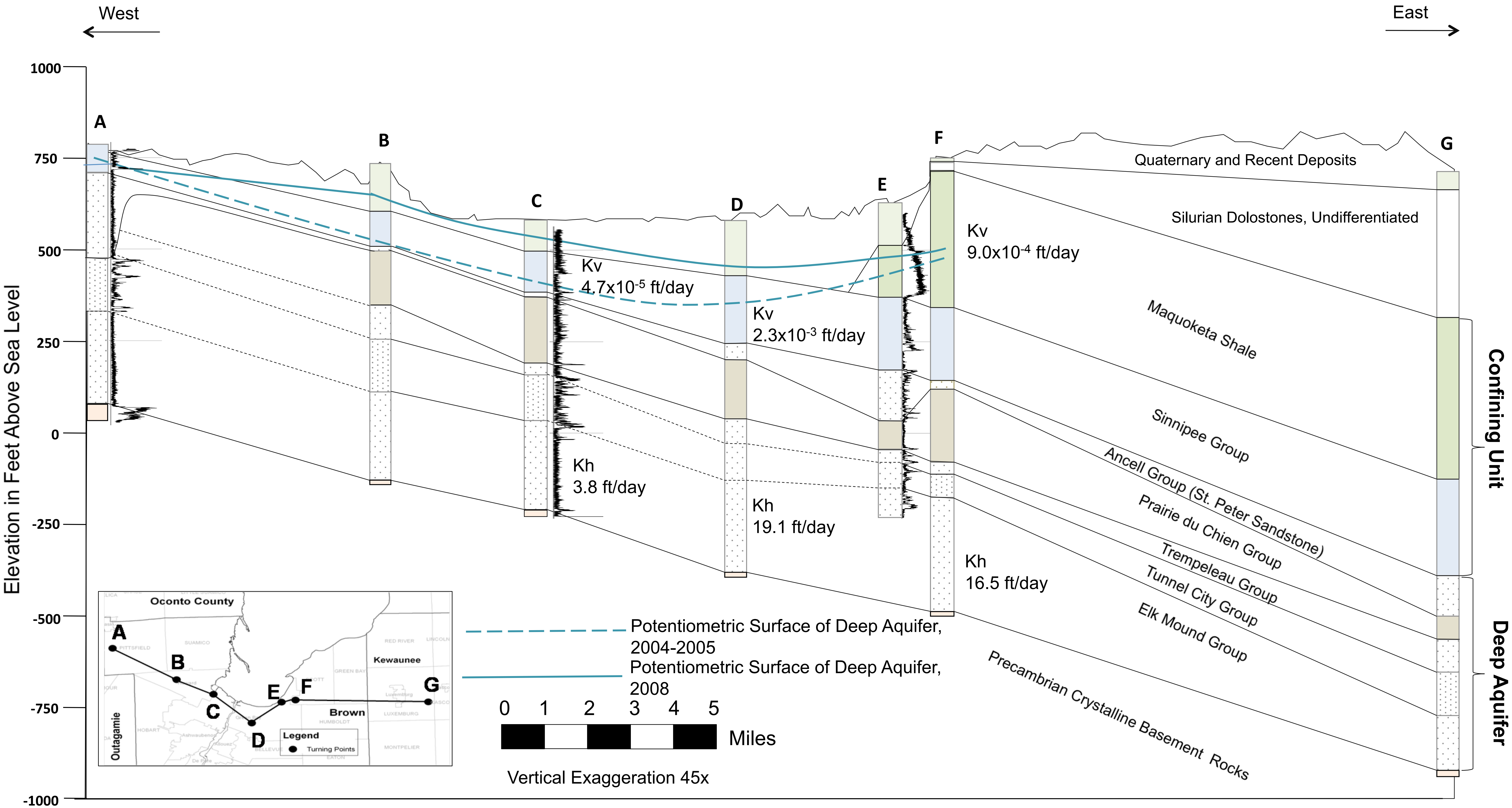


Figure 5. West to east cross section across Brown County. A is McKeefry Borehole, BN-424, Pulaski, Wisconsin; B is Village of Howard Well 2; C is City of Green Bay Well 10; D is City of Green Bay Well 4; E is Shorewood Golf Course Well at UW-Green Bay, BN-422; F is Town of Scott Well 1; G is former Green Bay and Western Railroad well, Luxemburg, Wisconsin. Gamma logs are shown for A and E, as well as a log from MW-1 near C. Vertical conductivity values (Kv) for the confining unit, as well as horizontal conductivity values (Kh) for the deep aquifer are shown for wells that were included in the Hantush pumping test analysis for this study. Dashed black lines indicated inferred contacts. The dashed blue line indicates the potentiometric surface in the deep aquifer in 2005, before eight communities switched to surface water. The solid blue line shows the piezometric surface in 2008, after the switch. Water levels for nearby wells were used for A and B, as water levels were not available for these specific wells at that time.

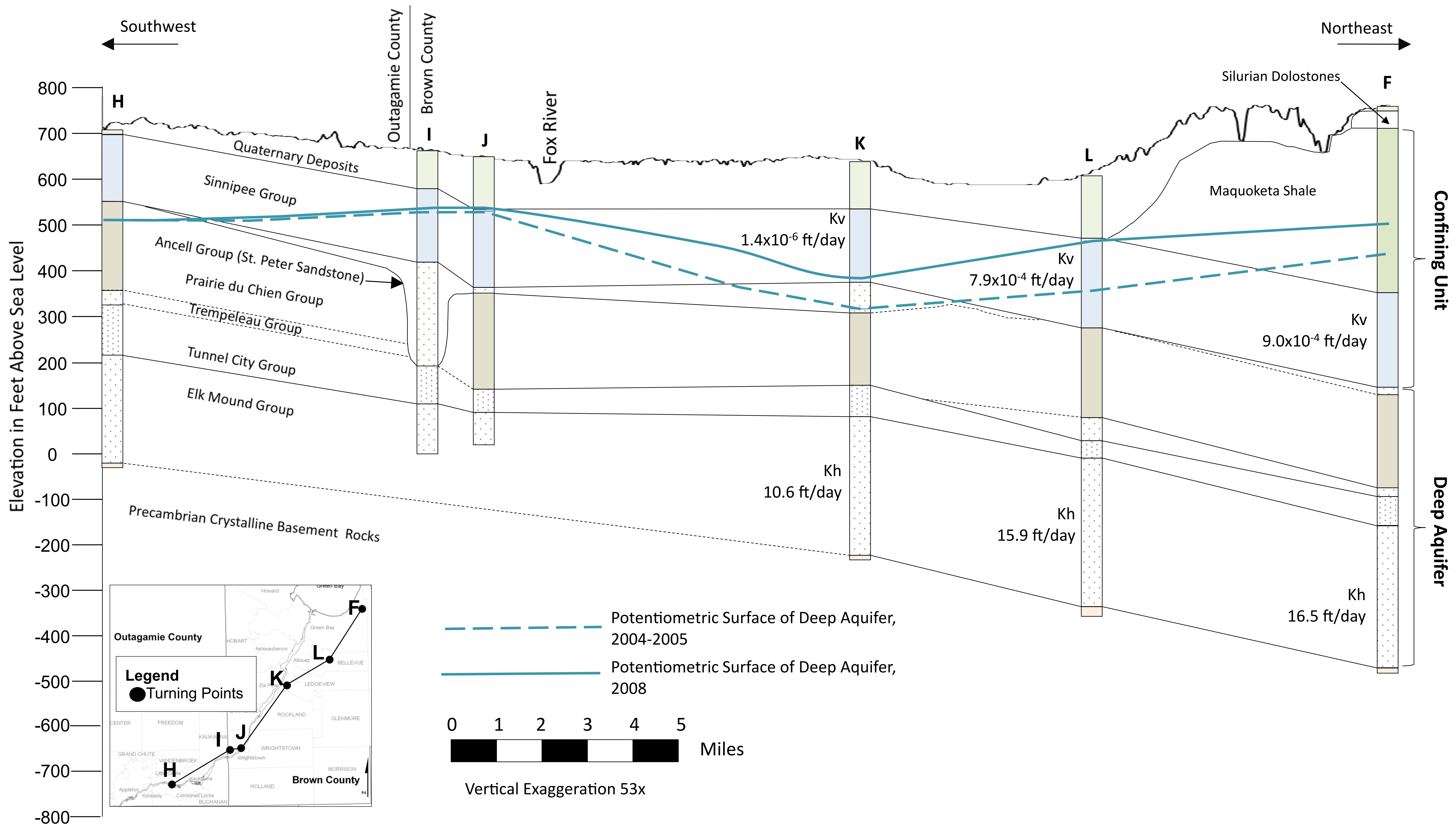


Figure 6. Southwest to northeast cross section across the northeastern GMA. H is Village of Little Chute Well 1; I is Village of Wrightstown Well 4; J is Village of Wrightstown Well 2; K is City of De Pere Well 5; L is Village of Bellevue Well 2; F is Town of Scott Well 1, which also appears on the west to east cross section in Figure 5. Vertical conductivity values (Kv) for the confining unit, as well as horizontal conductivity values (Kh) for the deep aquifer are shown for wells that were included in the Hantush pumping test analysis for this study. Dashed black lines indicated inferred contacts. The dashed blue line indicates the potentiometric surface in the deep aquifer in 2005, before eight communities switched to surface water. The solid blue line shows the piezometric surface in 2008, after the switch.

Cambrian

The Cambrian geologic units interpreted to be present in the northeastern GMA are presented in Table 1. The Elk Mound Group is the oldest Cambrian rock group and has a uniform thickness of 250 to 300 feet in the Northeast GMA. The Elk Mound contains, in ascending order, the Mount Simon, Eau Claire, and Wonewoc formations. The Mount Simon Formation consists of poorly cemented, subangular, fine to very fine-grained sandstone, which may be silty. The Wonewoc Formation consists of poorly cemented, subrounded, medium- to coarse-grained sandstone. Because it can be difficult to distinguish these formations, and because the Eau Claire Formation cannot be identified in Brown County, these rocks are referred to by their group name (Krohelski, 1986).

Above the Elk Mound Group lies the Tunnel City Group, a sandstone sequence 100-150 feet thick in the Northeast GMA. The Tunnel City Group includes the Lone Rock and Mazomanie Formations. The Lone Rock Formation, referred to as the Franconia Formation in older publications, ranges from a dolomitic, feldspathic, glauconitic siltstone or sandstone to a sandy glauconitic dolomite. Abundant glauconite gives these sandstones a distinctive green color. Either or both of these formations can be present throughout the study area (Krohelski, 1986). In the Pulaski borehole, there were no glauconite-rich stratigraphic horizons typical of the Tunnel City Group. We believe that this is because of a facies change within the unit as one moves toward the Wisconsin arch. Gamma logs suggest that much of the Tunnel City is still present at that location (Figure 5), but that most or all of the Trempelau Group was removed by erosion.

The Trempeleau Group, the youngest in the Cambrian sequence, overlies the Tunnel City Group and is typically 20-50 feet thick where present (Batten and Bradbury, 1996). The Trempeleau consists of the St. Lawrence and Jordan Formations. The St. Lawrence Formation is a silty, shaly dolomite that commonly contains glauconite and might be present in parts of the study area. The Jordan Formation is composed of very fine to very coarse sandstone and can contain dolomite, shale, and glauconite (Krohelski, 1986).

Ordovician

The early Ordovician Prairie du Chien Group overlies the Trempeleau Group in most of the northeast GMA. However, in some locations it is absent due to erosion that occurred before the deposition of the overlying Ancell Group. Where present, the Prairie du Chien can be up to 200 feet thick. The Prairie du Chien includes the Oneota and Shakopee Formations. The Oneota Formation consists of massive dolostone and oolitic chert (Krohelski, 1986). Overlying the Oneota, the Shakopee Formation contains grain- and matrix-supported dolostone, quartz sandstone, and shale.

While the lithostratigraphy of the Northeast GMA is generally similar to that of southeastern Wisconsin, the presence of the Prairie du Chien Group is an important difference between the two regions. In southeastern Wisconsin, the Prairie du Chien sequence is largely absent.
Above the Prairie du Chien is the Ancell Group, which consists of the St. Peter and Glenwood formations. The St. Peter is primarily a pure, poorly-cemented, fine- to medium-grained quartz sandstone that contains some sandy shale (Mai and Dott, 1985). The thickness of the St. Peter Formation ranges significantly in the study area. It is thickest (up to 300 feet) beneath the Fox River Valley near De Pere, thins rapidly to 40 feet over several miles to the east and west, and is nonexistent in some areas (Krohelski, 1986). The variations in thickness occur because of the erosion that took place on the surface of the underlying Prairie du Chien Group before the St. Peter was deposited. In northeastern Brown County, Krohelski (1986) describes, in cross section, a dramatic thickening of the Ancell Group that cuts entirely through the Prairie du Chien Group several miles southeast of Pulaski. Similar conditions were observed in the Pulaski borehole (BN-424; WUWN WH979) where the Prairie du Chien group was completely absent (Figure 7).

Table 1: Geology and hydrostratigraphy of the Northeastern GMA
(Modified after Knowles, 1964; Krohelski, 1986; and Conlon, 1998)

Geologic Age		Geologic Unit	Lithology	Hydrostratigraphic Unit
CENOZOIC	Quaternary (Pleistocene)	Unconsolidated deposits	Lacustrine silt and clay, till, fluvial sand and gravel, and other deposits.	Local unconfined aquifer (sand and gravel) or regional confining unit (lacustrine clays and tills)
PALEOZOIC	Silurian	Undifferentiated	Dolostone	Upper Aquifer
	Ordovician	Maquoketa Formation	Dolomitic shale.	Confining Unit
		Sinnipee Group	Dolostone with some shale.	
		Ancell Group	Silty sandstone, fine- to medium-grained sandstone, sandy shale.	Confined Deep Aquifer
		Prairie du Chien Group	Dolostone with varying amounts of oolitic chert and minor sandstone.	Acts as an aquitard, relative to the adjacent sandstones
	Cambrian	Trempealeau Group	Fine- to medium-grained sandstone with some silty glauconitic dolomite.	Confined Deep Aquifer
		Tunnel City Group	Fine- to medium-grained sandstone, silty sandstone to sandy dolomite.	
		Elk Mound Group	Very-fine to fine-grained sandstone and medium- to coarse-grained sandstone.	
PRE-CAMBRIAN	Precambrian	Undifferentiated	Crystalline rock, predominantly red granite, contains igneous and metamorphic rock.	Yields little to no water.

In Wisconsin, the St. Peter consists of two members, the Tonti and the Readstown. The Tonti Member is poorly cemented quartz sandstone, and makes up most to all of the thickness of the St. Peter, where present. The Readstown Member is described as a very poorly sorted deposits of white to red or orange cherty conglomerate that may contain clayey sandstone with red to brown shale (Krohelski, 1986 and Young, 1992). A unit that fits the shaly description of the Readstown Member is identified intermittently in well construction reports throughout the Northeast GMA. This unit is present in the Pulaski borehole (BN-424). The Glenwood Formation overlies the St. Peter and is a thin black/brown shale up to a few feet in thickness.

The Ordovician Sinnipee Group overlies the Ancell Group and is composed of dolostone and some shale. The unit is uniform 200 feet thick where not eroded, and thins to as little as 70 feet thick to the northwest. The unit consists of the Platteville and Galena formations, which are buff to gray medium- to thick-bedded dolostone. Substantial thicknesses of greenish shale interbeds are present at various intervals in the unit.

In the eastern part of the study area, the Sinnipee Group is overlain by the Ordovician Maquoketa Formation. The Maquoketa Shale is a relatively impermeable, soft, bluish-gray dolomitic shale that contains some beds of gray fossiliferous dolomite. The Maquoketa is present in a narrow belt (1 to 5 miles wide) just west of the Niagara escarpment (Knowles, 1964) and everywhere beneath the Silurian. Where not eroded, the unit thickens from 350 in the central part of Brown County to about 500 feet toward the northeast.

<u>Silurian Carbonates and Pleistocene to Modern Sediments</u>

There are several Silurian dolostone units that overlie the Maquoketa Shale. Their western erosional limit defines the Niagara escarpment that runs southwest to northeast across Brown County. In ascending stratigraphic order, these units are the Mayville Formation, the Burnt Bluff Group, the Manistique Formation, and the Engadine Formation. Together, they are as much as 450 – 500 feet thick in the eastern and southeastern portion of the GMA. Because these Silurian units are not specifically part of this investigation, they are not discussed in further detail in this report.

Pleistocene deposits overlie the Paleozoic rock and range in thickness from 0 to 200 feet throughout the Northeast GMA. The unconsolidated materials include glacial till, fluvial sand and gravel, and lacustrine sediments (mostly clays and silts) (Need, 1985). The glacial till "hardpan" and the lacustrine silt and clay sediments are thought to significantly contribute as a regional confining unit (Thomas Hooyer, personal communication).

Hydrostratigraphy

The rocks that comprise the lithologic sequence described above form the hydrostratigraphic units of the Northeast GMA. Several aquifers and confining units are present in this sequence and their characteristics provide the framework for groundwater movement within the region.

The deep sandstone aquifer ("deep aquifer"), which is the focus of this study, overlies the Precambrian basement crystalline rocks. The deep aquifer is a high-yield groundwater source for the region. It contains the Cambrian sandstones, the Prairie du Chien Group, and the Ancell Group and ranges in thickness from 550 to 640 feet in the Green Bay area (Knowles, 1964). The sandstones in the lower part of the aquifer are the most productive, and the Prairie du Chien carbonates are believed to contribute only small amounts of water from openings along fractures and bedding planes (Knowles, 1964). The Prairie du Chien Group dolostones likely act as an aquitard, where present, and have the potential to hydraulically disconnect the Cambrian sandstones from those of the Ancell Group. The thickness of the rock units within the deep aquifer varies considerably throughout the study area. In areas where the St. Peter Sandstone is thin or non-existent, the Prairie du Chien Group is very thick, and where the Prairie du Chien Group is thin, the St. Peter tends to be thick (Emmons, 1987). Because its thickness is highly variable, and because it is not always separated from the Cambrian sandstones by the Prairie du Chien Group, the St. Peter's contribution to the deep aquifer system is variable.

Previous researchers (Krohelski, 1986; Emmons, 1987; Mandle and Kontis, 1992; and Batten and Bradbury, 1996) have divided the lithologic sequence into multiple aquifers and confining units. Conlon (1998) grouped all Cambrian sandstones with the Ordovician Prairie du Chien and Ancell Groups as a single deep aquifer unit. For this study, Conlon's (1998) interpretation of the hydrostratigraphy is applied for a number of reasons. First, much of our water level data are from wells that penetrate the deep aquifer units to various depths or from wells in which parts of the aquifer are restricted by casing. Many deep aquifer wells are open to many different sandstone units, which allows interaquifer flow, thus potentially equalizing the water levels among the different sandstone units. Also, a confining unit that has been described as separating the Elk Mound Group into two aquifers is not easily distinguished from its neighboring sandstones and is not always present in the Northeast GMA. Finally, Emmons (1987) showed that water levels throughout the Paleozoic sequence below the Sinnipee Group are similar.

The hydrogeologic properties of the deep aquifer are generally similar throughout the study area. Published well test results have shown the horizontal hydraulic conductivity of the deep aquifer to range between 1.2 and 23.0 ft/day (Conlon, 1998). Table 2 contains a compilation of hydraulic values from this study and published sources.

Water enters the deep aquifer primarily when precipitation infiltrates outcrop areas in northwestern Brown County, eastern Outagamie and Shawano Counties, and southern Oconto County (Knowles, 1964). Recharge is favorable in these areas because the uppermost layers of the deep aquifer have a coarse texture and the Sinnipee-Maquoketa unit and the glacial lake clays of Glacial Lake Oshkosh are thin or absent, allowing vertical leakage through the confining units. Recharge occurs fairly quickly after precipitation, but does not occur uniformly over the study area, and is highest in the spring and fall (Krohelski, 1986).

The deep aquifer is confined from above by the overlying Maquoketa Formation and Sinnipee Group, which form a continuous low conductivity layer that thins and becomes absent toward the west. The Sinnipee Group (along with the Maquoketa Shale, where present) acts as a confining layer for the deep aquifer. Published well test results (Conlon, 1998) indicate that the vertical hydraulic conductivity of the Maquoketa-Sinnipee confining unit ranges from 0.000004 to 0.007 ft/day, with higher values generally to the west where the units thin (Table 2).

Above the confining unit is the upper aquifer, composed of Silurian dolostone. This aquifer produces large quantities of water but the water is poor quality in many places due to contamination by coliform bacteria and nitrates.

Glacial sediments above the upper aquifer can act as a confining unit to the underlying Silurian aquifer (Emmons, 1987; Moeller and others, 2007; Hooyer and others, 2009), particularly in areas where these deposits are thicker and composed of clays and silts. Where glacial deposits are absent, areas of exposed bedrock may indicate areas of recharge. While glacial materials are not a major focus of this study, Hooyer and others (2009) have indicated that glaciolacustrine clays, if sufficiently thick, can act as an important regional confining unit for the deep aquifer. As part of an ongoing bedrock geology investigation for Brown County, author Luczaj has recognized areas in which the Pleistocene glacial deposits are thin or absent, especially in areas near the Fox River between De Pere and Ashwaubenon. Work presently underway has revealed a greater variability in the thickness of these Pleistocene deposits. As a result, new thickness maps for unconsolidated deposits will differ substantially from those of Krohelski (1986, his figure 4).

Table 2: Hydraulic properties of deep aquifer and confining unit (modified after Conlon, 1998)

Hydrostratigraphic Unit	Horizontal Conductivity Kh (ft/day)	Storage Coefficient	Vertical Conductivity Kv (ft/day)	Source and Remarks
Maquoketa-Sinnipee Confining Unit			.000007	Krohelski 1986 (model calibration)
			.0005	Krohelski, 1986 (reevaluation of Knowles, 1964)
			.007	Krohelski, 1986 (reevaluation of Drescher, 1953)
			.0001-.000004	Emmons, 1987
			.00002	Aquifer Test, central Brown County, geometric mean values (This Study)
Sandstone Aquifer (Cambrian & Ordovician)	1.6-2.4	.01-.0002		Krohelski, 1986 (model calibration)
	5.1-5.5			Krohelski, 1986 (specific capacity test)
	5.4-6.1			Krohelski, 1986 (packer test)
	3.0-3.9	.001-0.002		Knowles, 1964 (aquifer test)
	2.8	.0002		Drescher, 1953 (aquifer test)
	2.5-8.3	.0002		Emmons, 1987 (model calibration)
		.0002		LeRoux, 1957 (aquifer test in Seymour, WI, using Theis solution)
		.00015		LeRoux, 1957 (aquifer test in Appleton, WI, using Theis solution)
	9.42	.0004		Aquifer Test, central Brown County, geometric mean values (This Study)
	.62-240			Packer test, McKeefry Quarry (BN-424) (This Study)

In addition to stratigraphic variability, structural features can also influence the behavior of groundwater. As part of ongoing research on the bedrock geology of Brown County, an east-west trending fault with at least 100 feet of vertical displacement has been identified approximately six miles north of Greenleaf, WI (Luczaj, 2009). This fault could be hydrologically important, as it occurs near the hydrologic divide between the Central Brown County and the Fox Cities cones of depression. It could potentially act as a barrier to flow in the deep aquifer, especially in the St. Peter Sandstone and the upper Cambrian where sandstone is juxtaposed against dolostone aquitards of the Sinnipee and Prairie du Chien Groups on either side of the fault.

Site Specific Hydrogeologic Research

McKeefry Quarry Borehole, Northwestern Brown County, WI (BN-424; WUWN WH979)

In April 2009, a borehole with a depth of 778 feet was drilled near a quarry approximately two miles south of Pulaski, Wisconsin as part of a STATEMAP project to map the bedrock geology of Brown County (Luczaj, 2009). The McKeefry borehole was drilled to understand the bedrock in the northwestern portion of Brown County, but it offered a special opportunity to study the hydrogeologic properties of an unusually thick section of aquifer where the Prairie du Chien Group is absent. WGNHS personnel conducted a variety of geophysical tests at the site.

Cuttings collected during the drilling of the McKeefry borehole indicated that the geology of this location consists of 75 feet of Sinnipee Group dolostone underlain by 660 feet of sandstone with minor red shale. Below the sandstone were 15 feet of granite underlain by 27 feet of black schist at the bottom of the borehole. The lack of additional dolostone below the Sinnipee Group indicates that the Prairie du Chien Group is absent at this location, along with a portion of the Cambrian section.

A variety of geophysical tests were performed in the borehole. A video log shows air bubbles, remnants of the air injected during the air rotary drilling conducted several days earlier, entering the borehole and moving downward through the hole starting at a depth of 80 feet. The volume and speed of the bubbles decrease with depth but some bubbles are still visible at 160 feet.

Flowmeter logs (Figure 7) show downward flow throughout the McKeefry borehole, which is typical of a recharge area. The flowmeter log taken under unstressed conditions shows a series of sudden reductions in flow instead of a gradual decrease in flow with depth. These results were not expected for this sandstone aquifer. The step-like nature of the flow log suggests that flow is dominated by discrete high permeability zones. Under non-pumping conditions, water entered the borehole from a fracture in the Sinnipee Group and moved downward at an average rate of more than 100 gallons per minute (gpm). Three abrupt decreases in the flow rate occurred at depths of 374, 516, and 619 feet in the borehole. These changes are indicative of locations where water was leaving the borehole through very high conductivity zones. The video log showed washouts or fractures at these depths.

Stressed flowmeter results obtained while pumping the well at various rates produced similar results. The flow logs for BN-424 (Figure 7) show how the flow rates were affected by pumping. The well was very prolific since there was still over 100 gpm flowing downward at 300 feet even though the well was pumping at 105 gpm. Even under pumping conditions, the flow was still downward and cross connecting the aquifers.

A gamma log (Figure 7) taken in the McKeefry borehole shows several gamma spikes between 330 and 470 feet, two of which are particularly significant. The first of these spikes occurs around 330 feet, where there are several feet of maroon fissile shale, possibly the Readstown Member of the St. Peter Sandstone. Beneath this shale, the sandstone contains small white fragments that are similar to silicified brachiopod shells observed in Cambrian sandstones from western Wisconsin. Another gamma spike occurs at 375 feet, apparently near the contact between a hard, cemented sandstone unit from 365-375 feet and thin maroon shale layers near 375 feet.

Packer tests were conducted at 17 intervals within the McKeefry borehole. Slug tests were conducted at each interval and analyzed using Aqtesolv™. The Butler (1998) solution was used when oscillating water levels were present, and the KGS solution (Hyder and others, 1994) was used when the water levels were overdamped. Based on these slug tests, horizontal conductivity values within the deep aquifer range between 0.62 and 240 feet/day and are shown in Figure 7. Transmissivity in the deep aquifer ranged from 2,892 ft^2/day to 60,953 ft^2/day with a geometric mean value of 6,209 ft^2/day. In general, the St. Peter Sandstone had significantly higher horizontal hydraulic conductivities than the Cambrian Sandstone units, for parts of the formation away from discrete high permeability horizons at 375, 518, and 620 feet. The nature of these discrete high permeability horizons is not known with certainty, but might be related either to bedding plane fractures and/or to zones with little or no cement that produce washed out horizons during drilling. The vertical head profile derived from the packer tests indicates a 10-foot head drop at around 340 feet. This head drop corresponds to the shale layer shown in the geologic log and the gamma and normal resistivity logs and suggests that the thin shale layer is a regional aquitard that is separating the two sandstone aquifers above and below it.

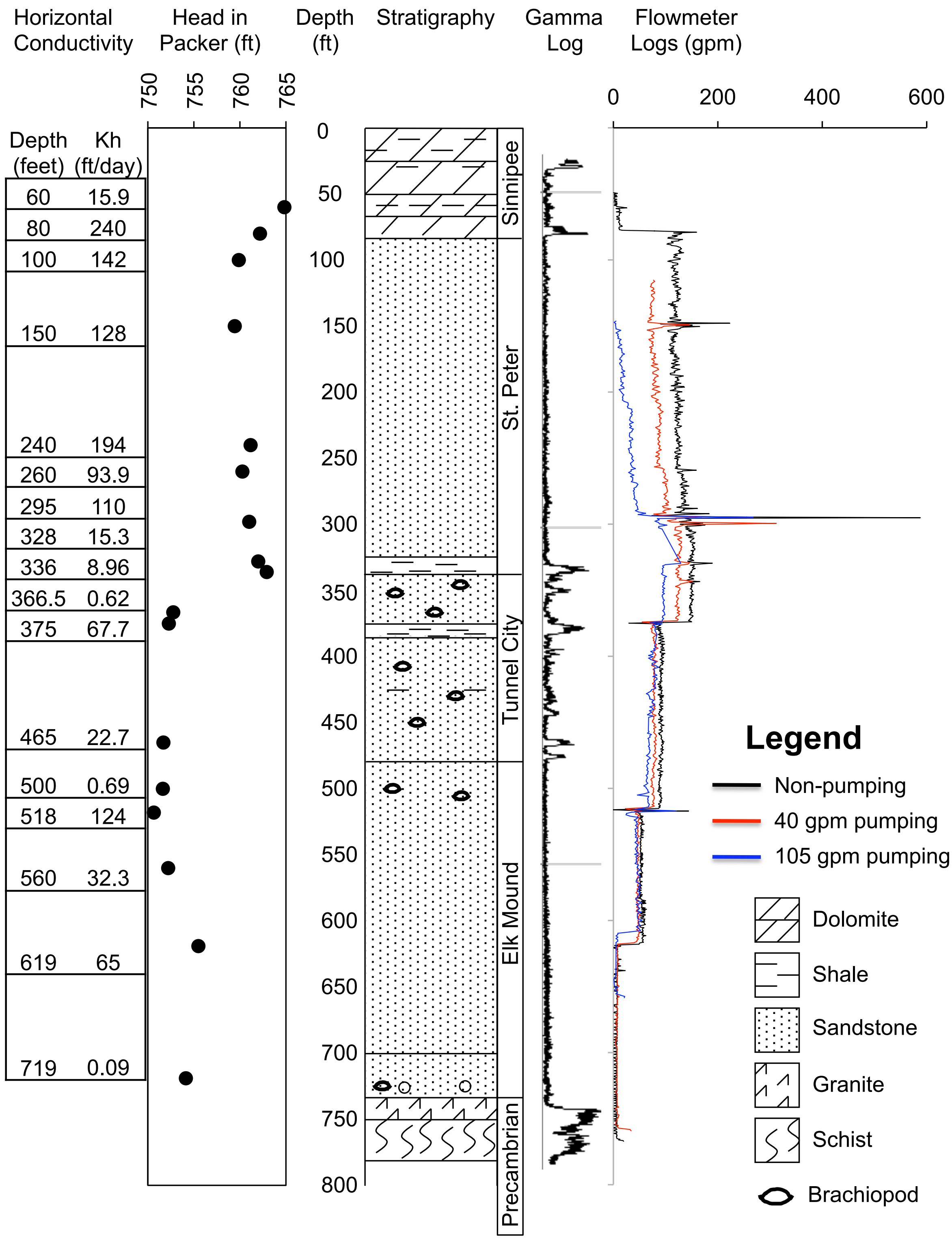


Figure 7. McKeefry Borehole, BN-424, Pulaski, Wisconsin. Hydraulic analysis includes transmissivity (T) and horizontal conductivity (Kh). Gamma logs and flowmeter testing results are shown with the stratigraphy of the borehole.

Shorewood Golf Course, Green Bay, WI

Shorewood Golf Course, located on the University of Wisconsin - Green Bay campus, uses an irrigation well that is 860 feet deep. The pump was removed for repair in May 2008. While the pump was out, geophysical testing was performed on the well. A video log revealed a sub-vertical parabolic fracture at a depth of 786 feet (Figure 8). Geophysical test results, including gamma values, caliper readings, flow rates, fluid temperatures, and fluid conductivities can be seen in Figure 9.

Heat pulse flow meter readings indicate that flow is upward in this well, which is typical of a discharge area, unlike the McKeefry Quarry borehole discussed above, where all flow was downward.

Figure 8. Parabolic fracture at depth of 786 feet in Shorewood Golf Course well (BN-422), Green Bay, Wisconsin.

Scray Hill, Ledgeview, Wisconsin

Geophysical tests were performed in a 925 feet deep well drilled at a golf course near Scray Hill in Ledgeview, Wisconsin (BN-316). The results are shown in Figure 10. Heat pulse flow meter testing shows divergent flow in this well at low flow rates. Within the St. Peter Sandstone, flow is upward. Within the Cambrian sandstones, flow is downward.

Green Bay Well 10, MW-1, and adjacent Core Hole

The City of Green Bay conducted a hydrogeologic study for Well 10 and two adjacent boreholes (MW-1 and an adjacent core hole) as part of an aquifer storage and recovery (ASR) project. The investigation was completed by CH2MHill and resulted in the generation of several unpublished reports. One of the reports (CH2MHill, 2000) contains geophysical logs for MW-1 and GB#10. As part of that study, a drill core was taken to a depth of 706 feet and provides valuable lithologic control for the stratigraphy in the northeastern GMA.

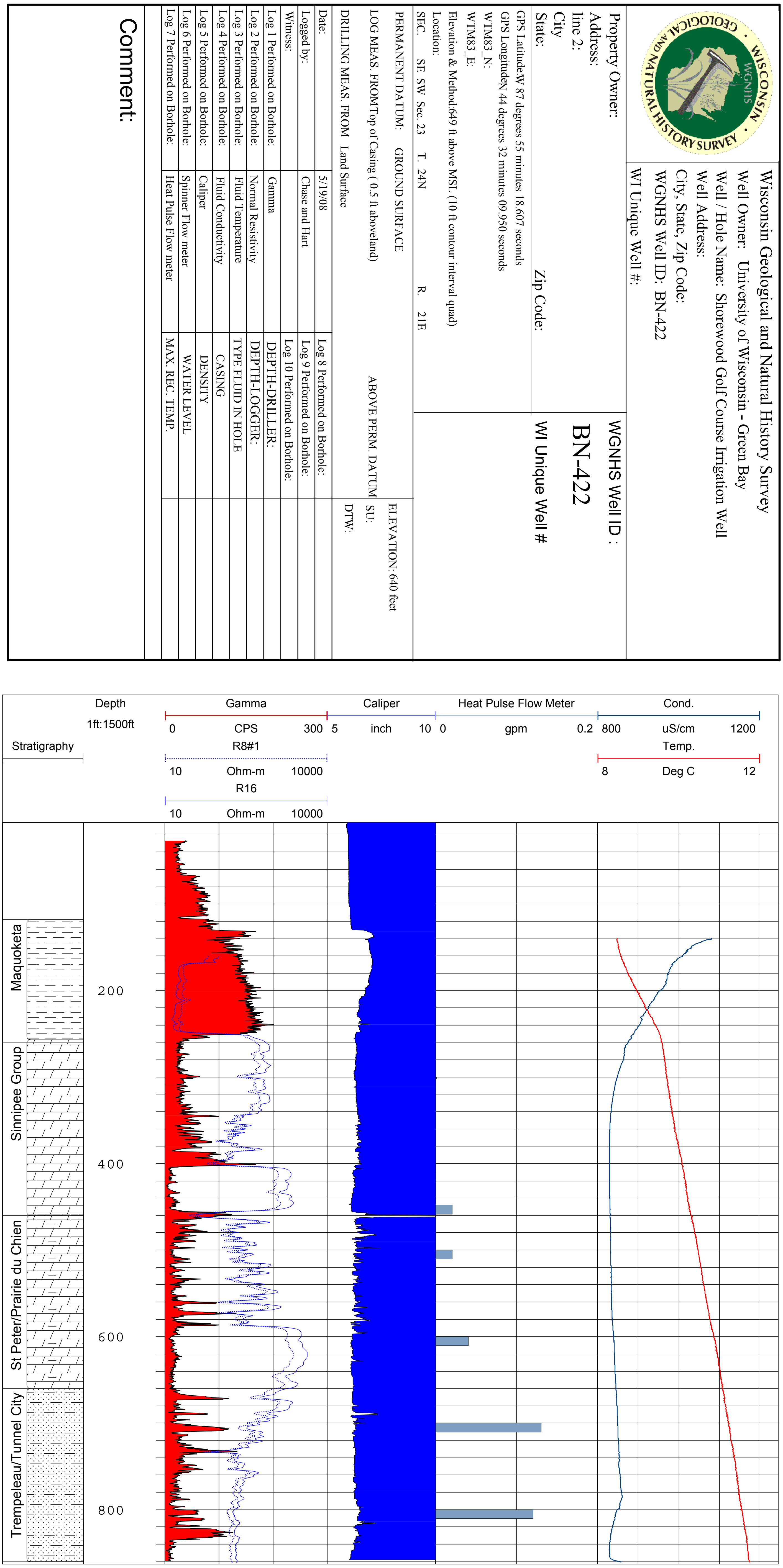


Figure 9. Geophysical and flowmeter logs from Shorewood Golf Course Well (BN-422) on the University of Wisconsin – Green Bay Campus.

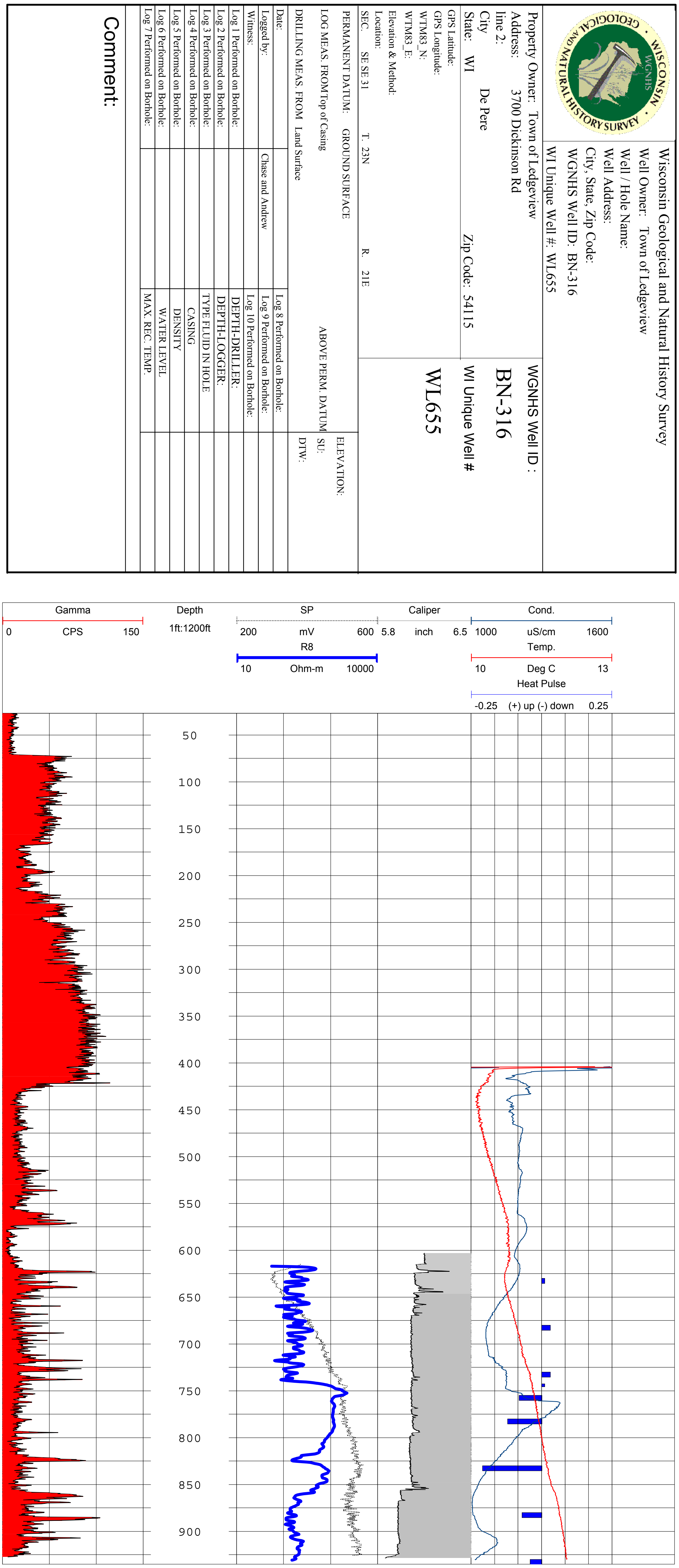


Figure 10. Geophysical and flowmeter logs for BN-316 from Scray Hill, Ledgeview, Wisconsin.

Hantush Analysis of Regional Aquifer Properties

Analyzing recovery curves from central Brown County wells with the Hantush method using an automated fit approach resulted in horizontal conductivity (Kh) values of the deep aquifer that ranged from 2.7 to 19.1 feet per day, with a geometric mean of 9.14 feet per day. Vertical conductivity values of the confining unit ranged from 2.8×10^{-7} to 2.3×10^{-3} feet per day with a geometric mean of 2.2×10^{-5} feet per day. Results are shown on a regional map in Figure 11. Horizontal conductivities are higher than those reported by others (summarized in Table 2), but vertical conductivity values are similar.

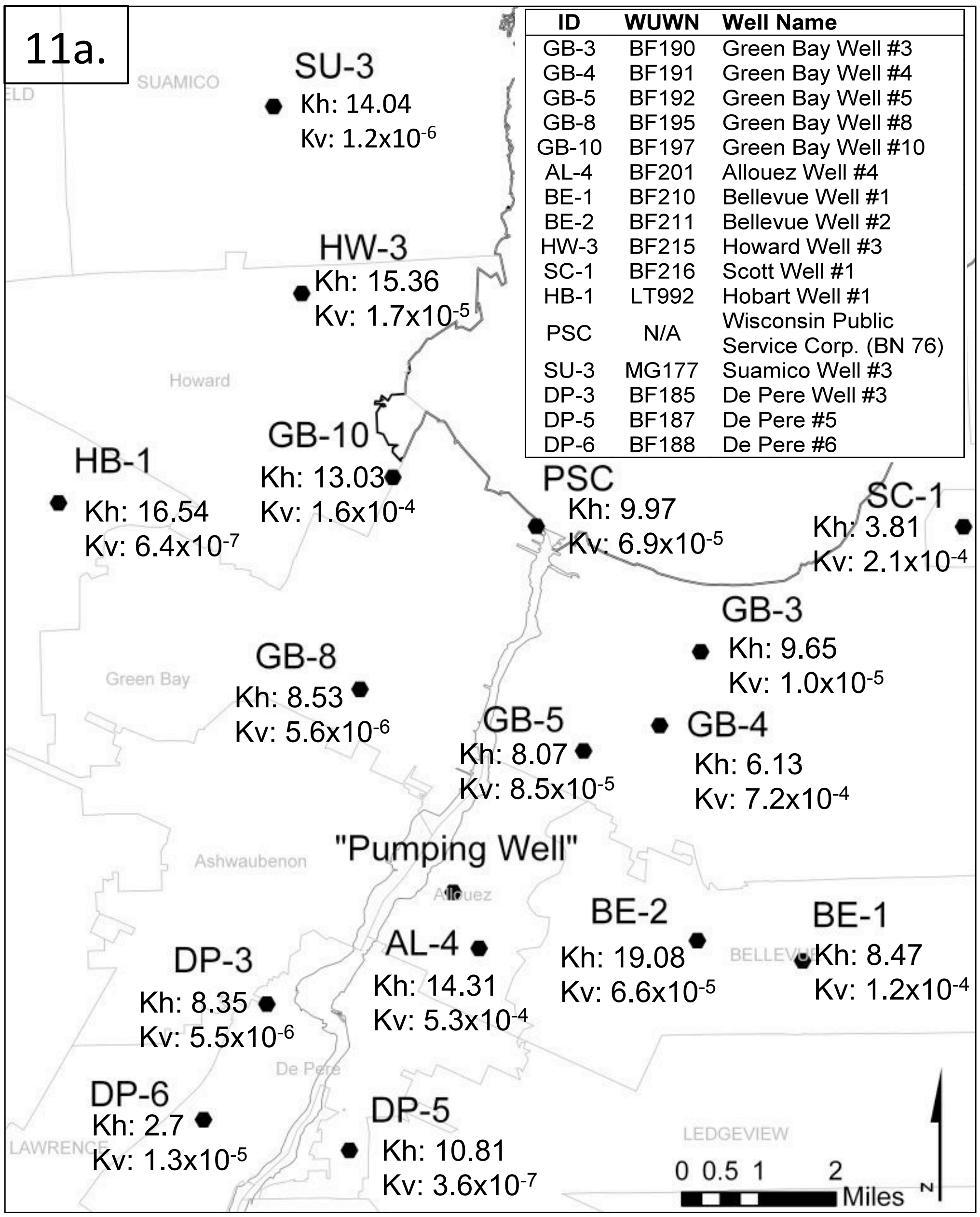
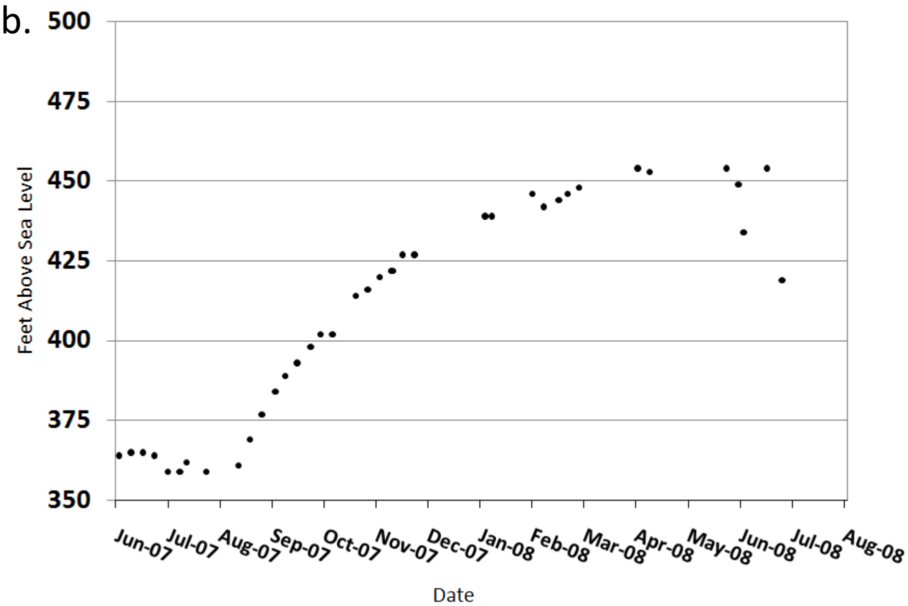
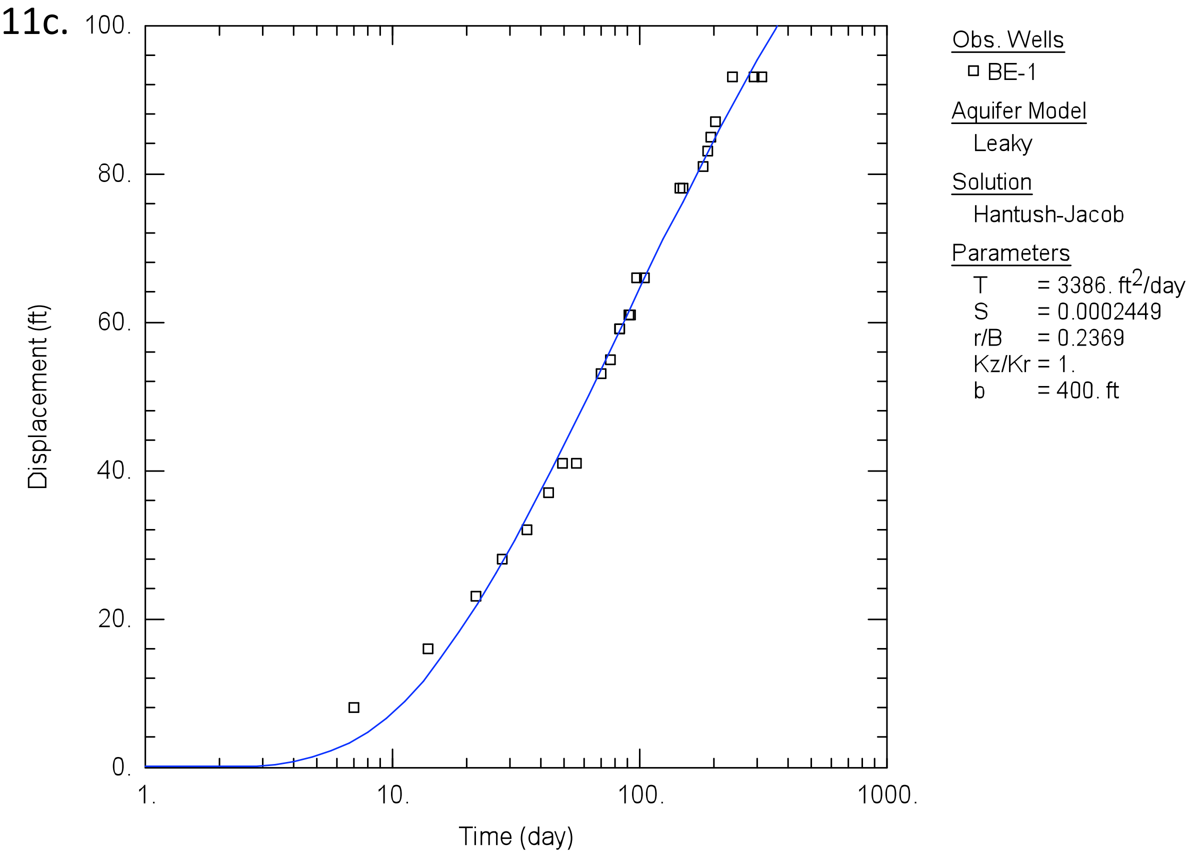


Figure 11. Results of Hantush analysis. (a) Spatial distribution of horizontal hydraulic conductivity (Kh) of the aquifer and vertical hydraulic conductivity (Kv) of the confining unit, based on recovery curves since August 2007. Values have units of feet per day. (b) Recovery curve of Bellevue Well #1 (BF210; BE-1) between June 2007 and July 2008. (c) Aqtesolv™ fit for Hantush pumping test analysis for data in Figure 11b.

11b.


500
475
450
425
400
375
350
Feet Above Sea Level
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Date

11c.


100.
80.
60.
40.
20.
0.
Displacement (ft)
1.
10.
100.
1000.
Time (day)
Obs. Wells
BE-1
Aquifer Model
Leaky
Solution
Hantush-Jacob
Parameters
T = 3386. ft2/day
S = 0.0002449
r/B = 0.2369
Kz/Kr = 1.
b = 400. ft

Water Levels

There are two cones of depression in the Northeast GMA. The larger cone is located in central Brown County, in an area that has experienced multiple changes in groundwater use throughout history. The second cone, located between Kaukauna and Little Chute in the Fox Cities area, has developed over several decades of regional growth. The two cones of depression are the results of groundwater use by two population centers. Hydrographs for wells located in each of these two pumping centers are discussed below.

Central Brown County

Central Brown County is unique in the world because this region has experienced two independent recovery events on a major cone of depression in its deep aquifer. The first event happened when the City of Green Bay switched from groundwater to surface water for its municipal supply in August 1957. Before Green Bay wells were turned off, a deep cone of depression, with relief of at least 350 feet, was centered in downtown Green Bay, near well BN-0009 (Knowles and others, 1964, their Plate 1). The northwest portion of the cone was more steeply sloped than other parts of the cone, indicating that the greatest movement of water toward the cone seemed to be from the northwest, the region's area of recharge (Knowles, 1964). Green Bay stopped pumping water from the deep aquifer in August 1957, and by February 1958 the shape of the piezometric surface had changed noticeably; the depression was much shallower. Figure 12 illustrates the recovery of water levels in several wells open to the deep aquifer after Green Bay switched to surface water. Water levels continued to rise in response to the reduction in pumping for 31 months, and by September 1960, a smaller cone of depression remained, which was likely due to industrial pumping that continued in the area (Knowles, 1964).

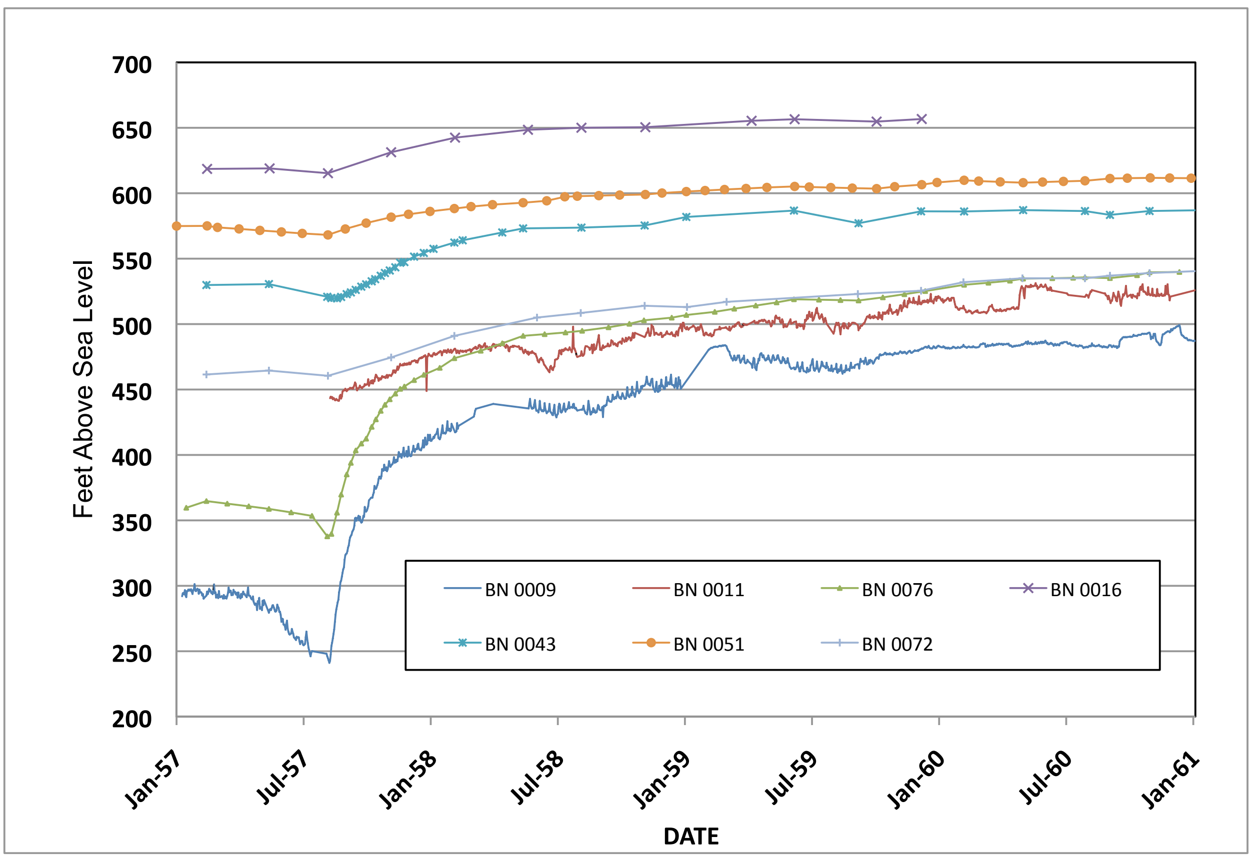


Figure 12. Water level response in seven Green Bay area wells after the city stopped using groundwater for its municipal supply in 1957.

The second recovery event in central Brown County occurred when eight communities in the Green Bay metropolitan area switched to surface water for their municipal supplies between 2005 and 2007. In the years immediately preceding this recent switch, the center of the Brown County cone of depression was located in the Allouez area. The cone was steepest on its northwest side, similar to the earlier cone of depression (Figure 13). The Town of Scott stopped pumping groundwater in October 2005, the Village of Ashwaubenon turned its wells off in June 2006, and the six CBCWA communities switched to surface water between June 2007 and August 2007. Water levels in the deep aquifer rose in response to the reduced withdrawals. Figure 14 shows the cone of depression approximately a year after the last communities switched. During that year, the cone became shallower, but remained at least 150 feet below pre-development conditions. Hydrographs showing the response of water levels to the reduction in pumping in the deep aquifer are shown in Figures 15 through 23. Wells closest to the center of the cone of depression experienced the greatest recovery. As of June 2009, the water levels in several wells continue to experience recovery. Future water level measurements for these wells will be included in Maas (in progress).

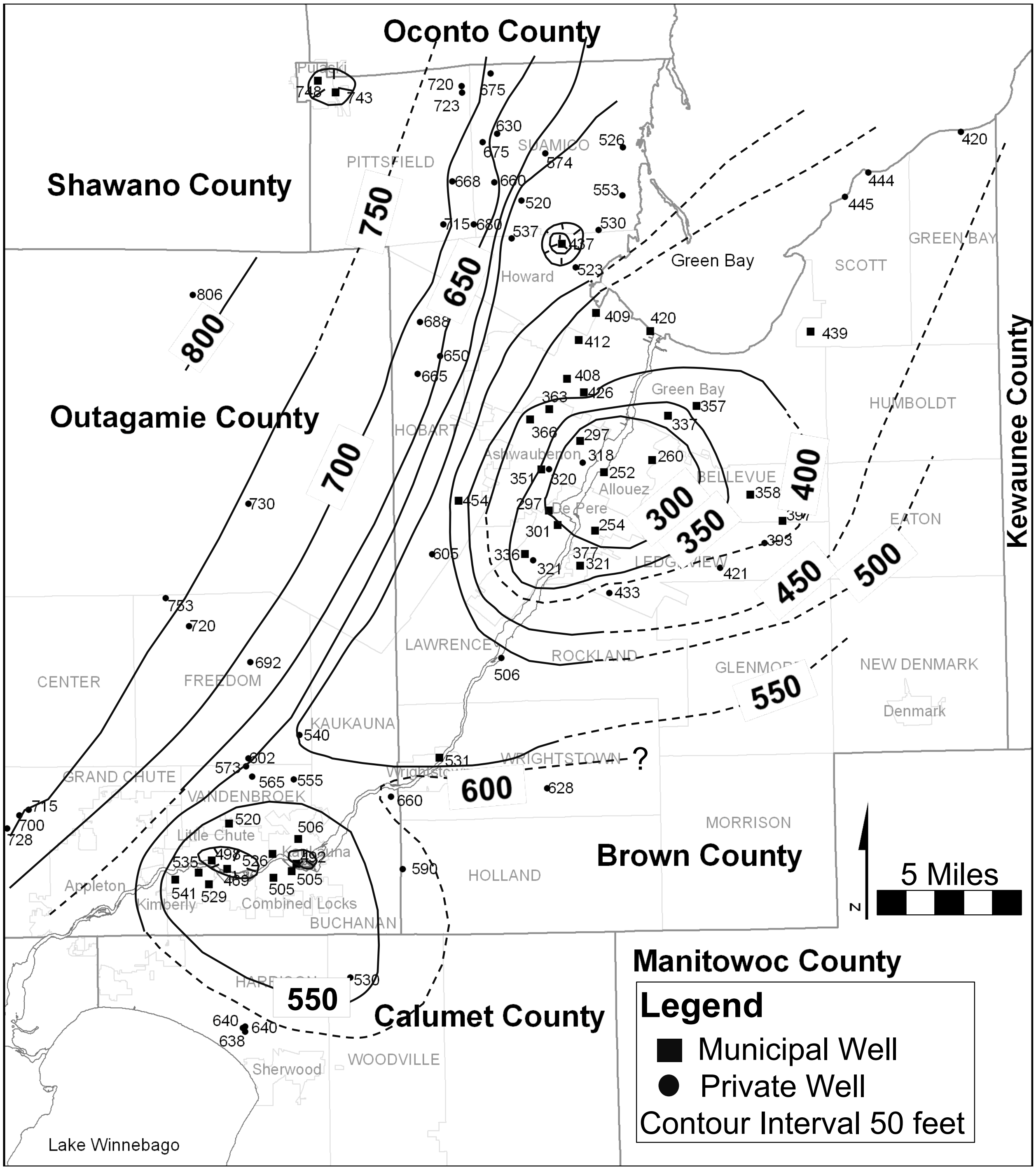


Figure 13. Deep aquifer potentiometric surface map of the northeastern GMA for the 2004-2005 period before the first switchover by the Town of Scott. Numbers indicate water level elevations above mean sea level. Two distinct cones of depression are visible here with the Central Brown County cone centered near Allouez and the Fox Cities cone to the southwest near Kimberly-Kaukauna.

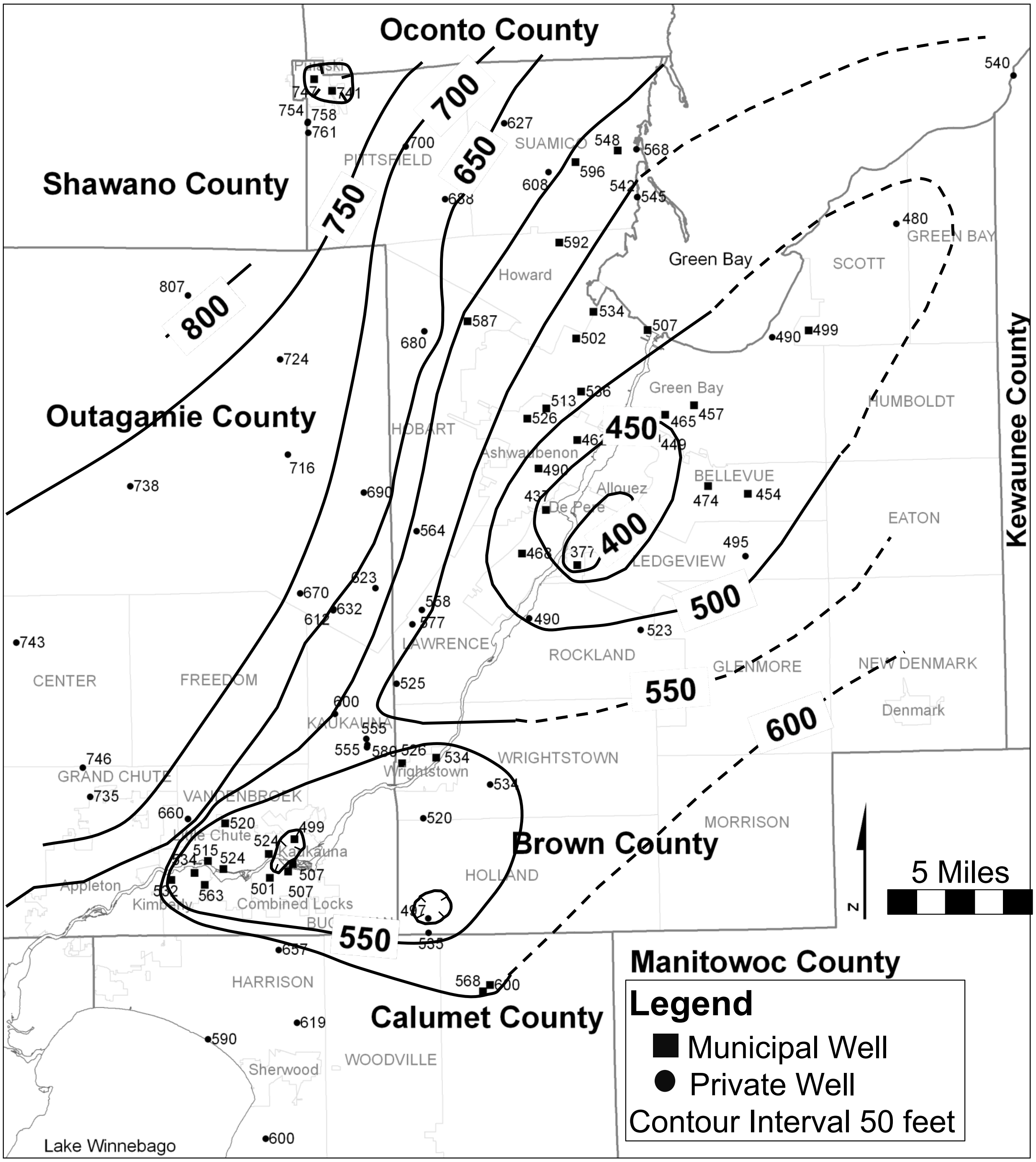


Figure 14. Deep aquifer potentiometric surface map of the northeastern GMA for 2008, approximately one year after the major switch to surface water by CBCWA communities in 2007. Numbers indicate water level elevations above mean sea level. Two distinct cones of depression are still visible, with the Central Brown County cone centered near Allouez and the Fox Cities cone to the southwest near Kimberly-Kaukauna. Significant recovery of water levels has occurred in the Central Brown County cone of depression.

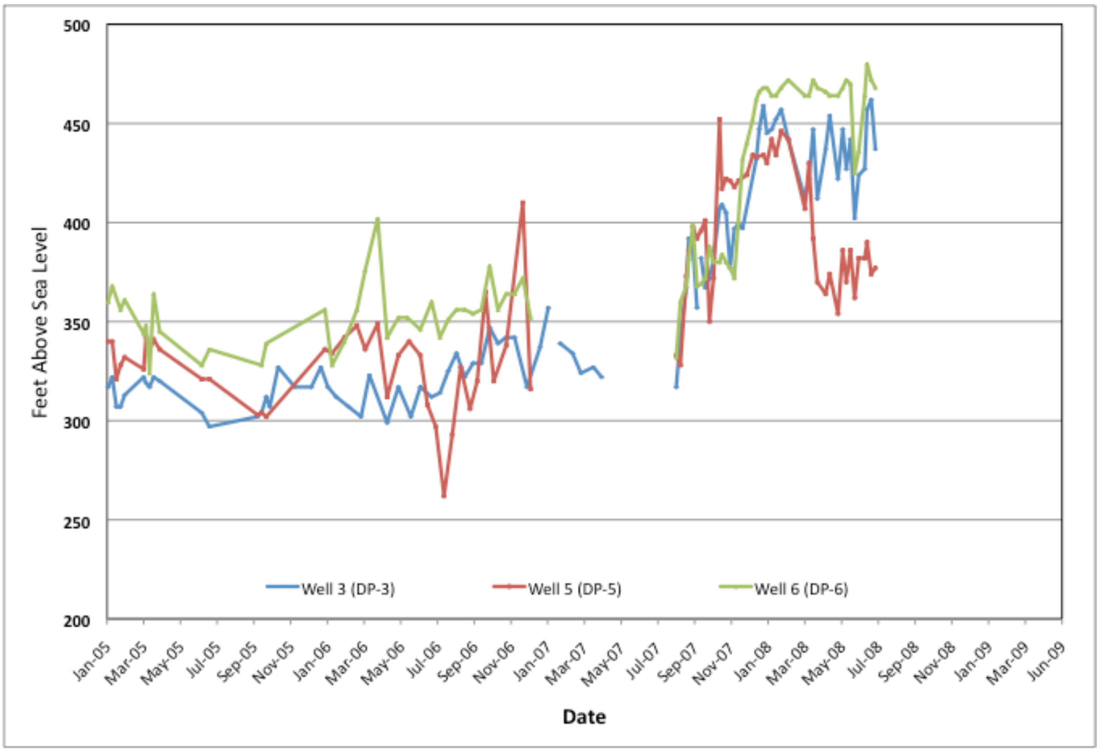


Figure 15. Static water elevations in De Pere, WI municipal wells, January 2005 – July 2008. Water levels were no longer collected after July 2008.

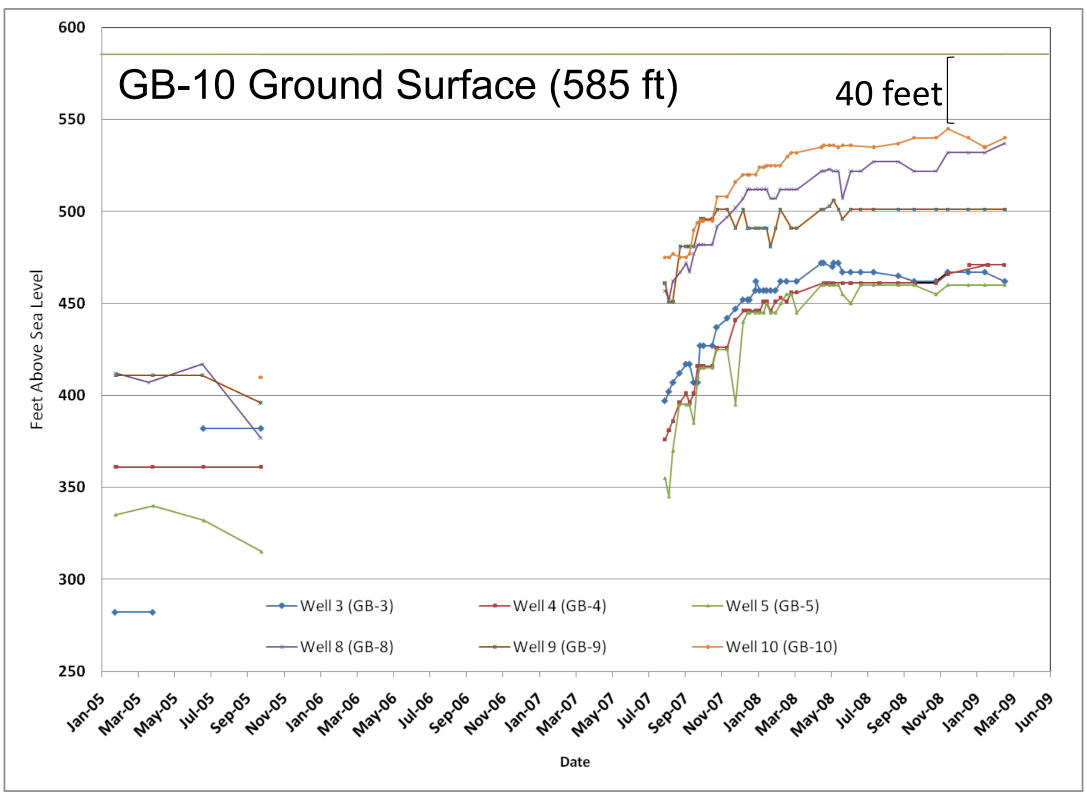


Figure 16. Static water elevations in Green Bay, WI municipal wells, January 2005 – March 2008. Water levels were not recorded between October 2005 and August 2007.

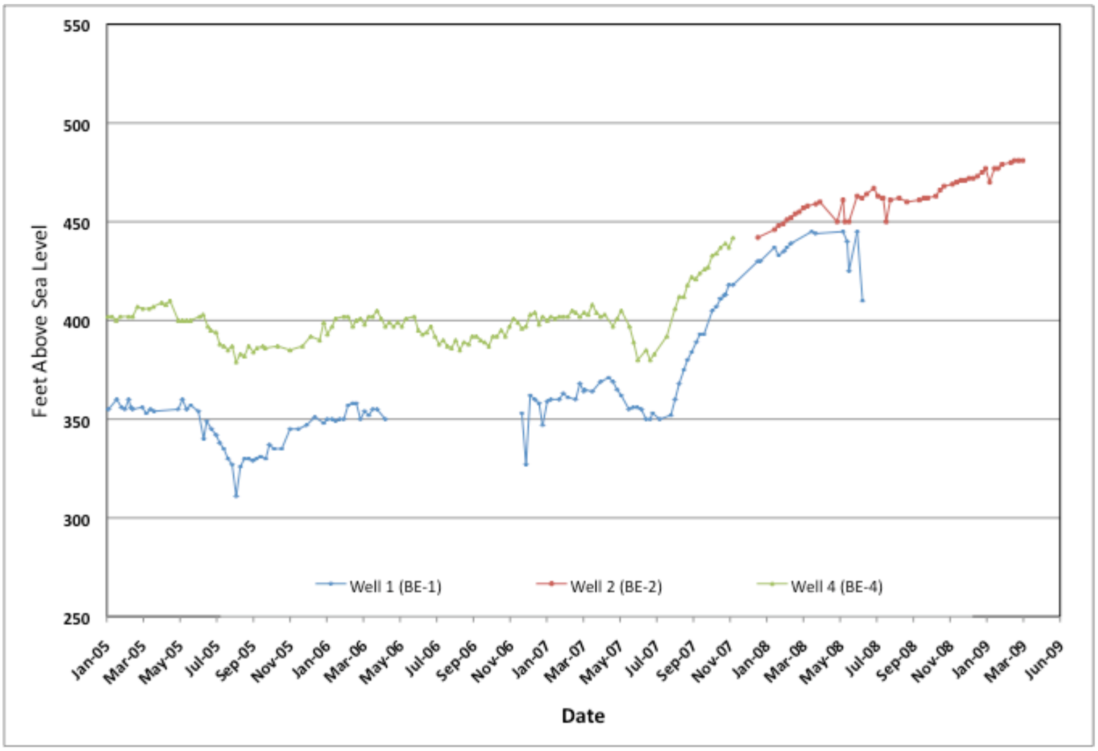


Figure 17. Static water elevations in Bellevue, WI municipal wells, January 2005 – June 2009. Well 4 water level was too high to measure after November 2007, Well 1 water level was too high to measure after June 2008 (Glen Simonson, personal communication, 2009).

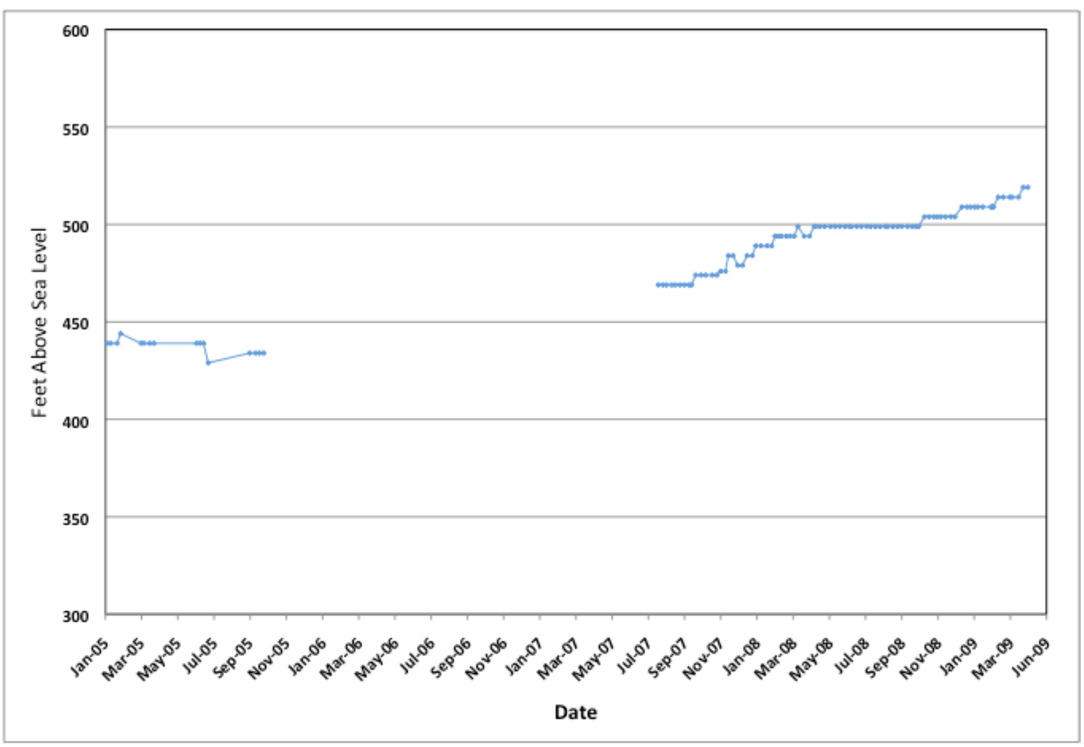


Figure 18. Static water elevations in Scott, WI municipal well, January 2005 – May 2009. No water levels were recorded between October 2005 and August 2007. Water levels continue to rise in this well.

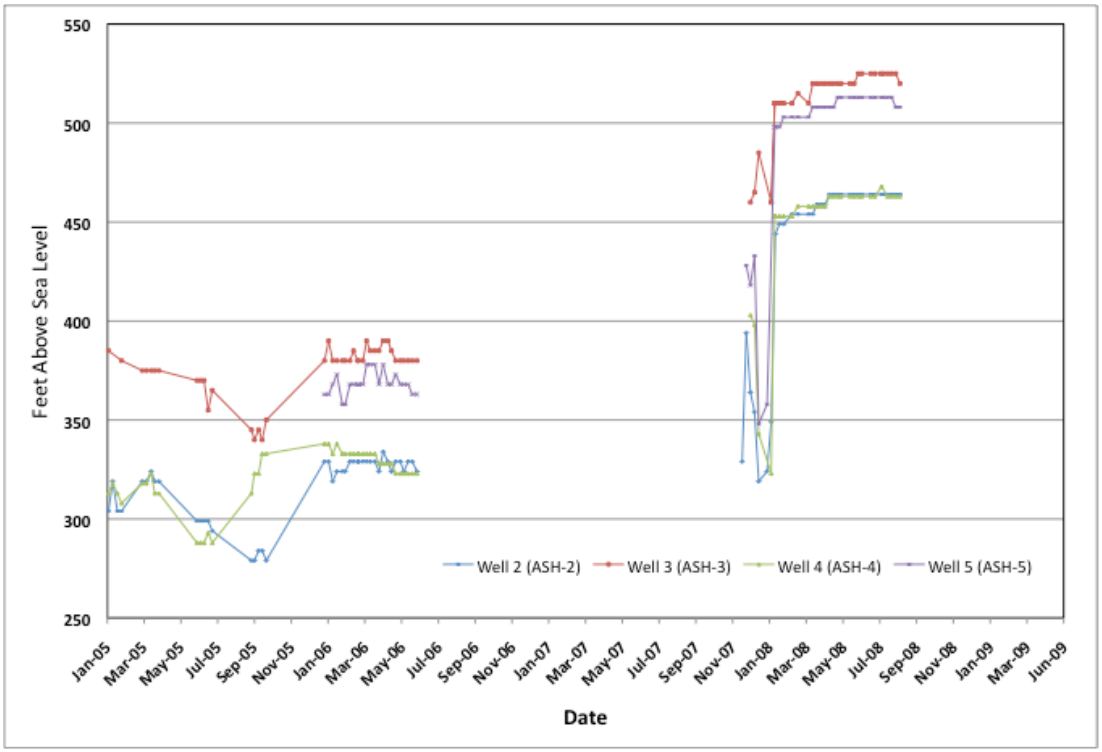


Figure 19. Static water elevations in Ashwaubenon, WI municipal wells, January 2005 – September 2008. Ashwaubenon began using surface water for public supply on June 6, 2006, but no water levels were recorded between June 2006 and December 2007. Municipal well testing and maintenance caused fluctuations in static water levels in January 2008.

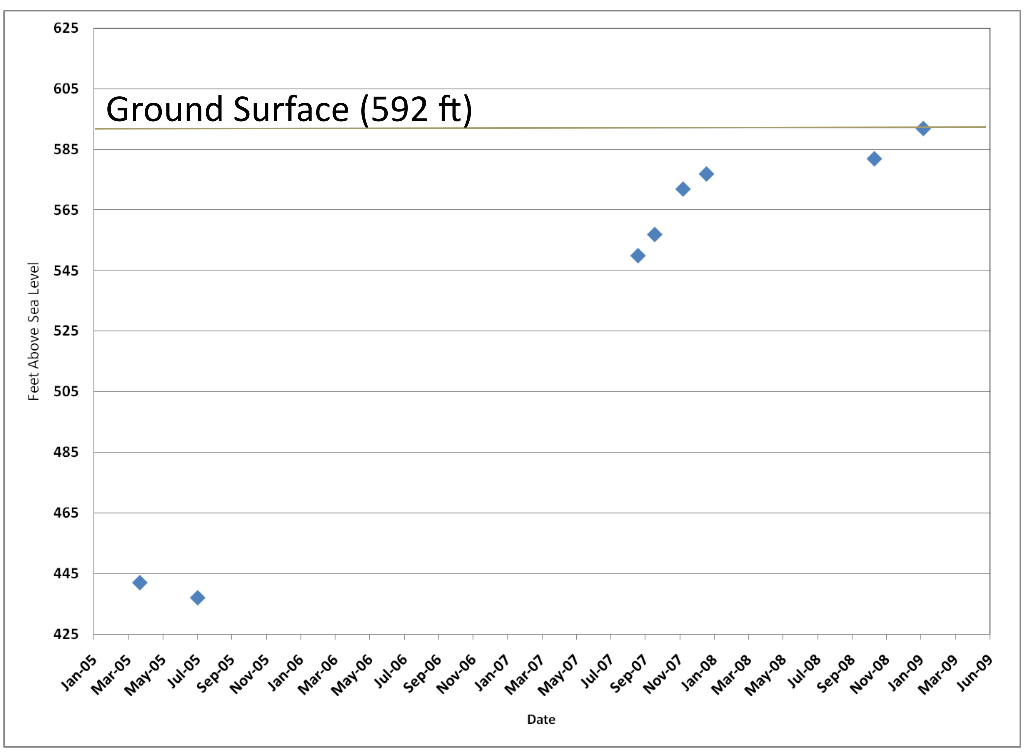


Figure 20. Static water elevations in Howard, WI municipal Well 3. This well began flowing in January 2009.

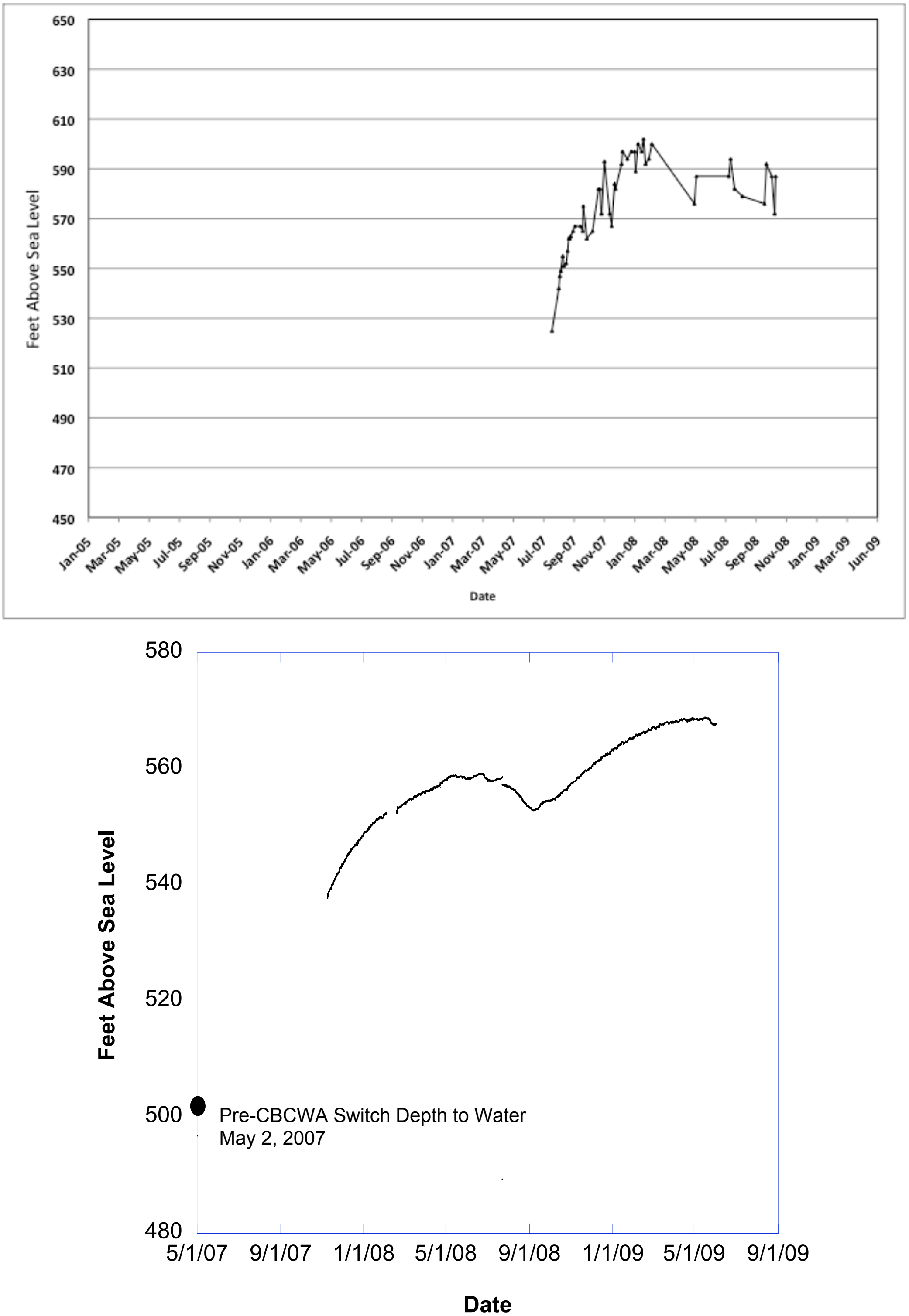


Figure 21. Static water elevations on the western limb of the Central Brown County cone of depression. (Top figure) Hobart, WI municipal Well 1. The airline in this well developed a hole in January 2009 and no water levels were recorded after then. Hobart continues to pump groundwater for public supply. (Bottom figure) Static water elevations for Oneida Tribe well (BN504-WCR of WGNHS Scanned Well Records CD for Brown County). This is the only well with an operating level logger at the present time.

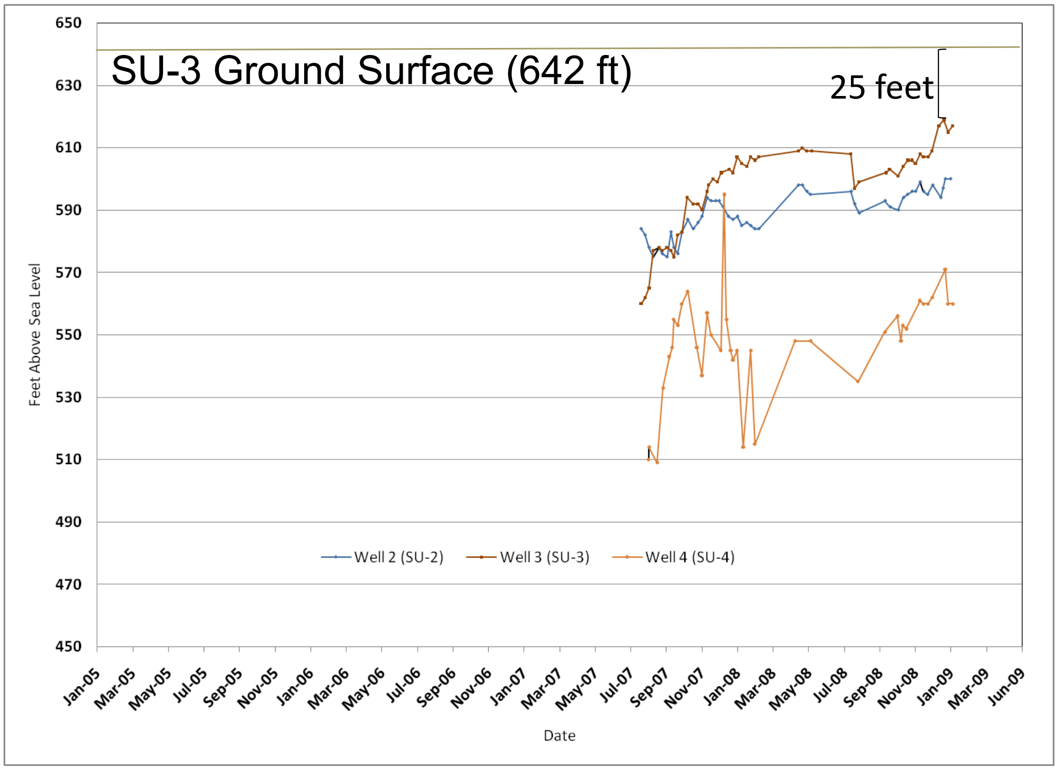


Figure 22. Static water elevations in Suamico, WI municipal wells. Suamico continues to pump groundwater for its public supply.

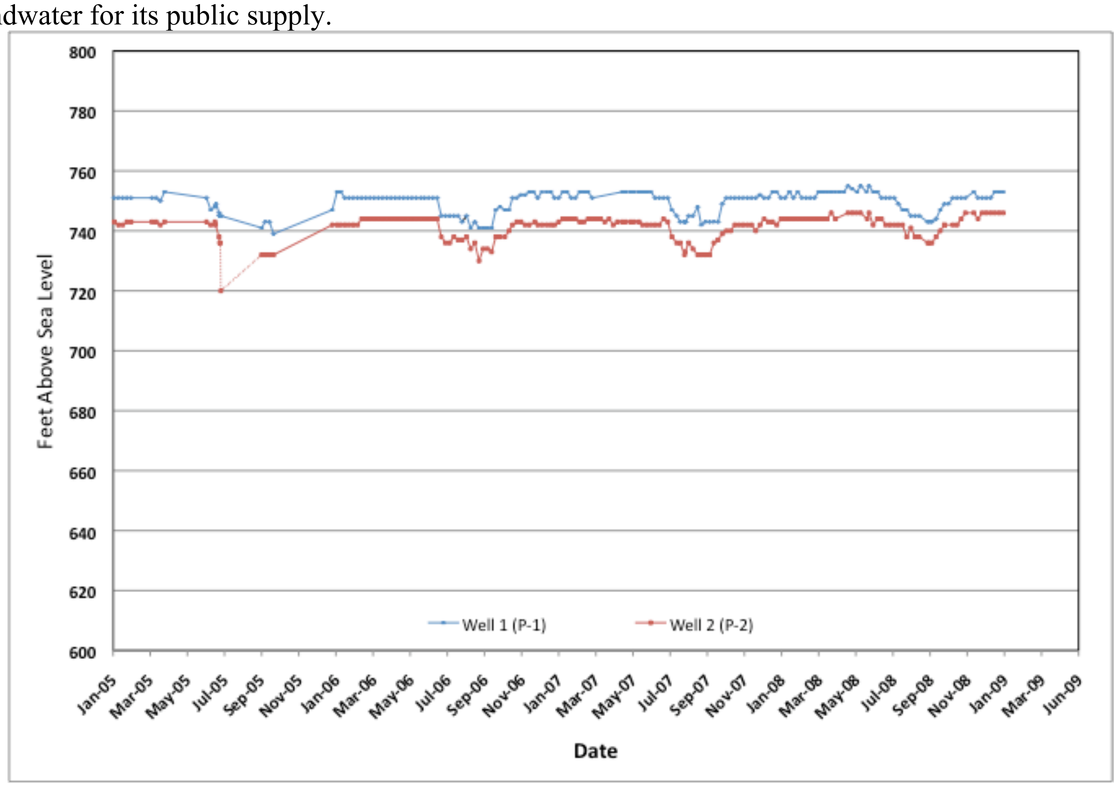


Figure 23. Static water elevations in Pulaski, WI municipal wells. Dotted line indicates possible outlier. Pulaski continues to pump groundwater for its municipal supply and these hydrographs suggest a seasonal fluctuation. Located away from the center of depression, Pulaski did not experience overall change in water levels as a result of the change in pumping.

Fox Cities Cone

While the central Brown County cone of depression has changed dramatically since the reduction in groundwater pumping from the deep aquifer by the communities in its vicinity, the second cone of depression, centered between Kaukauna and Little Chute, appears to have been unaffected by the Green Bay area pumping changes (Figure 13 and 14). Figures 24 and 25 show hydrographs between January 2005 and May 2009 for two communities in this area. Little Chute, Kimberly and Darboy are located in or near the center of pumping and longer-term static water level records from these communities show the decline of water levels over time (Figures 26-28). Pumping rates, discussed in the following section, will determine the future shape of the cone of depression in this area.

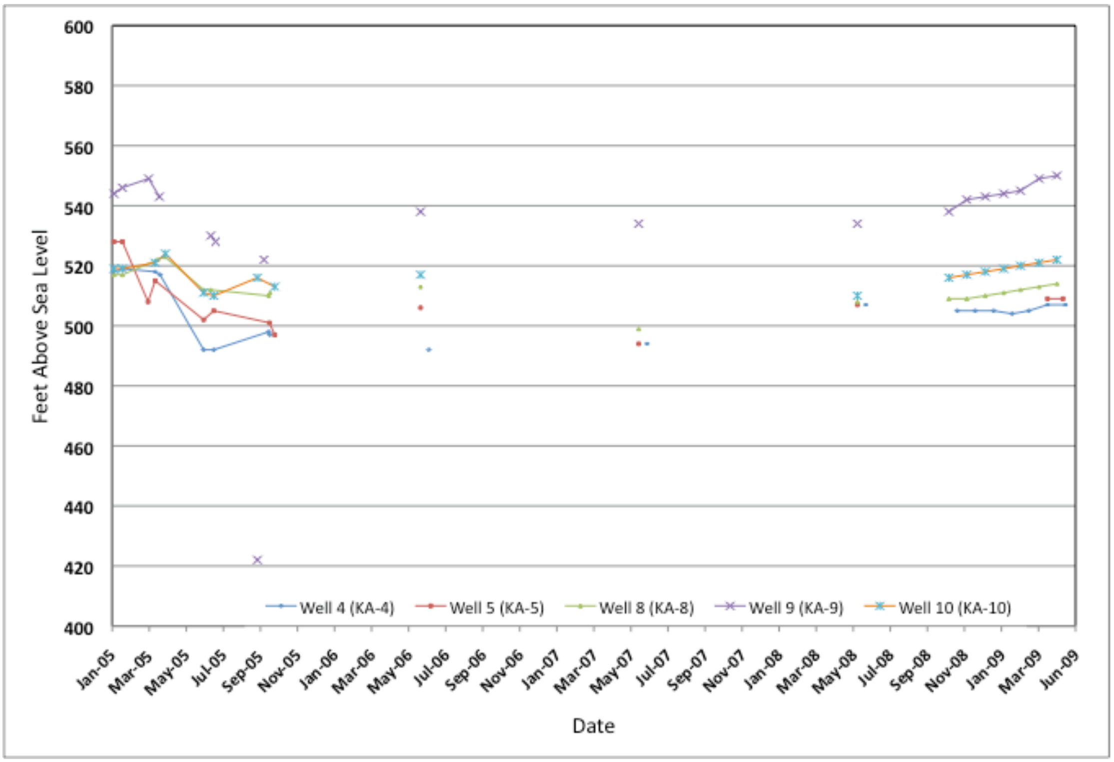


Figure 24. Static water elevations in Kaukauna, WI municipal wells, January 2005 through May 2009. Dotted line indicates outlier.

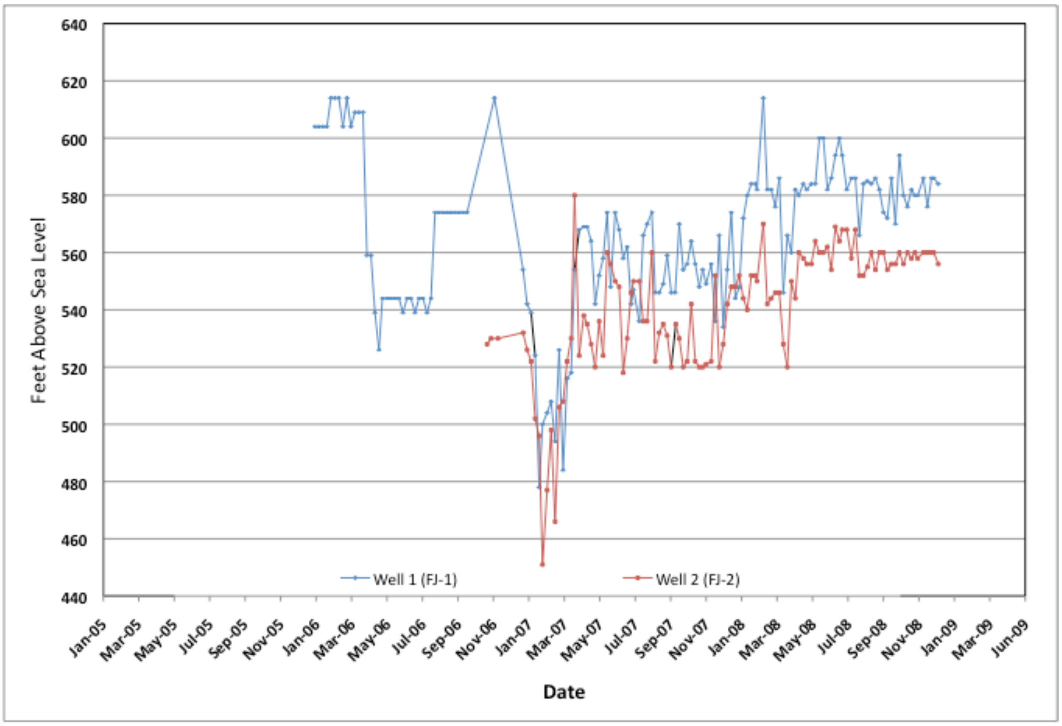


Figure 25. Static water elevations in Forest Junction, WI municipal wells, January 2006 through December 2008. Well 2 was drilled in March 2006.

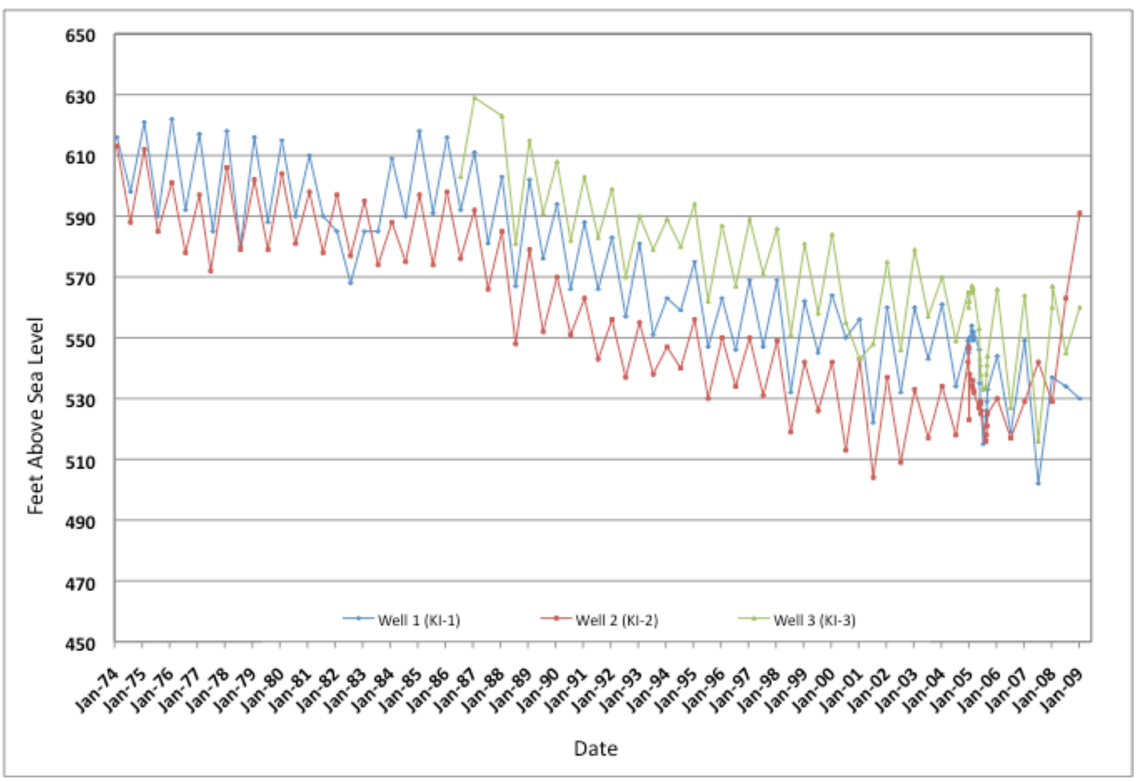


Figure 26. Static water elevations in Kimberly, WI municipal wells, January 1974 through February 2009. Water levels have typically been recorded in February and August each year.

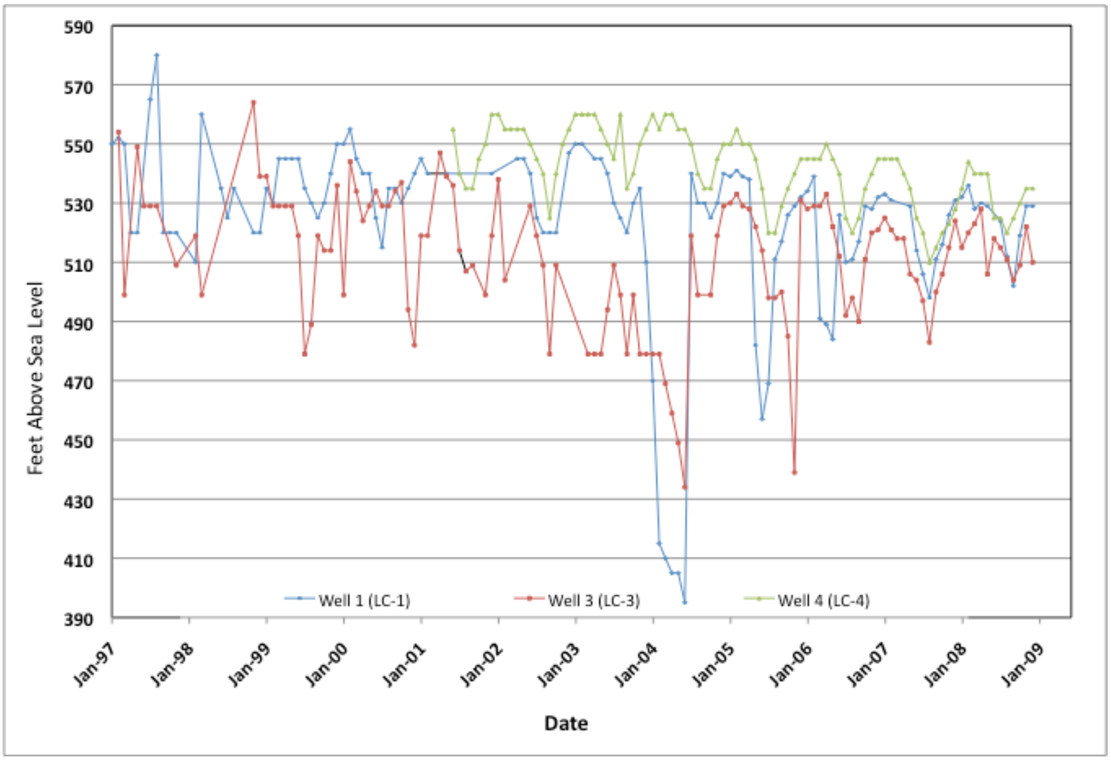


Figure 27. Static water elevations in Little Chute, WI municipal wells, January 1997 through December 2008. Water main break in February 2004 may explain low water levels for Well 1.

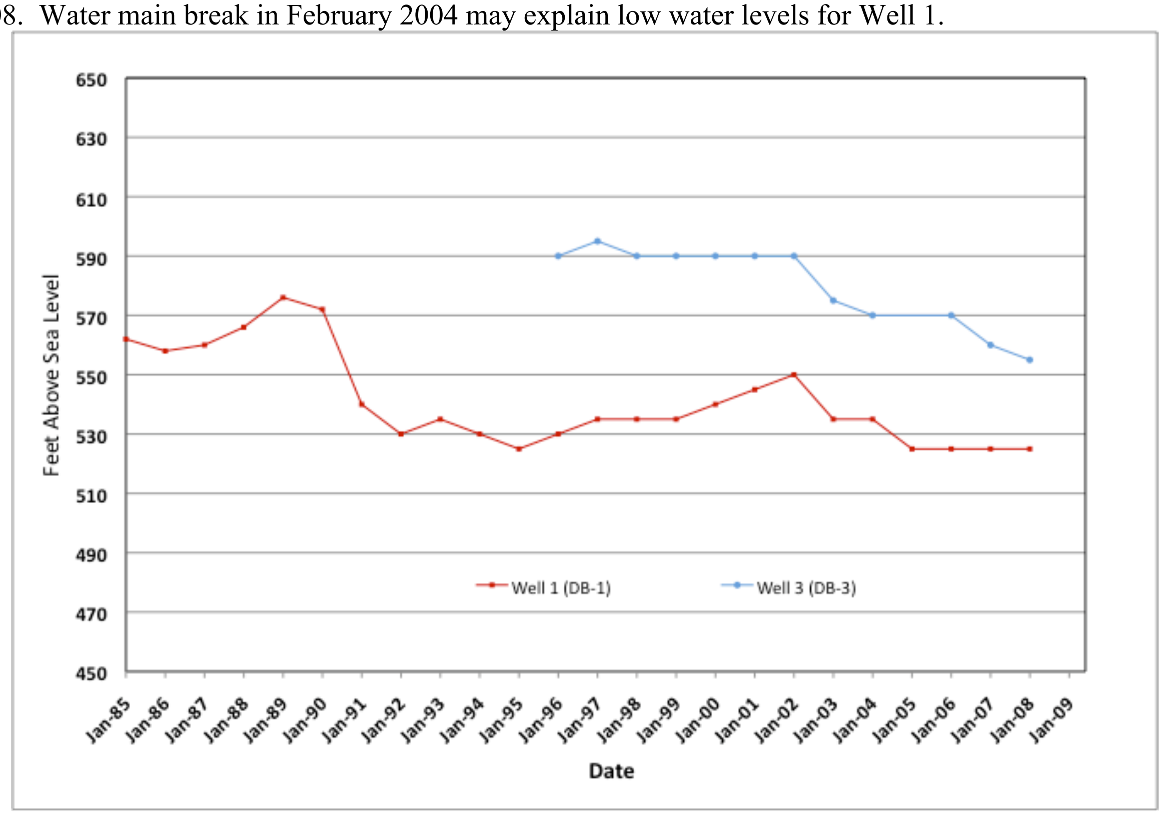


Figure 28. Static water elevations in Darboy, WI municipal Wells 1 and 3, January 1985 through January 2008. Darboy Well 2 (not shown) began operating in January 1991 and is located 75 feet from Well 1. Static water levels in Wells 1 and 2 have been identical since then.

Region of Cone Overlap

There is a hydrologic divide between the two cones of depression that is located in southwestern Brown County near Wrightstown. There is no obvious recovery in this region that resulted from switch to surface water in 2006-2007 (Figure 29). Wrightstown is on the northern edge of the Fox Cities cone. These wells typically show seasonal fluctuation due to increased demand during the summer season.

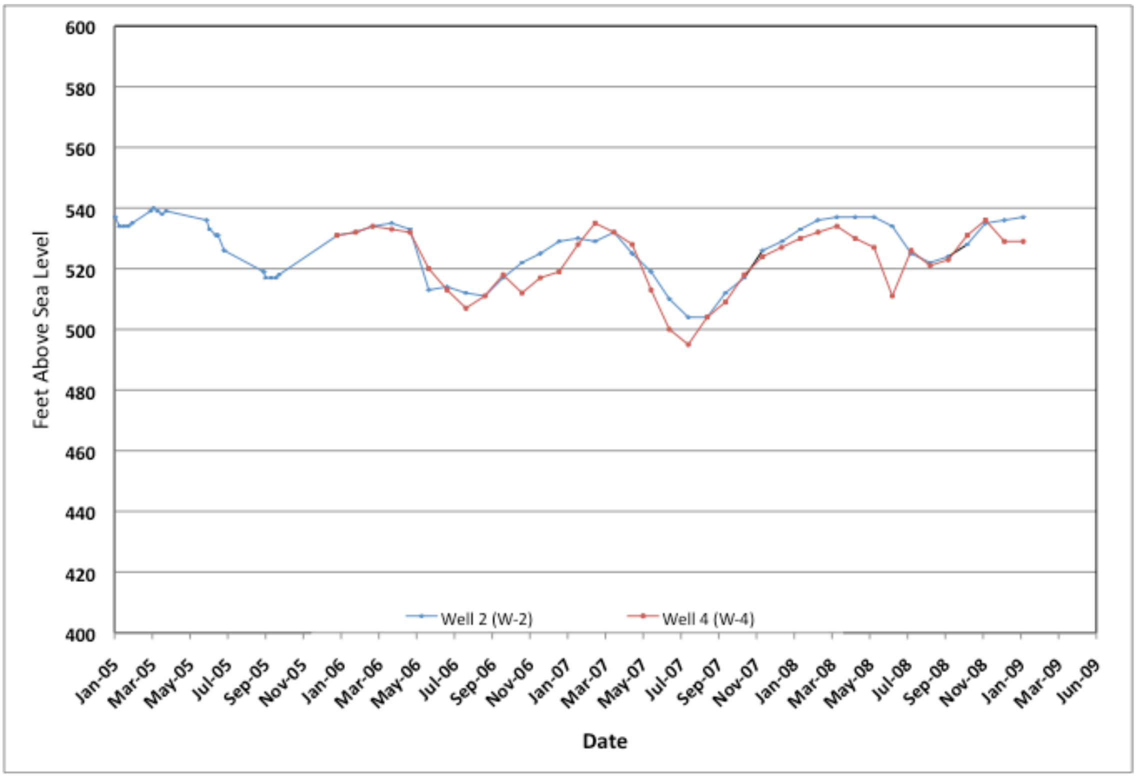


Figure 29. Static water elevations in Wrightstown, WI municipal wells, January 2005 through February 2009.

Pumping Rate

Historical Pumping

The Fox River Valley region of northeastern Wisconsin has experienced much growth during the past century. This growth is reflected in groundwater pumping over time.

Between 1950 and 1957, withdrawals from the sandstone aquifer in the Green Bay area ranged seasonally between 10 and 15 million gallons per day (mgd) (Drescher, 1957; Knowles, 1964). Before switching to surface water for its municipal supply in August 1957, the City of Green Bay made approximately 60 percent of those withdrawals (Knowles 1964). From the time Green Bay's wells were turned off until 1960, pumping in the area remained around 5.5 mgd. Industries, including paper manufacturers, dairy producers, and meat packing companies, used approximately 3.15 mgd in 1960, while public supply wells continued to withdraw 2.12 mgd. Figure 30 shows how groundwater withdrawals from the deep sandstone aquifer were reduced when Green Bay wells stopped pumping.

LeRoux (1957) estimated that in 1951 and 1952, total groundwater withdrawals in Outagamie County averaged about 9.0 mgd. Industrial, commercial, and public-supply pumping along the Fox River accounted for 48 percent of that total. Industries and businesses in the Appleton area withdrew 1.7 mgd and the cities of Kaukauna, Little Chute, Kimberly, and Combined Locks pumped 2.6 mgd from their deep municipal supply wells. An unspecified percentage of the total pumping in Outagamie County in the 1950s withdrew water from the shallow aquifer for domestic and general farm use (LeRoux, 1957).

By 1979, 22 years after Green Bay switched to surface water, approximately 8.9 mgd of groundwater were withdrawn from the deep aquifer in Brown County (Krohelski, 1986). At that time, six public supply systems and four industrial users were responsible for 60 percent of that amount.

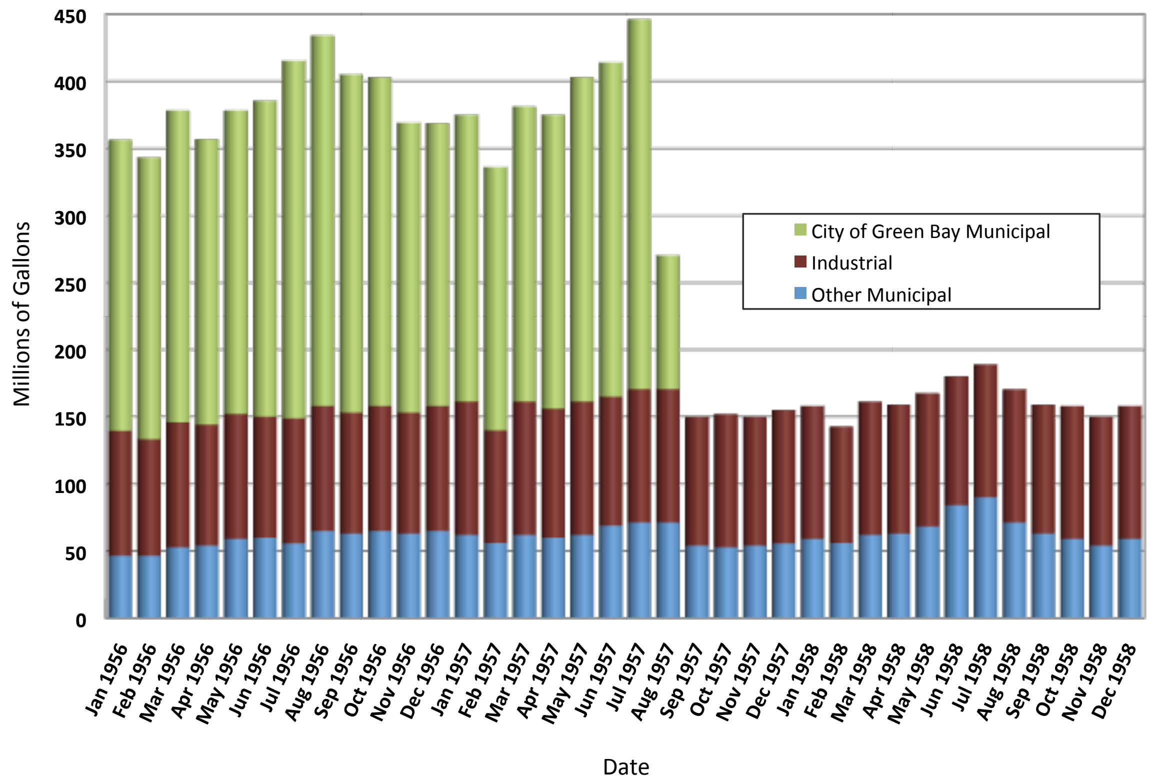


Figure 30. Monthly withdrawals from the deep sandstone aquifer in the Green Bay, WI, area between 1956 and 1958. The City of Green Bay stopped pumping groundwater for its municipal supply in August 1967. (Modified after Knowles, 1964.)

Until 2005, pumping continued to increase. Walker and others (1998) projected that if no management strategies were implemented by 2030, withdrawals from the deep aquifer could reach 24.7 mgd in central Brown County and 9.1 mgd in the Appleton area.

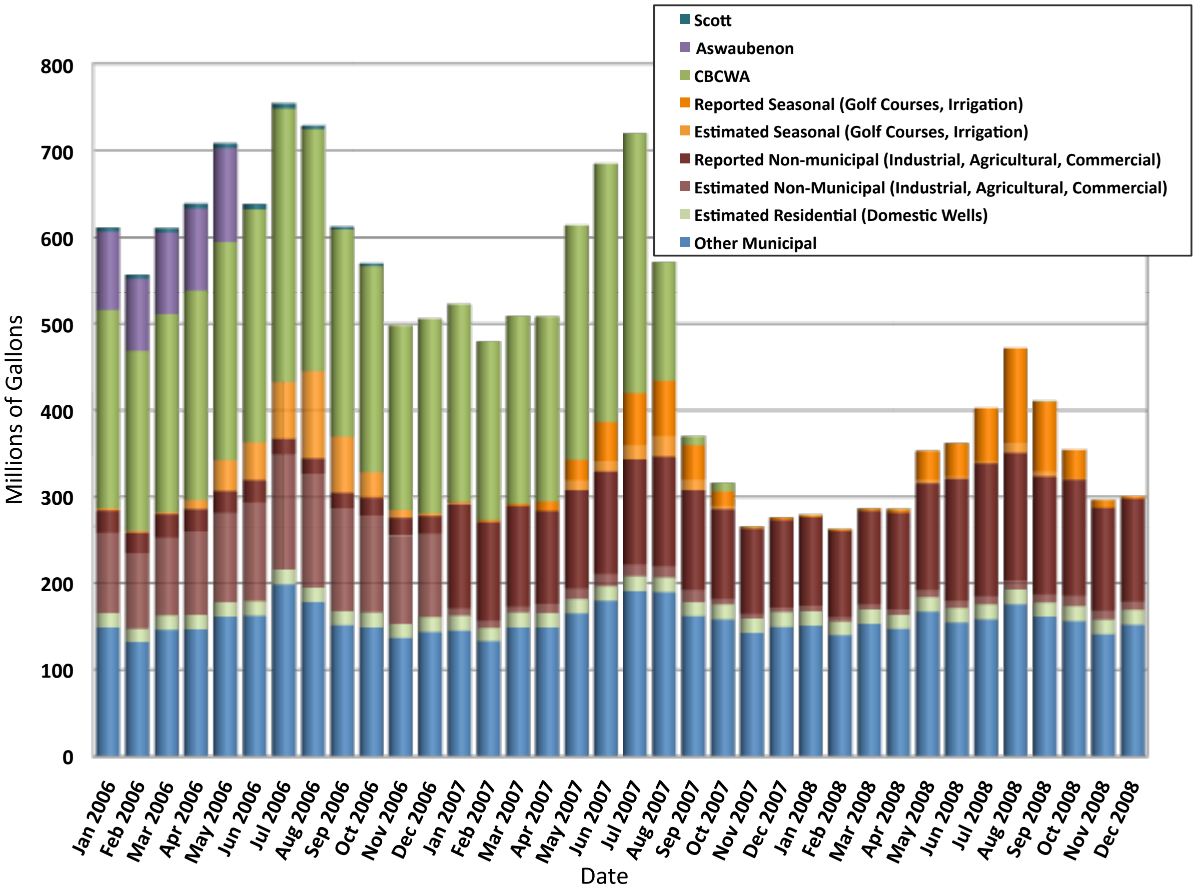
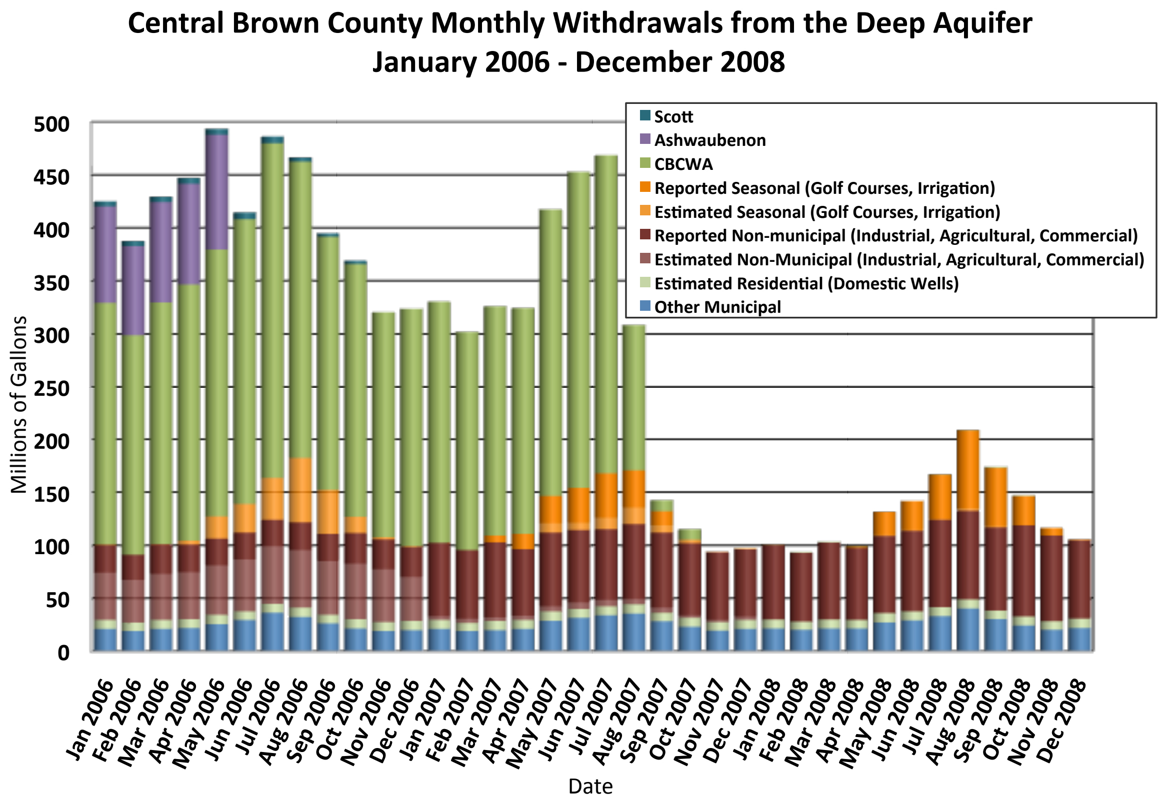


Figure 31. Monthly withdrawals from the deep sandstone aquifer in the Northeast GMA, Brown, Outagamie, and Calumet Counties, Wisconsin.

Today

Figure 31 shows monthly withdrawals from the deep aquifer in the northeast GMA between January 2006 and December 2008. When eight central Brown County communities stopped using groundwater for their municipal supplies between 2005 and 2007, withdrawals from the deep aquifer were reduced by 12.25 mgd. These eight communities accounted for an estimated 75% of total pumping in central Brown County before they switched to surface water.

As discussed in the previous section, there are two cones of depression in the northeastern GMA. One is centered in central Brown County, near Allouez and De Pere, and the other is located in the Fox Cities area northeast of Appleton, near Kaukauna and Little Chute. Each cone of depression is centered around the pumping center that forms it. The switch to surface water by communities in central Brown County did not affect drawdown in the Fox Cities. Figure 32 shows pumping over time in each pumping center.



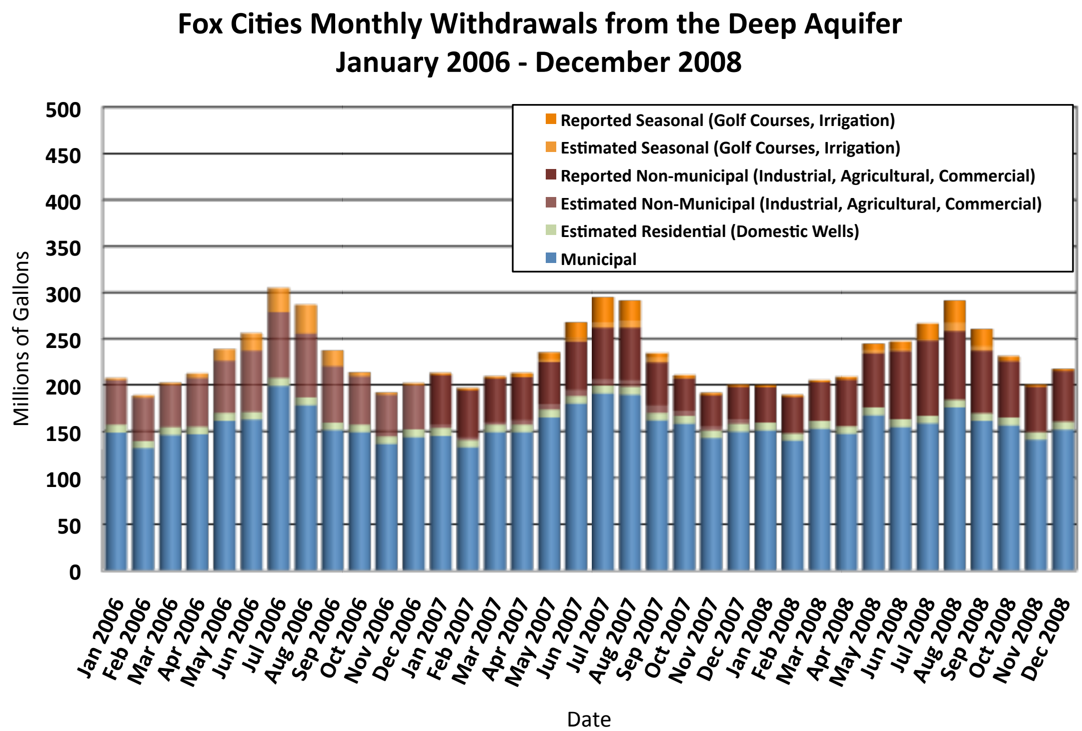


Figure 32. Monthly withdrawals from the sandstone aquifer in pumping centers around each cone of depression during the three-year period between January 2006 and December 2008. Upper graph shows pumping in central Brown County and lower shows pumping around the Fox Cities cone of depression.

Before the 2005-2007 switch to surface water, total withdrawals from the deep aquifer near the Central Brown County cone of depression were estimated to be at least 15.8 - 17.0 mgd. Tables 3 and 4 describe how water use changed after the switch.

Table 3. Water Use Categories for water withdrawn from the deep aquifer in Central Brown County before eight communities switched from ground to surface water in 2005 - 2007.

Category	Volume (mgd)	Percent of Total	
		Oct-March	April-Sept
Municipal	13.1	83.0	77.1
Industrial	2.4	15.2	14.1
Seasonal (Irrigation)	0.0 – 1.2 (April – September)	<1	7.1
Residential	0.28	1.8	1.7
Total:	**15.78 – 16.98 mgd (weighted average 16.44 mgd)**	**100**	**100**

Table 4. Water Use Categories for water withdrawn from the deep aquifer in Central Brown County after eight communities switched from ground to surface water.

Category	Volume (mgd)	Percent of Total	
		Oct-March	April-Sept
Municipal	0.83	23.6	17.6
Industrial	2.4	68.4	51.0
Seasonal (Irrigation)	0.0 – 1.2 (April – September)	<1	25.5
Residential	0.28	8.0	5.9
Total:	**3.51 – 4.71 mgd (weighted average 4.19 mgd)**	**100**	**100**

The reduction in municipal withdrawals from the deep aquifer shifted the nature of groundwater use in central Brown County. Previously, public water supplies were responsible for more than 80 percent of total withdrawals. After the switch, industrial users became the dominant users of groundwater from the deep aquifer. Today's largest volume users are summarized in Table 5.

Table 5. Current large-volume users of water from the deep sandstone aquifer in central Brown County, WI. (Volumes of Village of Pulaski's two public supply wells are combined.)

Well Operator	ID	Category	Volume (mgd)
Fox River Fiber	FRF	Industrial – paper production	1.0
Georgia Pacific	GPC	Industrial – paper production	0.64
Village of Pulaski	PU-1 PU-2	Municipal	0.32
Sanimax	SAN	Industrial – Rendering	0.25
Allen Canning	ALC	Seasonal – food production	0.23
Village of Hobart	HB-1	Municipal	0.23
Pioneer Metal Finishing	PMF	Industrial – metal finishing	0.19
Green Bay Country Club	GBC	Seasonal – golf course irrigation	0.16
Mid Vallee Golf Course	MVG	Seasonal – golf course irrigation	0.09

Paper production operations and municipal water suppliers account for the largest year-round withdrawals from the deep aquifer in the central Brown County region. During summer months, seasonal wells withdraw significant amounts, as well. Two large volume users, MVG and NHD in Tables 3 and 4, are located between the two cones of depression along the hydrologic ridge. Because their volumes pumped are relatively low compared to the other largest volume users, we assigned one to each center of pumping. Table 6 summarizes the users of the largest-volume withdrawals in the Fox Cities area.

Table 6. Current large-volume users of water from the deep sandstone aquifer in the Fox Cities area. (Volumes reported for public utility operators include combined total pumping of all wells operated by each utility.)

Well Operator	ID	Category	Volume (mgd)
Kimberly Municipal Water Utility	KI-1 KI-2 KI-3	Municipal	1.47
Kaukauna Utilities	KA-4 KA-5 KA-8 KA-9 KA-10	Municipal	1.42
Little Chute Municipal Water Department	LC-1 LC-3 LC-4	Municipal	1.36
Darboy Joint Sanitary District #1	DB-1 DB-2 DB-3	Municipal	0.56
Thrivent Aid Association	THR	Heating and Cooling	0.40
New Horizons Dairy	NHD	Agricultural – dairy	0.20
Appleton Papers	APP	Industrial – paper production	0.19

The Fox Cities area also has numerous large volume users that draw from high capacity wells. Overall, high capacity users in the Fox Cities area use significantly more groundwater than those in Central Brown County. While the City of Appleton and many industries use surface water supplies in this area, three public water utilities withdraw significant volumes of water from the deep aquifer.

Estimation of St. Peter Sandstone Dewatering Point

We used water levels and well construction reports to calculate the position of the potentiometric surface, relative to the top of the St. Peter Sandstone, both before and after the recent switch to surface water. Near the center of the cone of depression in central Brown County, the St. Peter Sandstone was saturated after approximately 80% of the recovery had taken place. Using linear interpolation, we estimate that wells in central Brown County can supply at least 5.8 to 7.5 mgd without potentially dewatering the St. Peter Sandstone. These are likely underestimates of possible pumping because none of the recovery in these wells since July 2008 has been taken into account. If additional recovery of water levels since 2008 is taken into account, this would allow for a somewhat higher regional pumping rate before dewatering of the St. Peter would occur. Still, this compares favorably to Krohelski's (1986) estimate that the deep aquifer in Brown County could supply a maximum of 6.7 mgd before becoming dewatered.

The wells in the center of the cone of depression near De Pere were most likely to have the most residual drawdown. Unfortunately, the most recent water data available for these wells are from July 2008, before water levels had approached full recovery. Water levels in some of these wells were only 10-24 feet above the top of the St. Peter Sandstone. If recovery continued after July 2008, as expected, then our target pumping estimate would be higher. Additional pumping west of the cone of depression (e.g., Howard, etc.) could also occur without substantially lowering those water levels below the top of the St. Peter.

The Problem of Flowing Wells

The rising water levels in central Brown County could have significant implications for residents, businesses, and policymakers. Well pumps and other equipment, particularly in older wells, may not perform properly, requiring costly repairs or replacement. Flooding could also cause property damage for homeowners. A municipal well in Howard began flowing early in 2009. If other locations experienced similar conditions in the future, the formation of new wetlands or springs could occur, and policymakers will be faced with determining what level of protection to provide them. The water levels in several wells in the Green Bay area are less than 50 feet from the ground surface. The Village of Howard's Well 3 (Figure 20) started flowing early in 2009. Static water levels in Suamico (Figure 22) have been as high as 25 feet below ground surface. The water level in Green Bay's Well 10 (Figure 16) is approximately 40-50 feet below ground surface. With some wells continuing to experience rising water levels in recent months (e.g., Bellevue and Scott, Figures 17 and 18), it is likely that the recovery from the reduction in pumping is not complete and could continue in the study area.

CONCLUSIONS AND RECOMMENDATIONS

The water levels in the deep sandstone aquifer in the northeastern GMA have risen more than 100 feet in response to the switch from ground water to surface by eight municipalities in Brown County, a reduction of 12 mgd in ground water pumping. The water levels continue to slowly increase and will likely do so for the next several years. Currently, the town of Howard's well #3 is flowing due to the increased water levels. It is possible that more wells will start flowing as water levels rise. Furthermore, if pumping rates decrease further, even more wells will have the potential to become flowing wells. The hydrostratigraphy of the region was refined by using multiple geologic and geophysical logs. Borehole geophysical logging and testing provided additional information on the individual units. For example, in the Pulaski borehole, BN-424, the flows in the deep sandstone aquifer are dominated by high K zones.

When Conlon (1998) modeled drawdown in northeast Wisconsin, measured hydraulic head values were available nearly everywhere in the study area. In the period between that study and this, few data were compiled or analyzed. Although the region had been the subject of many studies, differences between modeled and measured heads of more than 40 feet were evident in the central Brown County area. To understand that discrepancy, Conlon stressed the need for more accurate hydraulic data, particularly the regional vertical conductivity of the Sinnipee Group confining unit. This study contributes additional understanding of regional hydraulic properties and has the potential to be useful for future, more complete, modeling efforts in northeast Wisconsin.

We recommend that:

1. *The pumping rates and water levels in central Brown County continue to be monitored and if the pumping rate begins to increase once more that a groundwater flow model be created that can accurately model the impacts of pumping to surface waters and determine the flow paths of the pumped water so that the origins of contaminants such as radium and arsenic can be delineated.*
2. *If the pumping rates decrease much more than their current rate of 3 mgd in the central Brown County cone of depression, then the WDNR should be aware that many wells, especially those of private homeowners, may start flowing and will need to be capped or have the water routed to prevent flooding.*
3. *If the pumping rates in the central Brown County cone of depression rise above 7 mgd, then the St. Peter Sandstone may become dewatered and the WDNR should be aware of the potential for increased arsenic release in wells located there.*
4. *The cone of depression in the Fox Cities area should continue to be monitored so that any increase in water use will not create groundwater quantities or quality issues.*
5. *The 150-foot drawdown limit set by Act 310 will unlikely be met in the northeastern GMA, unless the pumping rate drops very low (<2 mgd). If this were to occur, the flowing well issue would need to be addressed.*

ACKNOWLEDGMENTS

We would like to thank the Wisconsin Department of Natural Resources for funding this research and Wendy Anderson (WDNR) for providing assistance with questions and data acquisition. We also thank the numerous municipal and industrial well operators for supplying water level and pumping data, without which, this project would not have been possible. McKeefry & Sons, Inc., UW Green Bay, the Oneida Nation, and the Town of Ledgeview provided property access for site specific well investigations. Members of the Wisconsin Geological and Natural History Survey (Pete Chase, Andrew Aslesen, and Leo Druar contributed to the project during packer testing and logging of wells. The USGS provided access to equipment used in packer testing of the deep Pulaski borehole. The City of Green Bay and CH2MHILL provided access to drill core and internal hydrogeologic reports. Bill Van de Yacht Water Well, Inc. performed installation and pump removal for site specific investigations.

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APPENDIX 1

PUMPING VOLUMES

Operator/Owner	WUWN	HiCap Perm	Jan 2006	Feb 2006	Mar 2006	Apr 2006	May 2006	Jun 2006	Jul 2006	Aug 2006	Sep 2006	Oct 2006	Nov 2006	Dec 2006
CENTRAL BROWN COUNTY														
MUNICIPAL														
CBCWA														
Allouez			35,680,000	33,707,000	37,720,000	38,315,000	41,161,000	42,678,000	51,546,000	44,659,000	38,654,000	38,102,000	35,035,000	37,532,000
Bellevue			39,052,000	35,690,000	37,125,000	41,781,000	40,541,000	44,546,000	50,617,000	48,791,000	40,890,000	44,137,000	37,691,000	39,732,000
De Pere			79,291,000	75,461,000	91,828,000	94,217,000	87,352,000	95,709,000	112,911,000	96,495,000	80,906,000	83,150,000	72,208,000	80,698,000
Howard			56,708,000	48,663,000	52,867,000	58,121,000	62,603,000	68,828,000	81,813,000	72,709,000	61,456,000	59,620,000	52,831,000	56,574,000
Lawrence			8,873,000	7,907,000	9,012,000	9,551,000	9,832,000	2,950,000	0	0	0	0	0	0
Ledgeview			9,114,000	6,413,000	0	0	10,628,000	14,751,000	19,225,000	17,520,000	17,403,000	13,889,000	14,941,000	9,783,000
Ashwaubenon			90,805,000	84,004,000	94,562,000	95,003,000	108,409,000	0	0	0	0	0	0	0
Scott			4,909,000	4,644,000	5,245,000	5,680,000	5,633,000	6,230,000	6,525,000	3,878,000	3,314,000	3,265,000	0	0
OTHER MUNICIPAL														
Green Bay			16,000	17,000	8,000	10,000	18,000	14,000	13,000	11,000	13,000	14,000	17,000	17,000
Hobart			5,999,000	4,850,000	5,590,000	5,845,000	6,775,000	8,950,000	12,203,000	9,509,000	6,423,000	5,804,000	4,480,000	4,806,000
Pulaski			9,516,000	9,080,000	9,739,000	10,242,000	10,548,000	12,767,000	15,225,000	15,318,000	12,249,000	8,544,000	7,300,000	7,782,000
Suamico			5,399,000	5,196,000	5,513,000	5,814,000	8,279,000	7,669,000	8,898,000	7,634,000	7,379,000	7,192,000	7,312,000	7,381,000
INDUSTRIAL														
Atlas Cold Storage	N/A	392	*491,040*	*471,240*	*790,020*	*1,172,160*	*1,152,360*	*1,435,500*	*1,570,140*	*2,105,730*	*1,974,060*	*1,697,850*	*1,354,320*	*918,720*
Fox River Fiber Co	TQ318	4470	*30,824,550*	*27,946,450*	*30,432,550*	*29,528,850*	*30,989,100*	*32,018,550*	*32,755,050*	*33,938,750*	*32,916,850*	*32,842,300*	*31,949,250*	*29,904,800*
Georgia Pacific	N/A	40518	20,989,449	19,152,000	21,477,606	20,003,040	18,440,629	18,576,000	17,314,554	17,986,820	18,198,720	20,495,526	21,119,340	20,904,478
Pioneer Metal Finishing (PMF)	WG604	3938	*6,114,700*	*4,953,600*	*5,679,400*	*5,677,400*	*5,731,500*	*5,685,100*	*5,955,900*	*6,647,400*	*5,766,700*	*7,237,600*	*6,366,900*	*5,195,400*
Putney Capital (Bay Towel)	RG481	3937	*1,874,825*	*1,669,600*	*1,874,850*	*1,902,800*	*1,904,200*	*1,773,050*	*1,832,400*	*1,824,400*	*1,684,600*	*1,936,000*	*1,591,000*	*1,650,525*
Sanimax (formerly Anamax)	N/A	1337	5,378,100	4,505,400	6,232,200	5,911,767	6,641,728	6,925,282	7,768,950	7,911,565	7,447,200	8,464,895	7,165,955	7,394,715
Belgioioso Cheese	AC644	40525	*1,420,586*	*1,323,054*	*1,208,284*	*1,198,843*	*1,160,454*	*1,003,295*	*982,295*	*1,045,990*	*1,445,181*	*1,351,284*	*604,775*	*455,623*
Brown County Reforestation Camp	LK690	1980	*3,283,200*	*3,360,000*	*3,379,200*	*3,888,000*	*4,665,600*	*4,180,800*	*5,232,000*	*4,195,200*	*4,003,200*	*3,384,000*	*2,568,000*	*2,808,000*
Brown County Reforestation Camp	N/A	1982	*465,000*	*489,000*	*0*	*405,000*	*348,000*	*1,845,000*	*729,000*	*771,000*	*723,000*	*291,000*	*256,500*	*514,500*
Brown County Reforestation Camp	MO957	1984	*9,600*	*7,200*	*12,000*	*1,200*	*30,000*	*51,600*	*64,800*	*46,800*	*42,000*	*10,800*	*4,200*	*66,600*
Northeast Asphalt	TQ667	67412	*0*	*0*	*0*	*0*	*0*	*0*	*4,325,000*	*3,410,000*	*1,944,000*	*3,525,000*	*4,851,000*	
Lannoye School	FB672	90312	*48,850*	*42,850*	*45,600*	*52,800*	*49,250*	*14,200*	*16,950*	*27,800*	*58,350*	*54,400*	*42,250*	*33,550*
Schroeder's Flowers	CR897	21713	*48,596*	*108,746*	*310,206*	*609,378*	*848,410*	*902,316*	*623,118*	*576,295*	*307,065*	*237,241*	*210,681*	*100,402*
SEASONAL														
Brown County Park Dept	KQ397	1466	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Mark Giardino (Ledgeview Golf Course)	BB739	4702	*0*	*0*	*0*	*188,161*	*2,324,895*	*3,451,150*	*4,134,800*	*5,802,150*	*2,352,200*	*312,950*	*0*	*0*
Oneida Golf and Country Club	BF173	75505	*0*	*0*	*0*	*964,000*	*3,380,000*	*5,285,000*	*6,745,000*	*2,259,500*	*1,160,500*	*270,000*	*20,000*	*0*
Roland Bruntz (Sunny Hill Farm)	BB747	4710	*0*	*0*	*0*	*0*	*405,000*	*2,636,700*	*2,388,060*	*6,556,050*	*4,565,040*	*555,360*	*0*	*0*
Thornberry Creek Country Club	MR031	2575	*0*	*0*		*2,317,140*	*2,879,100*	*4,017,160*	*5,101,740*	*7,445,340*	*4,473,000*	*2,104,200*	*0*	*0*
Thornberry Creek Country Club		1207	*0*	*0*	*0*	*211,050*	*776,400*	*900,150*	*1,042,500*	*1,329,600*	*970,000*	*561,900*	*189,750*	*0*
Green Bay Country Club	FM185	982	*0*	*0*	*0*	*0*	*5,555,400*	*2,848,200*	*7,078,200*	*9,277,800*	*3,344,500*	*1,534,080*	*0*	*0*
Green Bay Country Club	WG321	68068	*93,000*	*66,000*	*58,000*	*48,000*	*404,000*	*60,000*	*86,400*	*92,000*	*114,800*	*213,600*	*429,900*	*642,900*
Bay Beach Wildlife Sanctuary	UK839	68964	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Highland Ridge Golf Club	CR858	1638	*0*	*0*	*0*	*0*	*57,600*	*331,200*	*547,200*	*518,400*	*165,600*	*28,800*	*0*	*0*
Hilly Haven Golf Course	GO113	1901	*0*	*0*	*0*	*0*	*1,095,213*	*844,246*	*325,411*	*3,288,922*	*924,317*	*0*	*0*	*0*
Mid Vallee Golf Course	OP093	2572	*0*	*0*	*0*	*0*	*329,400*	*62,655*	*81,450*	*553,950*	*1,098,000*	*0*	*0*	*0*
Mid Vallee Golf Course	BB742	4705	*0*	*0*	*0*	*0*	*2,048,970*	*1,101,060*	*539,725*	*5,282,880*	*2,920,025*	*118,800*	*0*	*0*
Moder Farms	BB744	4707	*0*	*0*	*0*	*0*	*72,500*	*97,200*	*109,800*	*229,900*	*84,000*	*0*	*0*	*0*
Tillmann Wholesale Growers	NK736	2741	*0*	*0*	*0*	*0*	*1,320,000*	*2,580,000*	*2,550,000*	*2,670,000*	*2,250,000*	*1,344,000*	*0*	*0*
Richard Williams		4711	*0*	*0*	*0*	*0*	*0*	*110,400*	*244,200*	*641,600*	*88,500*	*92,250*	*0*	*0*
Brown County Park Department (Barkh	KQ397	1466	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*2,692,800*	*4,009,500*	*5,217,300*	*1,529,550*	*0*
Allen Canning	RR865	3484	*0*	*0*	*0*	*0*	*0*	*1,745,000*	*7,967,500*	*10,577,423*	*12,183,548*	*2,852,000*	*18,500*	*0*
Shorewood Golf Course						*94,081*	*587,908*	*576,858*	*594,497*	*1,454,873*	*796,278*	*53,969*	*0*	*0*
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,700,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Italicized text indicates estimated value

Operator/Owner	WUWN	HiCap Perm	Jan 2007	Feb 2007	Mar 2007	Apr 2007	May 2007	Jun 2007	Jul 2007	Aug 2007	Sep 2007	Oct 2007	Nov 2007	Dec 2007
CENTRAL BROWN COUNTY														
MUNICIPAL														
CBCWA														
Allouez			37,088,000	32,679,000	34,728,000	36,951,000	44,605,000	49,952,000	49,535,000	15,803,000	0	0	0	0
Bellevue			38,655,000	31,983,000	34,321,000	33,996,000	44,298,000	47,007,000	41,250,000	11,041,000	269,000	159,000	177,000	0
De Pere			83,248,000	79,978,000	83,879,000	76,763,000	100,298,000	111,944,000	119,702,000	49,714,000	199,000	47,000	68,000	163,000
Howard			58,725,000	52,359,000	54,380,000	54,291,000	67,787,000	70,333,000	69,209,000	54,210,000	10,000,000	10,000,000	0	0
Lawrence			0	0	0	0	0	0	0	0	0	0	0	0
Ledgeview			10,237,000	9,161,000	9,543,000	11,451,000	13,807,000	19,515,000	20,695,000	6,635,000	0	0	0	0
Ashwaubenon			0	0	0	0	0	0	0	0	0	0	0	0
Scott			0	0	0	0	0	0	0	0				
OTHER MUNICIPAL														
Green Bay			31,000	14,000	10,000	22,000	13,000	13,000	7,000	9,000	24,000	22,000	51,000	15,000
Hobart			4,788,000	4,477,000	5,229,000	5,677,000	8,077,000	9,234,000	10,920,000	10,405,000	7,292,000	5,847,000	4,323,000	4,875,000
Pulaski			8,584,000	7,602,000	7,317,000	7,418,000	9,467,000	10,136,000	10,766,000	12,876,000	10,625,000	8,473,000	7,033,000	7,380,000
Suamico			7,521,000	6,849,000	7,438,000	7,941,000	11,285,000	12,264,000	12,117,000	12,339,000	10,296,000	8,756,000	7,966,000	8,739,000
INDUSTRIAL														
Atlas Cold Storage	N/A	392	491,040	471,240	790,020	1,172,160	1,152,360	1,435,500	1,098,900	1,873,080	2,249,280	1,960,200	1,730,520	1,100,880
Fox River Fiber Co	TQ318	4470	30,845,500	28,045,900	29,948,700	29,613,400	32,405,500	32,081,200	32,467,200	32,984,300	31,541,000	32,491,500	31,975,800	30,392,300
Georgia Pacific	N/A	40518	20,946,235	20,875,680	22,338,724	14,888,160	18,620,646	17,496,000	16,365,613	15,914,873	18,198,720	13,597,933	13,870,440	17,932,322
Pioneer Metal Finishing (PMF)	WG604	3938	6,114,700	4,953,600	5,679,400	5,677,400	5,731,500	5,685,100	5,955,900	6,647,400	5,766,700	7,237,600	6,366,900	5,195,400
Putney Capital (Bay Towel)	RG481	3937	1,921,100	1,712,800	2,021,000	1,848,900	2,067,000	1,794,500	1,758,100	1,889,400	1,569,400	2,001,500	1,718,400	1,632,350
Sanimax (formerly Anamax)	N/A	1337	7,311,813	7,382,517	8,479,954	7,556,000	7,584,000	7,861,778	7,377,720	8,103,120	7,449,280	8,945,360	7,238,380	6,813,250
Belgioioso Cheese	AC644	40525	1,420,586	1,323,054	1,208,284	1,198,843	1,160,454	1,003,295	982,295	1,045,990	1,445,181	1,351,284	604,775	455,623
Brown County Reforestation Camp	LK690	1980	*3,283,200*	*3,360,000*	*3,379,200*	*3,888,000*	*4,665,600*	*4,180,800*	*5,232,000*	*4,195,200*	*4,003,200*	*2,169,600*	*1,521,600*	*2,640,000*
Brown County Reforestation Camp	N/A	1982	*465,000*	*489,000*		*405,000*	*348,000*	*1,845,000*	*729,000*	*771,000*	*723,000*	*267,000*	*216,000*	*429,000*
Brown County Reforestation Camp	MO957	1984	*9,600*	*7,200*	*12,000*	*1,200*	*30,000*	*51,600*	*64,800*	*46,800*	*42,000*	*7,200*	*2,400*	*9,600*
Northeast Asphalt	TQ667	67412	0	0	0	0	0	0	0	1,620,000	1,944,000	0	0	0
Lannoye School	FB672	90312	63,100	53,400	61,200	59,300	57,500	17,400	22,900	25,600	49,200	60,100	47,100	28,300
Schroeder's Flowers	CR897	21713	65,101	134,936	370,441	609,257	896,808	973,854	697,358	600,979	359,980	304,239	325,358	152,679
SEASONAL														
Brown County Park Dept	KQ397	1466	0	0	0	0	0	0	0	5,385,600	4,019,400	4,197,600	0	0
Mark Giardino (Ledgeview Golf Course)	BB739	4702	0	0	0	376,322	2,558,990	4,892,700	5,539,600	4,588,900	2,398,600	0	0	0
Oneida Golf and Country Club	BF173	75505	0	0	0	778,000	5,054,000	6,769,000	8,088,000	2,767,000	1,167,000	183,000	0	0
Roland Bruntz (Sunny Hill Farm)	BB747	4710	0	0	0	0	0	4,058,400	4,101,120	4,485,600	5,404,080	1,110,720	0	0
Thornberry Creek Country Club	MR031	2575	0	0	0	4,634,280	5,758,200	5,814,120	6,075,720	5,697,720	5,342,400	2,819,880	0	0
Thornberry Creek Country Club		1207	0	0	0	422,100	1,004,400	975,000	1,268,700	1,015,500	932,000	848,700	0	0
Green Bay Country Club	FM185	982	*0*	*0*	*0*	*0*	*5,555,400*	*2,848,200*	*7,078,200*	*9,277,800*	*3,344,500*	*1,534,080*		0
Green Bay Country Club	WG321	68068	*93,000*	*66,000*	*58,000*	*48,000*	*404,000*	*60,000*	*86,400*	*92,000*	*114,800*	*213,600*	*429,900*	*642,900*
Bay Beach Wildlife Sanctuary	UK839	68964	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0	0
Highland Ridge Golf Club	CR858	1638	0	0	0	0	0	432,000	576,000	576,000	216,000	0	0	0
Hilly Haven Golf Course	GO113	1901	*0*	*0*	*0*	*0*	*1,095,213*	*844,246*	*325,411*	*3,288,922*	*924,317*	0	0	0
Mid Vallee Golf Course	OP093	2572	0	0	0	0	0	15,510	16,500	9,900	0	0	0	0
Mid Vallee Golf Course	BB742	4705	0	0	0	0	19,140	83,520	129,050	111,360	18,850	0	0	0
Moder Farms	BB744	4707	0	0	0	0	1,000	2,400	3,600	3,800	0	0	0	0
Tillmann Wholesale Growers	NK736	2741	*0*	*0*	*0*	*0*	*1,320,000*	*2,580,000*	*2,550,000*	*2,670,000*	*2,250,000*	*1,344,000*	0	0
Richard Williams		4711	0	0	0	0	0	108,000	240,000	585,000	81,000	76,500	0	0
Brown County Park Department (Barkh	KQ397	1466	0	0	0	0	0	0	0	5,385,600	4,019,400	4,197,600	0	0
Allen Canning	RR865	3484	0	0	0	0	0	2,460,000	6,677,000	11,452,000	11,351,000	0	0	0
Shorewood Golf Course			*0*	*0*	*0*	*47,040*	*322,266*	*623,966*	*710,644*	*588,770*	*302,181*	*0*	*0*	*0*
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,700,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Red text indicates estimated value

Operator/Owner	WUWN	HiCap Perm	Jan 2008	Feb 2008	Mar 2008	Apr 2008	May 2008	Jun 2008	Jul 2008	Aug 2008	Sep 2008	Oct 2008	Nov 2008	Dec 2008
CENTRAL BROWN COUNTY														
MUNICIPAL														
CBCWA														
Allouez			0	0	0	0	0	0	0	0	0	0	0	0
Bellevue			235,000	0	0	130,000	0	0	0	0	255,000	98,000	0	0
De Pere			49,000	68,000	471,000	169,000	85,000	208,000	101,000	62,000	666,000	202,000	13,000	86,000
Howard			0	72,000	97,000	150,000	152,000	84,000	166,000	120,000	120,000	118,000	105,000	89,000
Lawrence			0	0	0	0	0	0	0	0	0	0	0	0
Ledgeview			0	0	0	0	0	0	0	0	0	0	0	0
Ashwaubenon			0	0	0	0	0	0	0	0	0	0	0	0
Scott														
OTHER MUNICIPAL														
Green Bay			19,000	13,000	11,000	11,000	13,000	14,000	18,000	18,000	14,000	13,000	16,000	18,000
Hobart			5,054,000	4,829,000	5,377,000	5,302,000	7,442,000	7,776,000	11,288,000	11,626,000	8,010,000	5,886,000	4,433,000	5,385,000
Pulaski			7,917,000	7,120,000	7,268,000	7,488,000	9,528,000	10,966,000	9,863,000	12,641,000	10,458,000	8,941,000	6,697,000	7,778,000
Suamico			8,407,000	8,102,500	8,688,800	8,535,000	10,209,000	10,384,500	11,837,100	16,142,300	11,647,900	9,289,800	8,927,100	8,776,300
INDUSTRIAL														
Atlas Cold Storage	N/A	392	491,040	471,240	790,020	1,172,160	1,152,360	1,435,500	2,041,380	2,338,380	1,698,840	1,435,500	978,120	736,560
Fox River Fiber Co	TQ318	4470	30,803,600	27,847,000	30,916,400	29,444,300	29,572,700	31,955,900	33,042,900	34,893,200	34,292,700	33,193,100	31,922,700	29,417,300
Georgia Pacific	N/A	40518	18,832,314	17,156,168	20,440,811	15,043,680	19,153,443	18,512,640	19,337,769	18,502,567	20,723,040	24,292,800	23,653,440	24,969,600
Pioneer Metal Finishing (PMF)	WG604	3938	6,114,700	4,953,600	5,679,400	5,677,400	5,731,500	5,685,100	5,955,900	6,647,400	5,766,700	7,237,600	6,366,900	5,195,400
Putney Capital (Bay Towel)	RG481	3937	1,828,550	1,626,400	1,728,700	1,956,700	1,741,400	1,751,600	1,906,700	1,759,400	1,799,800	1,870,500	1,463,600	1,668,700
Sanimax (formerly Anamax)	N/A	1337	7,419,340	7,704,530	8,272,860	8,559,460	8,501,260	9,078,780	8,160,180	7,720,010	7,445,120	7,984,430	7,093,530	7,976,180
Belgioioso Cheese	AC644	40525	1,420,586	1,323,054	1,208,284	1,198,843	1,160,454	1,003,295	982,295	1,045,990	1,445,181	1,351,284	604,775	455,623
Brown County Reforestation Camp	LK690	1980	3,283,200	3,360,000	3,379,200	3,888,000	4,665,600	4,180,800	5,232,000	4,195,200	4,003,200	4,598,400	3,614,400	2,976,000
Brown County Reforestation Camp	N/A	1982	465,000	489,000		405,000	348,000	1,845,000	729,000	771,000	723,000	315,000	297,000	600,000
Brown County Reforestation Camp	MO957	1984	9,600	7,200	12,000	1,200	30,000	51,600	64,800	46,800	42,000	14,400	6,000	123,600
Northeast Asphalt	TQ667	67412	0	0	0	0	0	0	4,325,000	5,200,000	0	3,525,000	4,851,000	0
Lannoye School	FB672	90312	34,600	32,300	30,000	46,300	41,000	11,000	11,000	30,000	67,500	48,700	37,400	38,800
Schroeder's Flowers	CR897	21713	32,090	82,555	249,971	609,498	800,011	830,777	548,878	551,611	254,150	170,242	96,003	48,124
SEASONAL														
Brown County Park Dept	KQ397	1466	0	0	0	0	0	0	0	0	3,999,600	6,237,000	3,059,100	0
Mark Giardino (Ledgeview Golf Course)	BB739	4702	0	0	0	0	2,090,800	2,009,600	2,730,000	7,015,400	2,305,800	625,900	0	0
Oneida Golf and Country Club	BF173	75505	0	0	0	1,150,000	1,706,000	3,801,000	5,402,000	1,752,000	1,154,000	357,000	40,000	0
Roland Bruntz (Sunny Hill Farm)	BB747	4710	0	0	0	0	810,000	1,215,000	675,000	8,626,500	3,726,000	0	0	0
Thornberry Creek Country Club	MR031	2575	0	0	0	0	0	2,220,200	4,127,760	9,192,960	3,603,600	1,388,520	0	0
Thornberry Creek Country Club		1207	0	0	0	0	548,400	825,300	816,300	1,643,700	1,008,000	275,100	379,500	0
Green Bay Country Club	FM185	982	0	0	0	0	5,555,400	2,848,200	7,078,200	9,277,800	3,344,500	1,534,080	0	0
Green Bay Country Club	WG321	68068	93,000	66,000	58,000	48,000	404,000	60,000	86,400	92,000	114,800	213,600	429,900	642,900
Bay Beach Wildlife Sanctuary	UK839	68964	0	0	0	0	3,561,200	7,122,400	7,122,400	7,122,400	7,122,400	3,561,200	0	0
Highland Ridge Golf Club	CR858	1638	0	0	0	0	115,200	230,400	518,400	460,800	115,200	57,600	0	0
Hilly Haven Golf Course	GO113	1901	0	0	0	0	1,095,213	844,246	325,411	3,288,922	924,317	0	0	0
Mid Vallee Golf Course	OP093	2572	0	0	0	0	658,800	109,800	146,400	1,098,000	2,196,000	0	0	0
Mid Vallee Golf Course	BB742	4705	0	0	0	0	4,078,800	2,118,600	950,400	10,454,400	5,821,200	237,600	0	0
Moder Farms	BB744	4707	0	0	0	0	144,000	192,000	216,000	456,000	168,000	0	0	0
Tillmann Wholesale Growers	NK736	2741	0	0	0	0	1,320,000	2,580,000	2,550,000	2,670,000	2,250,000	1,344,000	0	0
Richard Williams		4711	0	0	0	0	0	112,800	248,400	698,200	96,000	108,000	0	0
Brown County Park Department (Barkh	KQ397	1466	0	0	0	0	0	0	0	0	3,999,600	6,237,000	3,059,100	0
Allen Canning	RR865	3484	0	0	0	0	0	1,030,000	9,258,000	9,702,845	13,016,096	5,704,000	37,000	0
Shorewood Golf Course			*0*	*0*	*0*	*0*	*853,550*	*529,750*	*478,350*	*2,320,975*	*1,290,375*	*107,938*	*0*	*0*
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,975,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Red text indicates estimated value

Operator/Owner	WUWN	HiCap Perm	Jan 2006	Feb 2006	Mar 2006	Apr 2006	May 2006	Jun 2006	Jul 2006	Aug 2006	Sep 2006	Oct 2006	Nov 2006	Dec 2006
MUNICIPAL														
Darboy			14,013,000	12,939,000	14,054,000	14,560,000	16,051,000	17,736,000	26,914,000	22,527,000	17,230,000	14,968,000	14,055,000	14,891,000
Forest Junction			1,082,000	1,097,000	1,109,000	104,000	1,151,000	1,190,000	1,396,000	1,300,000	1,100,000	987,000	921,000	1,025,000
Freedom			0	0	0	0	0	0	252,000	135,000	146,000	103,000	153,000	87,000
Holland			2,283,000	2,062,000	2,309,000	2,316,000	2,398,000	2,340,000	2,808,000	2,749,000	2,333,000	2,650,000	2,826,000	2,677,000
Kaukauna			43,624,000	37,437,000	41,711,000	42,122,000	45,318,000	43,409,000	52,573,000	47,429,000	39,434,000	43,989,000	38,807,000	40,523,000
Kimberly			42,548,000	37,380,000	40,944,000	40,730,000	43,682,000	46,490,000	57,063,000	49,679,000	44,430,000	41,857,000	37,694,000	41,215,000
Little Chute			39,778,000	36,403,000	40,674,000	41,421,000	46,732,000	45,245,000	50,330,000	47,384,000	40,826,000	38,119,000	36,373,000	37,360,000
Village of Wrightstown			5,274,000	4,641,000	5,312,000	5,660,000	5,853,000	6,077,000	7,367,000	6,703,000	5,639,000	6,191,000	5,680,000	5,918,000
INDUSTRIAL														
Appleton Papers	BE770	56433	*5,726,497*	*5,305,833*	*5,638,396*	*5,549,841*	*5,923,668*	*6,041,376*	*6,375,791*	*6,240,531*	*6,025,592*	*5,979,704*	*5,610,946*	*5,580,370*
Brightside Dairy	GO113	1901	*585,000*	*586,800*	*583,200*	*588,600*	*595,800*	*570,000*	*579,600*	*588,600*	*594,000*	*561,000*	*559,800*	*563,400*
Meadowlark Dairy	UA331	68555	*1,102,938*	*743,124*	*1,060,746*	*975,168*	*933,103*	*867,355*	*1,019,629*	*913,346*	*912,324*	*532,811*	*200*	*0*
New Horizons Dairy	OP704	3229	*5,885,000*	*5,875,000*	*5,875,000*	*5,885,000*	*5,890,000*	*5,890,000*	*5,895,000*	*5,895,000*	*5,890,000*	*5,890,000*	*5,880,000*	*5,880,000*
Arla Foods	BE296	40510	*2,548,950*	*1,874,500*	*1,273,500*	*401,700*	*1,402,650*	*1,800,000*	*3,925,000*	*3,700,000*	*2,945,000*	*3,920,000*	*3,645,000*	*3,770,000*
Tinedale Farms	MY393	2707	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*	*1,600,000*
Bud Gerrits	OI192	69341	*126,050*	*126,050*	*126,050*	*126,100*	*131,150*	*131,150*	*131,150*	*131,150*	*126,050*	*126,050*	*126,050*	*126,050*
Foremost Farms USA	BE743	56402	*3,831,297*	*3,354,774*	*3,697,446*	*3,196,621*	*3,305,359*	*3,732,703*	*3,857,650*	*3,899,515*	*3,818,616*	*3,442,537*	*2,039,713*	*3,817,008*
Foremost Farms USA	BE744	56403	*3,831,297*	*3,354,774*	*3,697,446*	*3,196,621*	*3,305,359*	*3,732,703*	*3,857,650*	*3,899,515*	*3,818,616*	*3,442,537*	*2,039,713*	*3,817,008*
Foremost Farms USA	BE742	56401	*800,200*	*303,800*	*0*	*2,740,890*	*2,800,106*	*0*	*0*	*0*	*0*	*2,496,399*	*2,516,700*	*0*
Ted Vosters (Farm)	HU575	2727	*1,890,500*	*1,745,050*	*1,807,100*	*1,906,800*	*1,745,750*	*1,936,850*	*1,767,000*	*1,932,400*	*1,704,650*	*1,949,750*	*1,819,750*	*1,977,550*
Tidy View Dairy	NC480	2728	*1,024,700*	*949,850*	*955,900*	*979,500*	*1,077,650*	*1,174,250*	*1,264,150*	*1,259,700*	*1,333,825*	*1,235,875*	*1,224,150*	*1,510,150*
North Lake Village	TP817	2937	*82,700*	*73,650*	*86,450*	*87,300*	*97,450*	*106,750*	*124,550*	*132,800*	*112,950*	*86,850*	*87,750*	*96,750*
Neighborhood Dairy	SU271	67726	*870,850*	*849,525*	*836,950*	*839,600*	*843,600*	*978,200*	*1,101,500*	*845,650*	*857,250*	*875,200*	*868,875*	*871,400*
Tidy View Dairy	VL576	68045	*617,825*	*605,400*	*637,650*	*587,850*	*651,000*	*687,200*	*849,850*	*865,017*	*738,917*	*693,000*	*654,400*	*676,600*
Tidy View Dairy	BL577	68046	*3,114,700*	*3,028,100*	*3,309,700*	*3,162,850*	*3,362,000*	*3,361,650*	*3,366,800*	*3,376,850*	*3,213,900*	*3,290,350*	*3,154,050*	*3,208,550*
Ken Verhasselt (farm)	RN063	68384	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*
Ken Verhasselt (farm)	WH934	68385	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*	*1,080,000*
Belgioioso Cheese	WK846	68858	*1,611,876*	*1,687,075*	*940,788*	*3,214,800*	*4,298,739*	*5,545,830*	*5,287,980*	*5,425,744*	*6,225,690*	*4,187,325*	*4,152,600*	*4,508,516*
Thrivent Aid Association	AE086, AE087, EM215		*8,643,100*	*10,720,300*	*9,127,650*	*12,444,848*	*12,458,275*	*19,393,470*	*20,773,452*	*18,620,213*	*14,511,746*	*6,628,120*	*4,701,245*	*5,421,750*
Fox Valley Technical College			*1,759,250*	*1,729,250*	*1,969,250*	*2,413,750*	*3,818,250*	*6,314,250*	*7,849,750*	*7,663,750*	*4,147,750*	*2,625,750*	*1,914,250*	*1,789,300*
SEASONAL														
Eagle Link Golf Course	KQ496	1892	*0*	*0*	*0*	*376,322*	*2,351,633*	*2,307,433*	*2,377,988*	*5,819,490*	*3,185,113*	*215,875*	*0*	*0*
Country Aire Farms	MV479	2580	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*	*2,138,750*
Country Aire Farms	SG743	67732	*172,100*	*172,100*	*172,100*	*177,150*	*177,150*	*177,150*	*182,400*	*182,400*	*177,350*	*177,100*	*177,100*	*177,100*
USA Youth	LG839	1873	*0*	*0*	*0*	*1,158,570*	*2,099,550*	*3,353,780*	*491,500*	*983,000*	*294,900*	*0*	*0*	*0*
Riverview Country Club		2205	*0*	*0*	*0*	*189,000*	*1,085,500*	*1,761,500*	*2,247,500*	*1,675,000*	*1,156,500*	*0*	*0*	*0*
Paper Valley Corp (Chaska Golf)	BC615	21705	*0*	*0*	*0*	*0*	*0*	*542,700*	*1,641,600*	*1,411,020*	*576,180*	*115,020*	*0*	*0*
Paper Valley Corp (Chaska Golf)	BC614	21704	*0*	*0*	*0*	*3,025*	*6,010*	*37,850*	*44,895*	*25,215*	*17,755*	*2,400*	*559*	*0*
Paper Valley Corp (Chaska Golf)	BC616	21706	*0*	*0*	*0*	*0*	*231,120*	*1,235,520*	*1,994,220*	*1,926,720*	*961,200*	*0*	*0*	*0*
Fox Valley Golf Club	BC612	21701	*0*	*0*	*0*	*279,600*	*818,400*	*2,364,000*	*7,409,600*	*4,536,800*	*1,076,100*	*549,150*	*0*	*0*
Reid Municipal Golf Course	BC617	21707	*0*	*0*	*0*	*0*	*1,474,000*	*2,320,000*	*2,449,000*	*4,396,000*	*3,658,000*	*329,000*	*0*	*0*
Royal St. Patrick Dev (Golf Course)	QO558	3499	*0*	*0*	*0*	*926,779*	*1,984,339*	*3,145,099*	*4,943,641*	*8,348,902*	*3,658,995*	*1,074,178*	*0*	*0*
Country Aire Farms	UN534	69343	*0*	*0*	*0*	*8,000*	*9,000*	*12,000*	*18,500*	*19,000*	*18,000*	*18,500*	*18,000*	*18,000*
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,700,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Italicized text indicates estimated value

Operator/Owner	WUWN	HiCap Perm	Jan 2007	Feb 2007	Mar 2007	Apr 2007	May 2007	Jun 2007	Jul 2007	Aug 2007	Sep 2007	Oct 2007	Nov 2007	Dec 2007
MUNICIPAL														
Darboy			14,750,000	12,954,000	15,013,000	14,967,000	17,750,000	21,319,000	22,051,000	20,813,000	16,356,000	16,392,000	14,984,000	15,500,000
Forest Junction			100,000	910,000	1,119,000	1,142,000	1,184,000	1,325,000	1,366,000	1,253,000	1,094,000	1,277,000	955,000	1,021,000
Freedom			90,000	83,000	95,000	114,000	235,000	335,000	622,000	304,000	0	2,131,000	2,625,000	2,423,000
Holland			2,736,000	2,380,000	2,673,000	2,509,000	2,607,000	2,901,000	3,401,000	3,053,000	2,667,000	3,251,000	2,382,000	2,433,000
Kaukauna			41,486,000	37,897,000	41,149,000	42,906,000	43,666,000	46,046,000	48,574,000	46,458,000	40,934,000	43,142,000	38,275,000	40,186,000
Kimberly			42,068,000	38,849,000	42,885,000	42,179,000	49,401,000	54,716,000	60,511,000	62,774,000	52,786,000	45,011,000	41,431,000	43,832,000
Little Chute			37,762,000	34,078,000	39,318,000	38,446,000	42,324,000	44,734,000	45,771,000	46,389,000	41,064,000	40,859,000	36,379,000	37,901,000
Village of Wrightstown			6,189,000	5,780,000	6,601,000	6,732,000	7,674,000	8,352,000	8,406,000	8,482,000	6,925,000	6,251,000	5,556,000	6,158,000
INDUSTRIAL														
Appleton Papers	BE770	56433	7,750,000	7,000,000	7,750,000	7,500,000	7,750,000	7,500,000	7,750,000	7,750,000	7,500,000	7,750,000	7,500,000	7,750,000
Brightside Dairy	GO113	1901	*585,000*	*586,800*	*583,200*	*588,600*	*595,800*	*570,000*	*579,600*	*588,600*	*594,000*	*561,000*	*559,800*	*563,400*
Meadowlark Dairy	UA331	68555	*1,102,938*	*743,124*	*1,060,746*	*975,168*	*933,103*	*867,355*	*1,019,629*	*913,346*	*912,324*	*532,811*	*200*	
New Horizons Dairy	OP704	3229	970,000	950,000	950,000	970,000	980,000	980,000	990,000	990,000	980,000	980,000	960,000	960,000
Arla Foods	BE296	40510	5,080,000	3,690,000	2,460,000	610,000	350,000	600,000	4,350,000	3,640,000	2,240,000	3,190,000	3,100,000	3,390,000
Tinedale Farms	MY393	2707	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000
Bud Gerrits	OI192	69341	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000
Foremost Farms USA	BE743	56402	3,773,783	3,218,252	3,855,621	3,590,326	3,824,268	3,705,130	3,760,258	3,804,850	3,869,187	3,715,371	3,710,785	3,782,219
Foremost Farms USA	BE744	56403	3,773,783	3,218,252	3,855,621	3,590,326	3,824,268	3,705,130	3,760,258	3,804,850	3,869,187	3,715,371	3,710,785	3,782,219
Foremost Farms USA	BE742	56401	800,200	303,800	0	0	0	0	0	0	0	0	0	0
Ted Vosters (Farm)	HU575	2727	1,490,900	1,378,900	1,596,400	1,580,500	1,670,200	1,660,300	1,400,500	1,720,000	1,377,400	1,760,000	1,494,800	1,653,600
Tidy View Dairy	NC480	2728	1,050,600	1,115,800	1,085,600	1,112,800	1,009,900	1,093,200	1,114,800	1,114,800	1,358,750	1,218,250	1,340,500	1,998,800
North Lake Village	TP817	2937	88,900	79,800	82,900	84,600	95,900	96,500	132,100	121,600	81,900	83,700	76,500	94,500
Neighborhood Dairy	SU271	67726	497,900	415,650	390,500	403,000	414,600	687,400	943,000	440,300	456,300	494,000	490,350	491,800
Tidy View Dairy	VL576	68045	640,700	640,000	650,300	654,200	652,300	660,500	670,500	651,133	691,534	650,200	660,500	670,600
Tidy View Dairy	BL577	68046	3,105,500	3,120,600	3,290,000	3,200,200	3,198,500	3,235,200	3,234,500	3,151,000	3,046,500	3,223,600	3,223,700	3,258,500
Ken Verhasselt (farm)	RN063	68384	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000
Ken Verhasselt (farm)	WH934	68385	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000	960,000
Belgioioso Cheese	WK846	68858	*1,611,876*	*1,687,075*	*940,788*	*3,214,800*	*4,298,739*	*5,545,830*	*5,287,980*	*5,425,744*	*6,225,690*	*4,187,325*	*4,152,600*	*4,508,516*
Thrivent Aid Association	AE086, AE087, EM215		17,257,700	18,523,700	13,816,200	15,957,146	14,545,950	20,705,350	20,705,350	22,860,348	13,878,542	1,041,250	114,710	0
Fox Valley Technical College			3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,500	3,458,600
SEASONAL														
Eagle Link Golf Course	KQ496	1892	*0*	*0*	*0*	*188,161*	*1,289,065*	*2,495,865*	*2,842,575*	*2,355,080*	*1,208,725*	*0*	*0*	*0*
Country Aire Farms	MV479	2580	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000	2,160,000
Country Aire Farms	SG743	67732	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000
USA Youth	LG839	1873	*0*	*0*	*0*	*0*	*0*	*0*	*491,500*	*983,000*	*294,900*	0	0	0
Riverview Country Club		2205	0	0	0	181,000	893,000	2,028,000	3,337,000	1,156,000	652,000	0	0	0
Paper Valley Corp (Chaska Golf)	BC615	21705	0	0	0	0	0	1,085,400	2,796,120	1,529,280	0	0	0	0
Paper Valley Corp (Chaska Golf)	BC614	21704	0	0	0	1,720	9,980	58,820	62,850	28,040	17,760	2,950	827	0
Paper Valley Corp (Chaska Golf)	BC616	21706	0	0	0	0	0	2,005,560	2,677,320	1,672,920	333,720	0	0	0
Fox Valley Golf Club	BC612	21701	0	0	0	300,000	600,000	3,000,000	8,000,000	6,000,000	500,000	30,000	0	0
Reid Municipal Golf Course	BC617	21707	*0*	*0*	*0*	*0*	*1,474,000*	*2,320,000*	*2,449,000*	*4,396,000*	*3,658,000*	*329,000*	*0*	*0*
Royal St. Patrick Dev (Golf Course)	QO558	3499	0	0	0	1,646,640	3,761,760	6,083,280	8,045,280	9,103,200	1,009,200	996,960	0	0
Country Aire Farms	UN534	69343				*8,000*	*9,000*	*12,000*	*18,500*	*19,000*	*18,000*	*18,500*	*18,000*	*18,000*
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,700,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Red text indicates estimated value

Operator/Owner	WUWN	HiCap Perm	Jan 2008	Feb 2008	Mar 2008	Apr 2008	May 2008	Jun 2008	Jul 2008	Aug 2008	Sep 2008	Oct 2008	Nov 2008	Dec 2008
MUNICIPAL														
Darboy			15,564,000	14,814,000	16,067,000	15,037,000	18,666,000	18,064,000	18,512,000	21,111,000	17,301,000	14,651,000	16,836,000	14,843,000
Forest Junction			1,197,000	1,022,000	1,038,000	1,143,000	1,105,000	1,288,000	1,163,000	1,289,000	1,042,000	988,000	978,000	1,179,000
Freedom			2,740,000	2,427,000	3,181,000	2,587,000	3,844,000	3,603,000	4,382,000	4,745,000	4,694,000	4,575,000	4,832,000	5,702,000
Holland			2,318,000	2,221,000	2,719,000	2,544,000	2,430,000	2,272,000	2,282,000	2,695,000	2,265,000	2,077,000	1,972,000	2,155,000
Kaukauna			39,738,000	38,842,000	43,029,000	39,756,000	46,782,000	39,843,100	42,650,000	46,455,999	42,357,000	44,104,000	38,691,000	42,098,000
Kimberly			44,323,000	38,996,000	41,658,000	40,766,000	45,322,000	42,781,000	40,885,000	45,791,000	40,804,000	39,623,000	31,143,000	37,444,000
Little Chute			38,746,000	36,036,000	39,165,000	39,323,999	41,775,000	40,115,000	41,103,000	44,880,000	44,783,000	42,039,000	39,109,000	41,102,000
Village of Wrightstown			6,145,000	5,468,000	6,016,000	5,989,000	7,110,000	6,702,000	7,430,000	8,624,000	8,020,000	8,255,000	7,376,000	7,479,000
INDUSTRIAL														
Appleton Papers	BE770	56433	3,702,994	3,611,665	3,526,792	3,599,681	4,097,335	4,582,751	5,001,582	4,731,062	4,551,184	4,209,407	3,721,892	3,410,740
Brightside Dairy	GO113	1901	585,000	586,800	583,200	588,600	595,800	570,000	579,600	588,600	594,000	561,000	559,800	563,400
Meadowlark Dairy	UA331	68555	1,102,938	743,124	1,060,746	975,168	933,103	867,355	1,019,629	913,346	912,324	532,811	200	
New Horizons Dairy	OP704	3229	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000	10,800,000
Arla Foods	BE296	40510	17,900	59,000	87,000	193,400	2,455,300	3,000,000	3,500,000	3,760,000	3,650,000	4,650,000	4,190,000	4,150,000
Tinedale Farms	MY393	2707	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000
Bud Gerrits	OI192	69341	102,100	102,100	102,100	102,200	112,300	112,300	112,300	112,300	102,100	102,100	102,100	102,100
Foremost Farms USA	BE743	56402	3,888,810	3,491,295	3,539,270	2,802,915	2,786,450	3,760,275	3,955,042	3,994,179	3,768,045	3,169,703	368,640	3,851,796
Foremost Farms USA	BE744	56403	3,888,810	3,491,295	3,539,270	2,802,915	2,786,450	3,760,275	3,955,042	3,994,179	3,768,045	3,169,703	368,640	3,851,796
Foremost Farms USA	BE742	56401	0	0	0	2,740,890	2,800,106	0	0	0	0	2,496,399	2,516,700	0
Ted Vosters (Farm)	HU575	2727	2,290,100	2,111,200	2,017,800	2,233,100	1,821,300	2,213,400	2,133,500	2,144,800	2,031,900	2,139,500	2,144,700	2,301,500
Tidy View Dairy	NC480	2728	998,800	783,900	826,200	846,200	1,145,400	1,255,300	1,413,500	1,404,600	1,308,900	1,253,500	1,107,800	1,021,500
North Lake Village	TP817	2937	76,500	67,500	90,000	90,000	99,000	117,000	117,000	144,000	144,000	90,000	99,000	99,000
Neighborhood Dairy	SU271	67726	1,243,800	1,283,400	1,283,400	1,276,200	1,272,600	1,269,000	1,260,000	1,251,000	1,258,200	1,256,400	1,247,400	1,251,000
Tidy View Dairy	VL576	68045	594,950	570,800	625,000	521,500	649,700	713,900	1,029,200	1,078,900	786,300	735,800	648,300	682,600
Tidy View Dairy	BL577	68046	3,123,900	2,935,600	3,329,400	3,125,500	3,525,500	3,488,100	3,499,100	3,602,700	3,381,300	3,357,100	3,084,400	3,158,600
Ken Verhasselt (farm)	RN063	68384	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000
Ken Verhasselt (farm)	WH934	68385	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000
Belgioioso Cheese	WK846	68858	1,611,876	1,687,075	940,788	3,214,800	4,298,739	5,545,830	5,287,980	5,425,744	6,225,690	4,187,325	4,152,600	4,508,516
Thrivent Aid Association	AE086, AE087, EM215		28,500	2,916,900	4,439,100	8,932,550	10,370,600	18,081,590	20,841,553	14,380,077	15,144,950	12,214,990	9,287,780	10,843,500
Fox Valley Technical College			60,000	0	480,000	1,369,000	4,178,000	9,170,000	12,241,000	11,869,000	4,837,000	1,793,000	370,000	120,000
SEASONAL														
Eagle Link Golf Course	KQ496	1892	*0*	*0*	*0*	*0*	*3,414,200*	*2,119,000*	*1,913,400*	*9,283,900*	*5,161,500*	*431,750*	*0*	*0*
Country Aire Farms	MV479	2580	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500	2,117,500
Country Aire Farms	SG743	67732	164,200	164,200	164,200	174,300	174,300	174,300	184,800	184,800	174,700	174,200	174,200	174,200
USA Youth	LG839	1873	0	0	0	0	0	0	491,500	983,000	294,900	0	0	0
Riverview Country Club		2205	0	0	0	197,000	1,278,000	1,495,000	1,158,000	2,194,000	1,661,000	0	0	0
Paper Valley Corp (Chaska Golf)	BC615	21705	0	0	0	0	0	0	487,080	1,292,760	1,152,360	230,040	0	0
Paper Valley Corp (Chaska Golf)	BC614	21704	0	0	0	4,330	2,040	16,880	26,940	22,390	17,750	1,850	290	0
Paper Valley Corp (Chaska Golf)	BC616	21706	0	0	0	0	462,240	465,480	1,311,120	2,180,520	1,588,680	0	0	0
Fox Valley Golf Club	BC612	21701	0	0	0	259,200	1,036,800	1,728,000	6,819,200	3,073,600	1,652,200	1,068,300	0	0
Reid Municipal Golf Course	BC617	21707	0	0	0	0	1,474,000	2,320,000	2,449,000	4,396,000	3,658,000	329,000	0	0
Royal St. Patrick Dev (Golf Course)	QO558	3499	0	0	0	206,917	206,917	206,917	1,842,002	7,594,603	6,308,789	1,151,395	0	0
Country Aire Farms	UN534	69343	0	0	0	8,000	9,000	12,000	18,500	19,000	18,000	18,500	18,000	18,000
RESIDENTIAL														
Self-supplied domestic wells			*8,525,000*	*7,975,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,525,000*	*8,250,000*	*8,525,000*	*8,250,000*	*8,525,000*

Note: Red text indicates estimated value

APPENDIX 2

ABANDONMENT LOG FOR MCKEEFRY BOREHOLE

State of Wis., Dept. of Natural Resources
dnr.wi.gov

Well / Drillhole / Borehole Filling & Sealing
Form 3300-005 (R 4/08)

[ ] Verification Only of Fill and Seal

Route to: [X] Drinking Water [ ] Waste Management [ ] Watershed/Wastewater [ ] Other: ____ [ ] Remediation/Redevelopment

1. Well Location Information

County	WI Unique Well # of Removed Well	Hicap #
BROWN	WH979	

Latitude / Longitude (Degrees and Minutes): 44° 37.752' N; 88° 13.698' W
Method Code (see instructions):

1/4 / 1/4	1/4	Section	Township	Range	E/W
SW	SW	17	25 N	19	[X] E [ ] W

or Gov't Lot #:

Well Street Address: Quarry Rd
Well City, Village or Town: Town of Pittsfield — Well ZIP Code:
Subdivision Name: — Lot #:

Reason For Removal From Service: end of use — WI Unique Well # of Replacement Well:

2. Facility / Owner Information

Facility Name:
Facility ID (FID or PWS):
License/Permit/Monitoring #:
Original Well Owner:
Present Well Owner: WGNHS
Mailing Address of Present Owner: 3817 Mineral Point

City of Present Owner	State	ZIP Code
Madison	wi	53705-

3. Well / Drillhole / Borehole Information

[ ] Monitoring Well
[ ] Water Well
[X] Borehole / Drillhole

Original Construction Date (mm/dd/yyyy): 3/17/2009
If a Well Construction Report is available, please attach.

Construction Type: [X] Drilled [ ] Driven (Sandpoint) [ ] Dug [ ] Other (specify): ____

Formation Type: [ ] Unconsolidated Formation [ ] Bedrock

Total Well Depth From Ground Surface (ft.)	Casing Diameter (in.)
778	6

Lower Drillhole Diameter (in.)	Casing Depth (ft.)
6	20

Was well annular space grouted? [ ] Yes [X] No [ ] Unknown
If yes, to what depth (feet)? — Depth to Water (feet): 20

4. Pump, Liner, Screen, Casing & Sealing Material

	Yes	No	N/A
Pump and piping removed?	[X]	[ ]	[ ]
Liner(s) removed?	[ ]	[ ]	[X]
Screen removed?	[ ]	[ ]	[X]
Casing left in place?	[X]	[ ]	[ ]
Was casing cut off below surface?	[X]	[ ]	[ ]
Did sealing material rise to surface?	[X]	[ ]	[ ]
Did material settle after 24 hours?	[ ]	[X]	[ ]
If yes, was hole retopped?	[ ]	[ ]	[ ]
If bentonite chips were used, were they hydrated with water from a known safe source?	[ ]	[ ]	[ ]

Required Method of Placing Sealing Material
[ ] Conductor Pipe-Gravity [ ] Conductor Pipe-Pumped
[X] Screened & Poured (Bentonite Chips) [ ] Other (Explain): ____

Sealing Materials
[ ] Neat Cement Grout [ ] Clay-Sand Slurry (11 lb./gal. wt.)
[ ] Sand-Cement (Concrete) Grout [ ] Bentonite-Sand Slurry " "
[ ] Concrete [X] Bentonite Chips

For Monitoring Wells and Monitoring Well Boreholes Only:
[ ] Bentonite Chips [ ] Bentonite - Cement Grout
[ ] Granular Bentonite [ ] Bentonite - Sand Slurry

5. Material Used To Fill Well / Drillhole

Material	From (ft.)	To (ft.)	Sacks Sealant	
3/4" Bentonite Hole Plug	Surface	257	77	
Chlorinated Pea Stone/Yards	257	778	6.5	

6. Comments

7. Supervision of Work

Name of Person or Firm Doing Filling & Sealing	License #	Date of Filling & Sealing (mm/dd/yyyy)
Bill Van De Yacht Water Well, Inc		4/27/2009

Street or Route: 3671 Monroe Rd — Telephone Number: (920) 336-3659

City	State	ZIP Code	Signature of Person Doing Work	Date Signed
De Pere	WI	54115-		

DNR Use Only

Date Received	Noted By

Comments: