MEMORANDUM

TO: Mr. Daniel Duchniak, P.E., Waukesha Water Utility

FROM: John Jansen, Leggette, Brashears & Graham, Inc.

SUBJECT: Predicting Future Water Levels in the Sandstone Aquifer of Southeastern Wisconsin

DATE: November 25, 2015

As per your request, Leggette, Brashears & Graham (LBG) has completed our analysis of water levels in the sandstone aquifer of Southeastern Wisconsin and prepared estimates of the trends in water levels that can be expected in the future. This memo summarizes our methods and findings.

<u>Executive Summary</u>

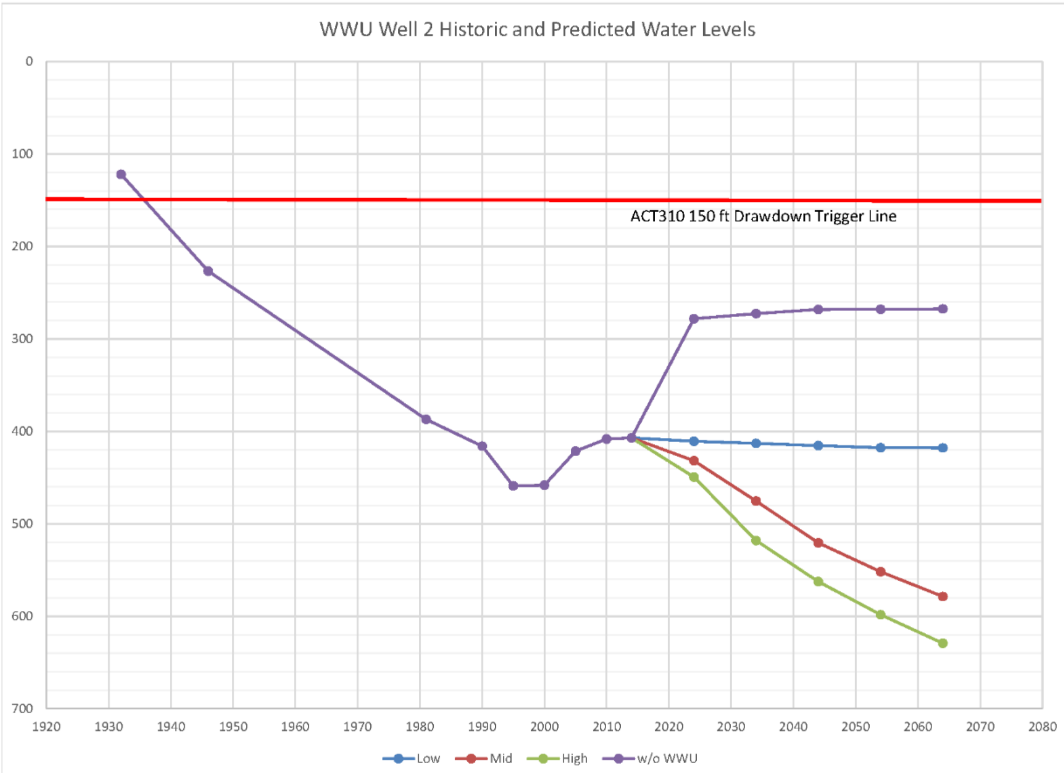
Water levels in the sandstone aquifer of Southeastern Wisconsin declined by hundreds of feet from the early 1900s to 2000. Water levels in the aquifer rose approximately 50 to 100 feet from 2000 to 2010. Our analysis was designed to explain the cause of the recent rise in water levels and predict future trends in the aquifer.

We reviewed municipal pumping data from the WDNR website and found that pumping from the sandstone aquifer in Waukesha County dropped by 49% from 2000 to 2010, largely due to municipal water systems drilling new wells in the shallow aquifer and shifting pumping away from the sandstone to avoid the cost of treating the wells for radium and to a lesser degree to a reduction in pumping that coincides with the recent recession. Using the USGS regional model for Southeastern Wisconsin developed for SEWRPC (SEWRPC, 2010) indicates that the observed rise in water levels was directly caused by the reduction in pumping from the sandstone aquifer.

From 2010 to 2014, pumping from the sandstone aquifer in Waukesha County has increased 9% and sandstone aquifer water levels have begun to decline again.

We predicted future water levels in the sandstone aquifer using the regional model and several potential pumping scenarios. As illustrated in the plot of historic and predicted water levels in the sandstone aquifer in WWU Well 2, the recent rise in sandstone aquifer water levels has ended. In the unlikely event that pumping from the aquifer remains constant, water levels will continue to decline slightly over time. More realistic estimates of future pumping suggest that water levels in the sandstone aquifer will drop another 200 feet or more in portions of Southeastern Wisconsin over the next 50 years. Water levels declines of this magnitude will reduce the pumping capacity of some wells and will cause water quality to deteriorate.

The modeling also demonstrates that existing pumping by the WWU wells has reduced base flow to streams, lakes and wetlands by nearly 5% in several townships, causing adverse environmental impacts.



The modeling also indicates that if the WWU is permitted to use Lake Michigan water and can turn off its wells, water levels in the aquifer will rise approximately 90 to 120 feet beneath the city and over 10 feet in much of Southeastern Wisconsin. The rise in water levels would bring portions of Waukesha country to within 120 feet of the regulatory trigger needed to remove Southeastern Wisconsin from Groundwater Management Area status, assuming pumping does not increase in other wells. A Lake Michigan supply for Waukesha would reduce adverse impacts on the sandstone aquifer and help mitigate adverse environmental impacts to lakes, streams and wetlands.

Introduction

The Cambrian-Ordovician Aquifer System is a thick and extensive sequence of permeable sandstone and dolomite units separated by lower permeability shale units. It covers parts of Wisconsin, Illinois, Minnesota and Iowa. It reaches thicknesses well over 1,000 feet and is commonly called the sandstone aquifer. The USGS has identified the sandstone aquifer as one of the principal aquifer systems in the United States (USGS, 2003).

The sandstone aquifer has been extensively used as a source of water in Wisconsin and Illinois and in several surrounding states for over a century. In the last few decades it has become apparent that pumping from the aquifer has grown beyond the sustainable capacity of the aquifer in several metropolitan areas such as Chicago, Milwaukee, Green Bay, and the Fox Cities. Several of these areas have been forced to reduce or elimínate their reliance on the sandstone aquifer by finding alternative sources of water. Waukesha is the latest area to be forced to acknowledge the limits of the sandstone aquifer and adjust its planning to find an alternative source of water.

A History of Over-Pumping the Sandstone Aquifer

Several communities have faced capacity limitations in the sandstone aquifer in the past. In the 1950s, water levels in the sandstone aquifer in the Green Bay area had declined by over 400 feet from predevelopment conditions and were reaching a point where the future of the aquifer was in question (Krohelski, 1986). By 1957 the City of Green Bay abandoned its wells and switched to Lake Michigan for its water supply. Water levels in the Green Bay region recovered nearly 200 feet over the next few years. However, recovery in the aquifer was temporary. Increased demand from the surrounding Green Bay communities caused water levels in the aquifer to decline again. Between 2005 and 2008, six Green Bay Area communities abandoned their sandstone wells and developed a Lake Michigan water source at a cost of over $106 million. Water levels in the aquifer recovered over 50 feet within the first year with additional recovery in subsequent years (Luczaj and Hart, 2009). As of 2015, the USGS monitoring wells in the Green Bay area indicate that water levels have recovered to within 50 feet or less of simulated predevelopment water levels.

The City of Chicago and Northeastern Illinois used the sandstone aquifer extensively in the 1900s as the region grew and prospered. By the 1980s pumping from the sandstone aquifer in the Chicago region had reached three times the estimated rate of recharge and water levels had declined by over 800 feet in parts of the aquifer. Municipal water supplies in the Chicago region began switching their source of water to Lake Michigan to relieve over pumping of the sandstone aquifer. Water levels in the aquifer recovered 200 feet by 2000. Since then, continued growth in demand in the surrounding communities has caused water levels to decline in the southern and western parts of the Chicago Metropolitan area. The Illinois State Water Survey (ISWS) is predicting that current trends in use of the sandstone aquifer are not sustainable and will dewater portions of the aquifer (ISWS, 2015).

The sandstone aquifer in the Fox Valley (Appleton area) region of Wisconsin is currently experiencing declines in water levels of 2 to 3 feet per year. In addition many communities are dealing with rising sulfate levels in the sandstone aquifer caused by over pumping. Many private water supply wells have experienced elevated arsenic levels tied to the regional decline in water levels. There are few alternate sources of groundwater in the area and the largest surface water body, Lake Winnebago, has water quality issues that make it a more difficult source.

The Sandstone Aquifer in Southeastern Wisconsin

The sandstone aquifer in Southeastern Wisconsin has been a major source of water for the region for over 100 years. By the 1990s it was becoming obvious that just like in other metropolitan areas, the aquifer was being over pumped by the numerous communities in Southeastern Wisconsin and that existing trends were unsustainable. A modeling study funded by a consortium of water utilities in Southeastern Wisconsin (BRA, 1998) determined that future demands on the sandstone aquifer could be expected to create continued declines. A more extensive follow up study by the Southeastern Wisconsin Regional Planning Commission (SEWRPC, 2010) determined that pumping from the sandstone aquifer had created over 500 feet of decline in Waukesha County. In addition, dissolved minerals levels were rising in several deeper wells in response to the heavy pumping.

Figure 1 shows the growth of the cone of depression in the sandstone aquifer in Southeastern Wisconsin from 1950 to 2000. In 1950, while industrial pumping of the aquifer in Milwaukee County was heavy, the cone of depression from pumping was approximately 300 feet deep and centered in western Milwaukee County. By 2000 the cone was approximately 500 feet at its deepest point and centered in eastern Waukesha County.

Figure 2 shows the change in water levels in USGS monitoring well WK-06/19E/02-006, the monitoring well with the longest period of record in the sandstone aquifer in Waukesha County. This monitoring well also happens to be located near the current center of the regional cone of depression in the aquifer. The earliest wells drilled in the sandstone aquifer in the late 1800s reported flowing artesian conditions in Waukesha. The depth to water in this well was 122 feet below the surface in 1932. By 1997 the depth to water dropped to 493 feet below ground level. Unfortunately the water levels were not measured from 2000 to 2013. By 2013 the water level had increased to about 380 feet below ground. The water level in the well has oscillated between about 360 to 380 feet below ground surface for the last two years.

The water level data for this well is typical for the sandstone aquifer in Southeastern Wisconsin showing a steady decline until about 2000 and a limited increase in levels between 2000 and about 2010. **Figure 3** presents the median depth to water in the Waukesha Water Utility (WWU) sandstone aquifer wells from 1983 to 2015. The plot illustrates that water levels reached their deepest levels in most wells between about 1997 and 2002, and then increased between 50 to 100 feet by 2010 to 2012. As in other areas, the recovery in water levels is likely to be a temporary condition caused by short term pumping fluctuations. The rate of increase flattened out in most wells in about 2010 and several wells have shown a small decrease in water levels in the last few years.

Previous groundwater modeling conducted by the USGS for SEWRPC (Feinstein et al, 2005) predicted increased drawdown in the aquifer from 2005 to 2035 based on projected pumping rates that anticipated a continued increase in pumping from the sandstone aquifer to about 39 million gallons per day (mgd) in 2035 (SEWRPC, 2010). **Figure 4** illustrates that water levels in the aquifer were expected to decline across the region with peak declines of about 64 feet in southern Washington County and 32 feet in Kenosha County.

The USGS modeling work used to construct **Figure 4** began before 2005. At that time pumping rates in the sandstone aquifer were believed to be increasing and there were no indications that the pumping rates in the aquifer were deviating from the projections made by SEWRPC based on historic trends and projected population and economic growth. What was not known at the time of the projection was that most communities had begun to switch pumping to the shallow sand and gravel and dolomite aquifers in response to the cost of complying with a new radium standard and concerns over the declining head and deteriorating water quality in the sandstone aquifer. Of the 23 municipal wells drilled in Waukesha County between 1998 and 2010, 21 were drilled in the shallow aquifer and only 2 were drilled in the sandstone. The shallow wells were used to replace existing sandstone wells or used to blend down radium levels in existing sandstone wells thereby significantly reducing the pumping from the sandstone aquifer. Many of these new wells in the sand and gravel aquifer were controversial and fostered public opposition and litigation over concerns over impacts on surface water and the environment.

Predicting Future Water Levels in the Sandstone Aquifer

Pumping from the sandstone aquifer has not followed SEWRPC (2010) projections. The recent rise in water levels was unexpected and created some degree of uncertainty about future aquifer conditions. We used our updated pumping data and the regional groundwater model to evaluate if the change in pumping rates was sufficient to explain the recent change in water levels and predict future water levels in the aquifer based on possible future pumping conditions.

To obtain current pumping data for the sandstone aquifer we extracted the 2000 and 2005 pumping rates from the SEWRPC groundwater model (SEWRPC, 2010) and downloaded municipal pumping data for 2010 through 2014 from the WDNR website. This approach does not capture changes in pumping from industrial and non-municipal wells, but those wells represent less than 10% of the wells in the SEWRPC model (Feinstein et al, 2005) and most of those wells are constructed in the shallow aquifer. Non-municipal and industrial pumping from the sandstone aquifer was estimated to be 15.7 mgd in 1975 but only 3.4 mgd in 1995 (BRA, 1998). Industrial and non-municipal pumping from the sandstone is believed to have continued to decline since 1995. As such, the pumping from the sandstone aquifer attributed to these wells is minimal compared to municipal pumping.

Figure 5 illustrates the change in pumping from the sandstone aquifer from 2000 to 2014 for Waukesha County. Pumping from the sandstone aquifer peaked in 2000 at about 21.1 mgd and dropped 49% to 10.7 mgd by 2010. The drop in pumping from the sandstone aquifer coincides with the rise in water levels in the aquifer and suggests a natural response to the shift in pumping from the sandstone to the shallow aquifer system. Pumping from the sandstone aquifer in Waukesha County rose 9% from 2010 to 2014 which suggests the apparent trend toward declining water levels in the last few years is real and represents a return to the trend of falling water levels in the sandstone aquifer.

Predicting future water levels in the sandstone aquifer requires accurately predicting future pumping rates. Recent experience demonstrates how unforeseen regulatory or economic factors can upset short-term predictions based on historic trends. In the past, short-term rises in water levels in the sandstone aquifer in other places have been followed by a return to declining water levels as growing demand for water drove increased pumping in surrounding areas.

By necessity, prediction of future pumping levels requires a series of projections and estimates that are inherently uncertain. To address this, we prepared three sets of projections of future regional pumping rates based on current economic and regulatory forces. The upper two levels of predicted pumping rates are based on different assumptions as to which factors will dominate future development in the aquifer and bracket the range of reasonable scenarios that can be expected. The low range simulations are based on the assumption that pumping from the sandstone aquifer will remain flat at current usage. While this scenario has been proposed by the Compact Impact Coalition (CIC, 2015), it is not consistent with regional projections and historic patterns from other areas and does not account for the increased pumping from the aquifer since 2010. While we included the low-level pumping scenario in our simulations, it is considered to be very unlikely to reflect future pumping and perhaps is most useful to compare future changes to current conditions.

To predict future changes in pumping rates we used estimates prepared by SEWRPC for the period between 2005 and 2035 (SEWRPC, 2010). These projections were based on historical trends in pumping in each community and projections of economic and population growth by community.

The pumping data we collected for this study indicated that the SEWRPC projections did not predict the significant reduction in pumping that was observed from 2005 to 2010, particularly in the sandstone aquifer. While many factors such as increased water conservation are probably involved, the recent recession was not anticipated and probably caused some of the disparity. Most of the reduction in pumping from the sandstone aquifer was a result of municipal water utilities developing new wells in the sand and gravel aquifer or switching to Lake Michigan water and shifting pumping away from the sandstone aquifer. This change appears to have been a response to enforcement of the radium standard that made water from the sandstone aquifer more expensive to treat and concerns over the sustainability of the aquifer. Recent changes in well permitting requirements have made developing wells in the shallow aquifer more difficult and time consuming and there is likely to be a renewed interest in the sandstone aquifer for new wells.

The changes in pumping that occurred from 2005 to 2010 appear to be from one or more short term factors and future pumping can be expected to return to projections based on long term averages and economic and population projections. We applied the SEWRPC average annual rate of pumping increase for projected rates of growth from 2005 to 2035 and applied this rate of increase starting in 2015 to 2064. We used the SEWRPC mid-level and high-level projections with continued conservation to develop our Mid-Level and High-Level Pumping Scenarios. These three pumping scenarios can be summarized as follows:

1) **Low-Level Pumping Scenario**. This scenario assumes flat-water demands for water and flat pumping rates. It is unclear exactly how much of the decline in pumping from the sandstone aquifer prior to 2010 has been caused by the recent recession and how much future conservation can partially offset water demand from population and economic growth. While this scenario was included in the modeling work, long-term projections indicate increasing water demand in the future and this scenario is not considered a reasonable projection of future conditions. Pumping data from the last few years indicates that pumping from the sandstone aquifer has begun to increase by about 2% per year since 2010.

2) **Mid-Level Pumping Scenario**. This scenario assumes that general economic recovery following the recent recession will cause water demands to return to growth following SEWRPC (2010) mid-level growth projections. Based on historic averages, this scenario can be viewed as the most likely prediction of future pumping if Waukesha is not allowed to use Lake Michigan water. The projected growth rate varies by community and includes estimates of future water conservation. The projected growth rate by community for the SEWRPC area range from 0.9 to 35% per year as provided on **Table 1.** The highest growth rates generally apply to small communities with low water use so they do not impact the overall increase in water usage as much as larger communities which tend to have lower projected rates of increase. **Figure 6** illustrates the projected rates for the municipal systems in Waukesha County. Similar pumping projections were prepared for the other 6 counties in the SEWRPC service area.

   Given that both the shallow aquifer and the sandstone aquifer have limitations that complicate siting new wells, it is impossible to predict which aquifer will be the preferred alternative for future demand. We assumed that the additional pumping will be split evenly between the sandstone and shallow aquifers for communities that have wells in both aquifers. In those cases we assigned the increased pumping to existing wells with half going to the sandstone aquifer and half going to the shallow aquifer. Geologic or environmental conditions limit the use of the shallow or the deep aquifer in some parts of the SEWRPC area and it is not reasonable to assume that future demands could be split between both aquifers in all areas. We assumed that communities that are currently only using one aquifer have legitimate reasons for that historic practice and will want to follow similar patterns in the future. We assigned all of the pumping to the aquifer in current use for communities that only use one aquifer. The net result was an annual increase in pumping from the sandstone aquifer of about 2.4% in Waukesha County, which is close to the rate of increase observed since 2010.

3) **High-Level Pumping Scenario**. This scenario assumes that economic growth will cause water demand to follow SEWRPC's high-level growth projections. History shows that high growth projections tend to overestimate future conditions, particularly in later years. While we have no way of knowing, it is likely that the estimated rate of growth in this scenario would not be sustained for extended periods. We included these projections to frame the high end of demand that could be forecasted from available data, recognizing that actual demand will probably be lower. This scenario can be thought of as a worst-case scenario and is useful in setting the upper bounds for potential impacts. We also assume that concerns over surface water impacts from groundwater development in the shallow aquifer will drive most communities to meet new demands from sandstone aquifer wells. We assigned all of the increased demand to the existing sandstone aquifer wells except for communities that do not use the sandstone aquifer due to geologic or other factors. In those cases the pumping was assigned to the communities existing wells in the shallow aquifer. The projected growth rate range from 3.3 to 42.1 per year as provided on **Table 1. Figure**

6 illustrates the projected rates for the municipal systems in Waukesha County. Similar pumping projections were prepared for the other 6 counties in the SEWRPC service area.

Simulated Water Levels in the Sandstone Aquifer

There are no current maps of the water level in the sandstone aquifer based on recent measurements from wells in the aquifer that reflect the recent short term increase in the aquifer levels. To estimate current conditions in the aquifer we updated the SEWRPC groundwater model (Feinstein et al., 2005 and SEWRPC, 2010) to include the 2010 and 2014 pumping rates for the municipal wells in the seven county SEWRPC service areas. We ran the model to predict the current head in the aquifer and estimate the change in water level in the aquifer around the SEWRPC area.

Because we are using an existing model that has been extensively calibrated we did not perform any additional calibration that would change the model design. We compared the predicted water level to the observed water levels in several of the WWU wells as a means to confirm the model was performing as expected. **Figure 7** presents the modeled water levels from 2005 to 2014 at WWU Well 6. The model reproduced the water level increase at this well within about 10 to 20 feet which is considered to be a reasonable correlation.

Direct comparisons between the model results and water levels observed in pumping wells has limitations. Pumping rates in the wells vary from day to day within a specific well and within the well field. The model was not designed with time steps to account for daily or hourly changes in pumping rates. It uses average daily pumping rates over a time step of five years so it calculates a single water level value that represents the average pumping rate for the well and surrounding wells. **Figures 2 and 3** demonstrate that water levels in the aquifer vary by tens of feet on time scales of a few days to a few years depending on short-term variations in pumping.

As a result, a direct comparison of modeled water levels and observed water levels from specific wells will depend on how closely the modeled pumping rate matches the variations in actual pumping rates in the well and to a lesser degree in the surrounding wells. For most wells the correlation between modeled and observed changes in water levels was within 10 to 20 feet. For example, for Waukesha Water Utility (WWU) Well 7, the model predicts 30 feet less increase than observed, and in WWU Well 9 the model predicts 40 feet more drawdown than was observed. These anomalies are believed to be a result of short-term variations in pumping rates at these wells and not an indication of a limitation of the model to predict long-term trends. Given these variables, the model appeared to be simulating the general trend in water levels reliably but short period variations in individual wells were not simulated and caused the degree of correlation between the modeled and observed results to vary by well and time period.

Figure 8 presents the results of the model simulation for 2014 water levels. The modeled water levels are presented in elevation above mean sea level (msl) which removes the effects of topography. Maps that show depth to water over large areas incorporate changes in the elevation of the land surface and can create the illusion of lower water levels in areas with higher surface elevations. Presenting regional water levels as elevation data eliminates this problem and allows the water levels in the aquifer to be more easily understood. Increasing depth to water corresponds to more drawdown and lower elevation and decreasing depth to water corresponds to less drawdown and high water elevation.

The recent reduction in pumping from the aquifer has caused water levels in the center of the cone of depression to rise by about 50 feet in eastern Waukesha County. The change in the surrounding area is smaller, which would be expected based on the lesser degree of change in the pumping rate in the aquifer outside of Waukesha County.

Figure 9 presents the future water levels in the aquifer under the Low-Level Pumping Scenario that assumes current pumping rates are maintained for the next 50 years. **Figure 10** presents the change in water levels from 2014 to 2064. Under this no growth scenario water levels still decrease slightly. Water levels in the aquifer can be expected to decline about 20 feet in the eastern portion of the SEWRPC service area and less than 10 feet in the western portion. However, it is not reasonable or good planning practice to assume no increase in future water demand, and this simulation is not a reliable prediction of future water levels. In fact in the last five years there was a 9% increase in demand. Any increase in growth during this period will result in additional declines in the water levels in the aquifer. This scenario is included as a modeling exercise at current sandstone aquifer pumping rates to be used for comparison with simulations of other pumping scenarios.

Figure 11 presents the predicted water level in the sandstone aquifer for the Mid-Level Pumping Scenario in 2064. The model predicts that water level in the aquifer will decline significantly if pumping rates follow the Mid-Level pumping predictions. The predicted water levels drop to an elevation of below 150 feet mean sea level (msl) in the center of the cone of depression and below 250 feet msl in Racine and Kenosha Counties. **Figure 12** presents the change in water levels from 2014 to 2064. Water levels decline 200 feet in parts of Milwaukee, Ozaukee, Washington and Waukesha Counties and over 100 feet in much of the SEWRPC area. This is a significant change that will dewater portions of the sandstone aquifer and may affect the ability of the aquifer to supply water in some wells. The model results indicate that the Mid-Level Pumping Scenario pumping rates will create future water supply problems for the region.

Figure 13 presents the predicted water level in the sandstone aquifer for the High-Level Pumping Scenario in 2064. The model predicts that water level in the aquifer will decline even more significantly than for the Mid-Level pumping predictions. The predicted water levels drop to an elevation of below 100 feet msl in the center of the cone of depression and below 200 feet in much of Milwaukee County and in significant portions of Ozaukee, Washington and Waukesha Counties. **Figure 14** presents the change in water levels from 2014 to 2064. Simulated water levels decline over 300 feet in portions of Washington and Ozaukee Counties and over 200 feet in much of Milwaukee County and in significant portions of Ozaukee, Washington and Waukesha Counties. Water levels will decline over 100 feet in much of the SEWRPC area. This is a significant change that will dewater portions of the sandstone aquifer and may affect the ability of the aquifer to supply water in some wells. The model results indicate that the High-Level Pumping Scenario pumping rates will create future water supply problems for the region.

Regional Drawdown from Waukesha's Current Water Supply

As industrial pumping declined in Milwaukee County and municipal pumping increased in Waukesha County, the center of the cone of depression in the aquifer migrated from Milwaukee County to Waukesha. The WWU has been the largest user of the sandstone aquifer for the past several decades. By the mid-1990s WWU was becoming concerned about the declining water levels in the sandstone aquifer and the rising salinity in several of its wells. The concerns have culminated in an application for a Lake Michigan supply with return flow to replace groundwater supplies. In addition to providing a sustainable source of water, cessation of pumping by WWU would have significant benefits to Waukesha County and the whole SEWRPC region. To estimate the magnitude of the regional benefits we conducted additional model simulations using the Low-Level Pumping Scenario pumping rates but with the pumping from the WWU wells set to zero. The Low-Level Pumping Scenario was used because it eliminates future changes in pumping rates and allows the impacts from eliminating WWU pumping to be isolated from other factors.

Figure 15 presents the predicted head in the sandstone aquifer in 2024 with the WWU wells turned off in 2014. **Figure 16** shows the recovery in the aquifer in the same time period. The two maps show that shutting down the WWU wells will create about 90 to 100 feet of increase in water levels in Waukesha within ten years with over 10 feet of increase in most of the SEWRPC area. **Figure 17** presents the predicted head in the sandstone aquifer in 2064 with the WWU wells turned off in 2014. **Figure 18** shows the recovery in the aquifer from 2014 to 2064. The area of recovery expands slightly but little change occurs in Waukesha beyond the 90 feet of recovery that occurred in the first ten years.

Figure 19 is a hydrograph of the historic water level data from WWU Well 2 with predicted water levels for the Low-Level, Mid-Level and High-Level pumping scenarios and for the Low-Level Pumping Scenario with the WWU wells turned off. The plot clearly illustrates how water levels consistently dropped from the 1930s to about 2000, dropping by about 350 feet over 70 years. Water levels recovered about 50 feet from 2000 to 2010. The future water levels in the aquifer will depend on future pumping. If current pumping rates are held constant, water levels will decline very slowly over the next 50 years. More realistic pumping scenarios suggest aquifer levels will decline by 175 to 200 feet over the next 50 years. However, if the WWU wells were turned off, water levels will recover by about 120 feet in Well 2. This recovery would bring water levels to within about 120 feet of the Groundwater Management Area (GMA) designation of more than 150 feet of drawdown as defined by 2003 Wisconsin ACT 310.

The recent reduction in pumping rates in combination with removing the pumping from WWU would result in approximately 200 feet of recovery in the cone of depression in the sandstone aquifer of Southeastern Wisconsin, assuming pumping in other wells does not increase. While this represents a substantial improvement in aquifer conditions, there will still be approximately 250 to 300 feet of drawdown from predevelopment conditions so the area would still fall under the GMA designation. While not suffiecient to eliminate the GMA designation for Southeastern Wisconsin, this recovery is a major and necessary step toward that goal. Similar reduction in pumping from other utilties in Waukesha and adjacent counties would be needed to reduce drawdown to levels below the trigger level. While it is not clear how these additional reductions in pumping would be accomplished, it is clear that meeting those targets would be nearly impossible without reducing or eliminating the sandstone pumping from the WWU wells.

Adverse Environmental Impacts of Waukesha's Current Water Supply

Like any groundwater pumping, the pumping from the WWU wells has reduced groundwater discharge to surface water. Groundwater discharge to surface water is an important component of stream flow, particularly in the winter or during periods of low precipitation. The contribution of groundwater to streams, lakes and wetlands is called base flow and is important for maintaining aquatic environments for wetland vegetation and aquatic life. Reducing groundwater pumping generally can be expected to improve base flow in streams and other surface water features.

WWU pumping from the deep aquifer creates a regional cone of depression in the sandstone aquifer that induces flow from the shallow aquifer, primarily from areas where the Maquoketa Shale is absent a few miles west of the city and to a lesser degree through the shale where the Maquoketa shale is present. The impacts to surface water from pumping the sandstone wells happen more slowly but affect larger areas. The shallow wells, Wells 11, 12 and 13, pump from the sand and gravel aquifer near the Fox River and Vernon Marsh. The pumping from these wells reduces the flow in the shallow aquifer in a smaller area around the well field. The surface water impacts from pumping the shallow wells has a more immediate impact on base flow in surface water but the changes tend to be restricted to the area around the well field.

We estimated the impact of the current groundwater pumping from the WWU well field by adjusting the pumping in the WWU wells to zero in the groundwater model and looking at the change in discharge to the surface water elements in the model for a period of 50 years. It should be noted that the SEWRPC model is a regional model with a minimum grid spacing of one half mile which is fairly coarse compared to the size of most streams and surface water features. Because of its design, the model is not ideally suited to simulate groundwater discharge to surface water features. Other models have been developed for the area (Ruekert & Mielke 2009, Feinstein et al 2009) to address this concern. Unfortunately these models do not include the sandstone aquifer so they cannot be used to estimate the change in base flow to surface water from changes in the sandstone aquifer. SEWRPC (2010) addressed this problem by using the regional model to look at changes in base flow from several pumping scenarios by calculating impacts over large areas, a process they called Base Flow Reduction Index. We applied a similar approach by calculating the change in simulated surface water flows on a township level to determine the magnitude and distribution of the change in base flow over time.

Shutting off the WWU wells causes base flow to increase. The distribution of the changes is a function of the location of the pumping, the geology of the aquifers, and the relative abundance of surface water features to receive groundwater discharge in an area. **Figure 20** shows the distribution of the increase in base flow by township in Waukesha County for the period a short time after the wells are turned off. The initial increase is on the order of 473,000 gallons per day (gpd) in Waukesha County and 594,000 gpd for the SEWRPC area. Base flow tends to increase the most in the area around Wells 11, 12, and 13 and near Vernon Marsh and the lakes west and north of the city. The increase seen in the southwest portion of the county near Vernon Marsh is probably largely due to the recovery in the shallow aquifer from the removal of Wells 11, 12, and 13. The changes in the western and northern parts of the county are probably caused by reduced induced recharge from the shallow aquifer to the sandstone aquifer in response to the reduced drawdown in the sandstone aquifer.

The rate of change increases rapidly over the first 10 years and then changes more slowly over the following 40 years. By 2064 the increase in base flow from current conditions is on the order of 2.2 mgd in Waukesha County and 4.3 mgd for the SWRPC area. To put this in some perspective, the increase in base flow represents an increase of 1% for the SEWRPC area and 2% for the county. After 50 years there is still over 1 mgd of reduced pumping that has not shown up as increased surface water flow. This probably represents a slow replenishment of the storage volume of the sandstone aquifer which will slowly show up as increased base flow as the sandstone aquifer slowly reaches a new equilibrium. While the absolute magnitude of the changes on base flow are small compared to regional surface water flows, the increase in specific townships can be nearly 5%, which could be significant during droughts.

Conclusions

The cost of complying with the radium standard in drinking water and economic factors caused pumping rates in the sandstone aquifer to decrease by nearly 50% from 2000 to 2010. Water levels in the sandstone aquifer in Waukesha County rose 50 to 100 feet in response. The rise in water levels in the aquifer has stopped and water levels appear to be dropping again. Future water levels in the aquifer will depend on future pumping rates. Some have suggested that future conservation measures will offset population growth and pumping from the aquifer will remain flat. Under those assumptions the water levels in the aquifer will remain essentially constant for as long as the pumping rates do not increase. However, the aquifer water levels would still be hundreds of feet below pre-development levels and well below the 150-foot Groundwater Management Area criteria.

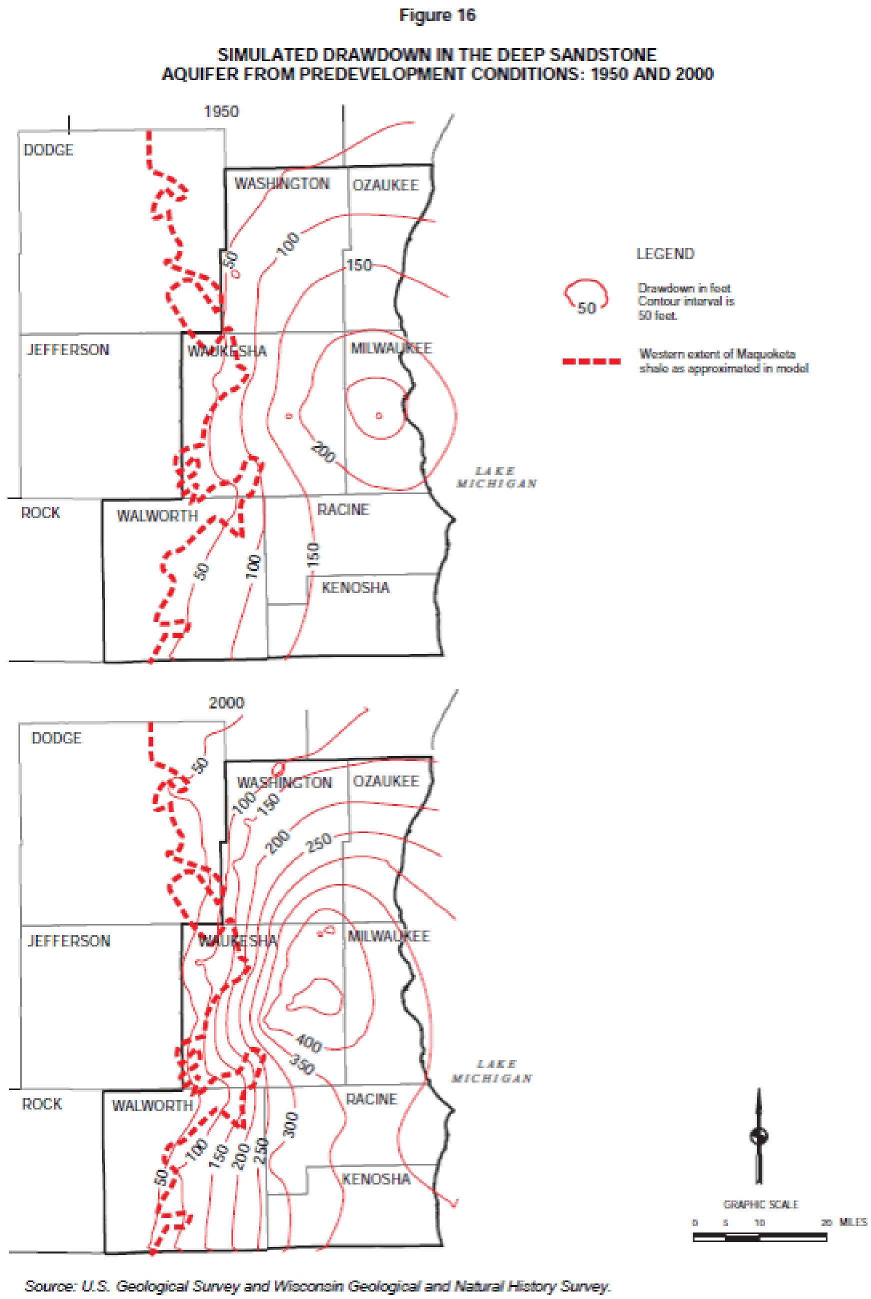
In the past, recoveries in the sandstone aquifer in other areas have proven to be temporary as population growth led to increased demand on the aquifer and a return to declining water levels. Pumping rates in the sandstone aquifer increased by 9% from 2010 to 2014. Using future water demand projections from the regional planning commission to predict water levels in the sandstone aquifer suggests that water levels may decline by 200 to 300 feet from current conditions over the next 50 years in portions of the SEWRPC service area. Drawdown of this magnitude will expose portions of the aquifer to the atmosphere, which may mobilize toxic metals, and may inhibit the ability of some wells to supply water. The decline in head and dewatering of portions of the aquifer may cause water quality to deteriorate beyond the recent changes that have been observed.

In recent decades, the WWU has been the largest single user of the sandstone aquifer in Southeastern Wisconsin. Over the last decade WWU has begun to use the shallow aquifer as well.

The current groundwater pumping by the WWU has had local and regional impacts on the groundwater as well as on the rivers, lakes, wetlands and streams of Southeastern Wisconsin. If WWU were to cease pumping groundwater, an additional recovery of about 90 feet would occur in the sandstone aquifer within Waukesha with over ten feet of recovery over much of the SEWRPC area. Removing the WWU pumping would also increase groundwater discharge to surface water and would increase base flow to streams and wetlands by nearly 5% in several townships. Most of the increase in base flow will happen in the first 10 to 20 years with small increases occurring more than 50 years after pumping stops. The current WWU well field has significant impacts on the groundwater and surface water resources of Southeastern Wisconsin.

Table 1: Summary of Assumed Pumping Rate Annual Increases

	Mid-Level Pumping Scenario		High-Level Pumping Scenario	
County	Range (%/yr)	Average (%/yr)	Range (%/yr)	Average (%/yr)
Kenosha	7.5-28.0	10.2	8.9-32.0	11.9
Ozaukee	3.8-5.9	4.5	4.3-6.8	5.5
Racine	0.9-35.0	5.7	3.3-42.1	5.9
Walworth	3.7-13.3	5.6	4.2-15.0	6.5
Washington	4.7-8.3	6.1	5.4-9.4	6.9
Waukesha	4.2-21.7	4.4	4.8-25.0	5.1



(SEWRPC, 2010)

Figure 1: Growth of the Regional Cone of Depression the Sandstone Aquifer In Southeastern Wisconsin.

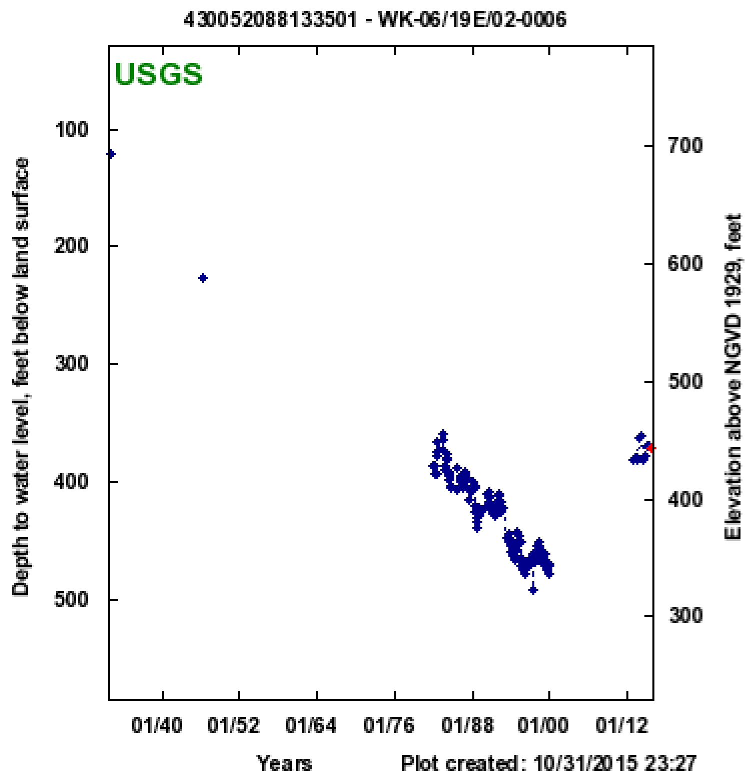


Figure 2: Water levels in USGS Monitoring Well WK-06/19E/02-006

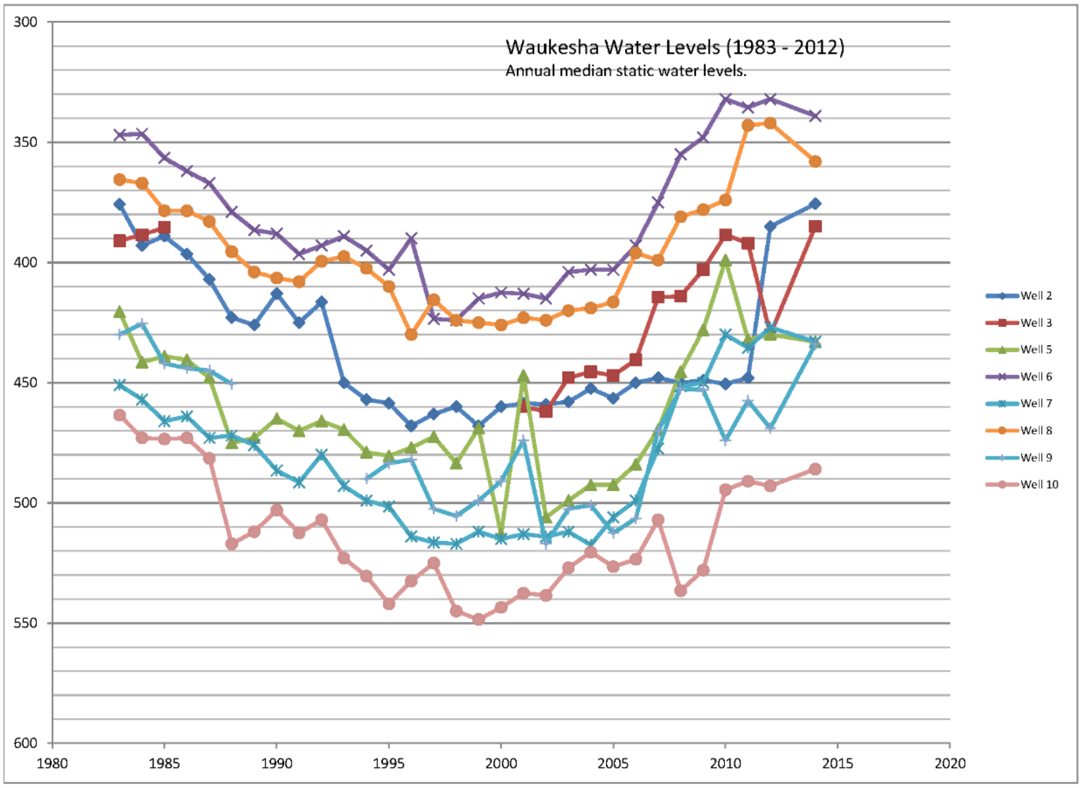


Figure 3: Median Depth to Water in the WWU Sandstone Aquifer Wells

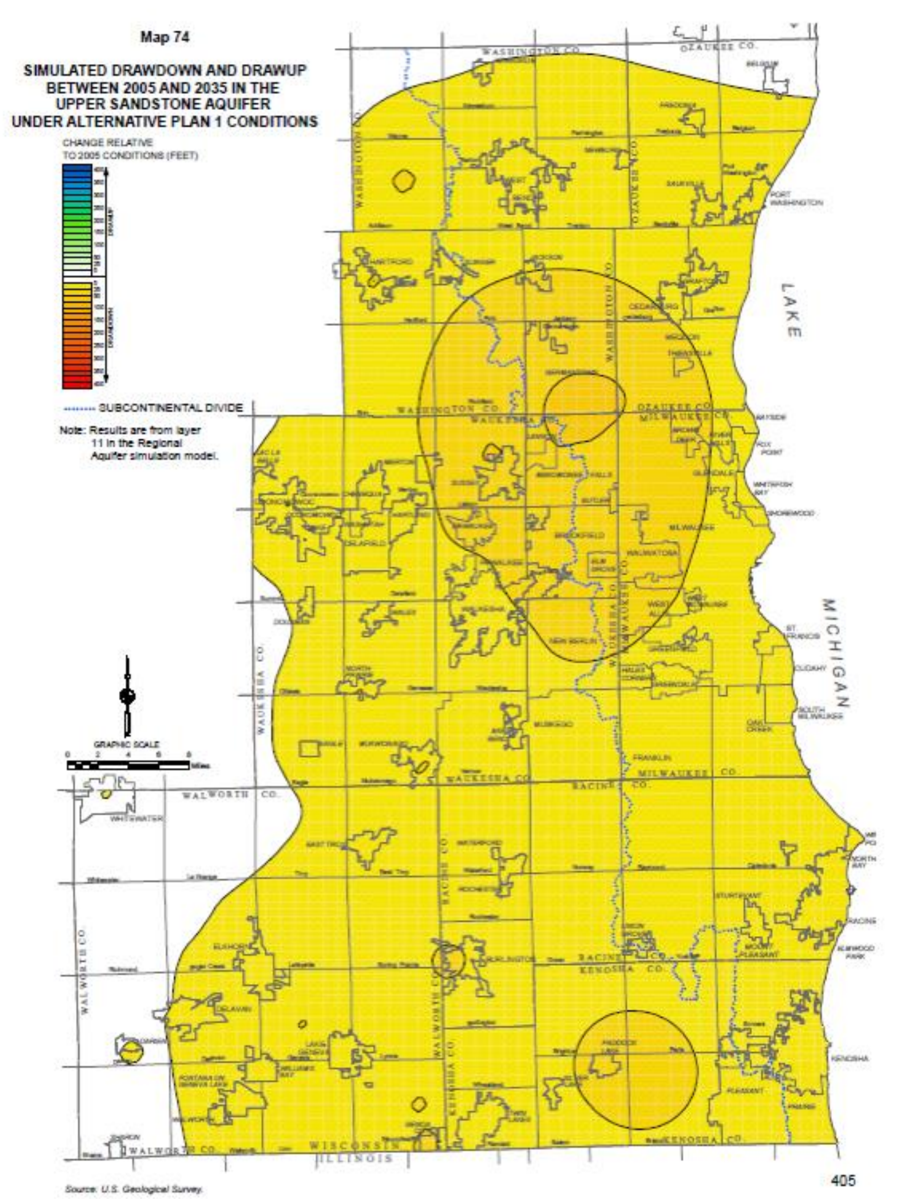


Figure 4: Predicted Additional Drawdown in the Sandstone Aquifer of Southeastern Wisconsin Using SEWRPC (2010) projected Pumping rates

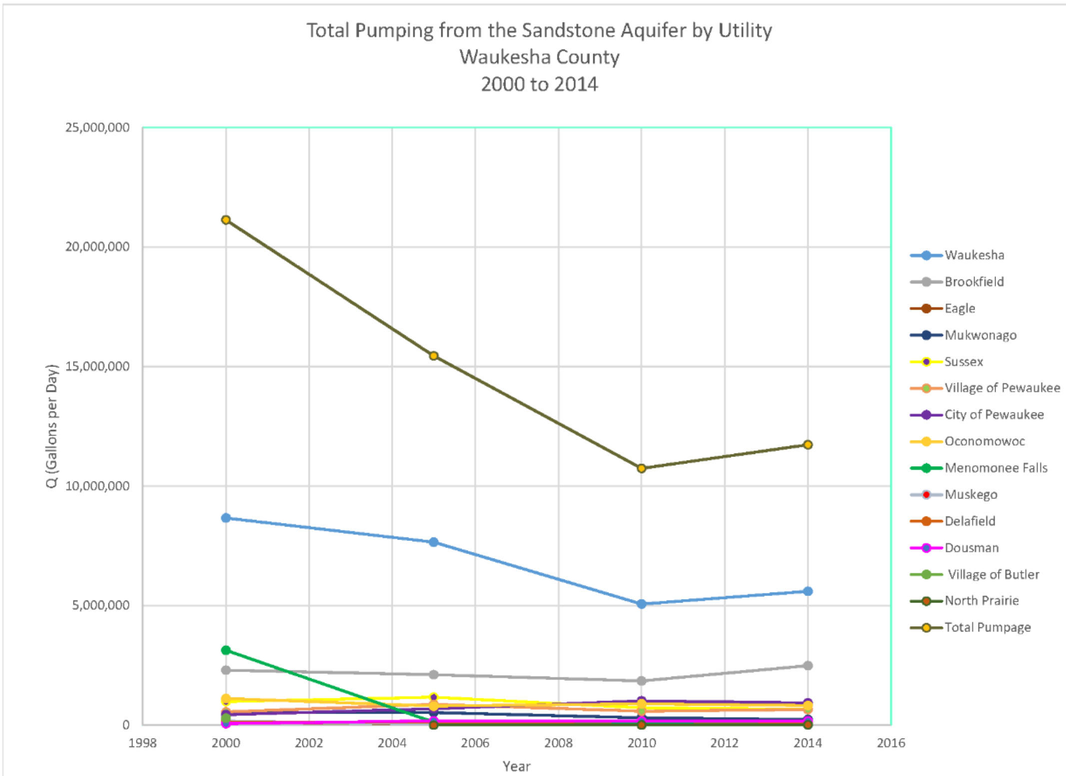


Figure 5: Changes in Pumping from the Sandstone Aquifer in Waukesha County 2000 to 2014

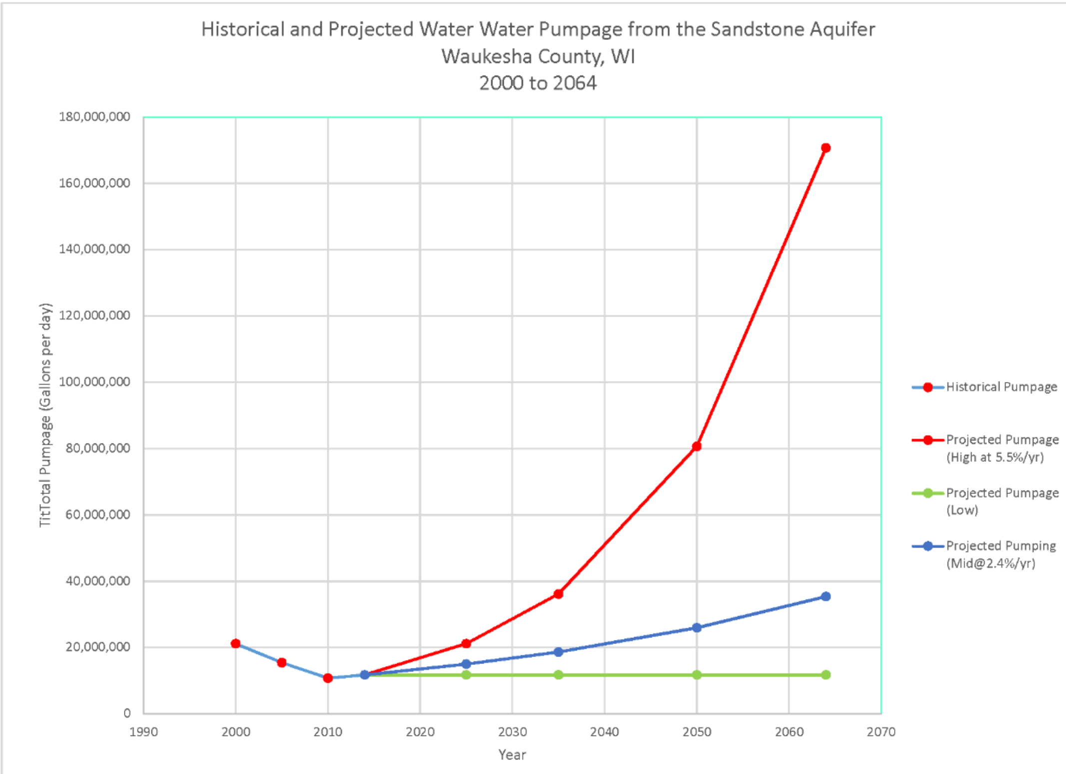


Figure 6: Projected Pumping Rates in Waukesha County

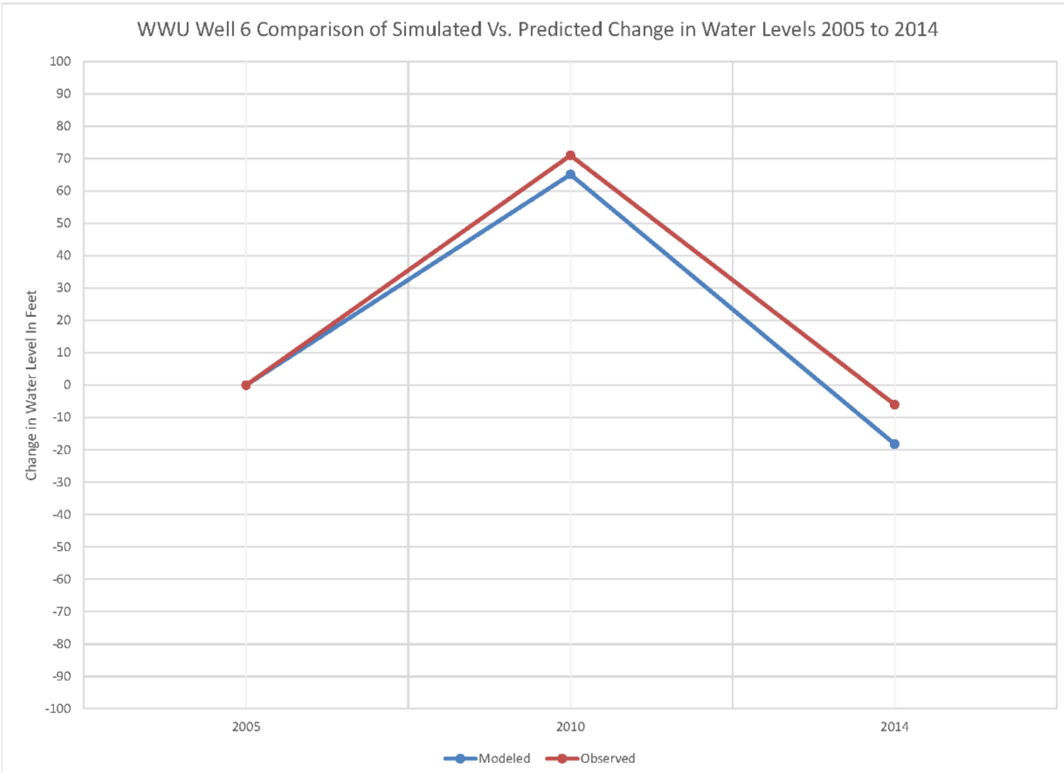


Figure 7: Simulated Vs. Observed Recovery in WWU Well 6

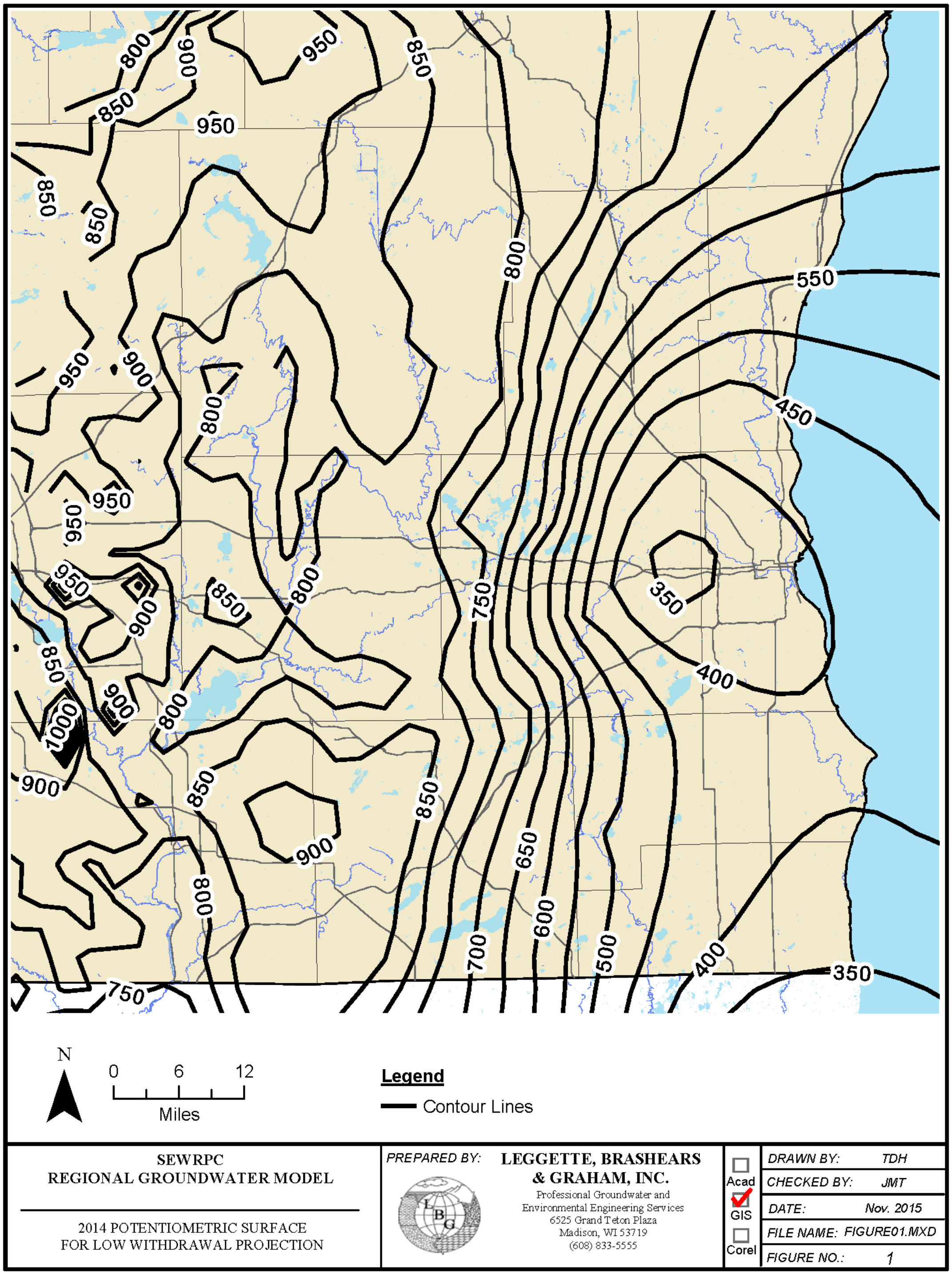


Figure 8: Modeled 2014 Water Levels in the Sandstone Aquifer

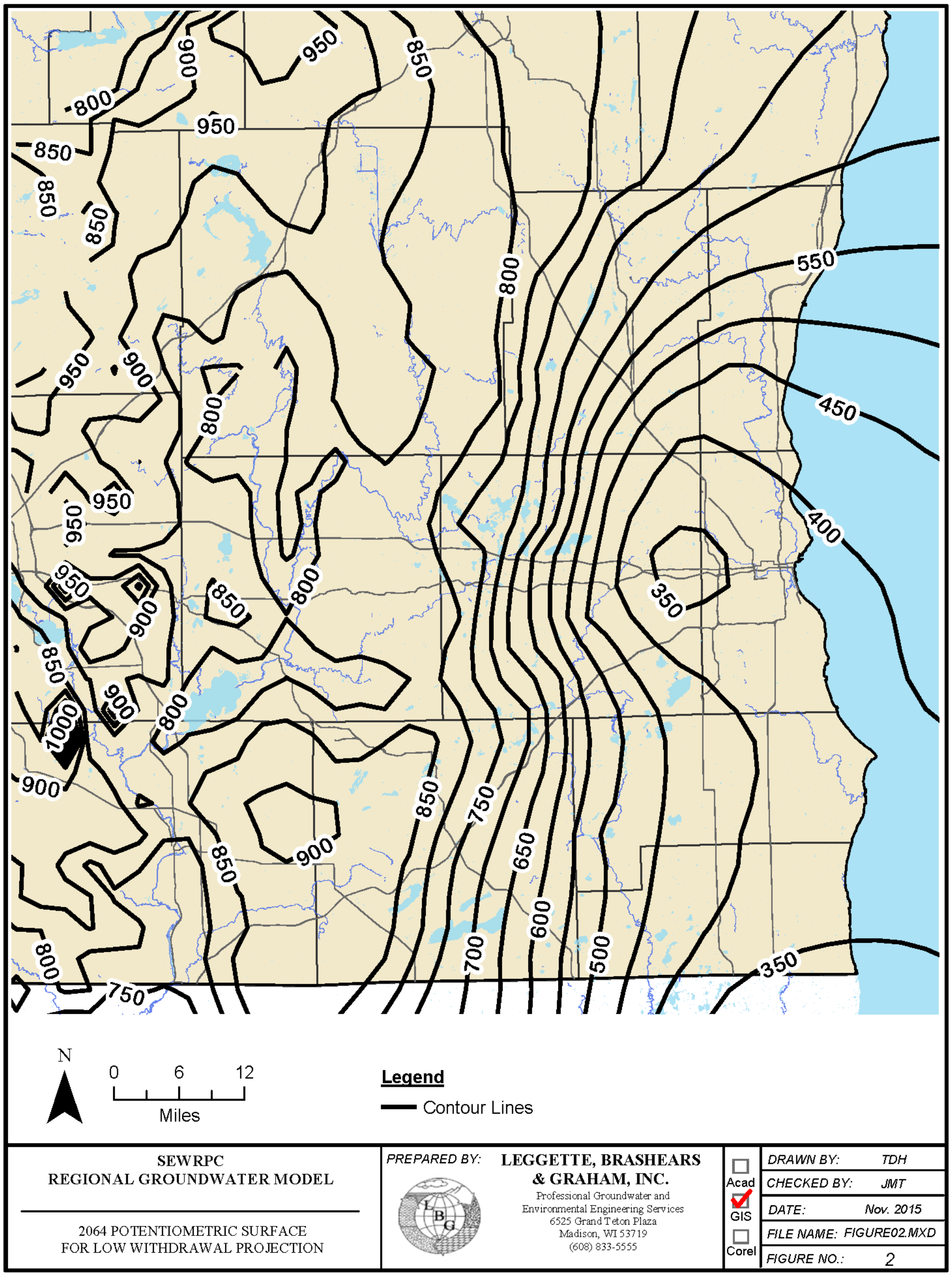


Figure 9: Predicted 2064 Water Levels in the Sandstone Aquifer Using Low-Level Pumping Rates

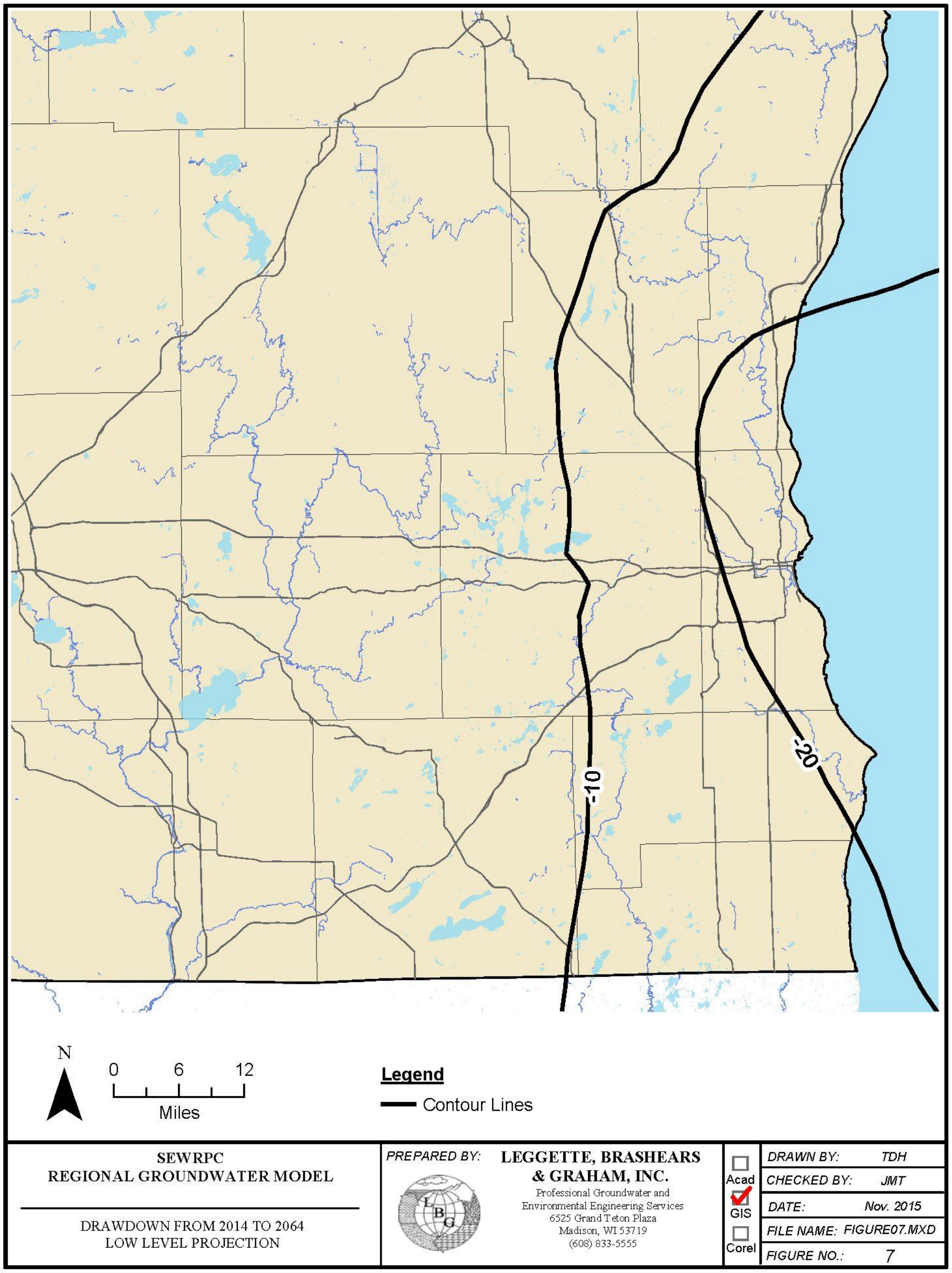


Figure 10: Predicted Change in Water Levels in the Sandstone Aquifer From 2014 to 2064 Using Low-Level Pumping Rates

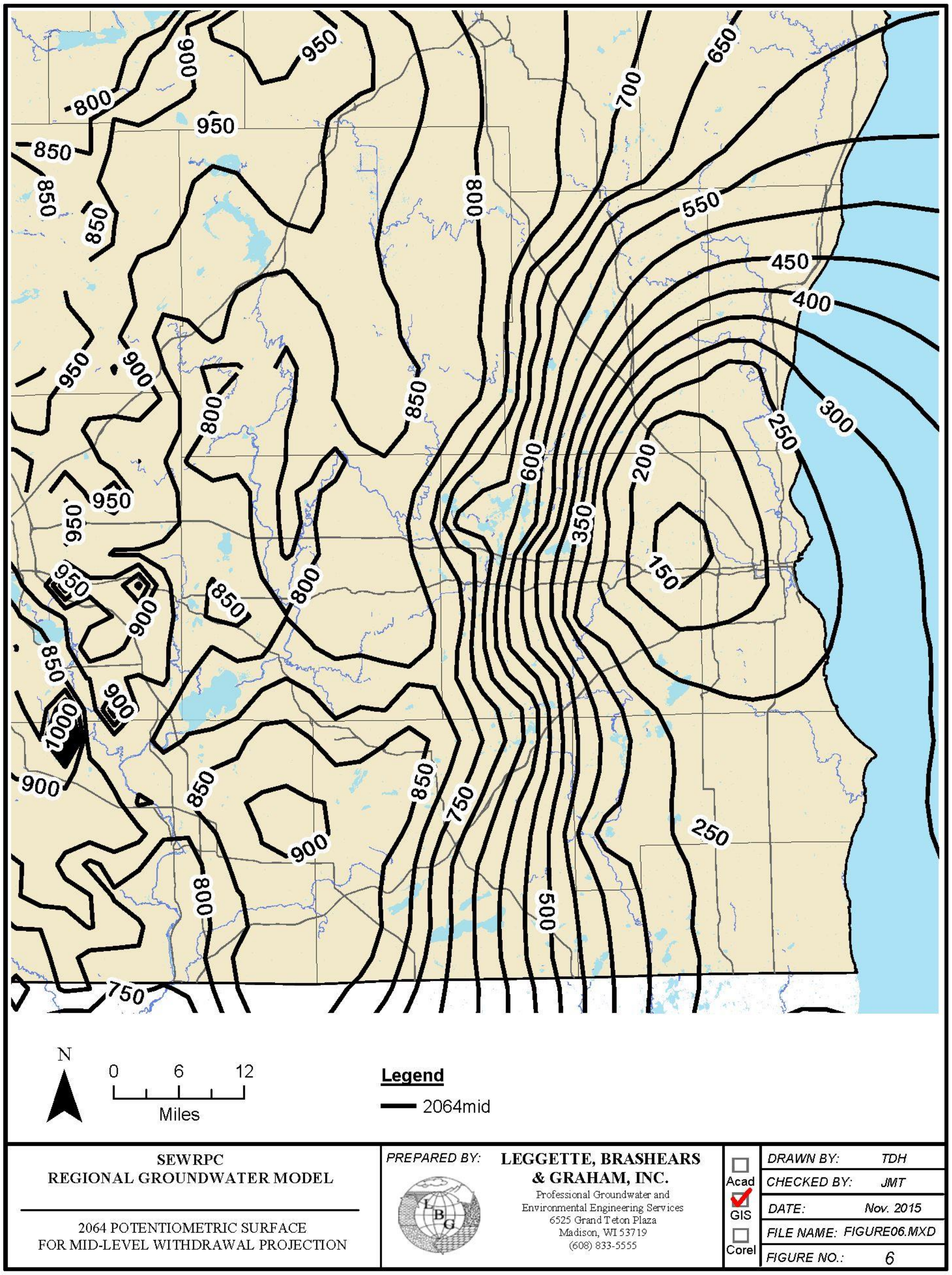


Figure 11: Predicted 2064 Water Levels in the Sandstone Aquifer Using Mid-Level Pumping Rates

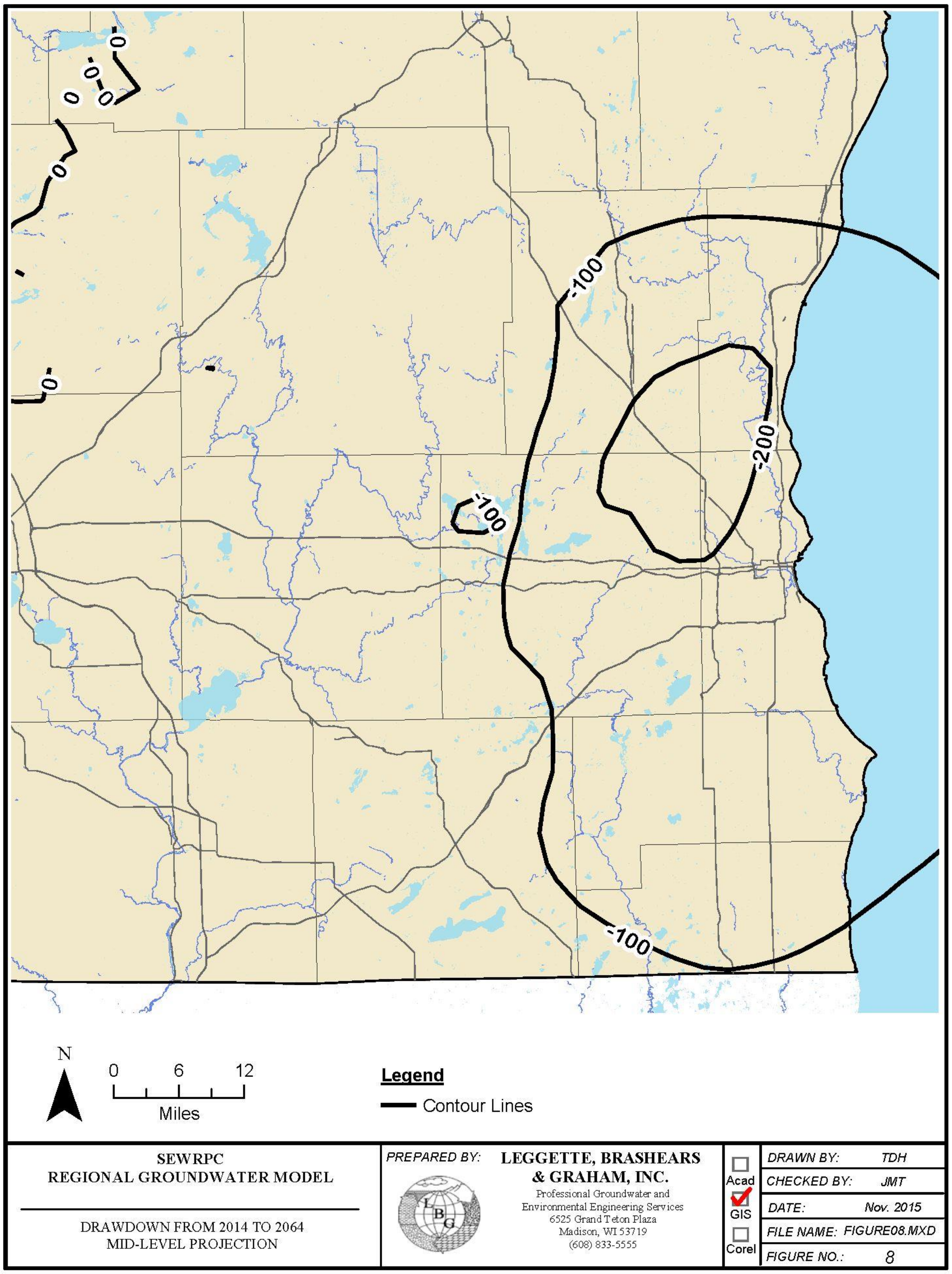


Figure 12: Predicted Change in Water Levels in the Sandstone Aquifer From 2014 to 2064 Using Mid-Level Pumping Rates

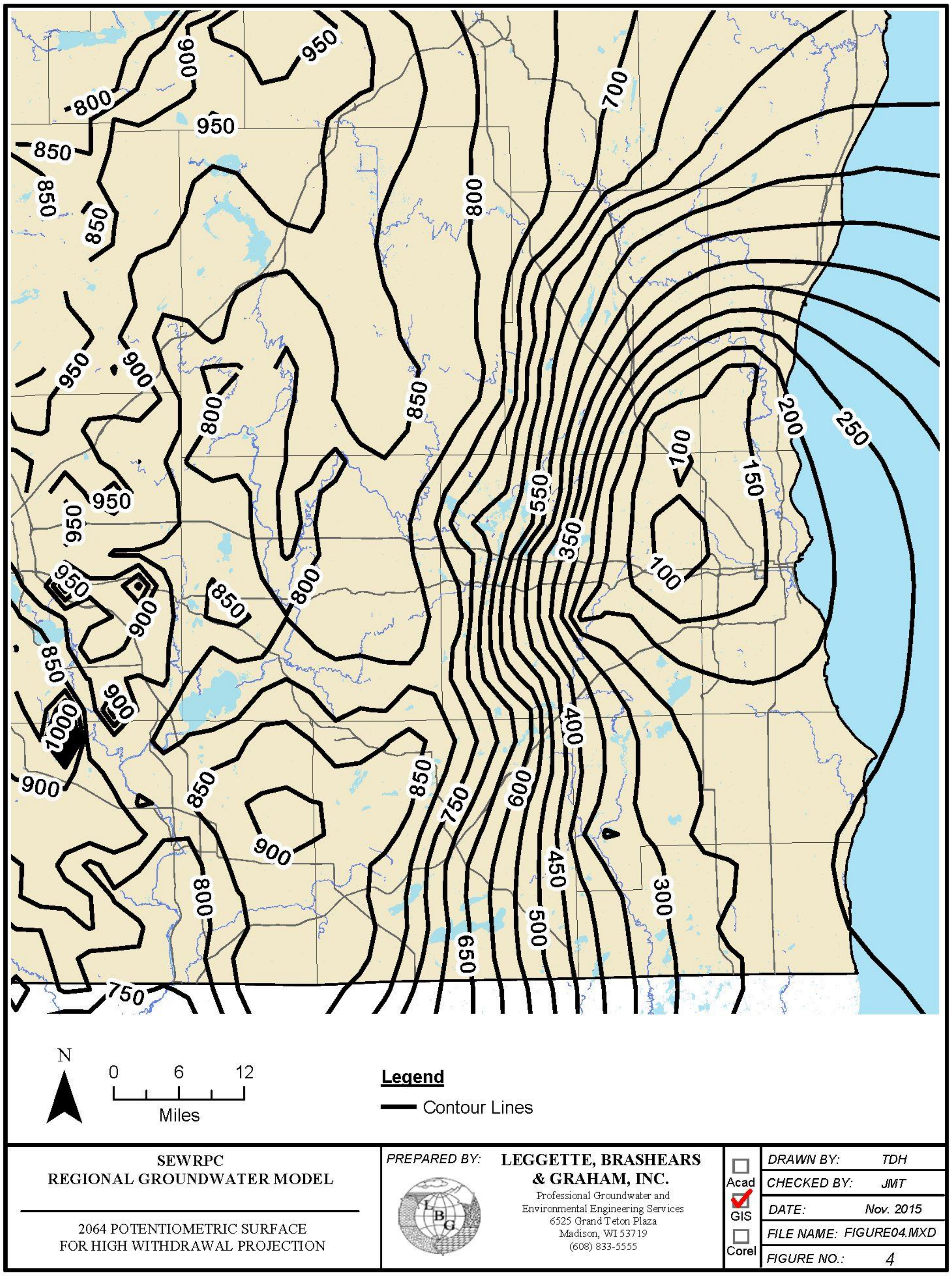


Figure 13: Predicted 2064 Water Levels in the Sandstone Aquifer Using High-Level Pumping Rates

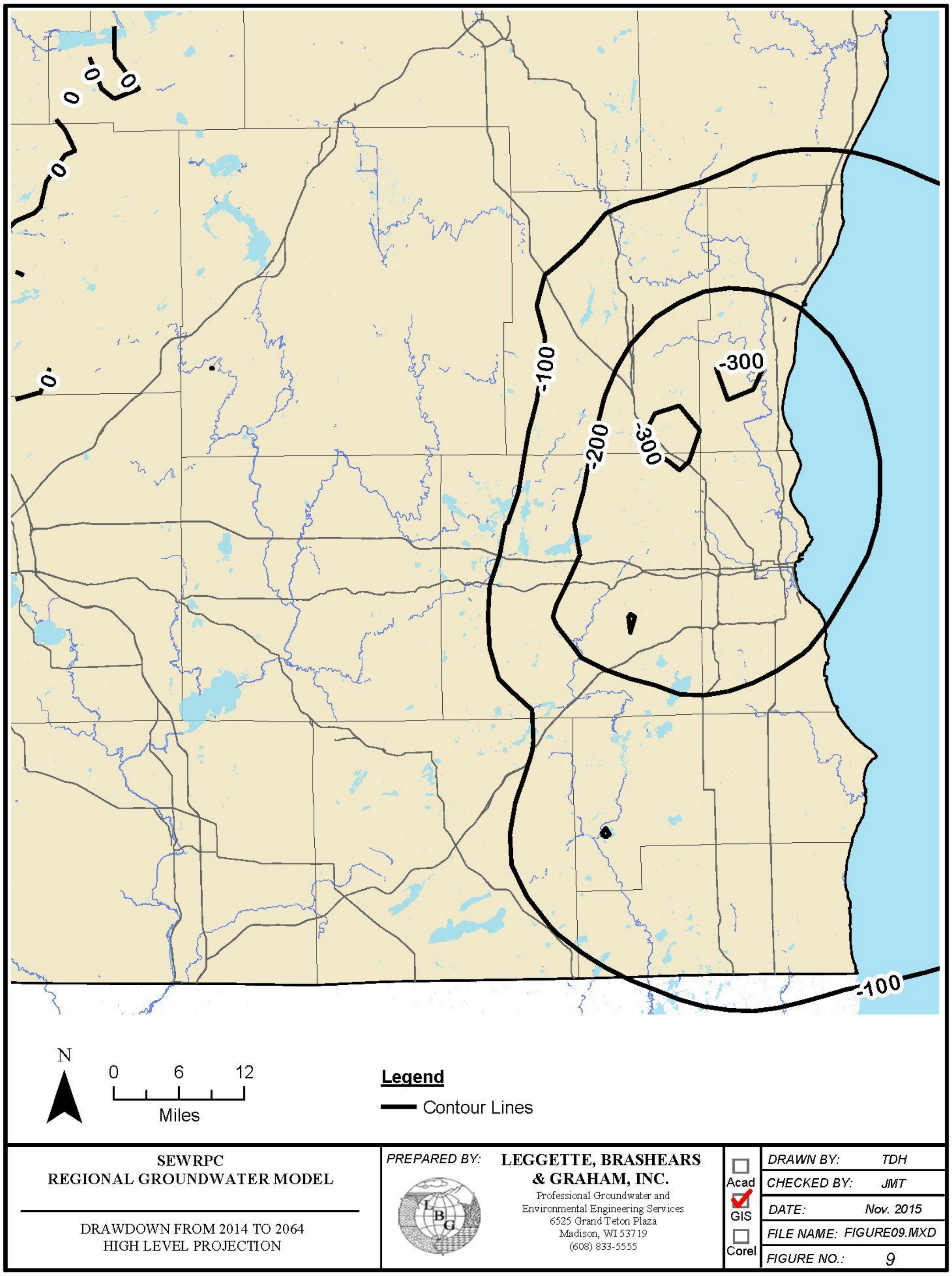


Figure 14: Predicted Change in Water Levels in the Sandstone Aquifer From 2014 to 2064 Using High-Level Pumping Rates

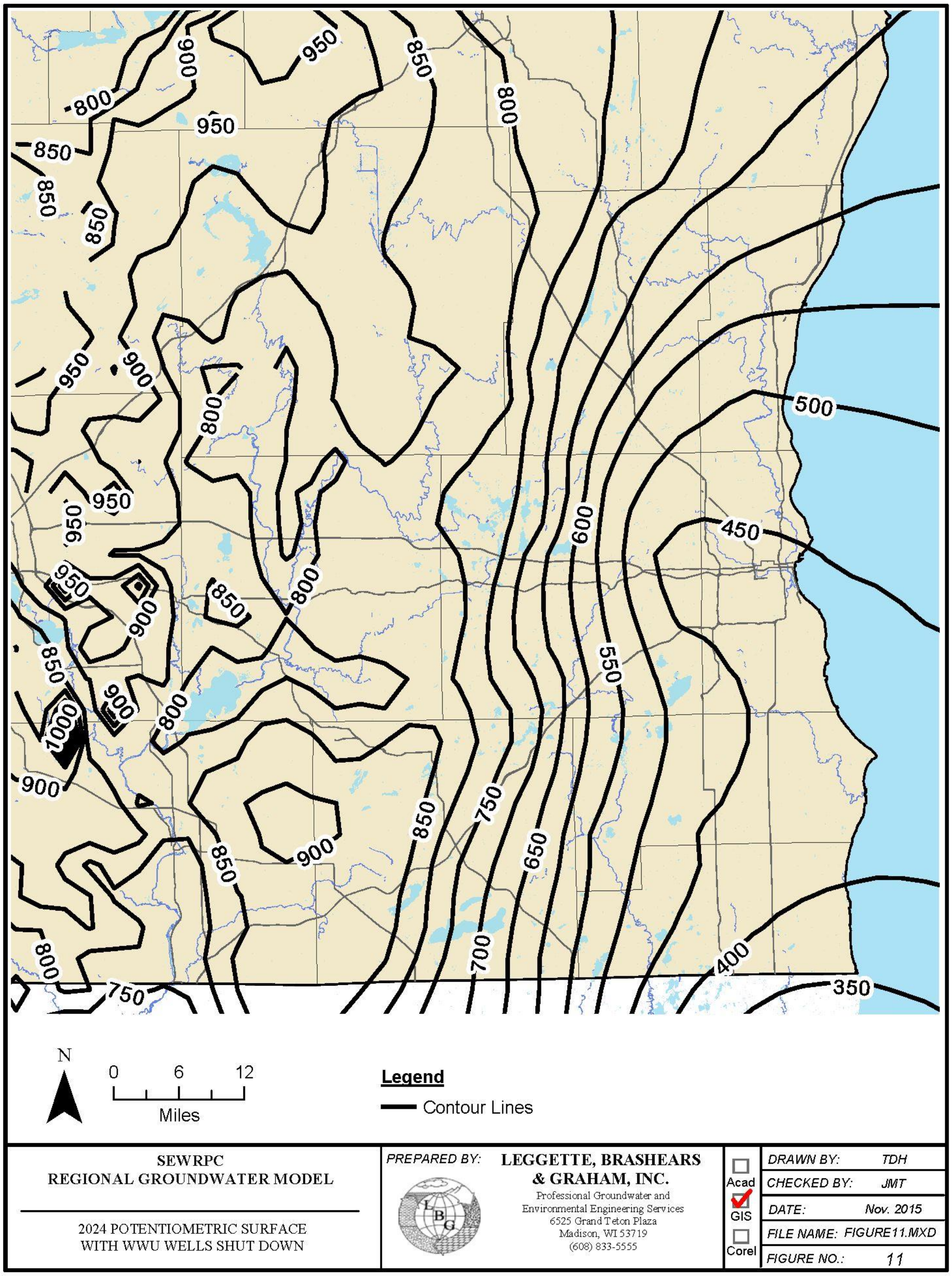


Figure 15: Modeled 2024 Water Levels in the Sandstone Aquifer without the WWU wells

Figure 16: Modeled Recovery in Water Levels in the Sandstone Aquifer without the WWU wells pumping from 2014 to 2014

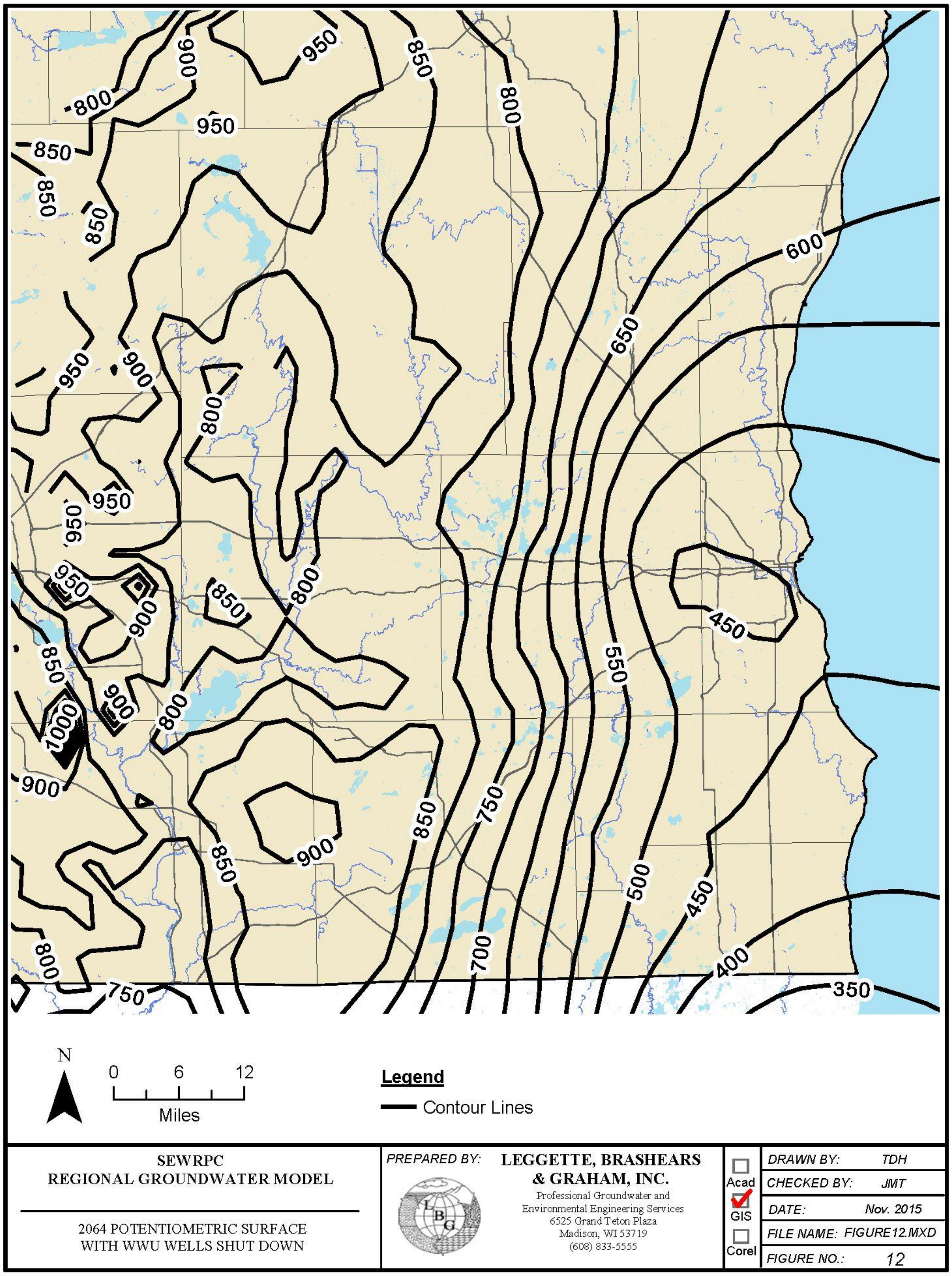


Figure 17: Modeled 2064 Water Levels in the Sandstone Aquifer without the WWU wells

Figure 18: Modeled Recovery in Water Levels in the Sandstone Aquifer without the WWU wells pumping from 2014 to 2064

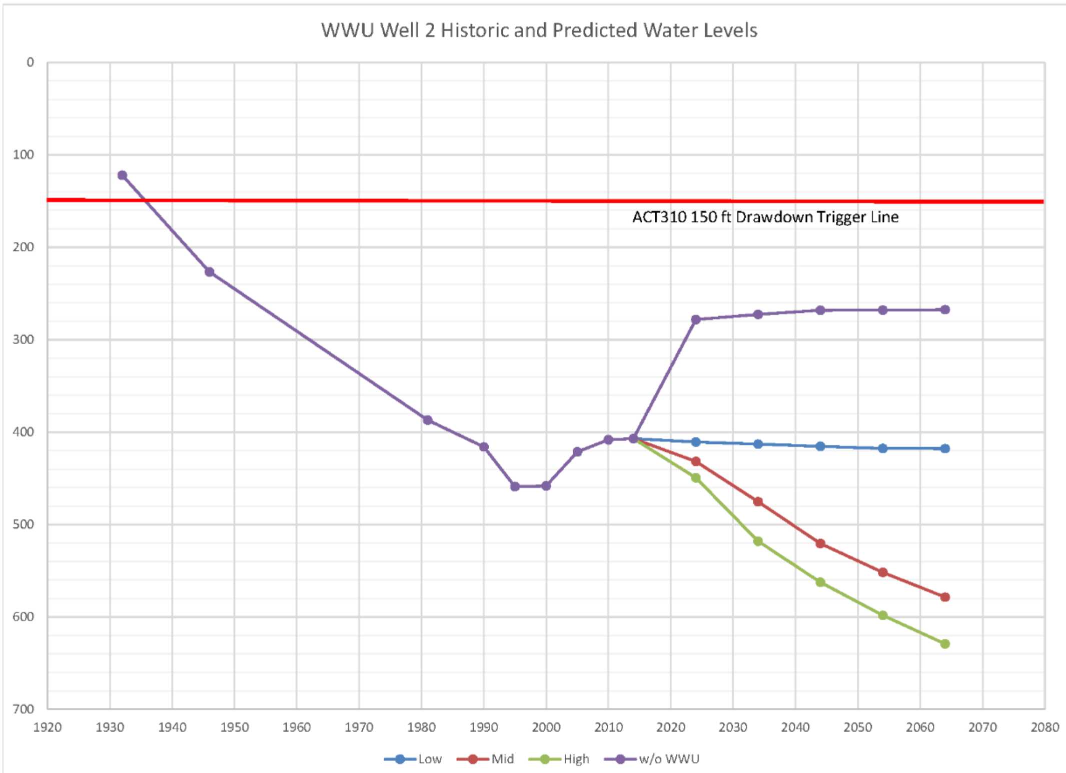


Figure 19: Historic and predicted water levels for WWU Well 2

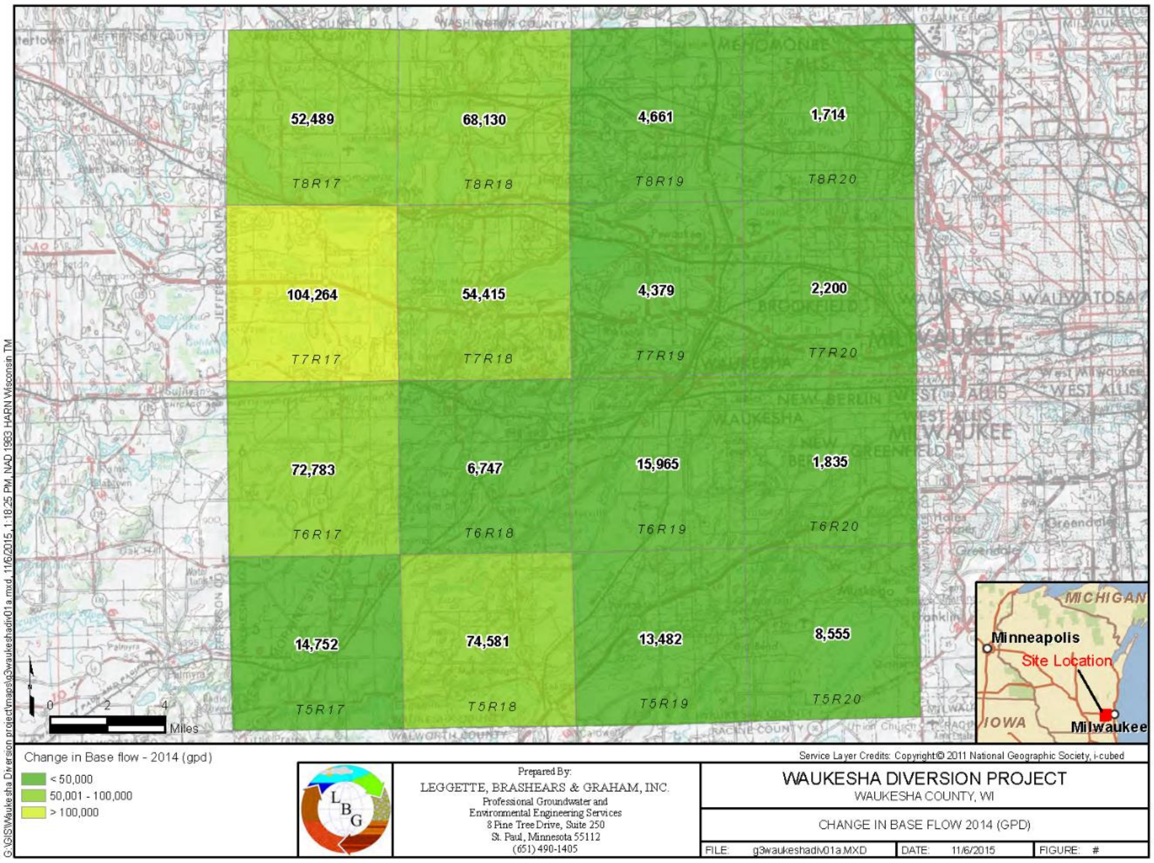


Figure 20: Modeled Change in Base Flow by Township in Waukesha County without the WWU wells pumping in 2014

References

Bonestroo, Rosene, Anderlik and Associates, Inc., 1998. Southeastern Wisconsin Sandstone Aquifer Screening Model Report.

CIC, 2015. Non-diversion solution provides Waukesha with abundant supply of safe, clean drinking water. Compact Impact Coalition Press Release, July 9, 2015

Feinstein, D. T., M.N. Fienen, J.L. Kennedy, C.A. Buchwald, and M.M. Greenwood, 2009. Development and Application of a Groundwater/Surface-Water Flow Model using MODFLOW-NWT for the Upper Fox River Basin, Southeastern Wisconsin. USGS Scientific Investigation Report 2012-5108.

Feinstein, D.T., D.J. Hart, J.T. Krohelski, T.T. Eaton, and K.R. Bradbury, 2005. Simulation of Regional Groundwater Flow in Southeastern Wisconsin, Report 2: Model Results and Interpretation. Final Administrative Report to the Southeastern Wisconsin Regional Planning Commission.

Illinois State Water Survey, 2015. Increased Water Demand Threatens Deep Bedrock Aquifer Water Supplies in Northeastern Illinois. ISWS Press Release, October 12, 2015, http://www.sws.uiuc.edu/hilites/press/151012watdemand.asp.

Krohelski, J.T., 1986. Hydrogeology and Ground-Water Use and Quality, Brown County, Wisconsin. Wisconsin Geologic and Natural History Survey Information Circular 57.

Luczaj, J. A., and D. J. Hart, 2009. Drawdown in the Northeast Groundwater Management Area (Brown, Outagamie, and Calumet Counties, WI). A final report prepared for the Wisconsin Department of Natural Resources. Wisconsin Geologic and Natural History Survey, June 30, 2009.

Ruekert & Mielke, Inc., 2009. Troy Bedrock Valley Aquifer Model, Waukesha and Walworth Counties, Wisconsin. Memorandum Report No. 188.

SEWRPC, 2010. A Regional Water Supply Plan for Southeastern Wisconsin, Planning Report Number 52, Volume One.

USGS, 2003. Principal Aquifers of the 48 conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands