UW Extension WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

3817 Mineral Point Road
Madison, WI 53705-5100
Tel 608/262.1705
Fax 608/262.8086
www.uwex.edu/wgnhs/

James M. Robertson
Director and State Geologist

Evaluation of groundwater pumping to reduce the level of Crystal Lake Columbia County, Wisconsin

Report prepared for the Crystal, Fish, and Mud Lake District

Scott Johnson
Madeline Gotkowitz

2012

Open-File Report 2012-05

Contents:

- Report, 14 p. [7 color]
- 8 appendices [zip file of PDFs , comma-delimited text files]

This report represents work performed by the Wisconsin Geological and Natural History Survey and colleagues and is released to the open files in the interest of making the information readily available. This report has not been edited or reviewed for conformity with the Wisconsin Geological and Natural History Survey standards and nomenclature.

Evaluation of groundwater pumping to reduce the level of Crystal Lake

Columbia County, Wisconsin

Prepared for the Crystal, Fish and Mud Lake District

Prepared by

Scott Johnson
Madeline Gotkowitz
Wisconsin Geological and Natural History Survey
University of Wisconsin-Extension
August, 2012

Introduction

Levels in Crystal, Fish and Mud Lakes, located along the border between Dane and Columbia Counties (Plate 1), have risen as much as ten feet over the past 45 years. This long-lasting rise in lake stage has had significant impacts on lakeside roads and property. Efforts to limit this damage have focused on control of lake stage by pumping water from the lakes. Such a surface water withdrawal system has operated in Fish Lake since2005. In 2010, the Crystal, Fish and Mud Lake District began planning for a similar system to pump water from Crystal Lake. Construction on a pipeline to convey water from the lake to Roxbury Creek began in2011. However, due to concerns about the quality of lake water, the Lake Association is considering pumping groundwater from wells near Crystal Lake to control the lake stage as an alternative to pumping directly from Crystal Lake.

Purpose and Scope

The purpose of this study is to evaluate the feasibility of lowering the water level of Crystal Lake by pumping groundwater from a near-by well or wells. This study was requested and funded by the Crystal, Fish and Mud Lake District, and was completed by the Wisconsin Geological and Natural History Survey, UW-Extension, in July, 2012.

Our evaluation relies primarily on information provided by the Lake District, analysis of well constructor reports near the lakes, a study by the U.S. Geological Survey (Krohelski et al 2000), and our interpretation of glacial and bedrock geology in northern Dane and southern Columbia Counties. The new data collected for this study is limited to a test of hydraulic conductivity performed at an existing monitoring well, described below. Data provided by the Lake District is included in an appendix to this report.

Lakes and Physical Setting

The Mud, Fish, and Crystal Lakes system straddles the border between Dane and Columbia counties, near the Wisconsin River. The stage in Fish Lake has risen about nine feet over the past four decades (Figure 1). Figure 1 shows that Devils Lake, located 30 miles to the northwest, experienced a similar increase in lake level from 1970 to the early 1990s. Groundwater elevations in the region also increased over this period, as demonstrated in the hydrograph from a bedrock monitoring well (IW-110) located 17 miles to the southwest. Fish Lake's stage has continued to increase since the mid-1990s, although regional groundwater levels and Devil's Lake stage have not. Records of annual precipitation from Baraboo and Prairie du Sac show an increase over this time period.

Only 12 years of lake level records are available from Crystal Lake. These records show generally similar patterns of rise and fall to Fish Lake until mid-2008 (figure 2). Fish Lake attained its highest stage in 2008 while Crystal Lake has continued to rise, gaining about 2 feet in stage. Based on information provided by Bill Rose of the U.S. Geological Survey, notable differences between water levels in the two lakes since 2008 are due to pumping from Fish Lake. Mud Lake's stage is assumed to match that of Fish Lake because they are connected by a culvert.

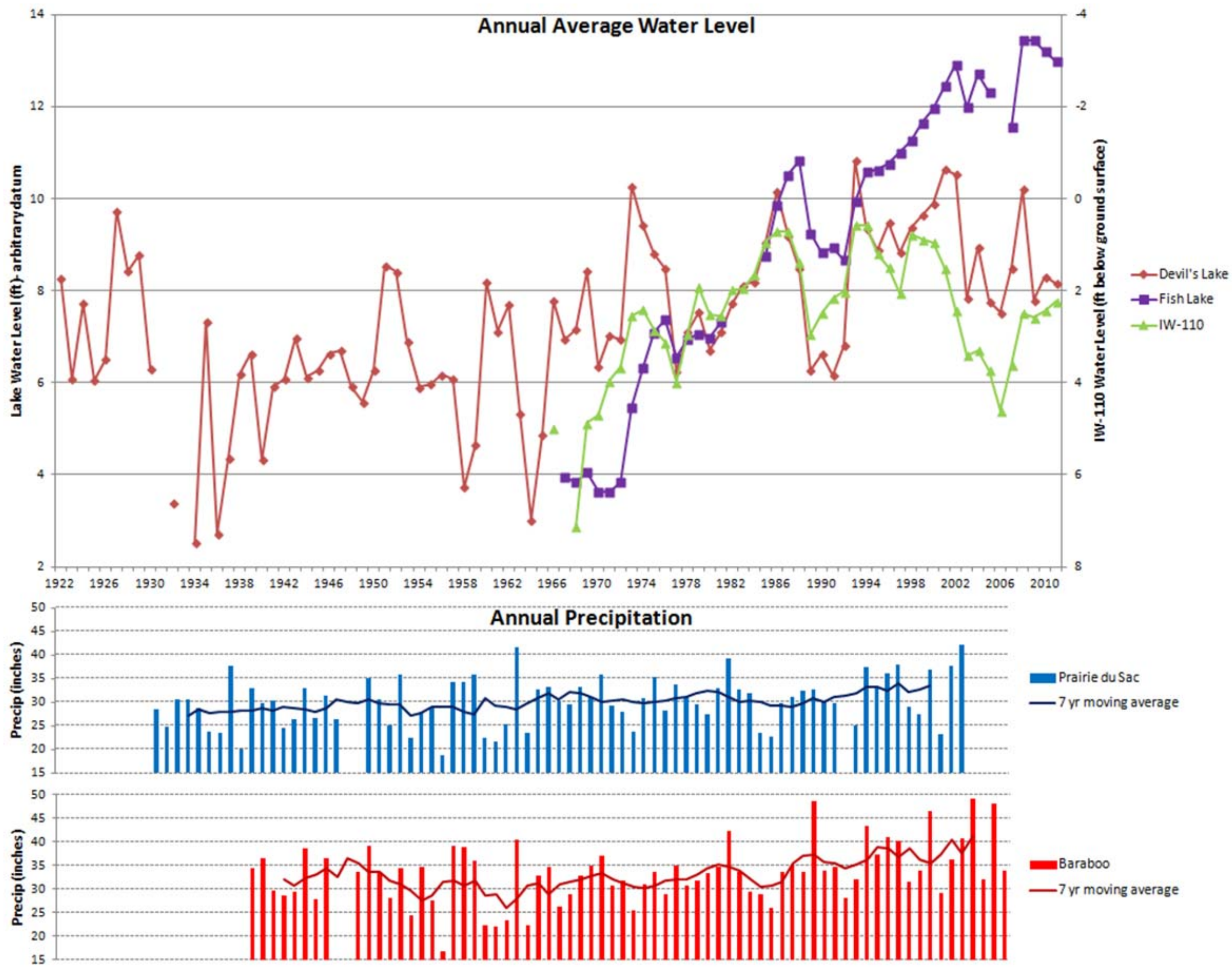


Figure 1. Annual average water levels for Devil's Lake, Fish Lake, and monitoring well IW-110, with annual precipitation records from Prairie du Sac and Baraboo shown below. The seven-year moving average of annual precipitation is included to illustrate trends in precipitation. Fish Lake water levels provided by Bill Rose, U.S.Geological Survey.

There are several potential causes of recent high stage in Crystal Lake, although it is beyond the scope of this project to evaluate which causes are more likely. One factor is the overall increase in precipitation that can be seen in Figure 2, below. An increase in precipitation can affect the water budget of a lake in several ways. The most direct route by which rainfall increases lake stage is to increase storm water runoff to the lake.

Precipitation can impact lake stage indirectly though changes to the groundwater system. More precipitation and snow melt result in more groundwater recharge; Dane County experienced higher than average recharge rates in 2006, 2007 and 2008 (Hart et al 2012). Elevated groundwater recharge can cause elevated water table conditions, which in turn would be reflected in higher lake levels where lakes are well-connected to the groundwater system. High recharge can also increase hydraulic gradients, which in turn can increase the volume of groundwater that discharges to surface water. The extent to which an increase in recharge affects the water balance of Fish and Crystal Lakes depends on the degree of hydraulic connection between the groundwater and surface water systems. Each of the lakes may respond differently to local water table rise due to their different positions within the groundwater flow field.

Additional speculation with respect to causes of high lake level in the Fish-Crystal basin regards a long-term change in the permeability of the lake bed. Eutrophication of the lakes and related algal growth could cause organic matter to accumulate on the lake bed. If, over the long term, this organic matter reduces the permeability of the lake bed, the hydraulic connection between groundwater and surface water could be reduced. This could lead to the lake level responding more to storm water runoff.

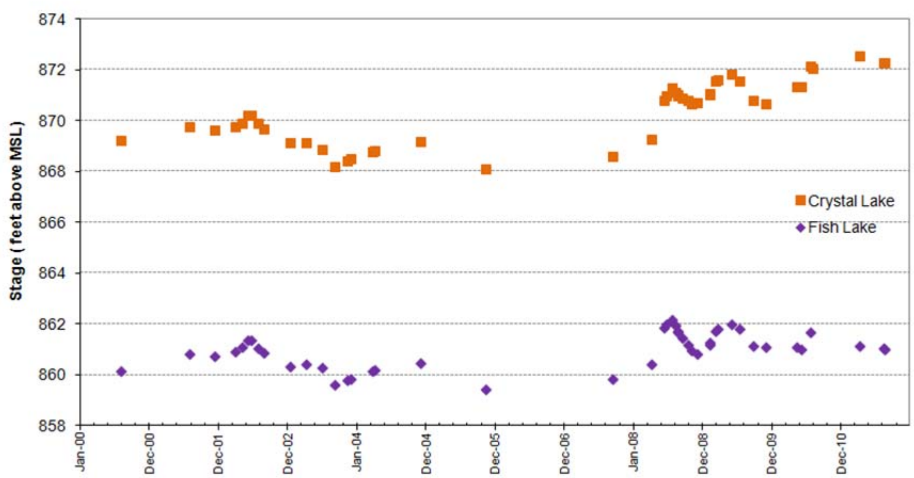


Figure 2. Fish and Crystal lakes have similar but not identical lake stage histories. Data provided by Bill Rose, U.S. Geological Survey.

Hydrogeologic Setting

Fish and Crystal Lakes (Plate 1) are situated in a glacial tunnel channel (Clayton and Attig, 1997). Tunnel channels are formed by erosion related to sub-glacial rivers, and they eventually fill in with sediment deposited by melt water streams and lakes. The resulting landform contains spatially heterogeneous deposits that span a large range of grain sizes and vary over short horizontal and vertical distances.

Cambrian-age Wonewoc sandstone is the uppermost bedrock underlying tunnel channel deposits. Beneath the sandstone, the Eau Claire shale acts as a regional aquitard, separating the Wonewoc from the deeper Mount Simon aquifer. In the lake basin, the upper aquifer consists of unlithified sediments and the Wonewoc sandstone. In the hills and ridges surrounding the lakes, younger bedrock formations overlie the Wonewoc sandstone, including the Cambrian Tunnel City and Trempeleau groups, and dolomite of the Ordovician Prairie du Chien group. Where present, these layers form part of the upper aquifer.

A geologic cross section constructed from well and soil boring records illustrates the heterogeneous mix of sediment overlying bedrock (Plate 2; cross section location on Plate 1). We standardized descriptions on well and boring records into three general categories: primarily sand or gravel, primarily silt or clay, sand or gravel with silt or clay. Correlation of continuous bodies of sediment along the cross section, such as lenses of sand, was difficult due to the heterogeneous nature of the sediment in the lake basin. The heterogeneity could be an artifact of inconsistent descriptions on well construction reports. However, these drilling records as a whole indicate that sediment beneath Crystal Lake is finer-grained than sediment underlying Fish and Mud Lakes. There is no indication of a continuous or extensive deposit of sand or gravel underlying Crystal Lake.

These lakes are seepage lakes, meaning there are no surface water inflow or outflows to the lakes. Water gains and losses, or the "water budget" at seepage lakes are controlled by precipitation, evaporation, surface runoff, and groundwater flow. Krohelski, et al. (2002) used a groundwater flow model to estimate the water budget for Fish Lake in 1990. They estimated that direct precipitation on the lake accounts for 66% of inflow to the lake, with surface runoff and groundwater inflow providing 23% and 11% of inflow, respectively. Evaporation dominated water loss from the lake (62%) with 38% of water loss from the lake occurring as seepage to groundwater. This analysis was not performed for Crystal Lake.

Groundwater flow in the vicinity of the lakes is from the southeast, towards the Wisconsin River to the west (Plate 3). Based on this water table map and the work of Krohelski et al. (2001), groundwater discharge into the lakes occurs primarily along the southeastern sides. Seepage from the lakes to groundwater likely occurs along the western and northern sides.

Aquifer properties

The amount of water that can be pumped from an aquifer depends on properties of the well and properties of the aquifer. The *specific capacity* of a well is a measure of the amount of water produced. It is defined as a discharge rate (gallons per minute, gpm) divided by the amount of drawdown in the well, during pumping. For example, a well pumped at 20 gpm with two feet of water level decline has a specific capacity of 10 gpm/ft. Well drillers typically record these values on well construction reports.

Hydraulic conductivity describes the permeability of a geologic deposit. Rock or sediment with large, well-connected pores or fractures (such as sand or sandstone) transmits water more readily than fine-grained sediment or crystalline rock (such as silt or granite). Aquifers with high hydraulic conductivity yield more water to wells and have less drawdown than aquifers of lower hydraulic conductivity. For the purposes of this project, hydraulic conductivity was estimated with the TGUESS computer program (Bradbury and Rothschild, 1985). Additionally, a slug test performed at monitoring well MW-1 provided an estimate of hydraulic conductivity of the sand layer at a depth of 65 feet.

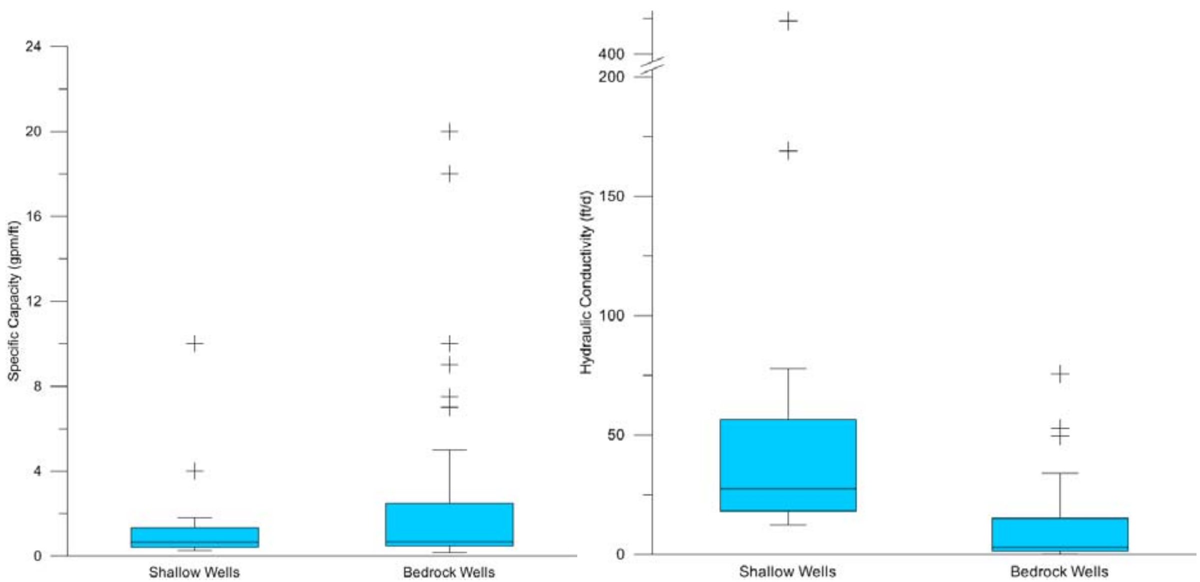


Figure 3. Specific capacity (left) and hydraulic conductivity (right) estimated from wells screened in shallow, unlithified deposits and 50 wells screened in bedrock. The top and bottom of the boxes mark the 25th and 75th percentiles of the measurements, meaning that 50 percent of the field estimates are within the shaded box areas. The horizontal line within each box indicates the mean, or most probable, value, and the "whiskers"show the minimum and maximum estimates. Outliers are indicted with symbols beyond the whiskers.

Estimates of specific capacity and hydraulic conductivity were derived from records from 65 wells, 15 of which are completed in unlithified deposits and 50 of which are open to bedrock. As illustrated in Figure 3, specific capacity of bedrock wells is on the order of 1 to 3 gpm/ft and ranges up to 20 gpm/ft. Hydraulic conductivity in bedrock wells averages about 3.0 ft/d. For the 15 shallow wells, the median specific capacity was 0.66 gpm/ft, with a median hydraulic conductivity of 27.6 ft/d. No trend in either hydraulic conductivity or specific capacity with depth was apparent. The hydraulic conductivity values compare well to that arrived at by Krohelski, et al. (2002) through model calibration, of 27.8 ft/day for the upper aquifer, which includes the unlithified sediments and bedrock above the Eau Claire shale.

A slug test was performed in well MW-1, a test well located on the southwest shore of Crystal Lake. MW-1, which was installed by Sam's Well Drilling in November, 2011, is screened from 65 to 70 ft below ground surface. The screened interval was described as "fine to medium sand with trace fine gravel", in contrast with the upper 60 feet of "sandy silt [with] trace gravel". Analysis of the slug test data, using the Bouwer-Rice (1976) method, indicated a hydraulic conductivity of approximately 200 ft/day.

Aquifer sediment

At the time of our site visit to Crystal Lake in June 2012, several soil borings had been completed along the lake shore immediately west of MW-1. Cuttings from these borings were spread along the lake shore. Visual inspection of this material indicates that sediment recovered from depths to 12 ft below ground surface is primarily fine grained sediment with some sand and gravel. The sediment was highly variable along the ~200 -yard transect—one boring contained clean, medium sand and another contained silty clay. In addition, though the borings were drilled well below lake level, Mr. Padley, representing the Lake District, reported that they filled with water very slowly, such that water was not reported in the hole during drilling. This observation suggests sediment of low hydraulic conductivity, however no direct measurements of hydraulic conductivity were performed in these borings.

Soil boring 1-11 (Plate 1, Appendix A) was installed approximately 10 feet from MW-1, to 60 feet below ground surface, by River Valley Testing (RVT) in May 2011. Sediment descriptions for this boring differed from those reported for MW-1. The majority of 1-11 is described as sand with silt and gravel or silty sand with gravel. Between 35 and 53 ft, the sediment is significantly coarser. Sieve analyses provided by RVT indicate that the dominant grain size between the depths of 25 and 35 ft is fine sand. Between 40 and 50 ft, coarse sand and gravel comprise the largest fraction. Soil boring 2-11, also installed by RVT in 2011, is largely described as outwash sand with silt.

Feasibility of Groundwater Withdrawal to Lower Lake Levels

Groundwater pumping to reduce the stage of a near-by lake is an indirect method of influencing lake level. As illustrated in figure 4a, the natural direction of groundwater flow in a seepage lake is towards the lake. A well placed in close proximity to the lake will meet the demand of the pump primarily with groundwater intercepted from the natural flow path towards the lake (figure 4b). Under a sufficiently high pumping rate, the drawdown caused by pumping may reverse the natural direction of groundwater flow and pull water *from* the lake into the groundwater system, as illustrated in figure 4c.

Quantifying the concepts illustrated in figure 4, for example calculating the pumping rate necessary to affect lake stage by a specific amount, requires use of numerical model of the groundwater and lake system. Such a model can account for the volume of groundwater flowing to the well from up-gradient of the lake and the amount of lake water induced to flow towards the well. The model used by Krohelski et al. (2002) to evaluate pumping from Fish Lake, named the Dane County Regional Groundwater Flow Model (Krohelski et al., 2000), is being updated and is expected to be available in late 2012.

As an alternative to evaluating Crystal Lake hydrologic system with a model, the Lake District requested that we review of existing information. We have concluded that it is not feasible to lower the level of Crystal Lake by pumping groundwater. In order for a well to impact a near-by surface water body to a measurable extent, the shallow sediment beneath the lake must be in excellent hydraulic connection to the pumping well. Our review of existing information indicates *the lack* of a laterally extensive and thick, high permeability aquifer in contact with the lake sediment.

Monitoring well MW-1 was drilled to a depth of 65 feet, presumably because this was the first highly permeable material encountered. The drillers log for MW-1 and other well construction records from the lake basin support the conclusion that shallow sediment near the lake is a mix of fine grained silt or clay with sand. Of the 15 wells constructed in unlithified deposits, the shallowest screen is set at 72 feet, with an average screen depth of 93 feet. Thus, the records as a whole support the conclusion that there is no highly permeable and extensive sand or gravel deposits in the shallow subsurface near the lake. Although the hydraulic conductivity of the screened zone in MW-1 is high, the sediment between the screen and Crystal Lake is not as permeable. The hydraulic connection between the lake and a pumping well completed at a depth of 65 feet would be limited by the less permeable material in between.

An April, 2012 report from General Engineering estimated a well yield of 100 to 200 gpm for a well screened from 63 to 75 ft below ground surface, based on the sieve analyses at MW-1. The report went on to suggest that even a yield of 200 gpm is insufficient to control lake levels for two reasons. First, it is unlikely that such a well would pump primarily lake water (see figure 4), and second, given the lake size of approximately 620 acres, six years of pumping at 200 gpm would be necessary to draw down the lake three feet. It is unlikely that their estimate considered the additional water withdrawal necessary to overcome replenishment of lake water over that time period from precipitation and groundwater inflow.

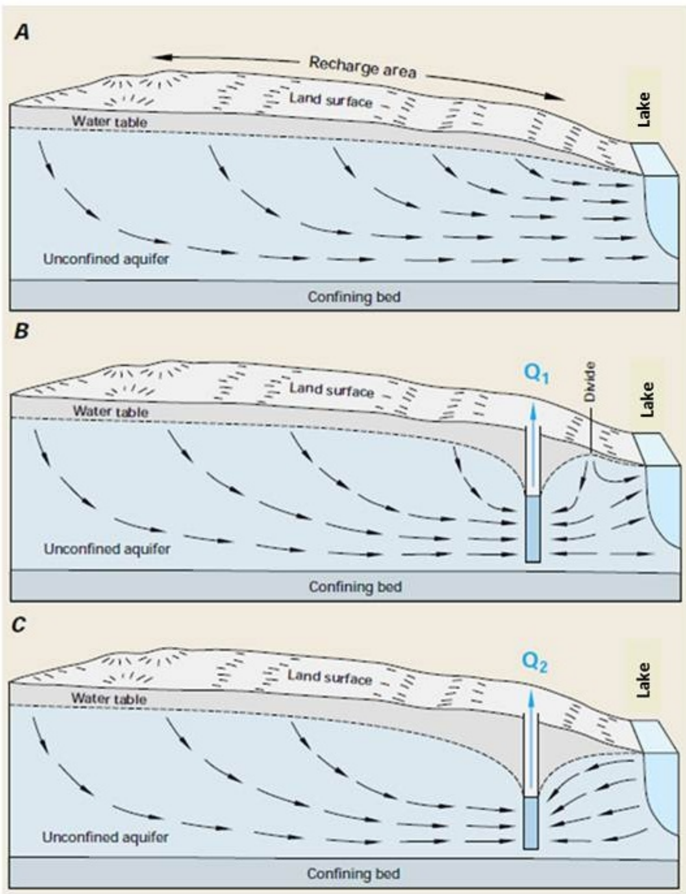


Figure 4. Conceptual model of groundwater pumping near a lake. Adapted from Winter et al. 1998.

Based on our estimates of hydraulic conductivity and specific capacity for shallow wells, a well located near the lake would likely have a conductivity and specific capacity on the order of 30 ft/day and 1 gpm/ft, respectively. Such a well would be unable to sustain a pumping rate sufficient to control lake level. At a minimum, a network of such wells would be required. Additional analysis would be required to evaluate the potential for well interference and the number and spacing of wells within such a network.

Conclusion

The purpose of this study was to evaluate the feasibility of lowering the water level of Crystal Lake by pumping groundwater from a near-by well or wells. Our evaluation relied primarily on information provided by the Lake District, analysis of well constructor reports near the lakes, a study by the U.S. Geological Survey, and our interpretation of glacial and bedrock geology in northern Dane and southern Columbia Counties. The new data collected for this study was limited to a test of hydraulic conductivity performed at an existing monitoring well.

We have concluded that it is not feasible to lower the level of Crystal Lake by pumping groundwater. In some hydrogeologic settings in Wisconsin, the shallow aquifer surrounding a lake is very permeable. In these locations, pumping groundwater can affect nearby surface water, such as lakes, streams or springs. There is no indication that pumping groundwater could be successful in lowering the level of Crystal Lake because there is a notable absence of suitable permeable deposits in the shallow subsurface.

Suggested Future Work

If the Lake District and other interested parties were to proceed with a plan to pump surface water from the lake, we recommend use of a numerical model to estimate the pumping rate necessary to lower lake level to the desired level under various rates of precipitation and groundwater inflow. Such a model could be developed from the new regional Dane County Flow Model.

An alternative recently under consideration by the District is installation of a horizontal well along the lake edge. Such a system would only be successful in reducing lake stage if it was installed in high permeability sediment in excellent hydraulic contact with the lake bottom. The Lake District recently reported that an investigation by the DeWitt Company and General Engineering found no evidence of higher permeability material adjacent to the lake.

A final recommendation involves data collection and management at the lakes. The Lake District would be well served by a long-term, consistent data collection system at the lakes, including at a minimum precipitation and lake levels. The University of Wisconsin-Extension could be of assistance in designing such a system so that volunteers might be enlisted to perform most of the work involved.

References

Hart DJ, Schoephoester PR, Bradbury KR. 2012. *Groundwater recharge in Dane County, Wisconsin: Estimating recharge using a GIS-based water-balance model*, Wisconsin Geological and Natural History Survey Bulletin 107.

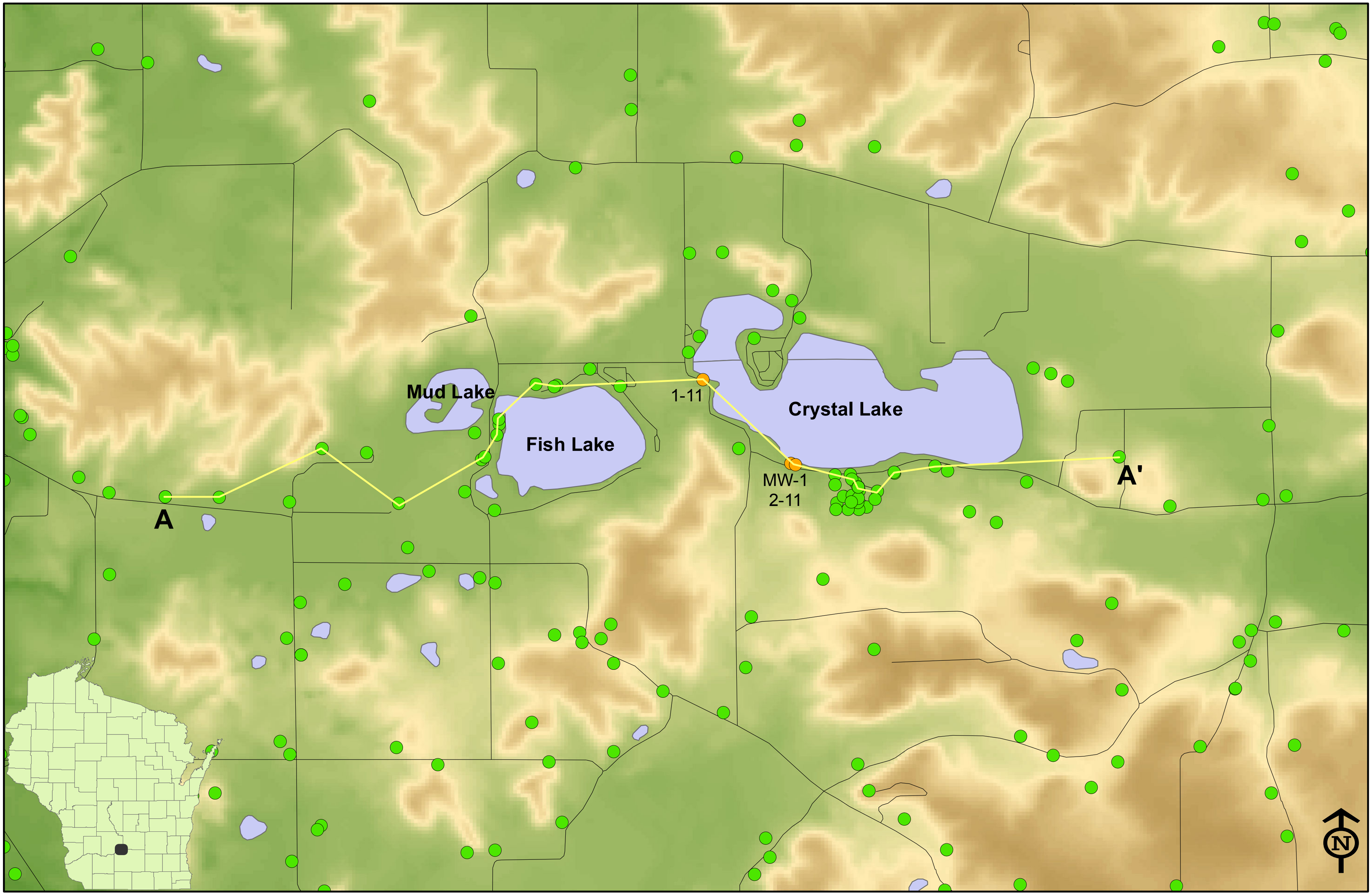
Krohelski JT, Bradbury KR, Hunt RJ, Swanson SK. 2000. Numerical simulation of groundwater flow in Dane County, Wisconsin, Wisconsin Geological and Natural History Survey Bulletin 98

Krohelski JT, Lin Y-F, Rose WJ, Hunt RJ. 2002. *Simulation of Fish, Mud, and Crystal Lakes and the shallow ground-water system, Dane County, Wisconsin*, United States Geological Series

Winter TC, Harvey JW, Franke OL, Alley WM. 1998. *Ground Water and Surface Water: A Single Resource*, U.S. Geological Survey Circular 1139, Denver, Colorado

Groundwater Data Summary for Fish, Mud, and Crystal Lakes

Plate 1
Regional Topography



Road data from USGS (2001), lake data from USGS (1998), and terrain data from DNR and USGS (2003).

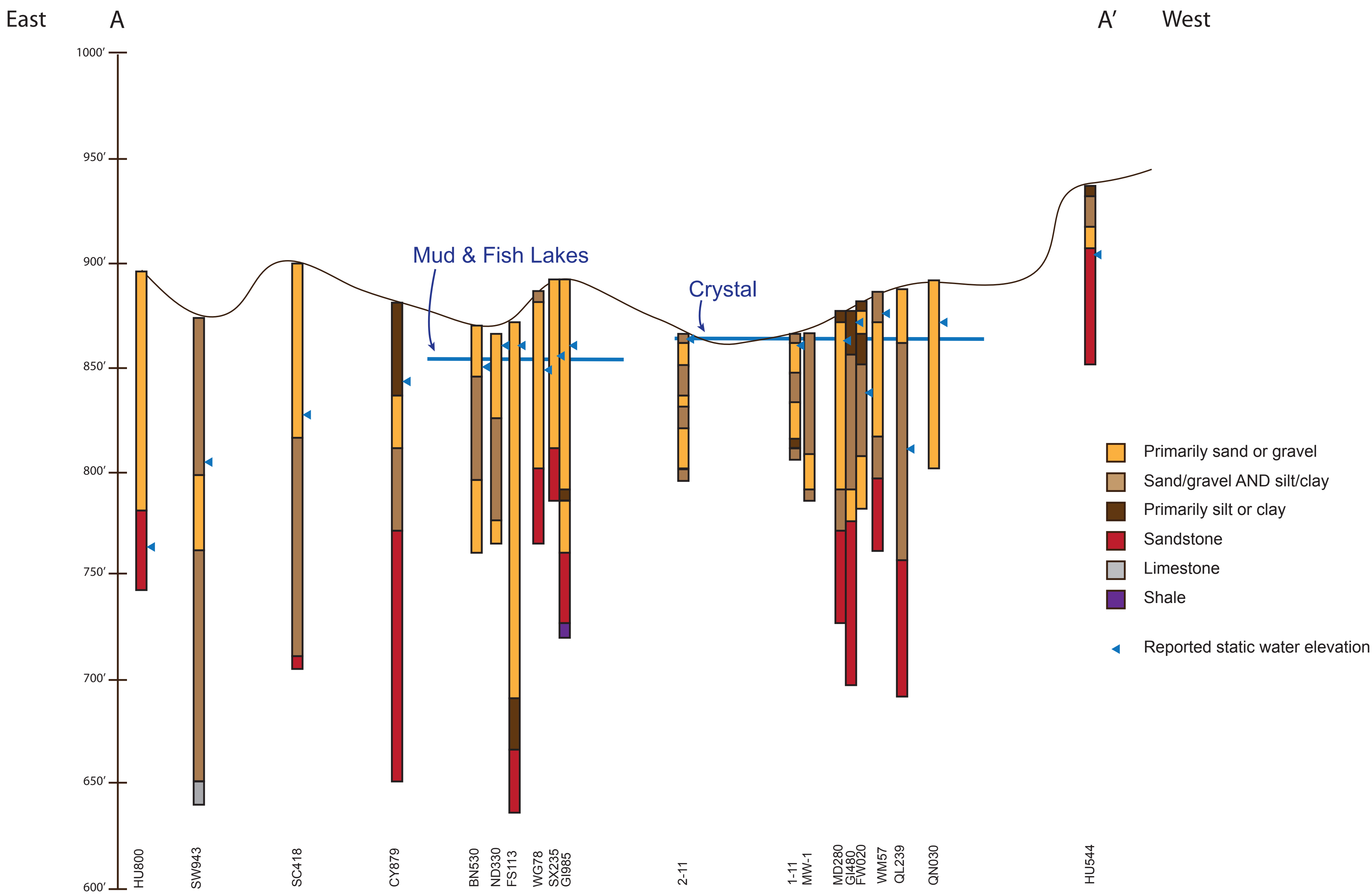
Scale 1:45,000
0 0.25 0.5 1
Miles

Well Construction Reports
Additional Soil Borings
Cross Section A-A'

UW Extension
Wisconsin Geological and Natural History Survey
July 2012

Groundwater Data Summary for Fish, Mud, and Crystal Lakes

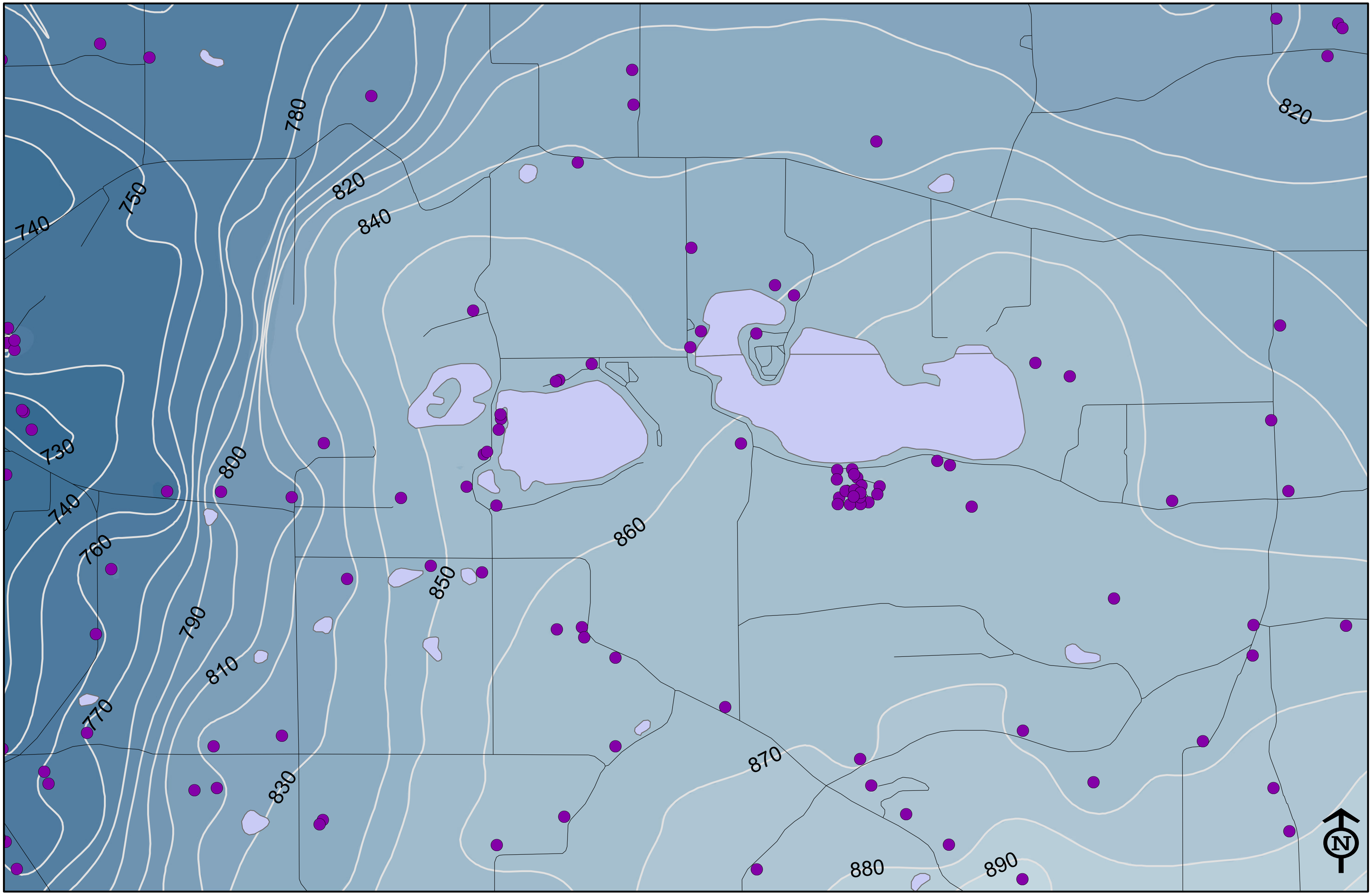
Plate 2
Cross Section



Geologic cross section along A-A' (Plate 1) prepared from well construction reports (identified by Wisconsin Unique Well Numbers) and soil borings (1-11, 2-11, MW-1). Due to the variability in descriptions, sediments were categorized as primarily sand or gravel, primarily silt or clay, and sand or gravel with silt or clay. Lines representing the location and water level elevation of the lakes are included as the section largely passes around the lakes. Topographic profile is approximate.

Groundwater Data Summary for Fish, Mud, and Crystal Lakes

Plate 3
Water Table Elevation



Data Points

Water Table Elevation
(feet above sea level)
High : 890
Low : 730
Contour Interval of 10 ft

Scale 1:45,000
0 0.25 0.5 1
Miles

Road data from USGS (2001),
lake data from USGS (1998),
and terrain data from DNR
and USGS (2003).

UW Extension
Wisconsin Geological and Natural History Survey
July 2012