Wisconsin Geological and Natural History Survey,
University of Wisconsin-Extension,

Chippewa County Groundwater Study - Interim Report

Report prepared for the Chippewa County Department of Land Conservation and Forest Management, Chippewa County, WI

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Abstract

In mid-2012, a five-year groundwater study was commissioned by Chippewa County to evaluate the impacts of industrial sand mining and irrigated agriculture on the county's water resources. The project includes estimating groundwater recharge and developing a three-dimensional steady-state groundwater flow model. The model will be used to evaluate the impacts of changes in land use and groundwater pumping on water resources in western Chippewa County both today and into the future.

This interim report documents work completed over the first two years of the five-year study. This includes data collection and interpretation, development of a conceptual hydrostratigraphic model and its translation into groundwater flow model layers, estimates of groundwater recharge in the study area prior to development of industrial sand mines, and public outreach and stakeholder engagement. A final report will be submitted to Chippewa County in autumn 2017.

Introduction

The quantity of surface and groundwater resources is critical to the ongoing quality of life and economic well-being of residents and businesses in Chippewa County, Wisconsin. Current economic trends are placing more intensive demands on the land and natural resource base of the west-central region of Wisconsin. For example, areas of western Wisconsin are experiencing an increase in the number of acres of cropland that are irrigated.

Coincident with these changes in agricultural practices is a global demand for energy and a related increase in demand for "frac sand" from Wisconsin. When injected into gas and oil production wells, frac sand props open fractures in bedrock formations surrounding the well, increasing well yield. While there are no oil or gas producing wells in Wisconsin, demand for sand is growing because of production wells in other regions of the United States. In response to high demand for this sand, numerous industrial sand mines are being developed to extract high-quality sand from within the Jordan and Wonewoc Formations. These sandstone formations extend throughout upland areas in west-central Wisconsin.

Residents, local officials, and other concerned citizens recognize these changes and are interested in better understanding the potential cumulative impacts of changes in groundwater recharge and groundwater use on water resources in west-central Wisconsin. Potential recharge changes are due to landscape changes associated with mine reclamation while changes in groundwater use are tied to the expected expansion of irrigated agriculture, industrial sand mining, and other high-capacity groundwater withdrawal operations.

The study seeks to develop a better understanding of groundwater resources within western Chippewa County. The project scope includes development of two dynamic tools, a soil-water-balance (SWB) model and a groundwater flow model, to evaluate the impacts of changes to groundwater recharge and withdrawal on the hydrologic system. This groundwater study will benefit water resources management efforts in the region by characterizing hydrogeologic conditions and incorporating this characterization into a computer model capable of evaluating a set of scenarios associated with alternative management plans and/or hydrologic conditions. The results will provide interested parties with technical information to support informed decision making regarding water resources within western Chippewa County. The project is designed to provide general information that will be transferable to other areas with similar terrain and geology, and support groundwater resource related decision making throughout west-central Wisconsin.

Study extent

The study area includes western Chippewa County and adjacent portions of Dunn and Barron Counties (Figure 1). The project focuses on this area of Chippewa County due to the increase in groundwater use and changes to the landscape related to industrial sand mines and irrigated agriculture. The proximity of additional groundwater withdrawals to streams and rivers poses potential challenges to water resource management. The study includes development of a groundwater flow model, which requires that data collection and analysis extend to the hydraulic boundaries of the groundwater system. Thus, information beyond western Chippewa County was compiled where available.

Setting

Chippewa County is located in west-central Wisconsin within the Chippewa River drainage basin. Several glacial ice advances covered this area, dating to about 780,000 years ago to the Reeve Phase (Syverson, 2007). The western part of the county is dominated by upland hills and ridges with relatively well developed surface-water drainage systems. Hills and ridges are commonly forested. Land adjacent to hills and ridges consists of extensive tracts of pastureland and row crops. Sand mines and processing facilities are now in operation at several locations that were previously forested hilltops.

Land use in western Chippewa County is predominately agricultural, with most activity directed toward row crops. Population centers within the study area are primarily found along the Highway 53 corridor, and include the City of Bloomer and the Village of New Auburn. The study area encompasses two public groundwater supply systems; these are operated by the communities of New Auburn and Bloomer (Figure 2).

Objectives

Major objectives of this project are as follows:

1. Develop recharge estimates and a groundwater flow model to evaluate the impacts of current and future water use and land use on the hydrologic system;
    a. Evaluate impacts of current groundwater use for frac sand mining, irrigated agriculture, and municipal supplies to water resources;
    b. Evaluate potential impacts to water resources from future scenarios of irrigation and industrial sand production, including peak frac sand production, post-mine reclamation, and potential expansion in irrigated lands;
2. Disseminate the study results to project stakeholders and the general public;
3. Transfer the study results to similar geologic/hydrologic settings as appropriate.

Tasks

Major tasks planned to meet these project objectives are as follows:

1. Technical investigation and modeling:
    a. Data collection and interpretation – Collect and interpret available surface and subsurface hydrologic and geologic data for the groundwater flow model;
    b. Recharge estimation – Apply a soil-water-balance (SWB) model (Westenbroek et al., 2009) to evaluate recharge under current and future conditions;
    c. Groundwater modeling – Develop and calibrate a steady-state groundwater model;
    d. Scenario testing – Evaluate the impacts of changes in pumping and recharge for scenarios representing peak sand mine operations, post-mine reclamation, and potential expansion in irrigated lands;
    e. Transferability – Apply the models to evaluate generalized system responses to changes in pumping and recharge associated with frac sand mining and irrigation operations common to west-central Wisconsin.

2. Public outreach and reporting:
    a. Fact sheet – Prepare a fact sheet describing Chippewa County's water resources and the objectives and methods of this study (Parsen and Gotkowitz, 2013);
    b. Annual public outreach and stakeholders meetings – Present project progress and findings, provide general education about water resources and solicit feedback from project stakeholders and the interested public to inform project work;
    c. Interim and final reporting – Complete this report and a final report to document data collection, model and applications, and outreach efforts.

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Technical investigation

Introduction

This interim report focuses on data collection, hydrostratigraphic interpretation, and soil-water-balance modeling. Remaining tasks will be documented in the final report, scheduled for release in late 2017.

Hydrogeologic data collection

Review of previous studies

The initial phase of the technical investigation involved review of prior geological and hydrogeological studies conducted within the study area. Geologic mapping and research by Ostrom (1966), Ostrom et al. (1970), Brown (1988), Mudrey (1987), Mudrey et al. (1987), Havholm et al. (1998), and Syverson et al. (1998) provided a basis for interpreting the general geology of Chippewa County and neighboring areas. Pleistocene geologic maps of Chippewa County (Syverson, 2007) and Barron County (Johnson, 1986), and depth-to-bedrock maps for Wisconsin (Trotta et al., 1973; WGNHS unpublished), Chippewa County (Lippelt, 1988), Dunn County (Lippelt et al., 1988), Barron County (Zaporozec, 1987), and Eau Claire County (Johnson, 1993) provided insights into the spatial extent of bedrock and the overlying unconsolidated sediments. Land surface mapping consisted of the updated National Elevation Dataset 10-m DEM (Gesch, 2007; Gesch et al., 2002).

Hydrogeologic data sources

Hydrogeologic data available from the study area provide a basis for the hydrogeologic conceptual model of aquifers and aquitards that comprise the groundwater flow system. These data include well construction reports and water-use records from the WDNR, geologic logs developed by the WGNHS, published outcrop descriptions, and newly acquired geophysical logs. Mining companies also contributed geophysical logs and geologic observations from several active industrial sand mines. Chippewa County LCFM compiled water-use and water-level data from industrial sand mines within the study area. Data compiled by the LCFM is not presented in this report but will be used for model calibration.

Hydrogeologic data compilation and processing

Data compilation and processing involved evaluating data quality, developing databases to manage the data, and making corrections or modifications where appropriate. Water-use data from the WDNR, well construction records, and geologic logs are managed with Access and ArcGIS. Geophysical logs were processed using the WellCAD software by ALT Technologies. ArcMAP was used to visualize and create model input layers from geologic maps and digital elevation models (DEMs). Geologic descriptions of outcrops and mine sites provided information about geologic units and contacts within the study area.

Location and identification of high-capacity withdrawal points

The location and pumping rates of high-capacity wells and surface water withdrawal points were obtained from the WDNR. These are wells and pumps that are permitted to withdraw greater than 70 gallons per minute (gpm), or approximately 100,000 gallons per day (gpd). The reported well locations were verified and corrected as necessary. Well and surface water withdrawal locations are known with varying degrees of accuracy, from within 100 feet at some wells to only within section or quarter section at some older wells.

Monthly water-use records are available from the WDNR for most high-capacity withdrawal points beginning in 2011. Records from 2011 through 2013 will be used in the groundwater flow model, because this is the period over which surface water flow was measured at several streamgaging stations in the study area. The high-capacity water-use data include active (i.e., pumping) and inactive (i.e., non-pumping) wells and surface water withdrawal points. Wells in the study area that were abandoned prior to 2011 were not included in the project water-use database.

High-capacity withdrawals

The project water-use database contains 565 high-capacity wells and 27 high-capacity surface water withdrawal points within a large region surrounding the primary study area (Figure 2). Of these, 59 wells and 4 surface water points were present in the study area at the end of 2013 (Table 1). Table 2 provides reported water-use rates at these wells and surface water systems. Data include 2011 through 2013 because such information was not routinely collected by the DNR prior to this period. The water-use database will continue to be modified during model construction and calibration, as errors or omissions in records are identified, or if the model domain is changed.

	2011	2012	2013
Total withdrawal points	58	61	63
Total wells	54	57	59
Active wells	31	40	45
Inactive wells	23	17	14
Total surface water withdrawal points	4	4	4
Active surface water withdrawals points	0	2	2
Inactive surface water withdrawals points	4	2	2

Table 1. High-capacity wells and surface water withdrawal points in the study area, 2011-2013.

Water user	2011 Total withdrawals	2011 Active withdrawal points	2011 Average withdrawal per point	2012 Total withdrawals	2012 Active withdrawal points	2012 Average withdrawal per point	2013 Total withdrawals	2013 Active withdrawal points	2013 Average withdrawal per point
	MGY	-	*MGY/point*	*MGY*	-	*MGY/point*	*MGY*	-	*MGY/point*
Industrial Sand Mining	10.93	1	10.93	129.42	5	25.88	105.08	5	21.02
Irrigated agriculture	153.60	20	7.68	531.2	22	24.15	689.13	25	27.57
Municipal supply	101.73	5	20.35	98.76	5	19.75	98.86	5	19.77
Other	18.76	5	3.75	32.2	6	3.58	6.36	8	0.53

Notes: MGY = Millions of gallons per year, MGY/point = Millions of gallons per year per withdrawal point

Table 2. Reported water use, 2011 – 2013.

A number of new wells were drilled at industrial sand mines in 2011 and 2012, and water withdrawals increased as these operations came on-line. The total withdrawals decreased from 2012 to 2013, which could reflect more efficient water-use practices at some mines or variations in sand production over time at some facilities. Irrigated agricultural systems show higher numbers of withdrawal points and total withdrawals over the 2011 to 2013 time period. The two surface water withdrawal points in the study area were used for irrigation. The LCFM attributes the increase in water used for irrigation to growing practices that improve crop yields and reduce the impact of extended periods of drought (personal communication, D. Masterpole). The number of municipal supply wells and the pumping rates at these systems remained consistent during this time period.

Although not presented in Table 2, the water-use database contains monthly reports of water use. Depending upon the weather conditions, sand mine wash plants in Wisconsin operate up to 10 months out of the year. Irrigation withdrawals primarily occur during the growing months, from May through September. Municipal withdrawals occur throughout the year and typically increase during summer months.

Geophysical logging

Downhole geophysical logging is an important tool for subsurface characterization. Seven geophysical logs have been collected in or near the study area; six by WGNHS staff and one by Preferred Sands at the LaGesse Mine west of Bloomer. Logs include fluid temperature and conductivity, resistivity, natural gamma, and borehole caliper. Optical borehole imaging and borehole flow were also recorded at several wells. These logs provide information about the hydrogeologic properties of the rock, such as evidence of preferential flow along fractures or high-conductivity zones, and the spatial extent and thickness of aquitards (aquitards are fine-grained geologic formations that restrict the flow of groundwater). The high quality of geophysical logs compared to other sources of subsurface data, such as well construction reports (WCRs) make them a primary source of data for subsurface characterization. A geophysical log from the Superior Silica Sand Culver Mine (WGNHS ID: 9000341), highlighting some of the high-quality imagery from the optical borehole imager is included in Figure 3. The seven geophysical logs which were collected and processed for this project are included in Appendix A.

Stream flow measurements

Stream flow measurements were obtained within the study area from three USGS gaging stations and a one-time synoptic survey conducted in October 2012 (Figure 4). The gaging stations provide daily streamflows between 2011 and 2014. The synoptic survey provided a snap-shot of streamflow conditions at 54 locations over a two-day period. These data will be used during calibration of the groundwater flow model.

Streamflow measurements recorded at the three USGS gaging stations are available on the USGS website at the following addresses:

Como Creek Tributary:
http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=05364422

Trout Creek at CTH DD:
http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=053674962

Trout Creek at 10th St:
http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=053674967

Hydrostratigraphic interpretation

Overview

Hydrogeologic data and maps from prior studies described above were integrated into the hydrostratigraphic interpretation. These interpretations include developing a map of the top of bedrock, the top of the Precambrian formation, and several intermediary hydrostratigraphic layers which function as aquifers or aquitards.

Top-of-bedrock surface

The top-of-bedrock surface represents the bottom of the unconsolidated aquifer system and the top of the bedrock aquifer system. This was constructed using depth-to-bedrock maps and geologic data sets using the Natural Neighbor interpolator in ArcGIS 10.1 and manual editing of contour lines.

The highest bedrock elevations are located along the prominent ridges within the study area and reach approximately 1,300 feet above mean sea level (ft-msl). The lowest bedrock elevations are located in valley and lowland areas at elevations of about 700 ft-msl. The variation in the elevation of the bedrock surface is shown in Figure 5. The thickness of unconsolidated materials was calculated as the difference between the top-of-bedrock surface elevation and the land surface elevation. The thickness of unconsolidated material ranges from thin to absent in upland areas, where bedrock is near or at land surface, to almost 300 feet thick in principal lowlands and river valleys (Figure 6).

Top-of-Precambrian surface

In Wisconsin, the Precambrian crystalline bedrock is generally regarded as a very low-permeability environment compared to overlying sandstone formations. In the study area, the Precambrian surface represents the base of the groundwater flow system and will be represented in the groundwater model as a no-flow boundary. We estimated the elevation of the Precambrian surface by incorporating mapped outcrops of this rock and geologic and geophysical logs that intersected Precambrian crystalline rock. Similarly to the bedrock surface map, a map of the elevation of the Precambrian surface was generated using the Natural Neighbor interpolator in ArcGIS 10.1.

Hydrostratigraphic units

Geophysical logs were most useful in delineating hydrostratigraphic units due to their detail and accuracy. Figure 7 provides an example of how geophysical logs are useful to delineate distinct hydrostratigraphic units. The available geophysical logs were used in a similar fashion and combined with geologic logs to estimate the extent of each hydrostratigraphic unit. In areas where these geologic deposits were eroded and are now absent, the bedrock surface map was used to constrain the elevation of these deeper surfaces. Figure 8 shows a comparison of the hydrostratigraphic framework developed for this study to the general geologic stratigraphy in the study area.

Hydrostratigraphic layers

The hydrostratigraphic units described above form the framework for layers in the three-dimensional groundwater flow model. Figure 9 illustrates the extent of each bedrock hydrostratigraphic surface in plan view. The unconsolidated materials are omitted from this figure to more clearly show the bedrock hydrostratigraphy. A generalized east to west cross section, Figure 10, illustrates the thickness of these layers. The layering will be simplified during model development and calibration to improve computational efficiency. This is accomplished by lumping layers into a fewer number of aquifers and aquitards across the model domain.

Estimating groundwater recharge

Overview

Groundwater recharge is water that reaches the water table and becomes part of the groundwater flow system. Recharge estimates are an important step in developing a groundwater flow model because recharge is the source of water to the groundwater system, both in reality and in the model's representation of the physical system.

Recharge is difficult to measure directly because it varies spatially (due to changes in soil, vegetation and topography) and temporally (due to daily and seasonal differences in climate). An alternative to measuring recharge to the water table is to model or measure the infiltration of water through soil. One can then assume that deep infiltration, or water that passes through the root zone, flows through the unsaturated aquifer (the vadose zone) to reach the water table. This is a reasonable assumption for the Chippewa County area, where climatic conditions are typical of the humid Upper Midwest United States and where the water table is generally close to land surface.

The groundwater flow model developed for this project will be used to simulate the effect of groundwater pumping during pre-mining, mining, and post-mining conditions. Evaluation of pumping in regions with expanded agricultural irrigation will be an additional application of the model. With these purposes in mind, we selected the soil-water-balance (SWB) computer code (Westenbroek et al., 2009) to estimate recharge across the study area. This method provides estimates of deep infiltration based on precipitation, which varies over time, and soil type and land use, which vary spatially across the landscape.

The SWB model applies a mass-balance approach to account for all precipitation that reaches the land surface. To accomplish this, the model tracks each process that can divert precipitation prior to it reaching the water table as recharge. The model accounts for the following processes:

- Interception of water by the plant canopy
- Runoff that flows across the land surface
- Evapotranspiration of water through evaporation or use by plants
- Soil moisture capacity, which is the amount of water that may be retained in soil pores

The model is developed using GIS computer techniques, overlaying a grid of cells on digital maps of soil, land use, and topography (described below). The model calculates a value of recharge at a daily time step in each model cell:

Recharge = precipitation – interception – runoff – evapotranspiration – change in soil moisture storage

In a cell with no available soil moisture storage, excess precipitation (that is, the precipitation that is not intercepted, evapotranspired, or stored in soil pores) is routed to the adjacent downstream cell as runoff. The runoff may infiltrate or transpire in this cell, or continue as runoff to the next downstream cell. This determination is made on the basis of available soil-moisture capacity in each cell. Precipitation and temperature are input to the model at a daily time step. Temperature is tracked over time to determine periods of snowfall and frozen ground, both of which decrease infiltration. Temperature is also used in the model to calculate the rate of water use by plants. Westenbroek et al. (2009) provide additional detail.

One challenge in applying the SWB model is developing the conceptual model for simulating recharge in reclaimed areas. Soil structure is altered during excavation, storage, and eventual replacement of soil in reclaimed areas. Drainage and infiltration in reclaimed areas may change over time as plants are established and roots, worms, and other biological activity result in development of macropores. To facilitate use of the SWB for simulating reclaimed areas, a series of field measurements of infiltration were made in and near the study area in 2014. Preliminary results are presented in this report; these measurements will inform additional modeling with the SWB in 2015.

Recharge estimates for pre-mining conditions

Several data sets are necessary to run the SWB. Daily precipitation and temperature records were available from Bloomer, Wisconsin. Missing climate records were supplemented with those available from Eau Claire, Wisconsin. Topographic data is also used in the model to route runoff. To achieve reasonable model computation times, the updated 30-m digital elevation model (DEM) was used for this purpose and obtained from the National Elevation Dataset (Gesch, 2007; Gesch et al., 2002). The spatial resolution of the model is approximately 98 feet, which is determined by the DEM resolution.

Additional model inputs include soil characteristics. The soil hydrologic group and the available water storage are data contained in the Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). Finally, land-use data are needed in the SWB to calculate interception, runoff, evapotranspiration, and root zone depth. The 2006 National Land Cover Database was used for the SWB simulation described here.

A 61-year period, 1950 to 2010, was simulated with the SWB. This long time period provides insight into recharge over the study area under a variety of climate patterns. During this period, total annual precipitation in Bloomer averaged 31.2 inches, ranging from a minimum of 16.9 to a maximum of 44.6 inches (Figure 11). The average estimated annual groundwater recharge during this time period was 8.2 inches and ranged from 2.5 to 14.1 inches.

As reflected in Figure 11, climate affects recharge. Recharge estimates increase in 2001 and 2002, coincident with high precipitation in 2000-2002. Relatively dry conditions experienced in 1987-1989 result in several low-recharge years. Additionally, the timing and intensity of precipitation affect recharge by impacting runoff, infiltration, and evapotranspiration. For example, rain that arrives in August under high temperatures and growing crops will be subject to more use by plants than rainfall in October, when crop land is bare. These effects are simulated in the SWB and can be seen in model results. The relationship in simulated recharge and measured precipitation is shown in Figure 12. The graph illustrates that recharge increases with precipitation, but there is variation in recharge with similar precipitation. For example, at an annual precipitation rate of 30 inches per year, estimated recharge in the study area varies from about 7.5 to 9 inches. The variation is due to several factors including antecedent soil moisture, conditions during spring snow melt, the magnitude of individual rainstorms, and the temperature during the growing season.

Recharge varies spatially across the study area, as illustrated in Figure 13. This map shows simulated recharge in 1993, during which precipitation and recharge approximated average conditions. Estimated recharge varies from less than 3 to more than 15 inches across the study area. Climate patterns during other years result in different recharge estimates, but the overall pattern across the landscape is similar to that shown in Figure 13. This spatial variation in recharge reflects changes in soil type (sandy soils lead to increased infiltration compared to soil with more silt or clay) and land use (forested land generally allows higher infiltration compared to cropped land or urban areas). Low recharge areas can be seen in the map along stream valleys, and this generally reflects the presence of open water and wetland soil types, both of which conditions are typically associated with areas of groundwater *discharge* rather than recharge.

Soil type and land use have a large effect on recharge and the resulting estimates from the SWB. SWB results at 12 sites within the study area are illustrated in Figure 14 for dry (1994), average (1993) and wet (2002) years. These specific locations are shown because they are permitted for industrial sand excavation. However, the recharge estimates are based on conditions *prior to* such development; the land use simulated in the SWB was typically forested uplands. At each location, recharge can vary from year to year by more than ten inches due to climatic conditions alone. For example, at the LaGesse Mine (Preferred Sands), the SWB simulates recharge of 6.0 inches in a dry year and 17.6 inches in a wet year. By comparing locations, this figure illustrates differences in recharge within the study area due to soil type. For example, the Mine 2 site has less permeable soil than the LaGesse site. Thus, recharge is lower at the Mine 2 site under each of the three weather patterns: simulated recharge is 4.0 inches in a dry year and 13.0 inches in wet year.

Model limitations

The SWB model has several limitations which are fully described by Hart et al., (2012), and are briefly summarized here. One limitation concerns the accuracy of SWB estimates, which are affected by the uncertainty and resolution of the information supplied to the model. For example, the model uses a total daily precipitation amount to calculate a daily recharge value. Thus, the model does not differentiate between a two-inch rainfall that occurs over a 15-hour period or a two-inch rainfall than occurs in two hours. In reality, runoff would be greater in the two-hour duration storm than the 15-hour storm.

A second example concerns runoff into model cells that fall within closed depressions in the DEM. Including such closed depressions in the model can lead to erroneously high recharge estimates because the model cannot route runoff out of such low areas, nor does it simulate ponding of surface water in these areas. This application of the SWB overcomes this problem by altering the DEM to eliminate closed depressions. Thus, runoff is routed continuously along a flow path until it reaches a cell with soil capacity or until it reaches a surface water body that accepts the runoff.

A further simplification applied in the SWB relates to land use in the study area. Although the climate conditions simulated include 1950 to 2010, land use was held to that described in the 2006 National Land Cover Database. This is a reasonable assumption for this area because of the limited growth in urban areas in the region. Land use changes will be the focus of the SWB model application in 2015, as the recharge estimates are developed for actively mined areas and reclaimed areas.

Infiltration testing

Field infiltration rates were measured[1] by the U.S. Geological Survey (Juckem, written communication, Feb., 2015) during the summer and fall of 2014 at several sites in Barron, Chippewa, and Jackson counties. Tests were conducted at sites exhibiting a variety of land-use conditions including forest, prairie and grasses, agriculture fields, and reclaimed industrial mine sites. Infiltration measurements on soils that were reclaimed several decades ago were conducted at Badger Mining Company's Taylor mine in Jackson County, which began operation prior to 1985. Although this is south of the study area, it is useful to understand infiltration characteristics at a mature reclaimed site.

Double-ring infiltrometers were used to measure infiltration rather than a method similar to a perk-test. The infiltrometer was preferred because it reduces soil disturbance and can accommodate infiltration through macropores, such as wormholes or channels from decayed plants. In contrast, a perk test requires augering or digging a hole for infiltration, which disturbs the soil structure. Each test was initiated by hammering an approximately 12-inch diameter inner ring and an approximately 24-inch diameter outer ring at least an inch into the soil to ensure a tight seal. A neoprene fabric lining was placed inside each ring to minimize soil disturbance. Each ring was then filled with water. The outer ring provided a buffer around the inner ring, preventing horizontal flow out from the inner ring. This ensures that measurements made from the inner ring represent vertical, one-dimensional infiltration. During most tests, water level decline in the inner ring was monitored until the infiltration rate dropped to a constant value. The exception to this was at sites with very slow infiltration, where the water level decline was monitored for a minimum of two hours.

Results of these tests (Figure 15) illustrate a strong relationship between soil infiltration rates and the associated land use and vegetative cover, which control soil structure and macro-pore development. Associations between soil texture and infiltration rates will be evaluated after all soil samples have been dried and sieved to determine grain-size distributions. Forested soils in Chippewa and Jackson counties had the highest average infiltration rates among each land cover category. The highest infiltration rate was measured was at a prairie location in Chippewa County. Sites in cultivated agricultural fields had the lowest infiltration rates, similar to those measured at recently reclaimed industrial sand mine sites. The

[1] These data are preliminary or provisional and are subject to revision. They are being provided to meet the need for timely best science. The data have not received final approval by the U.S. Geological Survey (USGS) and are provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the data.

sites in reclaimed mining areas exhibited widely variable infiltration rates, but in general infiltration rates increased in association with the age of the prairie grass stand growing on the reclaimed area.

Public outreach and reporting

Introduction

Outreach and education efforts were designed to communicate study objectives, preliminary findings, and overall progress to a diverse group of stakeholders including the general public and consisted of general information about hydrogeology and the construction and use of groundwater flow models.

Stakeholders group

A stakeholders group was established to communicate study progress and findings, and to facilitate communication between the WGNHS, USGS, and the variety of stakeholder interests. Stakeholders agreed to serve as representatives of their respective organizations, actively participate in annual meetings, and provide feedback on project progress. A complete description of the Project Stakeholders Group Charge as well as a list of the original group of project stakeholders are included in Appendix C of the original project proposal. Since the start of the project in August, 2012, Western Wisconsin Sand Company and Great Northern Sand have also formally joined the stakeholders group.

The first stakeholders meeting was held on October 12, 2012 in Chippewa Falls at which the project proposal was presented to the group. Subsequent stakeholders' meetings were held on February 26, 2013 and March 18, 2014. Agendas, minutes, PowerPoint presentations and other materials presented at each meeting are available on the Chippewa County website. To access online, go to the web address "*co.chippewa.wi.us/lcfm*" and click on the tab "Chippewa County Groundwater Study".

Public outreach

Two educational outreach events have been held in Bloomer (February 26, 2013 and March 18, 2014) to summarize the information presented at the stakeholders' group meeting and provide an opportunity for citizens to ask questions about the groundwater study. At an open house gathering before a more formal presentation, Chippewa County, WGNHS, and USGS staff presented data collected or compiled for this project and demonstrated groundwater modeling techniques. Press releases, PowerPoint presentations, and other materials presented at each meeting are available on the Chippewa County website.

Factsheet

A factsheet published in 2013 (Parsen and Gotkowitz, 2013) describes the groundwater study and provides information about groundwater resources, industrial sand mining, and irrigated agriculture. The fact sheet is available at the Chippewa Co. webpage listed above and from the WGNHS at: http://wgnhs.uwex.edu/pubs/000922/.

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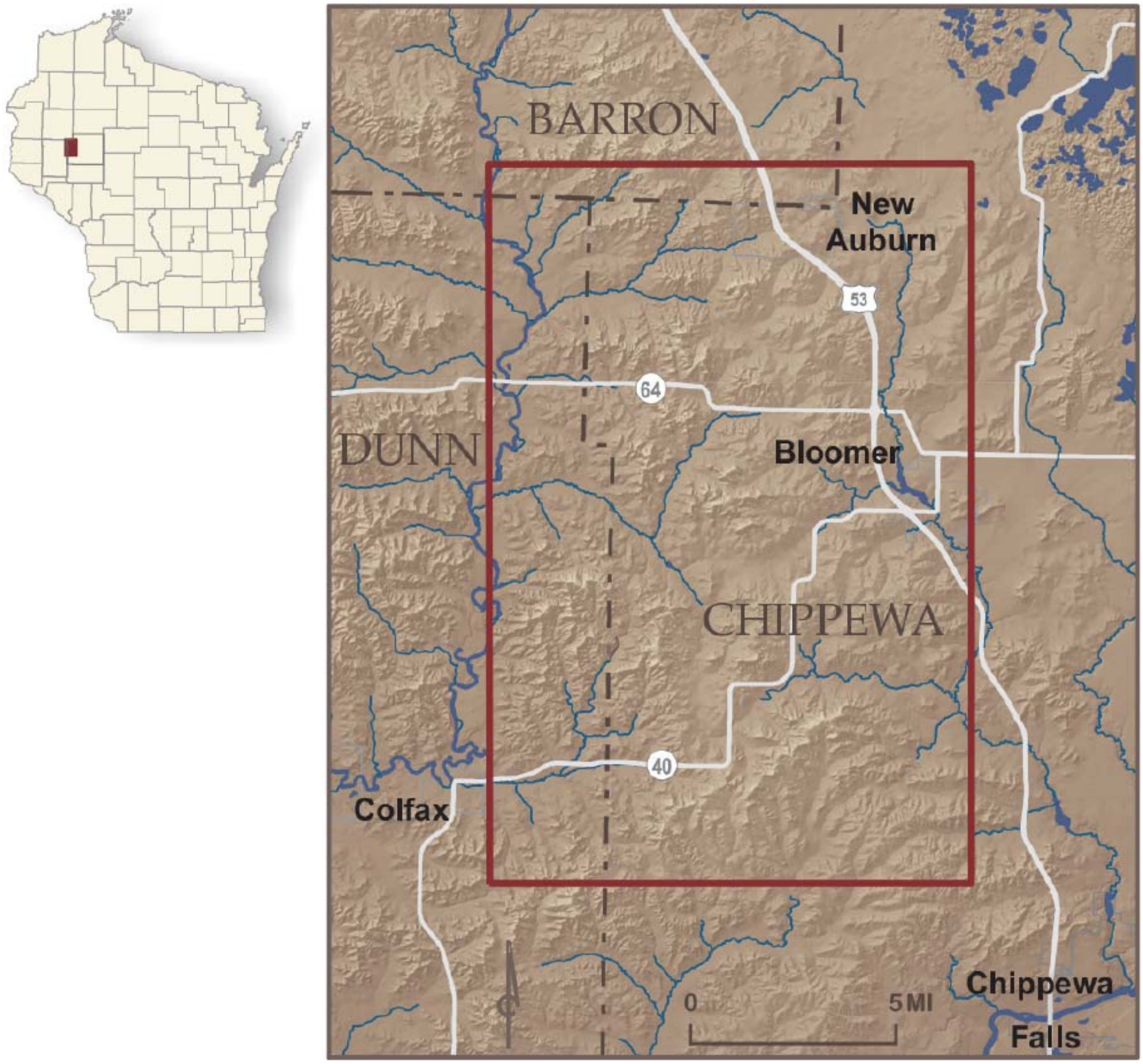


Figure 1. Study area in western Chippewa County is delineated by a red box and includes portions of neighboring Barron and Dunn counties.

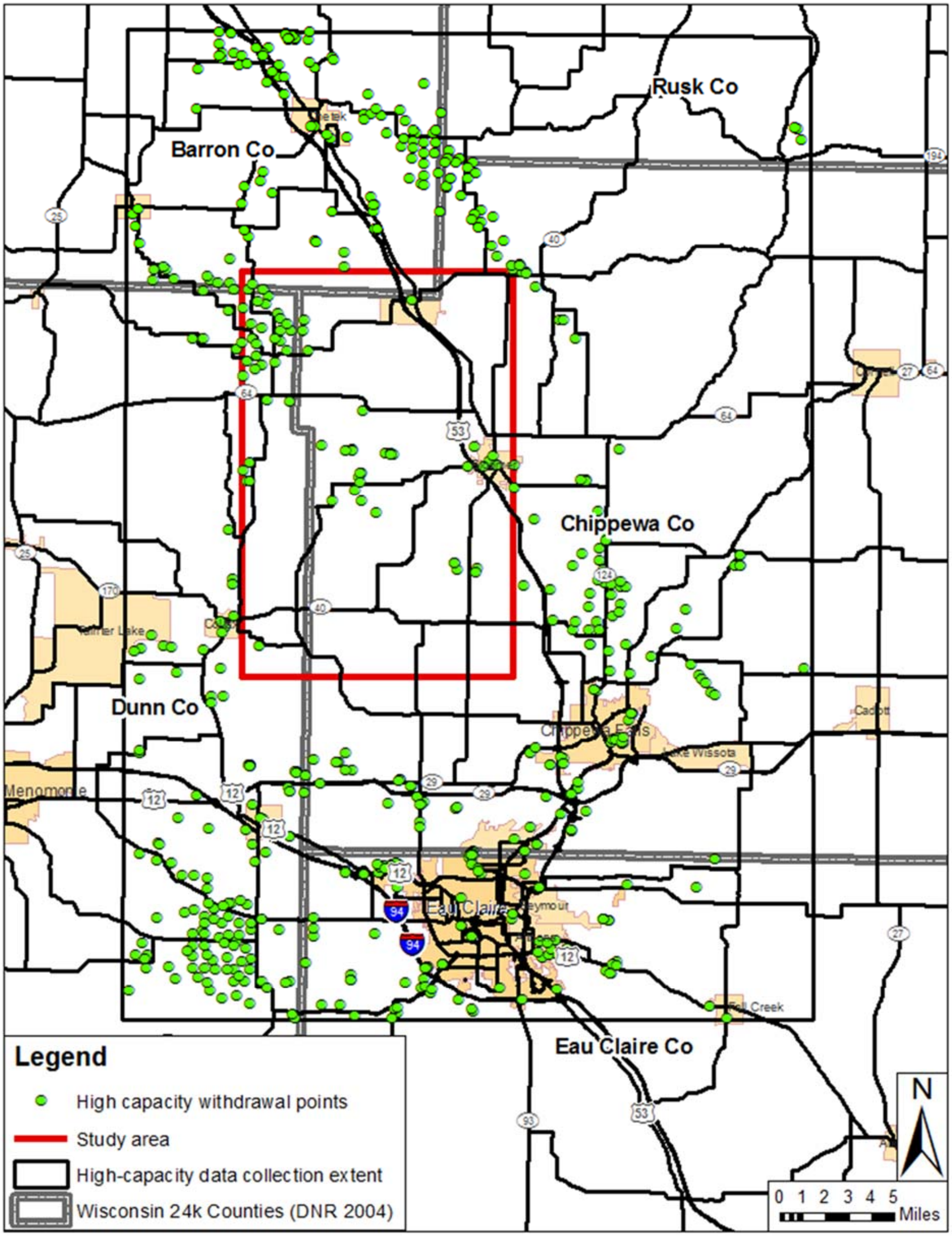
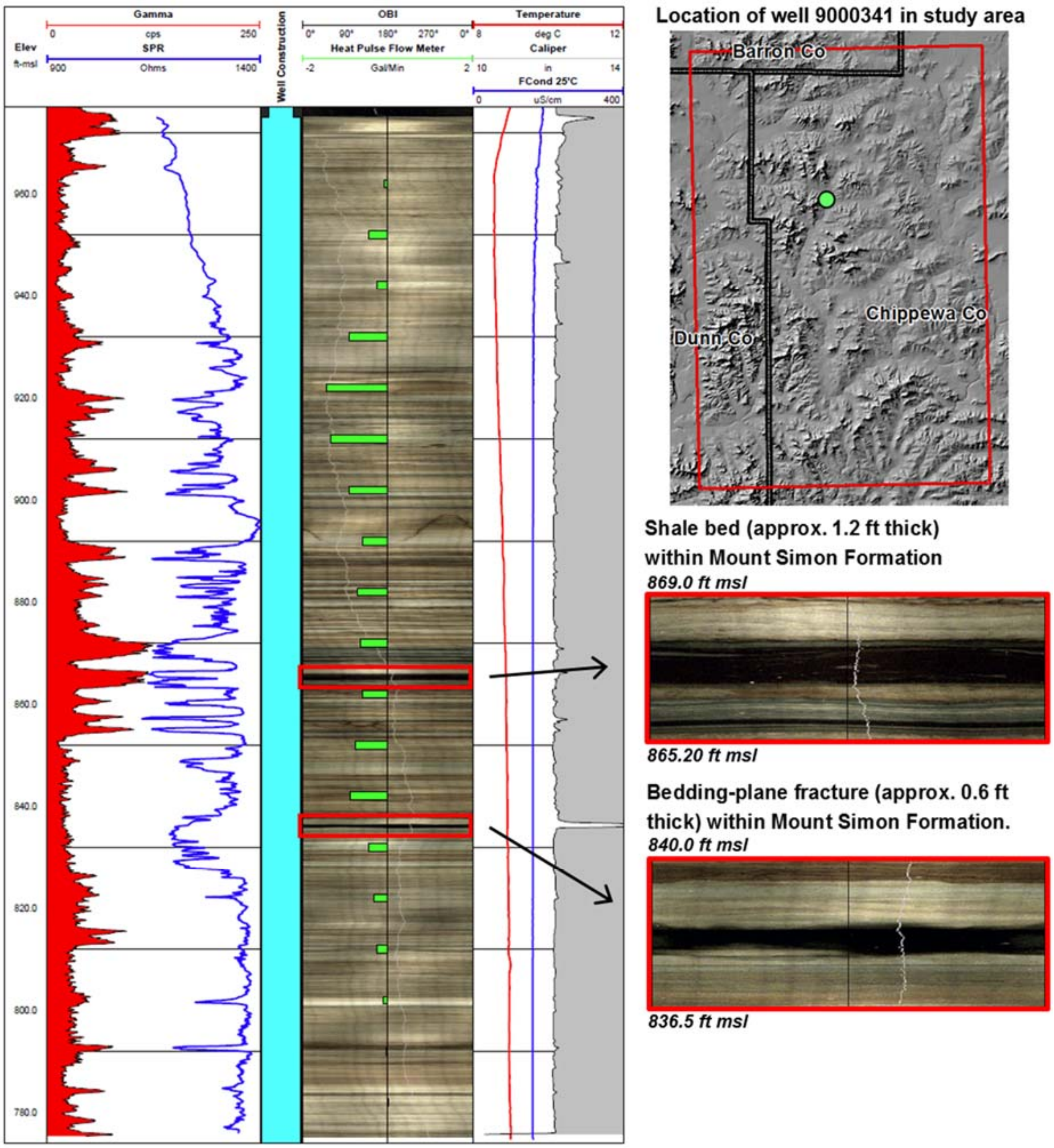


Figure 2. Location of high-capacity well and surface water withdrawal point data obtained from the WDNR and compiled for the study. The final number of high-capacity withdrawal points included in the groundwater model will depend on the extent of the model domain, which may extend beyond the study area shown here.



Legend

Title	Units	Description
Elev	Ft-msl	Elevation
Gamma	Cps	Natural-gamma radiation
SPR	Ohm-m	Single-point resistivity
FCond 25°C	µS/cm	Conductivity at 25° C
Temperature	C	Temperature
Well construction	-	Casing depth and well depth
Caliper	Inches	Borehole diameter
OBI	-	Optical borehole image
Heat Pulse Flow Meter	Gpm (negative is downward flow)	Vertical bore hole flow rate

Figure 3. Example borehole geophysical log from the Superior Silica Sand Culver Mine (WGNHS ID: 09000341) including high resolution imagery from the optical borehole imager (OBI) tool.

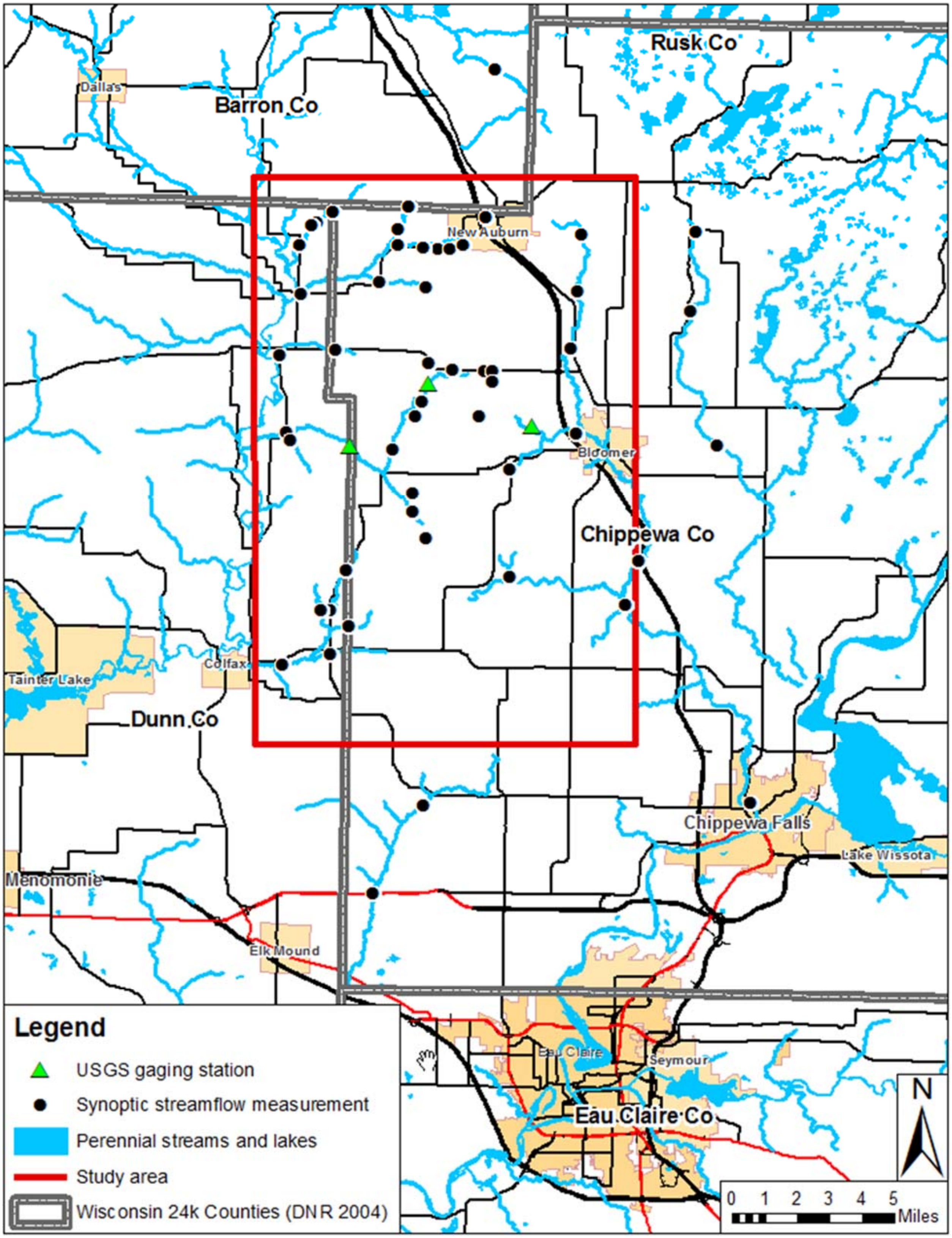


Figure 4. Streamflow measurement locations in or near to the study area.

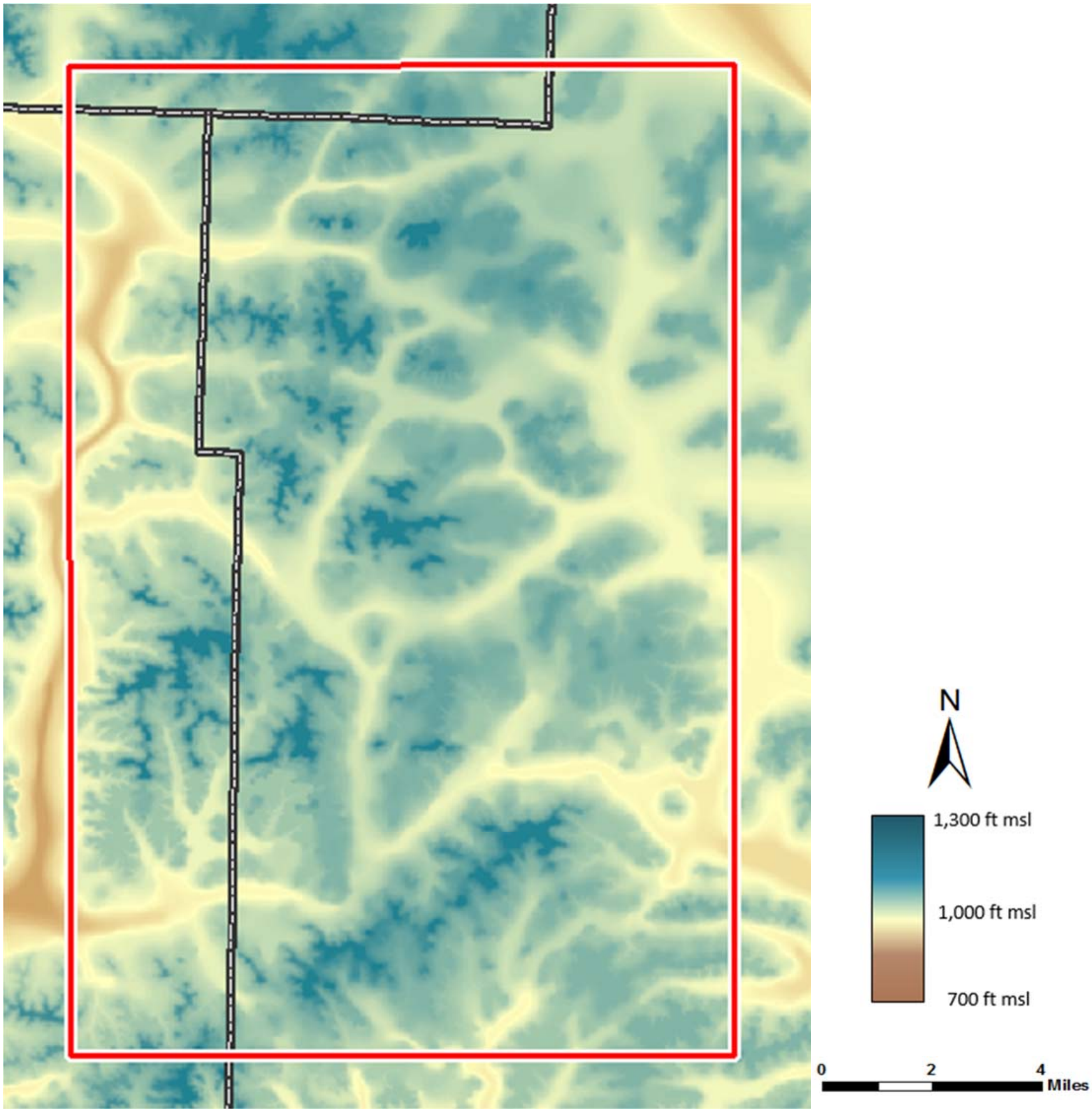


Figure 5. Bedrock elevation surface, feet above mean sea level. Sand and gravel deposits on the order of several hundred feet thick are present in erosional valleys, such as the modern-day Red Cedar River channel, along the western edge of the study area.

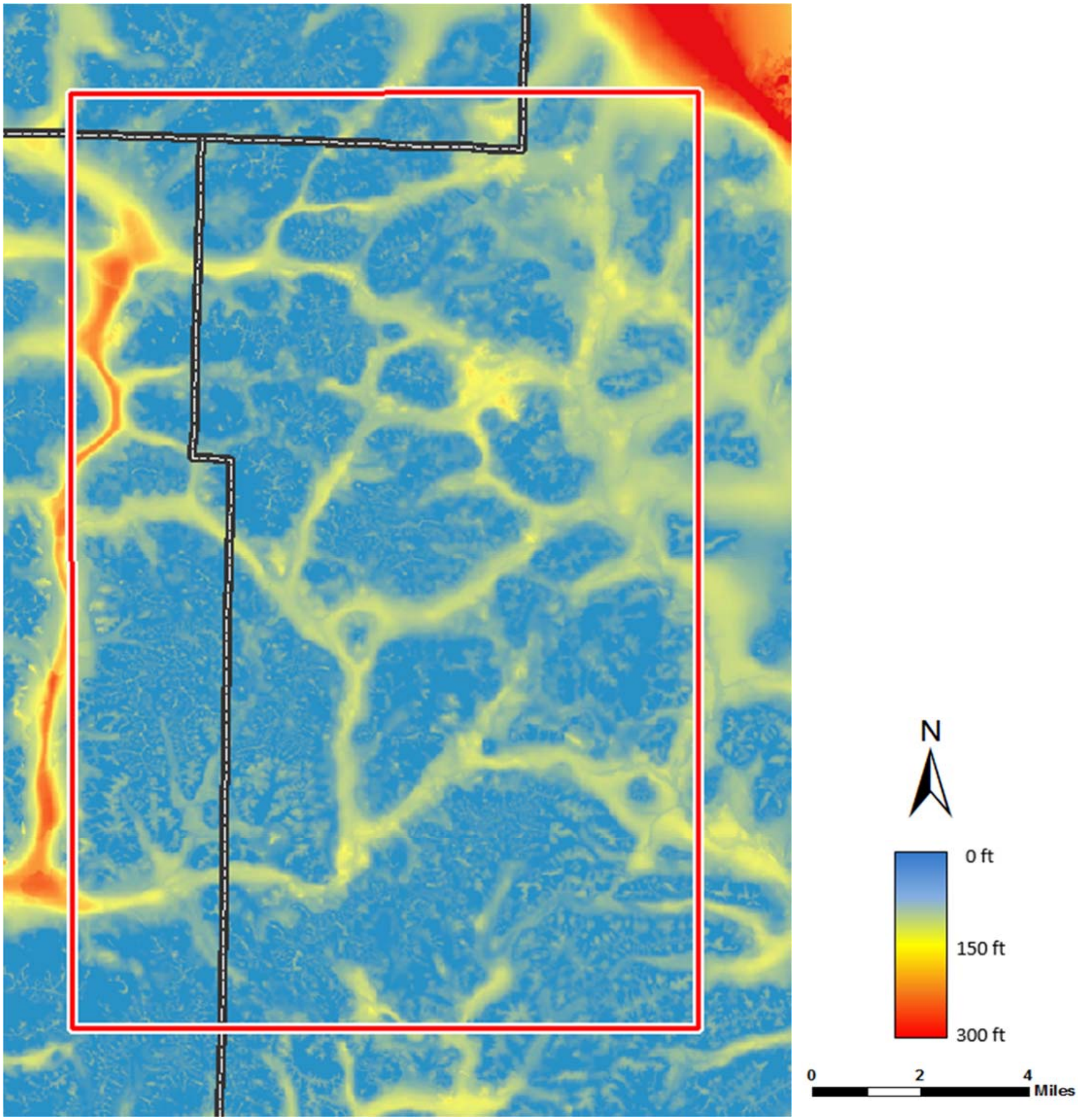


Figure 6. Thickness of unconsolidated sand and gravel deposits (model layer 1). These thicknesses are calculated as the difference between land surface and the top-of-bedrock surface shown in Figure 9. Sand and gravel deposits along the Red Cedar River Valley (along western edge of study area) approach 200 feet thick, while deposits northeast of modern-day McCann Creek (northeast of the study area) approach 300 feet thick. In upland areas, the thickness of unconsolidated materials can thin to zero in areas where bedrock is near or at land surface.

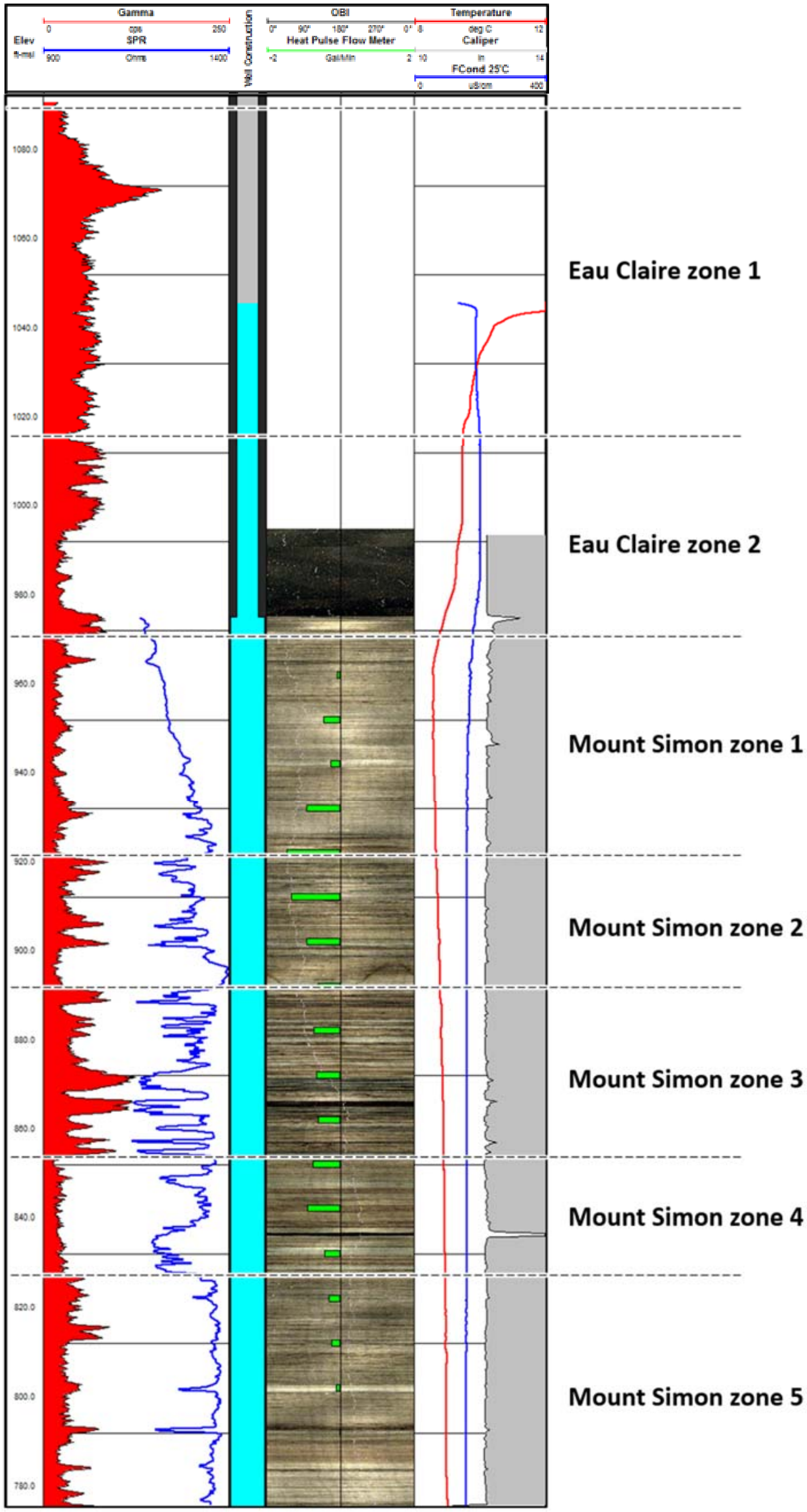


Figure 7. Example showing delineation of hydrostratigraphic zones based on geophysical logging of a well at the Superior Silica Sand Culver Mine (WGNHS ID: 9000341). Refer to Figure 3 for additional information about this borehole geophysics log.

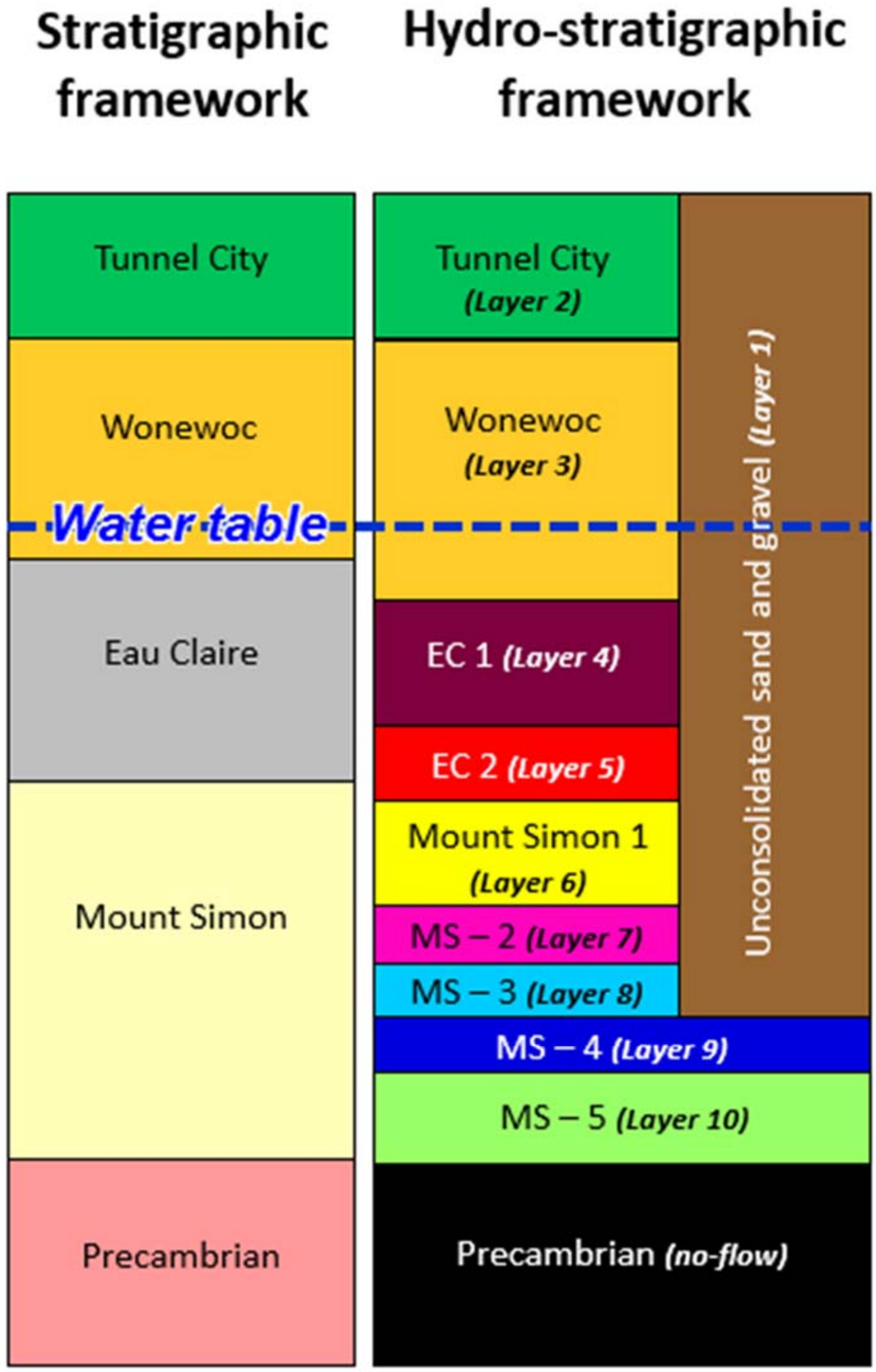


Figure 8. Stratigraphic and hydrostratigraphic framework for the study area. The number of layers in the final flow model is expected to change from that shown here.

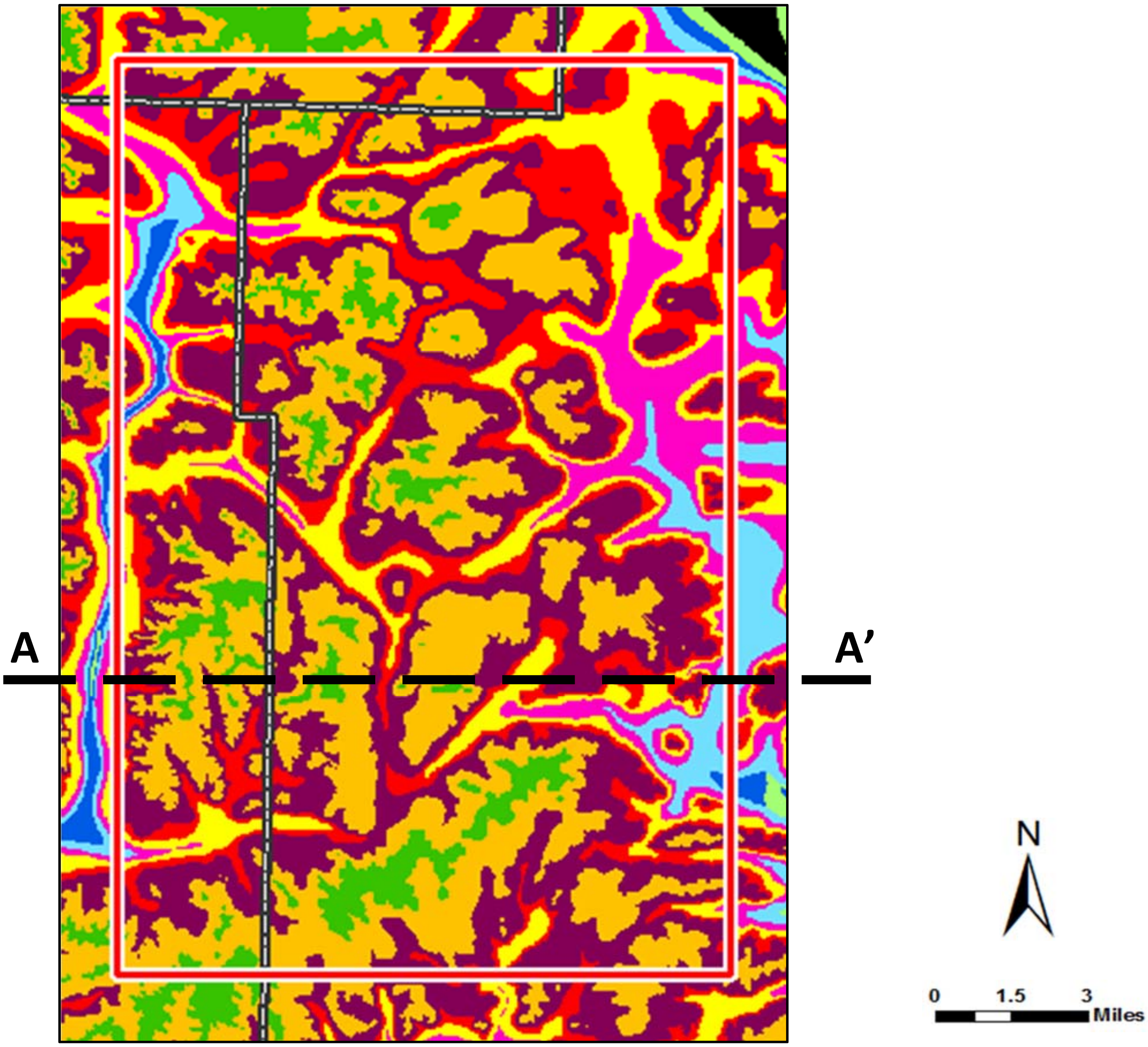


Figure 9. Extent of hydrostraitraphic layers 2 to 10. The color scheme is shown in Figure 6. Precambrian rock, visible in the northeast, underlies all model layers at depth and will serve as the lower limit to the groundwater model. A generalized cross-section along transect A-A’ is depicted in Figure 10 below.

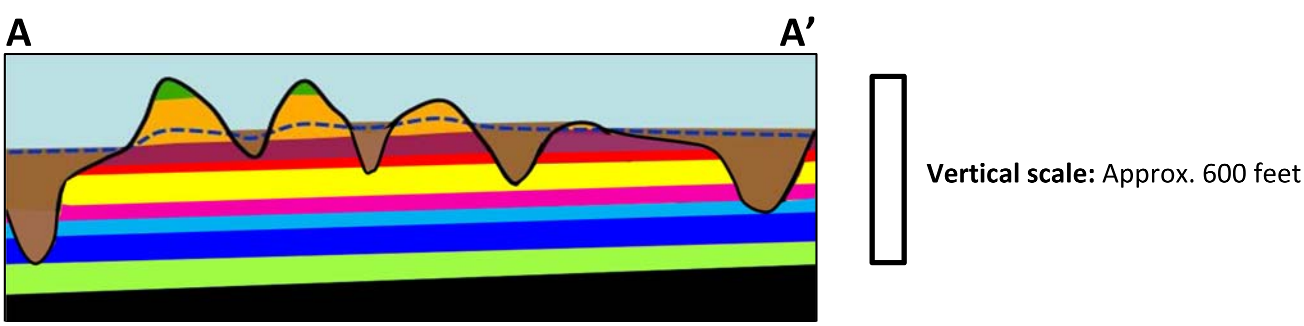


Figure 10. Generalized cross-section along transect A-A’ showing the distribution of all hydrostratigraphic layers with depth. NOTE: Unlike Figure 9, Layer 1 (unconsolidated sand and gravel shown as brown) and the approximate location of the water table (dashed blue line) have been added to this transect.

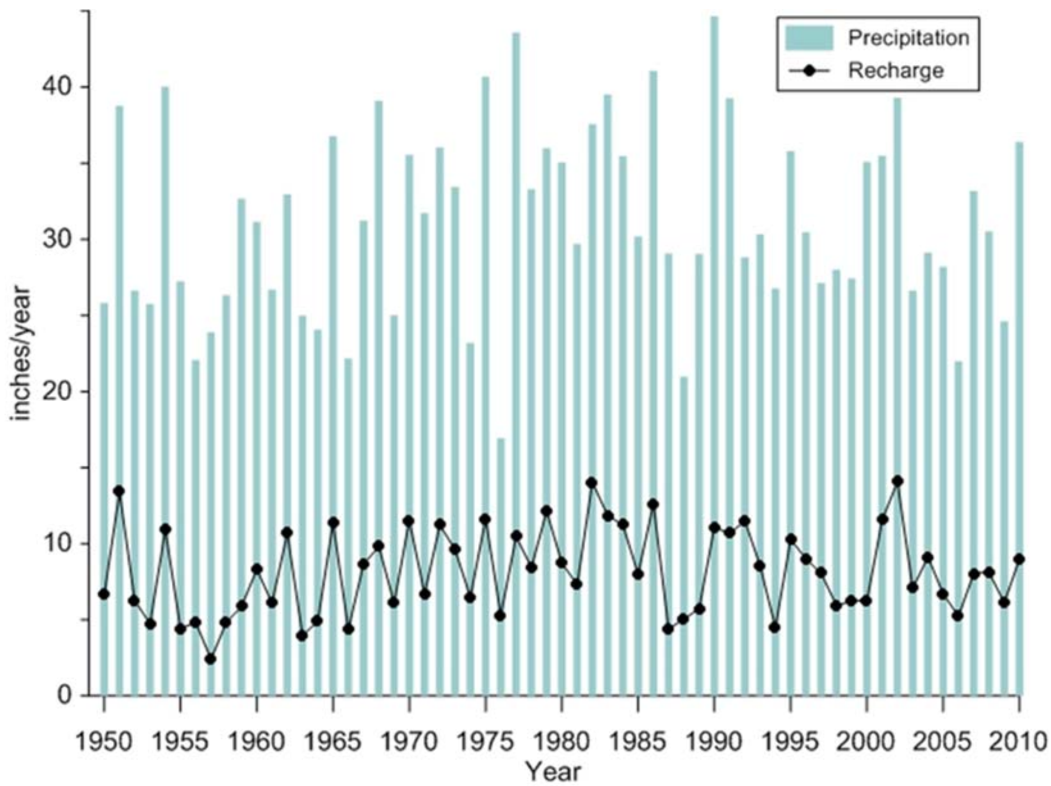


Figure 11. Annual recharge averaged over the model domain and annual precipitation at Bloomer, Wisconsin, 1950 – 2010.

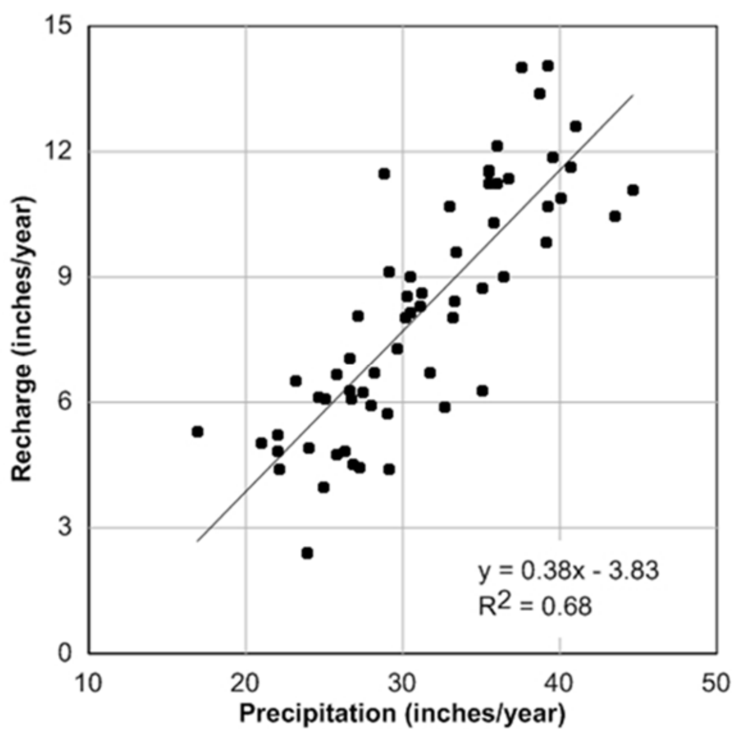


Figure 12. Precipitation and variation in estimated recharge.

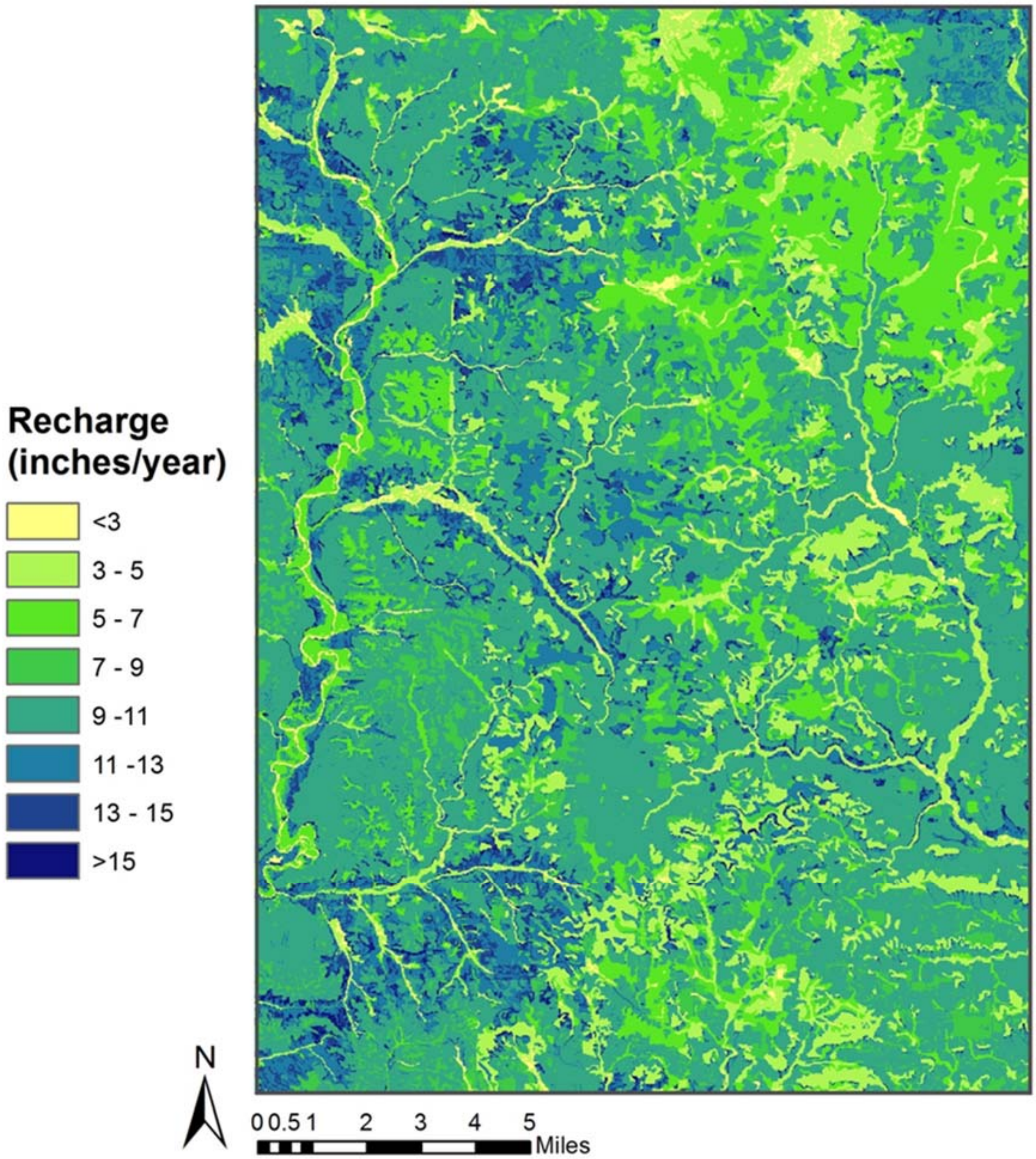


Figure 13. Simulated groundwater recharge in 1993.

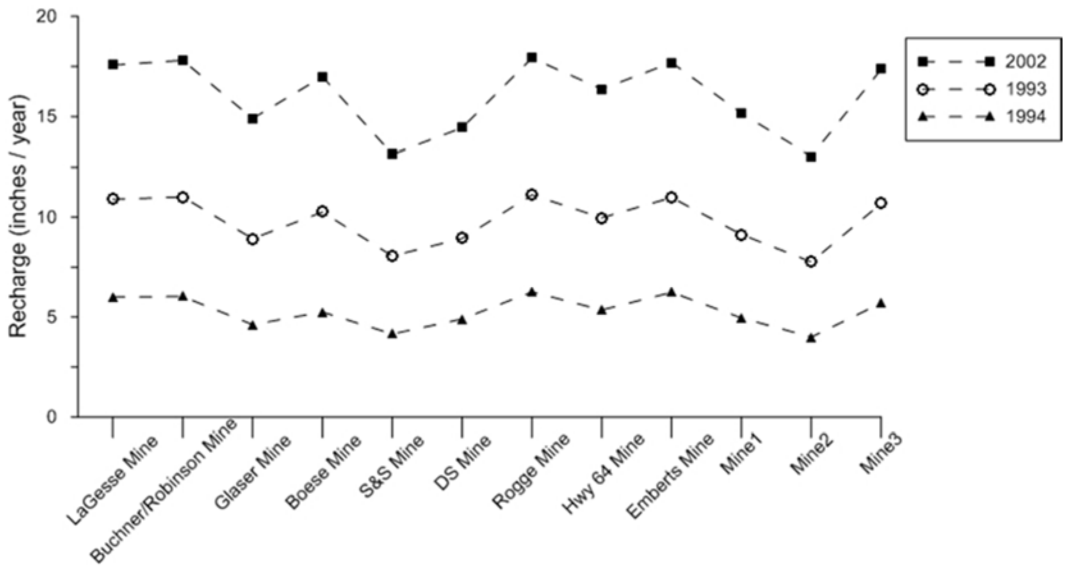


Figure 14. Recharge in dry, average and wet years prior to mine development.

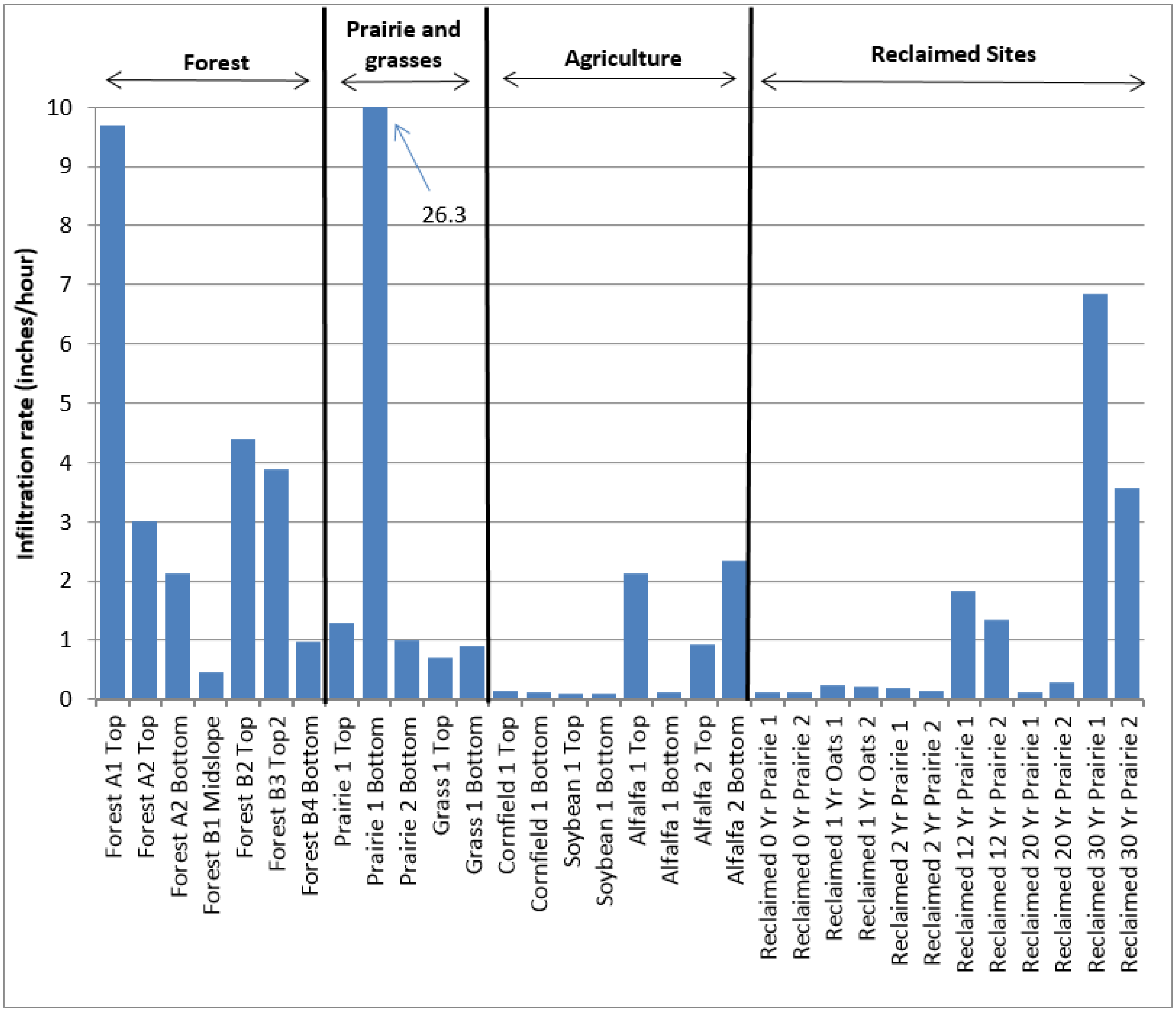


Figure 15. Summary of field infiltration measurements at sites in Chippewa and Jackson counties.

Geophysical Logs WGNHS Well ID 09000341

DATE 7/7/2011 WELL NAME Superior Silica - Culver Mine (NV250)

LOCATION near Bloomer, WI

COUNTY Chippewa LOGGED BY WGNHS (M. Parsen & J. Krause)

LATITUDE 45.134013 LONGITUDE -91.606183

LOCATION METHOD: GPS [ ] AIR PHOTO/TOPO [ ] PLSS [ ] OTHER

ELEVATION ~1092 ELEVATION METHOD: DEM [X] TOPO [ ] OTHER

WELL DEPTH 320 CASING DEPTH 117 DEPTH TO WATER approx 46.5 ft

CASING STICK UP 2 File Created on: 8/10/2012 by: SJ

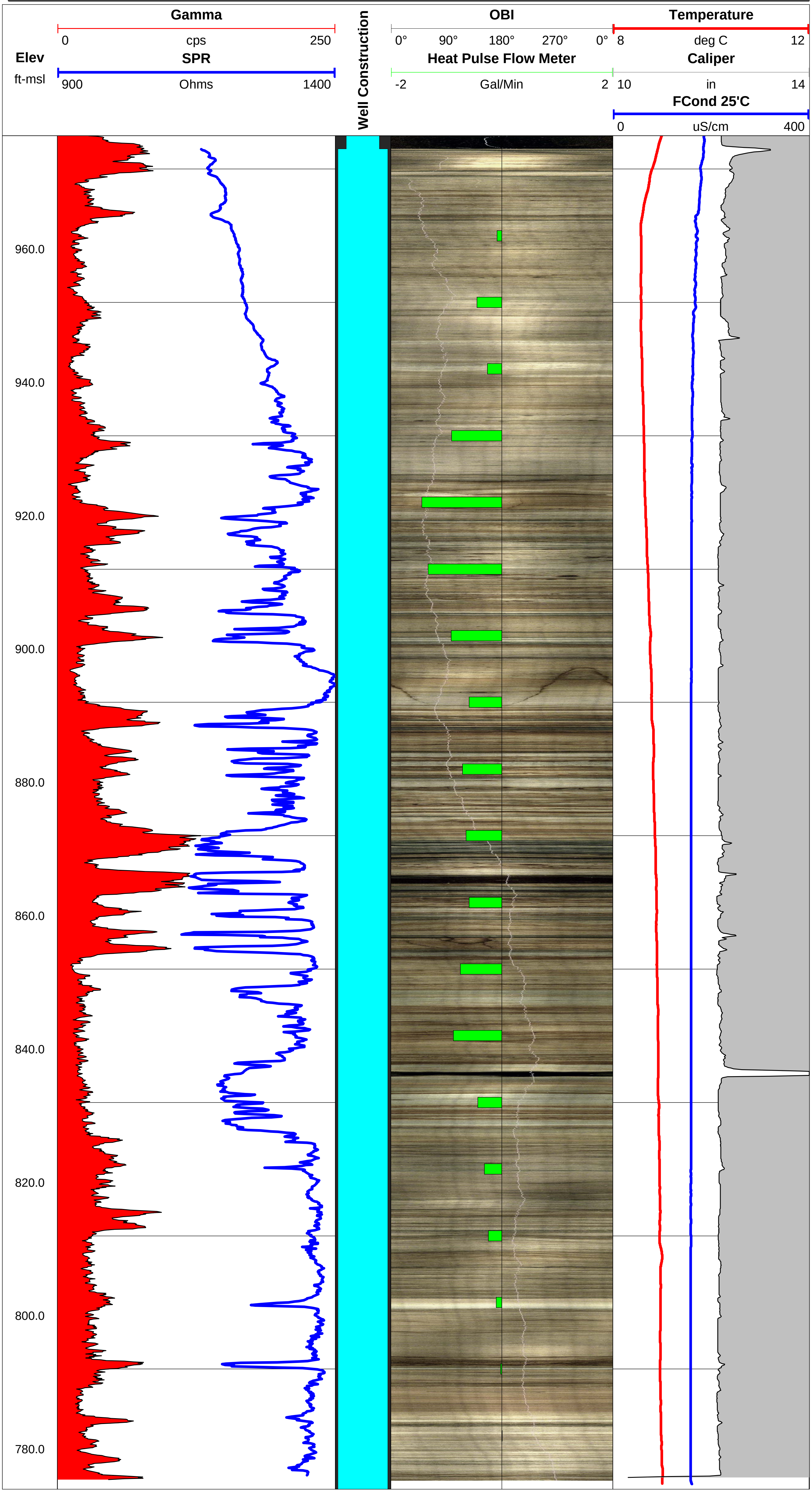
Comments: DNR High Cap Well #: 71507. Elevation is Ground Surface-- all depths reported from top of casing. Well was pumped at low flow rate during heat pulse flow meter logging. Negative flow is upward.

LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper	X	Flow Meter- HeatPulse	X
Single Point Resistivity	X	Flow Meter- Spinner	
Self Potential		Optical Borehole Imager	X
Normal Resistivity		Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:______	

Unless Noted:
- all depths are in feet
- casing and depth to water are interpreted from geophysical log
- datum is the top of casing

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu



Geophysical Logs **WGNHS Well ID** 9000400

DATE 8/14/2013 WELL NAME Stiehl (Operator) Well (YJ728)

LOCATION Bloomer

COUNTY Chippewa LOGGED BY WGNHS (P. Chase, M. Parsen)

LATITUDE 45.070040 LONGITUDE -91.592381

LOCATION METHOD: GPS [X] AIR PHOTO/TOPO [ ] PLSS [ ] OTHER

ELEVATION 1073.1 ELEVATION METHOD: DEM [ ] TOPO [ ] OTHER LiDAR

WELL DEPTH 318 CASING DEPTH 62.5 DEPTH TO WATER 38.11

CASING STICK UP 1.25 File Created on: 10/23/13 by: AMB

Comments: DNR High Cap Well #: 72895. Gradually decreasing caliper measurment below 200 ft is believed to be due to well deviation where caliper tool was inclined and not fully opening. Borehole flow measured under ambient and pumped conditions. Well pumped at 60 gpm. Final pumped flow log displayed is an average of upward and downward flow measurements. Negative flow is upward.

LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper	X	Flow Meter- HeatPulse	
Single Point Resistivity		Flow Meter- Spinner (- flow up is negative, flow down is positive)	X
Self Potential		Optical Borehole Imager	
Normal Resistivity	X	Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:	

Unless Noted:

- all depths are in feet
- well depth, casing depth and depth to water are interpreted from geophysical log
- datum is the top of casing

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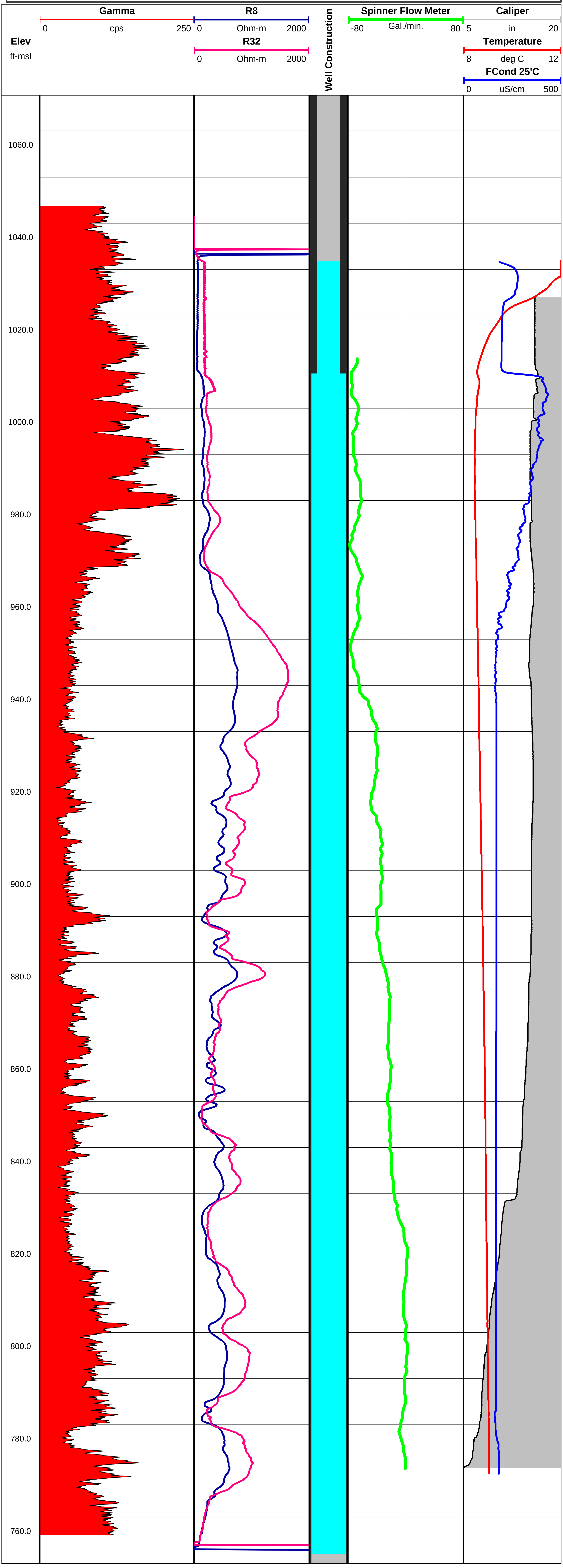


Geophysical Logs **WGNHS Well ID** *9000466*

DATE *10/12/2012* **WELL NAME** *Lake Hallie Well #4 Test Well (YI619)*

LOCATION *Lake Hallie, WI*

COUNTY *Chippewa* **LOGGED BY** *WGNHS (P. Chase)*

LATITUDE *44.879592* **LONGITUDE** *-91.398849*

LOCATION METHOD: **GPS** [ ] **AIR PHOTO/TOPO** [x] **PLSS** [ ] **OTHER** ______

ELEVATION *927.5* **ELEVATION METHOD:** **DEM** [x] **TOPO** [ ] **OTHER** ______

WELL DEPTH *113* **CASING DEPTH** *62* **DEPTH TO WATER** *~30.63 ft*

CASING STICK UP *2* **File Created on:** *10/25/2013* **by:** *MJP*

Comments: *DNR High Cap Well #: 72898. This test hole became Lake Hallie Well #4. Borehole flow was measured under ambient conditions (no pumping). Negative flow is upward.*

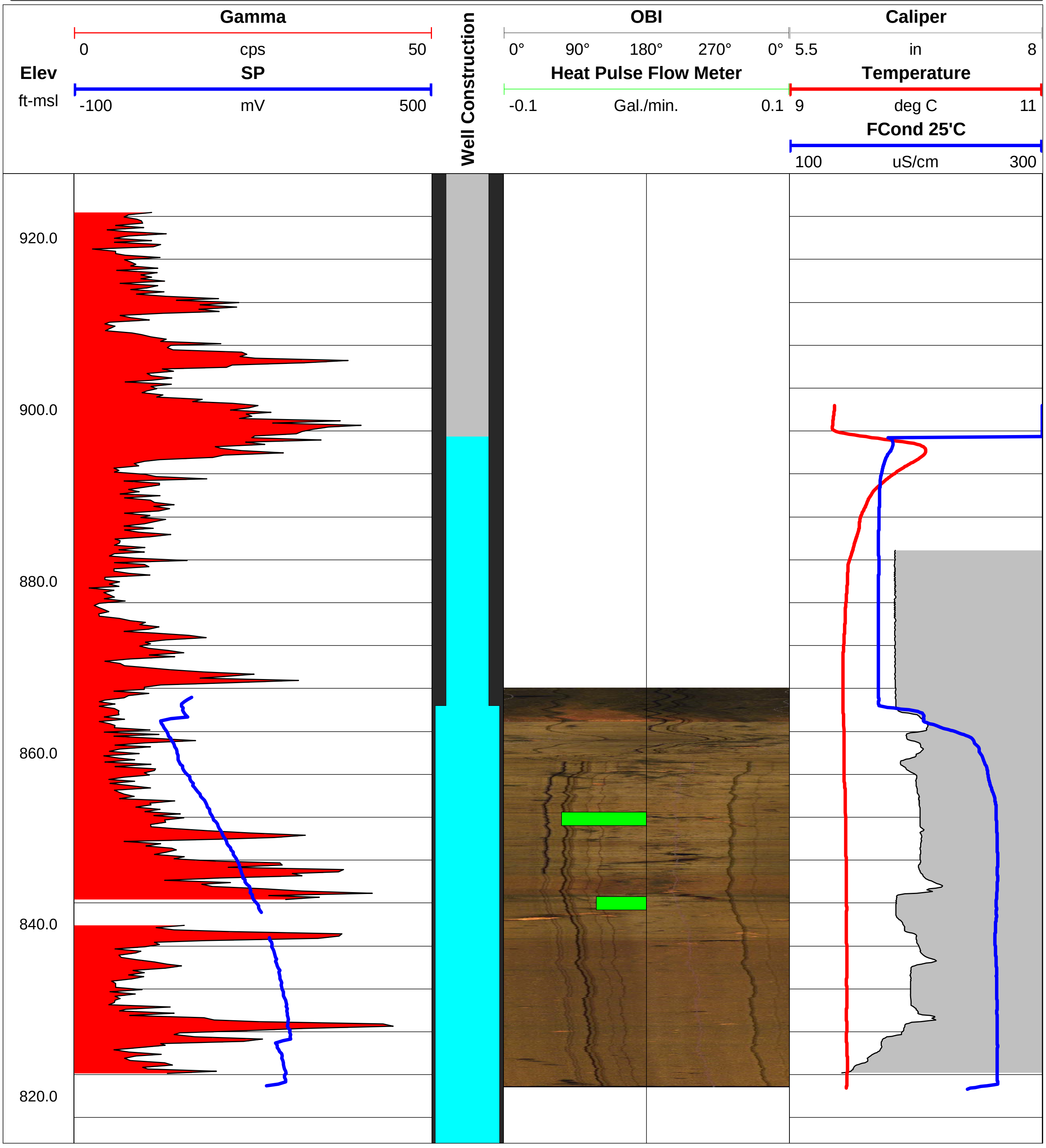
LOGS COLLECTED:

Gamma	x	Fluid Conductivity	x
Caliper	x	Flow Meter- HeatPulse	X
Single Point Resistivity		Flow Meter- Spinner	
Self Potential		Optical Borehole Imager	x
Normal Resistivity		Acoustic Borehole Imager	
Fluid Temperature	x	OTHER:______	

Unless Noted:

- *all depths are in feet*
- *well depth, casing depth and depth to water are interpreted from geophysical log*
- *datum is the top of casing*

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu



Geophysical Logs WGNHS Well ID 09000467

DATE 7/6/2011 WELL NAME Preferred Sands - LaGesse Mine (WT581)
LOCATION Bloomer
COUNTY Chippewa LOGGED BY BARR Engr (Downhole Services)
LATITUDE 45.10717 LONGITUDE -91.58042

LOCATION METHOD: GPS [ ] AIR PHOTO/TOPO [x] PLSS [ ] OTHER
ELEVATION 1123.1 ELEVATION METHOD: DEM [ ] TOPO [ ] OTHER Co. LiDAR
WELL DEPTH 335 CASING DEPTH 33 DEPTH TO WATER 38.11
CASING STICK UP 2 File Created on: 10/23/13 by: AMB

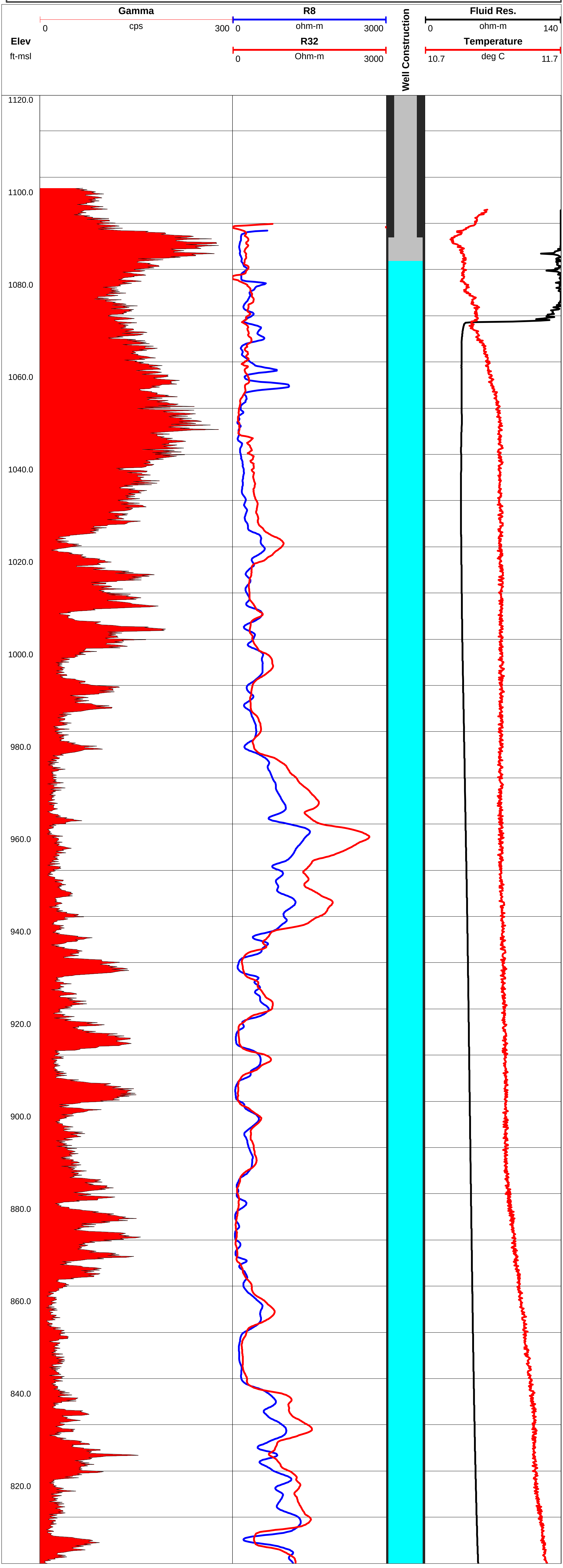
Comments: This well was a test hole and does not have a DNR High Cap Well #. Geophysical log performed by Downhole Well Services and provided to WGNHS by BARR Engineering. John Greer was the contact at BARR who organized the data transfer. Well was abaondonned (backfilled with bentonite chips) on 8/24/2011 by Shawano Well Drilling

LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper		Flow Meter- HeatPulse	
Single Point Resistivity		Flow Meter- Spinner (- flow up is negative, flow down is positive)	
Self Potential		Optical Borehole Imager	
Normal Resistivity	X	Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:________	

Unless Noted:
- all depths are in feet
- well depth, casing depth and depth to water are interpreted from geophysical log
- datum is the top of casing

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu



Geophysical Logs WGNHS Well ID 3000537

DATE 6/11/2014 **WELL NAME** Superior Silica - Thompson Mine (XK819)

LOCATION 150 W. River Rd. Chetek, WI

COUNTY Barron **LOGGED BY** WGNHS (P. Chase)

LATITUDE 45.227888 **LONGITUDE** -91.725610

LOCATION METHOD: GPS [ ] AIR PHOTO/TOPO [ ] PLSS [ ] OTHER

ELEVATION 1041 **ELEVATION METHOD:** DEM [X] TOPO [ ] OTHER

WELL DEPTH 305 **CASING DEPTH** 127.4 **DEPTH TO WATER** 28

CASING STICK UP 3.4 File Created on: 7/1/2014 by: AMB

Comments: DNR High Cap Well #: 73687. Borehole flow was measured under ambient conditions (no pumping). Positive flow is downward.

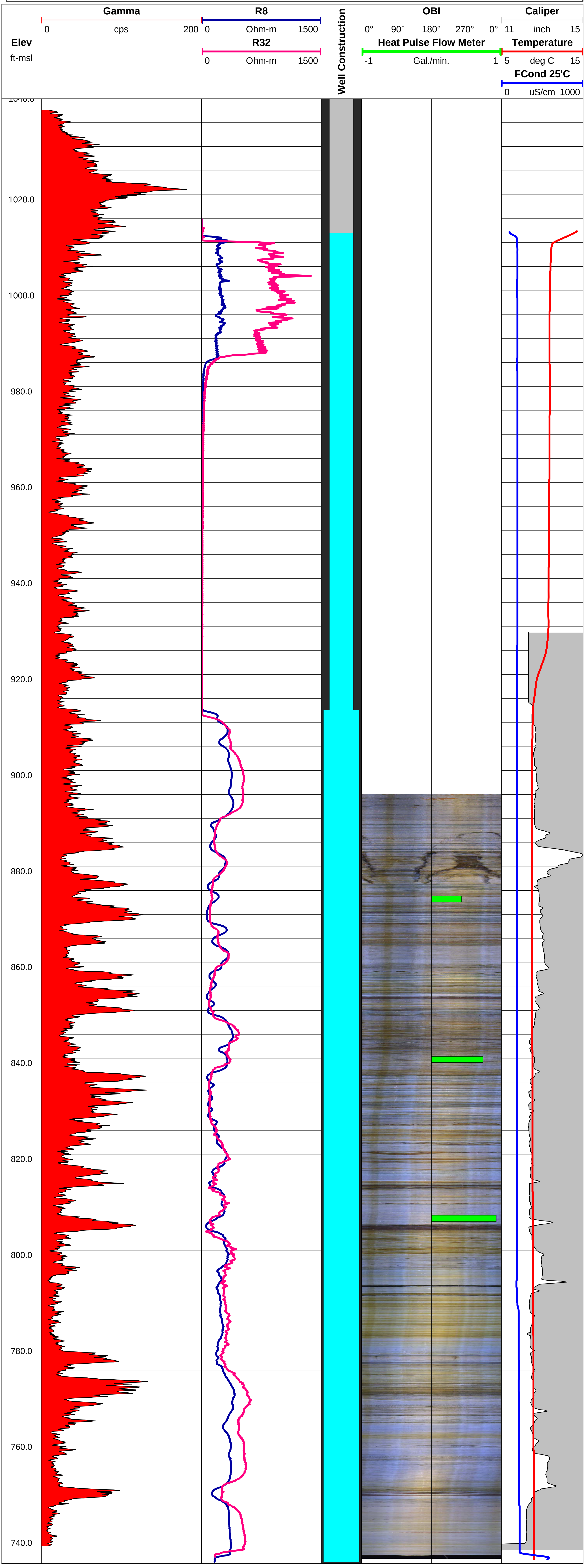
LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper	X	Flow Meter- HeatPulse	X
Single Point Resistivity		Flow Meter- Spinner	
Self Potential		Optical Borehole Imager	X
Normal Resistivity	X	Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:	

Unless Noted:

- all depths are in feet
- well depth, casing depth and depth to water are interpreted from geophysical log
- datum is the top of casing

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu



Geophysical Logs **WGNHS Well ID** 9000472

DATE 19 March 2014 WELL NAME Tony Pecha - DD Farms #1 (XH713)

LOCATION 16595 CTH DD Bloomer, WI. East side of CTH DD

COUNTY Chippewa LOGGED BY WGNHS (P. Chase)

LATITUDE 45.084181 LONGITUDE -91.611365

LOCATION METHOD: GPS [ ] AIR PHOTO/TOPO [X] PLSS [ ] OTHER

ELEVATION 1071 ELEVATION METHOD: DEM [x] TOPO [ ] OTHER

WELL DEPTH 296 ft CASING DEPTH 40 ft DEPTH TO WATER 55 ft

CASING STICK UP 0.9 ft File Created on: 4/08/2014 by: AMB

Comments: DNR High Cap Well #:73546

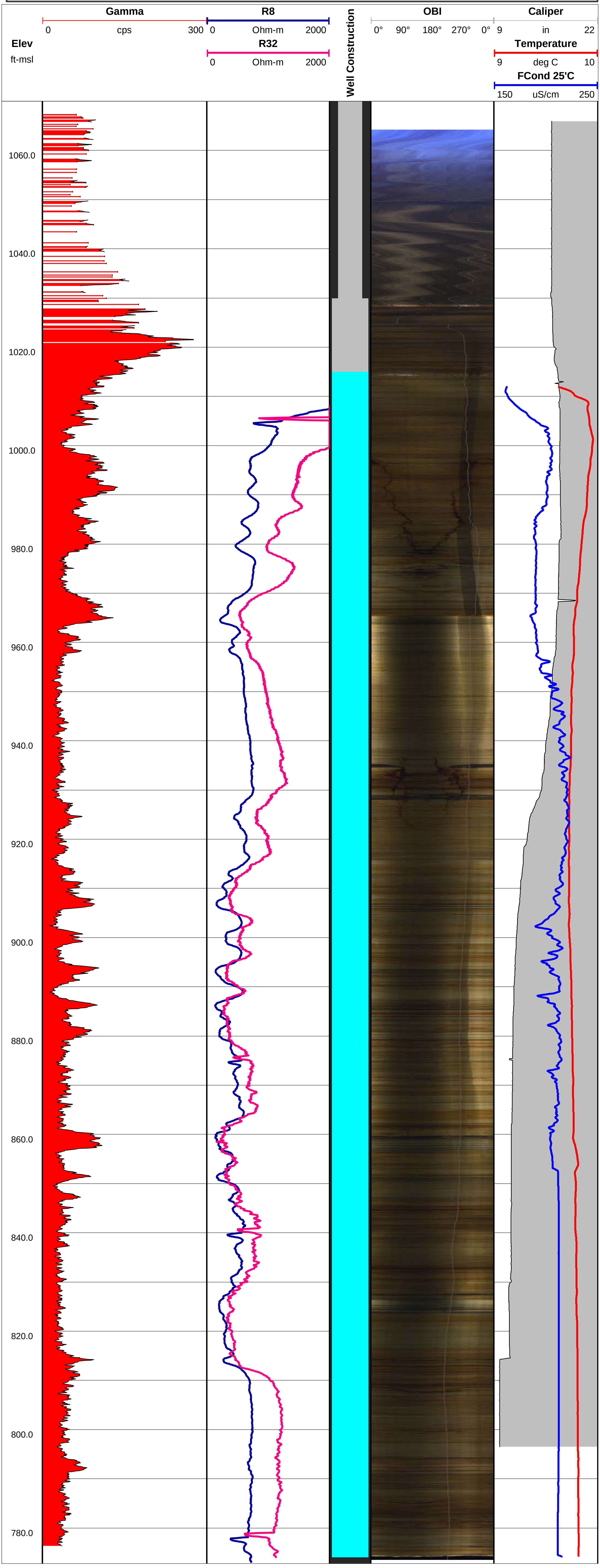
LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper	X	Flow Meter- HeatPulse	
Single Point Resistivity		Flow Meter- Spinner	
Self Potential		Optical Borehole Imager	X
Normal Resistivity	X	Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:	

Unless Noted:

- all depths are in feet
- well depth, casing depth and depth to water are interpreted from geophysical log
- datum is the top of casing

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu



Geophysical Logs **WGNHS Well ID** 9000474

DATE 5/30/2014 WELL NAME Tony Christopherson Well (XG744)

LOCATION East side of 1010st, N of STH 29 Elk Mound

COUNTY Chippewa LOGGED BY WGNHS (P. Chase)

LATITUDE 44.903538 LONGITUDE -91.650381

LOCATION METHOD: GPS [ ] AIR PHOTO/TOPO [ ] PLSS [ ] OTHER

ELEVATION 960 ELEVATION METHOD: DEM [X] TOPO [ ] OTHER

WELL DEPTH 296 CASING DEPTH 121 DEPTH TO WATER 51

CASING STICK UP 3.4 File Created on: 7/1/2014 by: AMB

Comments: DNR High Cap Well #: 73494

LOGS COLLECTED:

Gamma	X	Fluid Conductivity	X
Caliper	X	Flow Meter- HeatPulse	
Single Point Resistivity		Flow Meter- Spinner	
Self Potential		Optical Borehole Imager	X
Normal Resistivity	X	Acoustic Borehole Imager	
Fluid Temperature	X	OTHER:	

Unless Noted:

- all depths are in feet
- well depth, casing depth and depth to water are interpreted from geophysical log
- datum is the top of casing

For more information or to obtain collected data not shown please contact us at askageologist@uwex.edu