Wisconsin Geological
and Natural History Survey
DIVISION OF EXTENSION
UNIVERSITY OF WISCONSIN–MADISON

Assessing seasonal variations in recharge and water quality in the Silurian aquifer in areas with thicker soil cover

Final report to the Wisconsin Department of Natural Resources
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Background

The fractured Silurian dolomite aquifer is an important, but vulnerable, source of drinking water in northeast Wisconsin (Sherrill, 1978; Bradbury and Muldoon, 1992). Well contamination events in the Town of Morrison in Brown County (Green Bay Press Gazette, Feb 8, 2006) and Cooperstown in Manitowoc County (Green Bay Press Gazette, May 12, 2008) refocused public attention on the aquifer's susceptibility to contamination. In both events, it appears that manure-contaminated recharge impacted several domestic wells completed in the underlying dolomite aquifer. In Cooperstown, 17 of 31 wells sampled during the March 2008 snowmelt event tested positive for *E. Coli* bacteria. While these events generated media attention, they are not isolated incidents. Historically, "brown-water" events during spring have been noted in several other counties underlain by the Silurian aquifer – specifically in Door, Calumet, Kewaunee and Manitowoc Counties (Erb and Steiglitz, 2007). In response to these events, Kevin Erb of UW-Extension organized a Northeast Wisconsin Karst Task Force that was charged with developing recommendations for best management practices (BMPs) that would help minimize groundwater contamination in areas underlain by shallow carbonate aquifers with specific attention to BMPs relating to the storage and application of animal wastes.

Previous work in Door County, where soils are typically less than five feet thick, has demonstrated that recharge to the dolomite aquifer can be exceedingly rapid (e.g., Bradbury and others, 2002) and there was general agreement that the aquifer underlying the Door Peninsula is vulnerable to contamination. Deliberations of the Karst Task Force revealed that there was less consensus on the relative vulnerability of the aquifer in places where the soils were thicker (greater than 5 feet, but less than 50 feet). In reviewing the literature, we were able to locate few field studies of recharge variability in areas where these thicker soils occur over the dolomite aquifer. The need for field data in such settings motivated this study.

Wisconsin's groundwater level monitoring network provides some background data on water-level variations in the Silurian aquifer in areas of thicker soil cover. Wells completed in the Silurian aquifer in Kewaunee (KW030) and Manitowoc Counties (MN028) indicated seasonal variations in water levels on the order of 5 to 8 ft. There were no comparable data on water-quality variations, however, town- and county-based sampling programs have identified areas of degraded water quality in the Silurian aquifer in northeastern Wisconsin. Recent maps, compiled by the UW-Stevens Point Center for Watershed Science & Education, highlight areas with bacteria detections and elevated nitrate concentrations (Figure 1). These data clearly indicate that the Silurian aquifer has a high percentage of bacteria detections and elevated nitrate concentrations even in areas with greater than 5 ft of soil cover. A recent groundwater inventory project for Calumet County (Gotkowitz and Gaffield, 2006) also highlighted the susceptibility of the dolomite aquifer. This project has collected preliminary data on seasonal variations in recharge and resulting water quality variations in the Silurian aquifer in the areas with 15 feet or more of soil cover.

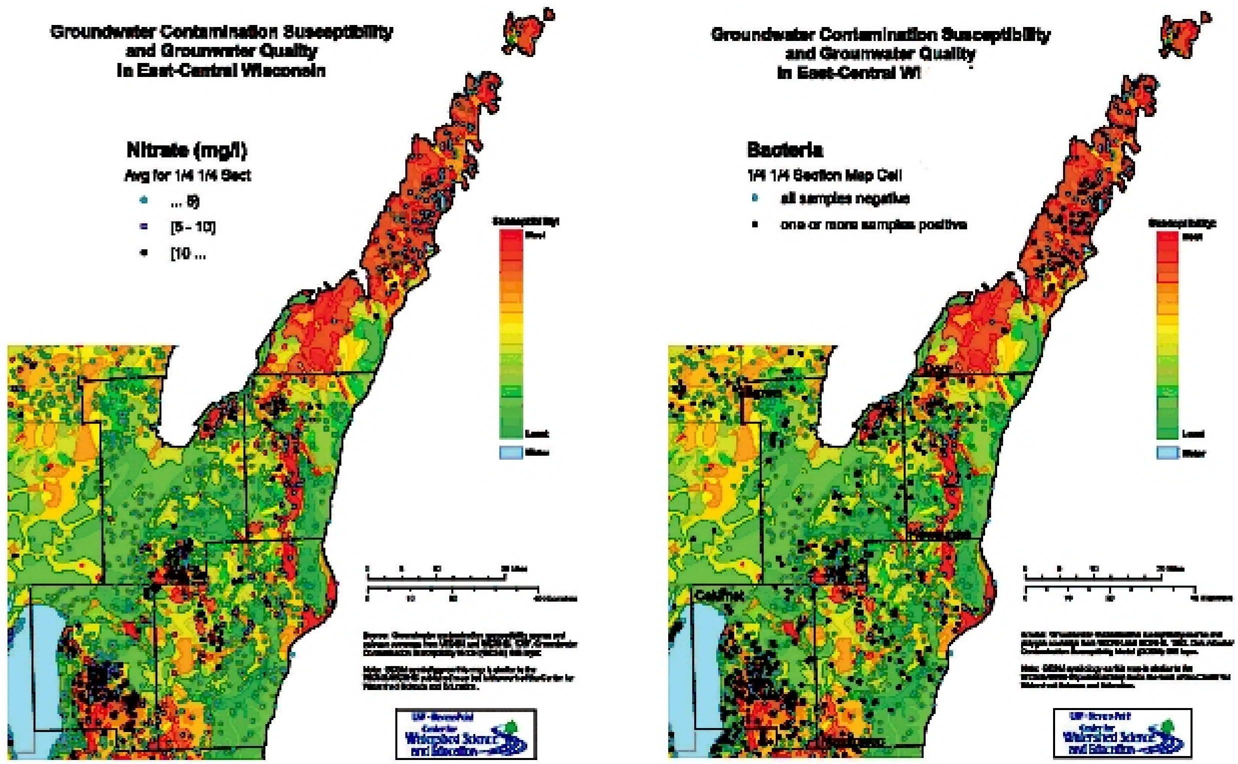


Figure 1. Maps showing results of domestic well sampling programs in northeastern Wisconsin (from Erb and Steiglitz, 2007).

Acknowledgments
This project was funded by the Wisconsin Department of Natural Resources through the State of Wisconsin joint solicitation of proposals to conduct research and monitoring on groundwater. We thank Andy Jansen, Mitch Nothem, and Derrick Wagner, UW-Oshkosh Department of Geology, for their assistance in collecting data at the field sites. County Conservationists Bill Hafs (Brown County), Andy Wallander (Kewaunee County), Eugene McLeod (Calumet County), and Tom Ward (formerly with Manitowoc County) were invaluable in identifying field sites. Todd Stuntebeck of the USGS graciously provided detailed temperature and precipitation records from monitoring stations located at the Pagel and Saxon Discovery Farms. This project would not have been possible without the help of the following landowners who allowed us to install wells on their property: Jeff & Julie Gibbons (Brown County), Jim Strnad (Kewaunee County), Bill Fritsch (Manitowoc County) and the Town of Chilton in Calumet County.

Project Objectives

The objective of this project was to gain an understanding of seasonal variations in recharge, the timing of recharge events, and the resulting water-quality variations in the Silurian dolomite aquifer in areas with 15 feet or more of surficial sediment. Specifically we identified sites in four counties (Brown, Calumet, Kewaunee, and Manitowoc) where the Silurian aquifer was the uppermost bedrock aquifer, soil was greater than 15 feet thick, and manure or sewage sludge was being applied to nearby fields. At each site we installed a shallow bedrock well and monitored variations in water levels and water quality for one year. All wells are located at the edge of agricultural fields and were placed to avoid interference from any septic systems. Details of each site can be found in the "Site Description" section below.

Methods

Selection of Field Sites

In each county, we used existing depth to bedrock maps to identify two to four townships that appeared to have soil thicknesses in the range of 15 to 25 feet. For those townships, existing well construction reports were plotted in order to refine the soil thickness estimates and to identify sites where the depth to water was not too great (ideally < 50 ft). We relied on air photos and rough estimates of water-table configuration to assess whether the potential sites were downgradient of agricultural fields. After identifying possible sites, we worked with the county conservationist in each county in order to identify cooperative landowners. The four monitoring sites were identified by the third week in July 2007 and wells were installed in late July/early August 2007.

Site Characterization

Drilling, Well Installation & Construction

One six-inch diameter well was installed at each site using air-rotary methods. A casing hammer was used to advance the casing through the unconsolidated sediment. The casing was seated into firm rock and granular bentonite was used to seal the annular space. The borehole was advanced into the bedrock by air-rotary drilling. All holes were completed to a depth of ~30 ft below the water table. Samples were collected and described approximately every 5 feet. Diagrams of well construction and lithologies encountered during drilling are included in the section entitled "Site Descriptions". All wells were air-lifted for several minutes at the completion of drilling.

During drilling it became clear that drillers and geologists may define the "top of bedrock" in different ways. The drillers described "rock" as the top of firm/competent bedrock, even if the drill cuttings had been composed entirely of dolomite fragments at a shallower depth. Firm/competent rock was determined by when the casing hammer could no longer advance the casing. A geologist would report "depth to rock" as the transition from unlithified materials to dolomite even if the dolomite was somewhat weathered. Based on our experience in siting and drilling these wells, the "depth to rock" reported by well drillers and recorded on well construction reports is more accurately the depth to firm rock and as such it is an overestimate of the thickness of the unlithified materials.

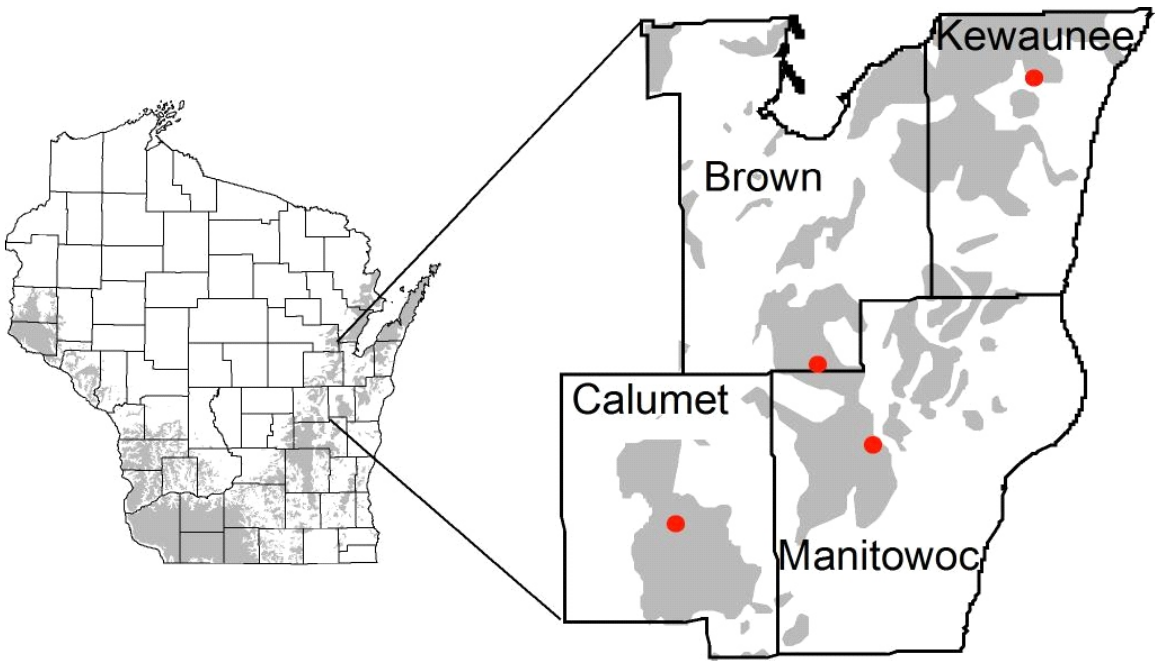


Figure 2. Map showing general location of monitoring sites (red dots). The shaded areas indicate regions where the uppermost bedrock is a carbonate unit and the depth to bedrock is less than 50 ft. Bedrock geology and depth to bedrock data are based on statewide coverages.

All wells were assigned WGNHS well numbers and Wisconsin Unique Well Numbers. The map in Figure 2 gives general locations of the monitoring sites; more details are provided in Table 1.

Geophysical Logging

Geophysical logs provide information both on the lithologic and hydrogeologic characteristics of stratigraphic units. We logged each well in late September 2007 using a Mt. Sopris MGX digital borehole logger. All geophysical data were recorded relative to the depth from the top of the casing. Logs completed as part of this study include caliper, which measures borehole diameter and can help identify fractures and dissolution zones; natural gamma, which measures natural

Table 1: Locations of monitoring wells used in this study

WGNHS Well Number	WUWN	County	1/4, 1/4	Section	Township	Range
BN-420	VZ573	Brown	NW1/4, NE1/4	33	T21N	R21E
CA-1143	VZ574	Calumet	NE1/4, SE1/4	3	T18N	R19E
KW-183	VZ575	Kewaunee	SW1/4, SW1/4	34	T25N	R24E
MN-544	VZ576	Manitowoc	NE1/4, SW1/4	4	T19N	R22E

radiation and can be used for stratigraphic correlation as well as to identify zones with shale or clay; and single-point resistivity and spontaneous potential, which are useful for stratigraphic correlation. Logs used to locate and characterize high-permeability zones include fluid temperature/resistivity and heat-pulse flowmeter. The geophysical logs are included in Appendix 1.

Site Descriptions

The following sections provide general descriptions of each site along with figures illustrating lithologic and well construction details. Table 2, at the end of the section, summarizes well construction information for all four wells.

Brown County Site: BN-4240

We chose a site near the community of Wayside in the Town of Morrison based on depth-to-bedrock maps and water-quality data compiled by the Brown County Land Conservation Department (Figure 3). These maps indicated a high percentage of wells testing positive for bacteria during the 2006 "brown water" event and depth to bedrock ranging from approximately 10 to 20 ft.

Well BN-420 is located adjacent to an agricultural field was planted in alfalfa for the duration of the project. Well location and details of lithology and well construction for BN-420 are shown in Figure 4. The approximate direction of groundwater flow was estimated from the elevations of surface water features and elevations of water levels in domestic wells as reported on well construction reports (WCRs). The location of significant horizon fractures was determined from the caliper and fluid temperature and conductivity logs. The caliper log indicates several bedding-plane-parallel fractures at the approximate depth of the water level when the well was drilled. It is common to have enhanced dissolution in the zone of annual water-level fluctuation. The sharp inflection in the fluid temperature/conductivity log at 34 feet depth suggests that the fracture at this depth is hydraulically significant. We collected water samples from this depth and also placed the dataloggers sensors at this depth.

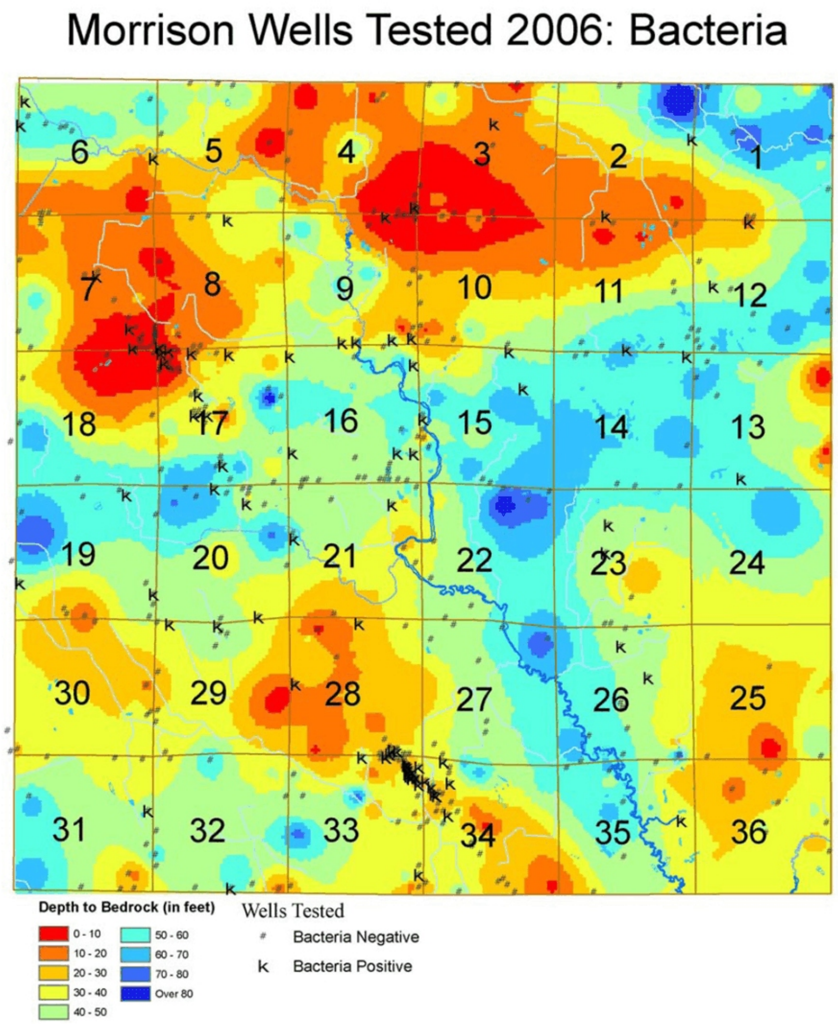


Figure 3. Map of the Town of Morrison showing depth to bedrock and well-testing results from a 2006 sampling event (from Erb and Steiglitz, 2007).

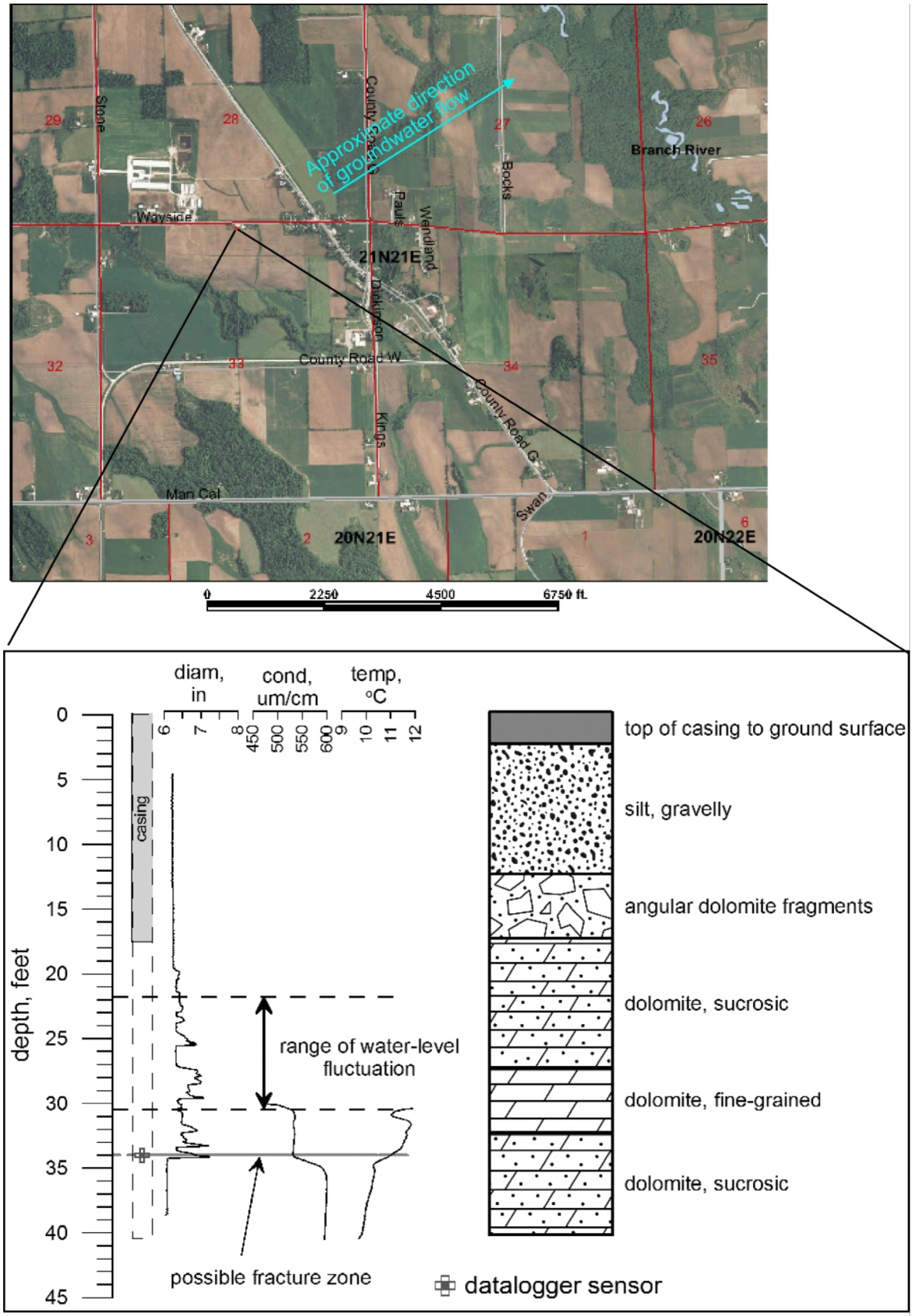


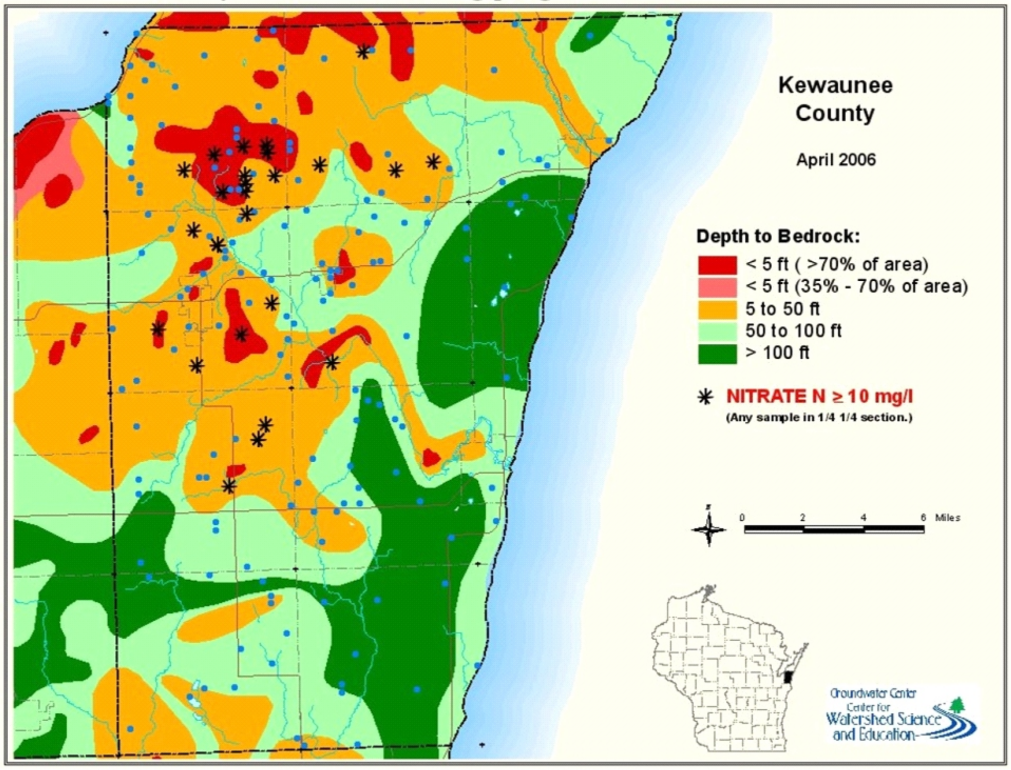
Figure 4. Air photo of Brown County site showing well location (red dot), land use, and approximate direction of groundwater flow. Lower diagram illustrates well construction, borehole fluid logs, range of water-level fluctuation, sensor placement and lithology.

Kewaunee County
We investigated sites in the Towns of Lincoln and Red River in Kewaunee County based on existing depth-to-bedrock and water-quality data that had been compiled by the Land Conservation Department (Figure 5). Based on landowner cooperation, we chose the Strnad site in section 34 of the Town of Lincoln.

Well KW-183 is located on the northwestern corner of an agricultural fields that was planted in alfalfa for the duration of the project. The field immediately to the north was planted in corn during the 2007 growing season and soybeans in 2008. Figure 6 illustrates well location, land use, and details of lithology and well construction for KW-183. The approximate direction of groundwater flow is eastward toward Rio Creek based on the elevations of surface water features and water levels reported on well construction reports (WCRs). The depth to rock at this site is less than the target depth of 15 feet or more. The specific site was chosen based on nearby well construction reports that all had 16 feet or more of unlithified sediment. This well encountered several significant fractures at approximately 21, 25 and 27 feet depth. In addition, it appears to be the highest yielding well within this study based upon the volume of water produced when the well was air-lifted at the completion of drilling.

Calumet County
We investigated sites in the Towns of Chilton and Charlestown in Calumet County based on depth-to-bedrock data compiled by Gotkowitz and Gaffield (2006) and water-quality data compiled by the Land Conservation Department. We chose the Chilton Town Hall site based on the above information as wells as access concerns and a desire to locate the well downgradient from active cropland.

Well CA-1143 is located on the eastern edge of an agricultural field. Figure 7 illustrates well location, land use and details of lithology and well construction for CA-1143. The approximate direction of groundwater flow is to the east-northeast based on the published water-table map (Gotkowitz and Gaffield, 2006). This well encountered fractures above the static water level at 20 and 24 ft depth and also below the static water level at 60 and 78 feet depth.



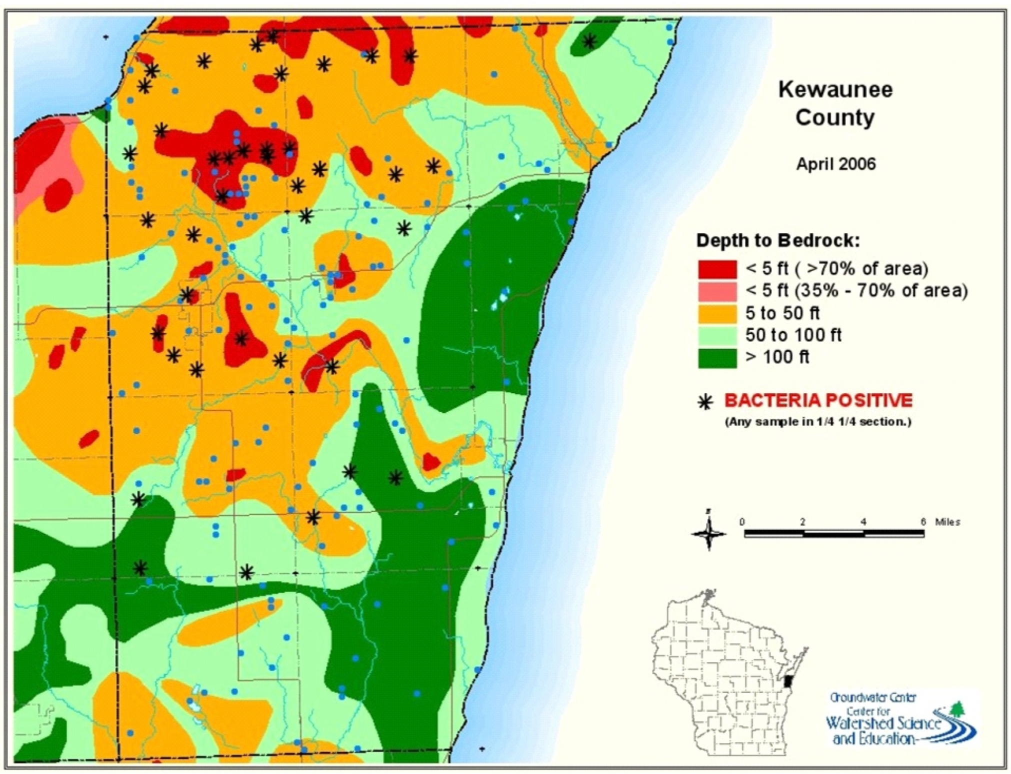


Figure 5. Maps of Kewaunee County illustrating depth to bedrock and results of well water sampling programs (from Erb and Steiglitz, 2007). The upper map shows nitrate results, the lower map shows bacteria results. Both maps indicate that well water in areas of shallow bedrock is more likely to contain bacteria and elevated nitrate concentrations.

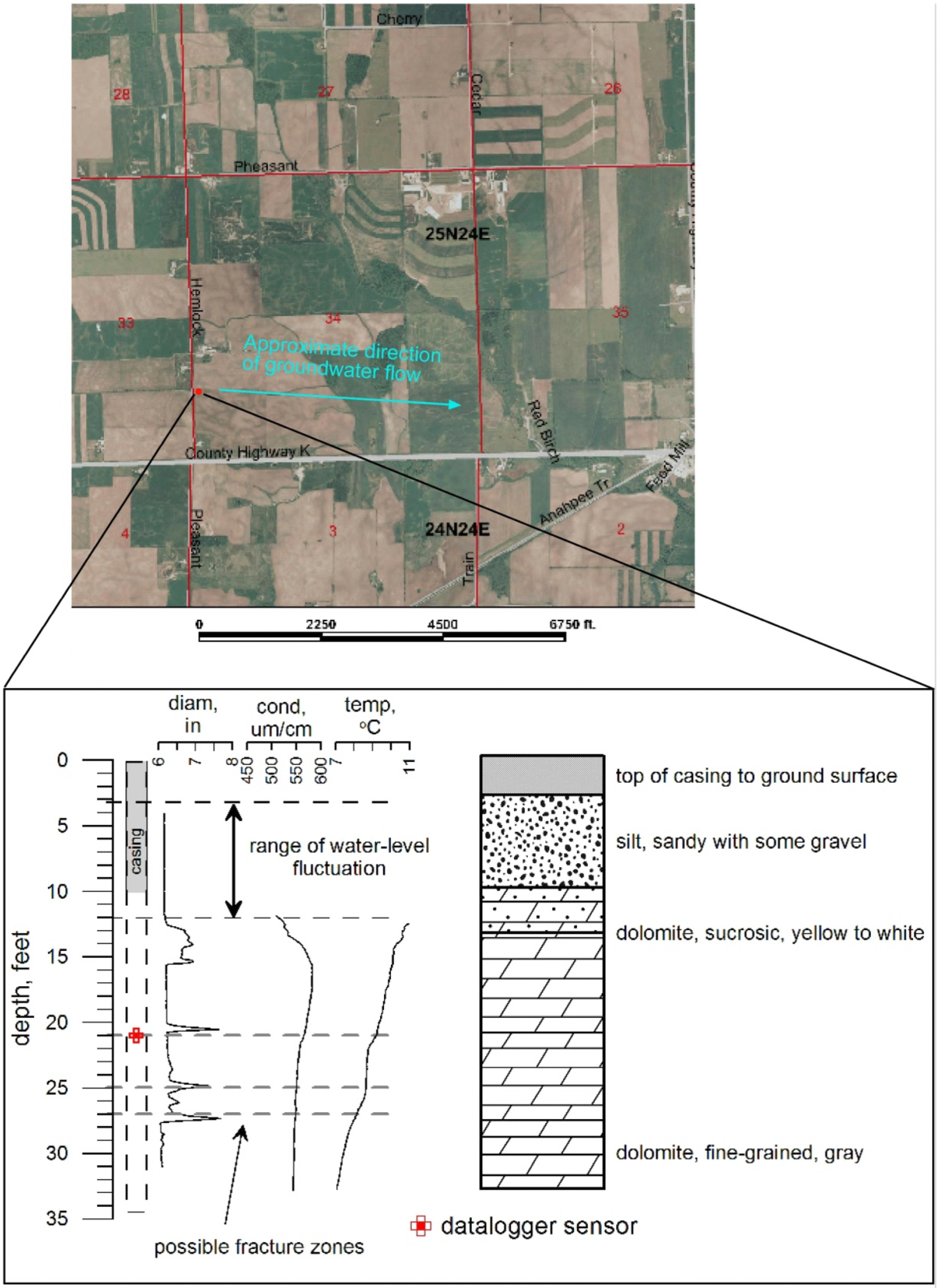


Figure 6. Air photo of Kewaunee County site showing well location (red dot), land use, and approximate direction of groundwater flow. Lower diagram illustrates well construction, borehole fluid logs, range of water-level fluctuation, sensor placement, and lithology.

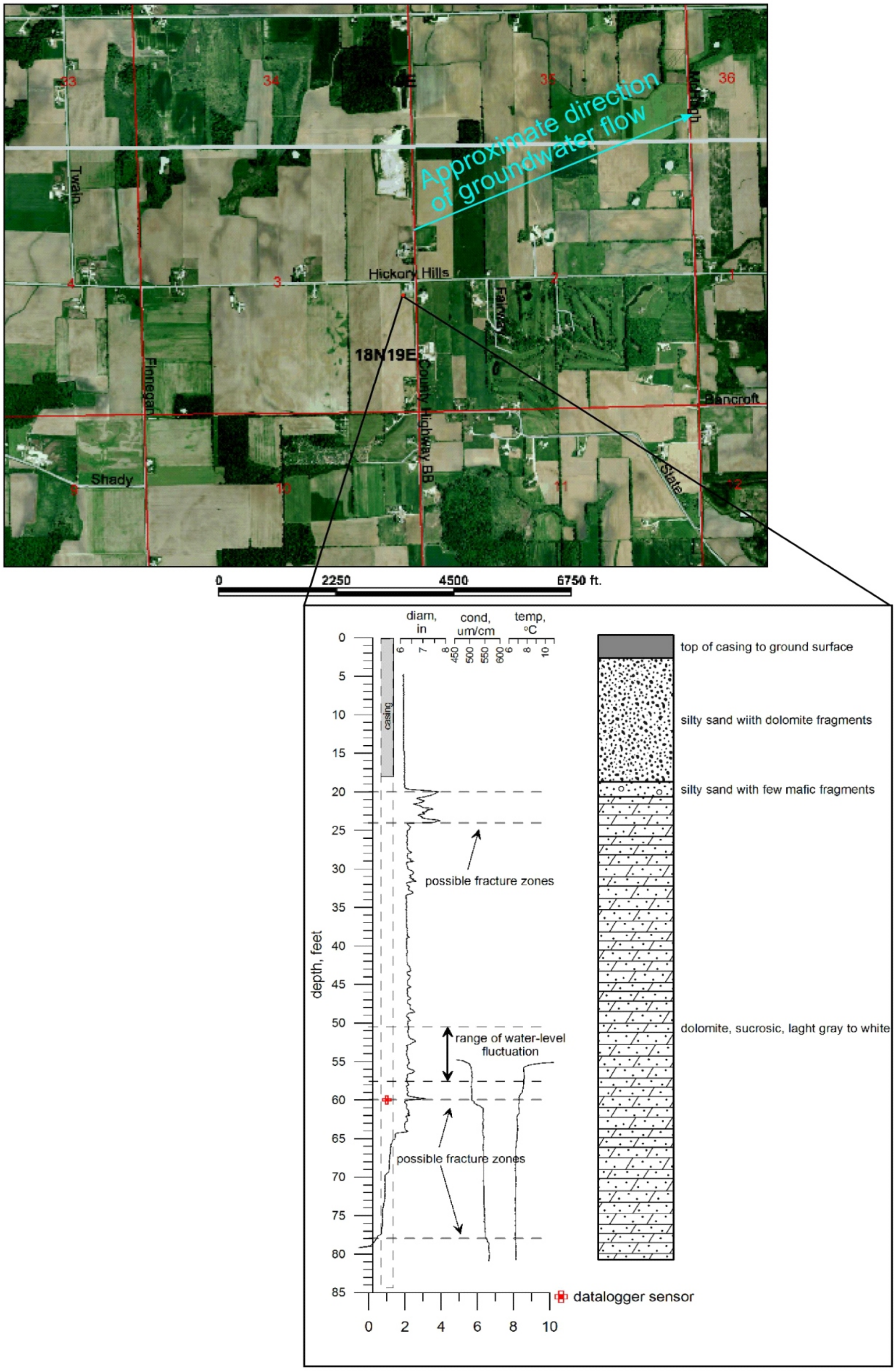


Figure 7. Air photo of Calumet County site showing well location (red dot), land use, and approximate direction of groundwater flow. Lower diagram illustrates well construction, borehole fluid logs, range of water-level fluctuation, sensor placement, and lithology.

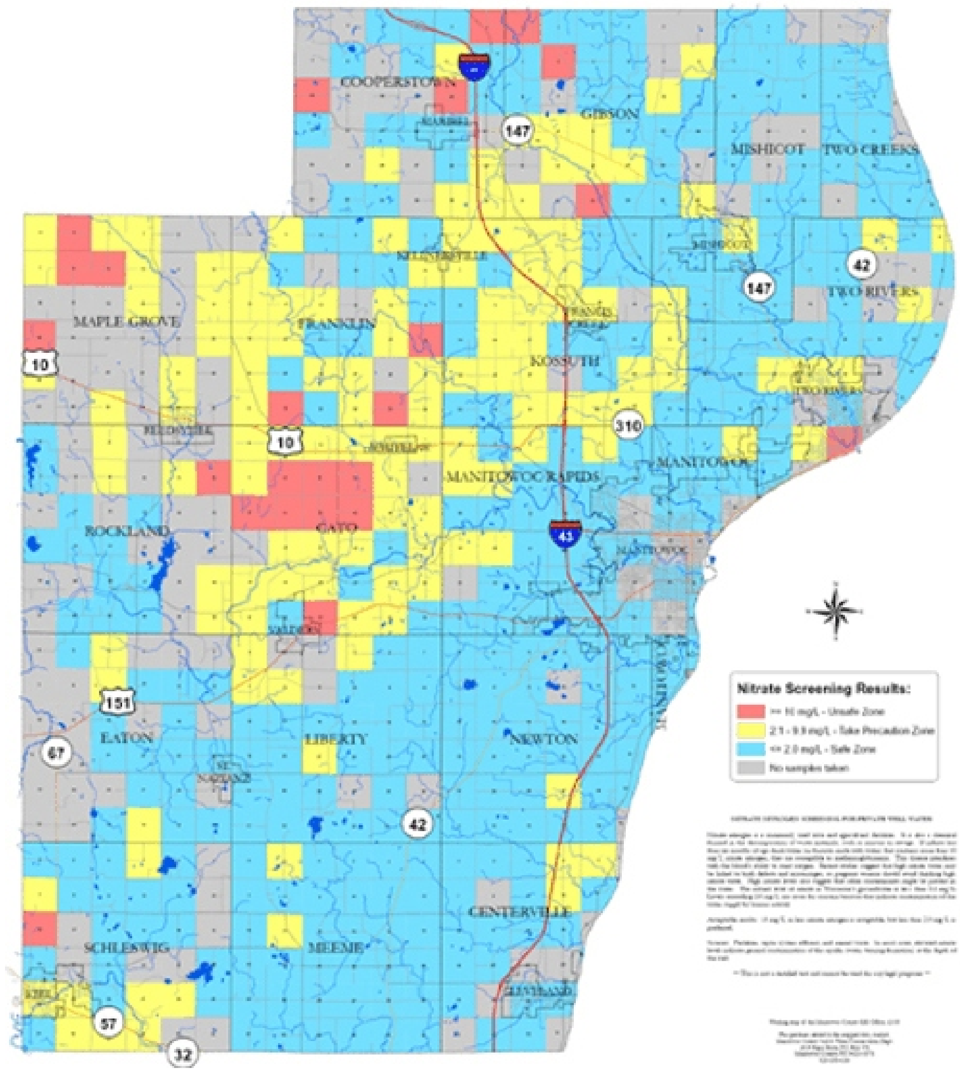


Figure 8. Nitrate map from Manitowoc County (from Erb and Steiglitz, 2007).

Manitowoc County

We investigated sites in the Towns of Cato and Kossuth in Manitowoc County based on existing water-quality data that had been compiled by the Land Conservation Department (Figure 8) and depth-to-bedrock data from WCRs. We chose the Fritsch site based on a desire to locate the well downgradient from active crop land as well as access concerns.

Well MN-544 is located on the western edge of agricultural fields that were planted in corn and alfalfa for the duration of the project. Figure 9 illustrates well location and details of lithology and well construction for MN-544. The well is located in the northwest corner of the southern alfalfa field. The approximate direction of groundwater flow is to the northeast towards the Branch River. The caliper log indicates enlarged borehole diameter at multiple depths. The significant jump in fluid temperature/conductivity at approximately 40 ft depth indicates a hydraulically significant feature. We collected water samples from this depth and also placed the dataloggers sensors at this depth. This well is generally low-yielding and the water level could be drawn down to the location of the pump during sampling events.

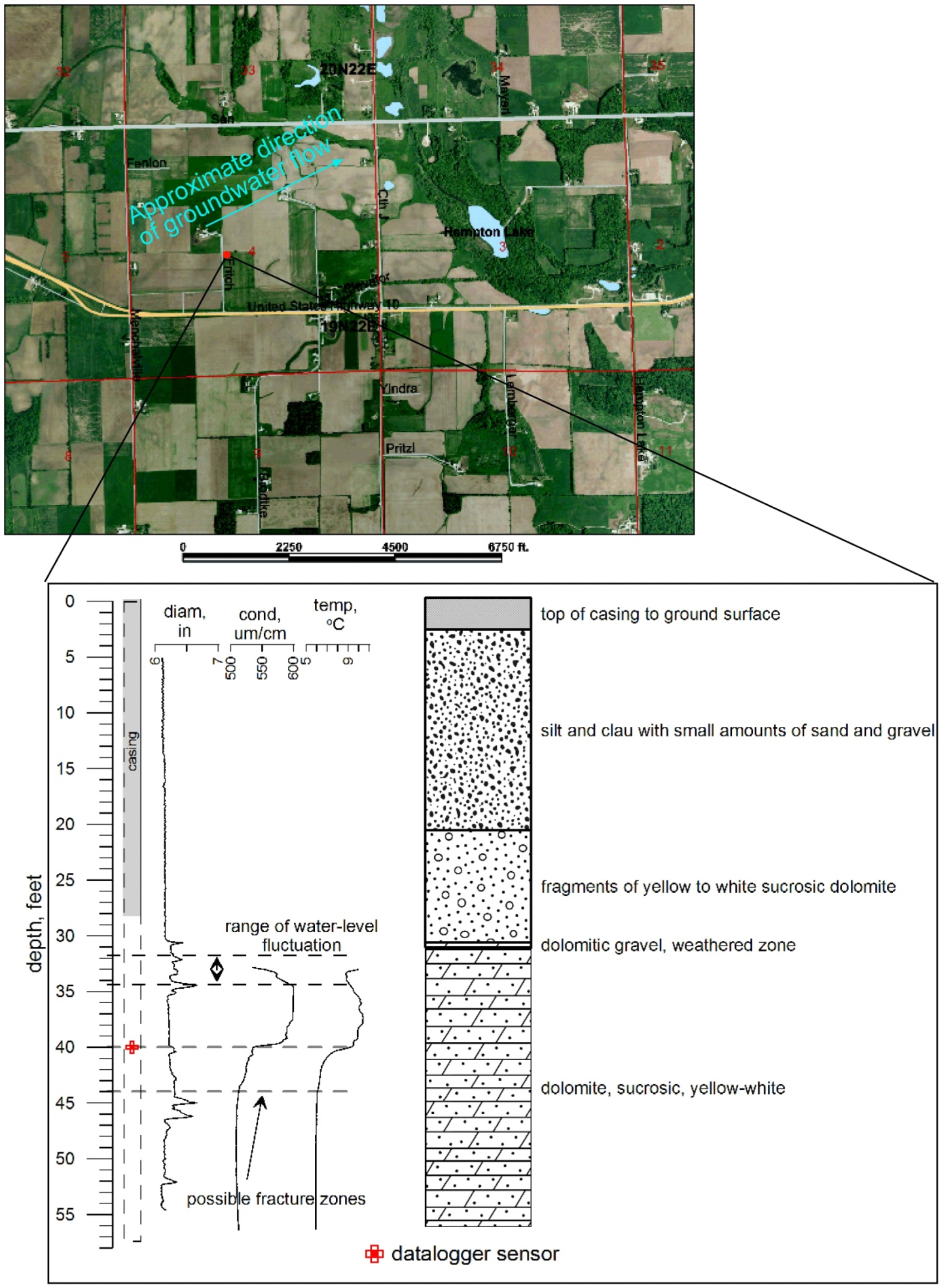


Figure 9. Air photo of Manitowoc County site showing well location (red dot), land use, and approximate direction of groundwater flow. Lower diagram illustrates well construction, borehole fluid logs, range of water-level fluctuation, sensor placement, and lithology.

Table 2: Summary of Well Construction Details*

Well	Total Depth (ft from TOC)	TOC to GS (ft)	Casing Depth (ft from GS)	Depth to Rock (ft from GS)	Avg Depth Water (ft from TOC)
BN-420	40.4	2.5	17.5	10	28.06
CA-1143	81	3	18	18	54.21
KW-183	33	3	10	7	8.52
MN-544	57.6	2.9	28.5	18	33.06

* TOC is an abbreviation for Top of Casing, GS in an abbreviation for Ground Surface

Instrumentation and Sample Collection

Monitoring sites were visited monthly from September 2007 to August 2008. During site visits we manually measured water levels, downloaded the datalogggers, and collected water samples.

Water Levels and Temperature

All wells were instrumented with Solinst Leveloggers™ that were programmed to record water levels and water temperature every 30 minutes. The Leveloggers were installed in early October 2007 and data collection continued through August 2008. These loggers are unvented pressure transducers and as such the readings must be corrected for variations in barometric pressure. A Solinst Barologger™ was suspended in well BN-420 and readings from this sensor were used to correct the Levelogger readings from all sites. A more detailed discussion of the barometric correction is included in the Water Level results section.

Leveloggers record the height of the water column above the sensors. We used the probe depth to calculate the depth to water in the well using the following conversion:

Depth to water From TOC = probe depth-measured water level.

We also manually measured the depth to water in each well during monthly site visits using an electrical water-level indicator tape.

Fluid Conductivity and Temperature

Each of the wells was instrumented with a downhole temperature/conductivity probe connected to a digital datalogger. The Brown and Kewaunee sites were instrumented with Campbell Scientific CR800 loggers and CS547A probes that were installed in late October 2007. The Calumet and Manitowoc sites were instrumented with Campbell Scientific CR10X loggers and 247/247W probes that were installed in mid-January 2008. All probes were suspended from cables lowered into the well bores to positions adjacent to major horizontal fractures (see Figures 5, 7, 8 and 10). Fluid temperature and conductivity at each site were measured once every five minutes and averaged over 60 minutes; the hourly averages were stored in the datalogger and downloaded each month to a portable computer.

Sample Collection and Analysis
We collected water samples from all wells at approximately monthly intervals from September 2007 to August 2008. Samples were collected by lowering a submersible Grundfos sampling pump into the well to a point opposite the major bedding-plane-parallel fracture penetrated by that well. The well was pumped slowly until the electrical conductivity, temperature, and pH of the discharge water stabilized; then samples were collected in 60-ml polyethylene bottles. The sample for phosphorus analysis was field filtered through a 0.45 micron filter and acidified using sulfuric acid whereas the nitrate and chloride samples were unfiltered and not acidified. All samples were placed on ice and shipped to the Wisconsin State Laboratory of Hygiene within 48 hours. Samples for nitrogen isotope analysis were collected from all wells in May 2008 and submitted to the UW Soil and Plant Analysis lab. Unfortunately, the Soil and Plant Lab's equipment failed and they were unable to complete the analyses.

Results

Precipitation, Water-level Fluctuations, and Recharge Events

Precipitation
Climatic data were not recorded as part of this study. Instead, we utilized climatic data available from the National Weather Service (NWS) for Green Bay and from two Discovery Farms monitored by the USGS. Figure 11 shows the location of sources of available climatic data in relation to this project's study sites.

Preliminary monthly climate data for Green Bay were accessed at the NWS web site http://www.weather.gov/climate/index.php?wfo=grb and include the following daily data: temperature (maximum, minimum, and average), 24-hr precipitation totals (including the water equivalent of any snow fall), snow depth, as well as information concerning heating/cooling degree days and wind conditions.

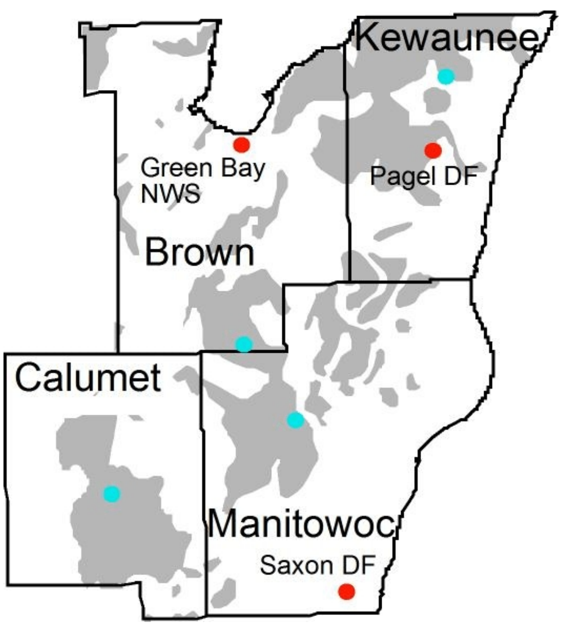


Figure 11. Map showing locations of study sites (blue dots) and sites with climatic data (red dots).

Data from the Discovery Farm sites are available from the USGS Real Time Monitoring Web interface. Daily data available for the Pagel site (http://waterdata.usgs.gov/nwis/nwisman/?site_no=442954087355700&agency_cd=USGS) include 24-hr rainfall total (does not include snowfall), and the maximum, minimum, and mean temperature, relative humidity, and wind speed. Daily data for the Saxon site (http://waterdata.usgs.gov/nwis/nwisman/?site_no=435449087463600&agency_cd=USGS) are the same as the Pagel site but also include soil temperature (maximum, minimum, and mean) at depths of 2, 5, 10, 20, 40, and 80 cm. Temperature data, both air and soil, are collected at 15-minute intervals and more detailed temperature records were obtained from Todd Stuntebeck of the USGS.

Figure 11 compares the daily precipitation records from all three locations for the period September 1, 2007 through August 31, 2008. The pattern of precipitation at all three sites is quite similar except for the winter months when only the Green Bay location recorded the water-equivalence of snowfall. The cumulative precipitation curve (top plot) best reflects the difference in these monitoring records. The cumulative precipitation for Green Bay shows greater increases during the winter months (late November through March) than the records from the Discovery Farm sites.

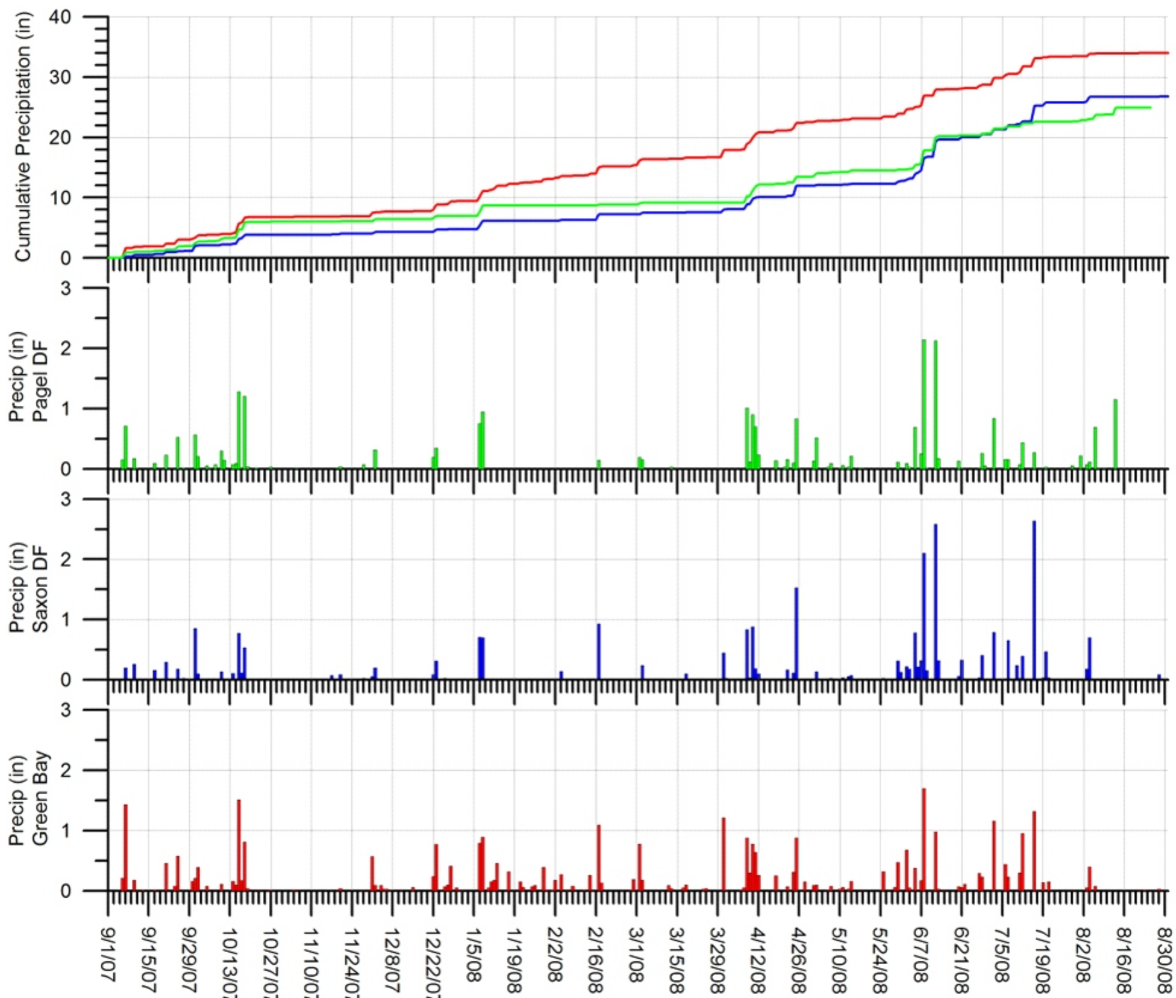


Figure 11. Daily precipitation records from three sites for the period September 1, 2007 to August 31, 2008. The bottom plot (red bars) is from the National Weather Service (NWS) Green Bay station; the second plot (blue bars) is from a USGS monitoring station at the Saxon Farm in Manitowoc County; the third plot (green bars) is from a USGS monitoring station at the Pagel Farm in Kewaunee County. The top plot shows cumulative precipitation for all thee sites.

Water Levels and Barometric Pressure Corrections
The Solinst Leveloggers™ are unvented and the total pressure measured by the transducer is a combination of the pressure due to the height of the overlying water column and the pressure due to the weight of the overlying atmosphere. As such, the readings must be corrected for variations in barometric pressure. Readings from a Solinst Barologger™ suspended in well BN-420 were used to correct the Levelogger readings from all sites. The initial barometric correction was performed using the the default "barometric compensation" option in the Levelogger 3.1.1 software provided by Solinst™ . This default correction assumes 1) a barometric efficiency of 100%, 2) that there is no lag time between a change in barometric pressure and response in the aquifer, and 3) that the barometric efficiency is constant. This initial correction was adequate for the Brown County well, however, records from other wells still appeared to have a residual barometric signal. In particular, the Manitowoc record (MN-544), as corrected with the Solinst™ software, exhibited a great deal of short-term variation that appeared to be inversely correlated with barometric pressure changes as illustrated in Figure 12.

We explored the assumption of 100% barometric efficiency by plotting the uncorrected pressure transducer data from well MN-544 and the barometric data for three-month intervals (Figure 13). If an aquifer is 100% barometrically efficient, a change in barometric pressure will produce an equivalent change in the uncorrected pressure transducer reading. We calculated a barometric efficiency by picking five to six times during each three-month interval when there was strong swing in barometric pressure and manually measuring the distance between "peaks & troughs" in both the uncorrected pressure transducer data and in the barometric data. The ratio of these values is the barometric efficiency. We avoided times of heavy precipitation or melt events when it was expected that water levels would be changing. An average barometric efficiency (based on the five to six measurement points) was calculated for each of the following time intervals: October to December 2007, January to March 2008, March to May 2008, and June to August 2008. The manually calculated barometric efficiencies for MN455 were 60% (October to December), 70% (January to March), 88% (March to May) and 87% (June to August).

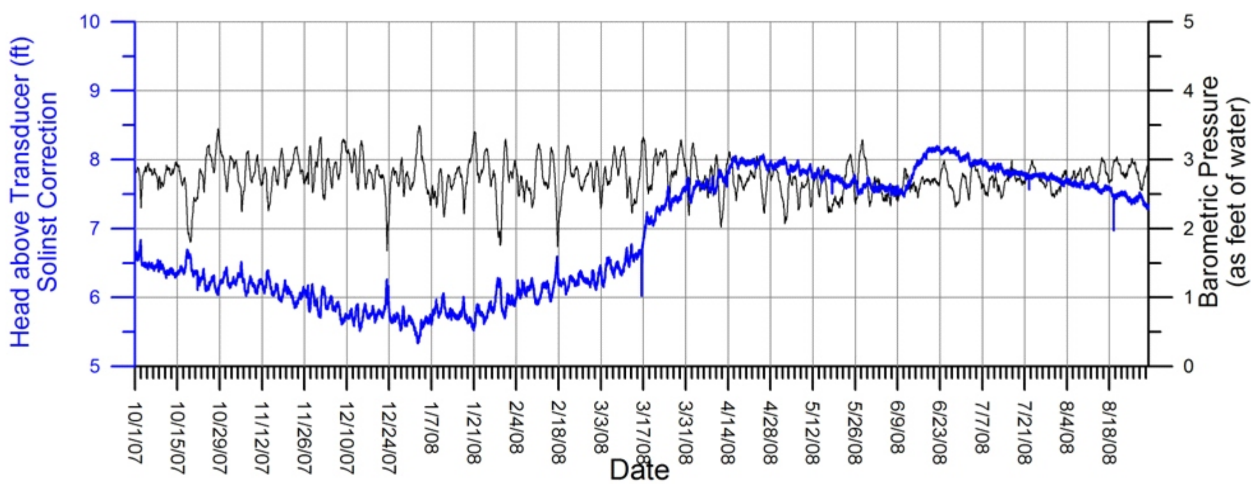


Figure 12. Water-level data from MN-544 (blue line) corrected using the default barometric correction in the Solinst™ software. Black line is barometric pressure data. Several short-term variations in water-level appear to be inversely correlated with barometric pressure variations.

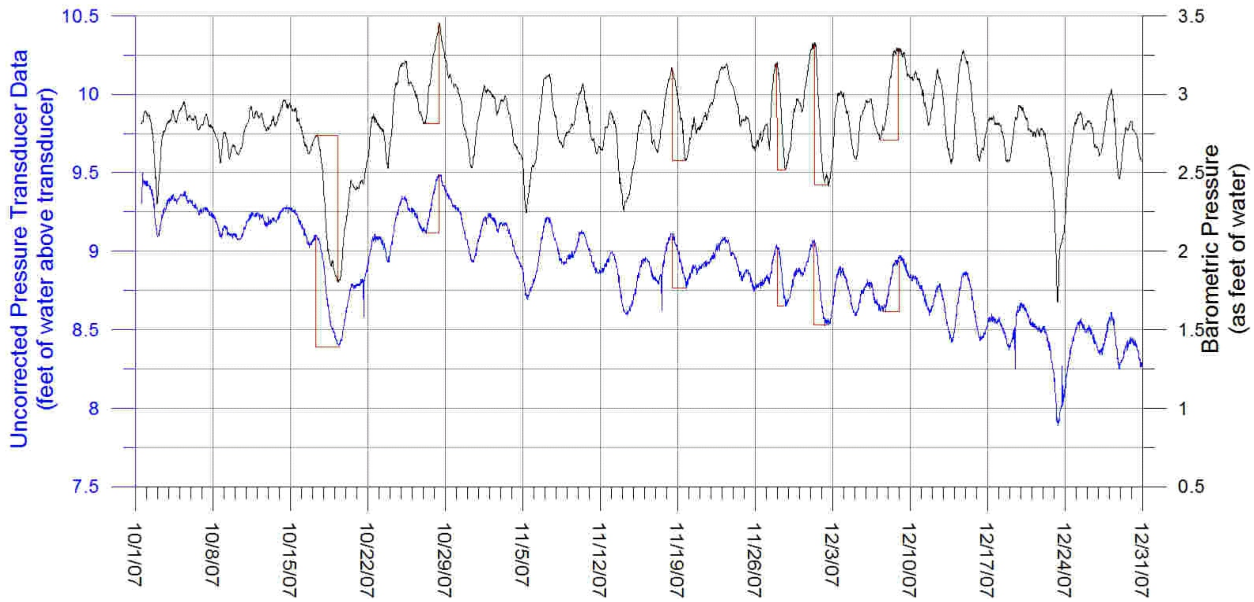


Figure 13. Graph of barometric pressure variations (black) and uncorrected pressure transducer readings (blue) from well MN-544 for the period 10/1/07 to 12/31/07. Barometric efficiency was estimated by taking a ratio of pressure transducer response/barometric response at six distinct times (shown in red) and averaging those values.

The Solinst™ software is not capable of incorporating variable barometric efficiencies, nor is it capable of correcting for any time lag. Toll and Rasmussen (2006) have developed a computer program, BETCO, for the removal of barometric pressure effects and Earth tides from observed water-level data. The program, which requires paired measurements of barometric pressure and water levels on short-time intervals, uses regression deconvolution to estimate the barometric response function. The corrected head is calculated once the response function is known. Regression deconvolution is a technique that can be used to estimate "how a parameter in a system responds to a stimulus when the response is not instantaneous and the magnitude of the response changes with time" (Toll and Rasmussen, 2006).

We used the BETCO program to correct the pressure transducer data from all four wells for barometric pressure effects; we did not correct for Earth tide effects. For unconfined aquifers, the program requires that the user vary the maximum response time parameter until the step response function reaches the first minimum. We used the following maximum response times: 3 hours for BN422; 1.5 hours for CA-1143; 3 hours for KW-183, and 12 hours for MN455. Graphs comparing Solinst-corrected and BETCO-corrected water-levels for each well are shown in Figures 14 and 15. Table 3 summarizes the depth-to-water data and range of water-level fluctuations in each well. These values were computed using the BETCO-corrected water-level data.

Table 3. Summary of Depth to Water Data (DTW) for study wells

Well	Max DTW (ft)	Min DTW (ft)	Average DTW (ft)	Range of fluctuation (ft)	Soil Thickness (ft)
BN-420	30.49	21.78	28.06	8.71	10
CA-1143	57.59	50.49	54.21	7.10	18
KW-183	12.03	3.23	8.52	8.80	7
MN-544	34.40	31.75	33.06	2.65	18

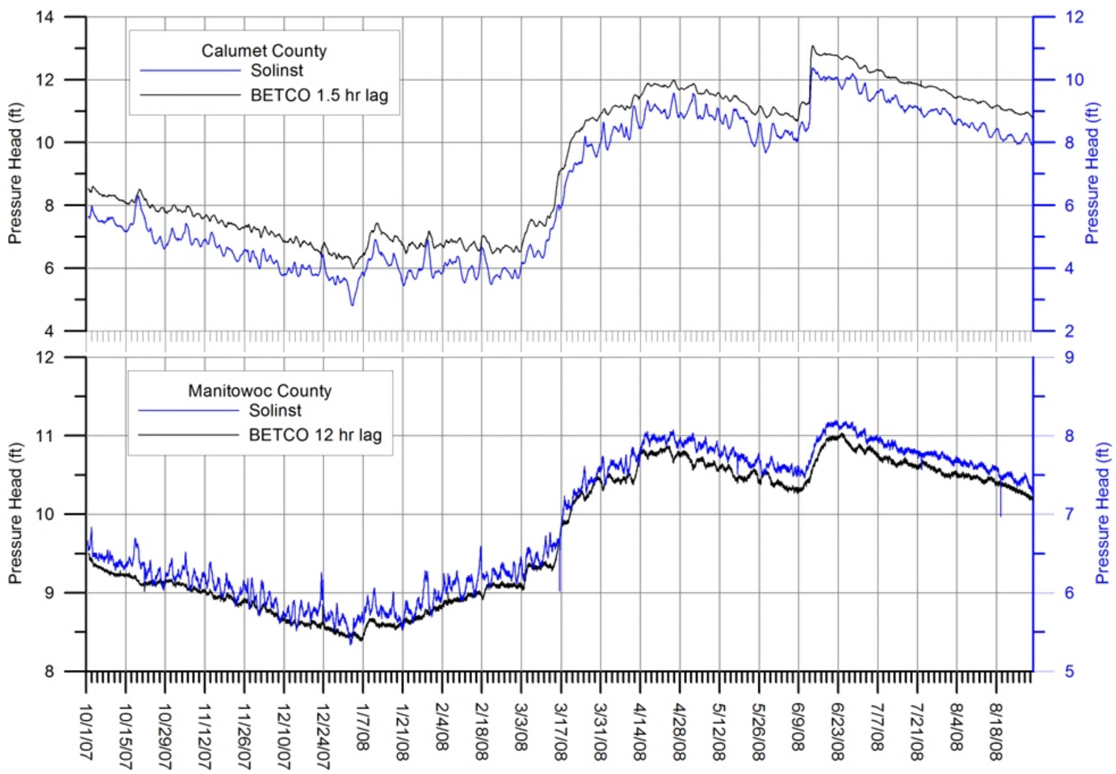


Figure 14. Water levels from the Calumet and Manitowoc County wells. Graphs illustrate the difference between Solinst and BETCO barometric correction methods. Note that the vertical scales for the pressure head in each well (right and left vertical axes) are slightly offset so that both water-level records can be easily seen.

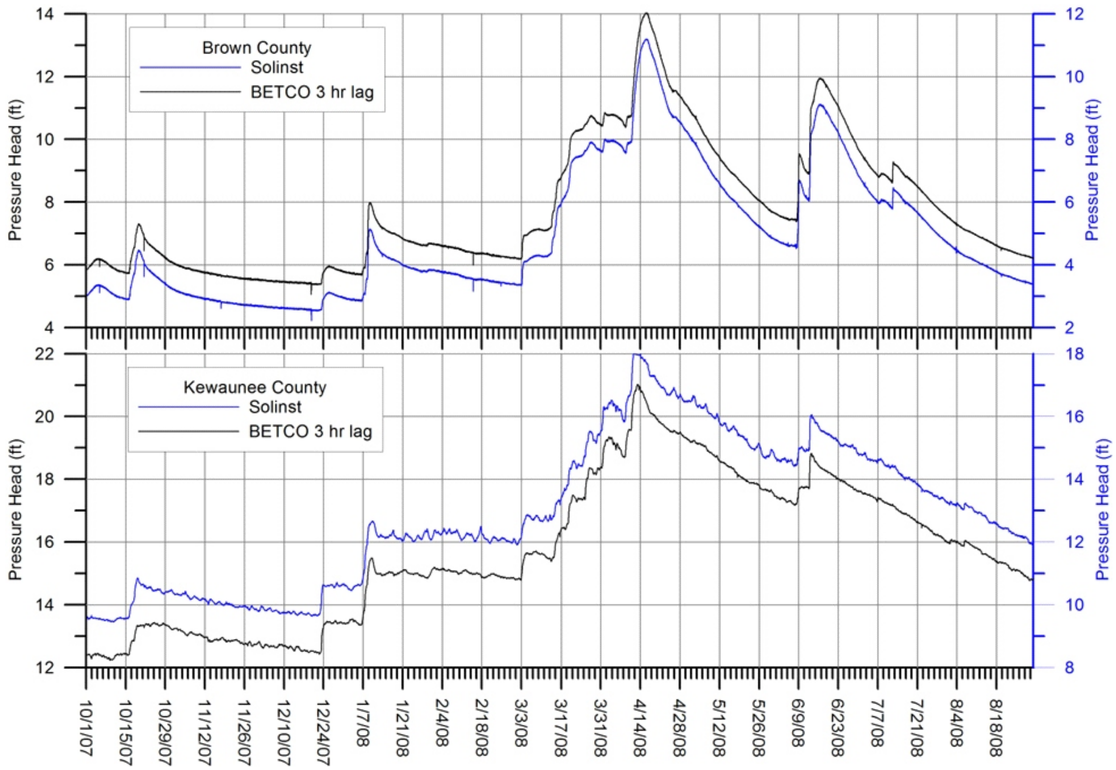


Figure 15 Water levels from the Brown and Kewaunee County wells. Graphs illustrate the difference between Solinst and BETCO barometric correction methods. Note that the vertical scales for the pressure head in each well (right and left vertical axes) are slightly offset so that both water-level records can be easily seen.

Recharge Events

Since only the Green Bay site recorded snowfall data, we used those data to generate Figure 16 which compares precipitation data to water levels in all four monitoring wells. The overall range in water level variation was least in the Manitowoc well (~ 2.65 ft). The other three wells showed water-level variations on the order of 7.1 to 8.97 ft. The wells show very similar water-level trends over the year. Water levels generally declined from early October to late December, although three wells responded to small recharge events in mid-October and late December. In early January, a period of warm weather contributed melting snow as well as rain to create a recharge event marked by sharp increases in water levels in all wells. The wells show varying behavior for the period from early January to early March. Water levels declined in the Brown County well, whereas the Kewaunee and Calumet wells exhibited generally stable water levels. The Manitowoc well showed generally rising water levels during this period. The major recharge event began in early March and water levels in all wells generally increase from early March to mid to late April. Water levels then declined until early June when exceptionally heavy rains created an early summer recharge event. Water levels then declined throughout the rest of the summer.

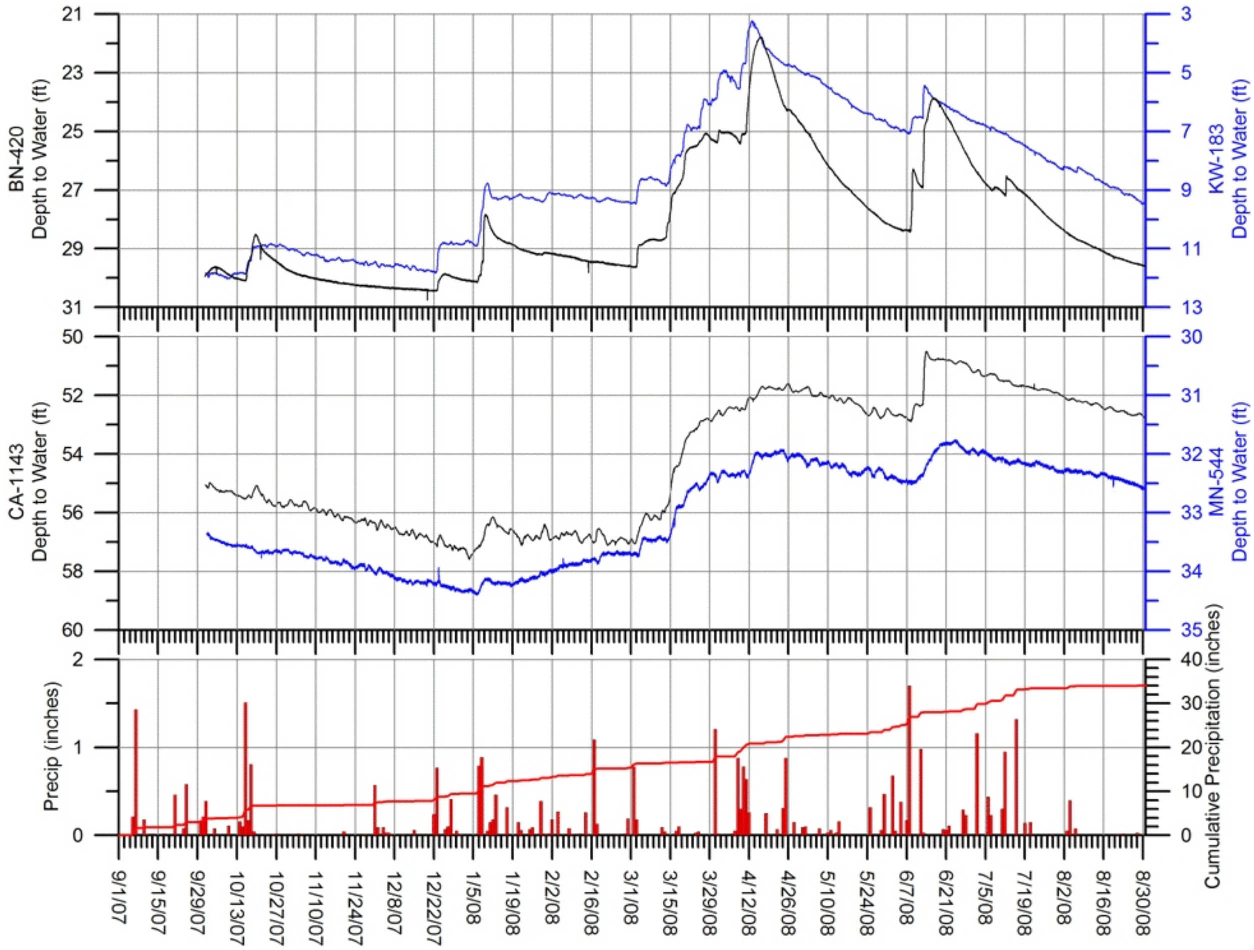


Figure 16. Water levels from the four monitoring wells. The top graph shows data from wells in Brown (black line, left axis) and Kewaunee Counties (blue line, right axis). The middle graph illustrates water levels from the Calumet (black line) and Manitowoc (blue line) wells. Note the vertical scale is 10 ft for all wells except Manitowoc, which has a vertical scale of 5 feet. The bottom bar graph is daily precipitation as measured at the NWS Green Bay location.

Details of the five recharge events are illustrated in Figures 17 to 21. Rainfall data for all graphs are from the Green Bay NWS station; soil temperature data are from the Saxon Discovery Farm. The October and June recharge events are well explained by rainfall records, whereas the recharge events in December, January, and March appear to be due to a combination of rainfall and snowmelt.

<u>October 2007</u> The 1.5-inch rainfall event on October 16 (Figure 17) produced water-level rises in three of the four wells within 24 hours. The only well not exhibiting a water-level rise was MN-544. The water level in BN-420 rose ~1.5 feet in response to the rain event, while the water level in KW-183 rose ~ 1 foot.

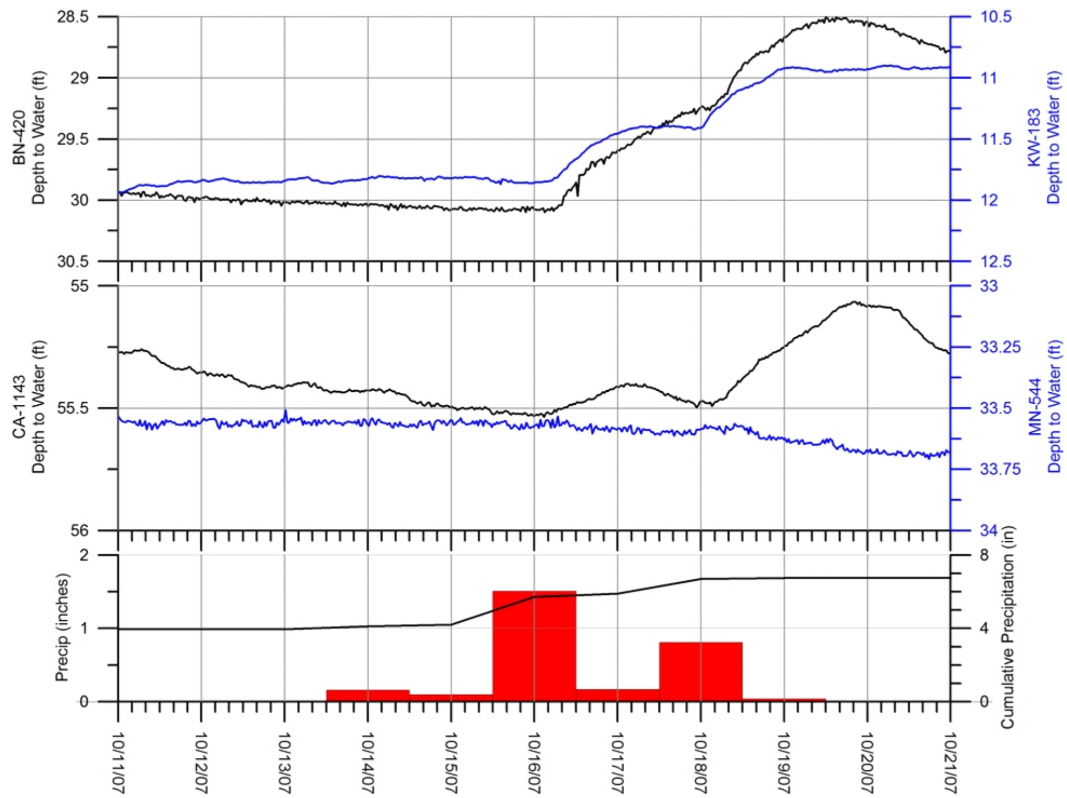


Figure 17. Water level data from all four wells and precipitation data from the Green Bay weather station for a 10-day period in October 2007.

<u>December 2007</u> Air temperatures rose above freezing for a period from mid-day December 20 to mid-day December 23. Snow depth at the Green Bay NWS station decreased from six to one inch during this period and the precipitation on the 22nd and 23rd appears to have been rain rather than snow. Even though soil temperatures suggest a frost depth of 10 cm, the rainfall, combined with melting snow contributed to significant water-level rises in the BN-420 and KW-183 (Figure 18) and a slight water-level rise in CA-1143 (Figure 16). The Manitowoc County well did not show an increase in water levels (Figure 16).

<u>January 2008</u> A second warm spell in mid-January led to significant water-level rises in all four wells (Figures 16 and 19). The air temperature was above freezing for much of the period January 5th to January 9th and snow depth decreased from seven to zero inches during this time. Water levels in BN-420 and KW-183 begin to rise on January 6th presumably in response to the snow melt. Rainfall on January 7th and 8th leads to a sharper water level rise in both wells. Soil temperature data suggest a frost depth of ~20 cm at the beginning of the warm spell, but that the entire soil profile was at or above freezing by January 6th.

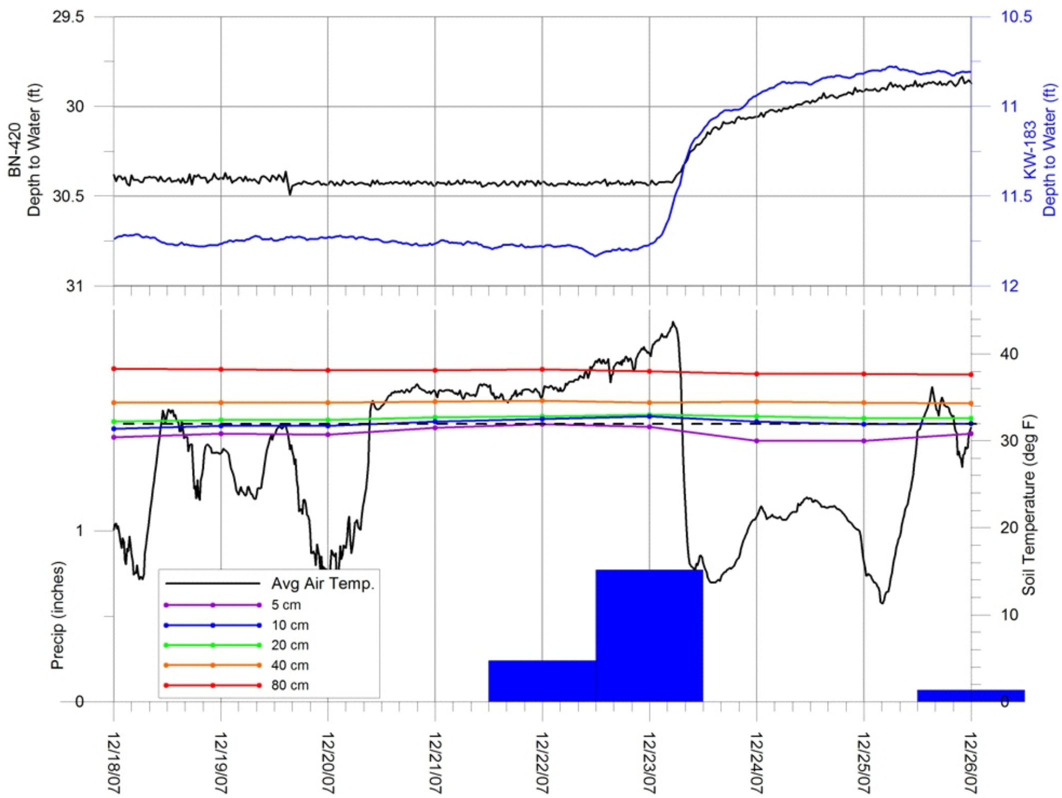


Figure 18. Water-level, precipitation, and soil temperature data for an eight-day period in December 2007. Only two well records are shown for clarity sake. Air temperatures were recorded at 15-minute intervals, while soil temperature data represent daily averages.

<u>March 2008</u> The reported snow depth at the Green Bay NWS station was 17 inches on March 1, 2008 and snow depths steadily decreased until March 26th. After March 26th, the air temperature was generally above freezing and precipitation was assumed to be rainfall (Figure 20). Water levels in all wells begin to rise in early March in response to periodic snow melt events. The northern wells, BN-420 and KW-183, exhibit strikingly similar water-level trends and periods of above-freezing air temperature produce rapid and sharp water-level rises. The southern wells (CA-1143 and MN-544) also exhibit striking similar water-level trends, however, the response to snow melt event is somewhat more muted that the northern wells (Figure 16).

<u>June 2008</u> Heavy rains on June 8th and 12th led to rapid water-level rises in three of the four monitoring wells (Figure 21). While BN-420, KW-183, and CA-1143 all show distinct water-level rises within 24 hours of each precipitation event, the Manitowoc well shows a gradual water-level rise for the period June 10th to 19th.

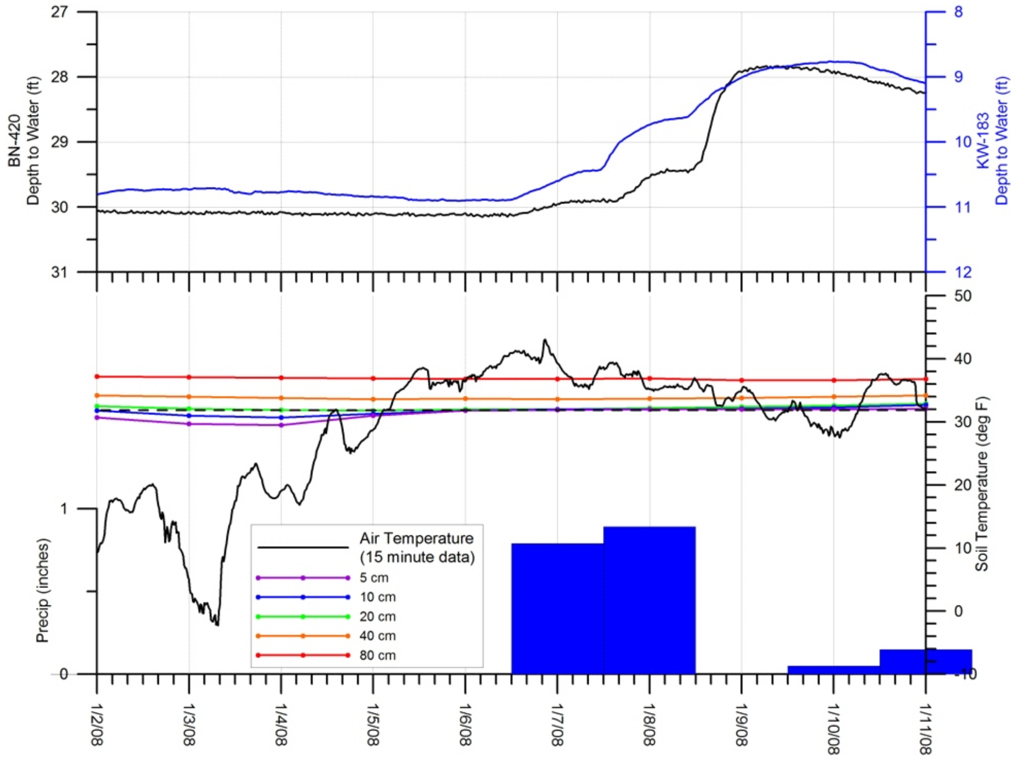


Figure 19. Water-level, precipitation, and soil temperature data for a nine-day period in January 2008. Only two well records are shown for clarity sake. Air temperatures were recorded at 15-minute intervals, while soil temperature data represent daily averages.

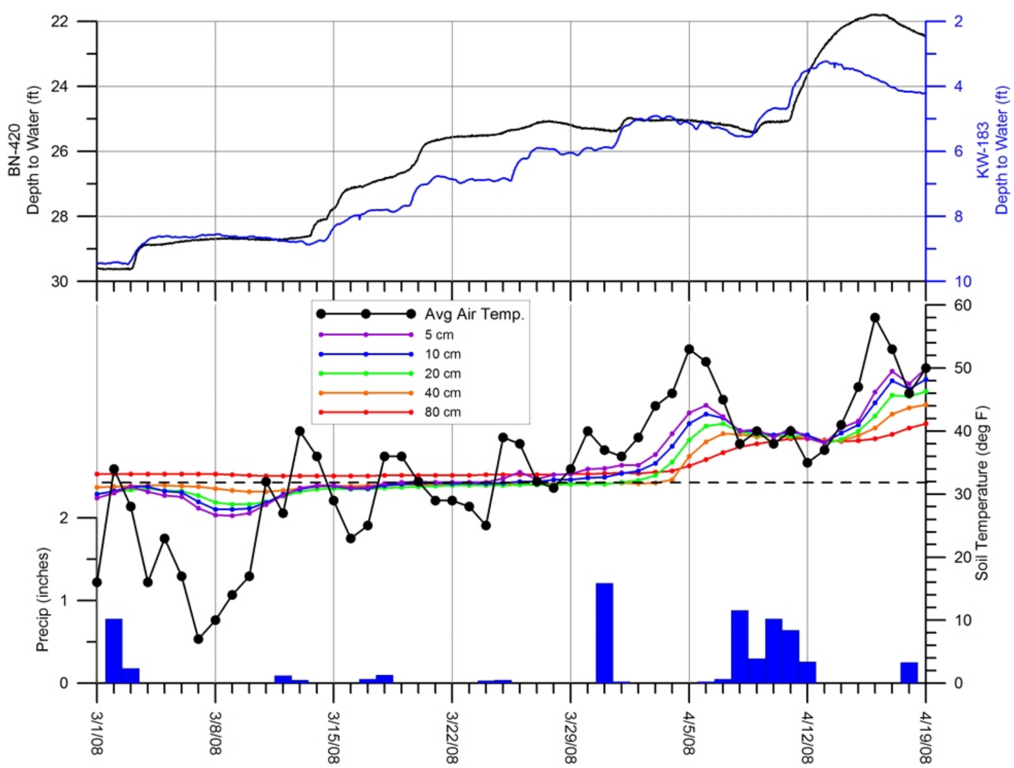


Figure 20. Water-level, precipitation, and soil temperature data for the period March 1 to April 19, 2008. Both the air temperature and soil temperatures are 24-hr averages.

Overall, the response to recharge seems to be a function of the both the thickness and the texture of the unconsolidated material. MN-544 shows the most muted response to recharge events. The surficial sediment in Manitowoc area is relatively thick (~18 feet) and consists red clay till, whereas siltier unconsolidated sediments are found at the other three sites. CA-1143 also shows a somewhat muted response to recharge when compared to the Brown and Kewaunee County wells. While the unlithified materials are also ~18 feet thick, they consist of silty sand. BN-420 and KW-183 both show very rapid responses to recharge events. Surficial sediments at these sites consist of silty sand and are generally thin; ~10 feet at the Brown County site and ~7 feet at the Kewaunee site. Water-table depth does not seem to be important an important control on the response to recharge. Wells BN-420, KW-183, and CA-1143 all exhibit rapid responses to recharge and their overall water-level fluctuations are similar ranging between 7.10 and 8.80 feet (see Table 3). Average depth to water table ranges from 8.52 ft for KW-183, 28.06 ft for BN-420, and 54.21 ft for CA-1143.

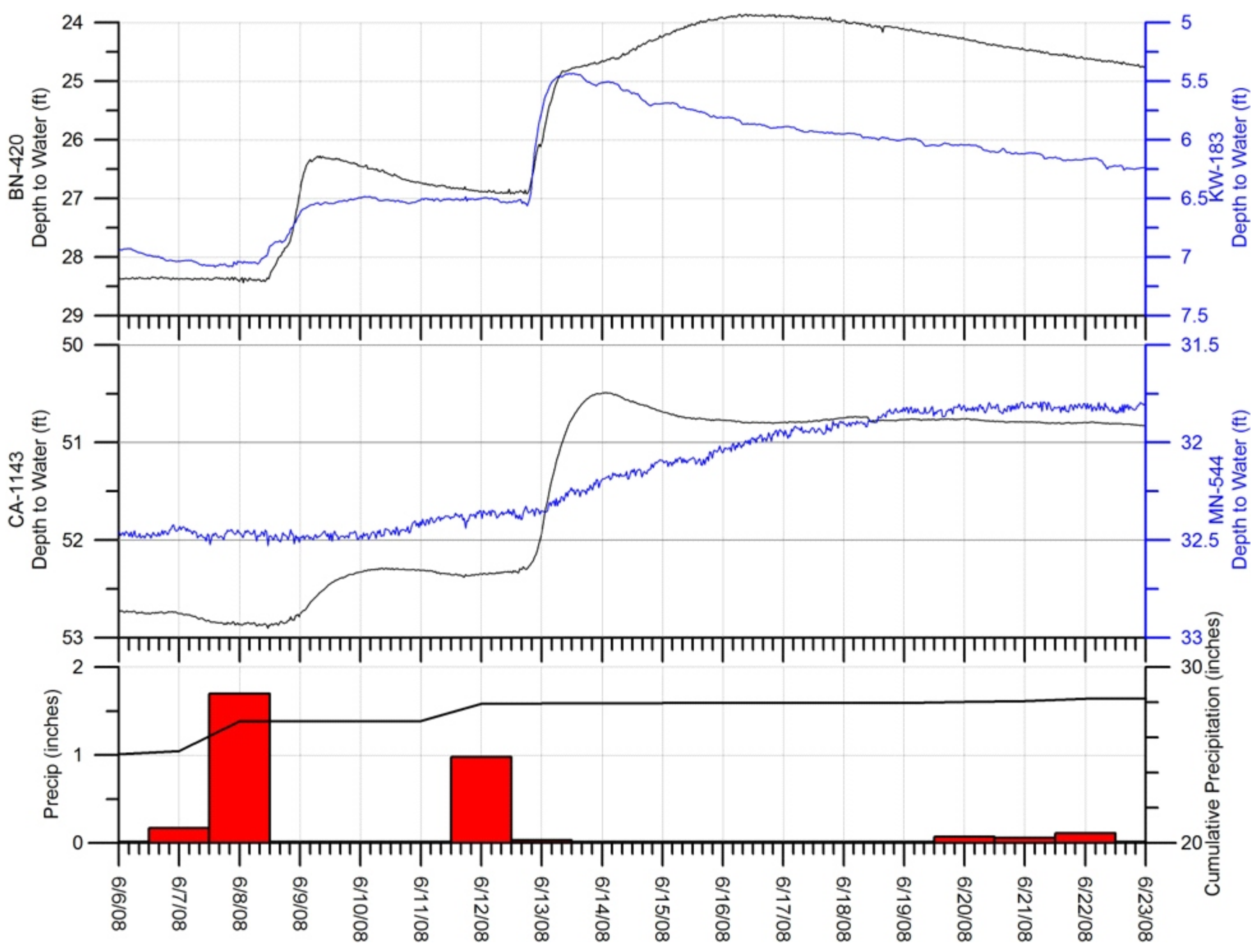


Figure 21. Water-level data from all fours wells and precipitation data from the Green Bay NWS sation for a 17-day period in June 2008.

Continuous temperature/electrical conductivity monitoring

Previous work in the Silurian dolomite aquifer (Bradbury and others, 2002) suggests that continuous records of fluid temperature and electrical conductivity are a good method for assessing how rapidly recharge reaches the saturated zone and for characterizing the water-chemistry changes that result from recharge events. Bradbury and others (2002) noted sharp changes in both fluid temperature and electrical conductivity within 24 hours of precipitation events. Throughout their study, they sampled the wells monthly for isotopic analysis and they did not note any sharp changes in fluid temperature or conductivity associated with sampling activities. Fluid temperature/conductivity records for the four wells used in this study, presented in Figures 22 to 25 and summarized in Table 4, are not as straightforward as those reported by Bradbury and others (2002).

Table 4. Summary of Fluid Temperature/Conductivity Data

Well	Sensor Depth (ft below TOC)	Avg Depth to Water (ft below TOC)	Temperature C°			Conductivity (µS/cm)			Water Level range (ft)
			min	max	range	min	max	range	
KW-183	21	8.52	7.18	11.82	4.64	185	671	486	8.80
BN-420	34	28.06	8.63	10.80	2.17	719	937	218	8.71
MN-544	41	33.06	8.38	9.36	0.98	573	679	106	2.65
CA-1143	60	54.21	9.48	9.95	0.47	480	817	337	7.10

Temperature variation is correlated with sensor depth and average depth to water. Table 4 presents the wells in the order of most to least variability in water temperature. The Kewaunee well (KW-183), with the shallowest sensor depth and average depth to water, showed the most variation in fluid temperature, while the Calumet well (CA-1143), with the deepest sensor depth and average depth to water, showed the least variation in water temperature. Variability in fluid conductivity appears to be somewhat correlated with water-level variation. The Kewaunee County well shows the greatest range of water-level variations (8.80 ft) and is the most variable is terms of conductivity and temperature while the Manitowoc County well shows the least variation in water levels and the least variation in fluid conductivity. The Calumet and Brown county wells, do not follow this trend. CA-1143 is the second most variable in terms of fluid temperature/conductivity, but third in terms of water-level variations. BN-420 is third in terms of fluid conductivity, but second in terms of water-level variations.

Temperature

All wells exhibit a strong seasonal variation in water temperature that is a lagged response to annual air temperature variations. Short-term, low-magnitude variations in temperature, occur in all four wells. Causes of these small temperature variations appear to be numerous. KW-183 exhibits small temperature variations that appear well-correlated with recharge events (red arrows in Figure 22). The majority of small temperature variations in BN-420 are short-lived and appear well-correlated with sampling events (sampling dates are shown as dashed black lines in Figure 23), while the temperature variations in late March and early April (solid red arrows in

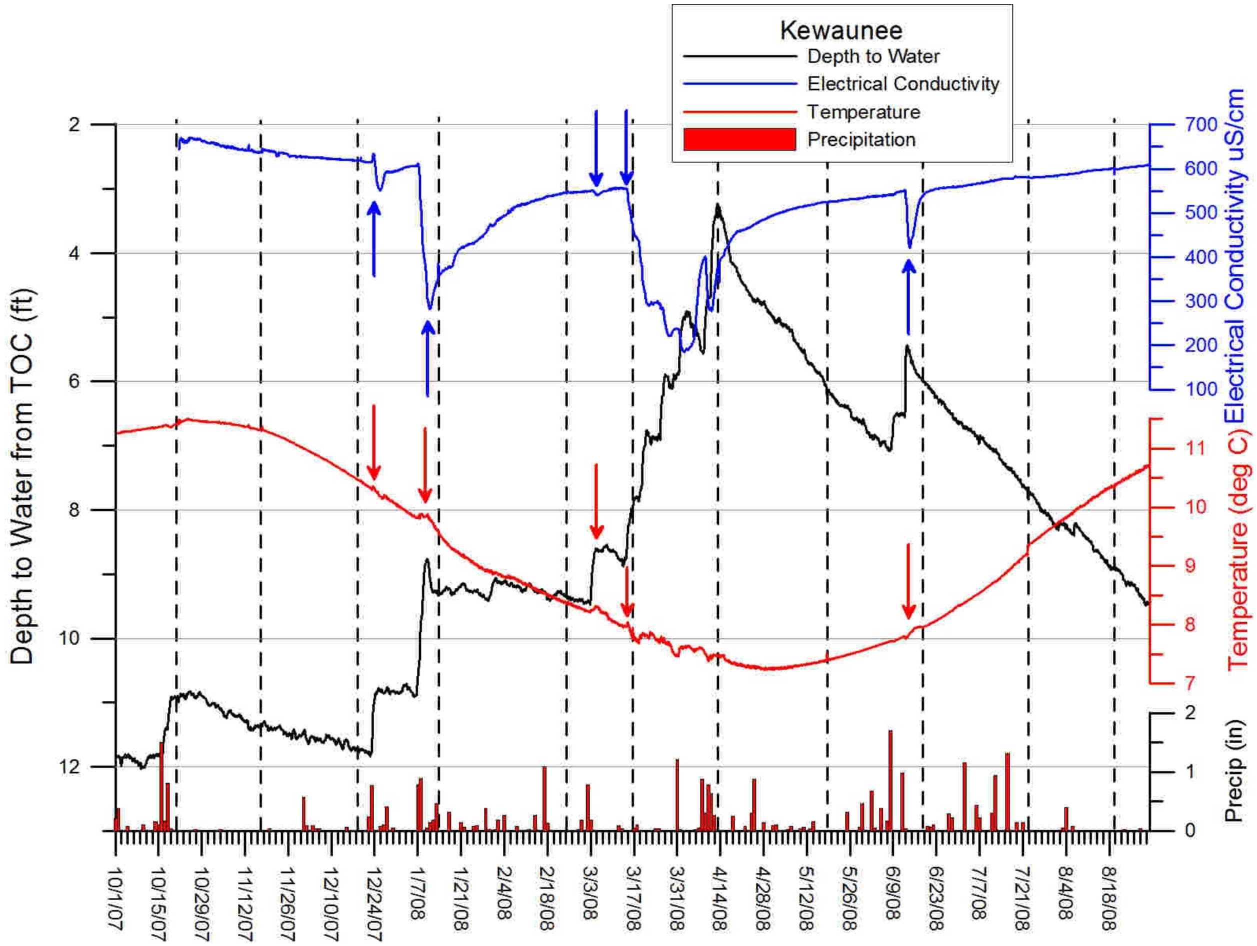


Figure 22. Variations in water level, fluid temperature, and electrical conductivity for KW-183 along with the precipitation record for the Green Bay NWS station. Red arrows indicate small variations in water temperature and blue arrows indicate sharp drops in electrical conductivity associated with recharge events. Dashed lines indicate sampling dates.

Figure 23) appear to be correlated with recharge events. Both MN-544 (Figure 24) and CA-1143 (Figure 25) exhibit frequent small temperature variations that are imposed on the larger seasonal variation in temperature. The cause of these smaller fluctuations in temperature is not clear as they do not appear to correlate with significant recharge events or with sampling events.

Conductivity

The electrical conductivity records of the wells generally show similar trends, except for well BN-420. Fluid conductivity tends to increase during periods of static or declining water levels and decrease in response to recharge events (Figures 22, 24, 25). The drop in conductivity typically occurs within 24 hours of a major precipitation and/or melt event and is seen within a few days of more gradual recharge events (such as spring smowmelt). The conductivity record for BN-420 (Figure 23) differs from the other three wells. For BN-420, the sharp changes in fluid conductivity appear to be more strongly associated with sampling events than with recharge and

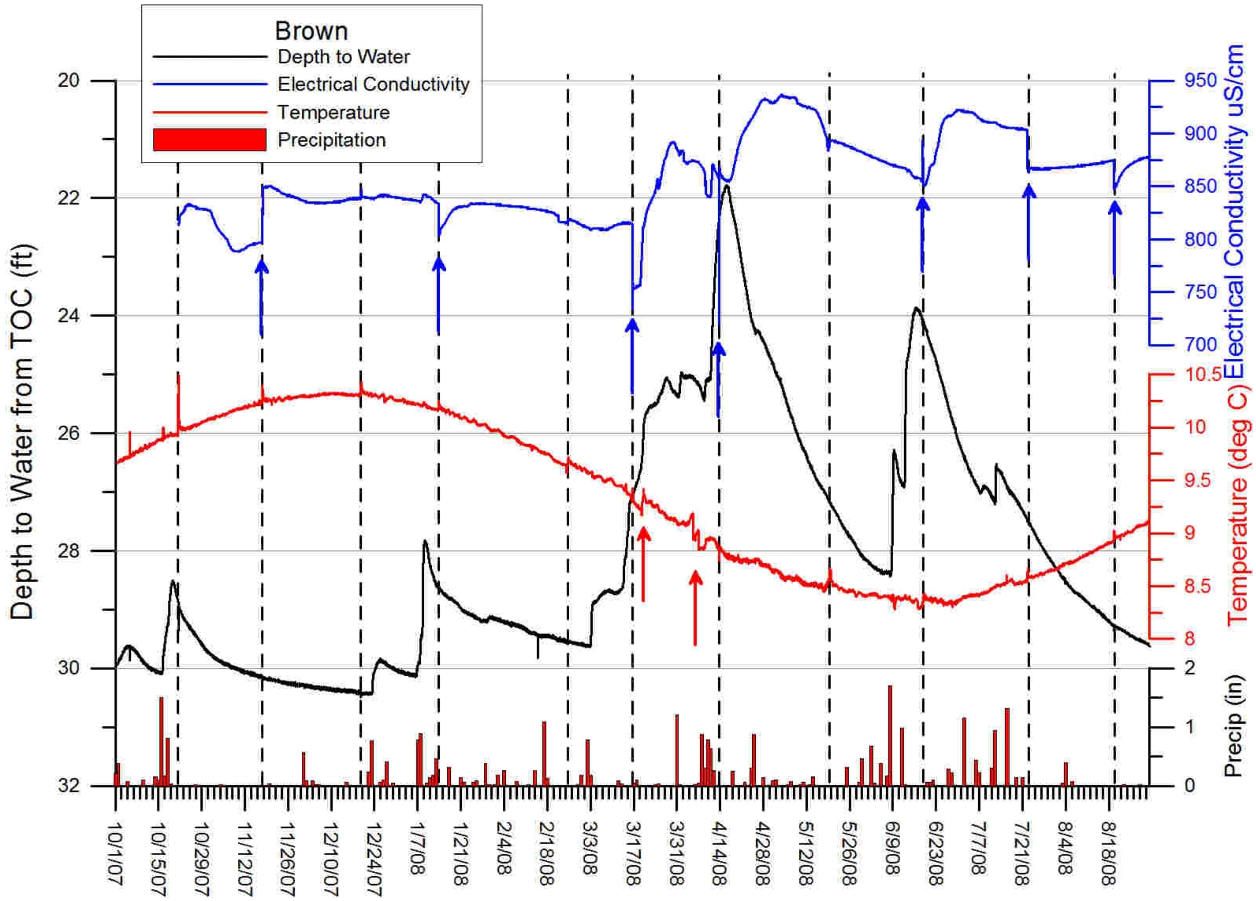


Figure 23. Variations in water level, fluid temperature, and electrical conductivity for BN-420 along with the precipitation record for the Green Bay NWS station. Red arrows indicate small variations in water temperature associated with recharge events. Blue arrows indicate sharp changes in electrical conductivity that correlate with sampling dates which are shown as dashed lines.

fluid conductivity appears to rise (rather than fall) in response to recharge events. The conductivity record of each well is discussed in more detail below.

The Kewaunee well (Figure 22) shows the greatest variability in fluid conductivity ranging from a low of 185 µS/cm to a high of 671 µS/cm. The monitoring probe for KW-183 sits adjacent to a large fracture at 21 feet depth (Table 4) which places it 10 to 19 feet into the saturated zone, depending on seasonal variations in water-table depth. Sharp changes in fluid conductivity values are correlated with the four recharge events that occurred between December 2007 to June 2008; the October 2007 recharge event occurred prior to the installation of the conductivity probe (Figure 22). Detailed examination of the conductivity record for KW-183 indicates that there is a slight rise in fluid conductivity at the start of three recharge events (December, January and June) followed by a sharp drop. We interpret the rise in conductivity as drainage of higher conductivity vadose water followed by recharge of new, low conductivity water.

As noted above, the conductivity record for the Brown County well is complicated by large changes in fluid conductivity values that appear to be correlated with sampling events (see blue

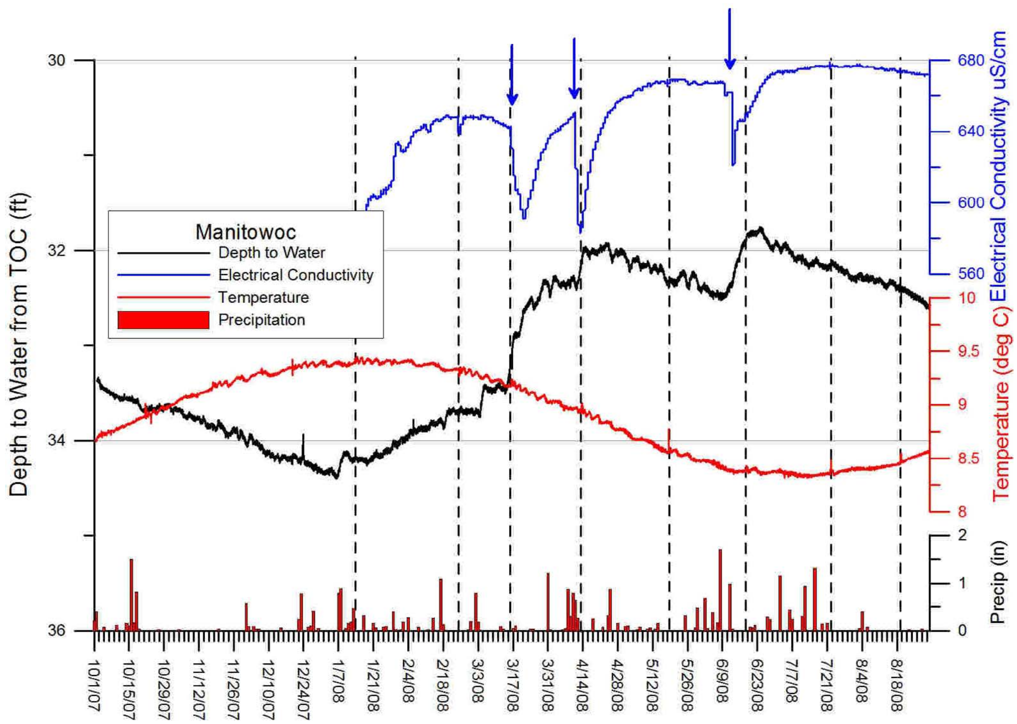


Figure 24. Variations in water level, fluid temperature, and electrical conductivity for MN-544 along with the precipitation record for the Green Bay NWS station. Blue arrows indicate sharp drops in electrical conductivity associated with recharge events. Dashed lines indicate sampling dates.

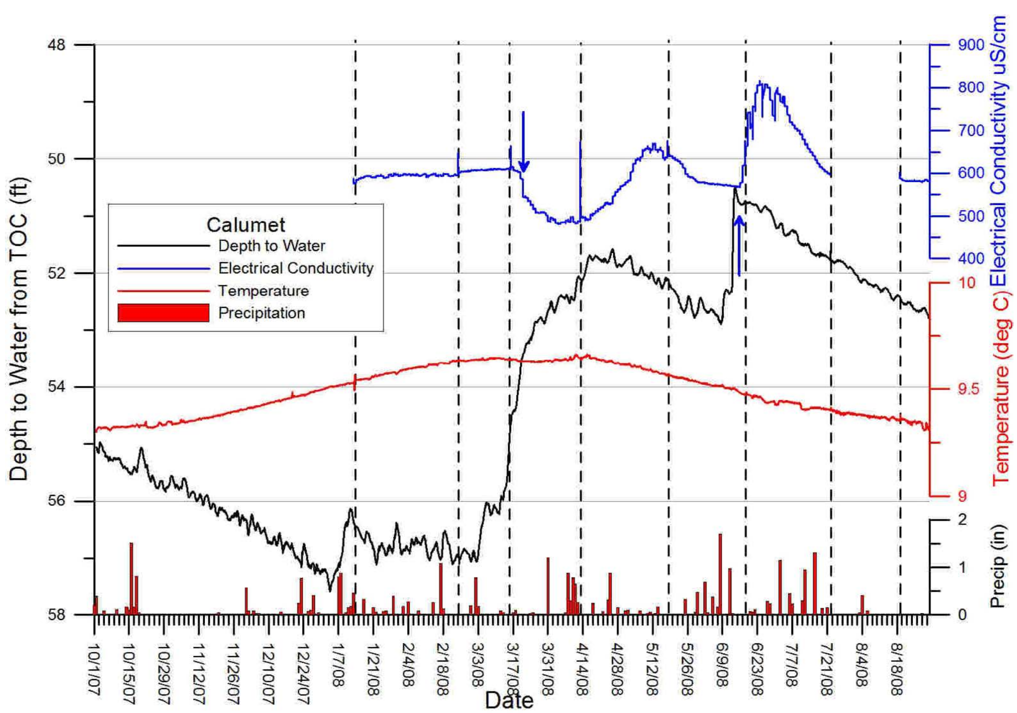


Figure 25. Variations in water level, fluid temperature, and electrical conductivity for CA-1143 along with the precipitation record for the Green Bay NWS station. Blue arrows indicate sharp changes in electrical conductivity associated with recharge events. Dashed lines indicate sampling dates.

arrows in Figure 23) caused by pulling new water (of differing conductivity) into the well as we sample. Since these "sampling effects" are not seen in the Kewaunee well, the highest yielding of the four wells, it is likely that sampling affects low-yielding wells to a greater degree than high-yielding wells. Trying to ignore the "sampling effects", it appears that conductivity is relatively consistent from late October until mid-March. The December 2007 and January 2008 recharge events do not seem to generate corresponding changes in conductivity. From mid-March until early May, conductivity generally increases, although there is a decrease in conductivity during the first two weeks in April. The spring recharge event was episodic and began in early March and continued until mid-April. In this well, the conductivity response to the spring recharge event is variable. From early May until the June 18th sampling event, the conductivity decreases. Water levels also decrease during this time, until they start to rise sharply on June 8 due to the precipitation-driven recharge events of early June. Conductivity generally rises from June 18th until early July, also a time of generally falling water levels. This rise in conductivity may be a delayed response to the early June recharge event, in which case, it is the opposite response to recharge than was observed in the Kewaunee well. For the reminder of the summer of 2008, conductivity appears generally stable except due to sampling-induced changes.

The conductivity probes were not installed in wells MN-544 and CA-1153 until January 13, 2008 and as a result there is no record of conductivity changes during the recharge events of October and December, 2007 or the melt event of January 2008. The Manitowoc well (Figure 24), which had the least variability in water levels, also displays the least variability in fluid conductivity with values ranging from a low of 573 µS/cm to a high of 679 µS/cm (Table 4). Despite this low variability in conductivity, there are three sharp drops in conductivity (blue arrows, Figure 24) that occur at the following times: March16 to21, April 10 to 13, and June 12 to 14. These time intervals occur during periods of sharply rising water levels which suggest that the conductivity changes are due to recharge events. The record is somewhat complicated by sampling effects. The slight drop in conductivity that occurs on February 24th appears to be caused by sampling. Close inspection of the data indicates that the large conductivity drops in March and April actually precede sampling events. The timing of the drops, and the corresponding rising water levels, indicate that these changes in conductivity are due to recharge rather than sampling.

The Calumet conductivity data indicate two differing responses to recharge events (Figure 25). In mid-March, the conductivity shows a short spike of elevated conductivity values caused by sampling on March 16, followed by a decline in values that last through early April. This decline in conductivity values occurs during generally rising water levels and is assumed to be caused by the spring recharge event. Water levels peak in mid-April and then generally decline until the extreme precipitation events in early June. During this same time frame, conductivity rises and then falls. Rising conductivity values during periods of static or declining water levels was also observed in KW-183 and MN-544. It is not clear why conductivity values in CA-1143 decrease throughout May. The early June recharge event appears to correlate with an increase in conductivity in CA-1143. The apparent differing responses to recharge may be due to the timing and rate of agricultural inputs on the upgradient fields.

Geochemical Data

All wells were sampled approximately monthly for nitrate-nitrogen, chloride, and dissolved phosphorus during the period September 2007 to August 2008. Sampling results for each well, shown in relation to water levels measured in that well, are presented in Figures 26 to 29 and summarized in Table 5.

Nitrate-nitrogen

All wells exhibit elevated nitrate-nitrogen values. Each well had at least six samples that exceeded drinking water standard of 10 mg/L (Figures 26-29) and three of the four wells have average nitrate values that exceed the drinking water standard (Table 5). CA-1143, the deepest well, had an average NO_3-N^- value of 23.85 mg/L, more than double the drinking water standard. Kewaunee had the lowest average NO_3-N^- value of 8.71 mg/L. Nitrate-nitrogen concentrations in shallow groundwater are strongly influenced by local land use and we did not expect to see any correlation between well depth and nitrate concentration.

Nitrate values varied over time in all wells (Figure 30) and most wells varied by 9 to 10 mg/L; the Calumet well varied by over 28 mg/L. Three of the wells (all but MN-544) show drops in nitrate values in January and April of 2008. Both of these sampling events followed a large recharge event. Thus it seems that recharge has a dilution effect in terms of nitrate-nitrogen.

Table 5. Summary of Chemical Data

			Chloride	**NO_3-N^-**	**Phos_P**
		pH	**mg/L**	**mg/L**	**µg/L**
BN-420	minimum	6	48.7	5.57	26
	maximum	7.07	84.1	14.6	137
	average	6.84	73.9	10.2	73
	range	1.07	35.4	9.03	111
CA-1143	minimum	7.18	26.7	2.75	8
	maximum	7.4	69.1	31.1	15
	average	7.3	46.8	23.85	11
	range	0.22	42.4	28.4	7
KW-183	minimum	6.98	11.4	2.99	9
	maximum	7.29	37.8	12.2	61
	average	7.13	25.2	8.71	16
	range	0.31	26.4	9.21	52
MN-544	minimum	6.36	35.6	10.2	10
	maximum	7.3	48.5	20.4	13
	average	7.08	40.5	13.6	12
	range	0.94	12.9	10.2	3

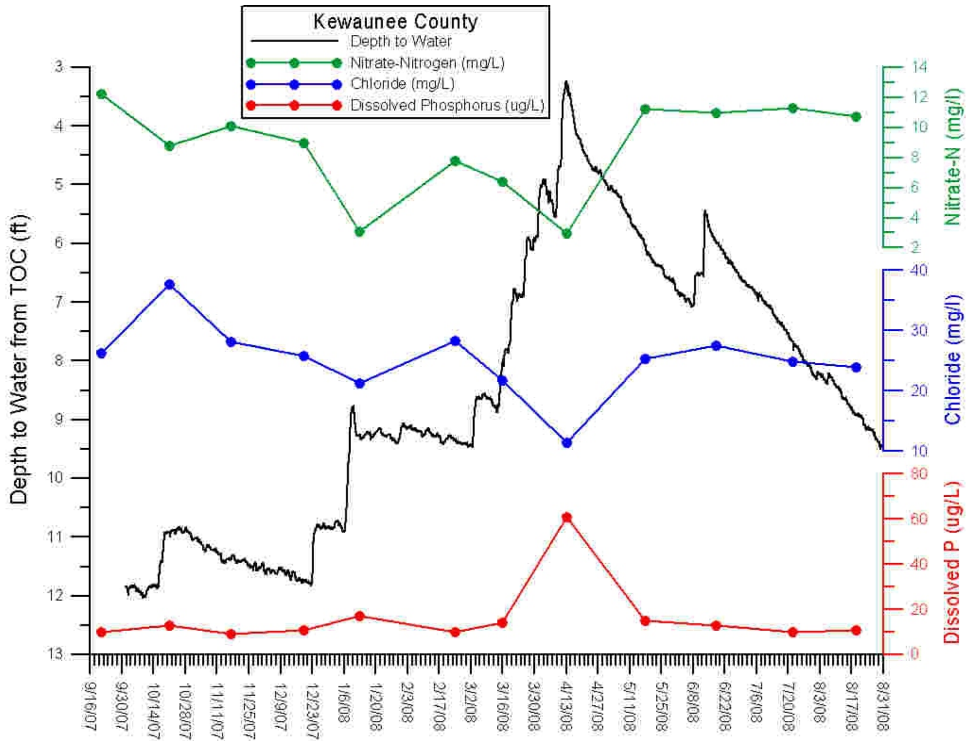


Figure 26. Water-quality results for KW-183 (right-side axes) shown in relation to the measured water levels in the well (left-side axis).

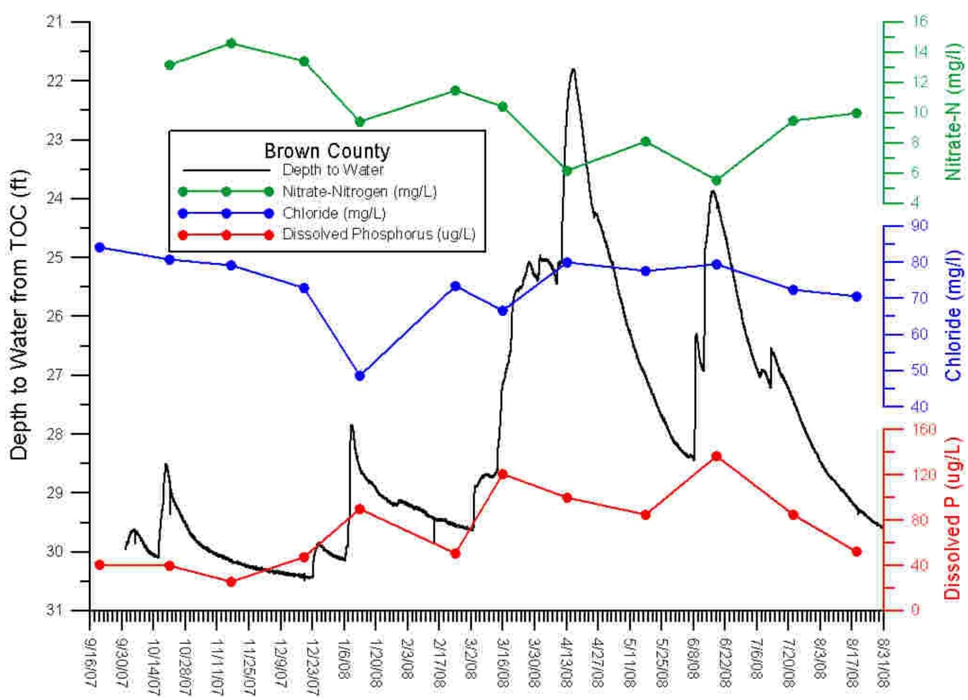


Figure 27. Water-quality results for BN-420 (right-side axes) shown in relation to the measured water levels in the well (left-side axis)

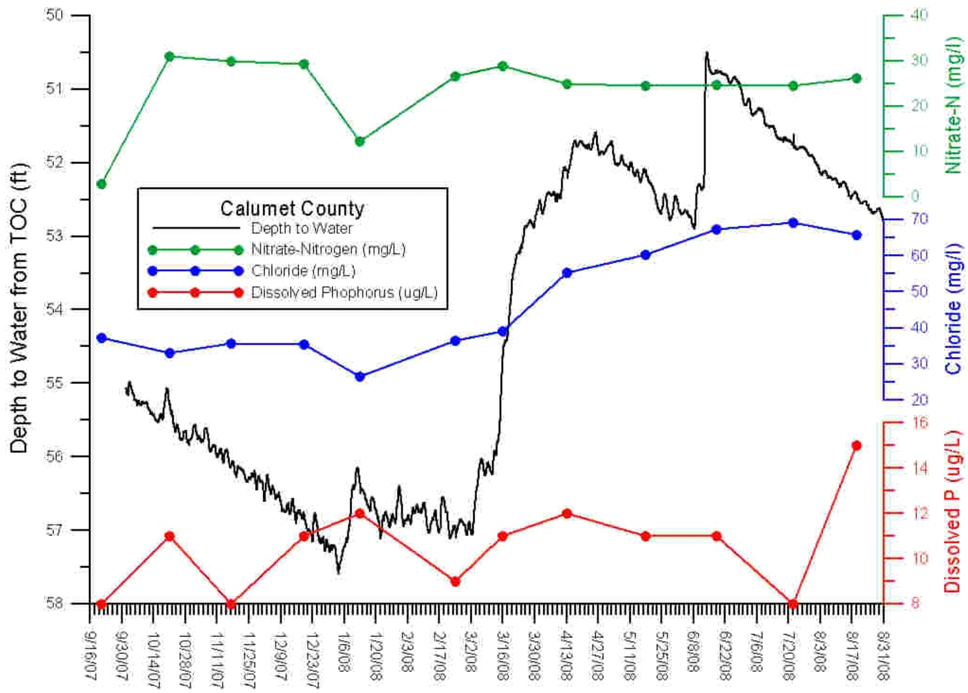


Figure 28. Water-quality results for CA-1143 (right-side axis) shown in relation to the measured water levels in the well (left-side axis)

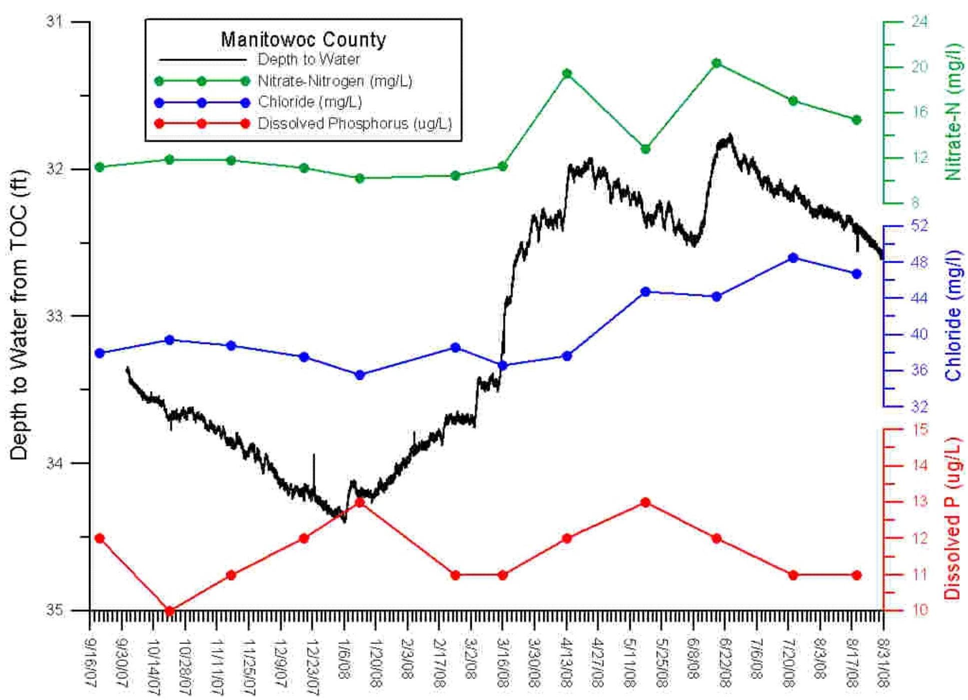


Figure 29. Water-quality results for MN-544 (right-side axis) shown in relation to the measured water levels in the well (left-side axis)

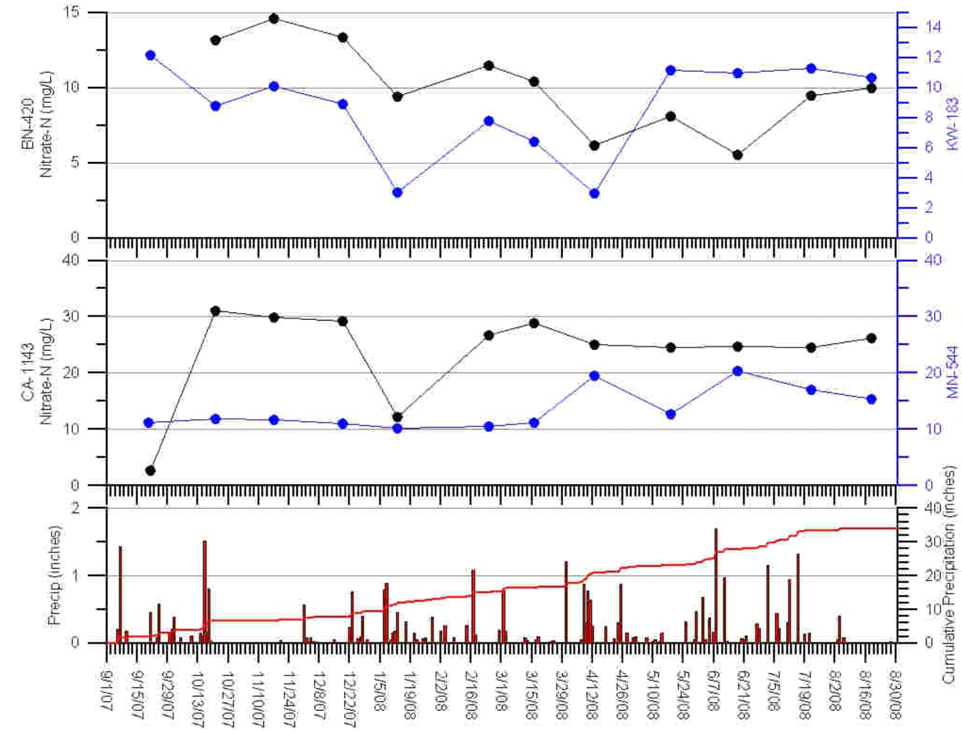


Figure 30. Nitrate-nitrogen values (mg/L) over time for all four wells. The bottom graph shows daily and cumulative precipitation from the Green Bay NWS station.

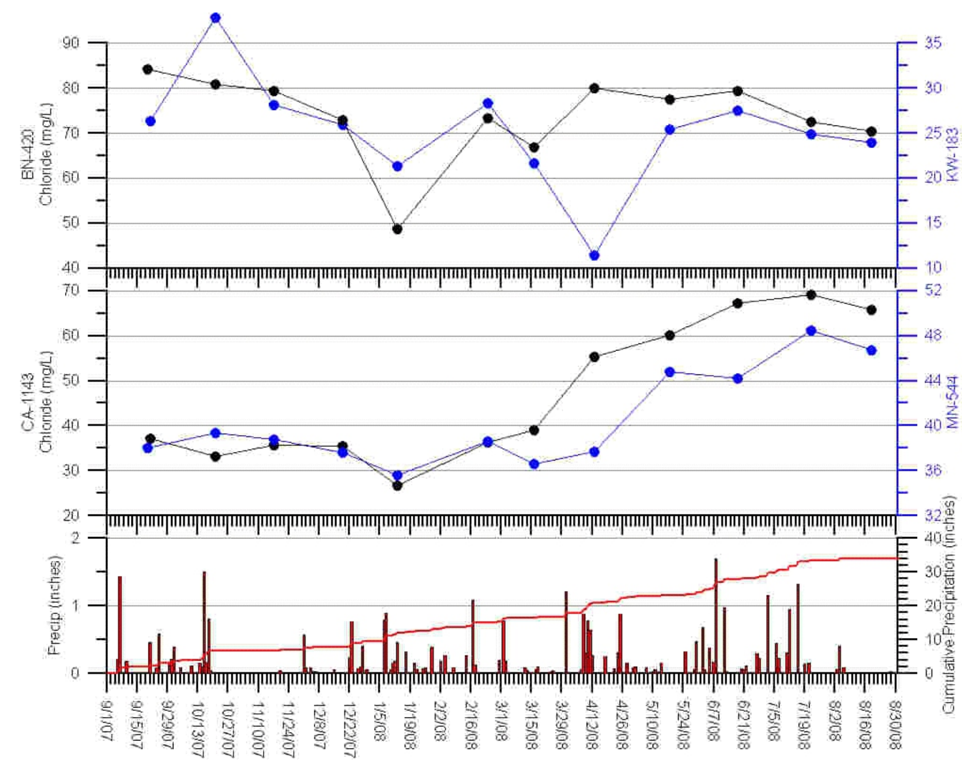


Figure 31. Chloride values (mg/L) over time for all four wells. The bottom graph shows daily and cumulative precipitation from the Green Bay NWS station.

Chloride

All wells had average chloride values in excess of 25 mg/L (Table 5) which are considered elevated. Ambient groundwater in Wisconsin's shallow aquifers typically has chloride concentrations less than 10 mg/L (Kammerer, 1995). Anthropogenic sources of chloride include human and animal wastes and road salt. Elevated chloride concentration are considered an indication that land-surface activities are impacting groundwater quality.

Chloride values varied over time in all wells (Figures 26 to 29). Generally variations in chloride concentration were similar to those of nitrate in that all of the wells show drops in chloride values following the recharge event in January 2008 and three of the wells show a drop in chloride during the March-April recharge event (Figure 31). Recharge appears to have a dilution effect in terms of chloride.

Phosphorus

Phosphorus is a relatively common element in many igneous and sedimentary rocks, however background concentrations in shallow groundwater are typically low, less that a few 10's µg/L (Hem, 1985). Phosphorus concentrations in the study wells are strongly related to well depth. The two deep wells, CA-1143 and MN-544, have low average phosphorus concentrations (Table 5) that show little variability over time (Figure 32). The shallow wells, BN-420 and KW-183, both exhibit higher average chloride concentrations that show variability over time (Figure 32).

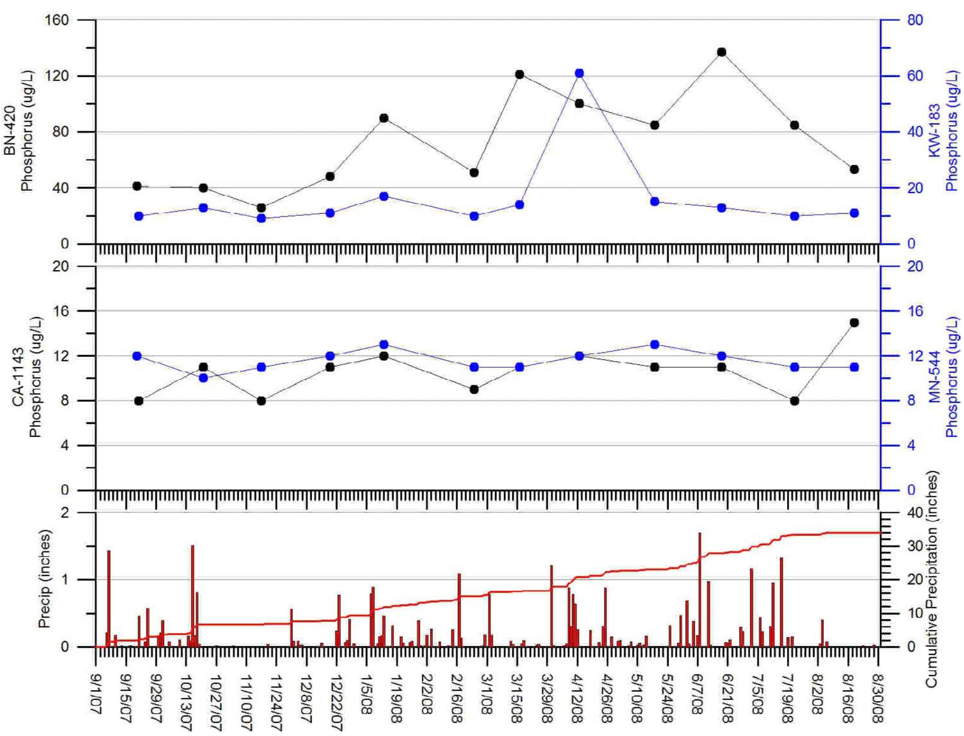


Figure 32. Phosphorus values (µg/L) over time for all four wells. The bottom graph shows daily and cumulative precipitation from the Green Bay NWS station.

KW-183 has a somewhat elevated average chloride concentration of 16 µg/L and exhibits a distinct peak in phosphorus concentrations in mid-April 2008. BN-420, with an extremely high average phosphorus concentration of 73 µg/L, exhibits the most variability in phosphorus concentrations. The "spikes" in phosphorus concentration occur in January, March, and June 2008, all immediately following a recharge event. The peaks in phosphorus concentration correlate with "dips" in either nitrate or chloride concentration (Figure 27). So it appears that while recharge events lead to drops in nitrate and chloride concentration in BN-420, they also lead to increases in phosphorus concentrations. KW-183 only exhibits one distinct spike in phosphorus concentration and this peak correlates with drops in both nitrate and chloride.

Summary and Conclusions

This study documented variations in water levels, fluid temperature and electrical conductivity, and selected water-quality parameters in four wells completed in the Silurian dolomite aquifer. The data collected provide a better understanding of seasonal variations in recharge and the resulting water-quality variations in the aquifer in areas with ~10 to 20 feet of surficial sediment.

Recharge Characteristics and Controls

Water levels in all four monitoring wells show rapid responses to episodic recharge events throughout the year. Most recharge occurred following snow melt and large rainfall events in the early spring. However, significant recharge also occurred in autumn, winter, and summer. The autumn and summer recharge events were in direct response to large rainfall events. The winter and early spring recharge events were due to a combination of snow melt and rainfall. The response to recharge seems to be a function of the thickness and texture of the unconsolidated material. Wells with seven to ten feet of surficial sediment exhibited "flashy" responses to recharge events. In these wells (BN-420 and KW-183) water levels varied almost nine feet throughout the year, rose rapidly (within 24 hours) in response to a large rain or melt event and exhibit steep water-level recessions. Wells with ~18 ft of surficial sediment (CA-1143 and MN-544) also responded rapidly to recharge, but the response was somewhat muted when compared to the wells with thinner soils. Water-level peaks were not as sharp and water-level recessions were more gradual. The texture of the surficial sediment appears to exert a strong control on the magnitude of water-level variations. Wells CA-1143 and MN-544 both have ~18 ft of surficial sediment and yet the magnitude of water-level variation is very different in the two wells. Water levels in MN-544 varied 2.65 ft over the course of the year while water levels in CA-1143 varied 7.10 feet. The surficial sediment at the Manitowoc site consists red clay till whereas sediments at the other sites consist of silty sand. Water-table depth does not seem to be important an important control on the response to recharge.

Variations in Water Quality

In all wells, rapid drops in fluid conductivity in response to recharge indicate that low-conductivity recharge water penetrated into the saturated zone within a day or two of recharge event. Therefore, it is clear that the correlated rise in water table is due to fresh recharge water and not just drainage from the vadose zone. In some wells, particularly BN-420, the interpretation of conductivity data was complicated by changes in conductivity that accompanied sampling.

Water from all four wells contained elevated nitrate-nitrogen and chloride. Average nitrate-nitrogen values in three of the wells exceed the drinking water standard of 10 mg/L and all wells exceeded nitrate standard at some time during year. Chloride values are elevated in all wells. Phosphorus values are elevated in the two shallow wells (BN-420 and KW-183), but not in the deeper wells (CA-1143 and MN-544). Elevated nitrate and chloride values suggest that land-use activities are affecting water quality in all wells. Recharge events tend to dilute nitrate and chloride values while causing increased phosphorus concentrations in the two shallow wells.

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APPENDIX A

GEOPHYSICAL LOGS

Wisconsin Geological and Natural History Survey

Well Owner: UW-Oshkosh

Well / Hole Name: Brown County/Wayside well

Well Address:

City, State, Zip Code:

WGNHS Well ID:

WI Unique Well #:

Property Owner: Jeff Gibbons

Address:

line 2:

City

State: Zip Code:

WGNHS Well ID :

BN420

WI Unique Well #

GPS Latitude:

GPS Longitude:

WTM83_N:

WTM83_E:

Elevation & Method:

Location: Town of Morrison,

SEC. 33 T. 21N R. 21E

PERMANENT DATUM: GROUND SURFACE

LOG MEAS. FROM top of casing ABOVE PERM. DATUM

DRILLING MEAS. FROM

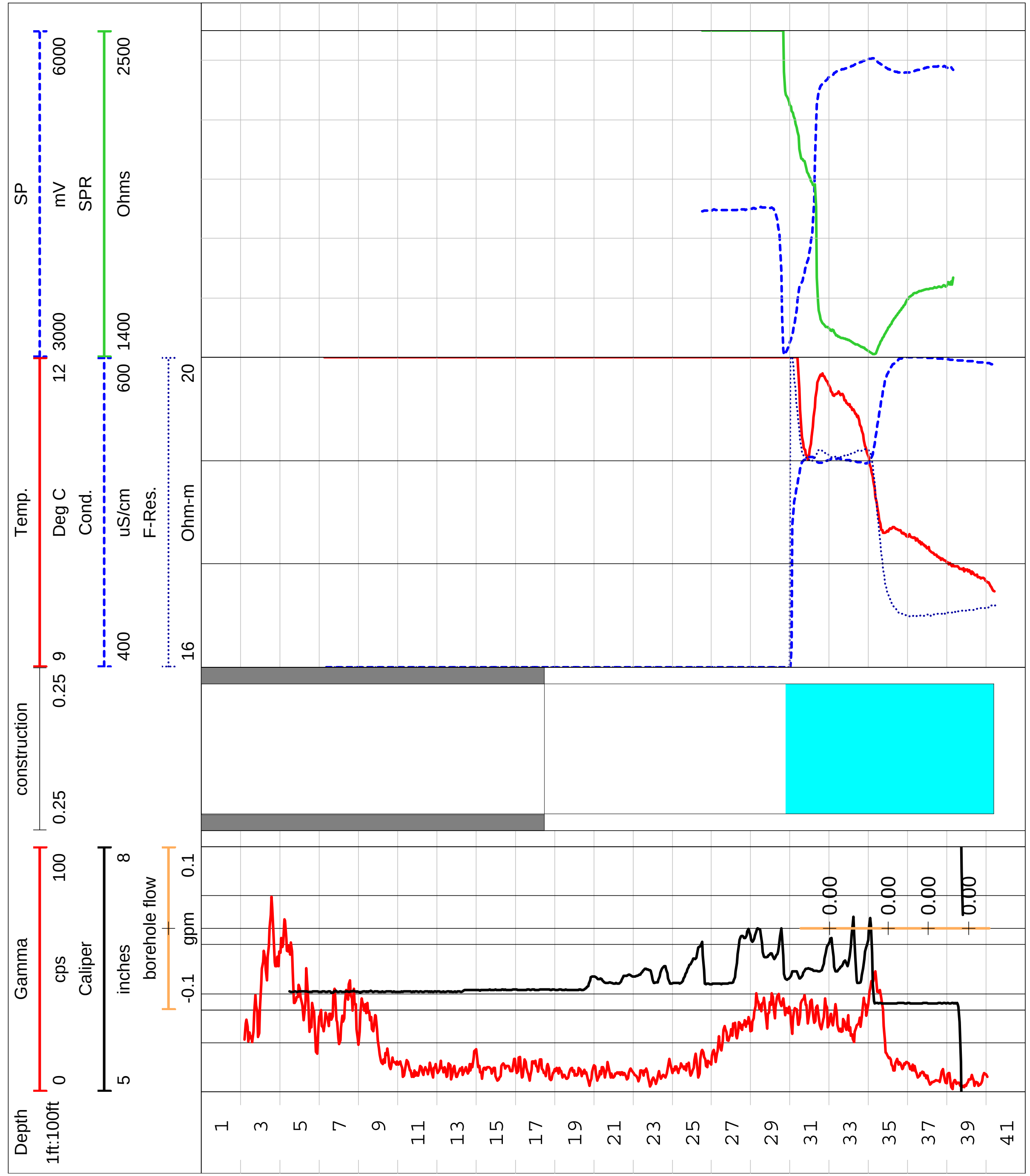
ELEVATION:

SU:

DTW:

Date:	9/20/07	Log 8 Performed on Borhole:	
Logged by:	Ken Bradbury	Log 9 Performed on Borhole:	
Witness:	Andy Jansen	Log 10 Performed on Borhole:	
Log 1 Performed on Borhole:		DEPTH-DRILLER:	40.4.ft
Log 2 Performed on Borhole:		DEPTH-LOGGER:	40.6 ft
Log 3 Performed on Borhole:		TYPE FLUID IN HOLE	water
Log 4 Performed on Borhole:		CASING	17.5 ft
Log 5 Performed on Borhole:		DENSITY	
Log 6 Performed on Borhole:		WATER LEVEL	30 ft
Log 7 Performed on Borhole:		MAX. REC. TEMP.	

Comment: Monitoring well for NE Wisconsin monitoing project.
No borehole flow on 9/20/07



Wisconsin Geological and Natural History Survey

Well Owner: UW-Oshkosh

Well / Hole Name: Kewaunee Co/Strnad Farm

Well Address: Hemlock Road

City, State, Zip Code:

WGNHS Well ID:

WI Unique Well #:

Property Owner: Jim Strnad

Address:

line 2:

City

State: Zip Code:

WGNHS Well ID :

KW-183

WI Unique Well #

GPS Latitude:

GPS Longitude:

WTM83_N:

WTM83_E:

Elevation & Method:

Location:

SEC. SW1/2 sec 34 T. 25N R. 24E

PERMANENT DATUM: GROUND SURFACE

ELEVATION:

LOG MEAS. FROM Top of 6" casing ABOVE PERM. DATUM

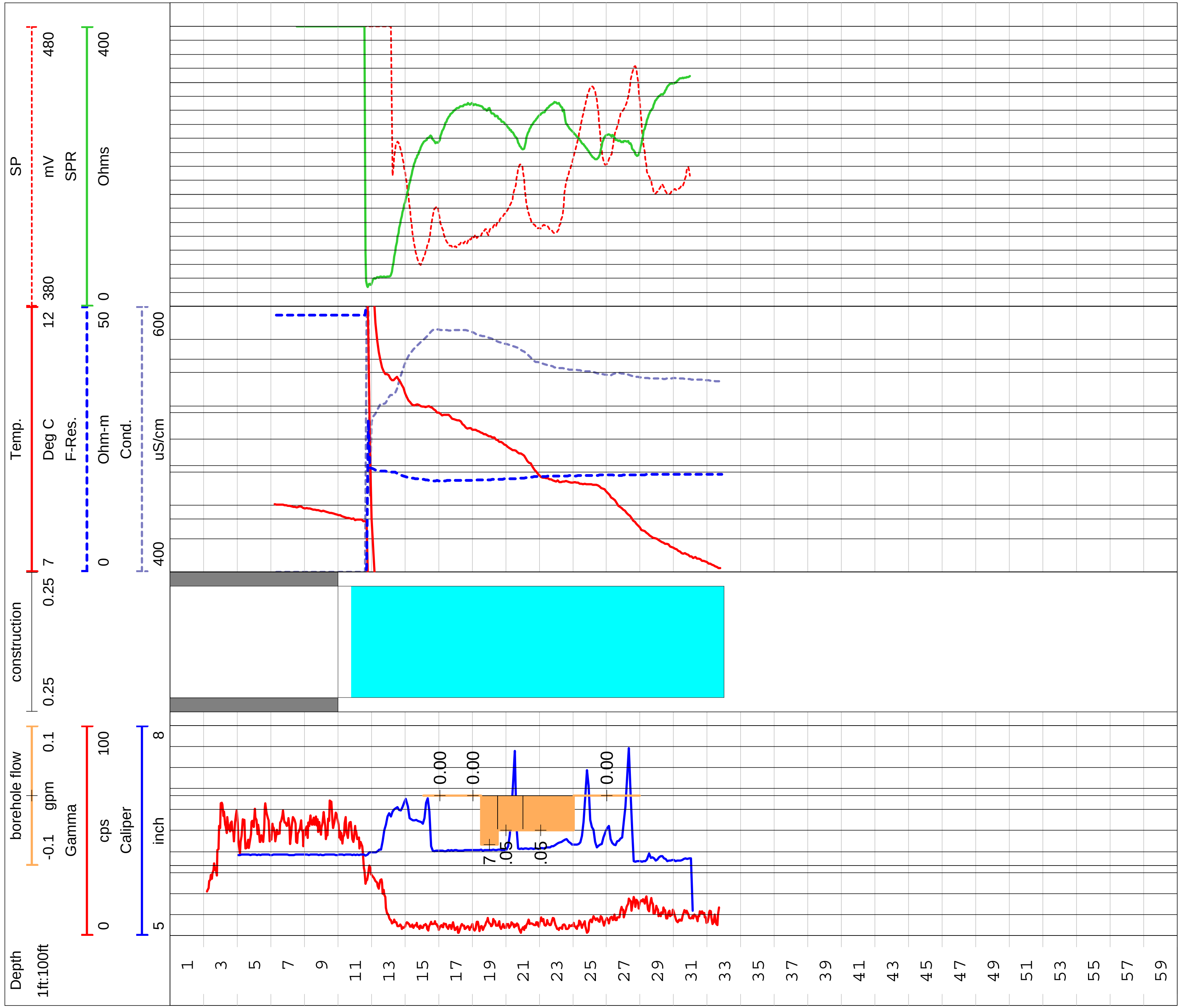
SU:

DRILLING MEAS. FROM

DTW:

Date:	9/21/07	Log 8 Performed on Borhole:	
Logged by:	Ken Bradbury	Log 9 Performed on Borhole:	
Witness:	Derrick Wagner	Log 10 Performed on Borhole:	
Log 1 Performed on Borhole:		DEPTH-DRILLER:	33 ft
Log 2 Performed on Borhole:		DEPTH-LOGGER:	33.04
Log 3 Performed on Borhole:		TYPE FLUID IN HOLE	water
Log 4 Performed on Borhole:		CASING	10 ft
Log 5 Performed on Borhole:		DENSITY	
Log 6 Performed on Borhole:		WATER LEVEL	11.76 ft
Log 7 Performed on Borhole:		MAX. REC. TEMP.	

Comment: This is a monitoring well installed for the NE Wisconsin monitoring project. There is significant downward flow in the borehole beginning about 19 ft. Well produces very well.



Wisconsin Geological and Natural History Survey

Well Owner: UW-Oshkosh

Well / Hole Name: Chilton Town Hall/Calumet County

Well Address:

City, State, Zip Code:

WGNHS Well ID:

WI Unique Well #:

Property Owner: Town of Chilton

Address:

line 2:

City Chilton

State: WI Zip Code:

WGNHS Well ID :

CA-1143

WI Unique Well #

GPS Latitude:

GPS Longitude:

WTM83_N:

WTM83_E:

Elevation & Method:

Location: at Chilton Town Hall

SEC. 3 T. 18N R. 20E

PERMANENT DATUM: GROUND SURFACE

ELEVATION:

LOG MEAS. FROM top of 6" casing ABOVE PERM. DATUM

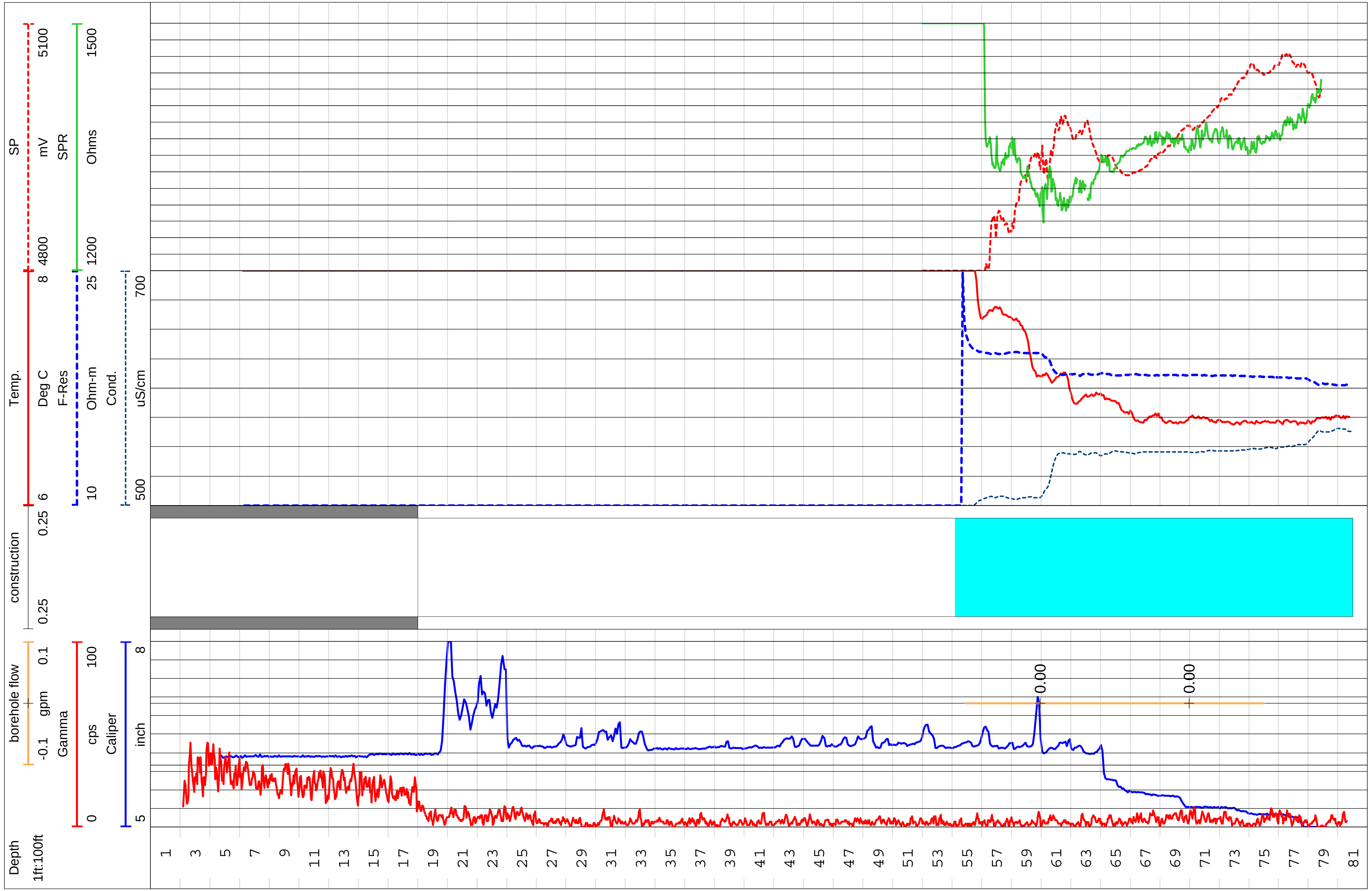
SU:

DRILLING MEAS. FROM

DTW:

Date:	9/21/07	Log 8 Performed on Borhole:	
Logged by:	Ken Bradbury	Log 9 Performed on Borhole:	
Witness:	Derrick Wagner	Log 10 Performed on Borhole:	
Log 1 Performed on Borhole:		DEPTH-DRILLER:	
Log 2 Performed on Borhole:		DEPTH-LOGGER:	81.04 ft
Log 3 Performed on Borhole:		TYPE FLUID IN HOLE	water
Log 4 Performed on Borhole:		CASING	18 ft
Log 5 Performed on Borhole:		DENSITY	
Log 6 Performed on Borhole:		WATER LEVEL	55 ft
Log 7 Performed on Borhole:		MAX. REC. TEMP.	

Comment: This is a monitoring well installed for the NE Wisconsin monitoring project.



Wisconsin Geological and Natural History Survey
Well Owner: UW-Oshkosh
Well / Hole Name: Manitowoc Co/Fritsch Farm
Well Address:
City, State, Zip Code:
WGNHS Well ID:
WI Unique Well #:

Property Owner: Bill Fritsch
Address:
line 2:
City
State: Zip Code:

WGNHS Well ID :

MN544

WI Unique Well #

GPS Latitude:
GPS Longitude:
WTM83_N:
WTM83_E:
Elevation & Method:
Location: Bill Fritsch farm
SEC. 4 T. 19N R. 22E

PERMANENT DATUM: GROUND SURFACE
LOG MEAS. FROM top of 6" casing ABOVE PERM. DATUM
DRILLING MEAS. FROM

ELEVATION:
SU:
DTW:

Date:	9/20/07	Log 8 Performed on Borhole:	
Logged by:	Ken Bradbury	Log 9 Performed on Borhole:	
Witness:	Andy Jansen	Log 10 Performed on Borhole:	
Log 1 Performed on Borhole:		DEPTH-DRILLER:	57.6 ft
Log 2 Performed on Borhole:		DEPTH-LOGGER:	56.6 ft
Log 3 Performed on Borhole:		TYPE FLUID IN HOLE	
Log 4 Performed on Borhole:		CASING	28.5 ft
Log 5 Performed on Borhole:		DENSITY	
Log 6 Performed on Borhole:		WATER LEVEL	32.8 ft
Log 7 Performed on Borhole:		MAX. REC. TEMP.	

Comment: Monitoring installed for NE Wisconsin monitoring project.
Static downflow between 39 and 45 feet.