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Hydrogeologic Properties of the Ordovician Sinnipee Group at Test Well BN-483, Better Brite Superfund Site, De Pere, Wisconsin

Water-Resources Investigations Report 99–4199

Prepared in cooperation with the
U.S. Environmental Protection Agency
Region 5

USGS

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By W.G. Batten, D.J. Yeskis, and C.P. Dunning

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Middleton, Wisconsin
1999

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Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
	Hydraulic Conductivity*	
foot per day (f/d)	0.3048	meter per day

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation.

°F = 1.8 (°C) + 32.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Other units of measurement used in this report are microsiemens per centimeter at 25°Celsius (µS/cm).

***Hydraulic conductivity:** The standard unit for hydraulic conductivity is cubic foot per day per square foot of aquifer cross-sectional area $(ft^3/d)/ft^2$. In this report, the mathematically reduced form, feet per day (f/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Oxidation-reduction potential (Eh) is given in millivolts (mv).

Other abbreviations:

g/cm^3 grams per cubic centimeter

gal/min gallons per minute

ρCi/L pico Curries per liter

The stratigraphic nomenclature used in this report is that of the Wisconsin Geological and Natural History Survey and does not necessarily follow usage of the U.S. Geological Survey.

Hydrogeologic Properties of the Ordovician Sinnipee Group at Test Well BN-483, Better Brite Superfund Site, De Pere, Wisconsin

By W.G. Batten[1], D.J. Yeskis[2], *and* C.P. Dunning[1]

Abstract

Test well BN-483, near the Better Brite Superfund Site, was drilled to a total depth of 169 feet below land surface. The Ordovician-age Sinnipee Group, which includes the Galena Dolomite, and the Decorah and Platteville Formations, was encountered from about 25 feet below land surface to a depth of about 160 feet. Analysis of core samples and single-well aquifer tests of the dolomites indicate low matrix porosity (1.8 to 7.7 percent) and low horizontal hydraulic conductivity (5.0 x 10^{-4} to 3.4 x 10^{-3} feet per day). Significant differences in hydraulic head between Sinnipee Group dolomites and the underlying Sandstone Aquifer (represented by the Glenwood Formation sandstones in test well BN-483) are the result of municipal pumping from the Sandstone Aquifer. The difference in hydraulic head, along with the low porosity and hydraulic conductivity of the Sinnipee Group dolomites, indicates limited hydraulic connection between the Sandstone Aquifer and the shallow aquifer within the glacial sediments.

Because of the low hydraulic conductivity of the dolomites, sufficient water for analysis was recovered from only the uppermost interval of test well BN-483 at a depth of 35–52 feet. No inorganic contaminants of environmental concern were detected. Toluene was the only VOC identified, at an estimated concentration of about 2 micrograms/liter.

INTRODUCTION

The Better Brite Plating facility is located in Brown County, Wisconsin, in the city of De Pere, a suburb of Green Bay (fig. 1). During its operation from the late 1960's until 1989, the facility consisted of a zinc-plating shop and a chrome-plating shop located several blocks apart. The shops were situated on parcels of land about 0.5 and 2.5 acres in size, respectively.

In 1990, following site investigations by the Wisconsin Department of Natural Resources (WDNR), the zinc and chrome shops were placed on the National Priority List of the U.S. Environmental Protection Agency (USEPA). The site was designated the Better Brite Plating Company Chrome and Zinc Shops Site (Better Brite Superfund Site). In July 1991, the WDNR contracted Simon Hydro-Search, Inc. to conduct a Remedial Investigation/Feasibility Study (RI/FS) at the site. Trace metals and organic compounds were detected in soil samples and shallow ground water at both shop sites, posing a potential threat to the deep aquifer system that supplies De Pere municipal wells. The RI/FS was followed by a Site Evaluation Report, which provided a comprehensive summary of data collection and analysis for the site, and presented a management strategy for remedial activities at the facility (Simon Hydro-Search, Inc., 1992).

In 1993, the USEPA and U.S. Geological Survey (USGS) began a study to summarize important hydrogeologic data for the Ordovician-age Galena Dolomite and Decorah and Platteville Formations (the Sinnipee Group in Wisconsin) where these dolomite units comprise the subcrop (upper-most bedrock) in Wisconsin and Illinois (Batten, and others, 1997; Brown, and others, 1997). As part of this study, a test well, BN-483, was drilled through the entire thickness of these units near the Better Brite Superfund Site. The location of the test well (fig. 1) was chosen to (1) provide detailed lithologic and hydraulic data on the Ordovician-age Galena, Decorah, and Platteville rock units in this area, (2) provide a monitoring well for background water-quality sampling near the Superfund Site, and (3) assess the potential for migration of contaminants vertically through the Sinnipee Group into the deep water-

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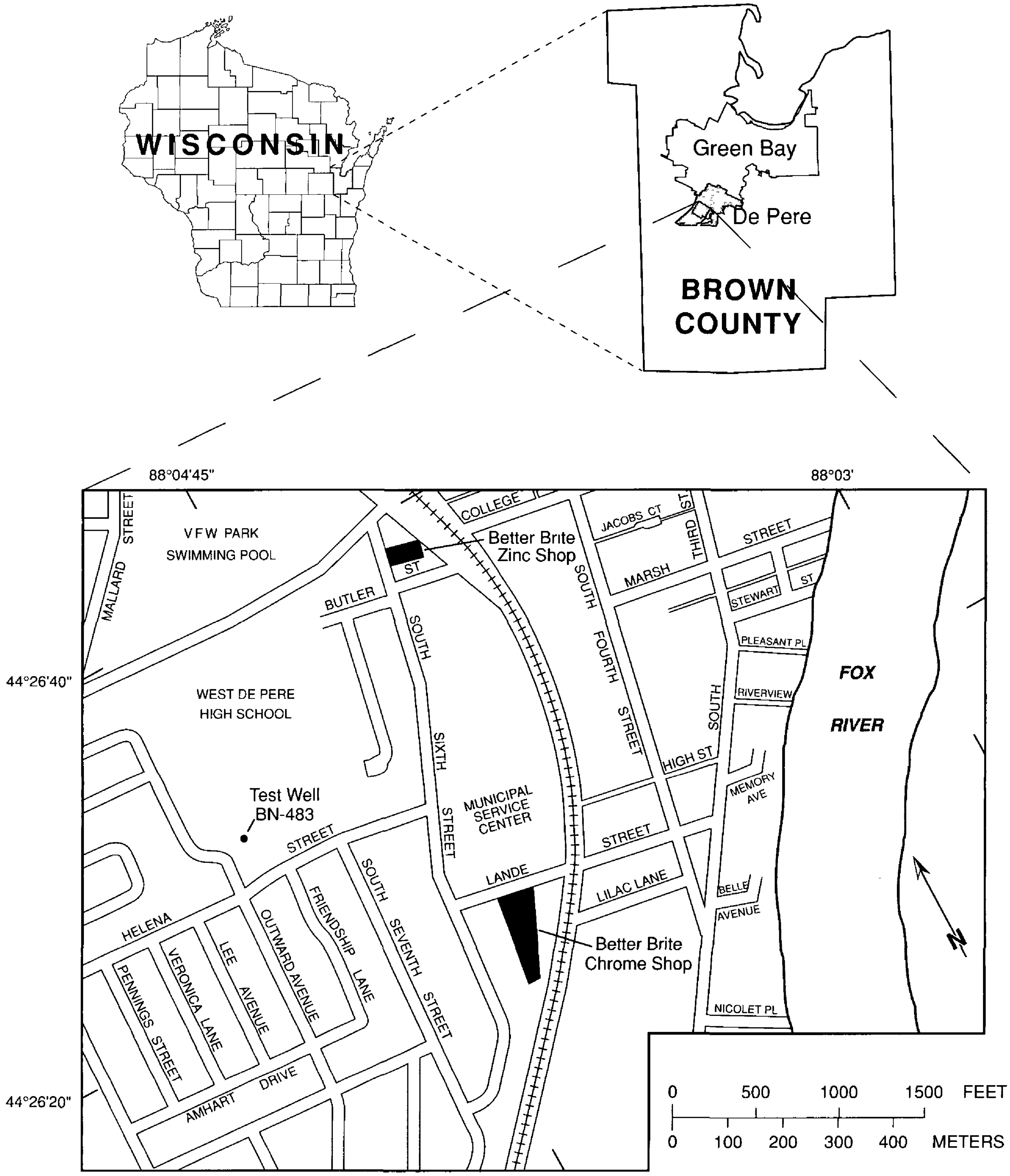

Base modified from Hydro-Search Inc, Milwaukee, WI, September, 1991

Figure 1. Maps showing location of study area, test well BN-483, and the zinc and chrome shops at the Better Brite Superfund Site, De Pere, Wisconsin.

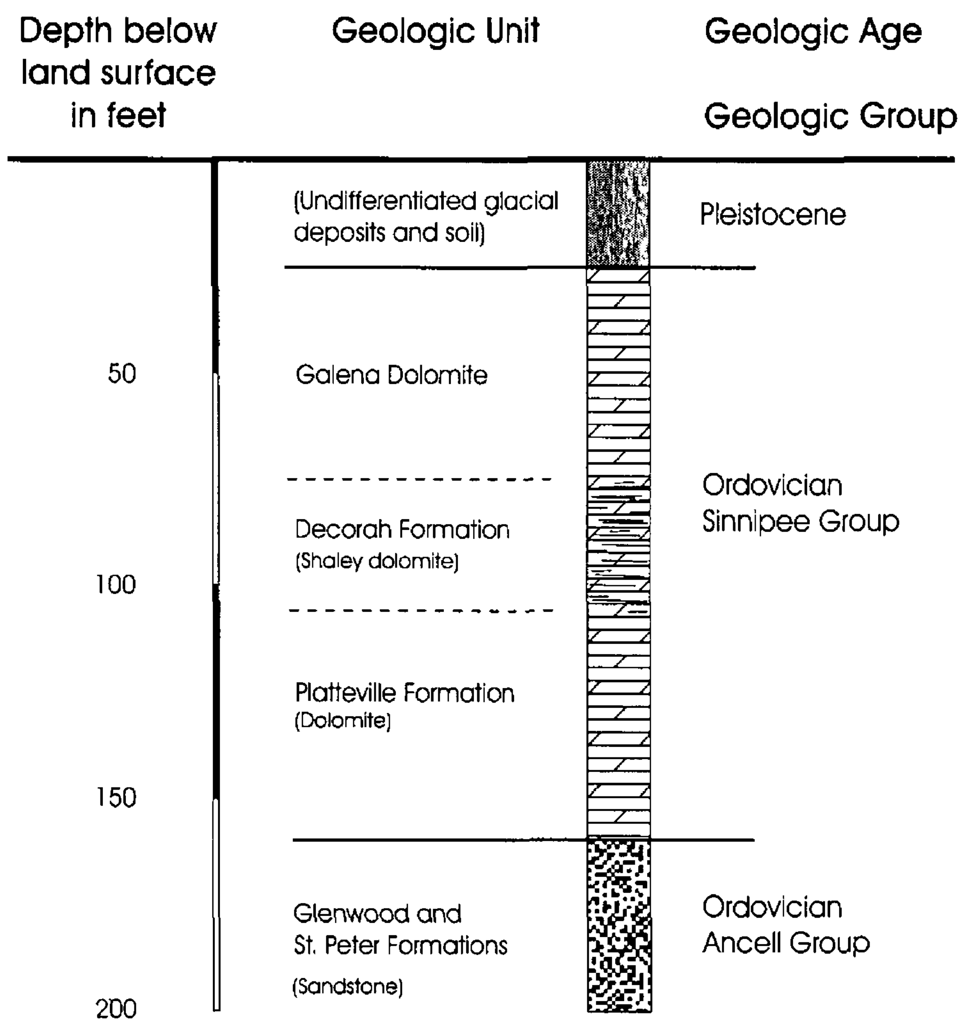

Figure 2. Diagram showing generalized stratigraphy in the study area.

supply aquifer. Information gained from this test well is expected to provide aquifer characteristics of the Sinnipee Group at this location, and help investigators predict the movement and fate of pollutants such as those introduced into the shallow ground-water system at the nearby Superfund site. The completed work at this site was consistent with the USGS and USEPA Sampling and Analysis Plan dated October 15, 1995 (U.S. Geological Survey and U.S. Environmental Protection Agency, 1995).

Purpose and Scope

This report describes the construction of test well BN-483, and the field methods used in collecting lithologic and hydraulic data from the well. Descriptions of continuous core and geophysical-log data, and the results of laboratory tests on selected core samples provide detailed physical information on the rock units of the Sinnipee Group. The vertical distribution of horizontal hydraulic conductivity of the rock units as determined from displacement/recovery (slug) tests over isolated depth intervals is discussed. The vertical distribution of hydraulic head in the open borehole as determined from static water levels measured over isolated depth intervals is discussed. Results of water analysis for common inorganic constituents, trace metals, and organic compounds are presented.

Physical Setting

Test well BN-483 is about 1,500 ft northwest of the chrome-plating shop and about 1,900 ft southwest of the zinc-plating shop at the Better Brite Superfund Site (fig. 1). Land surface at the test well site is about 601 ft above sea level. Land surface at the chrome-plating shop is about 610–615 ft above sea level and at the zinc-plating shop about 600–605 ft above sea level. The elevation of the Fox River, 1,500 to 2,000 ft east of the Better Brite shops (fig. 1), is about 590 ft above sea level. Surface sediments at the Better Brite Superfund Site typically are 25 to 30 ft thick, comprised of Pleistocene-age lacustrine clay and silt (Simon Hydro-Search, Inc., 1992). Surface sediments are directly underlain by the dolomite units of the Sinnipee Group, which total about 125 feet thick (fig. 2). The Sinnipee Group is directly underlain by Ordovician-age sandstones of the Ancell Group, including the Glenwood and St. Peter Formations. The Ancell Group sandstones are the uppermost units of a sequence of Cambrian- and Ordovician-age sandstones and dolomites with a combined thickness of about 600 to 700 ft in the De Pere area (Krohelski, 1986).

Hydrologic Setting

Twelve adjacent central Brown County municipalities, including the city of De Pere, pump municipal ground-water supplies from the Sandstone Aquifer (Krohelski, 1986; Walker and others, 1998). The Sandstone Aquifer consists of the Ordovician-age Ancell Group and underlying Cambrian- and Ordovician-age formations. Pumping from closely spaced municipal wells completed in the Sandstone Aquifer has resulted in a pronounced cone of depression in potentiometric head in central Brown County (Krohelski, 1986). This regional hydrologic feature influences local hydrology at the Better Brite Superfund Site in De Pere.

The unconsolidated glacial sediments and the underlying fractured Sinnipee Group bedrock constitute a shallow aquifer at the site. The shallow aquifer is about 44 ft thick at test well BN-483 and is underlain by unweathered bedrock, as indicated by the caliper log of the test well (fig. 3). The nature of the hydraulic connection between the shallow aquifer and the Sandstone Aquifer is important to understanding the local and regional groundwater-flow system and the potential threat to the Sandstone Aquifer from surface contamination.

Acknowledgments

The authors would like to acknowledge the assistance of a number of individuals in this study. The original borehole was drilled by the USGS Coal Branch drilling crew. Fred Paillet of the USGS National Research Center, and the USGS geophysical logging crew carried out the geophysical logging on site. James Rauman and Ty Sabin of the USGS Wisconsin District conducted the aquifer testing of test well BN-483, and carried out the final well construction. William Morrow of the USGS Illinois District assisted in water quality sampling. Technical review of the report was provided by James Krohelski and David Saad of the USGS Wisconsin District, and Patrick Mills of the USGS Illinois District. Editorial and graphics support was provided by Michelle Greenwood and Aaron Konkol of the USGS Wisconsin District. The authors would also like to thank Mr. Randy Freese, Superintendent, De Pere, Wisconsin, for permitting test well BN-483 to be located on the property of West De Pere High School.

TEST WELL CONSTRUCTION AND CORING

Test well BN-483 was constructed during October 13–19, 1993 by the USGS. Construction details are provided in figure 4. In summary, a nominal 10-in. diameter hole was drilled to a depth of about 35 ft below land surface using the air-rotary drilling method. Fractured dolomite bedrock with soft, clayey, fracture-fill was observed in drill cuttings below the surface sediments from about 24.5 ft to 35 ft. A 37.25-ft length of black-steel casing with a 6.06-in. inside diameter was set and cemented in place, the top of the casing extending about 2 ft above land surface. Continuous 3-in. bedrock core was cut from the bottom of the casing to a depth of 169 ft below land surface. A total of 126 ft of core was recovered from the 134-ft cored interval. Approximately 6 ft of core was not recovered from the fractured dolomite between 35 and 44 ft below land surface and 2 ft of soft sandstone was not recovered from the interval between 165 to 169 ft.

Once coring was completed, the hole was reamed to a nominal diameter of 6 in. Drill cuttings were removed by forcing compressed air down the drill stem for about 40 minutes, during which time water with cuttings flowed out of the top of the casing at an estimated 5 to 10 gal/min. Subsequently, a high capacity pump was used to purge and develop the borehole for several hours at a rate of about 17 gal/min.

HYDROGEOLOGIC-DATA COLLECTION

On November 9, 1993, a comprehensive suite of borehole geophysical logs was completed in test well BN-483 to determine the physical characteristics of the bedrock and to correlate with core samples. In addition, downhole-video-camera and acoustic-televiewer logs provided visual information regarding structural features such as fractures and bedding planes in the borehole wall. On the basis of lithologic descriptions of the core, 13 samples were taken and submitted to the USGS Illinois District for determination of porosity, bulk density, and grain density. The laboratory methods used in

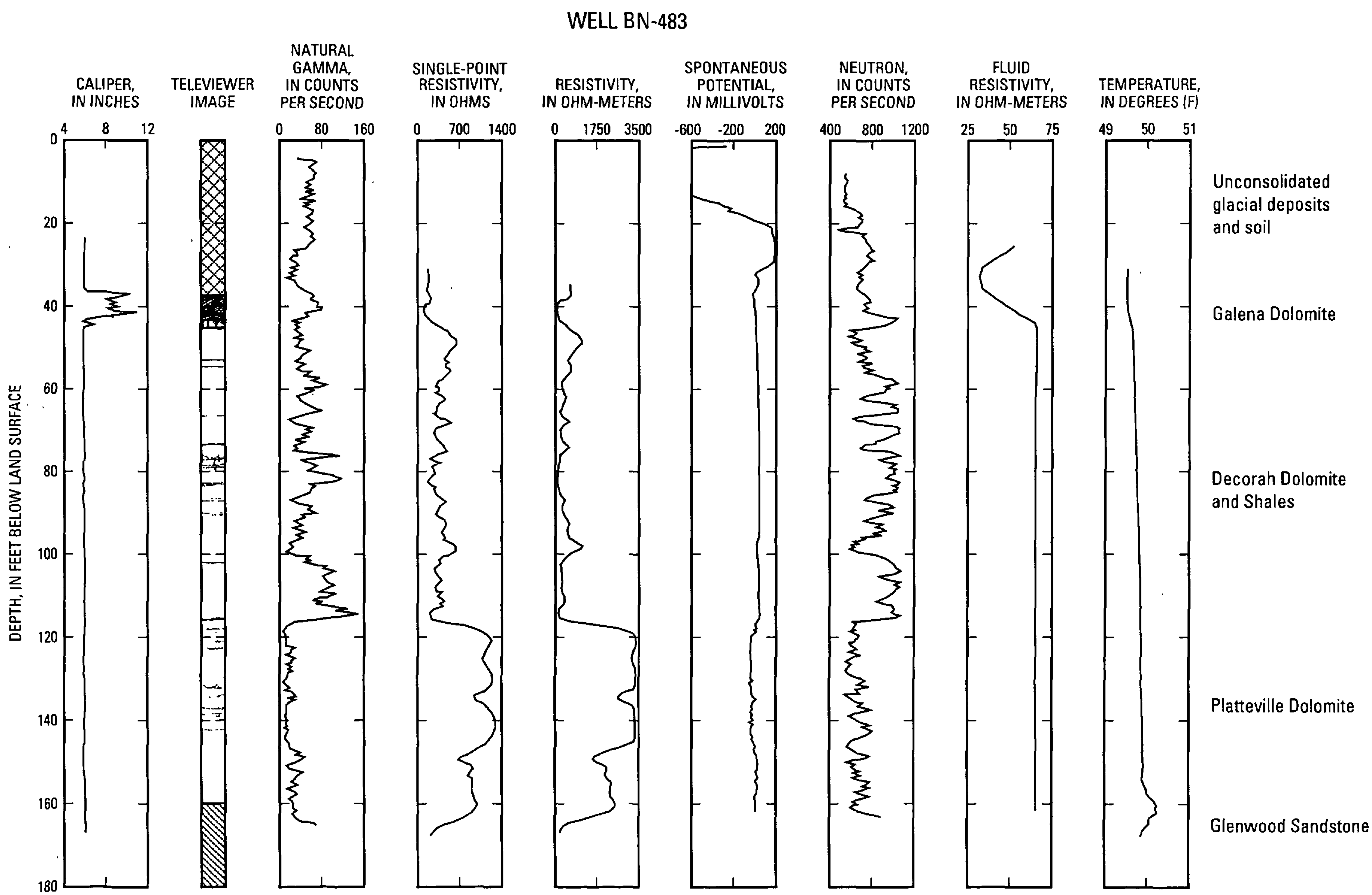

Figure 3. Geophysical logs of test well BN-483. (Data collected and log plots provided by Fred Paillet, U.S. Geological Survey, written commun., 1995. Stratigraphy follows Michael L. Sargent and Zakaria Lasemi, Illinois State Geological Survey, written commun., 1994.)

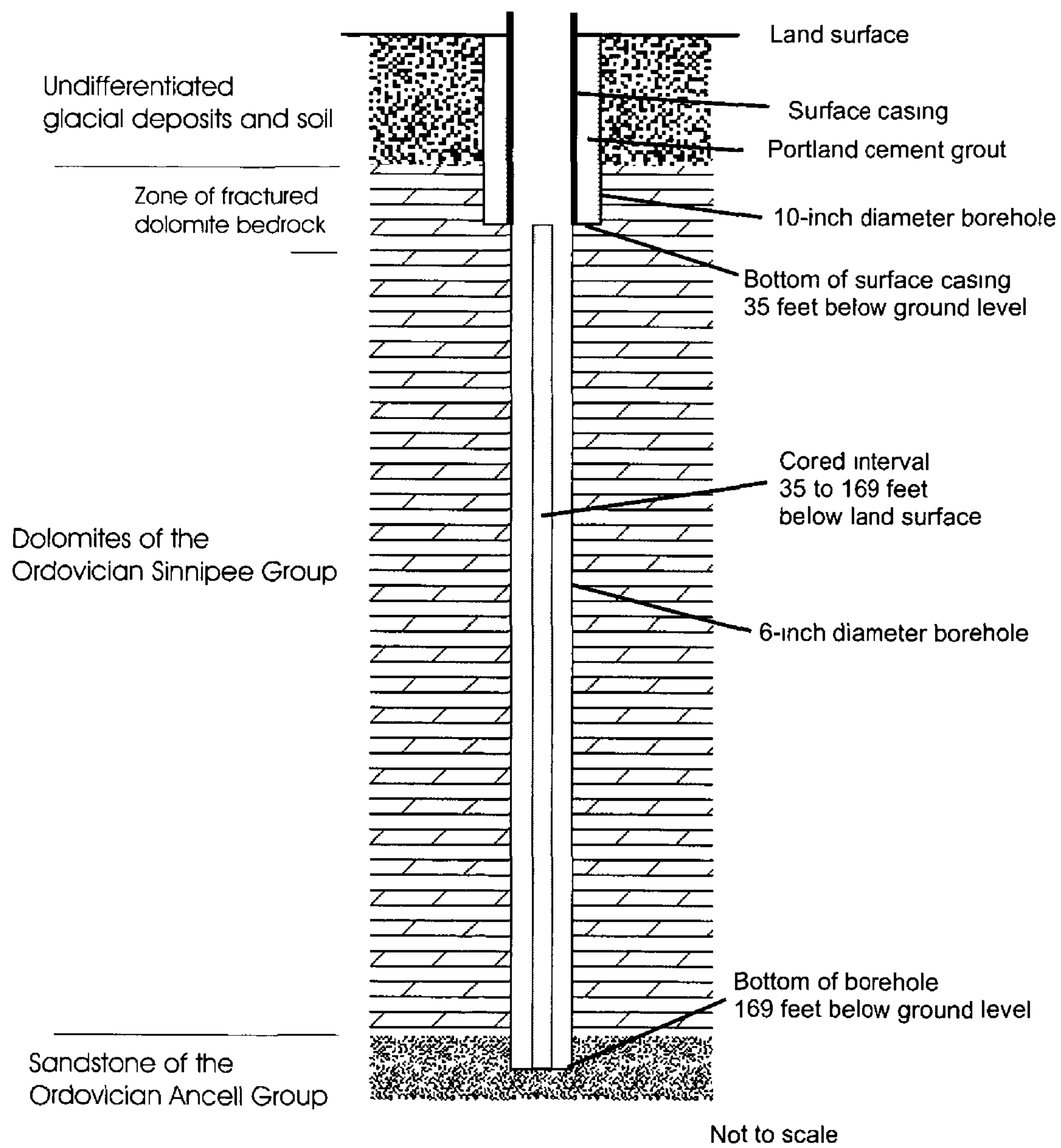

Figure 4. Construction of test well BN-483.

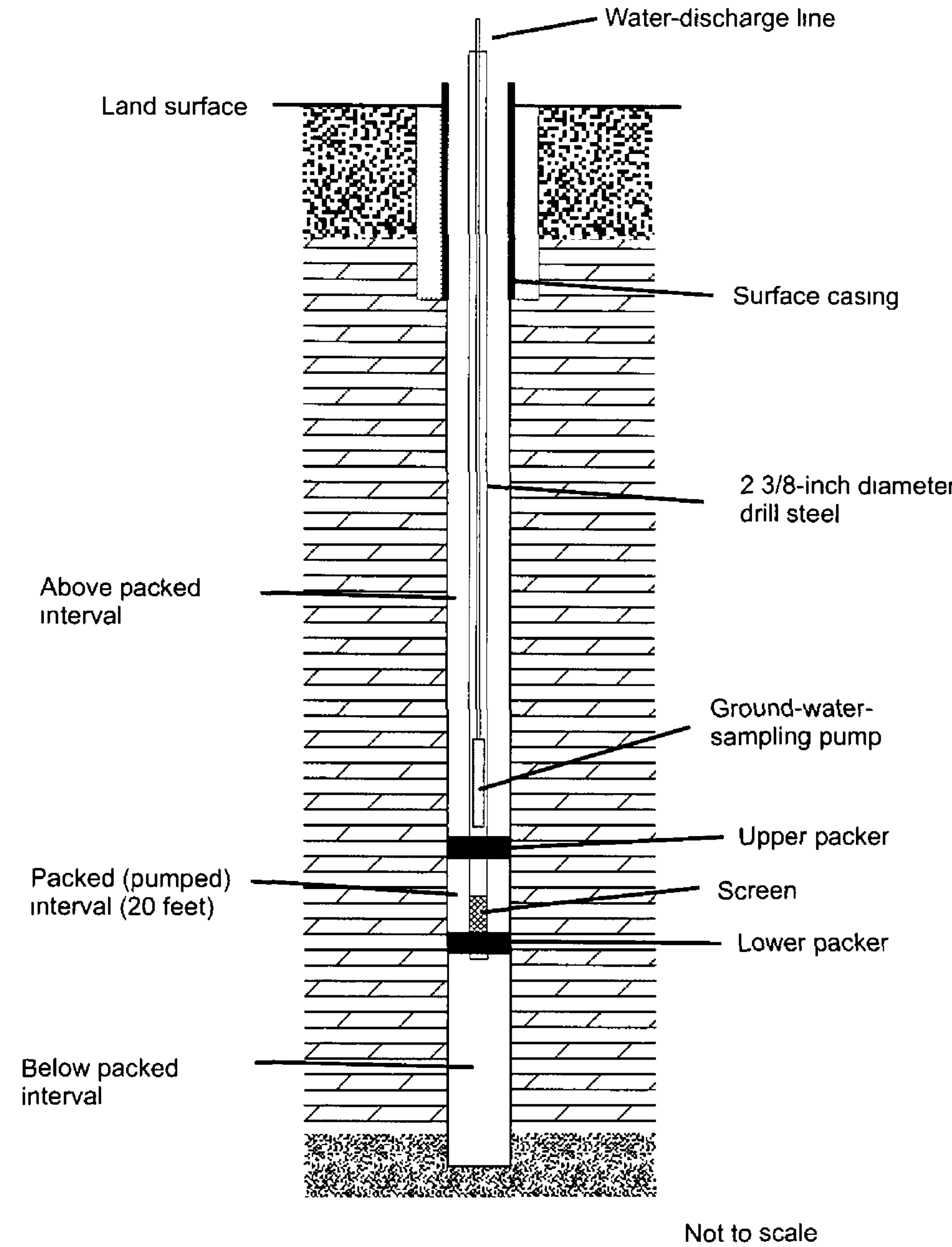

Figure 5. Generalized view of packer assembly and ground-water-sampling pump in test well BN-483.

this determination are described in Mills, and others (1998).

As originally planned, hydraulic tests were to be conducted and water samples were to be collected at 10-ft depth intervals in the borehole. However, the low matrix porosity of the dolomite and the apparent lack of secondary porosity in the form of fractures or partings along bedding planes indicated that the borehole would probably yield very little water. Therefore, it was decided to evaluate aquifer properties and to collect water samples over 20-ft intervals throughout the borehole. The 20-ft intervals of the open borehole were isolated by using a packer assembly shown schematically in figure 5. The assembly consists of two 4-ft-long inflatable neoprene packers separated by 20 ft of 2-in-diameter stainless-steel pipe, the bottom 10 ft of which is a wire-wound screen.

Water sampling and hydraulic testing of the aquifer were accomplished by lowering the packer assembly into the borehole on 2 3/8-in. diameter drill steel. The 20-ft interval between the packers was positioned at a predetermined depth in the borehole, and the two packers were inflated to create three test intervals including: (1) an interval between the two packers, (2) an interval above the top packer, and (3) an interval below the bottom packer (fig. 5). After both packers were properly inflated against the borehole wall, the hydraulic head in each of the three intervals was allowed to equilibrate to static, or near-static conditions. The water level in each test interval was measured manually with an electric tape. The variation of static water level in packed intervals at different borehole depths are a measure of the vertical hydraulic gradient in the aquifer.

The horizontal hydraulic conductivity of the rock unit open to the packed interval was evaluated by a displacement/recovery aquifer test. Displacement/recovery aquifer tests, also known as slug tests, are performed by creating an instantaneous rise or drop in water level (hydraulic head) in the packed interval of the borehole. This is accomplished by quickly dropping a weighted cylinder of sufficient volume (the slug) below the water surface, or by quickly removing the slug from below the water surface, to cause a measurable (2 ft or more) change in the water level in the packed interval. A pressure transducer connected to a datalogger is used to record the initial rise or fall in water level and its subsequent return to equilibrium. The horizontal hydraulic conductivity of the rock unit open to the packed interval is related directly to the rate at which the water level returns to its static level, and is estimated by applying an analytical method developed by Bouwer and Rice (1976).

To collect water samples, a low-flow, positive-displacement pump was lowered inside the drill steel to just above the top packer (fig. 5). Water was pumped from the packed interval (at a rate of 1 gal/min or less) to purge the equivalent of at least three packed-interval borehole volumes prior to sample collection. The pump was located above the screened interval so that the packed interval was not de-watered. Field characteristics of water quality, including temperature, pH, dissolved oxygen, specific conductance, and oxidation-reduction potential, were monitored during purging. Stabilization of these field characteristics ensured that a representative water sample was collected from the aquifer. Following purging, samples were collected using methods outlined in the Sampling and Analysis Plan (U.S. Geological Survey and U.S. Environmental Protection Agency, 1995). Collected samples were submitted to a USEPA Contract Laboratory Program (CLP) laboratory for analysis of selected volatile organic compounds (VOC's) and trace metals. Additional samples were submitted to the USGS National Water Quality Laboratory (NWQL) for analysis of common inorganic constituents and tritium.

Following hydrogeologic-data collection, test well BN-483 was converted to a monitoring well through the installation of a nested pair of wells with screens set in the bedrock at 69.5–79.5 and 109.0–119.0 ft below land surface. The well construction record for monitoring well BN-483 is contained in the appendix. An additional monitoring well was constructed nearby with a screen set in the glacial sediments at 17.5–22.5 ft below land surface. The well construction record for this monitoring well is also contained in the appendix.

HYDROGEOLOGIC-DATA ANALYSIS

Lithologic characteristics of the unconsolidated glacial sediments, the Galena Dolomite, and the Decorah and Platteville Formations were determined from detailed descriptions of drill cuttings and the core, and evaluation of geophysical logs. Bulk physical properties of the rock units were determined from porosity and density analyses of selected core samples. Hydraulic properties of these rock units generally were estimated on the basis of geophysical logs, physical analyses, and from the slug tests made at discrete intervals of the open borehole. Background concentrations of trace metals,

Table 1. Lithologic description and stratigraphic interpretation by Illinois State Geological Survey of core and drill cuttings from test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

[Modified from Michael L. Sargent and Zakaria Lasemi, written commun., 1994, Illinois State Geological Survey. Full description available upon request from U S. Geological Survey.]

Depth below land surface (feet)	Lithologic description of core and drill cuttings
0–24.5	Undifferentiated glacial deposits and soil, mostly red-brown sandy clay with trace of gravel.
24.5–41.5	Galena Dolomite; gray, very weathered, fractured (24.5–35.0 based on drill cuttings, 35.0–41.5 no return in core barrel)
41.5–55.8	Galena Dolomite; light olive gray to light brownish gray to pale yellow brown, occasional argillaceous shale or calcarenite interbeds, slightly fossiliferous becoming more fossiliferous in lower 7 feet, fossils include echinoderm and trilobite fragments and possibly bryozoans and brachiopods, predominant shale zone from 51.2 to 51.4 feet, quite fractured from 41.8 to 43.5 feet.
55.8–112.8	Decorah Formation; Interbedded dolomite and shale; section can be broken up into seven (possibly eight) cycles in which basal rock is pure dolomite that becomes progressively more argillaceous upward. Each cycle terminates at a hardground. Cycle thicknesses range from about 3 to 24 feet. Dolomites are mostly pinkish gray or very light brownish to medium dark gray and are finely crystalline. Some paper-thin shaley partings are present in the purer dolomite zones. A few small pin-head to about 0.5-inch size vugs are present throughout. Shale rocks are mostly dark grayish olive green. Entire formation is slightly fossiliferous but generally more fossiliferous in shaley zones. Bryozoans are most common recognizable fossil, but some zones contain abundant trilobite and brachiopod debris. Hardground surfaces are dark gray to dusky brown and are pyritic. Some of this dark colorization is probably phosphatization.
112.8–142.5	Platteville Formation (upper unit); very dense, fine-grained, mottled pinkish-gray to light gray; occasional paper-thin wavy dark shaley partings and olive-gray argillaceous streaks. slightly cherty (< 1 percent) with several 0.5 to1.5-inch thick chert beds and occasional scattered chert nodules, occasional small vugs throughout this zone; sublithographic calcarenitic beds (somewhat fossiliferous) from 116 8 to 118.9 feet. Upper unit includes rocks of the Quimbys Mill, Nachusa, and Grand Detour Formations in Illinois, but cannot be readily subdivided here using either Illinois or Wisconsin nomenclature.
142.5–159.8	Platteville Formation (lower unit); very fine-grained to lithographic; light brownish-gray matrix speckled with medium-gray to dark olive-gray, paper-thin wavy shale partings. This lower unit shows six sedimentation cycles ranging from about 2 to 5 feet thick; each cycle has a burrowed pure dolomite at it's base and becomes more argillaceous dolomite with wavy shale and argillaceous beds up to about 1-inch thick toward the top; very few pin-head to 0.5 inch vugs throughout this lower unit.The lower unit resembles only the Pecatonica Formation of Illinois and southern Wisconsin and cannot be subdivided. The contact with the underlying Glenwood Formation is sharp and at a hardground
159.8–166.8	Ancell Group - Glenwood Formation; quartz sandstone; pale-brown, medium-grained, dolomite cemented; 0.1-inch thick hematite accumulation at 159.9 to 160.0 feet; pale-red to grayish-red sandstone at 160.0 to 161.8 feet.; mostly medium-dark gray to very light gray medium-grained sandstone from 161 8 to 166.8 feet; poorly-cemented to friable below 162.6 feet

organic compounds, and common ions in ground water were determined from analysis of water samples.

Core and Geophysical Logs

A lithologic description and stratigraphic interpretation of the continuous rock core from test well BN-483 has been completed by Michael Sargent and Zakaria Lasemi of the Illinois State Geological Survey (ISGS) (written commun., 1994). The ISGS, which has described and interpreted all the cores that are a part of the larger USEPA study of the Sinnepee Group, found the units encountered in test well BN-483 to be very difficult to correlate with those of southern Wisconsin and Illinois. On the basis of their lithological description, ISGS identifies the Galena Dolomite as being present from 24.5 to 55.8 ft below land surface, the Decorah Formation unit present between 55.8 and 112.8 ft below land surface, and the Platteville Formation present between 112.8 and 159.8 ft below land surface. Sandstone of the Glenwood Formation is present below the Platteville Formation to the bottom of the test well—about 169 ft below land surface. [Choi (1988) completed a study correlating approximately 60 rock cores and outcrops in east central and southern Wisconsin (including core from BN-483). As a result of this work Choi interprets the Galena Dolomite in BN-483 to be in direct contact with the underlying Platteville Dolomite at a depth of 112.8 ft below land surface. The Decorah Dolomite is interpreted by Choi as being absent in test well BN-483.]

A summary of the lithologic description and stratigraphic interpretation of the core done by ISGS is provided in table 1. In general, the entire thickness (about 125 ft) of the unweathered Galena Dolomite, and Decorah, and Platteville Formations is very dense, pink to gray dolomite with occasional thin shaley beds and partings. Based on these descriptions and an evaluation of the geophysical logs, representative 0.3-ft sections of

Table 2. Physical properties of selected core samples from test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

[nd, no data available because of the condition of the core sample or errors in measurement]

Stratigraphic Interval	Core interval (feet below land surface)	Porosity (percent)	Bulk density (grams per cubic centimeter)	Grain density (grams per cubic centimeter)
Galena Dolomite	43.72–44.07	2.5	2 75	2.82
	53.75–54.15	1.8	2 78	2 83
Decorah Formation	77.97–78.29	6.2	2.64	2.81
	98.97– 99.29	nd	2.75	nd
	109.08–109.38	7.4	2.57	2.77
Platteville Formation	117.29–117.54	2.9	2.79	2 87
	129.42–129.67	2.7	2.73	2.80
	138.42–138.72	7.7	2.58	2.80
	144.73–145.08	2.2	2.76	2.83
	153.92–154.25	5.0	2.64	2.77
Glenwood Formation	161.70–162.00	4.2	2.56	2.67
	166.17–166.39	19.8	2.14	2.67

the rock core were analyzed for porosity and density. Two core samples of the Galena Dolomite, three samples of the Decorah Formation, and five samples of the Platteville Formation were analyzed. Two samples of the underlying Glenwood Formation (sandstone) also were analyzed for comparison. The results of these analyses are presented in table 2.

The highest measured porosity is 19.8 percent in the Glenwood Formation. Among the Sinnipee Group samples, porosity values ranged from 1.8 percent near the base of the Galena Dolomite samples to 7.7 percent in a sample from the Platteville Formation. Based on this limited number of samples it appears the Decorah Formation has a higher porosity than either the Galena Dolomite or the Platteville Formation. The mean porosity of two Decorah samples is about 6.8 percent compared to a mean of 3.5 percent for seven Galena and Platteville samples. The relatively high porosity of the Decorah Formation is apparent on the neutron log (fig. 3). The relatively low porosity of the Galena Dolomite and Platteville Formation likely is explained by the overall massive, crystalline nature of the dolomites in these units.

There appears to be no significant difference in either the bulk or grain densities in samples of the three Sinnipee Group units. Grain density ranges from 2.67 to 2.87 g/cm^3 (table 2), the higher of which are typical values for pure dolomite (Hurlbut and Klein, 1977, p. 308).

Lithologic core descriptions correlate well with the geophysical logs, particularly when comparing the shale or clay (argillaceous) content of the formations (table 1) to the natural-gamma log (fig. 3). Because of the relatively massive and uniform nature of the dolomite encountered in the test hole, the geophysical logs were of limited use in identifying small-scale lithologic changes or areas of ground-water inflow/outflow to the borehole. A major feature in the borehole is the washout zone from the bottom of the casing at 35 ft below land surface to a depth of 44 ft. This zone is identifiable on the caliper and acoustic-televiewer logs (fig. 3), indicating that the dolomite is very weathered and fractured in this zone. The acoustic-televiewer log also shows occasional thin horizontal features from about 50 to 142 ft of depth. Review of the log and inspection of the core show that these are not horizontal fractures, but thin (less than one inch) partings of soft shale or clay that separate massive dolomite units above and below.

A sharp contrast occurs at a depth of about 116 ft on the natural-gamma, single-point resistance, resistivity and neutron logs (fig. 3). The contrast represents the lithologic contact between the Decorah Formation and the underlying Platteville Formation and correlates well (within about 2 ft) with the stratigraphic description of the core (table 1). The sharp decrease in natural gamma activity on the natural-gamma log represents the less argillaceous nature of the Platteville Formation compared to the Decorah Formation and the Galena Dolomite. The increase in resistivity and decrease in spontaneous potential readings also are indicative of a major lithologic change at this depth. The neutron log indicates lower and less variable porosity and lower moisture content in the Platteville Formation than the in overlying Decorah Formation.

Table 3. Measured static water levels (hydraulic heads) in test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

Packed interval	Packed interval (feet below land surface)	Stratigraphic unit	Date of test (month-day-year)	Static water level (feet above sea level)
A	[1]35–52	Galena Dolomite	11-18-93	585.28
B	50–70	Galena Dolomite and Decorah Formation	11-17-93	583.56
C	66–86	Decorah Formation	11-23-93	583.68
D	72–92	Decorah Formation	11-18-93	[2]587.03
E	86–106	Decorah Formation	11-23-93	586.67
F	112–132	Platteville Formation	11-19-93	[2]586.56
G	131–151	Platteville Formation	11-22-93	[2]501.19
H	[3]160–169	Glenwood Formation	11-17-93	[2]452.02

[1]Packed interval is less than 20 feet, extending from the bottom of the casing to 52 feet.
[2]Water level had not reached equilibrium and reported level is probably higher than actual level.
[3]Packed interval is less than 20 feet, extending from 160 feet to total depth of the test well.

Table 4. Vertical hydraulic gradients in test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

Packed intervals compared	Stratigraphic intervals compared	Gradient[1] (feet per foot)
A–F	Galena Dolomite to Platteville Formation	0.02
A–G	Galena Dolomite to Platteville Formation	.86
A–H	Galena Dolomite to Glenwood Formation	-1.10
F–G	Platteville Formation to Platteville Formation	-4.49
F–H	Platteville Formation to Glenwood Formation	-3.17
G–H	Platteville Formation to Glenwood Formation	-2.09

[1]Downward gradient is denoted by "-"

Fluid resistivity and temperature measurements from geophysical logs (fig. 3) suggest that ground water is entering the borehole from an interval just below the bottom of the casing to about 46 ft (the wash-out zone described above). Also, these fluid column logs are fully consistent with weak downflow in the borehole below 46 ft and water exiting the borehole below 150 ft (Paillet, written commun, 1999).

Slug Tests

Slug tests were conducted at eight different vertical positions within the borehole, generally in 20-ft long packed intervals. Static water level was measured in each of the intervals (table 3). The static water level measured in the fractured zone from the bottom of the casing to a depth of about 52 ft below land surface (packed interval A) was about 585.3 ft above sea level. The static water level measured in the interval from about 160 ft to the bottom of the borehole (packed interval H) was 452.0 ft above sea level or possibly lower. Interval H tested the upper sandstone unit of the Ancell Group. The significantly lower static water level in the Ancell Group sandstones relative to the Sinnipee Group dolomites is the result of municipal pumpage from the Sandstone Aquifer (Krohelski, 1986). Comparison of static water levels in packed intervals A and H translates into a total head loss of more than 130 ft across the Sinnipee Group at this site. Vertical gradients were calculated between packed intervals, and are consistently downward with the greatest measured gradient between the depth intervals of 112–132 ft (packed interval F) and 131–151 ft (packed interval G) (table 4).

Four of the eight intervals isolated in test well BN-483 were successfully slug tested, and the

Table 5. Horizontal hydraulic conductivity of selected depth intervals in test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin, estimated from displacement/recovery (slug) tests

Test interval (feet below land surface)	Horizontal hydraulic conductivity (feet per day)	Comments
35–52[1]	0.2	Fractured and weathered dolomite from 35 to 44 feet. Hydraulic conductivity of this zone probably considerably higher than 0.2 feet per day.
50–70	--	No measurable response to slug injection. Water level recovered only 0.19 ft over a period of about 14 hours after pumping this borehole interval dry.
66–86	5.0×10^{-4}	Low quality data in first 20 seconds of slug test.
72–92	--	No slug test. Water level recovered about 3 feet over a period of about 14 hours after pumping this borehole interval dry.
86–106	3.4×10^{-3}	Low quality data in first 30 seconds of slug test.
112–132	--	No slug test. Water level showed no measurable recovery for about 40 minutes after pumping this borehole interval dry.
131–151	1.9×10^{-3}	Low quality data in first 30 seconds of slug test. Actual hydraulic conductivity value may be lower because static water level in tested interval was still dropping prior to the slug test.
160–169[2]	--	No slug test. Water level showed no measurable recovery over a period of several hours after pumping this borehole interval dry.

[1]Packed interval is less than 20 feet, extending from the bottom of the casing to 52 feet.
[2] Packed interval is less than 20 feet, extending from 160 feet to total depth of the test well.

horizontal hydraulic conductivity estimates from these tests are given in table 5. The values determined for the three intervals of the unweathered dolomite are quite low, ranging from about 5.0×10^{-4} to 3.4×10^{-3} ft/d. These values are indicative of confining units rather than aquifers (Freeze and Cherry, 1979, p. 29). The horizontal hydraulic conductivity of the other four unweathered intervals given in table 5 are believed to be lower than these three values, because water-level recoveries in the intervals were too slow to measure. The presence of shaley zones and partings in the core suggests that the vertical hydraulic conductivity of the unweathered dolomite is probably less than the horizontal hydraulic conductivity.

The estimated horizontal hydraulic conductivity of the interval that includes the weathered dolomite just below the bottom of the casing is about 0.2 ft/d (table 5). Because less than half of the 20-ft test interval is the weathered section, its conductivity is probably significantly greater than the 0.2 ft/d estimated for the entire interval.

Water Quality

Water samples were collected only from the uppermost packed test interval (interval A) in the bedrock, 35–52 ft below land surface (table 3). Adequate volumes of water could not be purged from other test intervals. One sample from interval A was analyzed by the USGS National Laboratory for major cations and anions, and tritium. These analytical results are presented in table 6 along with measured values for field parameters. Other samples from interval A were analyzed by the USEPA Contract Laboratory Program (CLP) for Routine Analytical Services (RAS), Volatile Organic Compounds (VOC's) and RAS Inorganics. The results of these analyses are presented in tables 7 and 8. The CLP samples included a sample, duplicate sample, and pump blank. A shipping blank was included for the VOC samples only.

The sampled water was slightly alkaline with a pH of 7.9. Low concentrations of dissolved oxygen (1 milligrams per liter) and low redox potential (-114 millivolts) indicate reducing conditions. The specific conductance of the water was 348 microsiemens per centimeter (at 25°C). Toluene was detected at an estimated concentration of 2 and 1 micrograms per liter (µg/L), respectively, in the sample and duplicate. All other VOC's were reported as non-detected at the 10 µg/L detection limit (table 7). Detected inorganic constituents were limited to major cations and aluminum (table 8). No other inorganic constituents were detected. Tritium was detected at 2.1 pico Curries per liter. Based on a trilinear classification diagram for anion and cation facies presented in Freeze and Cherry (1979, p. 250) the water is classified as a sodium-bicarbonate type.

Table 6. Field parameters, major ions and tritium analytical data results for test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

Field parameters, major ions and tritium	Sample (35–52 ft below land surface)
Field parameters	
pH	7.9
Dissolved oxygen	1.0 mg/L
redox potential	-114 millivolts
Temperature	9.5 degrees Centigrade
Specific conductance	348 microsiemens per centimeter (at 25°C)
Cations	
Calcium	19.0 mg/L
Magnesium	13.0 mg/L
Sodium	42.0 mg/L
Potassium	2.0 mg/L
Iron	32.0 mg/L
Manganese	3.0 mg/L
Anions	
Chloride	4.8 mg/L
Sulfate	31.0 mg/L
Fluoride	0.4 mg/L
Alkalinity	160.0 mg/L
Tritium	2.080 ρCi/L

SUMMARY AND CONCLUSIONS

As part of a regional investigation of the Galena Dolomite, and the Decorah and Platteville Formations in Wisconsin and Illinois, a test well (BN-483) was drilled and cored to evaluate the hydrogeology of these formations in the De Pere, Wisconsin area. Data collected from this well also were used in evaluating the hydrology and water quality near the Better Brite Superfund Site.

Rock core was cut from 35 ft below land surface to total well depth of 169 ft. Geophysical logs and visual description of recovered core identify Ordovician-age Sinnipee Group dolomites from about 25 ft below land surface to a depth of about 160 ft. The Glenwood Formation sandstone of the Ordovician-age Ancell Group was identified from a depth of approximately 160 to 169 ft. Analysis of selected intervals of recovered core reveals that porosity of the Sinnipee Group dolomites ranges from about 2 to 8 percent, and the Glenwood Formation sandstone porosity ranges from about 4 to 20 percent. Slug tests indicate that the unweathered dolomites have very low horizontal-hydraulic conductivity as well, ranging from about 5.0 x 10^{-4} to 3.4 x 10^{-3} ft/d.

Static-water levels measured within packed intervals show a considerably lower hydraulic head in the Glenwood Formation sandstone than the overlying dolomite. The difference in hydraulic head is evidence of the cone of depression resulting from municipal pumpage from the Sandstone Aquifer (of which the Glenwood Formation is a part). This suggests that the unweathered thickness (about 125 ft at test well BN-483) of the Sinnipee Group has very low vertical-hydraulic conductivity, and provides a low degree of interconnection between the shallow aquifer (glacial sediments and fractured bedrock) and the deeper Sandstone Aquifer. Vertical flow that may be present, is likely limited to direct interconnections provided by discrete vertical fractures.

Water samples were collected only in the uppermost packed interval at a depth of 35 to 52 ft. No inorganic contaminants of environmental concern were

Table 7. Organic analytical data results for test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin
[All results in µg/L; U, not detected above contract required detection limit; J, detected]

Compound	Sample (35-52 ft below land surface)	Duplicate sample (35-52 ft below land surface)
Chloromethane	10 U	10 U
Bromomethane	10 U	10 U
Vinyl Chloride	10 U	10 U
Chloroethane	10 U	10 U
Methylene Chloride	10 U	10 U
Acetone	10 U	10 U
Carbon Disulfide	10 U	10 U
1, 1-Dichloroethane	10 U	10 U
1, 1-Dichloroethane	10 U	10 U
1, 2-Dichloroethane (total)	10 U	10 U
Chloroform	10 U	10 U
1, 2-Dichloroethane	10 U	10 U
2-Butane	10 U	10 U
1, 1, 1,-Trichloroethane	10 U	10 U
Carbon Tetrachloride	10 U	10 U
Bromodichloromethane	10 U	10 U
1, 2-Dichloropropane	10 U	10 U
cis-1,3-Dichloropropane	10 U	10 U
Trichloroethane	10 U	10 U
Dibromochloromethane	10 U	10 U
Benzene	10 U	10 U
trans-1, 3-Dichloropropane	10 U	10 U
Bromoform	10 U	10 U
4-Methyl-2-Pentane	10 U	10 U
2-Hexanone	10 U	10 U
Tetrachloroethane	10 U	10 U
Toluene	2 J	1 J
Chlorobenzene	10 U	10 U
Ethylbenzene	10 U	10 U
Styrene	10 U	10 U
Xylene	10 U	10 U

Table 8. Inorganic analytical data results for test well BN-483 near the Better Brite Superfund Site, De Pere, Wisconsin

[All results in µg/L; U, not detected above contract required detection limit, B, detected in laboratory blank]

Constituent	Sample (35–52 ft below land surface)	Duplicate sample (35-52 ft below land surface)
Aluminum	533	599
Antimony	26.0 U	26.0 U
Arsenic	1.1 B	1.4 B
Barium	22.0 B	22.3 B
Beryllium	1.0 U	1.0 U
Cadmium	2.0 U	2.0 U
Calcium	21100	21100
Chromium	3.0 B	3.1 B
Cobalt	4.0 U	4.0 U
Copper	5.1 B	4.2 B
Iron	923	1020
Lead	2.1 B	2.2 B
Magnesium	14400	14200
Manganese	15.3	16.8
Mercury	0.20 U	0.20 U
Nickel	14.0 U	14.0 U
Potassium	2740 B	2720 B
Selenium	1.0 B	1.0 U
Silver	2.0 U	2.0 U
Sodium	42000	40900
Thallium	1.6 B	1.6 B
Vanadium	5.0 U	5.0 U
Zinc	9.1 B	7.6 B
Cyanide	10.0 U	10.0 U

detected. Toluene was the only volatile organic compound detected, and was found in estimated concentrations of 1 and 2 µg/L in duplicate samples.

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APPENDIX

WELL CONSTRUCTION RECORD

SITE: Better Brite Superfund at De Pere WI County: Brown Well #: Bn-23/20E/28-0483 Double Nested

Site Name: West De Pere High School Grid Coordinates: Northing 442630 Easting 0880452

Drilling Contractor: USGS Coal Branch Division Date Drilling Started. Oct. 15, 1993

Driller: Todd Hunter Geologist: W.G. Batten Date Drilling Ended: Oct. 19, 1993

Drilling Method: Air Rotary Drilling Fluid Type: Minor amount of water in the glacial deposits

ANNULAR SPACE DETAILS:

Type of Surface Seal: Portland Cement

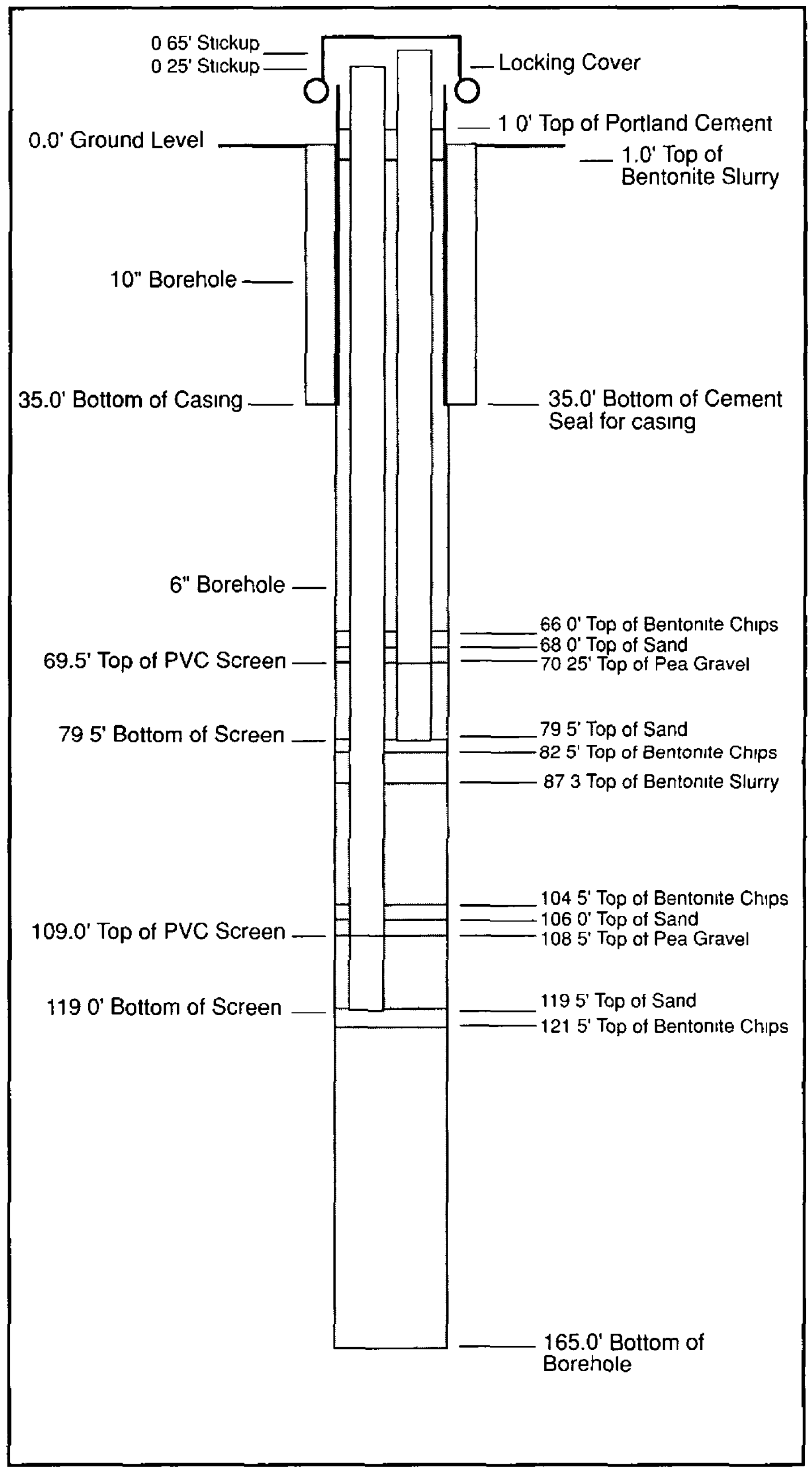
Amount of Surface Seal: # of Bags .25 lbs per Bag 90

Type of Annular Sealant: Baroid Bentonite Chip Hole Plug/Baroid Gold Seal Bentonite Aqua Gel

Amount of Annular Seal: # of Bags 11.5/4.25 lbs per Bag 50/50

Type of Filter Pack: 20-30 Sand/ 1/8x1/4 Pea Gravel

Amount of Filter Pack: # of Bags 2.75/6 lbs per Bag 50/50



WELL CONSTRUCTION MATERIALS:

Date of Construction:	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser Coupling				
Riser Pipe Above WT			Sch 80	
Riser Pipe Below WT			Sch 80	
Screen Coupling				
Screen			Sch 80	
Surface Casing				Steel
Protective Casing				Steel

MEASUREMENTS: To 0.01 ft. (where applicable)

Dimensions of Bore Hole	10":0'–35', 6": 35'–165'
Dimensions of Surface Casing	6" x 36'
Riser Pipe Length	108.75'/70.0'
ID of Riser Pipe	
Top of Screen to First Joint	0 2"/0.2"
Screen Length	10.0'/10.0'
Screen Slot Size	0 010" Wire Wound/10.0' Wire Wound
Number of Openings in Screen	
Bottom of Screen to End Cap	0.5'/0.5'
Dimensions of Protective Casing	6" x 2 0'

WELL CONSTRUCTION RECORD

SITE: Better Brite Superfund at De Pere WI County: Brown Well #. Bn-23/20E/28-0483 Background

Site Name: West De Pere High School Grid Coordinates: Northing 442630 Easting 0880452

Drilling Contractor: USGS Coal Branch Division Date Drilling Started: Oct. 15, 1993

Driller: Todd Hunter Geologist: W.G. Batten Date Drilling Ended: Oct. 19, 1993

Drilling Method: Air Rotary Drilling Fluid Type: Minor amount of water in the glacial deposits

ANNULAR SPACE DETAILS:

Type of Surface Seal: Portland Cement

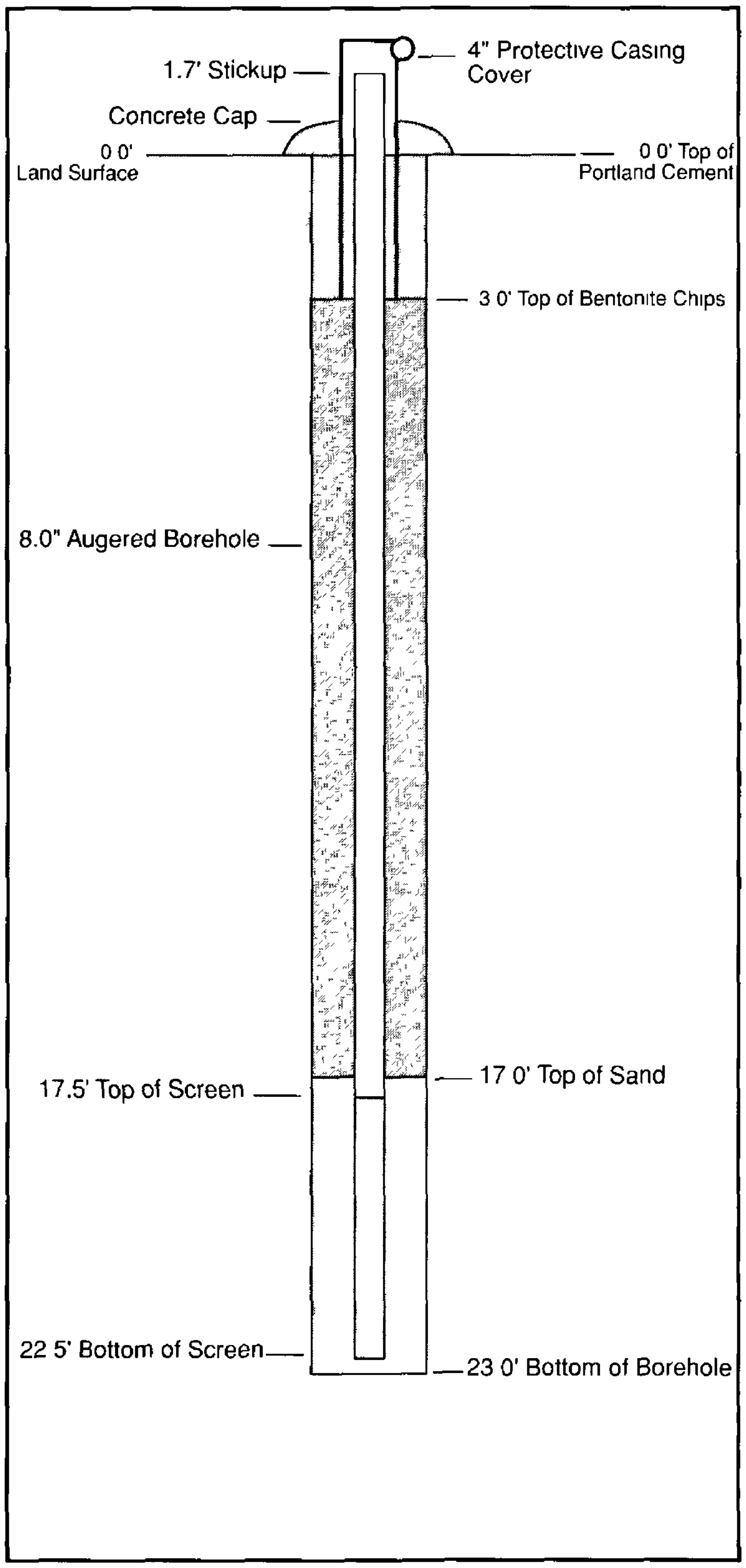
Amount of Surface Seal: # of Bags 2 lbs per Bag 90

Type of Annular Sealant: Baroid Bentonite Chip Hole Plug

Amount of Annular Seal: # of Bags 6 lbs per Bag 50

Type of Filter Pack: 20–30 Sand

Amount of Filter Pack: # of Bags 4 lbs per Bag 50



WELL CONSTRUCTION MATERIALS:

Date of Construction:	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser Coupling			Sch 80	
Riser Pipe Above WT			Sch 80	
Riser Pipe Below WT			Sch 80	
Screen Coupling				
Screen			Sch 80	
Surface Casing				
Protective Casing				Steel

MEASUREMENTS: To 0.01 ft. (where applicable)

Dimensions of Bore Hole	8": 0'–23'
Dimensions of Surface Casing	
Riser Pipe Length	18.7'
ID of Riser Pipe	
Top of Screen to First Joint	0.2"
Screen Length	5.0'
Screen Slot Size	0.010"
Number of Openings in Screen	
Bottom of Screen to End Cap	0.5'
Dimensions of Protective Casing	4.0" x 5.0'