Hydraulic Properties of the Prairie du Chien-Jordan Aquifer, Shakopee Mdewakanton Sioux Community, Southeastern Minnesota, 1997

Prepared in cooperation with the Shakopee Mdewakanton Si

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Water-Resources Investigations Report 99–4183

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior

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U.S. Geological Survey

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Mounds View, Minnesota, 1999

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	2.54	millimeter
foot (ft)	.3048	meters
foot per day (ft/d)	.3048	meter per day
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	.02832	cubic meter per second
square feet per day (ft^2/d)	.0929	square meter per day
gallons per minute (gal/mim)	6.309×10^{-5}	cubic meter per second
degrees Fahrenheit (°F)	(temperature °F - 32)/1.8	degrees Celsius

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

Hydraulic Properties of the Prairie du Chien-Jordan Aquifer, Shakopee Mdewakanton Sioux Community, Southeastern Minnesota, 1997

By James F. Ruhl

ABSTRACT

An aquifer test of the Prairie du Chien-Jordan aquifer was conducted in the Shakopee Mdewakanton Sioux Community located southwest of the Twin Cities metropolitan area. A well open to the Jordan Sandstone was pumped at 600 gallons per minute for 57 hours. Drawdown was monitored in three observation wells located near the pumped well. These wells were open to: (1) the Jordan Sandstone, the principal unit of the aquifer; (2) the Prairie du Chien Group, a secondary, carbonate-rock unit of the aquifer; and (3) a confined, glacial-drift sand aquifer. Test results indicate that the Jordan Sandstone had a transmissivity of 6,267 ft^2/d, a storativity of 1.193×10^{-4}, a horizontal hydraulic conductivity of 31 ft/d based on a saturated thickness of 204 ft, and a ratio of vertical to horizontal hydraulic conductivity of 5.29×10^{-4}. The pumped well was hydraulically connected to the Prairie du Chien Group observation well. No drawdown was observed in the observation well completed in the confined, glacial-drift sand aquifer; thus, a hydraulic connection of this observation well to the pumped well was not indicated.

INTRODUCTION

The Prairie du Chien-Jordan aquifer (fig. 1) is a major source of water for many communities of southeastern Minnesota. The Jordan Sandstone is the principal unit of the aquifer; the Prairie du Chien Group is a secondary, carbonate-rock unit of the aquifer. The Shakopee Mdewakanton Sioux Community (hereinafter, referred to as the Community) (fig. 2), located in the northern part of Scott County, Minnesota, has public-supply wells open to the Jordan Sandstone part of the aquifer.

Hydraulic properties of the Jordan Sandstone were previously estimated from an aquifer test conducted in the southern part of the Community (fig. 2) (Strobel and Delin, 1996). Transmissivities of 4,710 to 7,660 ft^2/d and storativities of 8.24×10^{-5} to 1.60×10^{-4} were reported from this previous study. The purpose of this report is to present additional information from an aquifer test conducted in the northern part of the Community (figs. 2 and 3). The test was conducted to better define the hydraulic properties of the Jordan Sandstone and to evaluate the hydraulic connection of the Jordan Sandstone to the Prairie du Chien Group and to a nearby confined, glacial-drift sand aquifer. Information from the test will be useful to tribal officials for development of Community water-management plans, to non-tribal government officials for development of regional water-management plans, and to water-resource investigators for subsequent studies on the hydraulic properties of the aquifer.

The aquifer test was conducted by pumping water from a public works well open to the Jordan Sandstone during a 57-hour period and measuring the drawdown in three observation wells. (After pumping was stopped, recovery in the observation wells could only be measured for about 4 hours, after which time operation of the pumped well had to be resumed because of the need to replenish community water supplies. Thus, the recovery phase of the test was judged to be of too short duration for reliable aquifer-test analyses.)

The three observation wells were open to the following units: (1) the Jordan Sandstone; (2) the Prairie du Chien Group; and (3) a confined, glacial-drift sand aquifer in a bedrock valley located about one mile east of the public works well. Hydraulic properties of the Jordan Sandstone were estimated from analyses of theoretical type curves developed by Neuman (1972, 1974, 1975) fitted to the drawdown data plotted for the observation well completed in the Jordan Sandstone.

Analyses of multiple aquifers and of multiple aquifer units were beyond the scope of the study; thus, the hydraulic properties of the Prairie du Chien Group and of the confined, glacial-drift sand aquifer were not estimated from test results. Test results were used to evaluate hydraulic connections of the pumped well to the Prairie Du Chien Group observation well and to the confined, glacial-drift sand aquifer observation well.

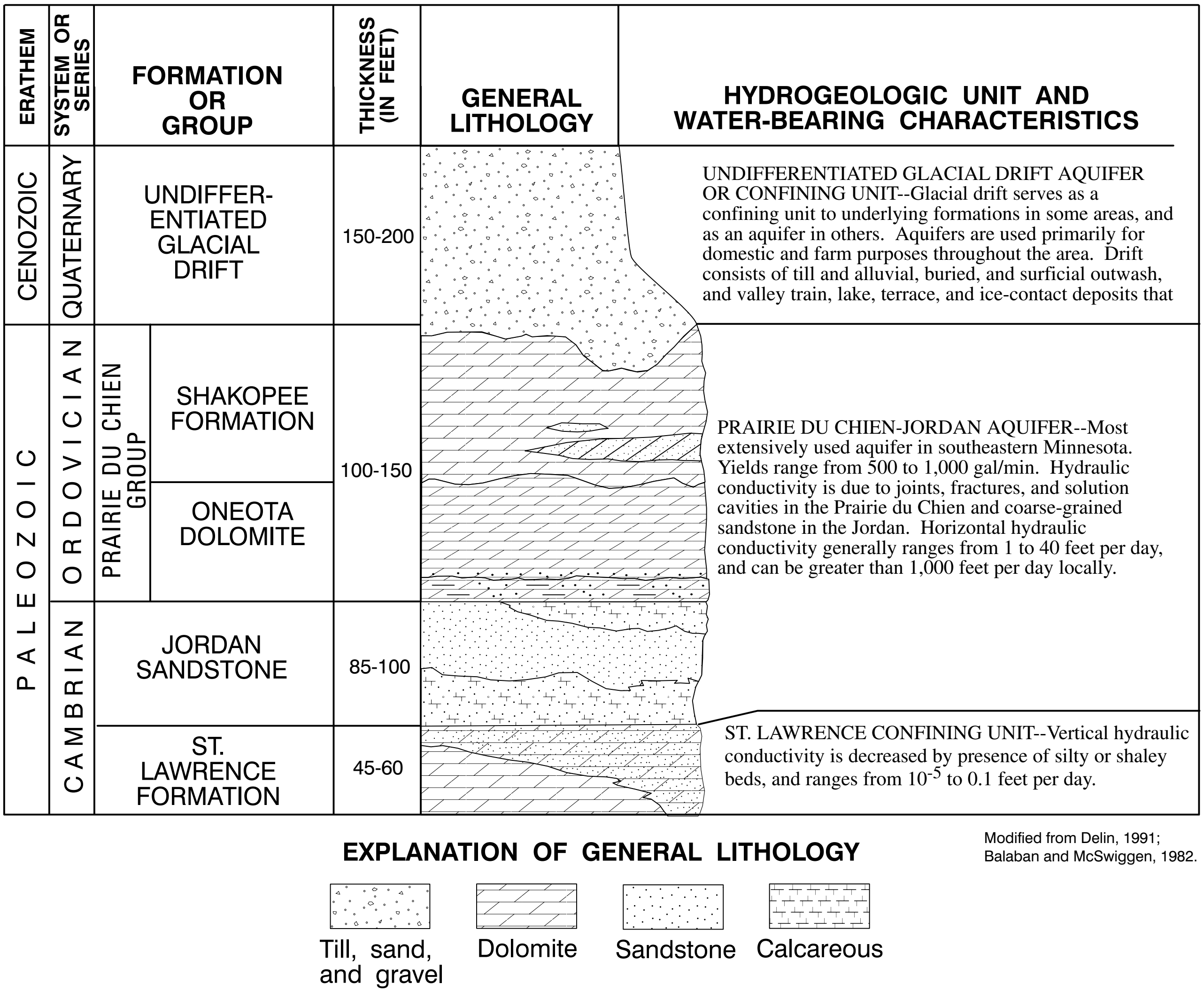

Figure 1. Generalized hydrogeologic column of regional aquifers and confining units in the study area.

HYDROGEOLOGIC SETTING

The Community is located in hummocky glacial terrain where local elevations range from 900 to 1,100 feet above sea level. Numerous lakes and wetlands are present in depressions and lowlands. The unconsolidated, surficial sediments consist of gray, calcareous, shale-rich, clayey till with small inclusions of reddish-brown drift that range in thickness from about 150 to 200 feet (Balaban and McSwiggen, 1982).

Bedrock units that underlie the surficial sediments in the study area are, in descending order, the Prairie du Chien Group, Jordan Sandstone, and St. Lawrence Formation. The Prairie du Chien Group consists of the Oneota Dolomite and overlying Shakopee Formation, which is a highly eroded limestone deposited as reefs and tidal-flat deposits (Balaban and McSwiggen, 1982). The thickness of the Prairie du Chien Group, which generally ranges from about 100 to 150 feet, is 153 feet at the test site. The Jordan Sandstone is a fine- to coarse-grained, poorly cemented, quartzose sandstone deposited as beach and near-shore sands (Balaban and McSwiggen, 1982). The thickness of the Jordan Sandstone, which generally ranges in thickness from about 85 to 100 feet, is at least 107 feet at the test site. The St. Lawrence Formation is a silty dolomite interbedded with siltstone, soft shale, and very-fine-grained quartzose sandstone (Balaban and McSwiggen, 1982). The St. Lawrence Formation generally ranges in thickness from about 45 to 60 feet.

The Community is located in the eastern part of a continuous subcrop of the Prairie du Chien Group (fig. 2). This subcrop extends over about a 40 mi^2 area, and the underlying Jordan Sandstone extends over about a 50 mi^2 area. Bedrock valleys formed by fluvial erosion bound the southern and

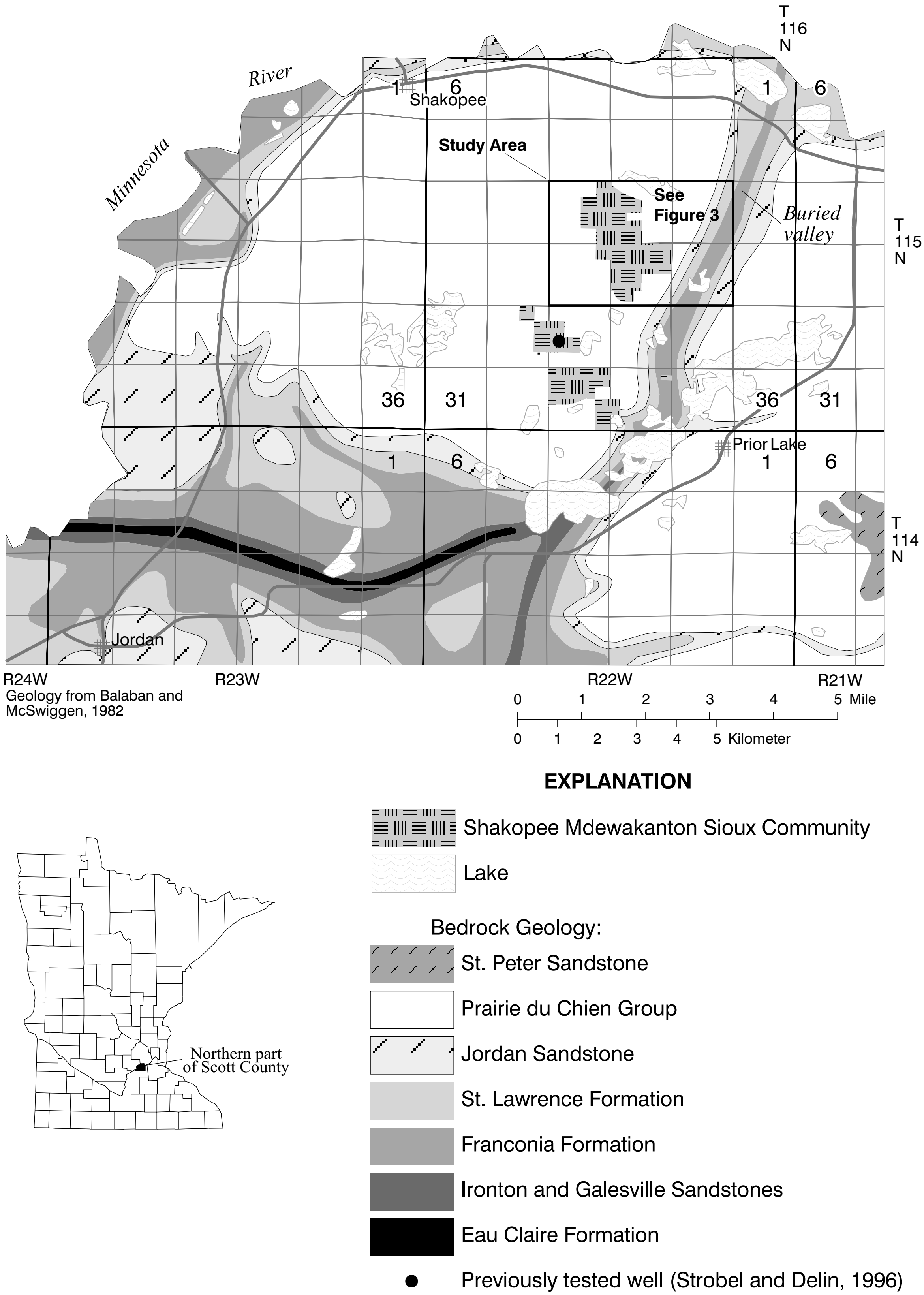

Figure 2. Locations of the Shakopee Mdewakanton Sioux Community, lakes, bedrock subcrops, and previously tested well, in the northern part of Scott County, southeastern Minnesota.

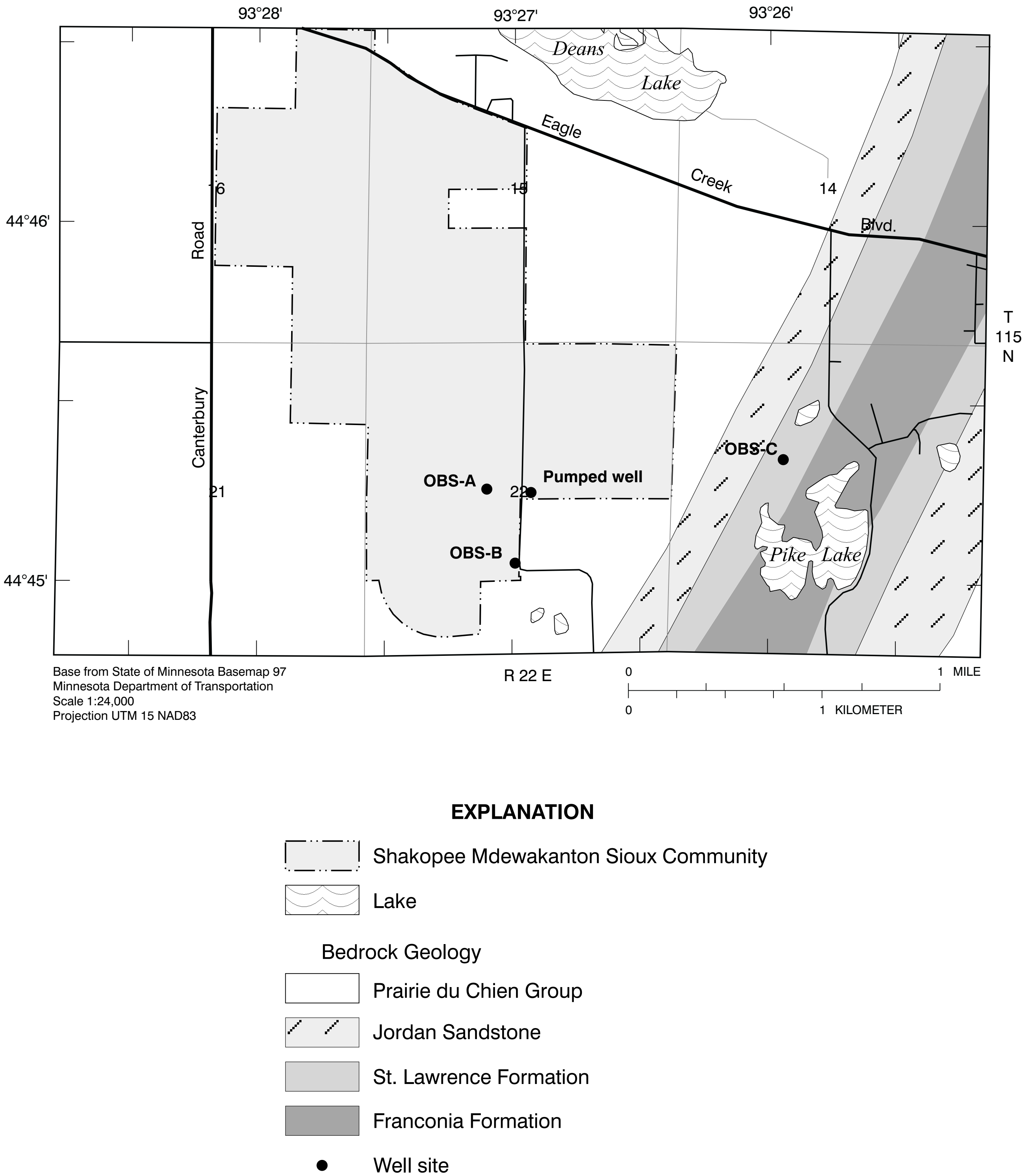

Figure 3. Locations of the aquifer-test wells in the study area and bedrock geology, southeastern Minnesota.

eastern sides of this subcrop. These valleys create discontinuities in the Prairie du Chien Group and Jordan Sandstone. The bedrock valley east of the test site extends downward into the St. Lawrence Formation (Balaban and McSwiggen, 1982). The Minnesota River flows through a bedrock valley to the north and west of the Community where bedrock units are exposed in some places.

The bedrock valleys are filled with Late Wisconsin drift that consists of sparse and discontinuous lenses of sand and gravel embedded within till. These surficial sediments, which have a relatively low hydraulic conductivity, overlie and confine the bedrock formations in some places. The water table typically is perched above the potentiometric surfaces of the underlying bedrock aquifers because of the low hydraulic conductivity of the surficial sediments. Ground water in the bedrock aquifers generally flows in a northwesterly direction through the study area and discharges into the Minnesota River.

The Prairie du Chien Group and Jordan Sandstone, which are hydraulically connected units, constitute a single aquifer. Hydraulic heads in the two units are similar (Delin, 1991). In some areas the potentiometric surface of the aquifer is below the top of the Prairie du Chien Grou;, thus, the aquifer is unconfined in these areas. Ground-water flow in the Jordan Sandstone is through intergranular pores (primary permeability). Ground-water flow in the Prairie du Chien Group is through dissolution channels and fractures (secondary permeability). The Jordan Sandstone is more important for ground-water supply than the Prairie du Chien Group because it typically has greater permeability than the Prairie du Chien Group.

AQUIFER-TEST DESIGN

A public works well completed in the Jordan Sandstone and located in the northern part of the Community was pumped at 600 gal/min for 57 hours. The pumping began on October 21, 1997 at 1:00 PM, a time when day-time water use in the Community normally declines. Thus, potential effects on early-time drawdown data from pumping privately owned domestic wells located near observation wells were minimized.

The pumping rate was monitored with a 4-inch Badger Recordall II Turbometer that had an operating range of from 8 to 1,250 gal/min. The water-level drawdown in this well and in three observation wells were measured during the pumping period. During a 4-hour period prior to the start of pumping, static water levels were measured in the pumped well and in the three observation wells to define pre-test conditions.

The three observation wells were: (1) the Brewer domestic well, hereinafter referred to as OBS-A, which is completed in the Jordan Sandstone and located 100 feet north and 750 feet west of the pumped public works well; (2) a public works well (now abandoned), hereinafter referred to as OBS-B, which is completed in the Prairie du Chien Group and located 1,200 feet south and 100 feet west of the pumped public works well; and (3) the YMCA Camp Kici Yapi well, hereinafter referred to as OBS-C, which is completed in a confined, glacial-drift sand aquifer and located 700 feet north and 4,300 feet east of the pumped public works well (fig. 3).

OBS-A was cased to a depth of 257 feet and was open to 83 feet of the Jordan Sandstone (table 1). Although the portion of the Jordan Sandstone open to the well could not be precisely determined, the well probably is open to nearly the full thickness of the formation. The well definitely is not open, however, to the full thickness of the Prairie du Chien-Jordan aquifer, which extends from 111 to 340 feet below land surface. The static water level in this well was 136 feet below land surface, which was about 754 ft above sea level.

OBS-B was cased to a depth of 151 feet and was open to 51 feet of the Prairie du Chien Group (table 1). Although the portion of the Prairie du Chien Group open to the well could not be precisely determined, the well probably is open to about one-third to one-half the full thickness of the formation. The well is not open, however, to the full thickness of the Prairie du Chien-Jordan aquifer. If the thickness of the Jordan Sandstone is assumed to be 100 feet, the full thickness of the aquifer would extend from 150 to 302 feet below land surface. The static water level was 154 feet below land surface, which was about 751 ft above sea level.

OBS-C was cased to a depth of 140 feet and screened to a depth of 150 feet (table 1). The screened interval was open to a confined, glacial-drift sand aquifer. The static water level was 61.8 feet below land surface, which was about 788.2 ft above sea level.

The pumped well was cased to a depth of 264 feet and was open to 106 feet of the Jordan Sandstone below the casing (table 1). The diameter of the open-hole portion of the well is 14 inches. Although complete, open-hole penetration of the Jordan Sandstone could not be verified, the well probably is open to nearly the full thickness of the formation. The well is not open, however, to the full thickness of the Prairie du Chien-Jordan aquifer, which extends from 110 to 370 feet below land surface. The static water level was 137 feet below land surface (static water-level altitude about 755 ft above sea level).

Water levels in the pumped well and in OBS-C were measured manu-

Table 1. Geologic logs of the pumped public works well and the three observation wells used in the aquifer test conducted in the Mdewakanton Sioux Community, southeastern Minnesota, 1997.

[BLS, below land surface]

Pumped Public Works Well
Minnesota Unique Well Number: 554090
Land surface elevation: 892ft
Open hole interval: 264 - 370 ft BLS

Geologic log	Depth BLS (ft)	Thickness (ft)	Color	Hardness	Bedrock aquifer unit
Sand and gravel	0-23	23	--	--	
Fine sand	23-100	77	--	--	
Fine sand and gravel	100-110	10	--	--	
Limestone	110-196	86	--	--	Prairie du Chien Group
Limestone with thin sandstone lay-ers	196-216	20	--	--	
Limestone with broken sandstone	216-220	4	--	--	
Broken limestone	220-225	5	--	--	
Limestone	225-263	38	--	Medium	
Sandstone	263-290	27	Yellow	--	Jordan Sandstone
Sandstone	290-315	25	Tan	--	
Sandstone	315-325	10	White	--	
Sandstone	325-370	45	Tan	--	

OBS-A (Brewer domestic well)
Minnesota Unique Well Number: Not Available
Land surface elevation: 890 ft
Open hole interval: 257 - 340 ft BLS

Geologic log	Depth BLS (ft)	Thickness (ft)	Color	Hardness	Bedrock aquifer unit
Top soil	0-1	1	Black	Low	
Course sand	1-8	7	--	--	
Clay	8-18	10	Brown	--	
Clay	18-48	30	--	--	
Cobbles	48-50	2	--	--	
Course sand	50-101	51	Gray	--	
Gravel	101-111	10	--	--	
Limestone	111-250	140	Brown	--	Prairie du Chien Group
Sandstone	250-315	66	White	--	Jordan Sandstone
Sandstone with green shale	315-325	10	--	--	
Sandstone	325-340	15	White	--	

Table 1. Geologic logs of the pumped public works well and the three observation wells used in the aquifer test conducted in the Mdewakanton Sioux Community, southeastern Minnesota, 1997. (Continued)

[BLS, below land surface]

OBS-B (Abandoned public works well)
Minnesota Unique Well Number: Not Available
Land surface elevation: 905 ft
Open hole interval: 151 - 202 ft BLS

Geologic log	Depth BLS (ft)	Thickness (ft)	Color	Hardness	Bedrock aquifer unit
Top soil	0-2	2	Black	--	
Clay	2-10	8	Brown	Medium	
Sand and gravel with boulders	10-68	58	Brown	High	
Sand with shale	68-145	77	Brown	Medium	
Shale	145-150	5	Brown	High	
Limestone	150-202	52	Brown	High	Prairie du Chien Group

OBS-C (Camp Kici Yapi well)
Minnesota Unique Well Number: 112217
Land surface elevation: 850 ft
Screen interval depth: 140 - 150 ft BLS

Geologic log	Depth BLS (ft)	Thickness (ft)	Color	Hardness	Bedrock aquifer unit
Top soil	0-2	2	Black	--	Top soil
Clay with pebbles	2-32	30	--	--	Clay with pebbles
Clay with sand	32-37	5	--	--	Clay with sand
Fine sand	37-47	10	--	--	Fine sand
Clay with cobbles	47-97	50	--	--	Clay with cobbles
Sand	97-102	5	Yellow	--	Sand
Clay with sand	102-114	12	--	--	Clay with sand
Sand	114-150	36	--	--	Sand

ally with electronic tapes. Water levels in OBS-A and in OBS-B were measured by a pressure transducer connected to a TROLL (SP4000) data logger manufactured by In-Situ Inc. Time increments between measurements, which initially were at a scale of seconds, were increased logarithmically to one-hour intervals. The operating range of the pressure transducers was from 0 to 30 pounds per square inch (0 to 69 feet of water) with an accuracy of +/-0.05% throughout the range. Water levels in OBS-A were measured manually with an electronic tape (at intervals of one hour) to verify the accuracy of the data logger; water levels in OBS-B were not measured manually because of condensation on the well casing that prevented accurate readings.

Discharge from the public works well during the aquifer test was directed down a local hillside. The hydraulic conductivity of the surficial sediments was assumed to be sufficiently small to disregard potential recharge to the Prairie du Chien-Jordan aquifer from this surface discharge.

Atmospheric effects on water levels during the test were not considered in the analyses. The ambient barometric pressure measured at Minneapolis-St. Paul International Airport, located about 20 miles northeast of the aquifer test site, did not change during critical phases of the test. During the first four hours of the test, when most of the drawdown occurred, the barometric pressure was constant at 1,026 millibars. During the fifth hour of the test the barometric pressure increased to 1,027 millibars and then gradually decreased to 1,011 millibars by the end of the drawdown phase of the test.

AQUIFER-TEST RESULTS

Pre-test water levels did not show visible effects from changes in barometric pressure. Water-level changes that were within a range of one foot during the pre-test period were probably related to pumping of local domestic wells. Although the potential effects of pumping local wells on water levels in the observation wells during the test were not determined, these effects are assumed to have been insignificant.

The drawdown curve for OBS-A were automatically matched by AQTESOLV, a computer software package developed by Geraghty & Miller, Inc., to various type curves derived by Neuman (1972, 1974, 1975). The Neuman (1974) type curves are valid for unsteady flow to a well in an unconfined aquifer with delayed gravity response and are based on the following assumptions: (1) the aquifer is homogeneous, unconfined, infinite in areal extent, and uniformly thick; (2) the water table in the aquifer is horizontal prior to pumping; (3) ground-water withdrawal from the pumped well is at a constant rate; (4) the specific yield is at least 10 times larger than the storativity; and (5) storage of water in the pumped well is negligible (small diameter well) (Neuman, 1975). AQTESOLV corrected for partial penetration of the aquifer by both the pumped and observation wells.

The drawdown equation given by Neuman (1974) is:

$$= \frac{Q}{4\pi T} W(u_A, u_B, \beta) \qquad (1)$$

where $W(u_A, u_B, \beta)$ is the well function for the aquifer, and

$$u_A = \frac{r^2 S_A}{4Tt} \qquad (2)$$

$$u_B = \frac{r^2 S_Y}{4Tt} \qquad (3)$$

$$\beta = \frac{r^2 K_v}{b^2 K_h} \qquad (4)$$

where s = drawdown,

Q = pumping rate (ft^3/d),

T = transmissivity (ft^2/d),

r = radial distance from the pumping well to the observation well (ft),

S_A = the volume of water instantaneously released from storage per unit surface area per unit decline in head (elastic early-time storativity) (ft^3/ft^3),

S_Y = the volume of water released from storage per unit surface area per unit decline of the water table (specific yield) (ft^3/ft^3),

t = time (in days),

K_v = vertical hydraulic conductivity (in ft/d),

K_h = horizontal hydraulic conductivity (in ft/d), and

b = initial saturated thickness of the aquifer (in ft).

Drawdown in OBS-A was detected about 2 minutes after the start of pumping. The total drawdown was slightly greater than 9 feet. The type curve for $\beta = 0.013$ best fit the early-time drawdown data for OBS-A (fig. 4). Transmissivity and storativity were calculated to be 6,267 ft^2/d and 1.193×10^{-4}, respectively. These calculations describe the hydraulic properties of the Jordan Sandstone part of the aquifer. Determination of specific yield, which requires late-time drawdown data, was not done because of the short duration of the pumping period. The ratio of the vertical hydraulic conductivity to the horizontal hydraulic conductivity of the Jordan Sandstone was 5.29×10^{-4}. The horizontal hydraulic conductivity of the Jordan Sandstone was 31 ft/d, based on a saturated thickness of 204 ft.

Drawdown was detected in OBS-B about 40 minutes after the start of pumping. The total drawdown was about 0.32 feet. These results indicate a hydraulic connection between the pumped well and OBS-B. The rate and duration of pumping were insufficient to cause drawdown in OBS-C. Therefore, the hydraulic connection of the pumped well to OBS-C could not be evaluated from the test results.

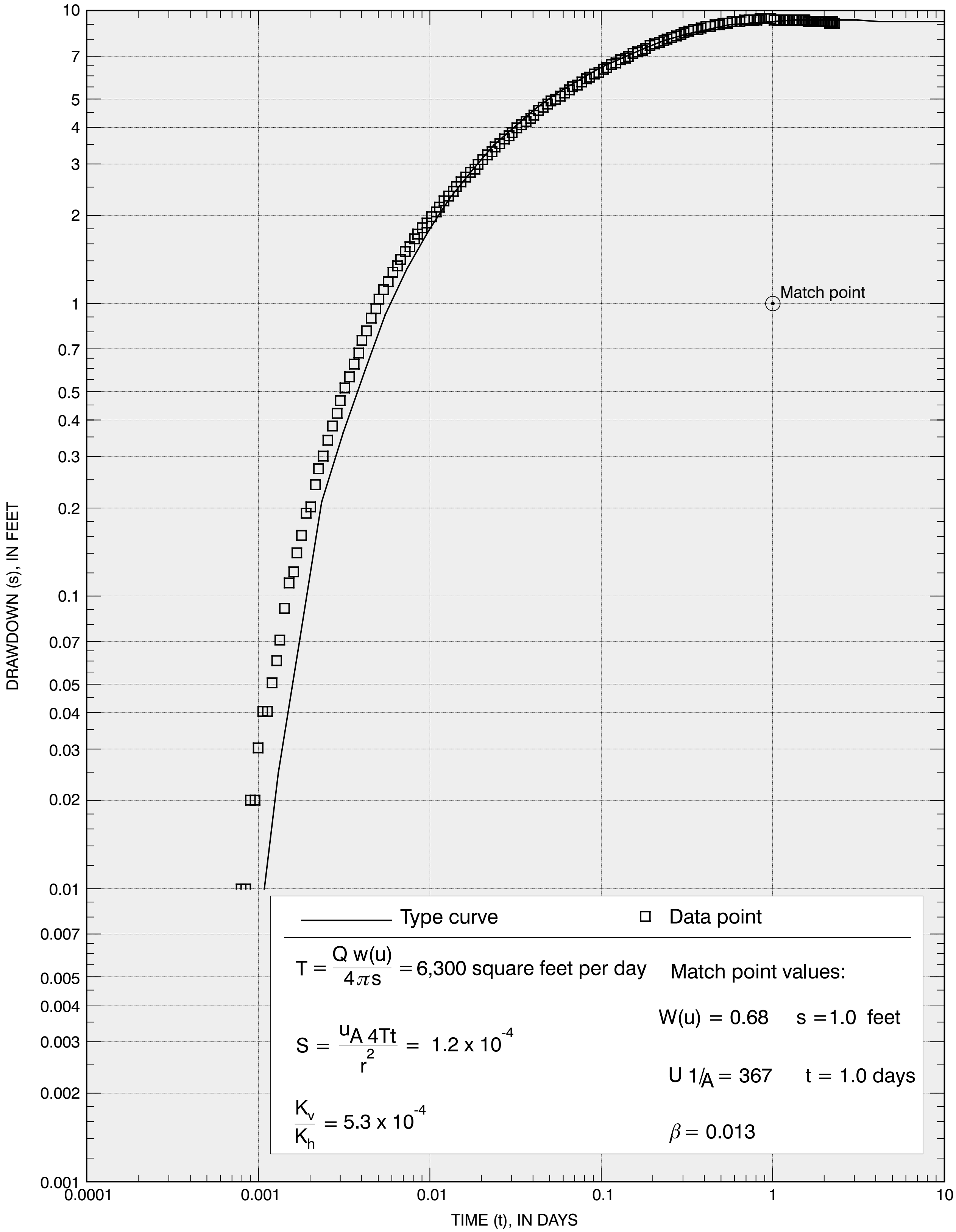

Figure 4. Relation of the Neuman (1975) type curve to the time vs. drawdown curve for OBS-A.

SUMMARY

An aquifer test of the Prairie du Chien-Jordan aquifer was conducted in the Shakopee Mdewakanton Sioux Community located southwest of the Twin Cities metropolitan area. A public works well completed in the Jordan Sandstone part of the Prairie du Chien-Jordan aquifer was pumped at 600 gallons per minute for 57 hours. Drawdown was monitored in three observation wells located near the pumped well. These wells were open to: (1) the Jordan Sandstone, the principal unit of the aquifer; (2) the Prairie du Chien Group, a secondary, carbonate-rock unit of the aquifer; and (3) a confined, glacial-drift sand aquifer located in a local bedrock valley about one mile east of the pumped well.

Type curves developed by Neuman (1974) were used to analyze drawdown data for the observation well completed in the Jordan Sandstone. (Recovery data could only be collected for 4 hours--a period of time not sufficiently long to allow reliable analyses of the data.) Analyses of results from the drawdown phase of the test indicate that the Jordan Sandstone had a transmissivity of 6,267 ft^2/d, a storativity of 1.193 x 10^{-4}, a horizontal hydraulic conductivity of 31 ft/d based on a saturated thickness of 204 ft, and a ratio of vertical to horizontal hydraulic conductivity of 5.29 x 10^{4}. Analyses of the test results furthermore indicate that the pumped well is hydraulically connected to the Prairie du Chien Group observation well, which had a total drawdown of about 0.32 ft. The duration and rate of pumping were insufficient to cause drawdown in the observation well completed in the confined, glacial-drift sand aquifer; thus, a hydraulic connection of this well to the pumped well was not indicated.

REFERENCES

Balaban, N.H., and McSwiggen, P.L., eds., 1982, Geologic atlas, Scott County, Minnesota, County Atlas Series, Minnesota Geological Survey, Map C-1, 6 plates.

Delin, G.N., 1991, Hydrogeology and simulation of ground-water flow in the Rochester area, southeastern Minnesota, 1987-88: U.S. Geological Survey Water-Resources Investigations Report 90-4081, 102 p.

Neuman, S.P., 1972, Theory of flow in unconfined aquifers considering delayed response of the water table: Water Resources Research, v. 8, p. 1031-1045.

_____1974, Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response: Water Resources Research, v. 10, p. 303-312.

_____1975, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response: Water Resources Research, v. 11, p. 329-342.

Strobel, M.L., and Delin, G.N., 1996, Analysis of hydrogeologic properties in the Prairie du Chien-Jordan aquifer, Shakopee Mdewakanton Sioux Community, southeastern Minnesota: U.S. Geological Survey Water-Resources Investigations Report 96-182, 14 p.