Hydraulic Properties of Mt. Simon Aquifer, Prairie Island Indian Community, Southeastern Minnesota, 2001

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Water-Resources Investigations Report 02-4263

Prepared in cooperation with the Prairie Island Indian Community

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Conversion Factors

Foot (ft)	0.3048	meter
Foot per day (ft/d)	0.0348	meter per day
Foot squared per day (ft^2/d)	0.09290	meter squared per day
Gallon(gal)	3.785	liter
Pound (lb)	0.4536	kilogram

Sea level: Vertical coordinate information is referenced to the North American Vertical Datum of 1988.

Hydraulic Properties of the Mount Simon Aquifer, Prairie Island Indian Community, southeastern Minnesota, 2001

ABSTRACT

An aquifer test of the Mt. Simon aquifer was conducted at the northern end of the Prairie Island Indian Community, in cooperation with the Prairie Island Indian Community, September 10-11, 2001 to determine hydraulic properties. Two wells at the northern end of Prairie Island were used in the aquifer test. A production well, Water-Supply Well No. 3, completed in the Mt. Simon aquifer, was pumped for 24 hours at 1,530 gal/min. Drawdown and recovery water levels were measured in the pumped well and in an observation well located 458 ft from the pumped well that was open to the Mt. Simon aquifer. Recovery water levels were measured in both wells for 10 hours after pumping ceased at Water-Supply Well No. 3.

Hantush and Theis methods type curves were fitted to the measured drawdown and recovery curves in the observation well. The results of matching the type curves to the measured data indicate that leakage is negligible from the overlying Eau Claire confining unit into the Mt. Simon aquifer. The transmissivity and storage coefficients for the Mt. Simon aquifer, determined by both methods, are 3, 000 ft^2/d and 3 x 10^{-4}, respectively. The average hydraulic conductivity, assuming an aquifer thickness of 233 ft, is 10 ft/d.

INTRODUCTION

The Mt. Simon aquifer is the major source of water for the Prairie Island Indian Community (fig. 1). Woodward (1986) estimated transmissivities of 2,000-4,000 ft^2/d for the portion of the aquifer in the Prairie Island area, but additional information about the hydraulic properties of the aquifer is needed. The U.S. Geological Survey, in cooperation with the Prairie Island Indian Community, conducted an aquifer test on September 10-11, 2001 to better define the hydraulic properties of the Mt. Simon aquifer at the northern end of Prairie Island. 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 propose of this report is to describe the aquifer-test design and analysis and to present the hydraulic properties of the Mt. Simon aquifer at the northern end of Prairie Island determined from the aquifer test. The test was conducted by pumping water from a newly completed production well (Water-Supply Well No. 3) in the Mt. Simon aquifer during a 24-hour period and measuring the drawdown in one observation well and the pumped well. Recovery water levels in the observation well and pumped well were measured for 10 hours. The study area is located in southeastern Minnesota between the Mississippi and Vermillion Rivers about 40 miles southeast from the Twin Cities metropolitan area (fig. 1).

Figure 1. Locations of study area and water-supply and observation wells, Prairie Island Indian Community, Minnesota.

HYDROGEOLOGIC SETTING

The geologic units near Water-Supply Well No. 3 include thick glacial outwash and four bedrock units of Late Cambrian age (fig. 2). The bedrock units are, in descending order, the Franconia Formation, the Ironton and Galesville Sandstones, the Eau Claire Formation, and the Mt. Simon Sandstone. The Mt. Simon aquifer consists of the Mt. Simon Sandstone. The thickness of the geologic units are listed in table 1. The following description of the bedrock units is from Mossler and Tipping (2000).

The upper part of the Franconia Formation consists of sandstone and may be 100 ft thick in the southeastern part of the Twin Cities metropolitan area. The lower part consists of interlayered shale, siltstone, and lesser amounts of sandstone as thick as 30 ft that overlie sandstone interlayered with dolostone, also as thick as 30 ft. The contact with the underlying Ironton Sandstone is sharply defined, but apparently conformable.

The Ironton and Galesville Sandstones consist of sandstone interlayered with scattered thin beds of shale. Although separated by a disconformity, the two sandstones cannot be distinguished with certainty where geologic control consists of drill cuttings alone.

The Eau Claire Formation can be divided into three intervals. The upper one-third to one-fourth of the formation is sandstone interlayered with scattered thin partings of shale. The middle one-fourth to one-third of the formation consists of siltstone, sandstone, and shale. The basal one-third to one-half of the formation consists of sandstone and siltstone. The Eau Claire Formation has a conformable contact with the underlying Mt. Simon Sandstone.

The upper one-fifth of the Mt. Simon Sandstone consists of medium to thick, locally cross-stratified beds of fine- to medium-grained, moderately-sorted to well-sorted quartz sandstone interlayered with thin beds of gray-green shale, very fine-grained feldspathic sandstone and siltstone, and fine- to coarse-grained, silty, poorly-sorted, thick-bedded to massive quartzose to feldspathic sandstone.

The middle one-third to two-fifths of the Mt. Simon Sandstone consists of thick, crudely planar or cross-stratified beds of fine- to coarse-grained, moderately-sorted quartz sandstone interlayered with thin to very thick (as thick as 8 ft) beds of very fine-grained to fine-grained, well-sorted, feldspathic sandstone. The feldspathic sandstone is, in turn, interlayered with thin beds of green-gray, silty shale. Granule-sized grains of quartz or, rarely, intraclasts of siltstone and very fine-grained sandstone define the lower parts of the thick, coarser-grained sandstone beds.

The lower one-half of the Mt. Simon Sandstone consists of medium to thick cross-stratified beds of medium- to very coarse-grained, moderately sorted to well-sorted quartz sandstone. The interval contains thin intercalated lenses of granule- to pebble-sized quartz and scattered thin beds of light-gray siltstone and red-brown to pale-red to green-gray shale. A basal conglomerate as thick as 6 ft marks the base of the Mt. Simon Sandstone.

Sufficient amounts of borehole and well data are not available to describe the geologic units underlying the Mt. Simon Sandstone in the Prairie Island area (Bruce Bloomgren, Minnesota Geological Survey, oral commun., 2001). In some areas of the Minneapolis-St. Paul metropolitan area the Mt. Simon Sandstone overlies the crystalline bedrock of Proterozoic age, in other areas the Mt. Simon Sandstone overlies the Hinckley Sandstone, the Fond du Lac Formation, or the Solor Church Formation of middle Proterozoic age (Bruce Bloomgren, Minnesota Geological Survey, oral commun., 2001). Samples from a few deep water-supply wells that penetrated the entire thickness of the Mt. Simon Sandstone beneath the city of Red Wing, located about 12 miles southwest of Prairie Island, indicate that the rocks underlying the Mt. Simon Sandstone are the Hinckley Sandstone or the Fond du Lac Formation (Runkel, 1998).

AQUIFER-TEST DESIGN

Two wells were used in the aquifer test (fig. 1). The pumped well, Water-Supply Well No. 3, is cased from land surface to a depth of 480 ft and is open to the Mt. Simon aquifer from a depth of 480

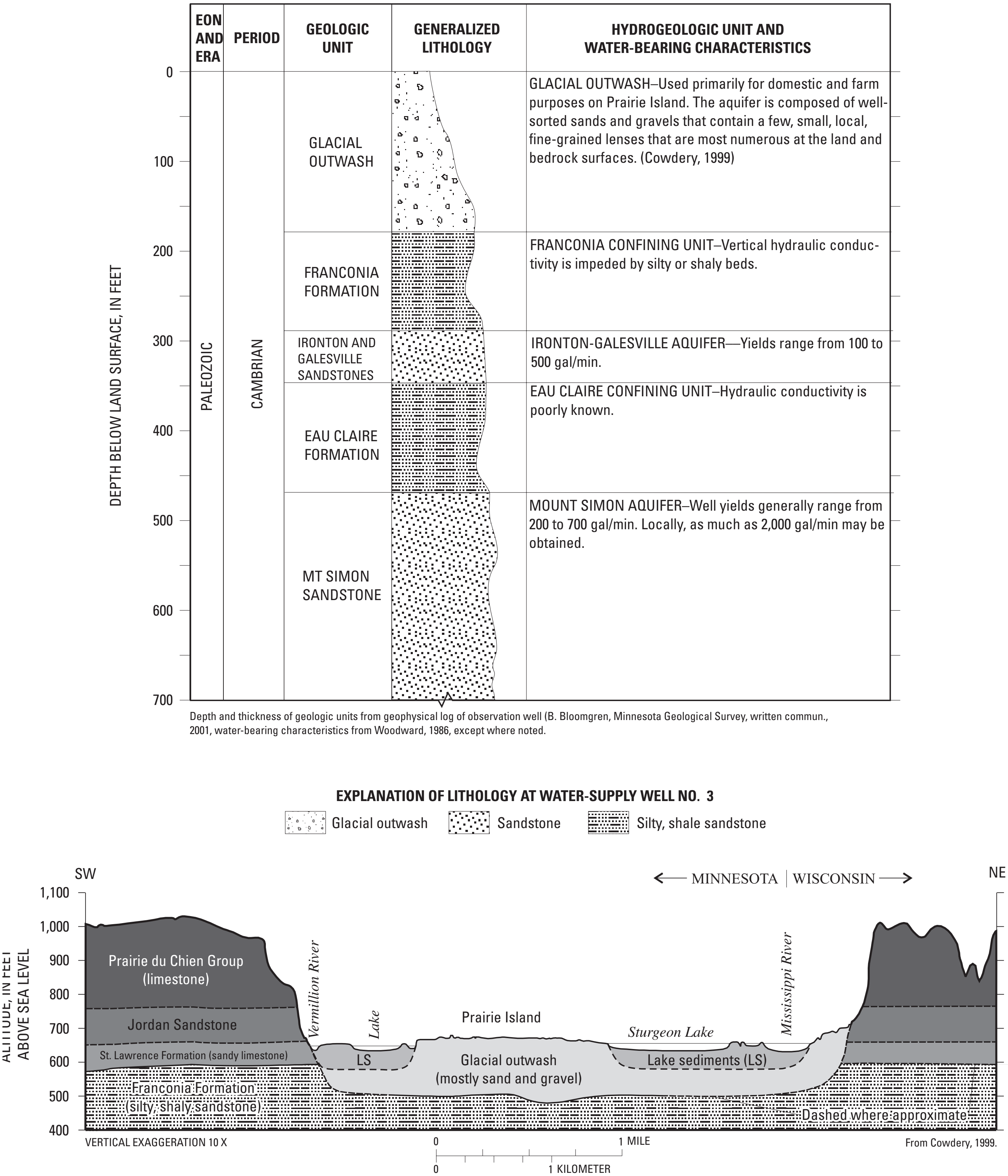

Figure 2. Lithology at Water-Supply Well No. 3 and the observation well and generalized geologic-section, Prairie Island Indian Community, Minnesota.

Table 1. Stratigraphy at Water-Supply Well No. 3 and the observation well, Prairie Island Indian Community, Minnesota

[ft, feet; --,does not apply; >, greater than; Data from Bruce Bloomgren, Minnesota Geological Survey, written comm., 2001]

Geologic unit	Hydrogeologic unit	Water-Supply Well No. 3		Observation well	
		Depth below land surface (ft)	Thickness (ft)	Depth below land surface (ft)	Thickness (ft)
Glacial outwash	Glacial outwash aquifer	0-167	167	0-168	168
Franconia Formation	Franconia Confining Unit	167-291	124	168-290	122
Ironton-Galesville Sandstones	Ironton-Galesville Aquifer	291-346	55	290-345	55
Eau Claire Formation	Eau Claire Confining Unit	346-468	122	345-470	125
Mt. Simon Sandstone	Mt. Simon Aquifer	468-701 (bottom of hole)	> 233	470-602 (bottom of hole)	> 132

ft to 701 ft. The observation well is located 458 ft south of the Water-Supply Well No. 3 and is cased from land surface to a depth of 480 ft and is open to the Mt. Simon aquifer from a depth of 480 ft to 602 ft. The stratigraphy at the wells is shown in table 1.

Water-Supply Well No. 3 was pumped at 1,530 gal/min for 24 hours. The pumping began on September 10, 2001 at 07:00. The pump was shut off at 07:02 September 11, 2001. The aquifer test ended at 17:03 September 11, 2001.

Water-Supply Well No. 3 was flowing under artesian conditions before the start of the test. The pumping rate was monitored by an orifice meter in the discharge line from the pump. Drawdown in Water-Supply Well No. 3 was measured as the depth of water below an initial measuring point on the well drilling platform at the well casing. Drawdown was measured with an electric tape every 5 minutes from 07:00 to 07:30 September 10, every half hour from 07:30 to 09:00, and every hour afterwards. When the pump was shut off, the depth to water was measured at intervals between 1.5 and 5.5 minutes from 07:05 to 07:29 September 11, 2001 and every half-hour thereafter to the end of the test. The well started flowing between 14:00 and 14:51 September 11, 2001 before the end of the aquifer test. Water flowing from the well under artesian conditions was drained through a pipe attached to the well casing about 4 ft below the measuring point. The overflow water was discharged to a field about 200 ft from the well. The drawdown and recovery water levels measured in Water-Supply Well No. 3 are shown in figure 3 and listed in table 2.

The observation well is under artesian conditions and was capped at the beginning of the test to prevent it from flowing. Drawdown below static head in the well was measured with a vented transducer every second and recorded every 90 seconds or when the pressure changed more than 0.004 lb/ft^2. Static head in the well was determined before the start of the aquifer test. Twelve minutes after the start of the aquifer test, when the water surface was below land surface, the valve on the cap was opened allowing air into the well to equalize the pressure above the water to atmospheric pressure. At least twice each hour the depth to the water was measured with a steel tape. The total drawdown in the observation well after 24 hours of pumping was 39.26 ft below static head. The water levels in the observation well began to recover about 12 minutes after pumping ceased at Water-Supply Well No. 3. The water level recovered 30.94 ft, but was still below land surface, when the transducer was pulled after 10 hours of recovery. Selected water levels measured in the observation well are listed in table 3 and shown in figure 3.

Water from Water-Supply Well No. 3 was discharged during the aquifer test to a holding pond 800 ft from the well. The water in the holding pond seeped into the ground. The surficial aquifer is separated by two confining units from the Mt. Simon aquifer. As a result, recharge to the Mt. Simon aquifer by the discharged water was not assumed to be a factor during the aquifer-test analysis.

AQUIFER-TEST ANALYSIS AND HYDRAULIC RESOURCES

For aquifer-test analyses, it was assumed that Water-Supply Well No. 3 fully penetrates the Mt. Simon aquifer and that the aquifer consists only of the Mt. Simon Sandstone. The Mt. Simon aquifer is at least 233 ft thick and Water-Supply Well No. 3 is open to 221 ft of the aquifer. The observation well partially penetrates the Mt. Simon aquifer for 132 ft. The amount of water that flowed under artesian conditions from Water-Supply Well No. 3 was very small compared to the amount of water pumped from the well and was

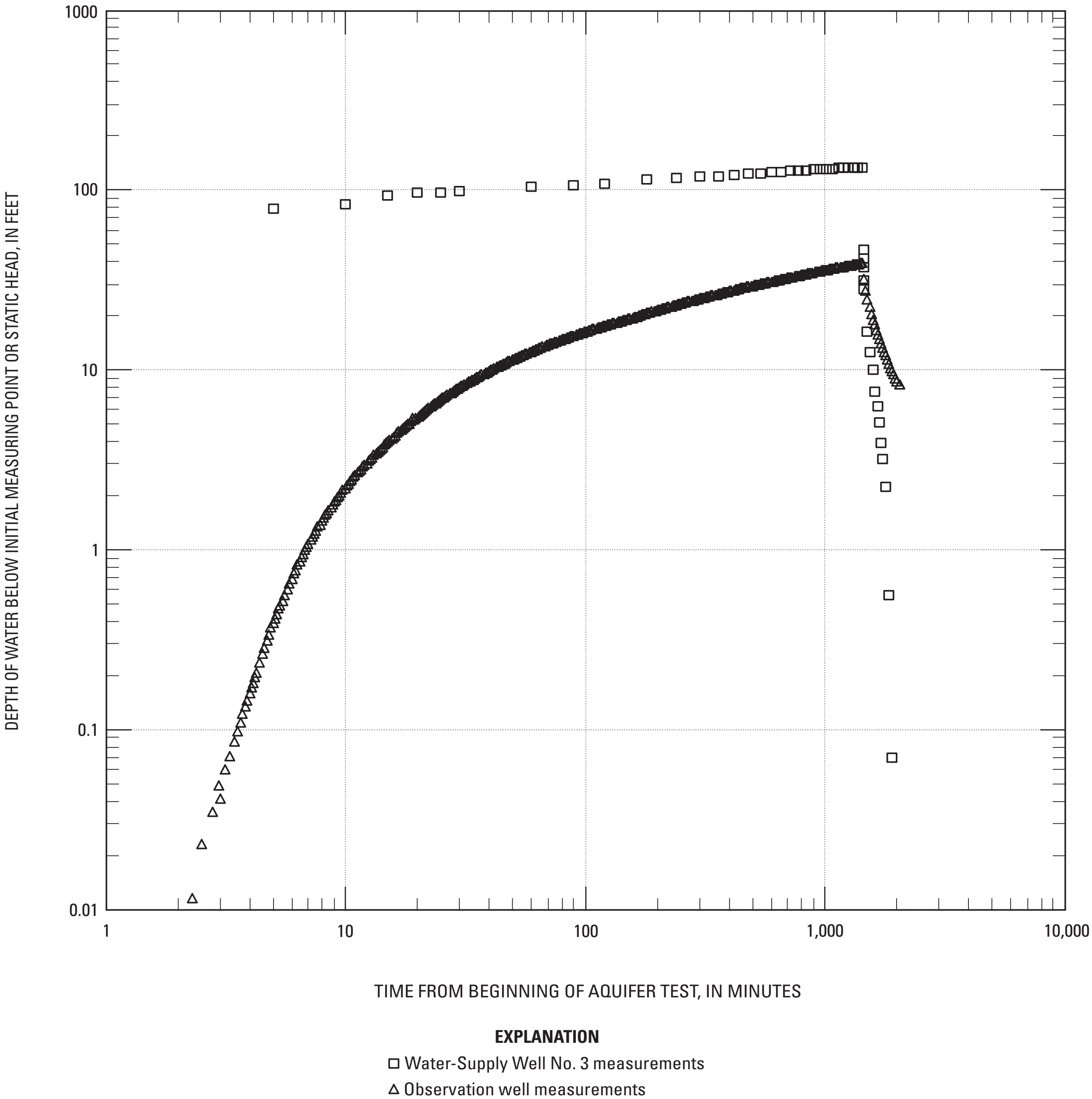

Figure 3. Measured water levels in Water-Supply Well No. 3 and the observation well, Prairie Island Indian Community, Minnesota, September 10-11, 2001

assumed to not significantly affect the aquifer test.

The computer software AQTESOLV (Hydrolsolve, 2000) was used to fit several type curves to the observed drawdown and recovery curves at the observation well. For initial analyses type curves from Theis (1935), Cooper and Jacob (1946), Hantush (1960) and Neuman and Witherspoon (1969) were fitted to the observed curves. Two type curves, Theis and Hantush, were selected for further analyses. The automatic curve fitting routine in AQTESOLV was used to fit the two type curves to the measured drawdown and recovery curves. AQTESOLV performs nonlinear weighted least-squared parameter estimation (Hydrosolve, 2000) to fit the type curves to the measured curves. AQTESOLV uses the method derived by Hantush (1961a, b) to correct for the partial penetration of the aquifer by the observation well (Hydrosolve, Inc., 2000).

The assumptions for the Hantush and Theis type curves and the equations defining the type curves are in the supplemental information section of this report. A major assumption for the Hantush type curve is that the Mt. Simon aquifer is leaky, which means that water flows from the overlying Eau Claire confining unit into the Mt. Simon aquifer (Hantush, 1960). The inflowing water comes either from storage in the Eau Claire confining unit or from the Ironton-Galesville aquifer that overlies the Eau Claire confining unit. The Theis type curve represents the limiting case where no water flows into the Mt. Simon aquifer from the overlying Eau Claire confining unit.

The Theis and Hantush type curves were fitted simultaneously to the measured water levels in Water-Supply Well No. 3 and the observation well (figs. 4 and 5) to determine hydraulic properties of the Mt. Simon aquifer. The horizontal axis in the figures is time, in minutes, divided by the square of the distance of the measured well from the pumped well, in feet. The distance from the

Table 2. Measured water levels in Water-Supply Well No. 3, Prairie Island Indian Community, Minnesota, Septermber 10-11, 2001

Time since pumping began (minutes)	Depth below measuring point(feet)	Time since pumping began (minutes)	Depth below measuring point(feet)
0	4.37[1]	1,080	135.77
5	83.7	1,140	136.45
10	87.82	1,200	136.78
15	96.92	1,260	137.57
20	100.68	1,320	137.65
25	101.5	1,380	138.00
30	102.49	1,440	138.43
60	109.53	1,441.75[2]	138.43
90	111.58	1,445.0	50.77
120	112.89	1,446.5	45.8
180	118.52	1,448.5	41.81
240	120.96	1,454.0	35.8
300	123.21	1,458.5	32.43
360	123.92	1,508	20.68
420	125.78	1,543	16.97
480	127.44	1,581	14.38
540	128.55	1,628	11.87
600	129.74	1,657	10.68
660	130.96	1,688	9.48
720	131.72	1,723	8.28
780	132.10	1,748	7.57
840	133.80	1,787	6.59
900	134.28	1,860	4.93
960	134.65	1,911	4.44[3]
1,020	135.15		

[1]Well is flowing

[2]Pumping ceased

[3]Well is flowing

Table 3. Selected measured water levels in the observation well, Prairie Island Indian Community, Minnesota, September 10-11, 2001

Elapsed time from beginning of aquifer test (minutes)	Depth below static head (feet)	Elapsed time from beginning of aquifer test (minutes)	Depth below static head (feet)
0.00	0.00	200.10	21.51
1.50	0.00	224.67	22.45
2.30	0.01	251.38	23.40
2.53	0.02	282.00	24.38
2.95	0.05	320.78	25.48
3.30	0.07	353.43	26.29
3.55	0.10	403.07	27.46
3.98	0.16	452.23	28.52
4.48	0.26	506.68	29.51
5.07	0.42	568.20	30.53
5.58	0.56	635.52	31.58
6.32	0.82	711.38	32.64
7.15	1.13	796.50	33.68
7.97	1.45	892.40	34.80
8.98	1.84	1,014.00	35.98
10.12	2.27	1,135.18	37.00
11.23	2.68	1,268.13	38.06
12.68	3.19	1,417.50	39.10
14.33	3.74	1,440.25	39.26
15.87	4.25	1,462.98	32.28
17.93	4.91	1,486.12	27.46
20.12	5.53	1,509.60	24.45
22.68	6.26	1,533.45	22.26
25.40	6.97	1,557.83	20.51
28.03	7.58	1,582.60	19.07
32.07	8.44	1,607.83	17.83
35.35	9.07	1,633.43	16.74
40.38	9.96	1,659.47	15.76
44.65	10.65	1,712.88	14.07
50.28	11.45	1,740.37	13.32
56.43	12.25	1,768.38	12.62
63.27	13.06	1,796.65	11.98
71.32	13.91	1,825.25	11.38
80.17	14.73	1,854.47	10.82
90.00	15.54	1,884.27	10.29
100.82	16.34	1,914.47	9.81
112.88	17.13	1,944.70	9.39
126.53	17.92	1,975.97	9.01
142.05	18.73	2,040.47	8.32

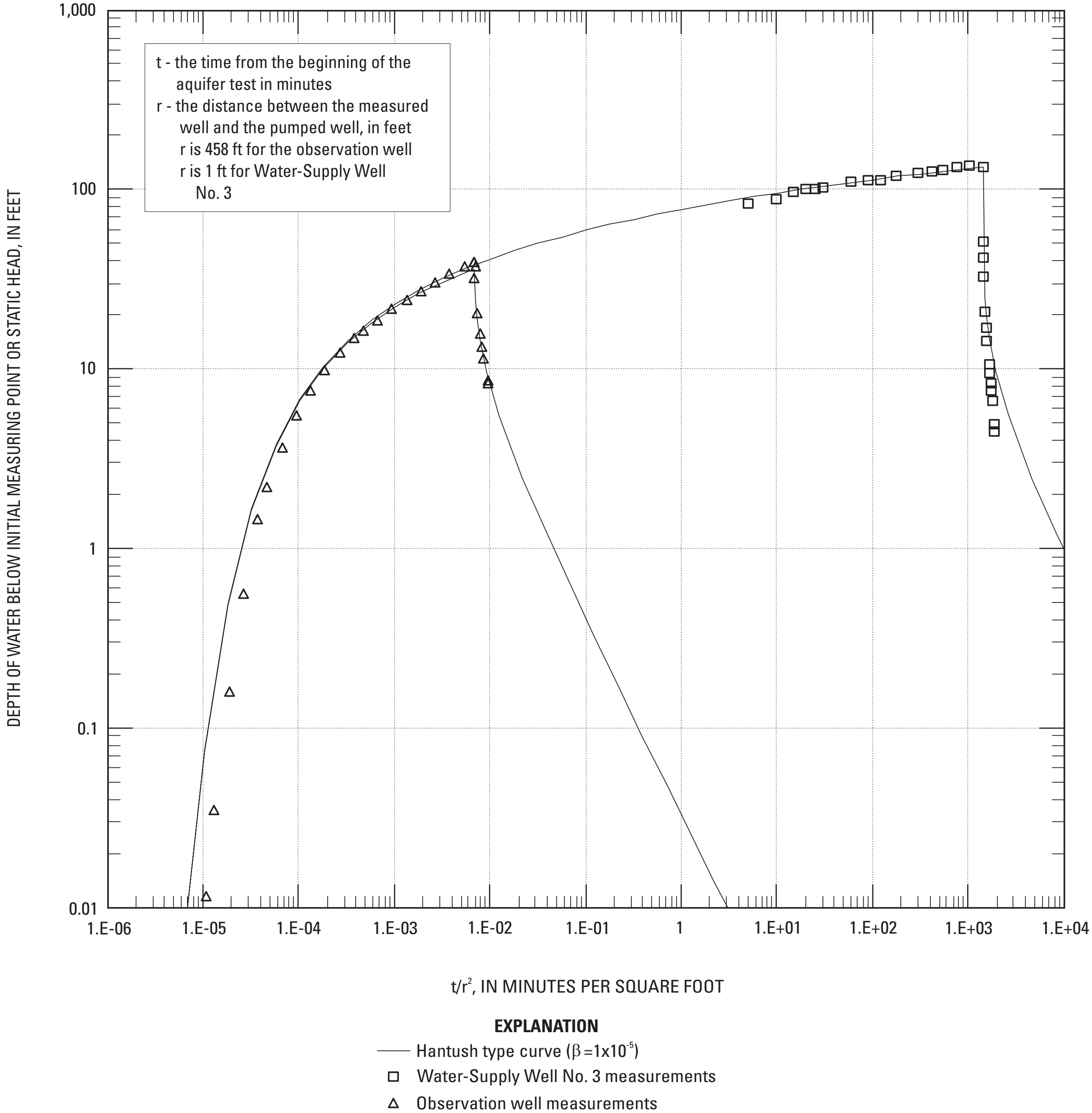

Figure 4. The fitted Hantush type curve and measured water levels in Water-Supply Well No. 3 and the observation well, Prairie Island Indian Community, Minnesota, September 10-11, 2001.

pumped well for Water-Supply Well No. 3 was set to 1 foot for this analysis. The best fit for the Hantush type curve had a very small β, 1 x 10^{-5}, indicating that leakage through the overlying Eau Claire confining unit is not significant. The fitted Hantush type curve is not significantly different from the fitted Theis type curve.The transmissivity and storage coefficients for the Mt. Simon aquifer, determined by the two methods, are 3,000 ft^2/d and 3 x 10^{-4}, respectively. The average hydraulic conductivity is 10 ft/d, assuming an aquifer thickness of 233 ft.

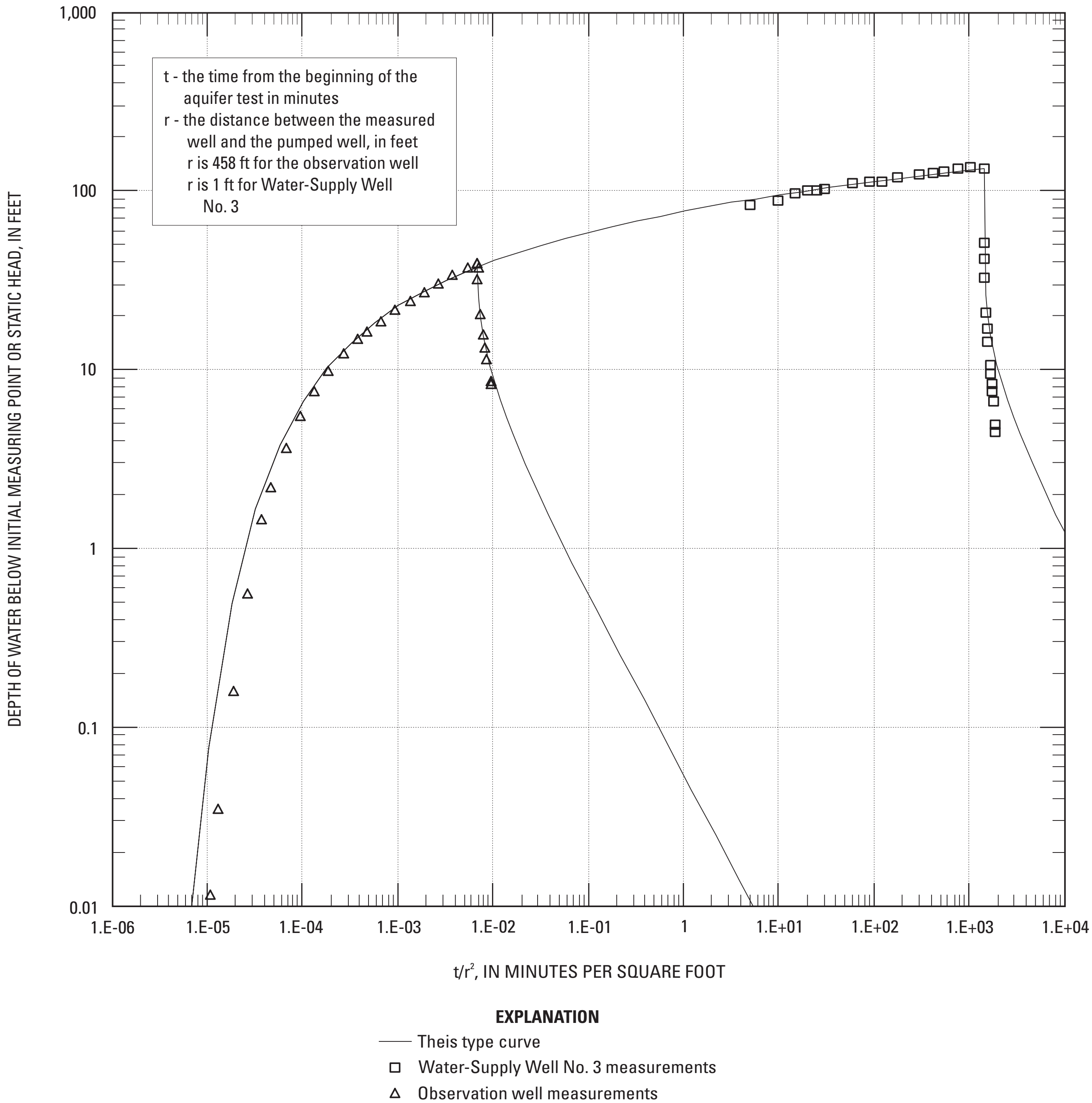

Figure 5. The fitted Theis type curve and measured water levels in Water-Supply Well No. 3 and the observation well, Prairie Island Indian Community, Minnesota, September 10-11, 2001.

SUMMARY

An aquifer test of the Mt. Simon aquifer was conducted at the northern end of the Prairie Island Indian Community, in cooperation with the Prairie Island Indian Community, September 10-11, 2001. Two wells at the northern end of Prairie Island were used in the aquifer test. The pumped well was Water-Supply Well No. 3, which is completed in the Mt. Simon aquifer. The well is cased from land surface to a depth of 480 ft and is open to the aquifer from a depth of 480 ft to 701 ft. The observation well is located 458 ft south of Water-Supply Well No. 3 and also is completed in the Mt. Simon aquifer. The observation well is cased from the land surface to a depth of 480 ft and is open to the aquifer from a depth of 480 ft to 602 ft.

Water-Supply Well No. 3 was pumped at 1,530 gal/min for 24 hours. The pumping began on September 10, 2001 at 07:00. The pump was shut off at 07:02 September 11, 2001. The aquifer test ended at 17:03 September 11, 2001. Drawdown and recovery water levels were measured in the pumped and observation wells.

The Theis and Hantush type curves were fitted simultaneously to the measured water levels in Water-Supply Well No. 3 and the observation well. The best fit for the Hantush type curve had a very small β, 1 x 10^{-5}, indicating that leakage through the overlying Eau Claire confining unit was not significant. The fitted Hantush type curve was not significantly different from the fitted Theis type curve. The transmissivity and storage coefficients for the Mt. Simon aquifer, determined by the two methods, are 3,000 ft^2/d and 3 x 10^{-4}, respectively. The hydraulic conductivity is 10 ft/d, assuming an aquifer thickness of 233 ft.

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SUPPLEMENTAL INFORMATION

THEIS TYPE CURVE

Assumptions (Hydrosolve, 2000)

1. Aquifer has infinite areal extent;
2. Aquifer is homogeneous, isotropic and of uniform thickness;
3. Pumped well is fully or partially penetrating;
4. Flow to pumped well is horizontal when pumped well is fully penetrating;
5. Aquifer is confined;
6. Flow is unsteady;
7. Water is released instantaneously from storage with decline of hydraulic head; and
8. Diameter of pumped well is very small so that storage in the well can be neglected.

Equations for type curve (Hydrosolve, 2000)

1.

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y}dy = \frac{Q}{4\pi T}w(u)$$

, where w(u) is the Theis well function

2.

$$u = \frac{r^2 S}{4Tt}$$

where

Q is pumping rate [ft^3/min];

r is radial distance [ft];

s is displacement [ft];

S is storage coefficient of the aquifer [dimensionless];

t is time since pumping began [min];

T is aquifer transmissivity [ft^2/min]; and

y is variable of integration.

HANTUSH TYPE CURVE

Assumptions (Hydrosolve, 2000)

1.Aquifer has infinite areal extent;
2. Aquifer is homogeneous, isotropic and of uniform thickness;
3. Aquifer potentiometric surface is initially horizontal;
4. Pumped well is fully or partially penetrating;
5. Flow to pumped well is horizontal when pumped well is fully penetrating;
6. Aquifer is leaky;
7. Flow is unsteady;
8. Water is released instantaneously from storage with decline of hydraulic head;
9. Diameter of pumped well is very small so that storage in the well can be neglected;
10. Confining unit(s) has infinite areal extent, uniform vertical hydraulic conductivity and storage coefficient, and uniform thickness;
11. Confining unit(s) is overlain or underlain by an infinite constant-head plane source; and
12. Flow in the confining unit(s) is vertical.

Equations (Hantush, 1960; Hydrosolve, 2000)

1.

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y} erfc \frac{\beta\sqrt{u}}{\sqrt{y(y-u)}}dy$$

2.

$$u = \frac{r^2 S}{4Tt}$$

3.

$$\beta = \frac{r}{4}\left(\sqrt{\frac{K'S'}{b'TS}}\right)$$

where

K' is the vertical hydraulic conductivity of the confining unit separating the aquifers [ft/d];

S' is the storage coefficient of the confining unit separating the aquifers [dimensionless];

b' is the vertical thickness of the confining unit separating the aquifers [ft]; and

all others as previously defined.