Analysis of Hydrogeologic Properties in the Prairie du Chien-Jordan Aquifer, Shakopee Mdewakanton Sioux Community, Southeastern Minnesota

By Michael L. Strobel and Geoffrey N. Delin

U.S. Geological Survey
Open-File Report 96-182

Prepared in cooperation with the
Shakopee Mdewakanton Sioux Community

Mounds View, Minnesota
1996

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
2280 Woodale Drive
Mounds View, MN 55112

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

Contents

Illustrations

Conversion Factors and Abbreviations

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	.3048	meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	.02832	cubic meter per second

Chemical concentrations: Chemical concentrations of substances in water are given in metric units of micrograms per liter (µg/L). Micrograms per liter is a unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

Analysis of Hydrogeologic Properties in the Prairie du Chien-Jordan Aquifer, Shakopee Mdewakanton Sioux Community, Southeastern Minnesota

by

Michael L. Strobel and Geoffrey N. Delin

Abstract

The Prairie du Chien-Jordan aquifer is a major source of water for many communities in southeastern Minnesota. The water-supply well for the Shakopee Mdewakanton Sioux Community derives water from the Jordan part of the aquifer. An aquifer test in the Prairie du Chien-Jordan aquifer in the area of the Shakopee Mdewakanton Sioux Community was completed in November 1995. The test consisted of pumping water from a public works well open to the Jordan part of the aquifer and measuring drawdown in this well and two observation wells. This was followed by measuring recovery in the wells after the pumping was terminated.

The Neuman (1974) method for unconfined aquifers was used to analyze data collected from the two observation wells during the drawdown and recovery periods, resulting in a range of estimated aquifer hydraulic properties. Aquifer transmissivity ranged from 4,710 to 7,660 ft^2/d and aquifer storativity ranged from 8.24×10^{-5} to 1.60×10^{-4}. These values are generally in close agreement for all four sets of data, given the limitations of the test, indicating that the test results are accurate and representative of the aquifer hydrogeologic properties. The lack of late-time data made it impossible to accurately assess aquifer specific yield.

Introduction

The Prairie du Chien-Jordan aquifer (fig. 1) is a major source of water for many communities in southeastern Minnesota. Most public-supply wells in this area are open only to the Jordan Sandstone part of the aquifer. Little information exists about the hydraulic properties of the Jordan Sandstone in the area. In order to better define these properties, the U.S. Geological Survey conducted an aquifer test in cooperation with the Shakopee Mdewakanton Sioux Community. The information obtained from the test will be of use to managers in developing water-management plans for the community.

The study area consisted of both the northern and southern parts of the Shakopee Mdewakanton Sioux Community (fig. 2). The aquifer test consisted of pumping water from a public works well open to the Jordan part of the aquifer and measuring drawdown in two observation wells. This was followed by measuring recovery in the

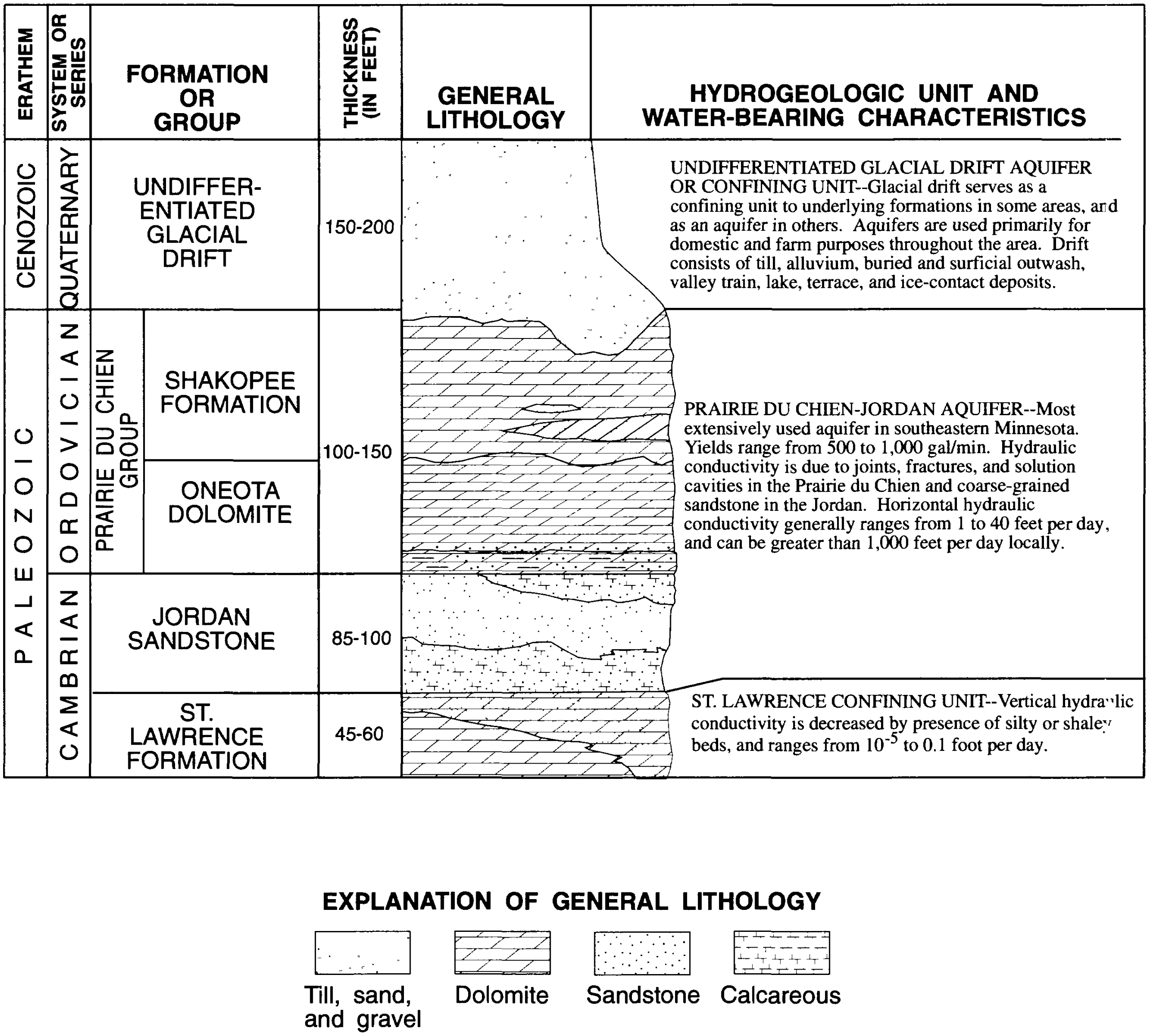

Figure 1. Generalized hydrogeologic column showing regional aquifers and confining units in the study area (modified from Delin, 1991; Olsen, 1982).

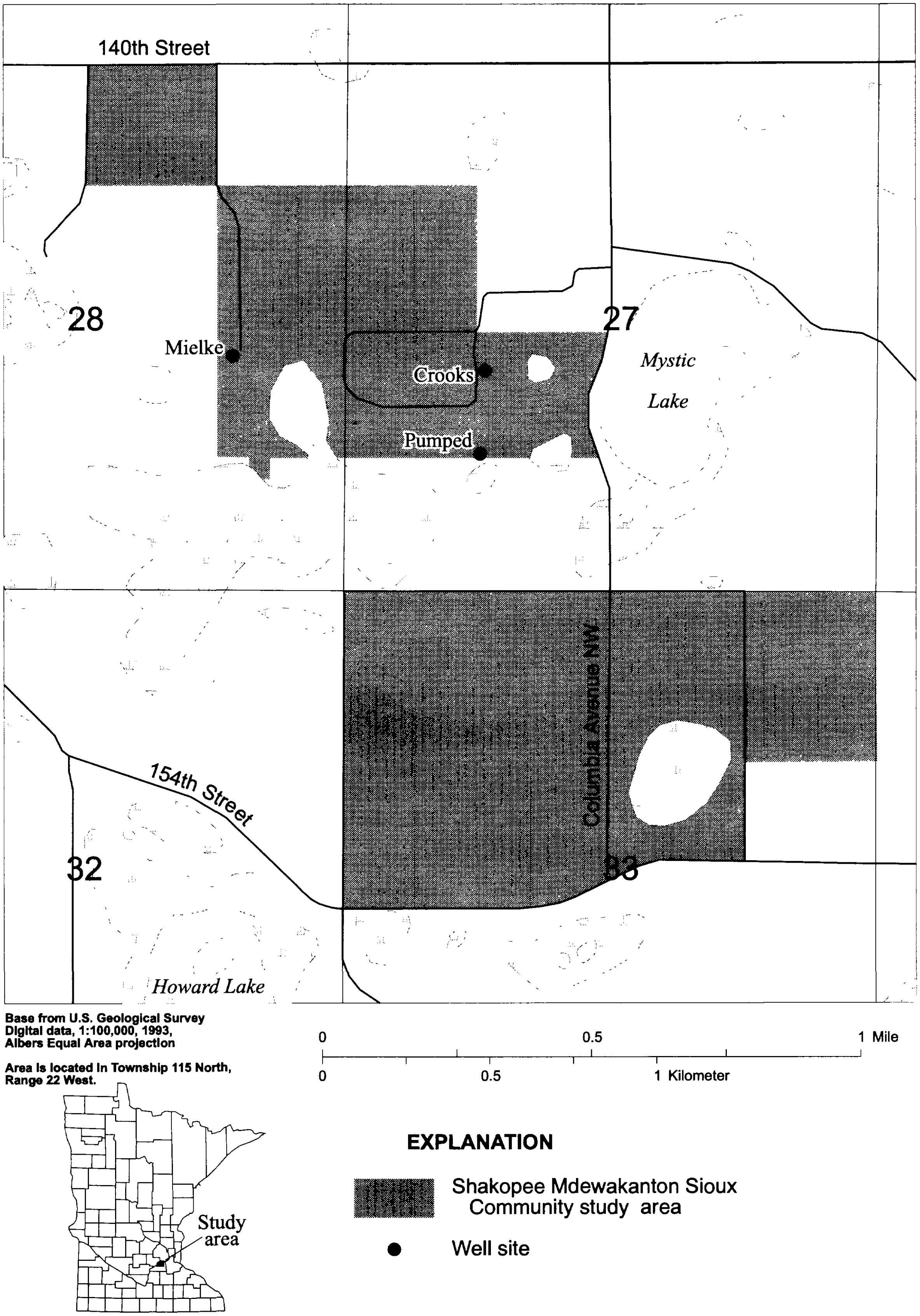

Figure 2. Location of Shakopee Mdewakanton Sioux Community study area, southeastern Minnesota.

wells after the pumping was stopped. The hydraulic properties of the aquifer were determined from this information.

Hydrogeologic Setting

The Shakopee Mdewakanton Sioux Community is located in hummocky glacial terrain. The local topographic relief ranges from 15 to 60 feet and elevations in the region are from 900 to 1,100 feet above mean sea level (Meyer, 1982). The surficial sediments consist of gray, calcareous, shale-rich, clayey till and contain small inclusions of reddish-brown drift (Aronow and Hobbs, 1982). Lakes and wetlands are present in depressions and low areas between hills. The surficial sediments generally range in thickness from about 150 to 200 feet (Olsen, 1982).

The surficial sediments in the study area are underlain by bedrock of the Prairie du Chien Group (fig. 3). This unit consists of the Oneota Dolomite overlain by the Shakopee Formation, a highly eroded limestone deposited as reefs and tidal-flat deposits (Olsen, 1982). The Prairie du Chien Group generally ranges in thickness from about 100 to 150 feet.

Underlying the Prairie du Chien Group is the Jordan Sandstone, which is a fine- to coarse-grained, poorly cemented, quartzose sandstone deposited as beach and near-shore sands (Olsen, 1982). The Jordan Sandstone generally ranges in thickness from 85 to 100 feet.

The St. Lawrence Formation underlies the Jordan Sandstone. This is a silty dolomite interbedded with siltstone, soft shale, and very-fine-grained quartzose sandstone (Olsen, 1982). The St. Lawrence Formation generally ranges in thickness from 45 to 60 feet.

These bedrock units have a limited areal extent in the vicinity surrounding the study area due to deeply incised buried valleys (fig. 3). The fluvial erosion that formed these valleys extended downward through the Prairie du Chien Group and Jordan Sandstone and into the St. Lawrence Formation, or the underlying Franconia Formation in nearby areas (Olsen, 1982). Late Wisconsin deposits fill the bedrock valleys to the south and east of the study area and the Minnesota River flows through the bedrock valley to the north and west, where bedrock units are either exposed or covered with Holocene and Pleistocene deposits. Because of these bedrock valleys, the Prairie du Chien Group and Jordan Sandstone are discontinuous in the vicinity surrounding the study area. The Prairie du Chien Group extends for about 41 square miles in the vicinity surrounding the study area, while the Jordan Sandstone extends for at least 50 square miles. A thin part of the Jordan Sandstone extends beneath the Minnesota River southwest of the study area. The Shakopee Mdewakanton Sioux Community is located near the eastern edge of the Prairie du Chien Group and Jordan Sandstone.

The hydrology near the study area is complex. The surficial sediments have a relatively low hydraulic conductivity and generally confine the bedrock aquifers, although some leakage through these sediments to the underlying bedrock aquifers probably occurs. Because of the low hydraulic conductivity in the surficial sediments, the water table is perched above the potentiometric surface in the bedrock units. There are numerous lakes and wetlands in low-lying areas in the surficial sediments. Lenses of sand and gravel within the till form shallow aquifers.

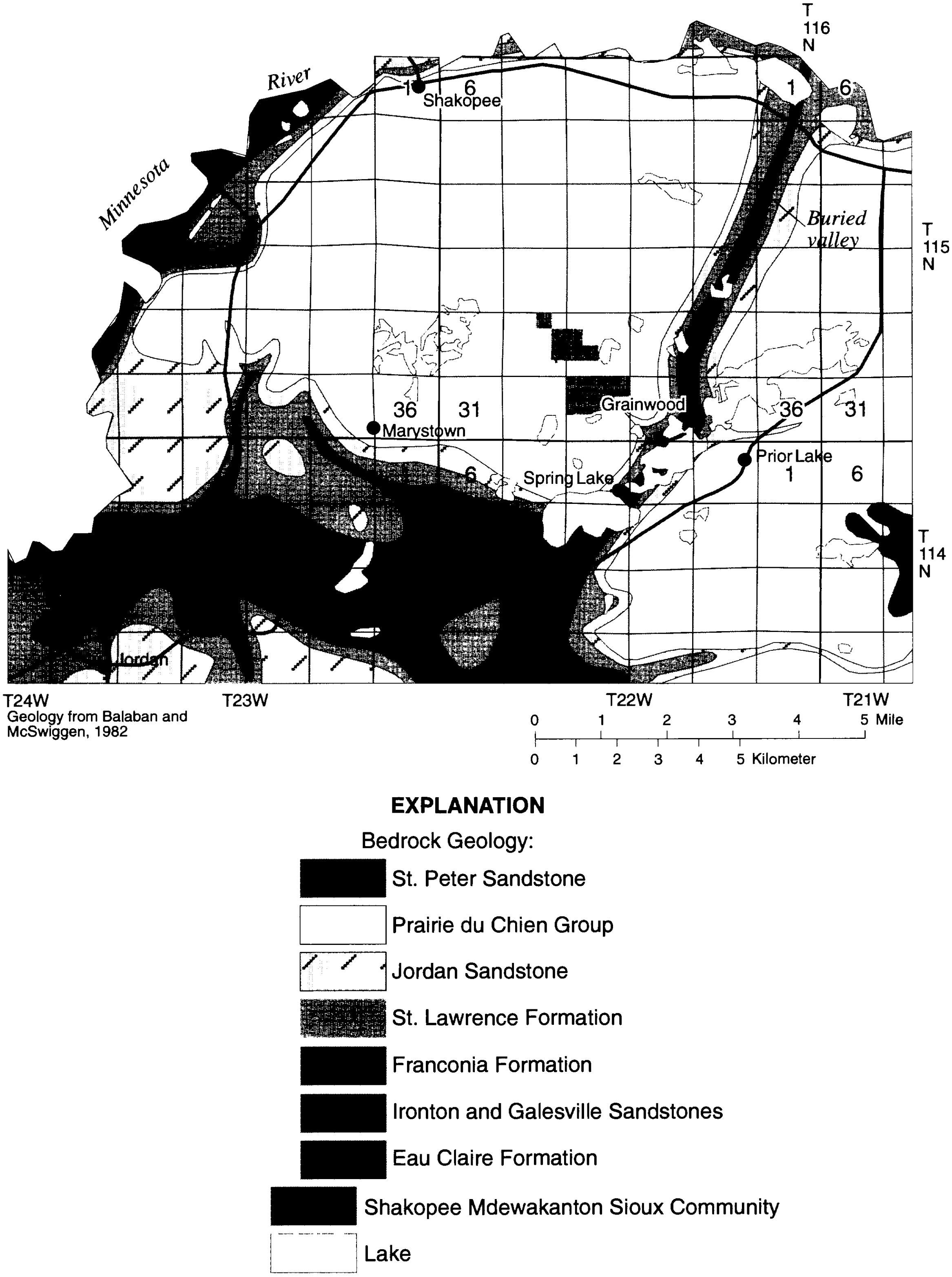

Figure 3. Bedrock geology near the study area (modified from Olsen, 1982)

The Prairie du Chien Group and Jordan Sandstone are hydraulically connected and form a single aquifer. The potentiometric surface of the Prairie du Chien-Jordan aquifer in the study area lies below the top of the Prairie du Chien Group; therefore, the aquifer is under unconfined conditions. Because the Prairie du Chien Group is only partially saturated in the area and most available water is present in zones of secondary porosity related to dissolution and fractures, the Jordan Sandstone is the most frequently used source of ground water from bedrock aquifers. It is uncertain how much recharge to the bedrock aquifers occurs through surficial sediments. Recharge comes partially from vertical leakage through the overlying glacial sediments and partially from lateral movement of water in the buried glacial valleys to the south and east of the area. Ground-water flow in the bedrock aquifer is generally to the northwest.

Aquifer Test Design

An aquifer test was designed to determine the hydraulic properties of the Prairie du Chien-Jordan aquifer near the public works well, which is the water-supply well for the Shakopee Mdewakanton Sioux Community. For this test, the public works well was pumped at 1,000 gallons per minute (gal/min), and water levels in this well and two observation wells were measured. The two observation wells included the Crooks well, located 845 feet to the northeast of the public works well, and the Mielke well, located 2,635 feet to the northwest of the public works well (fig. 2). The two observation wells are about 2,525 feet apart.

All three wells are cased from land surface to below the top of the Jordan Sandstone and are open through most of this formation. Because the thickness of the Jordan Sandstone varies throughout the study area, it is uncertain if the three wells completely penetrate the formation. Because the Prairie du Chien and Jordan Formations are hydraulically connected, for data analysis, it was assumed that the wells fully penetrate the entire aquifer. Drillers' logs for the public works well indicate an aquifer saturated thickness of 188 feet, which was used in analysis of the test data.

The public works well was pumped at 1,000 gal/min from 5:02 am on November 7th to 1:00 pm on November 8th for a total pumping time of about 32 hours. Pumping rates were maintained by periodic monitoring of hydraulic head in the discharge pipe. Water levels were measured throughout the aquifer test and for about 4 hours following cessation of pumping (recovery period). Water levels were measured using a Devar[1] water-level meter, which measures the water level as a percent of the full scale of the pressure transducer (0 percent = 300 feet below the measuring point, 100 percent = 206 feet below the measuring point, which is approximately the static water level) and manually by electronic tape. Insufficient water-level data were collected from the public works well during the test for determination of aquifer hydraulic properties.

Water levels in the two observation wells were measured both by In Situ[1] pressure transducers and manually by electronic tapes. Water levels were measured (1) from 10:30 am on November 6th to the start of the test to identify static conditions, (2) throughout the aquifer test, and (3) for about 3 hours during the recovery period. Static water

[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

levels prior to the start of pumping were measured in the observation wells at 30 minute intervals. Drawdown measurements were made until 12:25 pm on November 8th in the Crooks well and until 12:19 pm on November 8th in the Mielke well.

Discharge from the public works well during the aquifer test was directed to a local wetland located south and west of the well (fig. 2). It was assumed that the hydraulic conductivity of the surficial sediments was sufficiently small to disregard any recharge to the aquifer from this surface discharge during the test.

Barometric pressure was measured from before the beginning of the pumping through the recovery period. Plots of barometric pressure were used to observe atmospheric effects on water levels and to calculate the barometric efficiency of the aquifer.

Aquifer Test Results

Pre-pumping water levels did not show any visible effect from changes in barometric pressure. However, the water levels did vary less than one foot during this pre-test period and these changes are probably related to pumping from local domestic wells. There were insufficient data to accurately quantify the affects of the pumping from local domestic wells on the water levels in the observation wells during the aquifer test; however, because the pumping for the test began early in the morning and the pumping of domestic wells occurred primarily in the evening, their effects likely did not alter the drawdown measured in the observation wells.

Drawdown in the Crooks well was detected about 3.6 minutes after pumping began at 5:02 am on November 7th. Drawdown in the Mielke well was detected after about 10 minutes of pumping. Drawdown and recovery curves were compared to a number of curve-fitting methods to determine the best-fit conditions. The method that provided the best fit for the early part of the drawdown and recovery curves for an unconfined aquifer was that described by Neuman (1972, 1974, 1975). Neuman (1974) provides a set of type curves for analyzing unsteady flow to a well in an unconfined aquifer with delayed gravity response. The method is based on the assumption that the aquifer is unconfined, infinite in areal extent, homogeneous, of uniform thickness, has a horizontal water table prior to pumping, pumping is at a constant rate, flow is unsteady, the pumped and observation wells penetrate the full thickness of the aquifer, the specific yield is at least 10 times larger than the storativity, and the pumped wells have negligible storage (diameters of the wells are small) (Neuman, 1975).

The drawdown equation outlined by Neuman (1975) is

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

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,

T = transmissivity,

r = radial distance from the pumping well,

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

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

t = time,

K_v = vertical hydraulic conductivity,

K_h = horizontal hydraulic conductivity, and

b = initial saturated thickness of the aquifer.

Drawdown data for the two observation wells were matched to the type curves plotted to the same scale based on the solutions of Neuman (1974). In both wells, early-time drawdown exhibited curves that closely matched the type curves, but the aquifer test did not extend long enough to produce sufficient data for accurate specific yield (late-time) analysis. Likewise, the recovery data extended for about three hours and allowed only for analysis of early-time conditions. Thus, estimates of specific yield could not be made from the data available.

Drawdown data from the Crooks well showed a good match to the type curve for $\beta = 0.03$ (fig. 4). Analysis of the early-time data produced a transmissivity of 4,710 feet squared per day (ft^2/d) and a storativity of 9.47×10^{-5}. The ratio of the vertical hydraulic conductivity to the horizontal hydraulic conductivity was 1.5×10^{-3}. The horizontal hydraulic conductivity was 25.1 ft/d, based on a saturated thickness of 188 ft.

Recovery data from the Crooks well also showed a good match to the type curve for $\beta = 0.03$ (fig. 5). Analysis of the early-time data produced a transmissivity of 4,900 ft^2/d and a storativity of 8.24×10^{-5}. The horizontal hydraulic conductivity was 26.1 ft/d, based on a saturated thickness of 188 ft. These values agree well with those calculated from the drawdown data.

Drawdown data from the Mielke well showed a good match to the type curve for $\beta = 0.2$ (fig. 6). Analysis of the early-time data produced a transmissivity of 6,810 ft^2/d and a storativity of 1.60×10^{-4}. The horizontal hydraulic conductivity was 36.2 ft/d, based on a saturated thickness of 188 ft. The ratio of the vertical hydraulic conductivity to the horizontal hydraulic conductivity was 1.1×10^{-3}.

Recovery data from the Mielke well also showed a good match to the type curve for $\beta = 0.2$ (fig. 7). The early-time data produced a transmissivity of 7,660 ft^2/d and a storativity of 1.60×10^{-4}. The horizontal hydraulic conductivity was 40.7 ft/d, based on a saturated thickness of 188 ft. These values agree well with those calculated from the drawdown data.

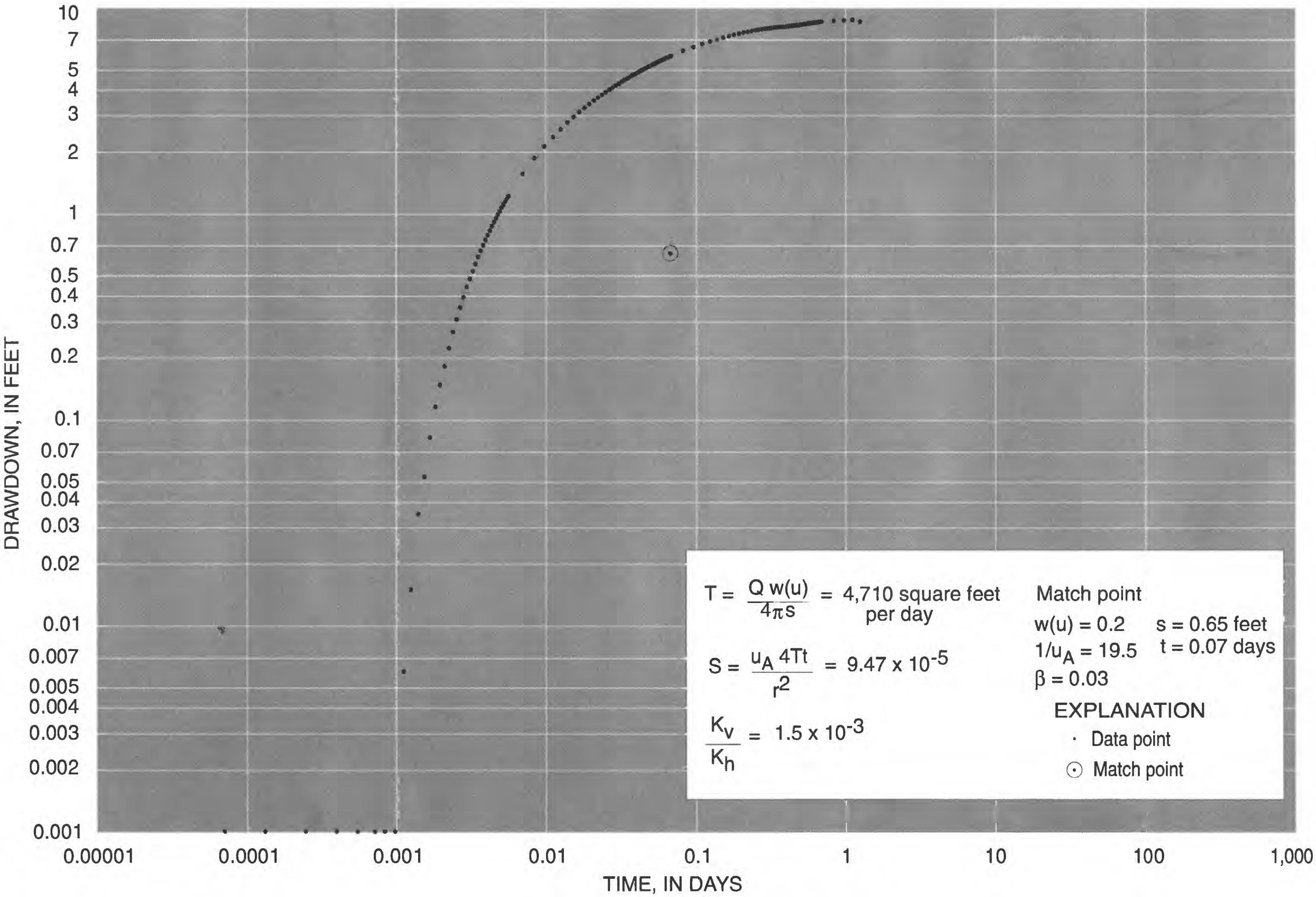

Figure 4. Log-log plot of drawdown for the Crooks well.

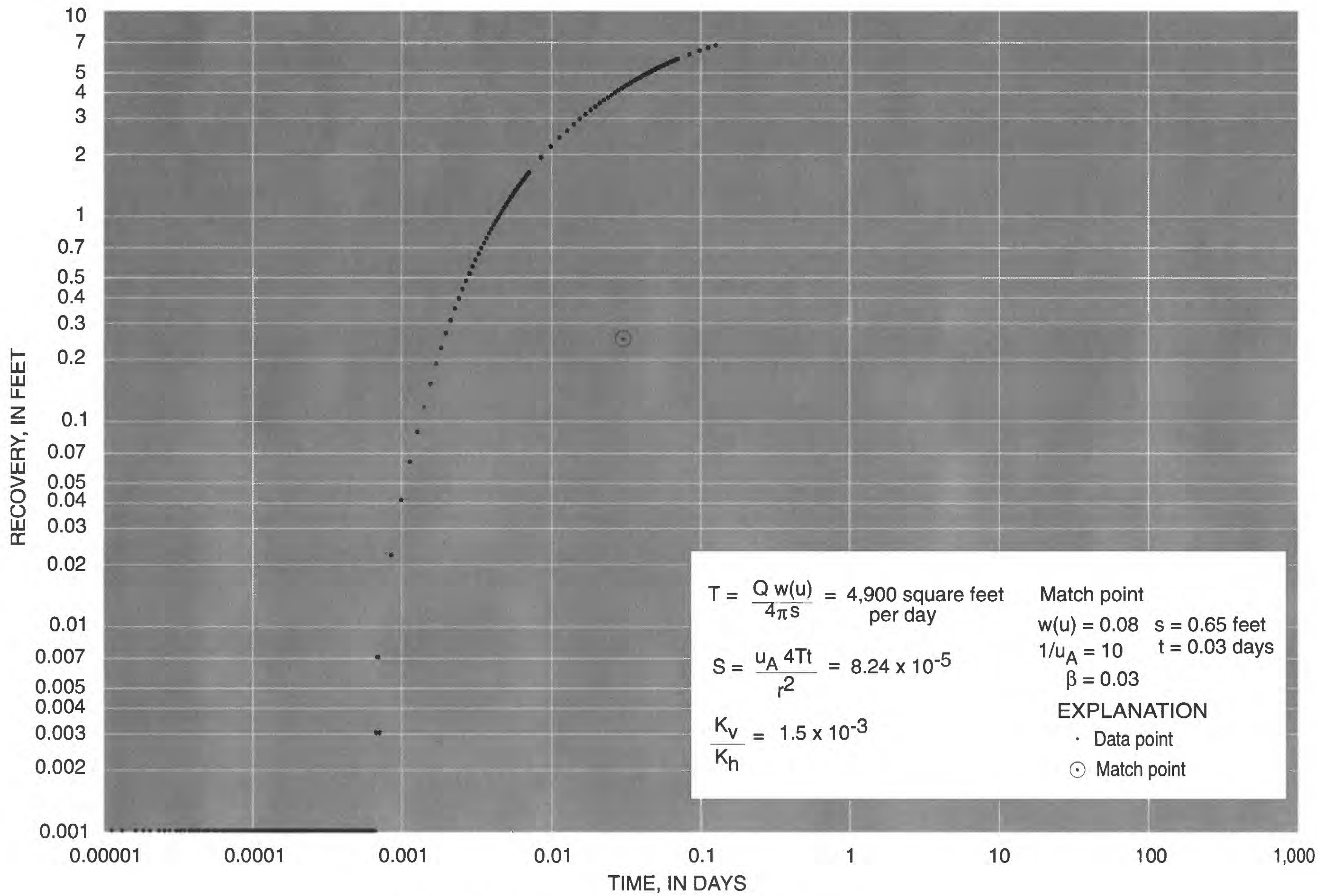

Figure 5. Log-log plot of recovery for the Crooks well.

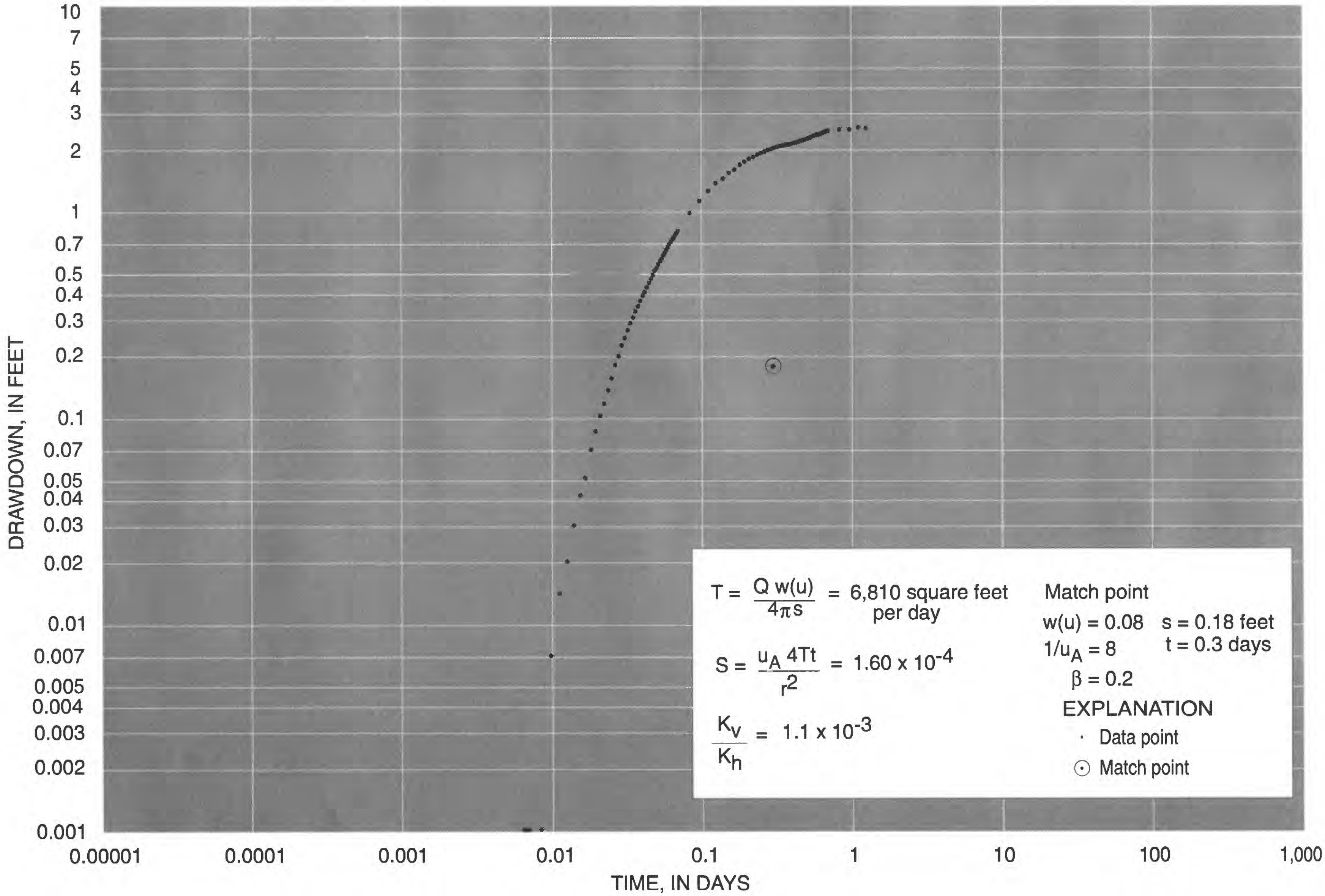

Figure 6. Log-log plot of drawdown for the Mielke well.

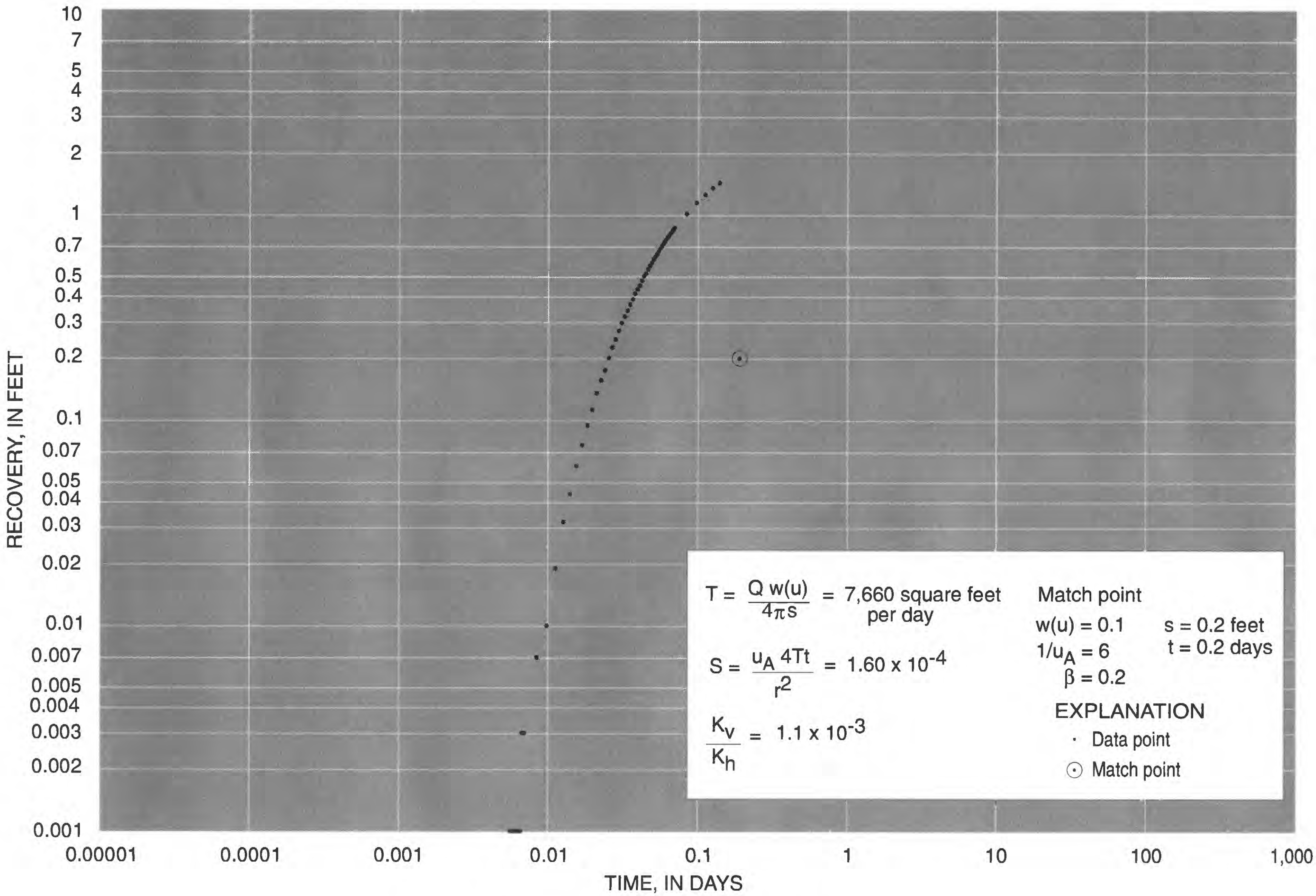

Figure 7. Log-log plot of recovery for the Mielke well.

Drawdown in both the Crooks and Mielke wells shows some deviation from the type curve during the second half of the aquifer test (figs. 6 and 7). Variations from the smooth curve may be the result of pumping from local domestic wells. However, it appears these effects are minor and don't significantly influence the test results.

Conclusions and Discussion

Using the Neuman (1974) method of analysis for the two observation wells resulted in a range of estimated aquifer hydraulic properties. The transmissivity for the aquifer ranged from 4,710 to 7,660 ft^2/d. The storativity ranged from 8.24 x 10^{-5} to 1.60 x 10^{-4}. Horizontal hydraulic conductivity ranged from 25.1 to 40.7 ft/d. These values are generally in close agreement for all four sets of data, given the limitations of the test, indicating that the test results are accurate and representative of the aquifers hydraulic properties. The lack of late-time data makes it impossible to accurately estimate aquifer specific yield.

The Prairie du Chien-Jordan aquifer is essentially isolated in the study area by buried valleys incised through these units and into the underlying geology. Had the aquifer test lasted longer, boundary effects from these unconformities probably would have been detected. It is important to consider the spatial extent of the aquifer when determining any management plans for the area.

It is uncertain whether the main source of recharge to the aquifer in the study area is from the buried valley directly to the east of the study area or from leakage through surficial sediments. The aquifer test was not extensive enough to stress the aquifer to its lateral boundaries. Additional observation wells in the aquifer and overlying surficial sediments would be required to better assess the sources of recharge to the aquifer. In addition, chemical analysis of the ground water may provide information about sources of recharge and flow paths. Further study is needed to assess the sources of recharge, thereby allowing adequate management plans for protecting the water quality of the aquifer. Future aquifer tests conducted using the community wells would need to be run for about 2 to 4 days to evaluate the effects of recharge, lateral boundaries, and aquifer specific yield.

The limitations of the aquifer test data creates some uncertainty about the test results. First, the lack of late-time data makes the analysis of specific yield impossible using type-curve techniques provided by Neuman (1975). The initial drawdown observed in the pumping well mimics confined conditions (compression of the aquifer skeleton and expansion of the water) and is only minimally affected by specific yield. This allows for the calculation of transmissivity and storativity, but neglects the major source of water to the public works well, that from specific yield. Second, without a value for specific yield, the validity of the Neuman (1975) method cannot be tested. Recall that for the method to be valid, the specific yield must be at least ten times larger than the storativity. This assumption cannot be supported from the data available.

References

Aronow, S., and Hobbs, H.C., 1982, Surficial geologic map, map C-1, plate 2, *in* Balaban, N.H., and McSwiggen, P.L., eds., 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.

Meyer, G.N., 1982, Surficial geologic cross sections, map C-1, plate 3, *in* Balaban, N.H., and McSwiggen, P.L., eds., Geologic atlas, Scott County, Minnesota, County Atlas Series, Minnesota Geological Survey, Map C-1, 6 plates.

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.

Olsen, B.M., 1982, Bedrock geology, map C-1, plate 5, *in* Balaban, N.H., and McSwiggen, P.L., eds., Geologic atlas, Scott County, Minnesota, County Atlas Series, Minnesota Geological Survey, Map C-1, 6 plates.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1996 - 774-384 / 06007 REGION NO. 8