Hydraulic Properties and Ground-Water Flow in the St. Peter-Prairie du Chien-Jordan Aquifer, Rochester Area, Southeastern Minnesota

By Richard J. Lindgren

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Contents

List of Illustrations

List of Tables

Conversion Factors and Vertical Datum

Multiply	By	To obtain
cubic foot per second (ft^3/s)	.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	.3048	meter per day
foot per mile (ft/mi)	.18943	meter per kilometer
gallon (gal)	3.785	liter
gallon per minute (gal/min)	.6308	liter per second
inch (in.)	25.4	millimeter
inch per year (in./yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
million gallon (Mgal)	3,785	cubic meter
million gallon per year (Mgal/yr)	.0001200	cubic meter per second
square foot per day (ft^2/d)	.09290	square meter per day
square mile (mi^2)	2.590	square kilometer

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 both the United States and Canada, formerly Sea Level Datum of 1929.

Hydraulic Properties and Ground-Water Flow in the St. Peter-Prairie du Chien-Jordan Aquifer, Rochester Area, Southeastern Minnesota

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Abstract

The hydraulic properties were updated and their effects on ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area in southeastern Minnesota were evaluated, using new information compiled since a study by Delin (1990). Since 1988, new information on the hydrogeology of the ground-water system in the Rochester area has become available from well-drilling and construction activity associated with Rochester's rapid growth. The St. Peter-Prairie du Chien-Jordan aquifer consists of the St. Peter Sandstone, the Prairie du Chien Group (limestones and dolomites), and the Jordan Sandstone. Horizontal hydraulic conductivity and transmissivity were determined from 15 aquifer tests and specific-capacity information compiled for 310 wells. A 140-square-mile area of the aquifer bounded on the west, south, and east by a ground-water divide contributes water to the Rochester, Minnesota, municipal wells.

Transmissivities for the St. Peter-Prairie du Chien-Jordan aquifer in the study area range from less than 5,000 square feet per day (ft^2/d) to greater than 20,000 ft^2/d. Transmissivities greater than 20,000 ft^2/d occur in the west-central, northwestern, and east-central parts of the study area. Transmissivities of less than 5,000 ft^2/d occur in the northern, northeastern, central, and southern parts of the study area. The areas of greatest potential well yield coincide with areas of greatest transmissivity.

Delin (1990) developed a ground-water-flow model to simulate flow of ground water in the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area. The 1988 Rochester model was rerun using revised horizontal hydraulic conductivity arrays in the model, based on the transmissivity distribution determined for this study. The results of the simulations using horizontal hydraulic conductivities based on the transmissivity distribution determined for this study may indicate that transmissivity values derived from specific-capacity information generally are too high. The transmissivity distribution determined for this study, however, is valid as an indicator of the spatial variability of the relative magnitude of transmissivity and potential well yield for the St. Peter-Prairie du Chien-Jordan aquifer in the study area.

Water-level changes in wells from January through February 1988 to February through March 1995 ranged from –6.8 to +15.3 feet. Water-level changes in 12 Rochester municipal wells for the same period ranged from –7.4 to +8.0 feet. Water levels in wells generally rose in the northern and eastern parts of the study area and generally declined in the southwestern and western parts. Near Rochester, water levels in wells generally declined near the city boundaries and showed little change or rose in the central part of the city. Water-level changes from 1988 to 1995 near the ground-water divide generally were less than 2 feet, resulting in no appreciable changes in the location of the divide.

Introduction

The primary source of ground water for the city of Rochester, Olmsted County, southeastern Minnesota (fig. 1), is the St. Peter-Prairie du Chien-Jordan aquifer. The aquifer is susceptible to contamination because it is near land surface. Based on a previous study (Delin, 1990), variable rates of recharge occur near Rochester, making evaluation of water availability complicated. For example, recharge along the edge of the overlying confining unit is about 13 in./yr compared to a rate of about 0.1 in./yr where the confining unit is present, and a rate of about 5 in./yr elsewhere. Ground water pumped by wells in the city of Rochester obtained as much as 50 percent of their 1988 water supplies from water entering the aquifer in the zone of increased recharge along the edge of the confining unit (Delin, 1990). Study results also indicated that water for six planned municipal wells would reduce seepage from

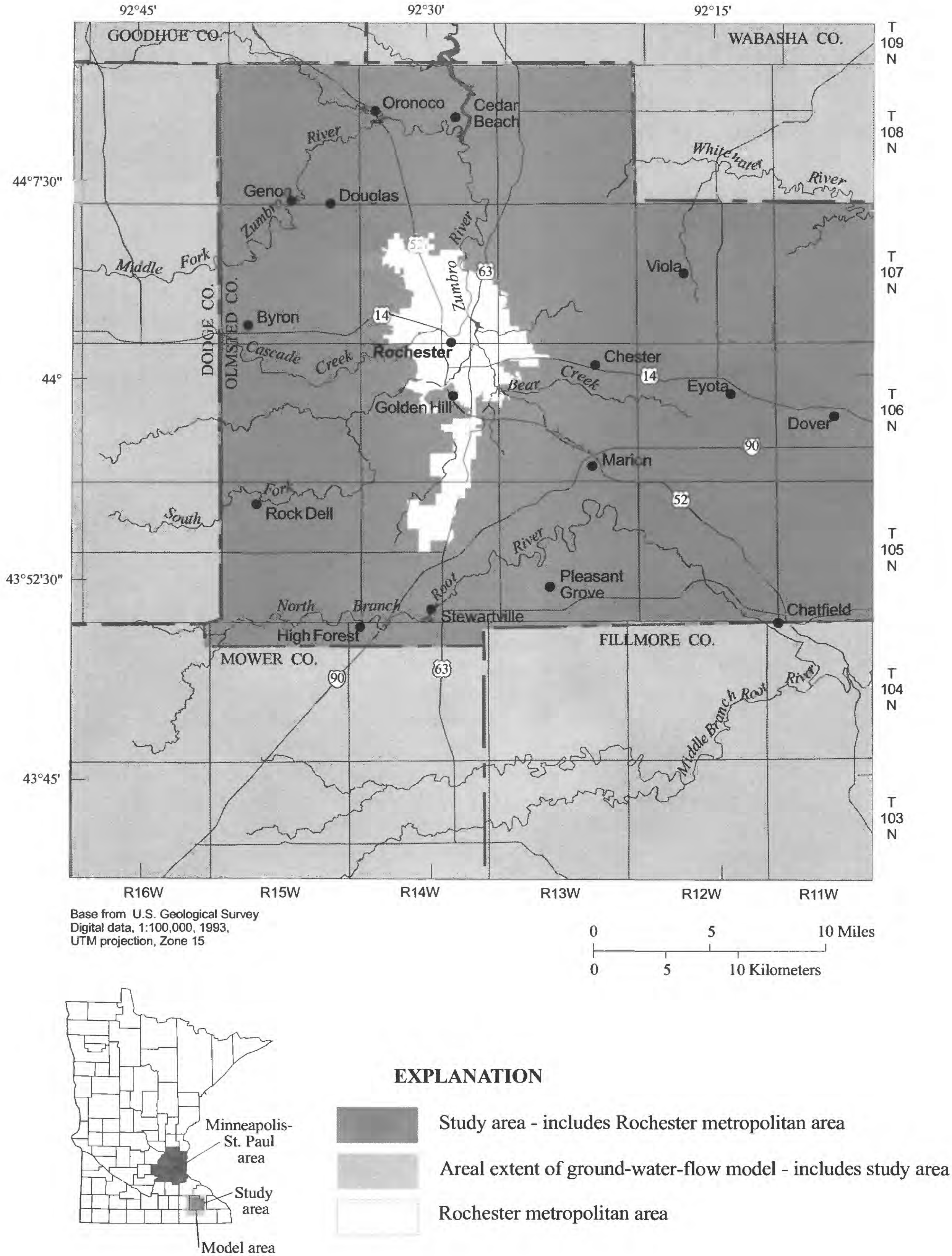


Figure 1. Location of study area and extent of ground-water-flow model.

the aquifer to streams in the area by about 39 percent. Therefore, management of both ground- and surface-water resources is critical for Rochester Public Utilities (RPU), which regulates Rochester municipal ground-water use. In addition, the Minnesota Department of Natural Resources (DNR) issues permits for ground-water use within the State and is promoting conservation and efficient use of water in the city of Rochester. Additional information is needed on the availability and sources of water in Rochester for the RPU and the DNR to better manage ground-water resources in the area.

In 1988, the Minnesota Geological Survey (MGS) published a geologic atlas for Olmsted County, describing the regional geologic and hydrologic framework of the ground-water system in the county. In 1990, the results of a ground-water study (Delin, 1990) described the hydrogeology and ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer during 1987–88. Since 1988, new information on the hydrogeology of the ground-water system in the Rochester area has become available from well-drilling and construction activity associated with Rochester's rapid growth. To manage the ground-water resources and to plan for additional development, the RPU and the DNR need the most current information available on the hydraulic properties and flow of water in the St. Peter-Prairie du Chien-Jordan aquifer. The RPU also is interested in potential changes in the potentiometric surface of the St. Peter-Prairie du Chien-Jordan aquifer and the contributing area of flow to the Rochester municipal wells due to increasing ground-water withdrawals since 1988.

The U.S. Geological Survey (USGS), in cooperation with the city of Rochester and the DNR, conducted a 2-year study (October 1994–September 1996) to update the hydraulic properties and evaluate their effects on ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area. Specific objectives of the study were to (1) develop an improved definition of the hydraulic properties of the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area, (2) evaluate the effect of the updated hydraulic-properties information on previous ground-water-flow-model results (Delin, 1990), and (3) determine changes in the potentiometric surface from 1988 to 1995 due to increased ground-water withdrawals. Results from the study will contribute to an improved understanding of ground-water systems in similar hydrogeologic settings.

Delin (1990) constructed a numerical ground-water-flow model, hereinafter termed the 1988 Rochester model, to simulate ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer near Rochester. The transmissivity distribution determined for the current (October 1994–September 1996) study was incorporated into the 1988 Rochester model, and the model was rerun. An improved mapping of horizontal hydraulic conductivity and transmissivity for an aquifer should presumably result in a more accurate simulation of hydraulic heads and flows in the aquifer. The changes in model-computed hydraulic heads and the model-computed water budget from the 1988 Rochester model, due to the change in horizontal hydraulic conductivities (derived from the updated transmissivity distribution) used in the model, were determined. The effects of the changes in model-computed hydraulic heads and the model-computed water budget on simulated ground-water flow were evaluated.

This report (1) presents the updated hydraulic-property information for the St. Peter-Prairie du Chien-Jordan aquifer, including maps showing aquifer transmissivity and potential well yield; (2) presents the evaluation of the effect of the updated hydraulic-property information on previous ground-water-flow-model results (Delin, 1990); and (3) describes changes in the potentiometric surface for the St. Peter-Prairie du Chien-Jordan aquifer from 1988 to 1995. Changes in the potentiometric surface in the St. Peter-Prairie du Chien-Jordan aquifer are based on a comparison of winter 1995 (February–March) water levels in wells and water levels in the same wells measured during winter 1988 (January–February). The purpose of describing changes in model-computed hydraulic heads and the model-computed water budget from the 1988 Rochester model, due to the incorporation of hydraulic conductivity values derived from the updated transmissivity distribution in this report, is to evaluate the effects of the transmissivity distribution on flow in the St. Peter-Prairie du Chien-Jordan aquifer. The only input data that changed in the 1988 Rochester model were horizontal hydraulic conductivities; the model was not recalibrated to recent measured hydraulic-head and stream-seepage values.

The study area covers about 700 mi^2 in Olmsted County and parts of surrounding counties in southeastern Minnesota (fig. 1). The city of Rochester is in the west-central part of Olmsted County. The model area covers approximately 1,050 mi^2 in parts of Olmsted, Fillmore, Mower, Dodge, Goodhue, and Wabasha Counties. This area is larger than the study area because the model area includes regional ground-water boundaries. The study area is drained by the Zumbro, Whitewater, and Root Rivers, which are tributaries of the Mississippi River. Topography is rolling to undulating in upland areas and steep near streams and drainageways. About 65 to 75 percent of the approximately 27.5 in. of mean annual precipitation (Baker and Kuehnast, 1978) is rainfall during May through September.

Hydrogeology

The sequence of sedimentary rocks in the Rochester area (fig. 2) has been divided into hydrogeologic units of regional aquifers and regional confining units (Delin and Woodward, 1984; Balaban, 1988). Regional bedrock aquifers, in descending order, are the upper carbonate, St. Peter-Prairie du Chien-Jordan, Franconia-Ironton-Galesville, and the Mount Simon (Balaban, 1988). Regional bedrock confining units, in descending order, are

Erathem	System or Series	Formation or Group	General Lithology	Thickness (in feet)	Water-Bearing Characteristics
Cenozoic	Quaternary	Undifferentiated Glacial Drift		0-250	**Undifferentiated Drift confining unit**--Glacial drift generally serves as as a cofining unit to underlying formations but locally may supply water to wells. Drift consists primarily of till, valley-train and lake deposits, and surficial outwash. Drift is thin or absent throughout much of the area.
Paleozoic	Ordovician	Maquoketa Shale		about 70	
		Dubuque Formation		about 30	**Upper carbonate aquifer**--Used for domestic purposes in upland areas of Olmsted County. Permeability is attributed to extensive karst development. The horizontal hydraulic conductivity generally ranges from 3 to 40 feet per day. Well yields range from 200 to 500 gallons per minute but are highly variable because solution cavities and channels differ in size and distribution.
		Galena Dolomite		210	
		Decorah Shale		40	**Decorah-Platteville-Glenwood confining unit**--The vertical hydraulic conductivity is probably about 10 feet per day.
		Platteville Formation		25	
		Glenwood Formation		5	
		St. Peter Sandstone		100	**St. Peter-Prairie du Chien-Jordan aquifer**--Most extensively used aquifer in Olmsted County. Ground-water flow is through joint, fractures, and solution cavities in the Prairie du Chien and is between grains in the St. Peter and Jordan aquifers. Horizontal hydraulic conductivity generally ranges from 1 to 40 feet per day but can be greater than 1,000 feet per day locally. Yields to wells commonly range from 500 to 1,000 gallons per minute and can exceed 2,000 gallons per minute.
		Prairie du Chien Group: Shakopee Formation		130	
		Prairie du Chien Group: Oneota Dolomite		170	
	Cambrian	Jordan Sandstone	NOT EXPOSED IN OLMSTED COUNTY	100	
		St. Lawrence Formation		75	**St. Lawrence confining unit**--The vertical hydraulic conductivity is probably about 10^{-6} and 0.1 foot per day.
		Franconia Formation		185	**Franconia-Ironton-Galesville aquifer**--Several Rochester municipal wells are completed in this aquifer. Hydraulic properties are not well known. The horizontal hydraulic conductivity is probably between 0.1 and 10 feet per day. Yields to wells commonly range from 100 to 500 gallons per minute in other parts of the state.
		Ironton and Galesville Sandstones		65	
		Eau Claire Formation		about 110	**Eau Claire confining unit**--Hydraulic properties are not well known. The vertical hydraulic conductivity is probably between 10^{-6} and 0.1 foot per day.
		Mt. Simon Sandstone		about 200	**Mount Simon aquifer**--Hydraulic properties are not well known. Based on data from other parts of Minnesota, the horizontal hydraulic conductivity is about 10 feet per day.
Proterozoic				about 1300	**Confining unit**--Hydraulic properties are not well known.

EXPLANATION OF GENERAL LITHOLOGY

- Till, sand, and gravel
- Dolomite
- Shale
- Limestone
- Sandstone

Figure 2. Generalized hydrogeologic column of regional aquifers and confining units, Olmsted County, Minnesota (geology modified from N.H. Balaban, 1988).

the Decorah-Platteville-Glenwood, St. Lawrence, and Eau Claire. Glacial deposits in the area locally confine the underlying bedrock aquifers. A generalized hydrogeologic column illustrating the vertical distribution of each unit and its water-bearing characteristics is shown in figure 2. The reader is referred to Balaban (1988) and Delin (1990) for a detailed description of the lithology and hydraulic characteristics of the hydrogeologic units in the Rochester area.

The St. Peter-Prairie du Chien-Jordan aquifer is composed of the St. Peter Sandstone, the Prairie du Chien Group (limestones and dolomites), and the Jordan Sandstone (fig. 2). The St. Peter Sandstone is a fine- to medium-grained sandstone, well sorted and poorly cemented; its average thickness is about 100 ft (Balaban, 1988). The St. Peter Sandstone, which underlies areas west, south, and east of Rochester (fig. 3), is exposed along road cuts and outcrops in the city. The underlying Prairie du Chien Group is composed of the Shakopee Formation, a sandy, shaley, thin-bedded dolomite, and the thick-bedded Oneota Dolomite. Average thickness of the Prairie du Chien Group is about 300 ft (Balaban, 1988). The Prairie du Chien Group, which underlies the entire area, is generally the uppermost bedrock unit beneath Rochester. The underlying Jordan Sandstone is a friable to well-cemented, fine- to coarse-grained sandstone with an average thickness of about 100 ft (Balaban, 1988). The Jordan Sandstone underlies the entire area.

Methods of Investigation

Field work for this study was conducted during 1995. The locations of wells used in this study to estimate horizontal hydraulic conductivity and transmissivity from specific-capacity and aquifer-test information are shown in figures 4 and 5. Selected data from commercial drillers' records of wells in the study area used to calculate specific capacity and estimate transmissivity are given in the "Supplemental Information" section. Well records were obtained from the files of the MGS and the USGS.

Horizontal hydraulic conductivity and transmissivity values for the St. Peter-Prairie du Chien-Jordan aquifer were estimated from the analysis of data from 310 well records containing specific-capacity information. Forty-nine of the wells are open to the St. Peter Sandstone, 141 are open to the Prairie du Chien Group, and 120 are open to the Jordan Sandstone. One hundred and forty-six of the wells were constructed after 1986, and the specific-capacity information on these logs is new information that was not available for the Delin (1990) study (fig. 5). Thirteen of the new wells are open to the St. Peter Sandstone, 54 are open to the Prairie du Chien Group, and 79 are open to the Jordan Sandstone. Aquifer transmissivities and horizontal hydraulic conductivities also were estimated from the analysis of data from aquifer tests conducted for 15 Rochester municipal wells open to the Prairie du Chien Group and Jordan Sandstone (7 wells) or only the Jordan Sandstone (8 wells). The aquifer tests were conducted and the results reported by consultants for RPU (Rochester Public Utilities, written commun., 1995). Thirteen aquifer tests were conducted for 13 wells before 1987 (fig. 4). Two of the 15 Rochester municipal wells were constructed after 1986 (fig. 5). Four aquifer tests were conducted for four wells during 1995 by Liesch Associates, Inc., on the Rochester municipal wells open to the Prairie du Chien Group and Jordan Sandstone (one well) or the Jordan Sandstone only (three wells). Aquifer tests were conducted for two of the Rochester municipal wells both before 1987 and during 1995. During November 1995, five specific-capacity tests were conducted for this study on domestic wells open to the Prairie du Chien Group (two wells) or the Jordan Sandstone (three wells) (fig. 5).

The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well. Specific capacity, available for many supply wells for which aquifer-test data are not available, was used to estimate transmissivity. The Theis equation, modified for the determination of transmissivity from specific capacity (Q/s), is (Heath, 1983, p. 60–61):

$$T = \frac{W(u)}{4\pi} \times \frac{Q}{s} \qquad (1)$$

where

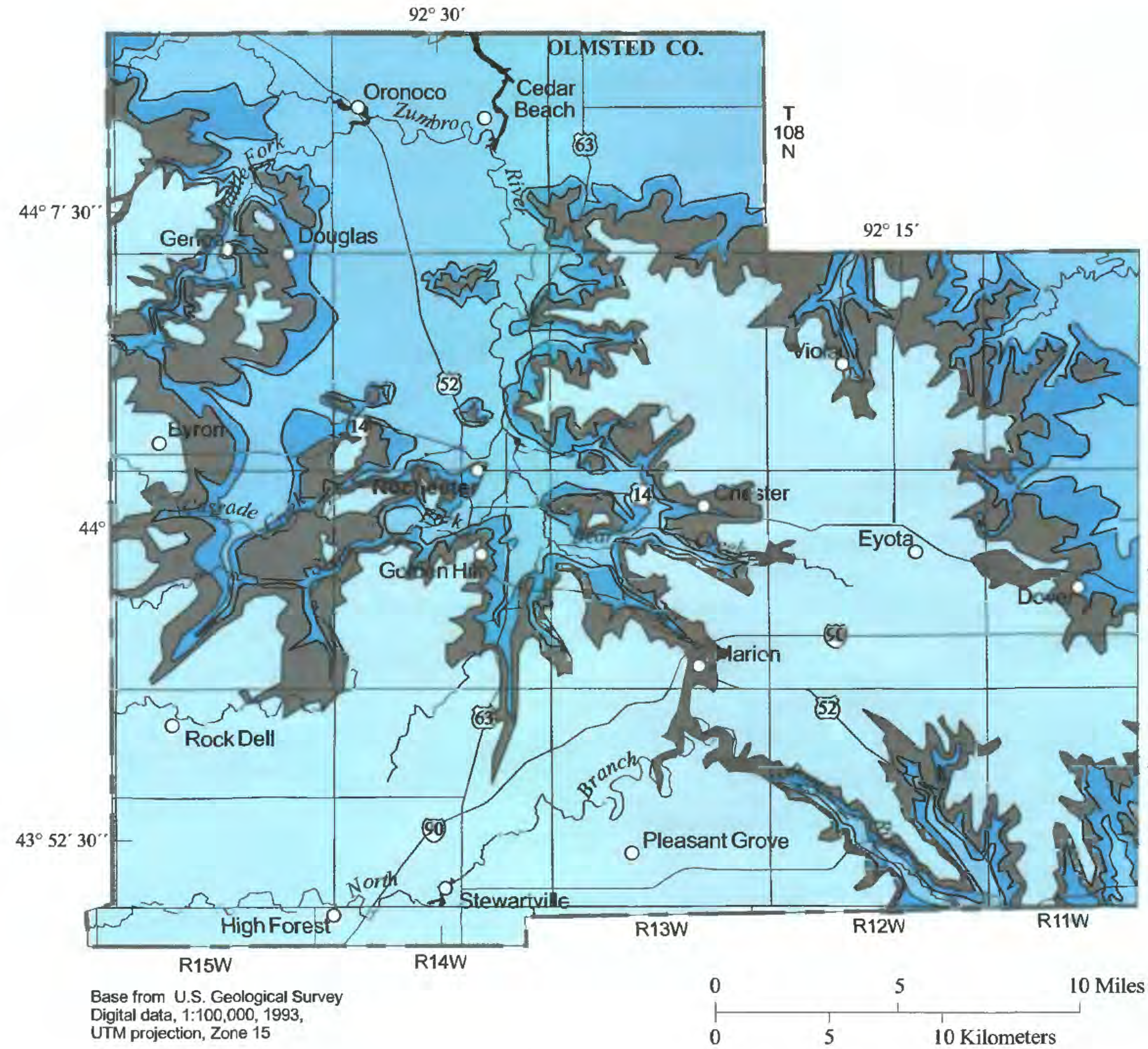
T = transmissivity $[L^2/T]$,
Q = pumping rate $[L^3/T]$,
s = drawdown $[L]$, and
$W(u)$ = the well function of u [dimensionless] (Heath, 1983, p. 60–61). W(u) is determined using a table of values of u (or 1/u) and W(u), and u is defined by

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

where

r = effective radius of the well $[L]$,
S = storage coefficient [dimensionless], and
t = length of the pumping period preceding the determination of specific capacity $[T]$.

Important factors that affect the use of the above equation are the accuracy with which the thickness of the zone supplying water to the well can be estimated, the magnitude of the well loss in comparison with drawdown in the aquifer, and the difference between the nominal radius of the well and its effective radius. The value of transmissivity estimated from specific-capacity information is assumed to apply only to the screened or open-hole zone of the aquifer (Heath, 1983, p. 60–61). The transmissivity estimated from specific-capacity information was divided by the length of the well screen or open hole to estimate the

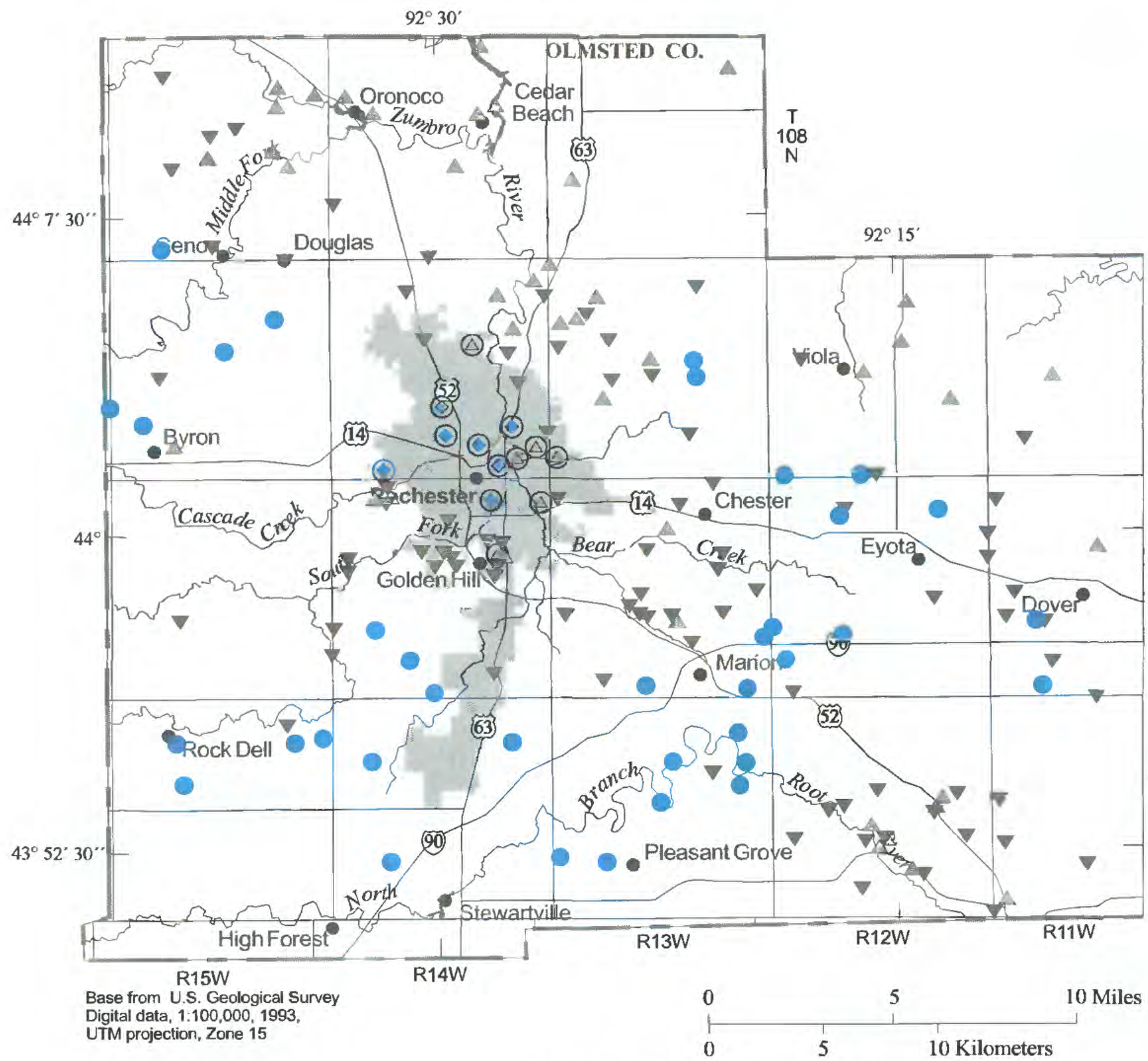


EXPLANATION

Extent of units:

- Upper carbonate aquifer
- Decorah-Platteville-Glenwood confining unit
- St. Peter Sandstone (aquifer)
- Prairie du Chien Group (aquifer)

Figure 3. Bedrock hydrogeology.

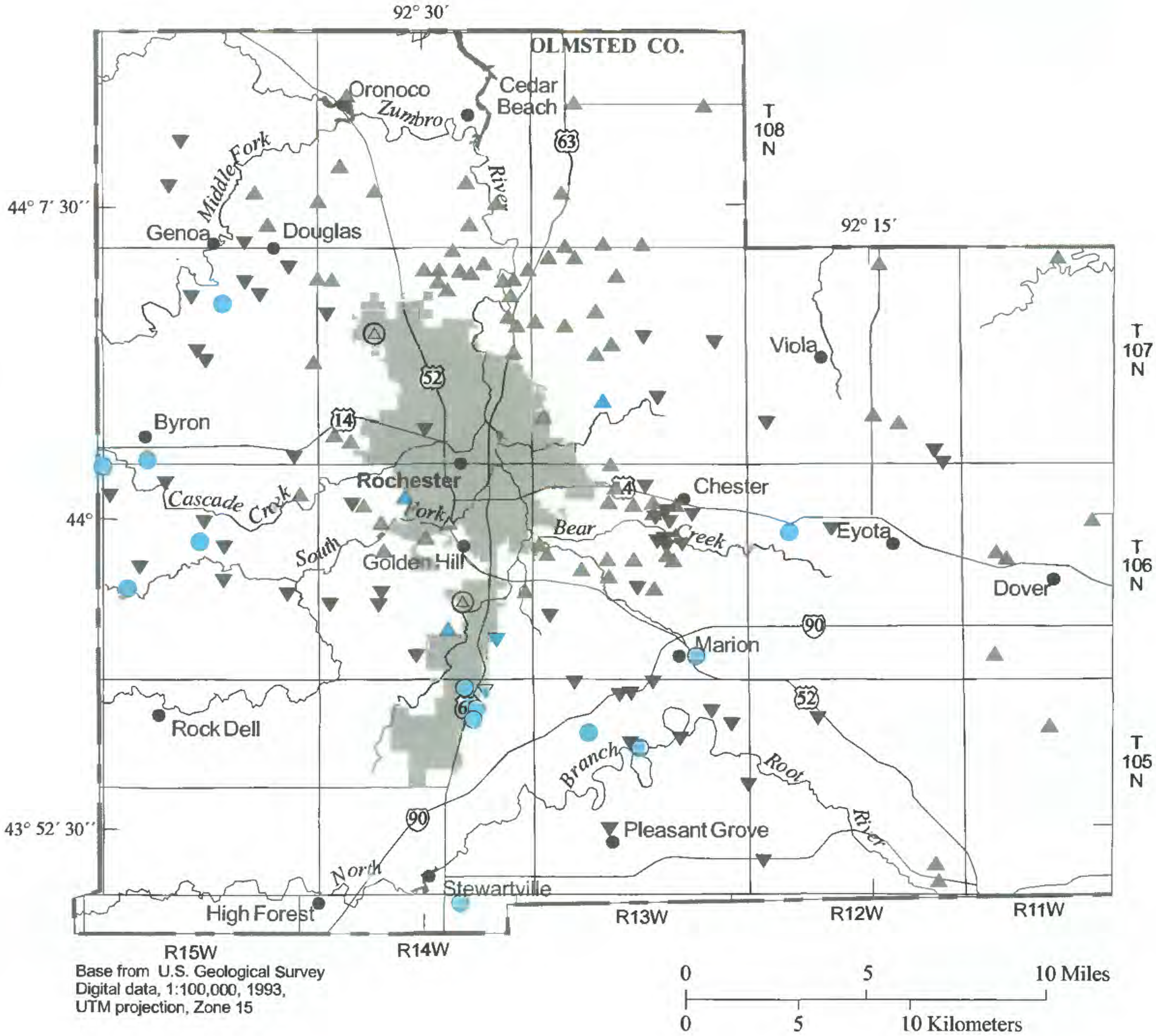


EXPLANATION

Well open to:
- St. Peter Sandstone
- Prairie du Chien Group
- Jordan Sandstone
- Jordan Sandstone, aquifer test conducted (Rochester municipal well)
- Prairie du Chien Group and Jordan Sandstone, aquifer test conducted (Rochester municipal well)

Rochester metropolitan area

Figure 4. Locations of wells constructed before 1987 used to estimate transmissivity for the St. Peter-Prairie du Chien-Jordan aquifer.



EXPLANATION

Well open to:

- St. Peter Sandstone
- Prairie du Chien Group--Blue indicates specific-capacity test was conducted in November 1995
- Jordan Sandstone--Blue indicates specific-capacity test was conducted in November 1995
- Jordan Sandstone, aquifer test conducted (Rochester municipal well)

Rochester metropolitan area

Figure 5. Locations of wells constructed after 1986 used to estimate transmissivity for the St. Peter-Prairie du Chien-Jordan aquifer.

horizontal hydraulic conductivity. To estimate transmissivity for an aquifer unit (St. Peter Sandstone, Prairie du Chien Group, or Jordan Sandstone), the horizontal hydraulic conductivity was multiplied by the entire thickness of the aquifer unit. Production wells often do not completely penetrate aquifers or aquifer units. Methods described by Butler (1957) were used to adjust the measured drawdown in a pumped well for the effects of partial penetration.

One of the factors that affect specific capacity is the length of the pumping period. For a given pumping rate and assuming no boundary effects, a specific-capacity test with a longer pumping period will create a larger cone of depression and be representative of hydraulic properties for a larger volume of the aquifer than a specific-capacity test with a shorter pumping period. Therefore, a 24-hour test is preferable to a 1-hour test, but few such long-term specific-capacity tests are generally available. The length of the pumping periods for the 310 well records with specific-capacity information used to estimate transmissivity was predominantly 4 hours or less, with only eight specific-capacity tests having a pumping period of 10 hours or longer. In some cases, unrealistically large values for horizontal hydraulic conductivity and transmissivity estimated from specific-capacity information may result from inaccuracies in reported drawdowns, pumping rates, and static water levels on domestic well records.

The transmissivity of the St. Peter-Prairie du Chien-Jordan aquifer was calculated as the sum of the transmissivities of the individual units (St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone). Supply wells generally are open only to one of the units and, therefore, transmissivities and horizontal hydraulic conductivities estimated from specific-capacity or aquifer tests apply only to that unit. Seven of the Rochester municipal wells with aquifer-test data, however, are open to both the Prairie du Chien Group and the Jordan Sandstone, and the transmissivity estimates at these sites apply to both units. The St. Peter Sandstone is absent at these locations. Transmissivities of the individual units at a site with specific-capacity information were calculated as the horizontal hydraulic conductivity multiplied by a thickness of 100 ft for the St. Peter Sandstone and Jordan Sandstone and 300 ft for the Prairie du Chien Group (Balaban, 1988).

Five specific-capacity tests were conducted for this study on domestic wells. Each well was pumped for a period of 4 hours. The pumping rate of the well was measured every 30 minutes. At the end of the 4-hour period, the water level in the well was measured using an electric or steel tape. The specific capacity at each site was calculated as the measured drawdown in the well divided by the average pumping rate of the well during the 4-hour pumping period.

Water levels were measured in 70 domestic, commercial, industrial, and observation wells and in 13 Rochester municipal wells during February through March 1995 (fig. 6) to map the potentiometric surface for the St. Peter-Prairie du Chien-Jordan aquifer. The wells measured were a subset of the 129 domestic, commercial, municipal, industrial, and observation wells comprising the well monitoring network for the Delin (1990) study. Water levels measured during February through March 1995 were compared to water levels measured in the same wells during January through February 1988 to construct a water-level change map.

Acknowledgments

The author is grateful to Rochester Public Utilities for providing technical assistance and water-level and other information that were instrumental in the investigation; and to well owners who permitted measurement of water levels and specific-capacity tests of their wells. Thanks also are given to Tony Runkel of the Minnesota Geological Survey, who provided maps and geologic information on the Jordan Sandstone, and to Bruce Liesch & Associates, consultants to the city of Rochester, Minnesota, who provided aquifer-test information for the Rochester municipal wells.

Hydraulic Properties and Potential Well Yield

The hydraulic properties of a hydrogeologic unit, including hydraulic conductivity and transmissivity, control the flow of water through the unit. Hydraulic conductivity is the capacity of a porous material, such as aquifers and confining units, to transmit water under pressure. It is the rate of flow of water passing through a unit section of area under a unit hydraulic gradient at unit kinematic viscosity. Transmissivity is a property used to describe the flow of water through aquifers and is described by the following equation (Heath, 1983, p. 26):

$$T = Kb, \tag{2}$$

where

T = transmissivity $[L^2/T]$,
K = hydraulic conductivity $[L/T]$, and
b = aquifer thickness $[L]$.

An updated transmissivity map showing the variability in transmissivity of the St. Peter-Prairie du Chien-Jordan aquifer in the study area was constructed using all available information, including new specific-capacity and aquifer-test information not available for the Delin (1990) study.

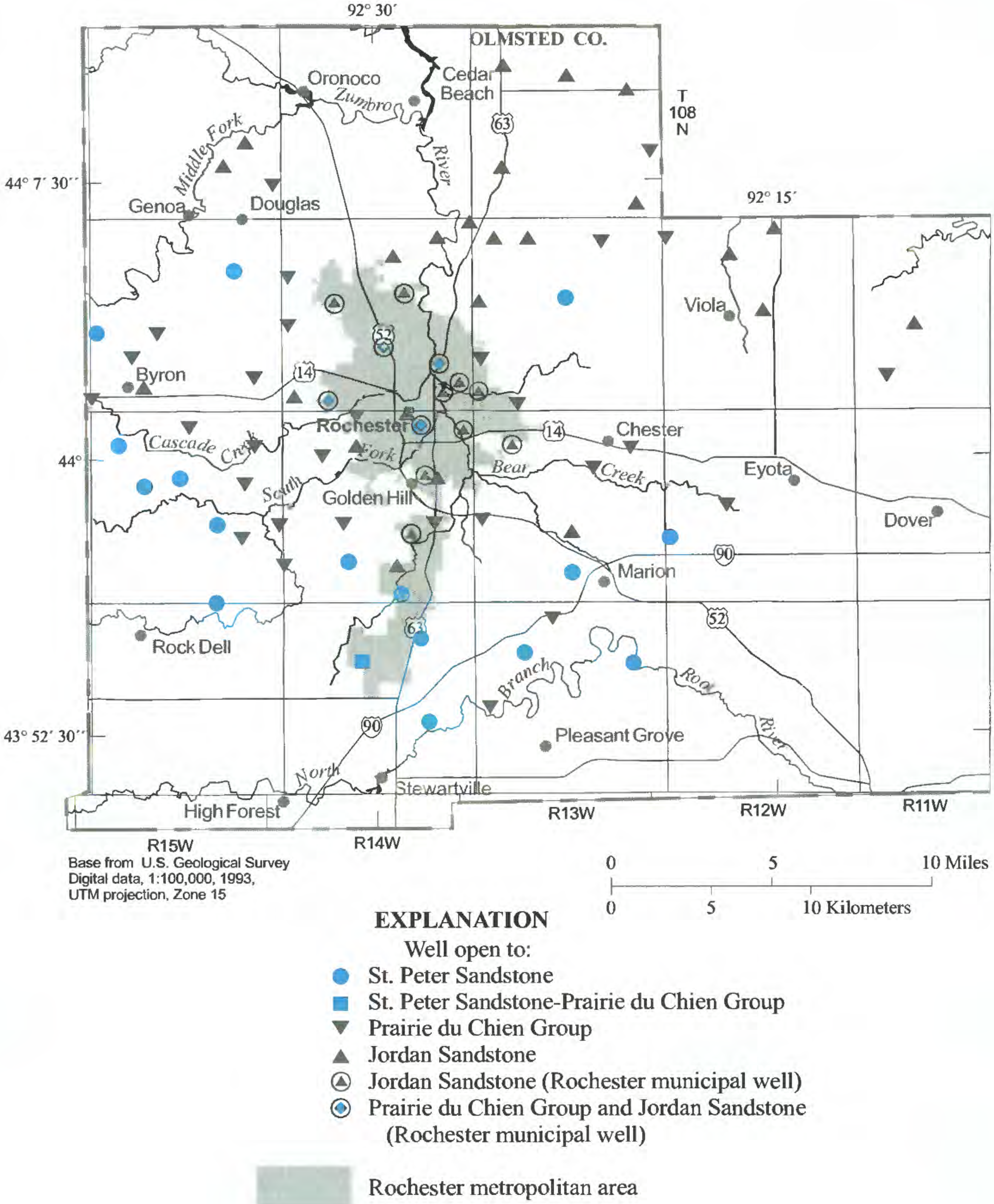


Figure 6. Locations of wells used to map the potentiometric surface, February through March 1995, and water-level change, 1988-95, for the St. Peter-Prairie du Chien-Jordan aquifer.

Previous investigations in the Rochester area (Balaban, 1988; Delin, 1990) indicated that the bedrock aquifers, such as the St. Peter-Prairie du Chien-Jordan aquifer, have laterally homogeneous hydrogeologic characteristics that are typical of the southeastern Minnesota region. However, water managers for the city of Rochester have recently recognized substantial variability in the productivity of municipal wells that withdraw water from the St. Peter-Prairie du Chien-Jordan aquifer. Runkel (1996) showed that parts of the aquifer have considerable heterogeneity in hydraulic properties across relatively short distances, and that such heterogeneity accounts for the variability in well productivity. Since 1979, municipal wells drilled in the part of the Rochester area where the Prairie du Chien Group is the uppermost bedrock are constructed so that only the Jordan Sandstone and lowermost part of the Prairie du Chien Group are exposed in the open-hole interval of the well. The Jordan Sandstone varies significantly from place to place in its hydraulic properties and its ability to yield water to wells (Setterholm and others, 1991; Runkel, 1994a, 1994b, 1996).

Hydraulic Properties

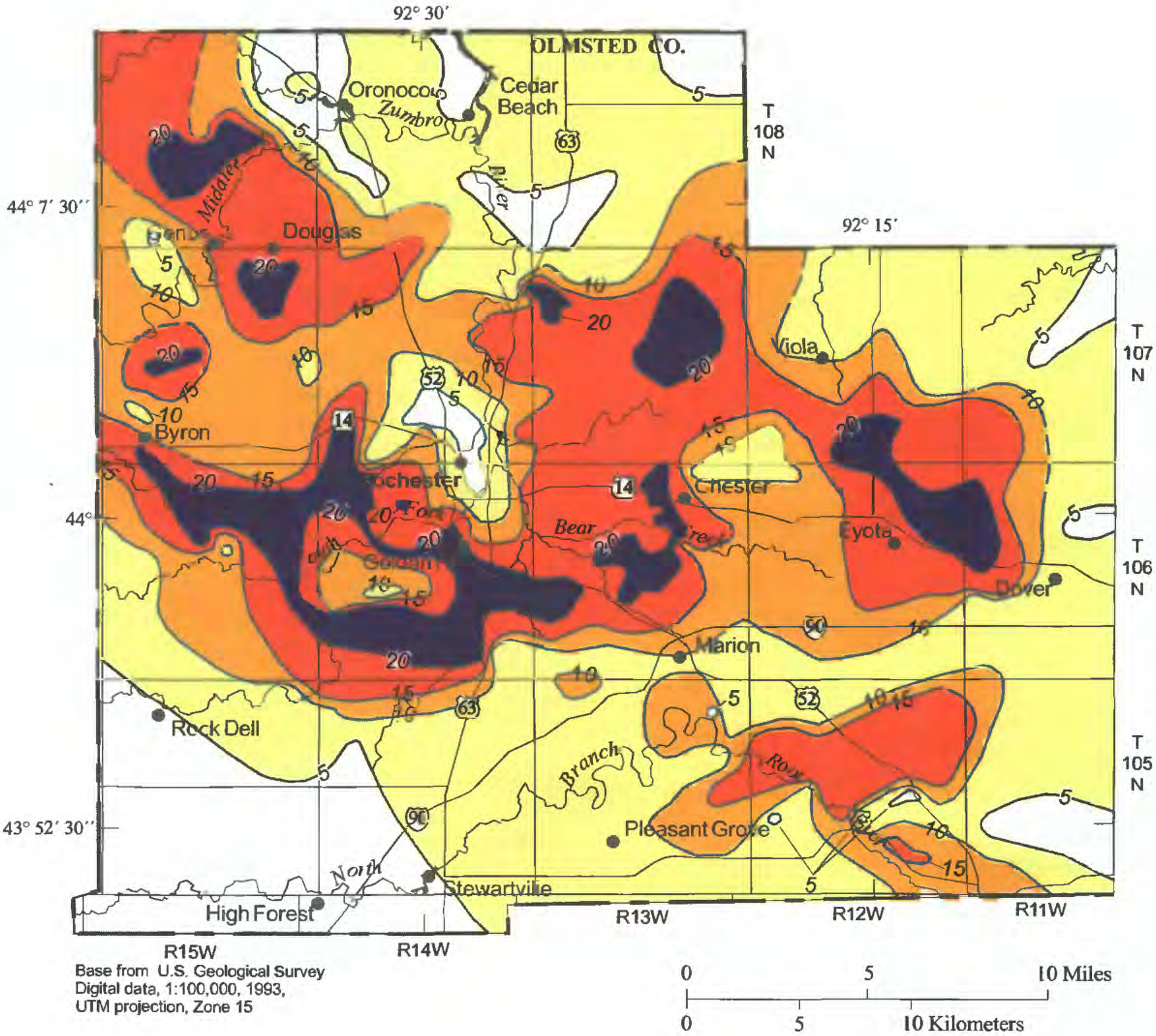
Delin (1990) reported that the transmissivity of the St. Peter Sandstone part of the St. Peter-Prairie du Chien-Jordan aquifer generally ranges from 200 to 3,000 ft^2/d, based on results of 58 specific-capacity tests in Olmsted County and on results of laboratory analyses of rocks from the Minneapolis-St. Paul area (Norvitch and others, 1974, p. 114–115). Transmissivities are generally uniform for the St. Peter Sandstone; however, some values greater than 30,000 ft^2/d were estimated from data obtained in specific-capacity tests (Delin, 1990). Movement of water in the St. Peter Sandstone is primarily intergranular.

Delin (1990) reported a typical range of transmissivity of the Prairie du Chien Group of from 300 to 1,000 ft^2/d, based on results of 101 specific-capacity measurements in Olmsted County. Transmissivity of the Prairie du Chien Group part of the St. Peter-Prairie du Chien-Jordan aquifer is highly variable due to secondary permeability caused by fractures and solution cavities. The Prairie du Chien Group transmits water primarily through fractures, joints, and solution channels. Transmissivities greater than 100,000 ft^2/d were calculated from specific-capacity measurements at some locations (Delin, 1990). Transmissivities of the Prairie du Chien Group were computed under the assumption that the formation is isotropic. Data generally are insufficient to determine the degree of anisotropy in the Prairie du Chien Group in southeastern Minnesota.

On the basis of results of aquifer tests at four municipal wells in Rochester, Delin (1990) reported that the transmissivity of the Jordan Sandstone part of the St. Peter-Prairie du Chien-Jordan aquifer ranges from 900 to 1,700 ft^2/d in the city. Transmissivities ranging predominantly from 100 to 5,000 ft^2/d were calculated based on data from 54 specific-capacity tests in Olmsted County, with calculated transmissivities exceeding 30,000 ft^2/d at some locations (Delin, 1990). Transmissivity based on results of laboratory analyses of Jordan Sandstone rocks from the Minneapolis-St. Paul area also exceeded 30,000 ft^2/d (Norvitch and others, 1974, p. 114–115). Movement of water in the Jordan Sandstone is predominantly intergranular.

The updated transmissivity distribution for the St. Peter-Prairie du Chien-Jordan aquifer in the study area is shown in figure 7. Maximum transmissivity computed for the St. Peter-Prairie du Chien-Jordan aquifer exceeded 20,000 ft^2/d, based on maximum horizontal hydraulic conductivities of 35 ft/d for the St. Peter Sandstone and 50 ft/d for the Prairie du Chien Group and the Jordan Sandstone. The corresponding maximum transmissivities are 3,500 ft^2/d for the St. Peter Sandstone, 15,000 ft^2/d for the Prairie du Chien Group, and 5,000 ft^2/d for the Jordan Sandstone. Minimum horizontal hydraulic conductivities computed from specific-capacity information were 1 to 3 ft/d for all three units. Delin (1990) reported a maximum horizontal hydraulic conductivity of 35 ft/d and a minimum of 1 ft/d for all three units (St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone) for the calibrated 1988 Rochester model. Norvitch and others (1974) reported a maximum horizontal hydraulic conductivity of 50 ft/d for the Prairie du Chien Group. Meyer (1933) reported a maximum horizontal hydraulic conductivity of 50 ft/d for the Jordan Sandstone. Horizontal hydraulic conductivities derived from specific-capacity information often exceed the maximum values cited above. Locally, horizontal hydraulic conductivities may exceed these maximums, but larger values are probably not representative of the aquifer units for extensive areas such as a township or larger.

Transmissivities for the St. Peter-Prairie du Chien-Jordan aquifer in the study area range from less than 5,000 ft^2/d to more than 20,000 ft^2/d (fig. 7). Transmissivities exceeding 20,000 ft^2/d occur in the west-central, northwestern, and east-central parts of the study area. Transmissivities of less than 5,000 ft^2/d occur in the northern, northeastern, central, and southern parts of the study area. The St. Peter Sandstone is absent in much of the northern, northeastern, and central parts of the study area, resulting in lower aquifer thicknesses in these areas. The predominant factor affecting the transmissivity of the St. Peter-Prairie du Chien-Jordan aquifer in the study area, however, is the transmissivity of the Prairie du Chien Group. The thickness of the Prairie du Chien Group is about three times greater than the thickness of each of the other two units (St. Peter Sandstone and Jordan Sandstone). The results of aquifer tests for seven Rochester municipal wells open to



EXPLANATION

Potential well yield in gallons per minute:
(modified from Balaban, 1988)

- <200
- 200 - 750
- 751-1,000
- 1,001- 1,500
- >1,500

——10—— Line of equal transmissivity of St. Peter-Prairie du Chien-Jordan aquifer--Interval, in thousands of feet squared per day, is 5. Dashed where inferred.

Figure 7. Transmissivity and potential well yield for the St. Peter-Prairie du Chien-Jordan aquifer.

both the Prairie du Chien and Jordan units of the aquifer indicated that transmissivities are less than 10,000 ft^2/d for much of the aquifer underlying the central part of the cityof Rochester (fig. 7). Results of aquifer tests for four of the seven wells indicated transmissivities are less than 5,000 ft^2/d. In general, transmissivities derived from aquifer tests were lower than transmissivities derived from specific-capacity information.

In the Rochester metropolitan area, the Jordan Sandstone and lower part of the Prairie du Chien Group contain three distinct formal and informal lithic components; a quartzose facies and a feldspathic facies of the Jordan Sandstone and the Coon Valley Member of the Oneota Dolomite (Runkel, 1996). The quartzose facies is a trough-cross-bedded, moderately sorted to well-sorted, fine- to coarse-grained sandstone composed of about 98 percent quartz. Runkel (1996) reported that the quartzose facies is a moderately to highly permeable unit, with increased cementation causing a decrease in conductivity. It is by far the most permeable of the three components, and it likely contributes the high yields reported for some wells in the Rochester metropolitan area that withdraw water from the Jordan Sandstone.

The thickness of the highly permeable quartzose facies of the Jordan Sandstone varies substantially from place to place. Runkel (1996) reported that transmissivity and well productivity is directly proportional to the thickness of the quartzose sandstone facies in the open-hole interval (fig. 8). For example, the open-hole interval in Rochester municipal well 31 includes about 50 ft of quartzose sandstone, whereas well 34 has only about 10 ft of quartzose sandstone in the open-hole interval. Aquifer-test data show that the specific capacity and transmissivity are about three to five times greater at well 31 than at well 34, even though the latter has a larger open-hole interval and has been chemically treated to enhance productivity (Runkel, 1996). The thickness of the quartzose sandstone facies, determined by Runkel (1996) for 31 sites in the study area, ranges from 0 to more than 60 ft (fig. 8). The quartzose sandstone facies is about 20 ft thick or less near the center of the Rochester metropolitan area; thus, the Jordan Sandstone is likely to have relatively low specific capacity and transmissivity in that area. Areas of large thicknesses of the quartzose sandstone facies generally correspond with areas of greater horizontal hydraulic conductivities for the Jordan Sandstone estimated for this study. Outside the Rochester metropolitan area, however, thickness data for the quartzose sandstone facies are sparse.

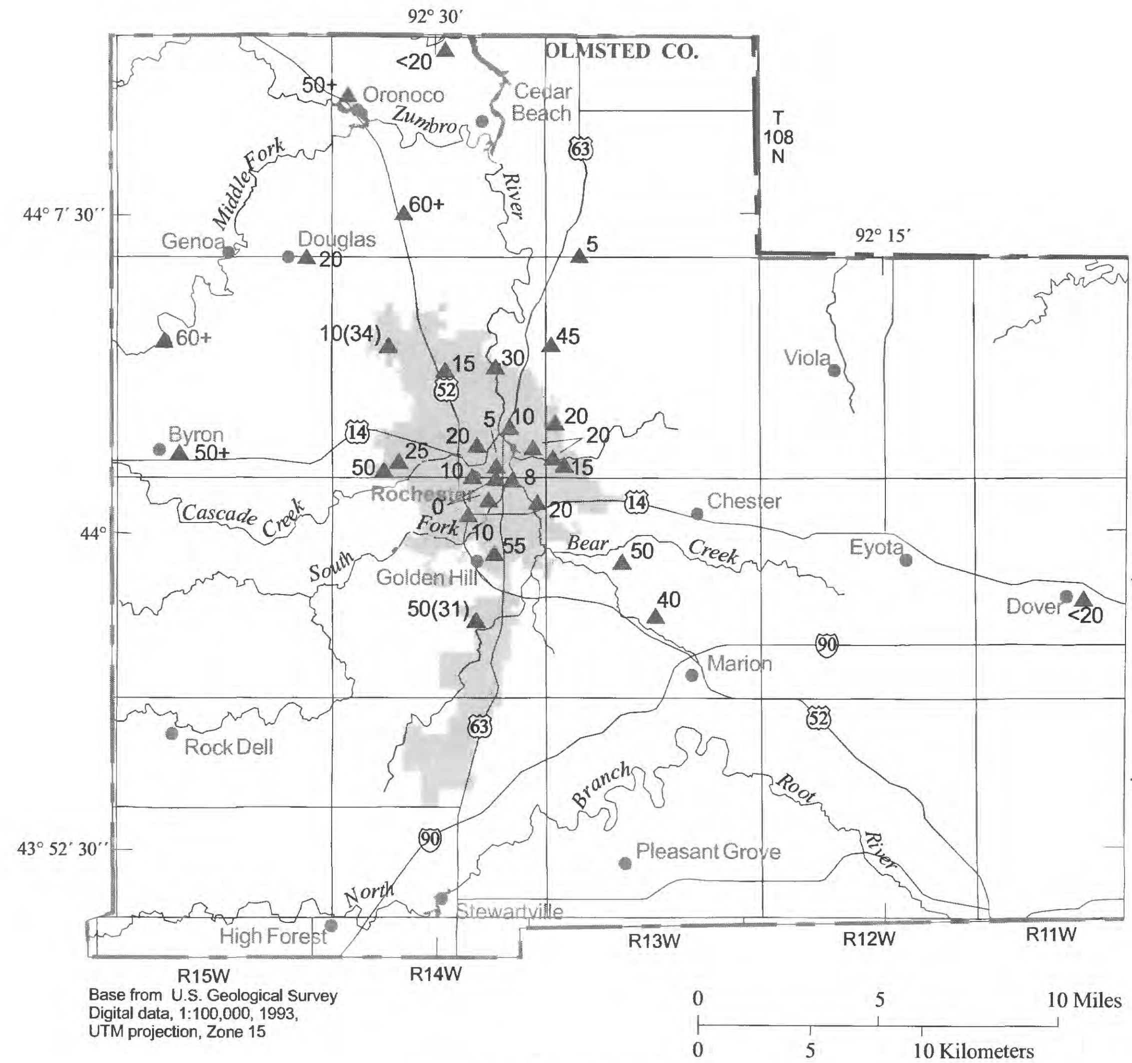
Potential Well Yield

Potential well yields for the St. Peter-Prairie du Chien-Jordan aquifer are shown in figure 7. The distribution of potential well yields is based on the updated transmissivity distribution determined for this study. The transmissivity contours constitute the boundaries of the assigned ranges in potential well yield. The ranges in potential well yield are modified from Balaban (1988) to correspond with the areas between the mapped transmissivity contours. For example, a transmissivity from 5,000 to 10,000 ft^2/d corresponds to a well yield of from 200 to 750 gal/min. The areas of greatest potential well yield coincide with areas of greatest transmissivity.

The saturated thickness of the St. Peter-Prairie du Chien-Jordan aquifer generally is relatively uniform in the study area, being about 500 ft in areas where the St. Peter Sandstone is present and about 400 ft in areas where the St. Peter Sandstone is absent. The saturated thickness of the aquifer is less in the valleys of the Zumbro and Whitewater Rivers in the north-central and northeastern parts of the study area, respectively, where the aquifer has been dissected by the river systems. Areal variations in the magnitude of potential well yields shown on figure 7 are caused predominantly by areal variations in hydraulic conductivity, particularly for the Prairie du Chien Group, rather than areal variations in aquifer thickness. In contrast, Balaban (1988, pl. 5) mapped potential well yields in the study area, assuming that no large-scale changes in the hydraulic properties of the aquifer occur.

Potential well yields for the study area range from less than 200 to more than 1,500 gal/min (Balaban, 1988). The potential well yields mapped by Balaban (1988, pl. 5) are estimates of the amount of water that can be obtained by continuous withdrawal from a properly constructed well that is at least 12 in. in diameter and (1) uses the total saturated aquifer thickness, (2) pumps continually while causing the maximum allowable drawdown (without causing irreversible depletion of the aquifer), and (3) is not interfered with by other wells using that aquifer. The variability in potential well yields, as shown on the map by Balaban (1988, pl. 5), is chiefly the result of ground-water discharge into valleys and the surface-water drainage system. Balaban (1988) assumed that no large-scale changes in the hydraulic properties of the St. Peter-Prairie du Chien-Jordan aquifer occur in the study area; thus, potential well yields are directly related only to the saturated thickness of the aquifer.

Local deviation from potential well yields are caused by local variations in aquifer hydraulic properties, recharge, proximity of the well to other pumping wells, effects of hydrologic boundaries (for example, rivers or the edge of the aquifer), well diameter and efficiency, and duration of pumping. The potential well yields estimated for this study are intended to show only relative differences in water-yielding capability. Actual well yields for the aquifer may be appreciably lower than shown on the map in areas where drawdown appreciably reduces the saturated thickness.



EXPLANATION

10(34) ▲ Measurement site for Jordan Sandstone quartzose facies--Number is thickness, in feet, "+" indicates the entire thickness of the quartzose facies was not penetrated, "<" indicates less than. Number in parentheses is Rochester municipal well number.

Rochester metropolitan area

Figure 8. Locations of wells and thickness of quartzose facies of Jordan Sandstone (modified from Runkel, 1996).

Determination of site-specific well yields requires hydraulic testing such as aquifer tests.

Ground-Water Flow

Ground water flows from areas of high hydraulic head toward areas of low hydraulic head. The direction of flow is related to locations of recharge to and discharge from the ground-water system. The rate of flow is related to the hydraulic conductivity of aquifer material and to the hydraulic gradient. Aquifers are less resistant to the horizontal flow of ground water than confining units because the hydraulic conductivity of aquifers is much greater than confining units. Flow in aquifers is predominantly horizontal, whereas flow in confining units is predominantly vertical. Recharge to the St. Peter-Prairie du Chien-Jordan aquifer in the study area is by leakage through overlying formations, infiltration from precipitation where the Decorah-Platteville-Glenwood confining unit is absent, and seepage from some reaches of major streams. Ground-water discharge from the aquifer is to most reaches of major streams, to production wells completed in the aquifer, and to underlying units as leakage. The 1988 Rochester model that simulated ground-water flow (Delin, 1990) was revised using horizontal hydraulic conductivities derived from the transmissivity distribution shown in figure 7.

Flow Simulation

The 1988 Rochester model (Delin, 1990) was calibrated for steady-state conditions. Delin (1990) reported that the model could not be calibrated to transient conditions due to a lack of long-term water-level data and a lack of information on seasonal variations in recharge. The model was used to estimate the hydrologic effects of (1) 1987–88 ground-water development on water levels, direction of ground-water movement, and streamflow; (2) projected future ground-water withdrawals; and (3) a hypothetical long-term drought. Horizontal ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer was simulated with three model layers that represent, in descending order, the St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone. Vertical flow in the ground-water system was simulated in the model by allowing leakage between layers. Calibration of the 1988 Rochester model consisted of comparing model-computed hydraulic heads to water levels measured in wells and model-computed ground-water seepages to streams to estimates of ground-water seepage derived from stream-discharge measurements during January 1988. The reader is referred to Delin (1990) for a detailed discussion describing the construction and calibration of the model and results for the model simulations.

Horizontal hydraulic conductivities within each layer of the 1988 Rochester model were based primarily on results of aquifer tests. Calculations from specific-capacity tests also were used but were considered to be less accurate than aquifer-test results. Initial horizontal hydraulic conductivity for the three model layers ranged from 3 to 10 ft/d. Following model calibration, the horizontal hydraulic conductivity for each layer in the model ranged from 1 to 35 ft/d. The horizontal hydraulic conductivities of the St. Peter Sandstone, the Prairie du Chien Group, and the Jordan Sandstone are similar but highly variable spatially near downtown Rochester (Delin, 1990). Delin (1990) reported that aquifer hydraulic conductivity may increase with distance from the central part of the city of Rochester to the southeast. Transmissivity determined for this study indicates an area of high transmissivity southeast of the central part of Rochester, based on specific-capacity information (fig. 7).

The 1988 Rochester model was rerun using revised horizontal hydraulic conductivity arrays in the model with hydraulic conductivities derived from the transmissivity distribution determined for this study (fig. 7). The Rochester model using the revised horizontal hydraulic conductivity arrays is hereinafter termed the modified Rochester model. The only change made in input data for the modified Rochester model was the horizontal hydraulic conductivity values for the three model layers. All other model input values were left unchanged. The horizontal hydraulic conductivity values used in the modified Rochester model for each model layer are available in electronic media from the USGS, Mounds View, Minnesota.

The model-computed hydraulic heads and ground-water seepage rates from the modified Rochester model were compared to the model-computed hydraulic heads and seepage rates from the 1988 Rochester model and to hydraulic heads and seepage measured during January 1988. Although the modified Rochester model was not recalibrated, the horizontal hydraulic conductivity values initially used were changed to better match hydraulic heads and seepage measured during 1988, as described below. The initial simulation for the modified Rochester model resulted in (1) model-computed hydraulic heads that were much lower than measured heads in the eastern and western parts of the model area and much higher than measured heads in the center of the model area, and (2) model-computed seepage rates between the aquifer and the major streams that were much higher than the measured seepage. The agreement between model-computed and measured hydraulic heads and seepage rates was appreciably improved by (1) decreasing the maximum horizontal hydraulic conductivity from 50 to 35 ft/d for model layers 2 and 3, representing the Prairie du Chien Group and the Jordan Sandstone, respectively; and (2) decreasing the horizontal hydraulic conductivity in model layers 2 and 3 from 5 ft/d to as low as 1.5 ft/d near many of the Rochester municipal wells. The above changes did not change the areal pattern of the hydraulic conductivity and transmissivity distributions determined for the current study, butrather decreased the magnitude of the highest and lowest values.

Tables 1 and 2 summarize the differences in model-computed hydraulic heads between the 1988 and modified Rochester models. Table 1 shows the differences between measured water levels in wells during January 1988 and model-computed hydraulic heads for the 1988 and modified Rochester models. The mean difference between model-computed hydraulic heads and measured water levels in non-high-capacity wells, computed as the algebraic sum of the differences divided by the number of wells, for the 1988 Rochester model was +0.6 ft for model layer 1, representing the St. Peter Sandstone; +1.5 ft for model layer 2, representing the Prairie du Chien Group; and −0.5 ft for model layer 3, representing the Jordan Sandstone. The corresponding values for the modified Rochester model were −2.3, −0.5, and −1.0 ft for model layers 1, 2, and 3, respectively. The mean difference between model-computed hydraulic heads and measured water levels in non-high-capacity wells, computed as the sum of the absolute values of the differences divided by the number of wells, for the 1988 Rochester model was 6.0 ft for model layer 1, 6.8 ft for model layer 2, and 9.5 ft for model layer 3. The corresponding values for the modified Rochester model were 6.1, 7.9, and 9.0 ft for model layers 1, 2, and 3, respectively.

Table 1 also shows the differences between measured water levels in wells and model-computed hydraulic heads for high-capacity wells. The mean difference between model-computed hydraulic heads and measured water levels in high-capacity wells, computed as the algebraic mean, for the 1988 Rochester model was −0.7 ft for model layer 2 and +2.8 ft for model layer 3. The corresponding values for the modified Rochester model were +2.8 and +1.0 ft, respectively. The mean difference between model-computed hydraulic heads and measured water levels in high-capacity wells, computed as the mean of the absolute values, for the 1988 Rochester model was 6.8 ft for model layer 2 and 8.9 ft for model layer 3. The corresponding values for the modified Rochester model were 2.8 and 6.5 ft, respectively. No high-capacity wells are open to the St. Peter Sandstone (model layer 1) in the study area.

The algebraic means of the differences between the model-computed hydraulic heads and measured water levels in wells for the 1988 and modified Rochester models ranged from −2.3 to +2.8 ft, indicating that the positive differences are approximately balanced by the negative differences (table 1). The absolute values of 6 of the 10 algebraic means were equal to 1.0 ft or less (table 1). The means of the absolute values of the differences between the model-computed hydraulic heads and measured water levels in wells are similar for the 1988 and modified Rochester models for the non-high-capacity wells. The means of the absolute values of the differences for each model layer differ by 1.1 ft or less between the two models for the non-high-capacity wells (table 1). The model-computed hydraulic heads for the modified Rochester model matched measured water levels in most of the high-capacity wells better than the model-computed hydraulic heads for the 1988 Rochester model (table 1). The means of the absolute values of the differences between the model- computed hydraulic heads and the measured water levels in wells were appreciably lower for the modified Rochester model than for the 1988 Rochester model for the high-capacity wells (table 1). The differences between the model-computed hydraulic heads for the 1988 and modified Rochester models and measured water levels in wells were plotted on a map, and the areal distribution of the differences were examined. No discernible pattern in areas of improvement in agreement between model-computed hydraulic heads and measured water levels in wells for the modified Rochester model compared to the 1988 Rochester model were found, except for the high-capacity wells. The agreement between model-computed hydraulic heads and measured water levels in wells was improved for high-capacity wells in the western and southern parts of the Rochester metropolitan area, but was worsened in the northeastern part. Also, no apparent correspondence was seen between areas of a better match between model-computed hydraulic heads for the modified Rochester model and measured water levels in wells and areas where additional hydraulic information became available since 1988.

Table 2 shows a summary of the differences in model-computed hydraulic heads between the 1988 and modified Rochester models. The algebraic mean difference is −1.5 ft for model layer 1, representing the St. Peter Sandstone, and −0.6 ft for model layers 2 and 3, representing the Prairie du Chien Group and Jordan Sandstone, respectively. The relatively low algebraic mean of the differences in model-computed hydraulic heads for all three layers indicates that positive differences in hydraulic heads are approximately balanced by negative differences. The mean of the absolute values of the differences also are relatively low for all three model layers (2.9 or 3.0 ft), indicating that the hydraulic heads computed by the two models generally are similar. However, the relatively large maximum differences between the models for each model layer indicate large differences in model-computed hydraulic heads for the two models at a few model cells. A large difference at a single model cell is propagated both horizontally within a model layer and vertically between model layers.

Comparison of estimates of ground-water seepage derived from stream-discharge measurements and model-computed ground-water seepage to streams also was used to evaluate how well the 1988 Rochester model simulated the ground-water-flow system. The 1988 Rochester model was

Table 1.--Differences between measured water levels in wells and model-computed hydraulic heads for the 1988 and modified Rochester models

[Measured water-level altitude is in feet above sea level. Water levels measured during January 1988. Positive difference indicates model-computed hydraulic head is greater than measured water level. Negative difference indicates model-computed hydraulic head is less than measured water level. --, not applicable. Algebraic mean calculated as the algebraic sum of the differences between model-computed hydraulic heads and measured water levels divided by the number of observations. Mean of absolute values calculated as the sum of the absolute values of the differences divided by the number of observations; ft, feet; --, no well name]

Model cell (layer, row, column)	Measured water-level altitude	Difference, 1988 Rochester model (ft)	Difference, modified Rochester model (ft)	Name of high-capacity well
		Non-high-capacity wells		
(1, 7, 6)	1,024.8	3.0	−1.3	--
(1, 10, 45)	1,026.7	2.8	−3.7	--
(1, 15, 4)	1,022.8	2.9	2.4	--
(1, 15, 46)	1,022.7	14.6	8.4	--
(1, 29, 46)	1,049.1	−0.2	−5.8	--
(1, 34, 4)	1,041.4	−7.6	−8.6	--
(1, 41, 4)	1,039.0	−3.8	−4.8	--
(1, 47, 6)	1,044.7	4.4	−0.5	--
(1, 49, 48)	1,066.2	−12.7	−12.9	--
(1, 54, 4)	1,031.3	0.7	3.6	--
(1, 54, 45)	1,061.6	−16.9	−21.7	--
(1, 55, 5)	1,040.0	4.4	5.6	--
(1, 55, 21)	1,030.2	8.5	5.3	--
(1, 55, 46)	1,046.1	−2.2	−7.9	--
(1, 57, 10)	1,035.4	2.2	3.3	--
(1, 57, 47)	1,021.0	9.4	1.6	--
Algebraic mean		+0.6	−2.3	
Mean of absolute values		6.0	6.1	
(2, 3, 45)	1,015.0	20.8	18.3	--
(2, 3, 47)	1,042.0	17.3	15.0	--
(2, 5, 48)	1,062.2	2.4	−1.3	--
(2, 5, 49)	1,055.7	16.0	14.1	--
(2, 6, 46)	1,048.2	−10.5	−17.4	--
(2, 7, 7)	1,022.4	−2.3	−5.0	--
(2, 10, 39)	1,006.4	3.8	−2.7	--
(2, 12, 46)	1,045.1	−8.5	−14.9	--
(2, 13, 6)	1,024.7	11.5	4.3	--
(2, 14, 7)	1,017.3	11.0	6.4	--
(2, 15, 18)	973.4	6.9	12.5	--
(2, 16, 5)	1,037.2	−6.5	−9.0	--
(2, 17, 27)	960.5	−1.0	3.4	--
(2, 20, 4)	1,037.0	−8.2	−9.1	--
(2, 20, 10)	1,020.5	0.6	−0.6	--
(2, 20, 34)	988.0	0.6	3.6	--
(2, 22, 5)	1,030.6	5.8	2.0	--
(2, 23, 6)	1,036.0	2.8	−2.3	--

Table 1.--Differences between measured water levels in wells and model-computed hydraulic heads for the 1988 and modified Rochester models--(Continued)

Model cell (layer, row, column)	Measured water-level altitude	Difference, 1988 Rochester model (ft)	Difference, modified Rochester model (ft)	Name of high-capacity well
		Non-high-capacity wells--Continued		
(2, 23, 46)	1,038.6	4.5	−3.5	--
(2, 26, 4)	1,032.5	−1.3	−2.1	--
(2, 26, 8)	1,021.8	11.5	8.1	--
(2, 27, 31)	986.8	−5.1	1.1	--
(2, 28, 6)	1,048.9	−6.8	−12.2	--
(2, 28, 40)	1,026.4	−11.9	−9.7	--
(2, 30, 14)	992.5	21.0	25.3	--
(2, 31, 5)	1,042.7	0.7	−5.3	--
(2, 32, 34)	1,012.4	−13.1	−11.2	--
(2, 33, 49)	1,063.2	0.3	−4.3	--
(2, 34, 6)	1,047.2	−1.5	−7.9	--
(2, 35, 19)	1,001.2	−0.8	11.1	--
(2, 35, 47)	1,066.0	−5.5	−10.3	--
(2, 36, 9)	1,016.8	17.4	15.2	--
(2, 37, 23)	995.1	3.0	7.6	--
(2, 37, 52)	1,076.6	−7.6	−7.6	--
(2, 38, 46)	1,059.9	−4.5	−5.7	--
(2, 41, 6)	1,045.5	3.1	−3.6	--
(2, 42, 7)	1,042.8	2.2	−2.3	--
(2, 42, 20)	1,013.6	3.3	9.4	--
(2, 42, 47)	1,062.3	1.0	−3.7	--
(2, 44, 49)	1,068.6	−8.4	−10.9	--
(2, 47, 7)	1,043.6	0.3	−0.4	--
(2, 47, 12)	1,030.6	4.2	2.6	--
(2, 47, 27)	1,039.1	−10.6	−11.2	--
(2, 47, 34)	1,035.1	−5.6	−7.8	--
(2, 49, 5)	1,044.0	3.6	0.1	--
(2, 54, 7)	1,034.6	15.8	12.6	--
(2, 54, 49)	1,057.7	−7.4	−10.7	--
(2, 55, 41)	1,041.1	−0.9	-6.2	--
(2, 56, 45)	1,044.9	−5.5	−11.8	--
(2, 58, 35)	1,015.5	15.7	12.7	--
Algebraic mean		+1.5	−0.5	
Mean of absolute values		6.8	7.9	
(3, 5, 27)	957.5	−14.6	−13.1	--
(3, 5, 32)	972.4	−1.6	−1.6	--
(3, 5, 37)	992.6	6.1	1.8	--
(3, 5, 42)	1,028.6	−13.4	−19.2	--
(3, 6, 20)	974.1	−2.4	−2.5	--

Table 1.--Differences between measured water levels in wells and model-computed hydraulic heads for the 1988 and modified Rochester models--(Continued)

Model cell (layer, row, column)	Measured water-level altitude	Difference, 1988 Rochester model (ft)	Difference, modified Rochester model (ft)	Name of high-capacity well
		Non-high-capacity wells--Continued		
(3, 6, 24)	968.2	−12.1	−10.2	--
(3, 6, 49)	1,072.0	−2.7	−4.7	--
(3, 10, 24)	951.4	11.1	13.3	--
(3, 10, 34)	993.6	0.8	−4.6	--
(3, 11, 45)	1,019.9	9.7	3.5	--
(3, 12, 30)	980.5	−1.3	−4.1	--
(3, 12, 49)	1,077.8	−12.3	−16.4	--
(3, 13, 42)	1,014.0	4.4	−1.3	--
(3, 14, 14)	1,004.7	−7.4	0.3	--
(3, 14, 16)	1,005.3	−16.6	−10.1	--
(3, 14, 51)	1,067.0	−11.0	−9.9	--
(3, 16, 14)	1,003.0	−3.1	6.6	--
(3, 2, 38)	978.7	19.7	18.9	--
(3, 2, 45)	998.0	25.8	24.7	--
(3, 2, 47)	1,028.4	8.1	6.9	--
(3, 3, 38)	996.6	4.6	3.0	--
(3, 4, 47)	1,042.0	15.2	11.2	--
(3, 24, 4)	1,029.9	0.6	−0.2	--
(3, 34, 14)	1,004.5	13.5	16.5	--
(3, 39, 27)	1,016.3	−13.4	−5.6	--
(3, 42, 51)	1,083.4	−12.9	−16.4	--
(3, 43, 45)	1,058.3	−11.0	−13.7	--
(3, 44, 29)	1,030.0	−10.6	−6.3	--
(3, 48, 45)	1,060.0	−9.5	−13.2	--
(3, 53, 20)	1,034.8	2.1	−1.0	--
(3, 57, 14)	1,020.0	17.2	17.4	--
Algebraic mean		−0.5	−1.0	
Mean of absolute values		9.5	9.0	
		High-capacity wells		
(2, 18, 18)	979.2	−6.1	1.3	Rochester #15
(2, 21, 27)	963.2	−5.2	2.3	Rochester #13
(2, 31, 25)	970.9	9.2	4.9	Rochester #11
Algebraic mean		−0.7	+2.8	
Mean of absolute values		6.8	2.8	
(3, 9, 21)	977.0	−19.9	−15.5	Rochester #28
(3, 13, 18)	962.2	13.6	8.6	Rochester #22
(3, 17, 25)	963.0	−2.4	1.3	Rochester #24
(3, 19, 29)	951.4	11.0	14.3	Rochester #17

Table 1.--Differences between measured water levels in wells and model-computed hydraulic heads for the 1988 and modified Rochester models--(Continued)

Model cell (layer, row, column)	Measured water-level altitude	Difference, 1988 Rochester model (ft)	Difference, modified Rochester model (ft)	Name of high-capacity well
		High-capacity wells--Continued		
(3, 23, 31)	967.3	2.7	5.1	Rochester #30
(3, 25, 28)	955.6	−3.9	0.4	Rochester #12
(3, 25, 33)	973.9	3.1	5.3	Rochester #27
(3, 27, 10)	1,016.5	7.0	7.0	Rochester #26
(3, 28, 19)	980.6	13.0	−6.8	Rochester #18
(3, 29, 22)	975.2	15.6	3.0	St. Mary's Hospital
(3, 29, 28)	945.8	19.7	14.6	Rochester #20
(3, 30, 27)	950.4	15.0	9.9	AMPI
(3, 31, 31)	993.2	−3.2	−3.8	Rochester #23
(3, 33, 41)	1,022.3	−1.5	0.1	Rochester #21
(3, 34, 22)	986.2	6.5	−5.0	Rochester #25
(3, 34,3 9)	1,017.1	−5.0	−1.4	Rose Harbor
(3, 37, 28)	994.3	4.1	−1.2	Rochester #19
(3, 38, 40)	1,035.1	−17.8	−14.0	Christopher Court
(3, 39, 25)	1,007.0	−7.1	−6.3	Rochester #29
(3, 47, 25)	1,022.4	5.0	5.4	Willow Heights
Algebraic mean		+2.8	+1.0	
Mean of absolute values		8.9	6.5	

Table 2.--Summary of differences in model-computed hydraulic heads between the 1988 and modified Rochester models

[Maximum difference is the largest of the absolute values of the differences in model-computed hydraulic heads between the 1988 and modified Rochester models at each active model cell in a model layer. Algebraic mean calculated as the algebraic sum of the differences between model-computed hydraulic heads for the 1988 and modified Rochester models at each active model cell in a model layer divided by the number of active cells. Mean of absolute values calculated as the sum of the absolute values of the differences divided by the number of active cells. An active cell for a model layer is a cell where the aquifer unit represented by the model layer is present, and ground-water hydraulic head and flow in the cell are computed; ft, feet]

Aquifer unit (model layer)	Maximum difference (model row, model column)	Algebraic mean (ft)	Mean of absolute values (ft)
St. Peter Sandstone (1)	14.7 (41, 25)	−1.5	2.9
Prairie du Chien Group (2)	19.7 (28, 19)	−.6	3.0
Jordan Sandstone (3)	19.9 (28, 19)	−.6	3.0

used to duplicate the correct order of magnitude of ground-water seepage to streams for all stream reaches simulated in the model. The estimated ground-water seepage derived from stream-discharge measurements and the model-computed seepage rates for entire simulated streams agreed or were close to agreement (Delin, 1990). Agreement, however, was variable between estimated and model-computed seepage rates for individual reaches of those streams.

Table 3 shows a comparison between estimates of and model-computed ground-water seepage to the South Fork Zumbro River, Bear Creek, and Cascade Creek. Ground-water seepage to streams in the Rochester area generally is greater than seepage from streams into the ground-water system. The seepage rates computed by the 1988 and modified Rochester models are the same or similar for each stream and stream reach. Differences of 1 to 2 ft^3/s in the rates of seepage between the aquifer and the streams were computed by the two models in a few stream reaches. These differences resulted in closer agreement between estimated seepage and model-computed ground-water seepage to the South Fork Zumbro River and Cascade Creek for the 1988 Rochester model than for the modified Rochester model. However, the correct order of magnitude of ground-water seepage to streams for all stream reaches also was simulated by the modified Rochester model.

Table 4 shows the steady-state water budgets for the model area and the approximate area of the aquifer contributing water to the Rochester municipal wells computed by the 1988 and modified Rochester models. A water budget is an accounting of inflow to, outflow from, and storage in the aquifer system. For steady state, which is based on a constant storage, inflow (sources) to the system equals outflow (discharges) from the system.

The simulated rates of recharge to the top of the aquifer and ground-water withdrawals are identical for the 1988 and modified Rochester models because these rates are input data that were not changed for the modified Rochester model (table 4). With the exception of seepage between the aquifer and the streams, the magnitudes of the other sources and discharges listed in table 4 and their percentages of the total sources and discharges are similar for the two models for the model area and for the approximate area of the aquifer contributing water to the Rochester municipal wells. Recharge from precipitation is the major source of inflow to the model area and to the area of the aquifer contributing water to the Rochester municipal wells in the water budgets for both models. The largest discharges in the water budgets for both models are flow out of the model area through constant-head cells. This simulated ground-water discharge represents flow from the ground-water divide (fig. 9) toward and through the east, south, and west model boundaries.

The largest differences in the water budgets for the 1988 and modified Rochester models occurs in the rates of seepage between the aquifer and the streams. Table 4 indicates large increases in both seepage from streams to the aquifer and ground-water seepage to streams in absolute magnitude, as well as a percentage of total sources and discharges, respectively, for the modified Rochester model. The increases in seepage rates of water between the aquifer and the streams seen in the water budget for the modified Rochester model reflect the increases in seepage between the aquifer and some stream reaches seen in table 3 for the modified Rochester model. These differences in rates of seepage between the aquifer and the streams for the 1988 and modified Rochester models are due to differences in model-computed hydraulic heads near streams for the two models. Differences in model-computed hydraulic heads resulted from different horizontal hydraulic conductivities being used in the two models.

Aquifer transmissivity has important effects on hydraulic heads and flows in the aquifer system. The effects of aquifer transmissivity on hydraulic heads and flows are indicated by the need to adjust the initial horizontal hydraulic conductivities (and, therefore, transmissivities) used in the modified Rochester model, discussed previously, to improve the agreement between model-computed and measured hydraulic heads and seepage rates. The transmissivity distribution in figure 7 is based primarily on specific-capacity information, due to a lack of aquifer-test information outside the Rochester metropolitan area. The need to reduce the maximum horizontal hydraulic conductivities (and, therefore, transmissivities) used in the modified Rochester model may indicate that transmissivity values derived from specific-capacity information generally are too high. The transmissivity distribution shown in figure 7, however, is valid as an indicator of the spatial variability of the relative magnitude of transmissivity and potential well yield for the St. Peter-Prairie du Chien-Jordan aquifer in the study area.

The fact that incorporating the horizontal hydraulic conductivity data from 146 wells did not appreciably improve the agreement between model-computed and measured hydraulic heads and seepage rates may be due to a number of causes. Transmissivity values derived from specific-capacity information generally may be too high, as discussed previously. A second cause may be that even nearly a 90-percent increase in the amount of horizontal hydraulic conductivity data cannot appreciably improve the representation of the actual heterogeneity in hydraulic conductivity in the aquifer. Related factors include that the new data were not evenly distributed over the study area and generally were applicable to only one of the aquifer units. A third, and probably most important, cause is that hydraulic heads and seepage rates computed by the ground-water-flow model are not as sensitive to changes in horizontal hydraulic conductivity values as they are to changes in recharge (Delin, 1990). Sensitivity of the model is an indication of the degree to which additional information could improve

Table 3.--Estimates of and model-computed ground-water seepage to the South Fork Zumbro River, Bear Creek, and Cascade Creek

[Seepage is in cubic feet per second. Stream reach numbers are listed in downstream order; location of stream reaches shown by Delin (1990, fig. 17, p. 37). Positive ground-water seepage value indicates flow from aquifer to stream. Negative value indicates flow from stream to aquifer]

		Ground-water seepage		
Stream reach	Stream reach length (miles)	Estimates derived from stream-discharge measurements, January 1988	Model computed for 1988 Rochester model	Model computed for modified Rochester model
South Fork Zumbro River				
1	2.89	–2	–2	–2
2	2.72	1	0	0
3	2.85	3	0	0
4	1.40	–2	0	0
5	1.78	2	2	3
6	1.02	–1	0	0
7	2.11	6	0	0
8	1.43	2	3	4
9	1.74	-6	1	1
10	1.39	1	3	4
11	2.79	8	7	7
12	2.63	4	3	3
Total seepage		16	17	20
Bear Creek				
13	2.46	3	1	2
14	2.72	2	2	3
15	1.00	0	1	1
Total seepage		5	4	6
Cascade Creek				
16	2.54	–1	0	–2
17	1.91	3	2	2
18	1.23	0	0	0
Total seepage		2	2	0

knowledge of the ground-water-flow system and improve calibration of the model.

Changes in Potentiometric Surface

Water levels in 70 domestic, commercial, industrial, and observation wells and in 13 Rochester municipal wells were measured during February through March 1995 to map the potentiometric surface of the St. Peter-Prairie du Chien-Jordan aquifer (fig. 9). Winter water levels better approximate unstressed steady-state-flow conditions than summer water levels because ground-water withdrawals generally are lower in the winter.

The direction of ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer is from a ground-water divide in the potentiometric surface, located west, south, and east of Rochester, toward the South Fork Zumbro River (fig. 9). The divide bisects high areas in the potentiometric surface. This ground-water divide represents a line of highest hydraulic head in the potentiometric surface that, in general, separates flow toward and away from Rochester. The location of the ground-water divide moves slightly in response to seasonal fluctuations in recharge to and discharge from the ground-water system. The hydraulic gradient is about 10 to 20 ft/mi and increases near the South Fork Zumbro River.

Table 4.--Steady-state water budgets for the model area and the approximate area of the aquifer contributing water to the Rochester municipal wells computed by the 1988 and modified Rochester models
[Mgal/yr, million gallons per year]

	1988 Rochester model		Modified Rochester model	
	Rate (Mgal/yr)	Percent	Rate (Mgal/yr)	Percent
Water budget for model area				
Sources				
Recharge to top of aquifer	23,350	90.0	23,350	83.5
Ground-water flow into the model area (constant-head cells)	1,600	6.2	1,900	6.8
Seepage from streams to aquifer	1,000	3.8	2,700	9.7
Inflow	25,950	100.0	27,950	100.0
Discharges				
Ground-water flow out of the model area (constant-head cells)	15,850	61.0	15,800	56.4
Ground-water seepage to streams	6,150	23.6	8,200	29.3
Ground-water withdrawal	4,000	15.4	4,000	14.3
Outflow	26,000	100.0	28,000	100.0
Water budget for approximate area of the aquifer contributing water to the Rochester municipal wells				
Sources				
Recharge to top of aquifer	6,500	90.9	6,500	74.7
Seepage from streams to aquifer	650	9.1	2,200	25.3
Inflow	7,150	100.0	8,700	100.0
Discharges				
Ground-water withdrawal	3,950	54.9	3,950	45.1
Ground-water seepage to streams	3,250	45.1	4,800	54.9
Outflow	7,200	100.0	8,750	100.0

High areas in the potentiometric surface of the St. Peter-Prairie du Chien-Jordan aquifer are caused partly by greater rates of recharge along the edge of the Decorah-Platteville-Glenwood confining unit than elsewhere (Delin and Woodward, 1984; Delin, 1990). The source of water for this greater recharge is the overlying upper carbonate aquifer. Topography and ground-water discharge to rivers and wells also affect the location of the high areas in the potentiometric surface.

The potentiometric surface was used to define the approximate area of the St. Peter-Prairie du Chien-Jordan aquifer contributing water to the Rochester municipal wells. The approximately 140-mi^2 contributing area is defined by the ground-water divide located west, south, and east of Rochester (fig. 9). However, at the north boundary of the area contributing water to the Rochester municipal wells, there is no ground-water divide or other natural hydrologic boundary. A flow line parallel to the general direction of ground-water flow in that area was arbitrarily selected; this line is treated as a no-flow boundary. The flow line, which extends from the divide to the South Fork Zumbro River (fig. 9), represents the approximate northern limit of water flowing toward Rochester's municipal wells.

Since 1988, the city of Rochester has experienced rapid population growth and increased ground-water withdrawals. The water levels in wells measured for this study during February through March 1995 and water levels measured in the same wells for the Delin (1990) study during January through February 1988 were compared, and a water-level change map was constructed (fig. 10). The water-level changes ranged from –6.8 to +15.3 ft in the study area. Water-level change in 12 Rochester municipal wells ranged from –7.4 to +8.0 ft. Water levels in wells generally rose in the northern and eastern parts of the study area and generally declined in the southwestern and western parts. Near Rochester, water levels in wells generally declined near the city boundaries and showed little change or rose in the central part of the city. Rises in water levels exceeding 5 ft occurred in the north-central and east-central parts of the study area and within the city of Rochester. Declines in water levels greater than 5 ft occurred in the west-central part of the study area and the southern part of the city of

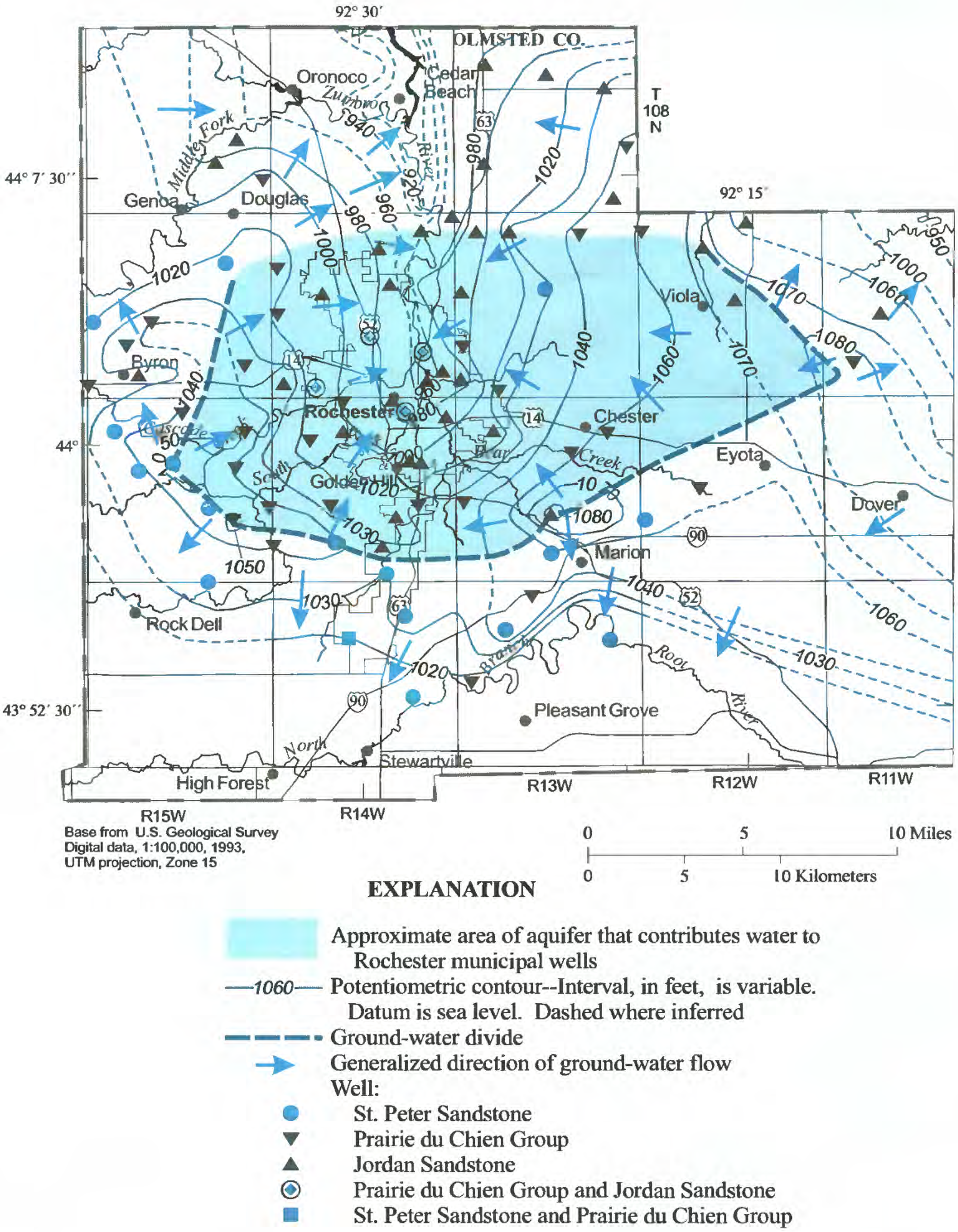
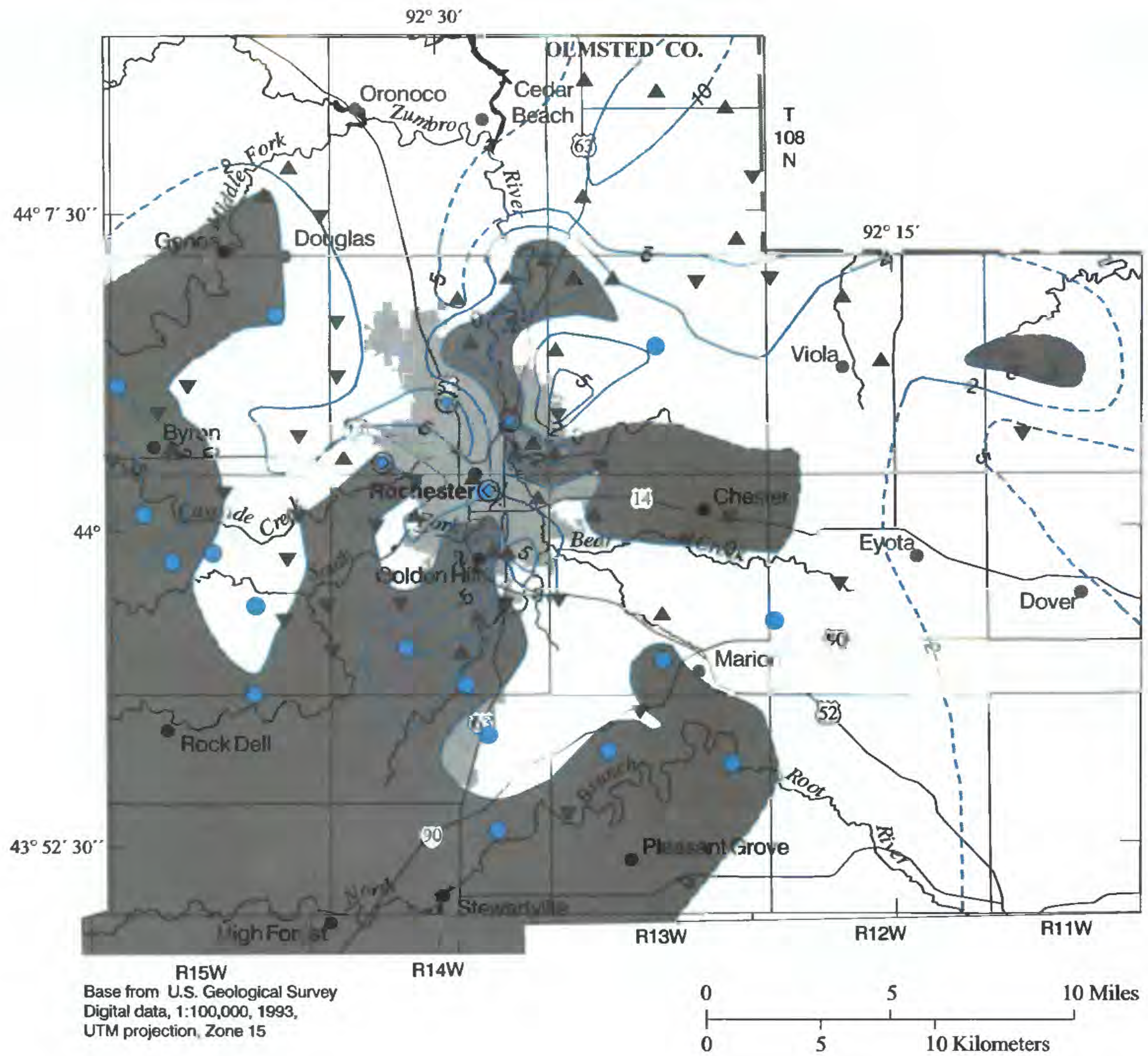


Figure 9. Potentiometric surface of the St. Peter-Prairie du Chien-Jordan aquifer, February through March 1995, and approximate area of the aquifer contributing water to the Rochester municipal wells.



EXPLANATION

Area of water level decline

Rochester metropolitan area

—5— Line of equal water-level change, in feet, in St. Peter-Prairie du Chien-Jordan aquifer. Interval is variable. Dashed where inferred

Well:

- ● St. Peter Sandstone
- ▼ Prairie du Chien Group
- ▲ Jordan Sandstone
- ◉ Prairie du Chien Group and Jordan Sandstone

Figure 10. Water-level change in the St. Peter-Prairie du Chien-Jordan aquifer, January through February 1988 to February through March 1995.

Rochester. The rises in water levels are probably due to generally greater precipitation during the 1990's compared to 1985–88, a period of below-normal precipitation (U.S. Department of Commerce, 1985–94). The declines in water levels probably are due to increased ground-water withdrawals from the aquifer. Population growth and increasing demands for water since 1988 have resulted in increased ground-water withdrawals from wells located near the northern, southern, and eastern Rochester city limits. Total annual withdrawals from the Rochester municipal wells increased from about 3,805 Mgal in 1987 to about 3,945 Mgal in 1994, an increase of about 140 Mgal (Rochester Public Utilities, 1995).

The potentiometric surface for the St. Peter-Prairie du Chien-Jordan aquifer and the area of the aquifer contributing water to the Rochester municipal wells shown in figure 9 are similar to the maps shown in Delin (1990, figs. 7 and 8, pp. 18 and 20). No appreciable changes in the location of the ground-water divide west, south, and east of Rochester have occurred since August 1987, despite increased ground-water withdrawals. Figure 10 indicates that water-level changes from January through February 1988 to February through March 1995 near the ground-water divide generally were less than 2 ft.

Summary and Conclusions

The primary source of ground water for the city of Rochester, Olmsted County, southeastern Minnesota, is the St. Peter-Prairie du Chien-Jordan aquifer. In 1990, results of the U.S. Geological Survey study by Delin (1990) were published describing the hydrogeology and ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer during 1987–88. Since 1988, new information on the hydrogeology of the ground-water system in the Rochester area has become available from well-drilling and construction activity associated with Rochester's rapid growth. The U.S. Geological Survey, in cooperation with the city of Rochester Public Utilities and the Minnesota Department of Natural Resources, made a 2-year study (October 1994–September 1996) to update the hydraulic properties and evaluate their effects on ground-water flow in the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area.

The St. Peter-Prairie du Chien-Jordan aquifer is composed of the St. Peter Sandstone, the Prairie du Chien Group (limestones and dolomites), and the Jordan Sandstone. The St. Peter Sandstone is a fine- to medium-grained sandstone, well sorted and poorly cemented; its average thickness is about 100 ft. The St. Peter Sandstone, which underlies areas west, south, and east of Rochester, is exposed along road cuts and outcrops in the city. The underlying Prairie du Chien Group is composed of the Shakopee Formation, a sandy, shaley, thin-bedded dolomite, and the thick-bedded Oneota Dolomite. Average thickness of the Prairie du Chien Group is about 300 ft. The Prairie du Chien Group, which underlies the entire area, is generally the uppermost bedrock unit beneath Rochester. The underlying Jordan Sandstone is a friable to well-cemented, fine- to coarse-grained sandstone whose average thickness is about 100 ft. The Jordan Sandstone underlies the entire area.

Transmissivities for the St. Peter-Prairie du Chien-Jordan aquifer in the study area range from less than 5,000 ft^2/d to more than 20,000 ft^2/d. Transmissivities exceeding 20,000 ft^2/d occur in the west-central, northwestern, and east-central parts of the study area. Transmissivities of less than 5,000 ft^2/d occur in the northern, northeastern, central, and southern parts of the study area. The results of aquifer tests for seven Rochester municipal wells open to both the Prairie du Chien Group and Jordan Sandstone units of the aquifer indicated that transmissivities are less than 10,000 ft^2/d for much of the aquifer underlying the central part of the city of Rochester. Results of aquifer tests for four of the seven wells indicate transmissivities are less than 5,000 ft^2/d. In general, transmissivities derived from aquifer tests were lower than transmissivities derived from specific-capacity information.

A revised distribution of potential well yields was mapped, based on the transmissivity distribution determined for this study, with ranges of potential well yield similar to those used by Balaban (1988). The areas of greatest potential well yield coincide with areas of greatest transmissivity. Areal variations in the magnitude of potential well yields mapped for this study are caused predominantly by areal variations in horizontal hydraulic conductivity rather than areal variations in aquifer thickness, as assumed by Balaban (1988).

Delin (1990) developed a ground-water-flow model to simulate flow of ground water in the St. Peter-Prairie du Chien-Jordan aquifer in the Rochester area. The 1988 Rochester model was rerun using revised horizontal hydraulic conductivity arrays in the model, based on the updated transmissivity distribution determined for this study. The algebraic means of the differences between the model-computed hydraulic heads and measured water levels in wells for the 1988 and modified Rochester models ranged from −2.3 to +2.8 ft, indicating that the positive differences are approximately balanced by the negative differences. The means of the absolute values of the differences between the model-computed hydraulic heads and measured water levels in wells are similar for the 1988 and modified Rochester models than for the non-high-capacity wells. The means of the absolute values of the differences between the model-computed hydraulic heads and the measured water levels in high-capacity wells were appreciably lower for the modified Rochester model than for the 1988 Rochester model. No apparent correspondence was seen between areas of a better match between model-computed hydraulic heads for the modified Rochester model and measured water levels in wells and areas where additional hydraulic information became available since 1988.

Seepage rates computed by the 1988 and modified Rochester models are the same or similar for each stream and stream reach. Differences of 1 to 2 ft^3/s in the rates of seepage between the aquifer and the streams were computed by the two models in a few stream reaches. These differences resulted in closer agreement between estimated seepage and model-computed ground-water seepage to the South Fork Zumbro River and Cascade Creek for the 1988 Rochester model than for the modified Rochester model. However, the correct order of magnitude of ground-water seepage to streams for all stream reaches also was simulated by the modified Rochester model.

The magnitudes of the sources and discharges of water to and from the St. Peter-Prairie du Chien-Jordan aquifer and their percentages of the total sources and discharges are similar for the 1988 and modified Rochester models for the model area and for the approximate area of the aquifer contributing water to the Rochester municipal wells, with the exception of seepage between the aquifer and the streams. Seepage from streams to the aquifer and ground-water seepage to streams as a percentage of total sources and discharges, respectively, were appreciably greater for the modified Rochester model than for the 1988 Rochester model.

The transmissivity distribution determined for this study is based primarily on specific-capacity information, due to a lack of aquifer-test information outside the Rochester metropolitan area. The need to reduce the maximum horizontal hydraulic conductivities (and, therefore, transmissivities) used in the modified Rochester model to improve the agreement between model-computed hydraulic heads and flows and measured water levels and flows may indicate that transmissivity values derived from specific-capacity information generally are too high. The transmissivity distribution determined for this study, however, is valid as an indicator of the spatial variability of the relative magnitude of transmissivity and potential well yield for the St. Peter-Prairie du Chien-Jordan aquifer in the study area.

Water levels in 70 domestic, commercial, industrial, and observation wells and in 13 Rochester municipal wells were measured during February through March 1995 to map the potentiometric surface of the St. Peter-Prairie du Chien-Jordan aquifer. Regional flow in the St. Peter-Prairie du Chien-Jordan aquifer generally is from a ground-water divide in the potentiometric surface, located west, south, and east of Rochester, toward the South Fork Zumbro River. The potentiometric surface was used to define the approximate area of the St. Peter-Prairie du Chien-Jordan aquifer contributing water to the Rochester municipal wells. The area representing conditions associated with the potentiometric surface of the aquifer during February through March 1995 is not appreciably different from the area delimited by Delin (1990, fig. 8, p. 20) for conditions during August 1987.

Rapid population growth and increased ground-water withdrawals have occurred for the city of Rochester since the Delin (1990) study. Comparison of water levels in wells measured for this study during February through March 1995 to water levels measured in the same wells for the Delin (1990) study during January through February 1988 showed changes range from −6.8 to +15.3 ft. Water-level changes in 12 Rochester municipal wells range from −7.4 to +8.0 ft. Water levels in wells generally rose in the northern and eastern parts of the study area and generally declined in the southwestern and western parts. Near Rochester, water levels in wells generally declined near the city boundaries and showed little change or rose in the central part of the city. Water-level changes from 1988 to 1995 near the ground-water divide were generally less than 2 ft, resulting in no appreciable changes in the location of the divide.

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Supplemental Information

 page 31 follows

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties

[The location is based on the Bureau of Land Management's system of land subdivision (township, range, and section). In this system, the first numeral of a location number indicates the township; the second, the range; and the third, the section in which the point is located. Upper-case letters after the section number indicate the location within the section; the first letter denotes the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and additional letters, increasingly smaller tracts, in multiples of 0.25. Letters A, B, C, and D are assigned in a counterclockwise direction, beginning in the northeast corner of each tract. CJDN, Jordan Sandstone; OPDC, Prairie du Chien Group; OSTP, St. Peter Sandstone; in., inches; hrs, hours; ft, feet; gal/min, gallons per minute; gal/min/ft, gallons per minute per foot of drawdown]

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
546918	105N11W09BACACB	CJDN	4	1	55	20	8	2.5
147095	105N11W31BDCBCC	CJDN	4	1	75	100	2	50
156974	105N12W14CDDAAB	CJDN	4	1	87	25	2	13
156991	105N12W14DBCADC	CJDN	4	1	88	20	7	2.9
192513	105N12W21ACDDBD	CJDN	4	1	82	10	2	5.0
148306	105N12W22CCCBDC	CJDN	4	3	16	18	41	.4
192514	105N12W27DAABBD	CJDN	4	1	54	10	4	2.5
156977	105N12W28AAABCA	CJDN	4	1	90	20	7	2.9
192501	105N12W36BBABAB	CJDN	4	1	74	30	7	4.3
192557	105N12W36CABBBA	CJDN	4	1	94	15	54	.3
179238	106N11W09DDDACD	CJDN	4	1	84	20	13	1.5
192562	106N11W10DBBADD	CJDN	4	1	80	20	22	.9
192541	106N11W17CBABBD	CJDN	4	1	83	15	16	.9
156976	106N11W18ADDDDC	CJDN	4	1	58	20	9	2.2
179218	106N11W31AADCBB	CJDN	4	1	80	40	10	4.0
449365	106N13W04CACBBB	CJDN	4	1	42	20	10	2.0
506815	106N13W09AACBDB	CJDN	4	1	47	30	10	3.0
519624	106N13W09BBBBBB	CJDN	4	1	58	30	10	3.0
449360	106N13W10AADACB	CJDN	4	1	61	35	10	3.5
535082	106N13W10BACDCC	CJDN	4	1	50	50	10	5.0
220629	106N13W10BCDBCC	CJDN	12	24	81	325	116	2.8
535081	106N13W10BDDBDC	CJDN	4	1	57	50	10	5.0
463997	106N13W10DDDABB	CJDN	4	1	56	50	10	5.0
476184	106N13W15DADCAD	CJDN	4	1	68	50	10	5.0
476179	106N13W15DBADDA	CJDN	4	1	60	50	10	5.0
449388	106N13W16CBCBBC	CJDN	4	1	36	20	10	2.0
449362	106N13W16DAACCB	CJDN	4	1	42	35	10	3.5
441687	106N13W17CDCDDC	CJDN	4	1	61	30	10	3.0
449368	106N13W18BCAABB	CJDN	4	1	38	20	10	2.0
517772	106N13W18BDCDAB	CJDN	4	1	72	40	42	1.0
517768	106N13W21BBCACC	CJDN	4	1	47	40	69	.6
476187	106N13W22CAACAD	CJDN	4	1	63	50	10	5.0
476177	106N13W22CDADCD	CJDN	4	1	53	50	10	5.0
101280	106N14W05CABAAC	CJDN	4	4	20	12	5	2.4
179235	106N14W05DBBADA	CJDN	6	1	104	50	21	2.4
506826	106N14W08BACBBD	CJDN	4	1	63	50	10	5.0

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
449394	106N14W08DBDDBB	CJDN	4	1	63	20	10	2.0
228256	106N14W14AABBDC	CJDN	4	4	86	25	20	1.3
519633	106N14W15BBCBAB	CJDN	4	1	61	30	10	3.0
519635	106N14W17ADDAAB	CJDN	4	1	63	50	10	5.0
463985	106N14W24DBAABC	CJDN	4	1	43	30	10	3.0
506817	106N15W01DCCBCD	CJDN	4	1	54	30	10	3.0
179119	107N11W04ACAABC	CJDN	4	2	20	20	5	4.0
156954	107N11W20ADBDBD	CJDN	4	1	71	20	4	5.0
482529	107N12W03ACDDCB	CJDN	4	1	53	30	10	3.0
147088	107N12W10AACCBA	CJDN	4	1	75	20	2	10
476607	107N12W15ACCCAA	CJDN	4	4	19	10	8	1.3
101409	107N12W21ABCADA	CJDN	4	1	45	10	1	10
156968	107N12W23DDDDCA	CJDN	4	1	75	20	7	2.9
519622	107N12W26CCDAAC	CJDN	4	1	63	30	10	3.0
179202	107N12W27DBBCBA	CJDN	4	1	87	20	4	5.0
463982	107N13W04CDABAA	CJDN	4	1	56	30	10	3.0
463999	107N13W05BCAAAD	CJDN	4	1	40	30	10	3.0
437183	107N13W06BADDDA	CJDN	4	2	62	250	7	36
156969	107N13W06BBBABC	CJDN	4	1	61	25	6	4.2
107691	107N13W07CACDBB	CJDN	4	3	40	25	2	13
101263	107N13W07DACDBD	CJDN	4	4	34	18	10	1.8
105496	107N13W08BAABCB	CJDN	4	2	30	20	1	20
192590	107N13W08DDBBCA	CJDN	4	1	86	40	34	1.2
497374	107N13W16CBADBD	CJDN	4	2	27	20	78	.3
220771	107N13W16DACBAC	CJDN	8	8	70	380	70	5.4
463297	107N13W17DDCBAD	CJDN	4	2	55	29	99	.29
482515	107N13W18AADDDB	CJDN	4	1	60	50	10	5.0
506834	107N13W18BBABCD	CJDN	4	1	56	50	10	5.0
220776	107N13W20CDAADD	CJDN	8	4	88	300	40	7.5
506819	107N13W30CACDDB	CJDN	24	24	87	980	193.8	5.1
506814	107N13W33CCCDCB	CJDN	4	1	41	30	10	3.0
192524	107N14W01CCDAAC	CJDN	4	1	81	40	16	2.5
179240	107N14W01CDDAAB	CJDN	4	1	91	20	4	5.0
105015	107N14W01DAACDC	CJDN	4	1	55	50	6	8.3
104975	107N14W01DBDBCC	CJDN	4	1	56	20	8	2.5
535075	107N14W02ACDAAB	CJDN	4	1	50	50	10	5.0
449391	107N14W02CACAAC	CJDN	4	1	39	30	10	3.0
449387	107N14W02CBCBCC	CJDN	4	1	49	30	10	3.0
449363	107N14W03AABDBA	CJDN	4	1	45	30	10	3.0
449370	107N14W03CAACDD	CJDN	4	1	58	30	10	3.0

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
449374	107N14W03CBBCAC	CJDN	4	1	43	30	10	3.0
482520	107N14W03CDDDBC	CJDN	4	1	44	50	10	5.0
482524	107N14W06CCBADB	CJDN	4	1	38	30	10	3.0
519629	107N14W06CDDDAD	CJDN	4	1	58	30	10	3.0
441663	107N14W10ABACAD	CJDN	4	1	52	80	10	8.0
104961	107N14W11ABBCAC	CJDN	4	1	43	50	12	4.2
179227	107N14W12BDACDA	CJDN	4	1	90	40	12	3.3
220810	107N14W12CCCCAA	CJDN	8	1	78	320	61	5.3
220811	107N14W12CDCDAA	CJDN	6	5	70	60	10	6.0
104968	107N14W13ABCBAD	CJDN	4	1	46	20	13	1.5
449361	107N14W13CDDAAB	CJDN	4	1	42	20	10	2.0
506840	107N14W31ABCABC	CJDN	4	1	56	50	10	5.0
506824	107N14W31ADDACC	CJDN	4	1	58	50	10	5.0
506816	107N15W24AADABA	CJDN	4	1	60	30	10	3.0
150352	107N15W32ACADDC	CJDN	12	4	81	200	15	13
156999	108N13W01CCCBBA	CJDN	4	1	105	20	9	2.2
428031	108N13W08CDCDBB	CJDN	4	1	38	30	10	3.0
178850	108N13W14AAAABD	CJDN	4	2.5	61	25	7	3.6
148305	108N13W19DCDDDB	CJDN	4	2	30	35	13	2.7
449420	108N13W30ADDDAC	CJDN	4	1	51	12	10	1.2
420668	108N13W31DDDDCC	CJDN	4	1	41	30	20	1.5
463988	108N13W33CCCCAC	CJDN	4	1	53	30	10	3.0
449349	108N13W34CCCCAA	CJDN	4	1	41	20	12	1.7
147078	108N14W02BCBDDA	CJDN	4	1	61	20	3	6.7
107679	108N14W07DBCDAA	CJDN	4	3	26	15	60	0.3
227545	108N14W07DDADAB	CJDN	4	1.5	70	66	7.5	8.8
105468	108N14W08CDCBDC	CJDN	4	2	40	17	1	17
148317	108N14W11DCCBAB	CJDN	4	2	35	15	1	15
101423	108N14W14BBACBA	CJDN	4	1	62	10	7	1.4
147059	108N14W19DBCABC	CJDN	4	1	65	20	7	2.9
107708	108N14W22DBBBDC	CJDN	4	4	34	30	5	6.0
192504	108N14W25CBCBBD	CJDN	4	1	72	20	14	1.4
192561	108N14W26BBDABD	CJDN	4	1	54	30	24	1.3
476154	108N14W29ACDBCD	CJDN	4	1	59	30	10	3.0
428038	108N14W30CBACDC	CJDN	4	1	65	35	10	3.5
506822	108N14W35BDCBCC	CJDN	4	1	44	50	10	5.0
147013	108N15W11ACACCB	CJDN	4	1	86	20	7	2.9
160838	108N15W11DCBBCD	CJDN	4	2	30	25	43	.6
148315	108N15W12DABBAD	CJDN	6	3	25	17	12	1.4
156971	108N15W21AACBDD	CJDN	4	1	43	20	2	10

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
101282	108N15W23ABBBBC	CJDN	4	4	25	18	10	1.8
147062	108N15W23ADDDAC	CJDN	4	1	69	20	7	2.9
476155	108N15W26BDCCAC	CJDN	4	1	59	30	10	3.0
403804	108N15W35ACACDB	CJDN	4	1	49	40	16	2.5
192555	105N11W04AABABC	OPDC	4	1	131	20	24	.8
105039	105N11W18CCBDAD	OPDC	4	1	69	20	14	1.4
147028	105N11W19CDCDBA	OPDC	4	1	99	10	27	.37
105019	105N11W28DBBBDD	OPDC	4	1	130	10	15	.67
227397	105N11W31CCCBCD	OPDC	4	3	28	18	30	.60
192599	105N12W08AAACCD	OPDC	4	1	91	30	22	1.4
105026	105N12W13CBBBBA	OPDC	4	1	48	20	7	2.9
156997	105N12W16DAADBD	OPDC	4	1	53	20	6	3.3
105005	105N12W17DDDDCC	OPDC	4	1	47	20	4	5.0
192556	105N12W19DCCCAC	OPDC	4	1	93	12	22	.55
179233	105N12W20ABBBCC	OPDC	4	1	52	20	19	1.1
101284	105N12W21CDDDCA	OPDC	4	4	28	10	15	.67
147073	105N12W22CCBBCD	OPDC	4	1	93	20	43	.47
147085	105N12W23BABDBA	OPDC	4	1	94	10	48	.21
101434	105N12W24CADCCC	OPDC	4	1	85	10	30	.33
104997	105N12W26CCCBDC	OPDC	4	1	47	20	11	1.8
179249	105N12W31BAACBA	OPDC	4	1	68	15	13	1.2
147060	105N12W33ABCBAB	OPDC	4	1	58	20	22	.91
144565	105N13W02DDDDAB	OPDC	4	1	75	20	100	.20
531236	105N13W03BACBBD	OPDC	4	1	45	30	30	1.0
192593	105N13W04ACDDCB	OPDC	4	1	87	25	24	1.0
192592	105N13W04CAABDC	OPDC	4	1	79	20	27	.74
531235	105N13W05BBDBAC	OPDC	4	1	46	30	25	1.2
531264	105N13W11CBCCBD	OPDC	4	1	85	50	10	5.0
507125	105N13W12BDAACA	OPDC	4	3	60	15	24	.63
519628	105N13W13DDDDBD	OPDC	4	1	38	30	10	3.0
101539	105N13W14BAABCB	OPDC	6	3	126	120	133	.90
192587	105N13W16AABBBD	OPDC	4	1	69	10	7	1.4
449409	105N13W28BBDCAC	OPDC	4	1	25	12	10	1.2
192546	105N15W02DDACAC	OPDC	4	1	97	20	19	1.1
148368	106N11W06CCBACC	OPDC	5	2	24	20	3	6.7
148354	106N11W19ABBBCA	OPDC	4	2	63	18	2	9.0
192512	106N11W19CDCDCB	OPDC	4	1	65	15	20	.75
107694	106N11W20CDCCAC	OPDC	4	3	38	15	104	.14
147047	106N11W32ABBBCB	OPDC	4	1	59	20	23	.87
535069	106N12W01BAADCD	OPDC	4	1	77	30	10	3.0

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
147007	106N12W04AAABBB	OPDC	4	1	43	20	11	1.8
104971	106N12W04CCCCAA	OPDC	4	1	52	20	29	.69
476611	106N12W09CDCDAB	OPDC	4	4	50	10	11	.91
105487	106N12W12DADABA	OPDC	4	2	44	18	1	18
148373	106N12W13ADADCD	OPDC	4	2	30	17	4	4.3
147094	106N12W23BDDBDC	OPDC	4	1	49	25	15	1.7
156960	106N12W31DCCCBD	OPDC	4	1	73	20	15	1.3
148320	106N13W02BDDADB	OPDC	6	10	49	15	36	.42
415301	106N13W03CCBAD	OPDC	4	2	35	60	34	1.8
147003	106N13W03CDDABB	OPDC	4	1	27	20	15	1.3
220626	106N13W06CCABCC	OPDC	4	2	40	40	5	8.0
196622	106N13W10ACDACD	OPDC	4	1	52	35	5	7.0
192565	106N13W10CAACBA	OPDC	4	1	47	30	12	2.5
192536	106N13W10DACCAC	OPDC	4	1	9	40	21	1.9
147071	106N13W11CAAABB	OPDC	4	1	39	20	17	1.2
147033	106N13W14ACAABD	OPDC	4	1	53	30	15	2.0
192574	106N13W14BCBCBA	OPDC	4	1	80	15	14	1.1
107688	106N13W14DBBCBC	OPDC	4	2	30	18	4	4.5
148360	106N13W15ABDBAB	OPDC	4	3	28	35	1	35
148342	106N13W15ACDABD	OPDC	4	87	40	27	3	9.0
179237	106N13W15BDABDB	OPDC	4	1	67	40	14	2.9
227638	106N13W16ABABDC	OPDC	4	3	41	25	10	2.5
148383	106N13W19CDDAAB	OPDC	5	2	30	17	2	8.5
228520	106N13W21BDCACD	OPDC	4	2.5	33	25	13	1.9
228532	106N13W21CAADDD	OPDC	4	3.5	50	15	4	3.8
148308	106N13W21CBAABB	OPDC	6	4	40	40	28	1.4
192564	106N13W21DAACBC	OPDC	4	1	48	30	12	2.5
227669	106N13W21DCAAAD	OPDC	4	3	45	15	6	2.5
101276	106N13W22CDCBCD	OPDC	4	1	28	20	40	.50
156961	106N13W23DCCBDC	OPDC	4	1	72	20	7	2.9
105489	106N13W24ABBCCB	OPDC	4	4	26	16	52	.31
192502	106N13W27DABDBA	OPDC	4	1	74	20	7	2.9
441658	106N13W30BDADAC	OPDC	5	1	38	20	10	2.0
179207	106N13W32CAADDB	OPDC	4	1	62	20	39	.51
220669	106N14W05ACCCDD	OPDC	4	11	27	24	9	2.7
227574	106N14W05DCBBCA	OPDC	4	5	42	20	6	3.3
476171	106N14W07AADDBC	OPDC	4	1	33	30	10	3.0
220676	106N14W10BDABAA	OPDC	4	6	44	25	25	1.0
228112	106N14W11CACDDA	OPDC	4	4	26	14	20	.70
228239	106N14W11DCDDBA	OPDC	4	5	38	20	36	.56

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
228260	106N14W14DBBAAB	OPDC	4	4	40	18	12	1.5
227682	106N14W14DCBDDA	OPDC	4	5	42	20	4	5.0
228503	106N14W15BBDCCD	OPDC	4	3	40	20	10	2.0
228509	106N14W15BDBDDD	OPDC	4	5	43	25	10	2.5
228507	106N14W15CAAABB	OPDC	4	3.5	43	25	10	2.5
228153	106N14W16ABCBAC	OPDC	6	4	35	20	7	2.9
228151	106N14W16DAABBD	OPDC	4	4	44	20	3	6.7
104969	106N14W18ACBBCA	OPDC	4	1	31	20	23	.87
104957	106N14W18CADDBA	OPDC	4	1	42	20	29	.69
192600	106N14W20DACAAB	OPDC	4	1	84	20	27	.74
489652	106N14W29ABAADA	OPDC	4	1	44	40	5	8.0
403803	106N14W30BAABDB	OPDC	4	1	92	40	14	2.9
160884	106N14W30BBCCDB	OPDC	4	2	40	15	1	15
105002	106N14W30CCCCBB	OPDC	4	1	42	20	4	5.0
437191	106N14W33ADCBBB	OPDC	4	1	42	18	9	2.0
107682	106N14W35ACCCAC	OPDC	4	2	34	18	15	1.2
519614	106N15W05DABAAC	OPDC	4	1	38	30	10	3.0
495139	106N15W06CDCCBD	OPDC	4	2	53	25	20	1.3
548894	106N15W09DAACCD	OPDC	4	2	30	25	19	1.3
518672	106N15W15BDDAAC	OPDC	4	2	65	30	42	.71
192596	106N15W17CCCDBB	OPDC	4	1	90	20	25	.80
192511	106N15W20DDDDDD	OPDC	4	1	65	10	5	2.0
192597	106N15W22BDADDC	OPDC	4	1	41	20	26	.77
449390	106N15W24CBDDDA	OPDC	4	1	35	20	10	2.0
148355	107N11W31AAAAAC	OPDC	4	3	51	20	2	10
105012	107N12W18DDDCBD	OPDC	4	1	58	20	4	5.0
489661	107N12W30DCCDDA	OPDC	4	1	68	30	27	1.1
192584	107N12W36CCABCD	OPDC	4	1	51	15	22	.68
105493	107N13W02CCCCCD	OPDC	4	2	28	14	1	14
228653	107N13W08CCBACC	OPDC	4	3	48	25	7	3.6
482534	107N13W13CBCABB	OPDC	4	1	50	30	10	3.0
105470	107N13W15CBBBAD	OPDC	4	2	30	17	2	8.5
220770	107N13W17ACCCDD	OPDC	4	4	20	15	10	1.5
228616	107N13W18CABBAA	OPDC	4	5	10	10	10	1.0
105455	107N13W20ACACAC	OPDC	4	2	32	13	1	13
105490	107N13W21ADCAAD	OPDC	4	3	39	25	3	8.3
196620	107N13W27BDAABB	OPDC	4	1	45	35	21	1.7
101443	107N13W27DDCCBB	OPDC	4	1	58	10	4	2.5
220797	107N14W04ABAABA	OPDC	4	9	43	20	3	6.7
482519	107N14W07CDCDDD	OPDC	4	1	28	30	10	3.0

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
220804	107N14W09BABBAD	OPDC	4	2	40	20	4	5.0
228560	107N14W12AADCBD	OPDC	4	5	51	22	4	5.5
228549	107N14W14DADAAB	OPDC	4	4	40	18	12	1.5
227580	107N14W16ACBBBD	OPDC	4	4	45	25	20	1.3
228586	107N14W24CBABAB	OPDC	4	4	37	25	6	4.2
228589	107N14W25DDDDBC	OPDC	4	6	25	30	15	2.0
228150	107N14W34BBBCBD	OPDC	16	2	203	636	27.2	23
148378	107N15W01CBDADB	OPDC	4	2	30	12	2	6.0
104985	107N15W02AABBAA	OPDC	4	1	28	20	16	1.3
192533	107N15W09ACCBCC	OPDC	4	1	79	15	16	.94
534338	107N15W11BBBBDA	OPDC	4	2	24	18	20	.90
428027	107N15W11BDDDAC	OPDC	4	1	47	30	12	2.5
449379	107N15W16DCDDCB	OPDC	4	1	22	12	10	1.2
148329	107N15W20BDADCB	OPDC	6	2	27	18	2	9.0
449395	107N15W21AADDBA	OPDC	4	1	40	12	10	1.2
531240	107N15W36CDDCBA	OPDC	4	2	83	30	15	2.0
220914	108N14W30CBAACB	OPDC	4	2	20	15	20	.75
105485	108N15W08ABBDBC	OPDC	4	2	35	15	2	7.5
141044	108N15W15DBBADC	OPDC	4	3	62	20	5	4.0
141019	108N15W16DADCBD	OPDC	4	2	33	30	68	.44
105008	108N15W20DABACB	OPDC	4	1	57	40	2	20.0
107700	108N15W21BABAAA	OPDC	4	4	28	14	3	4.7
506837	108N15W29ADAACA	OPDC	4	1	26	30	10	3.0
148325	108N15W33DADDAA	OPDC	4	4	40	17	3	5.7
428026	108N15W35CCCCDA	OPDC	4	1	33	20	12	1.7
156986	104N14W02ABDBDD	OSTP	4	1	79	20	9	2.2
104958	105N13W01CCCCBD	OSTP	4	1	36	20	21	.95
192520	105N13W08DBBCDB	OSTP	4	1	62	15	15	1.0
441672	105N13W09DDDACC	OSTP	4	1	29	20	15	1.3
104964	105N13W10CADCBC	OSTP	4	1	34	20	16	1.3
105460	105N13W12CCAABA	OSTP	4	36	21	20	3	6.7
148312	105N13W13BCBDCD	OSTP	6	4	35	14	2	7.0
219549	105N13W16DADAAA	OSTP	4	10	60	30	10	3.0
148303	105N13W29BDADCD	OSTP	6	3	45	15	3	5.0
105035	105N13W30BBBABC	OSTP	4	1	76	30	6	5.0
519617	105N14W02BBCDAC	OSTP	4	1	43	50	11.5	4.4
428033	105N14W02CDBDCC	OSTP	4	1	34	35	10	3.5
104960	105N14W08CBCABC	OSTP	4	1	43	25	20	1.3
105473	105N14W11AADAAB	OSTP	4	2	80	15	2	7.5
405116	105N14W11BABDDA	OSTP	4	2	70	35	10	3.5

Table 5.--Selected data from commercial drillers' records of wells in the study area used to estimate hydraulic properties--(Continued)

Unique number	Location	Unit well is open to	Screen diameter (in.)	Pumping duration (hrs)	Screen length (ft)	Pumping rate (gal/min)	Drawdown (ft)	Specific capacity (gal/min/ft)
165314	105N14W29ACDCBC	OSTP	4	3	39	15	30	.50
148327	105N15W08AACDDD	OSTP	4	2	55	18	20	.90
192503	105N15W12ABAADA	OSTP	4	1	84	20	7	2.9
148370	105N15W12BBCADC	OSTP	6	2	47	18	2	9.0
105038	105N15W16BBCCCA	OSTP	4	1	78	20	23	.87
107680	106N11W20CDCCAC	OSTP	4	24	53	18	1	18
105475	106N11W32CADCBA	OSTP	4	2	45	17	2	8.5
148301	106N12W02DCCDDA	OSTP	6	2	35	20	2	10
105453	106N12W08AAAAAC	OSTP	4	2	50	15	2	7.5
107695	106N12W08CCDCAD	OSTP	4	2	51	15	1	15
107657	106N12W29ADAAAC	OSTP	4	5	70	15	2	7.5
107689	106N12W30BBBBBC	OSTP	4	2	50	15	2	7.5
147087	106N12W30CDDCAC	OSTP	4	1	42	20	9	2.2
107693	106N13W25AACDAC	OSTP	4	2	79	18	5	3.6
101289	106N13W33DBDBCD	OSTP	4	4	23	10	25	.40
179236	106N13W35ACACCC	OSTP	4	1	77	20	4	5.0
104993	106N13W36CADDAC	OSTP	4	1	44	20	9	2.2
105001	106N14W28CCDDAB	OSTP	4	1	63	20	1	20
105500	106N14W29BBADBC	OSTP	4	3	35	18	3	6.0
107671	106N14W33DDDDCB	OSTP	4	2	91	15	3	5.0
449425	106N15W06BBBAAC	OSTP	4	1	19	30	10	3.0
105033	106N15W16AACCAC	OSTP	4	1	30	30	6	5.0
519640	106N15W19ACD	OSTP	4	1	40	30	10	3.0
107664	107N12W31CDCDDA	OSTP	4	4	63	15	5	3.0
107666	107N12W33CDDDDA	OSTP	4	4	62	15	2	7.5
105498	107N13W15DDDADC	OSTP	4	2	28	15	2	7.5
107658	107N13W22AADDBB	OSTP	4	3	50	25	4	6.3
104986	107N15W10CAABAA	OSTP	4	1	30	20	10	2.0
148359	107N15W11DBCCDB	OSTP	4	3	35	20	5	4.0
147016	107N15W15CBAACC	OSTP	4	1	42	20	12	1.7
105472	107N15W29BCCC	OSTP	4	2	60	15	8	1.9
105486	107N15W30BBBBBA	OSTP	4	2	31	16	3	5.3
241310	107N15W32CDDCDB	OSTP	4	4	49	25	6	4.2
105011	108N15W32DCBBBA	OSTP	4	1	67	20	8	2.5

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