# WATER LEVELS AND WATER-LEVEL CHANGES IN THE PRAIRIE DU CHIEN-JORDAN AND MOUNT SIMON-HINCKLEY AQUIFERS, TWIN CITIES METROPOLITAN AREA, MINNESOTA, 1971-80

By M. E. Schoenberg

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## ILLUSTRATIONS



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## CONVERSION FACTORS

| Multiply inch-pound unit | By | To obtain SI (metric) unit |
|---|---|---|
| foot (ft) | 0.3048 | meter (m) |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day ($m^2/d$) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| million gallons (Mgal) | 3785 | cubic meters ($m^3$) |

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National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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## ABSTRACT

The ground-water system in the Twin Cities Metropolitan Area includes five aquifers; two of these aquifers--the Prairie du Chien-Jordan and the Mount Simon-Hinckley--supply about 80 percent and 10 percent, respectively, of the ground water pumped for public supply. Water levels and changes in water levels in these two aquifers differ greatly in the Twin Cities Metropolitan Area. The Mississippi, Minnesota, and St. Croix Rivers are in hydraulic connection with and influence the pattern of flow in the upper aquifer, the Prairie du Chien-Jordan. Water generally flows toward these streams from water-level highs northeast, northwest, and south of Minneapolis and St. Paul. Consequently, heavy pumping has caused only localized cones of depression in the potentiometric surface of this aquifer. In contrast, the Mount Simon-Hinckley, which has only a slight hydraulic connection to the streams, is greatly influenced by pumping. Pumping in the urban centers of Minneapolis and St. Paul has caused a large cone of depression in the Mount Simon-Hinckley potentiometric surface. During 1971, the measurable cone was centered in east-central Hennepin County, was about 25 miles in diameter, and was as much as 150 feet deep at its center.

Between 1971 and 1980, average water levels in the Prairie du Chien-Jordan aquifer changed less than 5 feet in most of the study area, but rose or declined as much as 25 feet locally in response to pumpage and recharge. During this period, seasonal declines of water levels from winter to summer lessened, and the area where these declines exceeded 10 feet decreased.

In contrast, between 1971 and 1980, average water levels in the Mount Simon-Hinckley aquifer rose as much as 60 feet in the center of the cone of depression in response to decreased pumping. Also, the measurable cone of depression contracted from about 25 miles to about 15 miles in diameter. However, because of increased summer pumping due to below-average precipitation during 1980, seasonal water levels declined much more and over a wider area during 1980 than in 1971.

Water-level data suggest that (1) little variation in annual pumpage between 1971 and 1980 from the Prairie du Chien-Jordan aquifer produced generally stable water levels in that aquifer, (2) decreased annual pumpage from the Mount Simon-Hinckley aquifer from 1971 to 1980 caused water levels in that aquifer to rise, and (3) a greater seasonal component of pumpage from the Mount Simon-Hinckley aquifer than from the Prairie du Chien-Jordan produced larger and more widespread seasonal water-level declines in the Mount Simon-Hinckley than in the Prairie du Chien-Jordan, particularly during dry years.

## INTRODUCTION

The ground-water system in the Twin Cities area contains five aquifers (Guswa and others, 1982, table 1). Two of these aquifers, the Prairie du Chien-Jordan and Mount Simon-Hinckley, supply about 80 and 10 percent, respectively, of the ground-water pumped in the 3,000 $mi^2$, seven-county area (fig. 1). This report describes water levels and water-level changes in these aquifers in the Twin Cities during the period 1971-80.

State and local agencies, industries, and municipalities need information on water levels and water-level changes caused by pumping to anticipate the effects of increased pumping on the aquifers. For example, ground-water withdrawals have caused water-level declines of about 200 ft in the Mount Simon-Hinckley aquifer and 90 ft in the Prairie du Chien-Jordan aquifer since 1885 (Reeder, 1966; Norvitch and others, 1973, p. 118). In addition, water levels decline sharply during summer as pumping increases and recover during winter as pumping decreases. To provide the needed water-level data, the U.S. Geological Survey, in cooperation with the Metropolitan Council of the Twin Cities and the Minnesota Department of Natural Resources, measured water levels in wells throughout the Twin Cities area during winter and summer 1965, 1971, and 1980, summer 1977, and winter 1978. These water-level data will also be used to calibrate a digital ground-water-flow model of the Twin Cities area (Guswa and others, 1982).

### Purpose and Scope

This report documents water-level data collected during winter and summer 1980 for the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers and compares the data with those collected during winter 1971. Specific objectives are to (1) compare short-term and long-term changes in water levels in the two aquifers, (2) examine the effects of major pumping centers on water levels over the 1971-80 period, and (3) describe ground-water-flow patterns in the two aquifers. This report contains a brief description of the hydrologic setting, a description of the water-level observation network and methods used to collect data, water-level maps for winter 1971 and winter and summer 1980 for both aquifers, seasonal and long-term water-level-change maps, and hydrographs of selected wells. Water-level data for 1971 and 1980 were analyzed in detail because this was the calibration period chosen for the ground-water-flow model.

### Previous Investigations

In 1966, the U.S. Geological Survey released 14 maps depicting historical water levels and water-level changes for the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers in the Minneapolis-St. Paul Metropolitan Area (Reeder, 1966). The maps show water levels for both aquifers for 1885, 1949, 1959, and 1965 and changes in water levels from 1885 to each of the subsequent years. Norvitch and others (1973) provide water-level maps for both aquifers for winter 1970-71 and for the Prairie du Chien-Jordan for August 1971, and water-level-change maps for the Prairie du Chien-Jordan for December 1970 to August 1971 and winter 1965 to winter 1970-71. Hult and Schoenberg (1981) provide more detailed water-level data for both aquifers for 1979 in a 110-$mi^2$ area surrounding St. Louis Park, a western suburb of Minneapolis. In addition, a

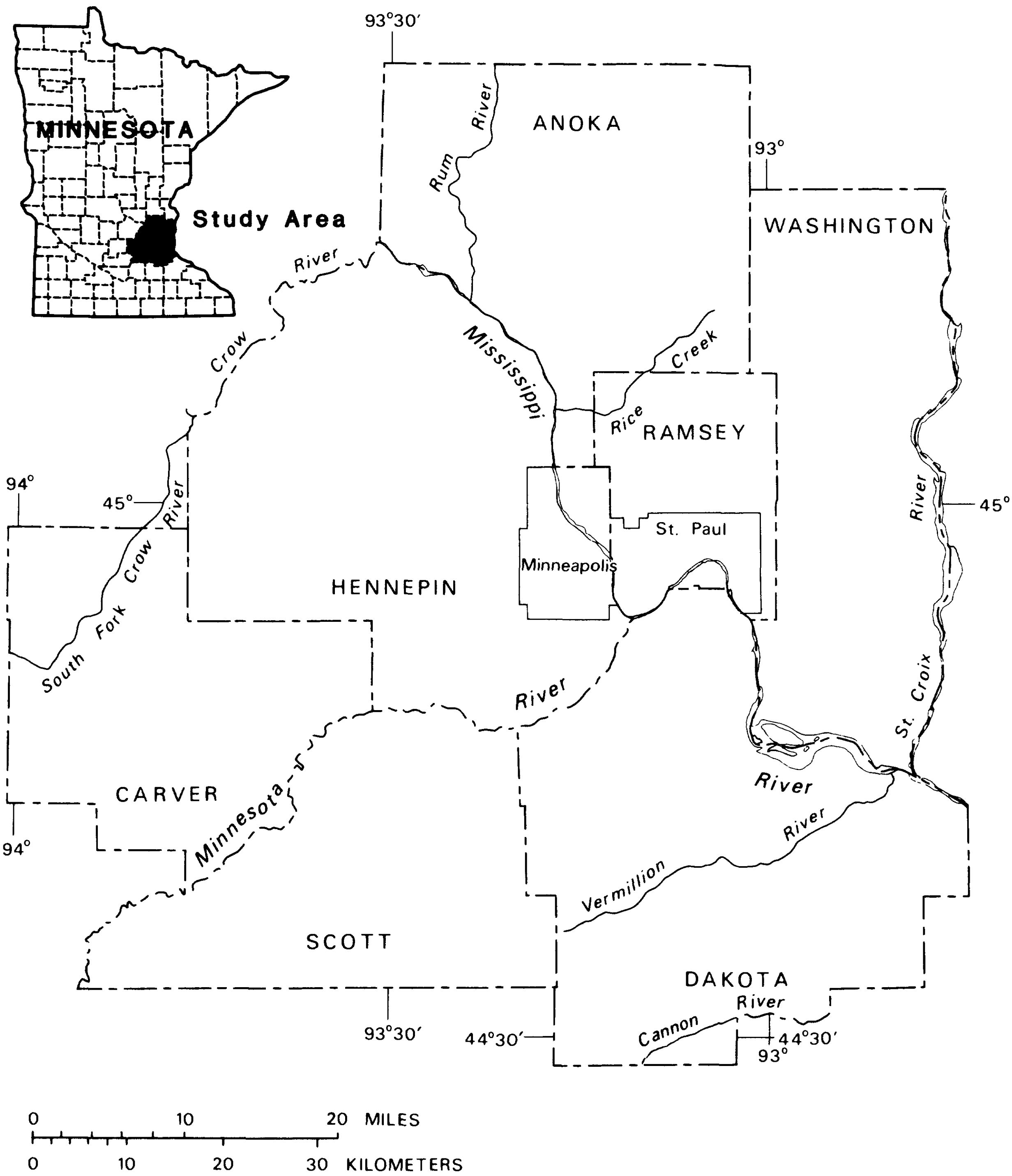



***Figure 1.--Location of Twin Cities Metropolitan Area, Minnesota***

report by Horn (1983) contains ground-water pumpage data that are very useful in understanding and interpreting water levels and water-level changes. Delin and Woodward (1982) constructed regional water-level maps for both aquifers in southeastern Minnesota, which includes the Twin Cities Metropolitan Area.

### Acknowledgments

The author is grateful to all the well owners who allowed measurements of water-levels in their wells. Special thanks are given to those municipalities, industries, and others who turned off their pumps the night prior to a water-level measurement in their well in order to allow adequate time for water-levels to recover from pumping.

## GEOLOGIC AND HYDROLOGIC SETTING

The ground-water system underlying the Twin Cities contains 14 geologic units that Guswa and others (1982; table 1) combined into 9 hydrogeologic units--5 aquifers and 4 confining units (fig. 2). The five uppermost hydrogeologic units are not continuous in the Twin Cities area because of erosion of bedrock units or nondeposition of drift or both. Bedrock valleys deeply incise the six uppermost hydrogeologic units. These valleys either contain drift or form present-day stream valleys and significantly affect flow in the Twin Cities ground-water system.

The Prairie du Chien-Jordan aquifer comprises two geologic units with different lithologies and correspondingly different hydraulic properties. The Prairie du Chien Group of Ordovician age is predominantly dolomite; it contains fractures, joints, and solution cavities that control the flow of water through it. The Jordan Sandstone of Cambrian age is a fairly uniform, highly permeable sandstone; flow through it is primarily intergranular. The two units act as a single aquifer because no extensive confining unit separates them.

Drift-filled bedrock valleys, present-day stream valleys, or both, interrupt the continuity of the Prairie du Chien-Jordan aquifer in many parts of the study area. In the major stream valleys, where the overlying confining units have been removed by erosion (fig. 2), a good hydraulic connection exists between the aquifer and the major streams. The degree of hydraulic connection between the Prairie du Chien-Jordan and these streams depends on the hydraulic conductivity of the valley-fill deposits.

The Mount Simon-Hinckley aquifer comprises two sandstone formations, the Mount Simon Sandstone of Cambrian age and the Hinckley Sandstone of Precambrian age. They are continuous throughout the study area and have similar hydraulic characteristics. A thick confining unit, the Eau Claire Sandstone, which overlies the Mount Simon-Hinckley aquifer (fig. 2), retards flow between the Mount Simon-Hinckley and the overlying aquifers and the surface-water system.

Norvitch and others (1973) present a detailed discussion of the geologic and hydrologic properties of the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers.

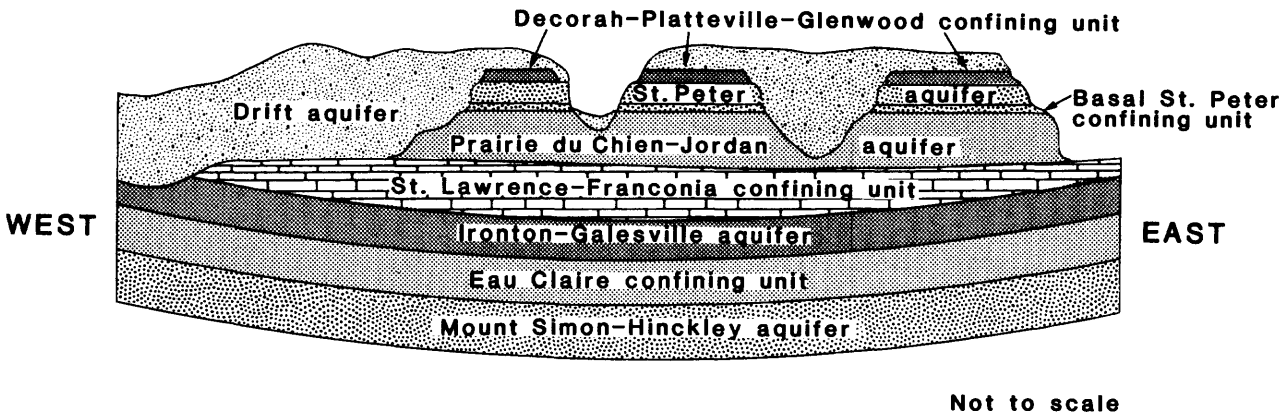



***Figure 2.--Schematic hydrogeologic section through the Twin Cities Metropolitan Area (after Guswa and others, 1982, fig. 2)***

## DESCRIPTION OF THE GROUND-WATER-LEVEL OBSERVATION NETWORK

Development of the ground-water-level observation network for the Twin Cities began in 1965. At that time the network was located in Minneapolis, St. Paul, and the surrounding suburbs. With successive measurements during 1971, 1977-78, and 1980, the network was expanded to cover the entire seven-county metropolitan area and parts of adjoining counties. In 1971, 329 water-level measurements were made during the winter and 308 during the summer. During 1980, observation-well density was increased in areas of greatest ground-water withdrawal, near natural boundaries such as major rivers, and in the uppermost bedrock unit. In 1980, water levels were measured in 431 wells, 406 during the winter and 420 during the summer; most wells were measured during both periods. Of the 431 wells measured, 310 are in the Prairie du Chien-Jordan aquifer and 28 in the Mount Simon-Hinckley aquifer. The addition of about 15 wells in the Mount Simon-Hinckley aquifer to the network in 1980 increased the density of wells north and northwest of Minneapolis and St. Paul.

### Network Rationale and Data Accuracy

Most wells in the network were originally installed for municipal, commercial, residential, and other kinds of water withdrawal; most are still used for those purposes. As a result, the network density is generally adequate in areas of large withdrawals, but sparse in areas of small withdrawals. Also, water levels in many wells in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers are greatly affected by nearby pumping. This factor significantly affects the strategy of measurement and the use of the water-level data.

The water-level observation network comprises two sets of wells. One set is measured during winter and summer at approximately 5-year intervals, while the other is measured at 6- to 8-week intervals. The basis for choosing wells differs for each set.

Wells measured every 5 years are as evenly and widely distributed as possible. Because of their availability and access, this set of wells contains many municipal, industrial, and commercial wells. Most of these wells withdraw water from the Prairie du Chien-Jordan aquifer, while a smaller number withdraw water from the Mount Simon-Hinckley aquifer.

The second set of wells form part of a statewide water-level network maintained in cooperation with the Minnesota Department of Natural Resources. These wells, measured every 6 to 8 weeks, were chosen to measure representative water-level fluctuations throughout each aquifer and to provide background (baseline) water-level data. This set contains a few widely distributed wells. Forty-one are located in the Twin Cities Metropolitan Area: 37 completed in the Prairie du Chien-Jordan aquifer and 4 completed in the Mount Simon-Hinckley aquifer. Most of these wells are no longer pumped and nine (one in the Mount Simon-Hinckley aquifer) are equipped with continuous water-level recorders.

The accuracy of water-level data from individual wells in the network differs because of the methods used to determine measuring-point altitudes. Only about one-fourth of the wells, primarily municipal wells and U.S. Geological Survey-Minnesota Department of Natural Resources observation wells, have had measuring-point altitudes surveyed to within 0.1 ft. Measuring-point altitudes for the remaining wells were estimated from topographic maps to an accuracy within 5 to 10 ft. The water-level altitudes used for the maps in this report, therefore, are accurate to within 5 to 10 ft, and adequately reflect regional ground-water flow. If detailed water-level data for a small local area are needed, the records of wells in that area need to be examined.

The accuracy of water-level data from individual wells in the network also may differ because of well-construction methods. Most wells in the network are open to the full thickness of the individual aquifer; these water levels represent the average water level for the aquifer. However, some wells are open only to part of the aquifer; water levels in these wells represent only the average water level for the section to which the well is open and may differ from the average water level of the aquifer at the same point. However, water levels from wells near each other but completed to different depths are similar. This indicates nearly vertical equipotentials within the aquifers, suggesting that the water levels used in this report represent the altitude to which static water would rise in each aquifer.

### Measurement Strategy

A measurement strategy was formulated to obtain a regional picture of water levels and to investigate long-term and seasonal water-level changes. The strategy has four basic features. First, recognizing that all wells should be measured simultaneously to represent the water-level surface at an instant of time, measurements were made over as short a time as possible (about 3 weeks). Secondly, measurements were made so that all wells within a pumping center were measured within a day or two, rather than over the 3-week period. Thirdly, municipal and other high-capacity wells were turned off the night before water-level measurements were made so that localized, short-term effects of pumping were minimized. Finally, water levels were measured twice during the year, once during winter (January-February) when pumping was at a minimum and once during summer (August) when pumping was near maximum. In the Twin Cities area, ground-water withdrawals in summer are commonly more than twice the withdrawals in winter because of use of ground water for air conditioning, lawn sprinkling, and crop irrigation (Horn, 1983).

## WATER LEVELS AND WATER-LEVEL CHANGES IN THE PRAIRIE DU CHIEN-JORDAN AQUIFER

The maps on plate 1 (A, B, and C) show that water levels in the Prairie du Chien-Jordan aquifer are highest (more than 900 ft above sea level) in northern Washington County, central Hennepin County, and southern Scott and Dakota Counties. The lowest water levels (less than 700 ft above sea level) occur along the Mississippi River where the river leaves the southeastern corner of the study area. The water-level contours indicate that ground water generally flows from the water-level highs toward the major streams, the Mississippi, Minnesota, and St. Croix Rivers. The water-level contours also indicate that water flows toward some smaller streams, such as the Vermillion and Cannon Rivers in the southeastern part of the study area. This general flow pattern indicates that the major streams in the Twin Cities area are the principal natural points of discharge for ground water in the Prairie du Chien-Jordan aquifer.

Water-level contours on maps A, B, and C on plate 1 that locally are irregularly shaped or closed indicate that major pumping centers disrupt the natural flow pattern in the Prairie du Chien-Jordan aquifer by diverting ground water enroute to the major streams. In some areas, such as near the depression in the water-level surface in southwestern Ramsey County (pl. 1A and 1B), pumping may have reversed the natural direction of flow and caused water from the Mississippi River to enter the aquifer. However, despite heavy pumpage that averaged about 154 Mgal/d from 1976 through 1979 (Horn, 1983, table 7), the water-level surface of the Prairie du Chien-Jordan aquifer has no large cones of depression. This indicates a highly transmissive aquifer (Woodward, 1984) that is in good hydraulic connection with the overlying drift and the major streams.

## Water-Level Changes, 1971-80

Water-level changes in the Prairie du Chien-Jordan aquifer between 1971 and 1980 (pl. 1E) were determined by comparing water levels measured during January-March 1971 (pl. 1A) with those measured during January-February 1980 (pl. 1B). Water levels measured during winter were chosen for this comparison because they seem to represent "average" annual water levels and because water levels are fairly stable during the winter months. Plate 1E shows that water levels in different parts of the Prairie du Chien-Jordan aquifer rose as much as 20 ft and declined as much as 30 ft between winter 1971 and winter 1980. Water levels rose more than 5 ft in eastern Dakota County south of the junction of the St. Croix and Mississippi Rivers, throughout most of Washington County, in central Ramsey County, and in eastern Hennepin County. Water levels declined more than 5 ft in central Dakota County and in central Hennepin County. The greatest water-level changes are centered around single wells, and reflect reductions or increases in ground-water pumpage by industries and municipalities. For example, the rise in water levels in northeastern Dakota County near the Mississippi River is due to reduced pumpage by the meat-packaging industry in that area (Horn, 1983, fig. 1). Also, the water-level declines in central Hennepin County are probably due to increased pumping from the Prairie du Chien-Jordan aquifer by suburban municipalities west of Minneapolis. The general rise in water levels in Washingtron County is probably related to long-term climatic trends, rather than changes in pumping. This phenomenon is the object of studies by Federal, State, and local agencies because of its possible relationship to high lake levels in the area (D. C. Gillies, U.S. Geological Survey, St. Paul, Minn., oral commun., 1983).

Although water levels changed significantly in certain parts of the Twin Cities area between 1971 and 1980 (pl. 1E), there was no region-wide trend for the Prairie du Chien-Jordan aquifer. This is not surprising considering that average daily pumpage from the aquifer remained fairly constant for 1970-79, averaging 152.7 Mgal. Table 1 below shows average daily pumpage for each year and indicates that pumpage peaked in 1974 and has declined since then.

Table 1.--Annual daily pumpage from the Prairie du Chien-Jordan aquifer, 1970-79

[Pumpage in million gallons]

| Year | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pumpage | 148.3 | 145.2 | 144.5 | 158.2 | 160.4 | 153.2 | 159.9 | 156.6 | 152.3 | 148.5 |

Water-level trends in the Prairie du Chien-Jordan aquifer also are apparent in the hydrographs of wells. However, depending on the proximity of an observation well to pumping centers and on the nature of the pumping, the characteristics of these hydrographs differ considerably. Figure 3A is a hydrograph of well 031N22W23CBC02 in the Prairie du Chien-Jordan aquifer in southern Anoka County (location shown in pl. 1E) where little or no water is pumped from the aquifer. The hydrograph shows that the water level rose slightly from 1971 through early 1976, due to climatic conditions, although the rise is hardly distinguishable from the seasonal change of 2 to 3 ft. The water level fell sharply about 3 feet in mid-1976 because of drought and rose slightly from 1977-80 as normal climatic conditions prevailed. Winter and Pfannkuch (1976) report that the Prairie du Chien-Jordan aquifer is in good hydraulic connection with several lakes in the area. In addition, the levels of some of these lakes are controlled. These two factors help explain why the water level in the well has been so stable during the period of record. Several downward spikes in the hydrograph during 1976-77 provide the only evidence of pumping. This pumping, apparently from standby supply wells in the area, affected the water level in the observation well for very short periods.

Figure3B is a hydrograph of well 117N23W11BBD01 in the Prairie du Chien-Jordan aquifer in west-central Hennepin County (location shown in pl. 1E). The well is at the western edge of the area west of Minneapolis where water levels declined during 1971-80 (see pl. 1E) because of municipal pumpage. The hydrograph shows relatively stable water levels during fall, winter, and spring of each year, but sharp declines due to increased summer pumping. It also shows that average water levels declined steadily between 1971 and 1980, accumulating a net decline of 6 to 7 ft.

## Seasonal Water-Level Changes

Water levels in the Prairie du Chien-Jordan aquifer fluctuate seasonally in much of the Twin Cities area, primarily in response to increased pumping during summer. Horn (1983, table 8 and fig. 16) determined that the seasonal component of ground-water pumpage varied among water-use categories and that total summer pumpage from all aquifers was significantly larger than winter pumpage. For example, in 1978, a year with normal amounts of precipitation, August pumpage was about 2.5 times greater than February pumpage. In 1976, a very dry year, July pumpage was about 3 times greater than January pumpage.

The effects of seasonal pumpage are indicated in the water-level change maps on plate 1D and 1F, which show the difference in water levels between January-March and August 1971, and between January-February and August 1980,

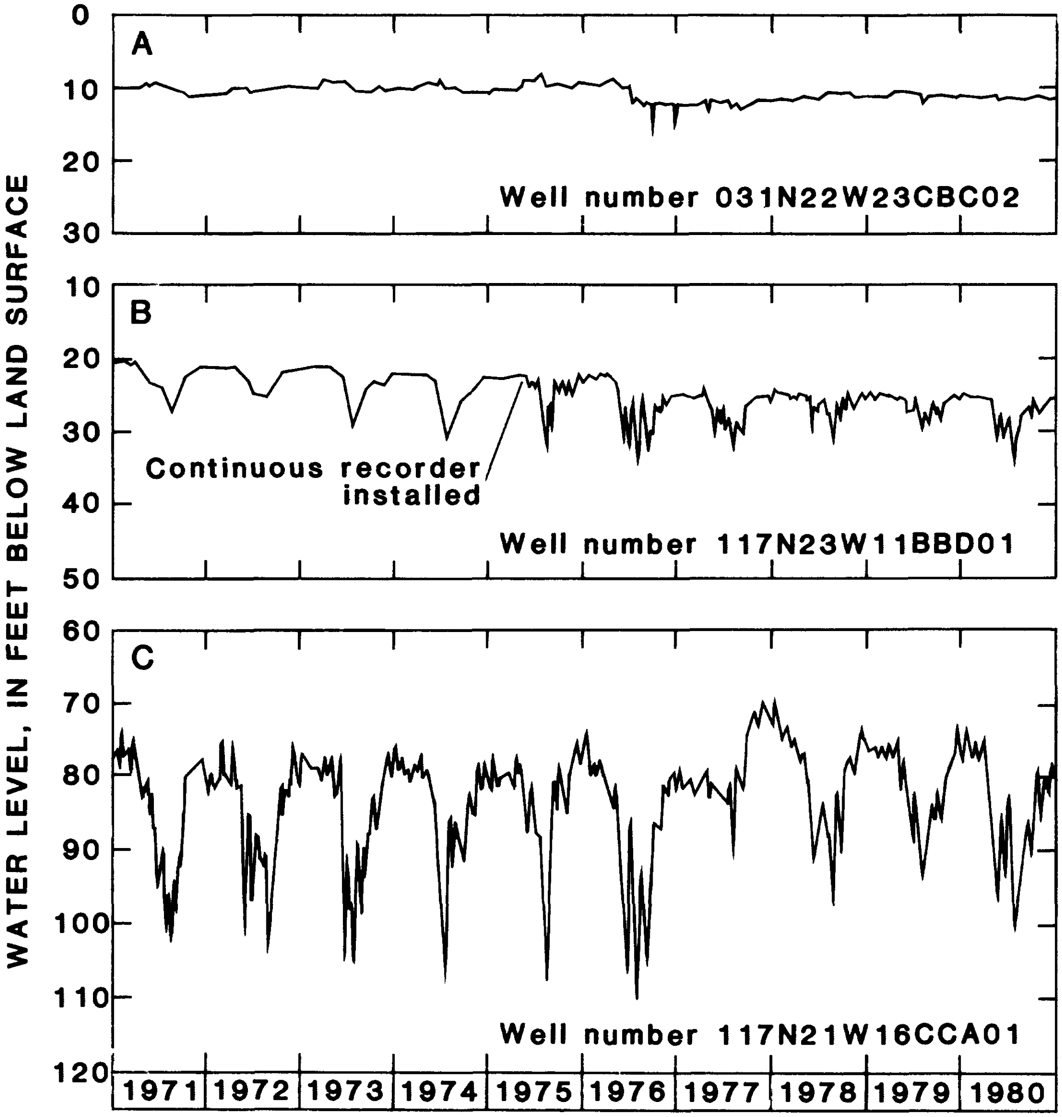
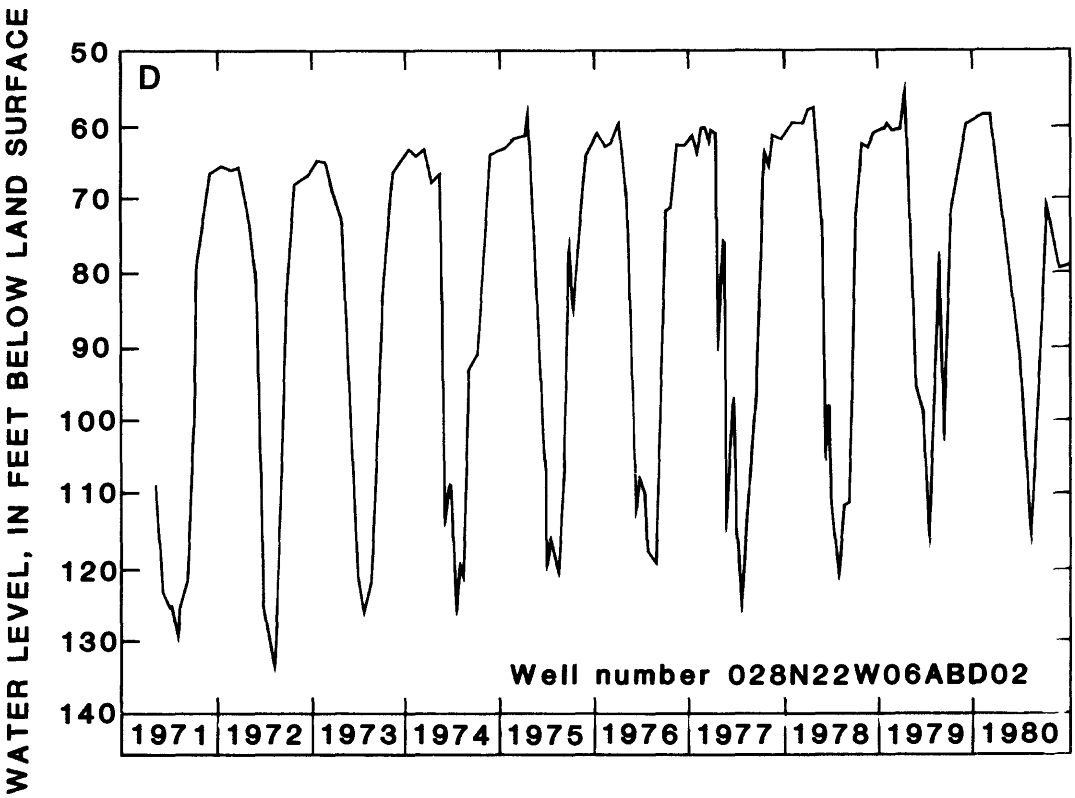



***Figure 3.--Hydrographs showing water-level***

***A. Well 031N22W23CBC02***
***B. Well 117N23W11BBD01***
***C. Well 117N21W16CCA01***
***D. Well 028N22W06ABD02***




***changes in the Prairie du Chien-Jordan aquifer in:***

***in southern Anoka County***
***in west-central Hennepin County***
***in east-central Hennepin County***
***in downtown St. Paul***

respectively. The water-level changes depicted in these maps may not represent the total seasonal change for the year, because they were calculated from two sets of one-time measurements rather than continuous measurements. In 1980, for example, hydrographs of wells influenced by pumping (see figs. 3B and 3C) indicate that water levels recorded in July in the primary pumping center were as much as 10 ft lower than in August. However, the maps are still very useful for analyzing seasonal water-level changes on a regional basis. Plate 1D shows that during 1971 water levels declined more than 10 ft in much of east-central Hennepin County and southwestern Ramsey County and that there were two major centers of water-level decline. One was in the Edina-St. Louis Park area in Hennepin County where municipal pumping caused water levels to decline as much as 50 ft. The other extended along the Mississippi River from St. Paul to Minneapolis where withdrawals for air conditioning in commercial buildings caused water levels to decline as much as 70 ft. Water levels also declined significantly in a relatively small area south of the Mississippi River near West St. Paul.

Water levels declined less during 1980 than during 1971 and the area where water-level declines exceeded 10 ft was smaller (pl. 1F), despite the fact that the summer of 1980 was dryer than the summer of 1971. Maximum water-level declines were about 40 ft in the Edina-St. Louis Park area and about 50 ft in Minneapolis. Comparison of maps D and F of plate 1 suggests that the seasonal component of pumpage for the Prairie du Chien-Jordan aquifer decreased between 1971 and 1980. This decrease is related to use of water from the Mount Simon-Hinckley aquifer and is discussed further in a later section of this report.

Changes in water level from winter to summer are well documented in the hydrograph of well 117N21W16CCA01 in the Prairie du Chien-Jordan aquifer (fig. 3C) at St. Louis Park in east-central Hennepin County (pl. 1D and 1F). Seasonal water-level fluctuations in this well are due primarily to pumping from municipal wells. From 1971 to 1980, the seasonal water-level changes ranged from about 10 to 30 feet. In 1976, the seasonal change was the maximum for the period and the summer low-water-level period was longer than that of other years, reflecting the extremely dry conditions and heavy pumping of that year. In contrast, the hydrograph shows a much smaller seasonal change in 1977 and water levels in late 1977 and early 1978. The hydrograph segment of 1980 is similar to that of 1971. The net change in water level over the 10-year period was small.

Figure 3D is a hydrograph of well 028N22W06ABD02 in the Prairie du Chien-Jordan aquifer (location shown on pl. 1E) in downtown St. Paul (pl. 1D and 1F) where water levels in the aquifer are strongly influenced by pumping for air conditioning in commercial buildings. The seasonal water-level changes are so large (as much as 70 ft) because pumpage for commercial buildings during August is commonly more than 10 times that during February (Horn, 1983, fig. 16). The magnitude of seasonal change (averaging about 60 ft) did not vary significantly over the period 1971-80, indicating that seasonal pumpage for air conditioning of commercial buildings near the well was uniform over the period. The hydrograph shows that the average water level rose between 1971 and 1980, probably because of a decrease in total industrial pumpage in the area (Horn, 1983, fig. 10). This rise in water levels is also indicated on plate 1E.

## WATER LEVELS AND WATER-LEVEL CHANGES IN THE MOUNT SIMON-HINCKLEY AQUIFER

The maps on plate 2 (A, B, and C) indicate that the highest water levels (about 900 ft above sea level) in the Mount Simon-Hinckley aquifer occur in the northwestern part of the study area. The lowest water levels (less than 600 ft above sea level) correspond to the location of major pumping centers in east-central Hennepin County. Delin and Woodward (1982, p. 38; pl. 6) show a water-level high (about 850 ft above sea level) to the south of the study area.

Water-level contours indicate that natural ground-water flow in the Mount Simon-Hinckley aquifer is from the northwest corner of the study area southeast to the vicinity of the Minnesota and Mississippi Rivers. Ground water also flows to that same vicinity from the ground-water high south of the study area (Delin and Woodward, 1982, p. 38). In eastern Washington County, ground water flows east toward the St. Croix River, while southeast of the Twin Cities area it generally flows east to the Mississippi River (Delin and Woodward, 1982, p. 38). Comparison of water levels in the Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers near the Minnesota and Mississippi Rivers suggests that ground water flows upward from the Mount Simon-Hinckley to the Prairie du Chien-Jordan aquifer in areas where the head in the Mount Simon-Hinckley aquifer exceeds 700 ft above sea level.

The natural flow pattern in the Mount Simon-Hinckley aquifer is interrupted by a large cone of depression in the water-level surface that was about 25 miles in diameter and 100 to 150 ft deep during winter 1971 (pl. 2A). The cone of depression encircles major pumping centers in St. Louis Park and Edina (Hennepin County) and in St. Paul (southern Ramsey County). Moreover, sites of significant withdrawals from the Mount Simon-Hinckley aquifer are scattered throughout the Twin Cities area (Horn, 1983, fig. 13), and all contribute to development of the cone.

The areal extent, depth, and shape of the cone of depression suggest that although the aquifer has a transmissivity of 2,000 to 4,000 $ft^2/d$ (Woodward, 1984), it is in poor hydraulic connection to the shallow ground-water system and the major streams. As a result, the shape of the cone and the flow pattern are controlled by the location of pumping centers and not by the major streams, which control the shape of the flow pattern in the Prairie du Chien-Jordan aquifer.

The decline in water levels in the Mount Simon-Hinckley aquifer has been large despite the relatively low rate of ground-water withdrawal (averaging 19.9 Mgal in 1976-79; Horn, 1983, table 7) when compared to Prairie du Chien-Jordan aquifer. This suggests that water originally pumped from storage is replaced from either one or both of two sources. Water may flow laterally into the pumping center or leak vertically into the aquifer through overlying hydrogeologic units. Limitation of the cone of depression to the area of the pumping center suggests that vertical leakage is probably the primary source of water.

## Water-Level Changes, 1971-80

Water-level changes in the Mount Simon-Hinckley aquifer between 1971 and 1980 (pl. 2E) were determined by comparing water levels measured during January-March 1971 (pl. 2A) with those measured during January-February 1980 (pl. 2B). As with the Prairie du Chien-Jordan aquifer, water levels in winter were used for this comparison because they represent "average" conditions in the aquifer and because water levels are generally most stable during the winter months. Plate 2E shows that water levels in the Mount Simon-Hinckley aquifer rose more than 10 ft throughout most of the cone of depression and more than 50 ft in the center of the cone. Water levels declined slightly in one small area in southern Anoka County due to increased municipal pumpage. Comparison of plates 2A and 2B indicates that the areal extent of the cone of depression decreased from about 25 miles to about 15 miles in diameter between 1971 and 1980. Water levels rose and the cone decreased in size because of a decrease in ground-water withdrawals from a daily average of 22.3 Mgal during 1971-75 to 19.9 Mgal during 1976-79 (Horn, 1983, table 7). Table 2 below indicates that average daily pumpage decreased 4.0 Mgal between 1970 and 1979.

Table 2.--Average daily pumpage from the Mount Simon-Hinckley aquifer, 1970-79

[Pumpage in million gallons]

| Year | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pumpage | 24.9 | 22.8 | 21.8 | 23.6 | 22.3 | 21.1 | 21.0 | 19.2 | 18.6 | 20.9 |

Interpretation and use of the water-level change map depicted in plate 2E requires some care. The map was derived from two sets of one-time water-level measurements and represents the net change between the two times. However, water levels in the Mount Simon-Hinckley aquifer change rapidly during the year in response to seasonally variable pumpage (Horn, 1983). Relating the change in water levels shown on plate 2E with the change in annual pumpage shown in table 2 may not be appropriate because, despite large seasonal variation in pumping rate, the pumpage is an average daily value of an entire year, whereas the water levels were measured over about a 3-week period.

Hydrographs of wells in the Mount Simon-Hinckley aquifer differ considerably depending on the location of observation wells in relation to nearby pumping. Seasonal ground-water use varies considerably among different uses (Horn, 1983, table 8, fig. 16). Thus, water levels in the observation wells are affected differently, depending upon the type of nearby water use.

Figure 4A is a hydrograph of well 036N23W32ACB01 in the Mount Simon-Hinckley aquifer in Cambridge, Minn., about 40 miles north of the Twin Cities where pumping from the aquifer is minimal (location indicated on pl. 2E). Although this observation well is outside the study area, its water-level pattern is similar to water-level patterns inside the study area away from pumping centers. Here the Mount Simon-Hinckley aquifer is the uppermost bedrock unit and is directly overlain by about 170 ft of outwash and till. This standby well is pumped sporadically to supply water during dry periods and for fire protection. The jagged nature of the hydrograph may be due to a combination of seasonal recharge and short-term pumping. Water-level changes within any single year are generally 3 to 4 ft, with a maximum of about 14 ft. The hydrograph indicates low water levels that may be due to increased pumping during dry periods in 1974 and 1976-80. Despite these short-term changes in water level, the hydrograph indicates no significant trend between 1972 and 1980, suggesting that water levels in the Mount Simon-Hinckley aquifer away from the cone of depression are not affected by pumping from the aquifer in the Twin Cities.

In contrast, the hydrograph of well 029N23W25CCD01 in the Mount Simon-Hinckley aquifer at St. Paul (fig. 4B; location shown on pl. 2E) shows a rise in water level of about 40 feet between 1971 and 1980. Unfortunately, the water-level record for 1971-80 is incomplete; two water-level measurements were made in 1971 but none were made during 1972-76. A continuous water-level recorder was installed on the well in 1977. The well is located in an old industrial area of St. Paul; the rise in water level reflects a general decrease in pumping from the Mount Simon-Hinckley aquifer for industrial use (Horn, 1983, table 3, fig. 12). Water-level changes recorded within single years (1977-80) are probably due to seasonal variations in pumpage from municipal wells elsewhere within the Mount Simon-Hinckley aquifer cone of depression.

Figure 4C is a hydrograph of well 117N21W32DAD01 in the Mount Simon-Hinckley aquifer in Edina, Minn., in east-central Hennepin County (location shown on pl. 2). This well, also known as Edina 9, is one of six high-capacity wells located in the deepest part of the cone of depression in the Mount Simon-Hinckley aquifer (pl. 2A, 2B, and 2E). These six wells are used to supply ground water to the cities of Edina and St. Louis Park along with their wells in the Prairie du Chien-Jordan aquifer. Edina 9 is used to supplement the pumpage from other wells, but the pumping rate is low (average 0.12 Mgal, 1970-80), less than one-fifth of the average of each of the other five wells. The hydrograph was prepared from 7 to 10 water-level measurements per year taken when the well was not pumping. The water level in Edina 9 has fluctuated widely between 1971 and 1980 in response to nearby pumping from the Mount Simon-Hinckley aquifer. The maximum change was about 80 ft in 1976 and the minimum about 15 ft in 1978. Despite these wide fluctuations, the high water levels in winter show a general upward trend.

The rise in water level in Edina 9 is even more apparent in figure 5, which shows the annual mean water level in Edina 9 for each year between 1970 and 1980, the combined annual pumpage for Edina 9 and the other five high-capacity wells nearby in the Mount Simon-Hinckley aquifer, and annual precipitation. Note that the pumpage scale is inverted. The annual mean water levels were calcuated from the 7 to 10 measurements made each year. The annual mean water levels rose overall about 10 ft between 1971 and 1980. In addition, rising water levels generally correspond to decreased pumpage and declining water levels with increased pumpage. Changing pumping rates elsewhere in the aquifer have also affected the water level in Edina 9, as suggested by the poor correspondence between water levels and pumpage for 1975-77. Figure 5 also

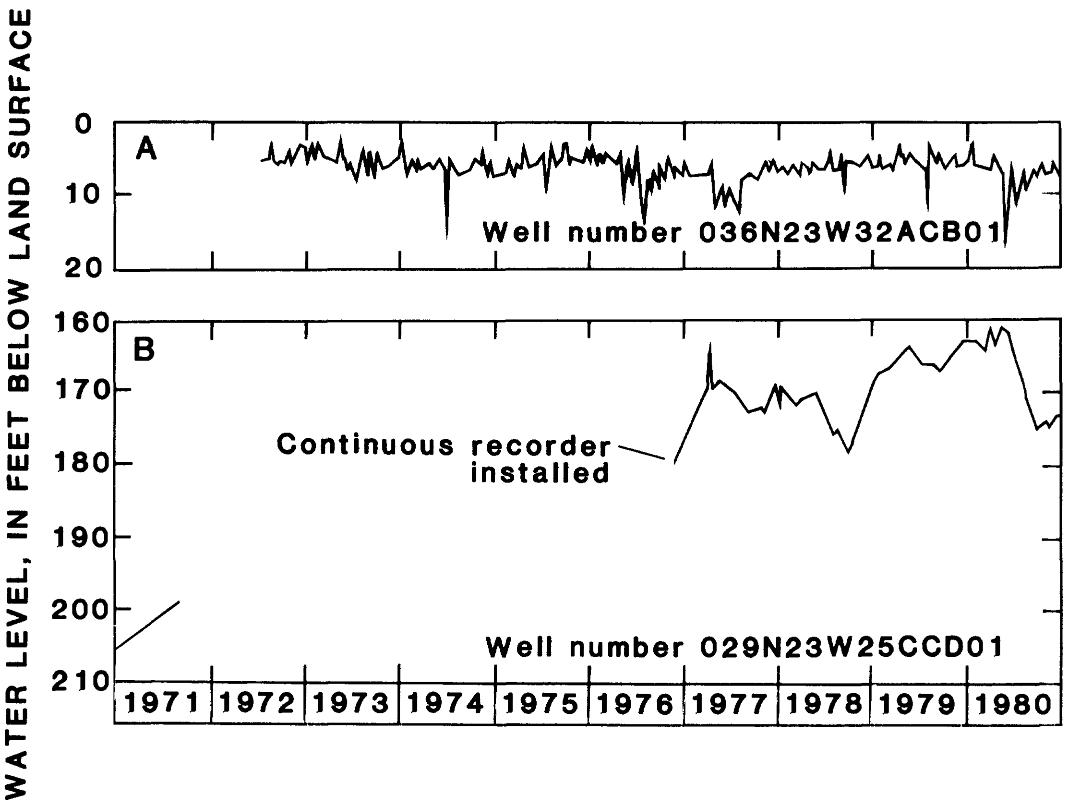
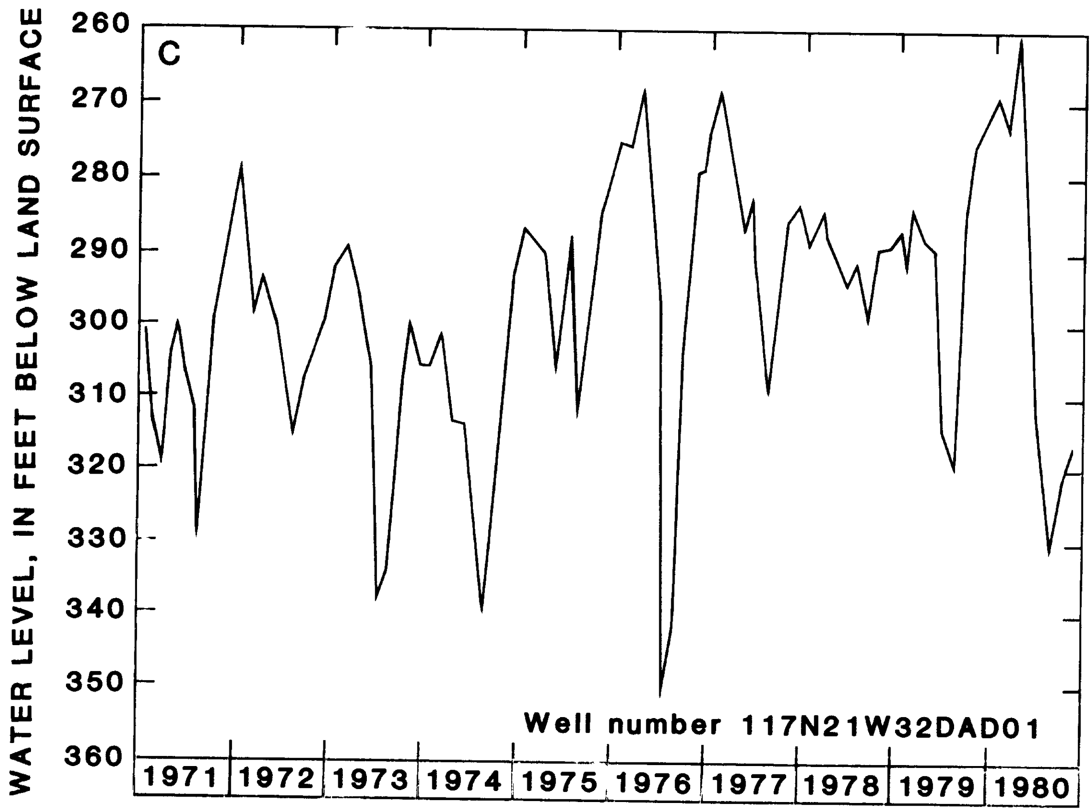



***Figure 4.--Hydrographs showing water-level***

***A. Well 036N23W32ACB01***
***B. Well 029N23W25CCD01***
***C. Well 117N21W32DAD01***




***changes in the Mount Simon-Hinckley aquifer in:***

***in Cambridge, Minnesota***
***in St. Paul, Minnesota***
***in Edina, Minnesota***

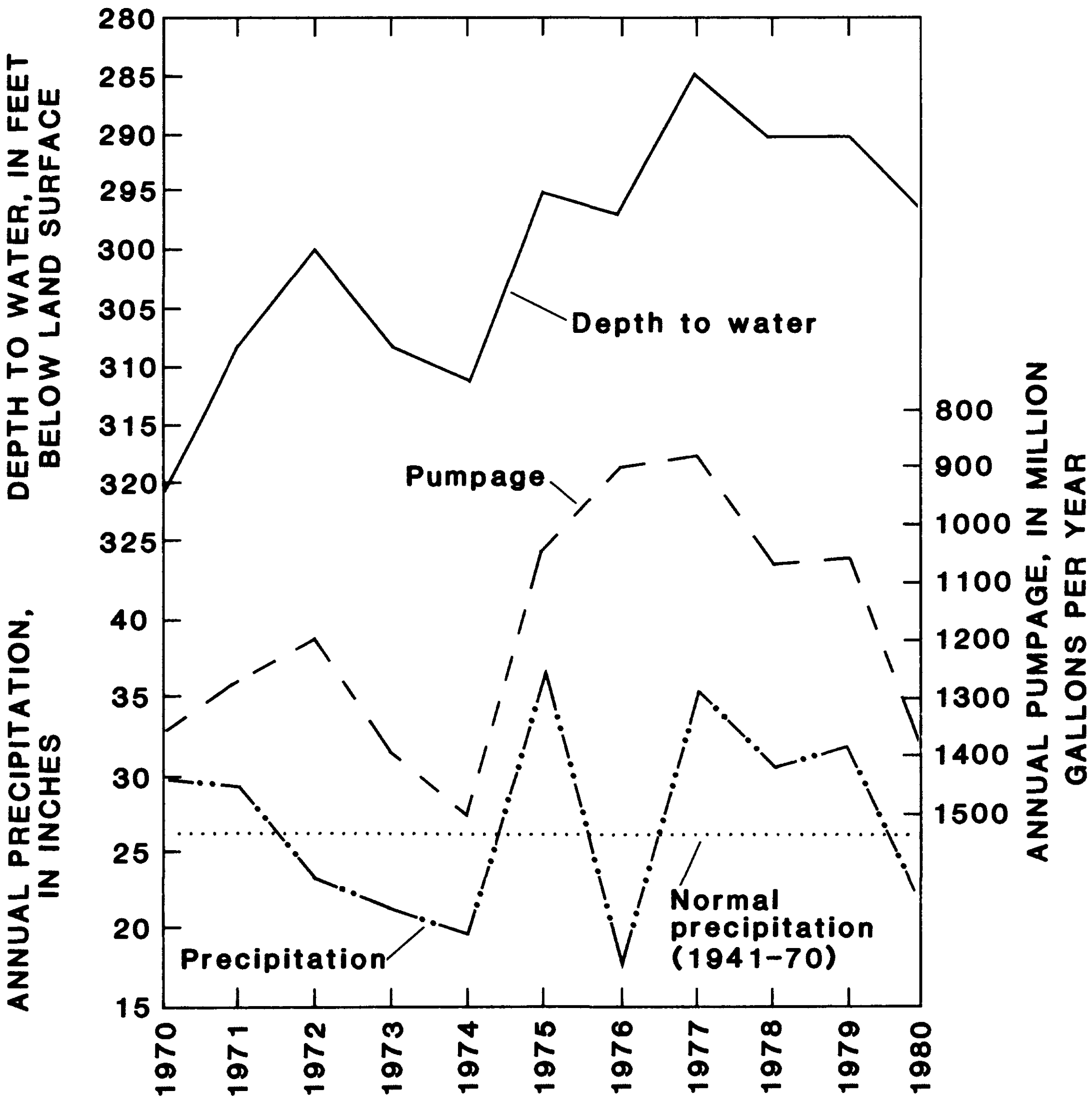



***Figure 5.--Annual mean water levels in well 117N21W32DAD01 (Edina 9), pumpage from six municipal wells in Edina and St. Louis Park, Minnesota, and annual precipitation at Minneapolis-St. Paul International Airport, 1970-1980***

shows some correspondence between annual pumpage and precipitation. Precipitation was recorded at the Minneapolis-St. Paul International Airport.

## Seasonal Water-Level Changes

Water levels in the Mount Simon-Hinckley aquifer generally decline sharply from winter to summer in response to increased pumpage (Horn, 1983, table 8 and fig. 16). Water-level-change maps (pl. 2D and 2F) depicting the seasonal change for 1971 and 1980 were prepared in the same way as those maps for the Prairie du Chien-Jordan aquifer. Because the water-level changes shown were computed from the two sets of one-time measurements, they do not necessarily represent maximum seasonal change for the years shown, which can, however, be seen in the hydrographs (figs. 4B and 4C).

Plate 2D indicates that during 1971 water levels in the Mount Simon-Hinckley aquifer declined more than 10 ft over a relatively small area. The greatest declines (less than 20 ft) were in the municipal well fields of Edina and St. Louis Park in the deepest part of the cone of depression. The relatively small declines in water level between winter and summer 1971 suggest that the increase in summer pumping was also relatively small. In contrast, plate 2F shows that between winter and summer 1980, water levels declined much more than in 1971 and did so over a much larger area. Water levels declined as much as 60 ft around the well fields of Edina and St. Louis Park and the area where declines exceeded 10 ft was about 10 times larger in 1980 than it was in 1971. Water-level declines in southern Anoka County and northwestern Ramsey County were also much larger in 1980 than in 1971.

The increase in summer withdrawals that produced the large water-level declines in 1980 was brought about by below-average precipitation for 7 out of 11 months between August 1979 and May 1980 (National Oceanographic and Atmospheric Administration, 1979-80). Much of the increased pumping may be due to municipalities meeting the increased demand for water for lawn sprinkling. Horn (1983, table 8) showed that municipal water use has a fairly large seasonal component, due largely to increased demand for water during dry weather. The dry weather and increased pumping in 1980 had a greater effect on water levels in the Mount Simon-Hinckley aquifer (pl. 2F) than on water levels in the Prairie du Chien-Jordan aquifer (pl. 1F) because of the division of pumping between the two aquifers. Many municipalities have wells in both the Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers. Normal demand, however, is primarily met by pumping from the Prairie du Chien-Jordan aquifer; wells in the much deeper Mount Simon-Hinckley aquifer are used mainly to meet peak demand because of greater operation and maintenance costs.

The seasonal water-level changes shown in plate 2D and 2F for 1971 and 1980, respectively, may not represent any long-term trend in the seasonal fluctuation of water levels in the Mount Simon-Hinckley aquifer. They probably represent two contrasting sets of hydrological conditions, either of which could be present in any given year. Water levels declined sharply during summer 1980 because of increased pumping brought on by below-normal precipitation. In contrast, water levels did not decline so much during 1971 because precipitation was near normal and pumping from the Mount Simon-Hinckley aquifer during the summer was not as great. Figure 4C shows that water-level patterns in other years are similar to those of 1971 and 1980. Water-level declines from winter to summer exceeded 50 ft during 1976 and 1980 in this well; were between 30 and 50 ft during 1972-74, 1977, and 1979; and were less than 30 ft during 1971, 1975, and 1978. Figure 5 shows that precipitation was below normal during 1972-74, 1976, and 1980, and above normal during 1971, 1975, and 1977-79. The relation between precipitation, pumpage, and the magnitude of summer water-level declines is affected by other factors such as the timing of below-normal precipitation (winter or summer), customary use of wells in the Mount Simon-Hinckley aquifer, and pumpage elsewhere in the aquifer.

## SUMMARY AND CONCLUSIONS

The Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers supply most of the ground water pumped in the Twin Cities Metropolitan Area. Withdrawals have caused water-level declines of about 200 ft in the Mount Simon-Hinckley aquifer and 90 ft in the Prairie du Chien-Jordan aquifer since 1890. In addition to long-term water-level changes, seasonal declines occur owing to increased summer pumpage. Future problems related to lowered water levels may be avoided or reduced by informed management of the resource through a better understanding of the hydrogeology of the Twin Cities Metropolitan Area. The present report presents preliminary results from the current "Appraisal of the Ground-Water Resources of the Twin Cities Metropolitan Area, Minnesota" study and describes and interprets water levels for 1971 and 1980 for both the Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers.

The water-level data indicate that the patterns of flow in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers differ greatly. Flow in the Prairie du Chien-Jordan aquifer is greatly influenced by the Mississippi, Minnesota, and St. Croix Rivers. In the Prairie du Chien-Jordan aquifer, water flows from water-level highs in central Hennepin, Washington, Scott, and Dakota Counties toward the major streams where it discharges. The aquifer supplies large quantities of water to wells in the Twin Cities area (average of 154 Mgal during 1976-79) and natural flow patterns in the aquifer are disrupted as water is diverted toward major pumping centers. However, despite heavy pumping, no large cones of depression have developed in the water-level surface, indicating that the aquifer is highly transmissive and in good hydraulic connection with the overlying drift and with the major streams. Between 1971 and 1980, water levels in the Prairie du Chien-Jordan aquifer rose or declined as much as 25 ft locally in response to changes in the rate and distribution of pumping and in response to short-term climatic changes. However, water levels changed less than 5 ft in most of the study area and no overall trend in water levels is apparent. This is consistent with water-use data that indicate only small changes in annual pumpage from the Prairie du Chien-Jordan aquifer between 1970 and 1979.

Water levels in the Prairie du Chien-Jordan aquifer generally decline during summer because of increased withdrawals for air conditioning, lawn sprinkling, and irrigation. Water levels declined during 1971 as much as 70 ft in Minneapolis and more than 10 ft in all of east-central Hennepin and south-eastern Ramsey Counties. Summer water-level declines during 1980 were less than during 1971 even though 1980 was a dryer year than 1971, suggesting that the seasonal component of pumpage for the Prairie du Chien-Jordan aquifer decreased between 1971 and 1980.

Water levels in the Mount Simon-Hinckley aquifer indicate that ground water flows from the northwest corner of the study area generally southeast to the vicinity of the Minnesota River and the Mississippi River north of its confluence with the St. Croix and north to that same vicinity from a water-level high south of the study area. Ground water also flows east to the St. Croix and the Mississippi south of its confluence with the St. Croix. However, the natural flow pattern is interrupted by a large cone of depression in the water-level surface near pumping centers in east-central Hennepin and southeastern Ramsey Counties. During 1971, the measurable cone of depression was about 25 miles in diameter and 100 to 150 ft deep. The location, depth, and shape of the cone suggest that the Mount Simon-Hinckley aquifer is in poor hydraulic connection with the shallow ground-water system and the major streams. Most of the water that flows into the cone of depression may be derived from leakage through the hydrogeologic units that separate the Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers. Between 1971 and 1980, water levels in the Mount Simon-Hinckley aquifer rose more than 10 ft throughout most of the cone of depression and more than 50 ft in the center of the cone, which decreased in area in response to decreased annual pumpage during this period.

Seasonal water-level declines due to increased summer pumping generally are greater in the Mount Simon-Hinckley aquifer than in the Prairie du Chien-Jordan aquifer and are generally greatest during periods of below-normal precipitation. During 1971, a year of above-average precipitation, water levels in a relatively small area declined more than 10 ft from winter to summer; maximum declines were less than 20 ft. However, during 1980, a year of significantly below-average precipitation, water levels in the Mount Simon-Hinckley aquifer declined more than 10 ft throughout most of the cone of depression with maximum declines of over 50 ft. This decline in water levels may result from use by municipalities of wells in the Mount Simon-Hinckley aquifer to meet peak demands for water, whereas wells in the Prairie du Chien-Jordan aquifer are used to meet normal demands.

In total, the water-level data suggest that (1) annual pumpage from the Prairie du Chien-Jordan aquifer was fairly constant between 1971 and 1980, producing fairly stable water levels; (2) annual pumpage from the Mount Simon-Hinckley aquifer decreased from 1971 to 1980 causing water levels in the aquifer to rise; and (3) the seasonal component of pumpage for the Mount Simon-Hinckley aquifer is greater than that for the Prairie du Chien-Jordan, producing seasonal water-level declines that are larger and more widespread in the Mount Simon-Hinckley than in the Prairie du Chien-Jordan, particularly during dry years.

A large amount of data presently are available to characterize water levels and water-level changes in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers in the Twin Cities area, but the current data-collection program has some inadequacies that limit application of the water-level data. One problem is that there are too few observation wells in the Mount Simon-Hinckley aquifer, so that there may not be enough control points to accurately define ground-water flow in the Mount Simon-Hinckley aquifer. The configuration of the cone of depression may be much more complex than depicted in this report. More observation points (wells) are needed to delineate this possible complexity and to determine the mutual interference of pumping centers. This is important because the effects on water levels of each pumping center may spread far out into the aquifer. Water-level data for the Mount Simon-Hinckley aquifer will become increasingly important if ground-water users in the Twin Cities area develop additional water supplies from this aquifer to avoid localized contamination of the Prairie du Chien-Jordan aquifer.

Another problem is insufficient water-level measurements at 6- to 8-week intervals, particularly in wells open to the Mount Simon-Hinckley aquifer. Although the measurement of a large number of wells twice in a year every 5 years may be adequate to define long-term water-level trends, this approach is inadequate for measuring seasonal changes. Seasonal water-level changes are large in the Twin Cities area as water levels decline rapidly in response to summer pumping. Consequently, the extreme seasonal water levels can easily be missed by one-time summer measurements. The potential problems associated with seasonal water-level changes and the accompanying reorientation of flow patterns may be much greater than those associated with long-term changes. The present water-level-data collection program is designed for analyzing long-term trends; significantly more observation wells are needed in which water levels are measured at least monthly, as well as more wells equipped with continuous water-level recorders.

Monthly pumpage data are currently (1982) available for over 60 percent (Horn, 1983, table 8 ) of the approximately 950 wells in the Prairie du Chien-Jordan aquifer and 150 wells in the Mount Simon-Hinckley aquifer for which pumpage data have been compiled. However, in 1982 there were only 6 observation wells in the Mount Simon-Hinckley aquifer and 32 in the Prairie du Chien-Jordan aquifer in which water-level measurements were made at least bimonthly. The water-level network must be denser in order to adequately define the relationship between seasonal pumpage and water levels.

## REFERENCES


Delin, G. N., and Woodward, D. G., 1982, Hydrogeologic setting and the potentiometric surfaces of the reqional aquifers in the Hollandale embayment, southeastern Minnesota, 1970-80: U.S. Geological Survey Water-Supply Paper 2219 [In press].

Guswa, J. H., Siegel, D. I., and Gillies, D. G., 1982, Preliminary evaluation of the ground-water-flow system in the Twin Cities Metropolitan Area, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 82-44, 71 p.

Horn, M. A., 1983, Ground-water-use trends in the Twin Cities Metropolitan Area, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 83-4033.

Hult, M. F., and Schoenberg, M. E., 1981, Preliminary evaluation of ground-water contamination by coal-tar derivatives, St. Louis Park, Minnesota: U.S. Geological Survey Open-File Report 81-72 (pending publication as U.S. Geological Survey Water-Supply Paper 2211).

National Oceanographic and Atmospheric Administration (NOAA), 1970-80, Climatological data, monthly summary: v. 76-86.

Norvitch, R. F., Ross, T. G., and Breitkrietz, Alex, 1973, Water resources outlook for the Minneapolis-St. Paul Metropolitan Area: Metropolitan Council of the Twin Cities area, 219 p.

Reeder, H. O., 1966, Fourteen maps of parts of the ground-water reservoir in the Minneapolis-St. Paul Metropolitan Area: U.S. Geological Survey open-file maps.

Winter, T. C., and Pfannkuch, H. O., 1976, Hydrogeology of a drift-filled bedrock valley near Lino Lakes, Anoka County, Minnesota: U.S. Geological Survey Journal of Research, v. 4, p. 267-276.

Woodward, D. G., 1984, Hydrogeologic framework and properties of regional aquifers in the Hollandale embayment, southeastern Minnesota: U.S. Geological Survey Hydrologic Investigations Atlas HA-677, 4 pls. [In press].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