Preliminary Evaluation of Ground-Water Contamination by Coal-Tar Derivatives, St. Louis Park Area, Minnesota

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Prepared in cooperation with the
Minnesota Department of Health

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By Marc F. Hult *and* Michael E. Schoenberg

Abstract

Operation of a coal-tar distillation and wood-preserving plant from 1918 to 1972 in St. Louis Park, a suburb of Minneapolis, Minn., resulted in ground-water contamination. This preliminary evaluation presents an overview of the problem based on the results of the first year (1979) of an ongoing study.

By 1932, water in the Prairie du Chien-Jordan aquifer, the region's major source of ground water, was contaminated 3,500 feet from the plant. It seems that this early contamination of the aquifer resulted in part from the introduction of coal tar directly into a multiaquifer well on the plant site. The Prairie du Chien-Jordan aquifer underlies the area at depths of 250 to 500 feet and is overlain by two bedrock aquifers (Platteville and St. Peter), two confining beds (Glenwood and the basal part of St. Peter), and 70 to 100 feet of drift.

The upper part of the aquifer (the Prairie du Chien Group) is carbonate rock having fracture and solution-channel permeability and low effective porosity. Contaminants in the Prairie du Chien Group can move more rapidly than those in drift and sandstone aquifers having intergranular permeability. The aquifer characteristics, the long contamination history, and seasonal potentiometric-surface fluctuations owing to heavy municipal and industrial withdrawals combine to create a complex distribution of coal-tar derivatives in the Prairie du Chien-Jordan aquifer.

In addition, at least 25 ungrouted or partly cased wells in the area may permit contaminated water from near-surface aquifers to flow downward into deeper bedrock aquifers along or through the well bores. Where possible, such wells have been geophysically logged and inspected by downhole television. Flow rates of 20 to 150 gallons per minute from the Platteville and St. Peter aquifers to the Prairie du Chien-Jordan aquifer were observed in five of nine wells. The water was contaminated in four of the five wells.

Drift materials on and south of the site have been contaminated by surface spills and by infiltration of contaminated process water. Near the contamination source, a hydrocarbon fluid phase is moving vertically downward relative to movement of the aqueous phase. Fluid pumped from an observation well in this area contained 6,000 milligrams per liter total organic carbon. Dissolved coal-tar constituents in the drift and the uppermost bedrock unit over most of the area, the Platteville aquifer, have moved at least 4,000 feet downgradient to a drift-filled bedrock valley. At the valley, it seems that the Platteville aquifer and the Glenwood confining bed have been removed by erosion and that contaminants with a concentration of approximately 2 milligrams per liter dissolved organic carbon are entering the underlying St. Peter aquifer. Chemical analyses of fluid pumped from observation wells suggest that soluble, low-molecular-weight compounds are moving preferentially through the drift and the Platteville aquifer.

INTRODUCTION

Between 1918 and 1972, a coal-tar distillation and wood-preserving plant operated on an 80-acre site in St. Louis Park, a suburb of Minneapolis, Minn. Coal-tar derivatives released to the environment have contaminated drift and bedrock aquifers. The major immediate problem is the presence of toxic coal-tar derivatives in water withdrawn by some municipal wells in the area. As early as 1932, the Prairie du Chien-Jordan aquifer, the principal ground-water resource of the Minneapolis-St. Paul metropolitan area, contained water having a coal-tar taste at least 3,500 feet from the plant site. During 1978, use of four municipal wells completed in this aquifer was discontinued because the wells yielded water containing trace amounts of coal-tar compounds, including benzo(a)pyrene, a carcinogen. Each of the five bedrock aquifers in the metropolitan area underlies the site, and each may have been affected to some degree by the contaminants.

The complicated ground-water hydrology, the diverse chemical and physical properties of coal-tar constituents, and the length of time the contaminants have been moving through the ground-water system have combined to produce a complex distribution of contaminants.

Individual coal-tar compounds differ widely in toxicity and chemical and physical properties. For example, phenol is about 10 million times more soluble in water than benzo(a)pyrene. Differences in solubility cause large variations in the proportion of each chemical that remains in a mixture of liquid hydrocarbons, dissolves into the ground water, or is sorbed onto geologic materials. The proportions change with chemical concentration, in space, and with time.

The health risks associated with long-term exposure to low concentrations of coal-tar compounds are poorly known. Moreover, the original coal-tar constituents can be changed into other compounds through chemical reactions and biological processes. These compounds have not yet been identified.

Coal-tar derivatives reached the water table by percolation through the unsaturated zone (see Glossary) and at ponds that received surface runoff and process water from the plant. The highest concentrations of contaminants are in the drift beneath and near the site. Parts of this volume of drift contain an undissolved liquid mixture of many individual coal-tar compounds. In the saturated zone (see Glossary), this hydrocarbon fluid phase has moved vertically downward relative to the direction of ground-water flow because it is denser than water. Because the hydrocarbon fluid is more viscous than water, it moves more slowly than the ground water that surrounds it.

Uncontaminated ground water entering the volume of drift near the site is contaminated by partial solution of the hydrocarbon fluids and by release of compounds sorbed on the drift materials. The contaminated water moves laterally to the east and southeast. Water in the drift 4,000 feet east of the site has a distinct chemical smell and contains a large proportion of coal-tar compounds of high solubility relative to compounds of low solubility.

Contaminants have moved into the uppermost bedrock aquifer (Platteville) directly from the drift. Contaminants have reached deeper bedrock aquifers through wells that hydraulically interconnect aquifers, probably through a confining bed, and through bedrock valleys where this confining bed (Glenwood) has been removed by erosion. In addition, coal tar has entered the bedrock aquifer system directly through a well on the former plant site that was drilled in 1917 to a depth of 909 feet.

The bedrock ground-water-flow system is continually adjusting to hydraulic stresses such as ground-water withdrawals and flow through wells that connect more than one aquifer. As these stresses change, the direction and rate of contaminant transport changes. Consequently, the concentration and composition of contaminants in water pumped from individual industrial and municipal wells fluctuates with time.

Purpose and Scope

On July 1, 1978, the U.S. Geological Survey (USGS) began a study of the St. Louis Park problem in cooperation with the Minnesota Department of Health. The study's purpose is to develop a detailed understanding of the ground-water-flow system and the transport of organic contaminants in the vicinity of the former plant. Results of the study will be used to guide management decisions by State and local agencies.

This report is based on the results of the first year of study. The purpose of the report is to evaluate the problem in a preliminary way and to make some of the collected data available. Because the problem is complex, the data are not interpreted in detail. The interpretations presented are preliminary and doubtless will be changed as additional field data are collected and working hypotheses are tested.

Future reports will further interpret data presented in this report and will present the results of laboratory experiments to assess the mobility of coal-tar derivatives in ground water, preliminary digital-computer simulations of the ground-water system, and additional fieldwork.

Location and Description of Study Area

The site of the former coal-tar plant is in the city of St. Louis Park, Hennepin County, Minn. (fig. 1). The city adjoins Minneapolis on the east and the cities of Golden Valley, Minnetonka, Hopkins, and Edina on the north, west, southwest, and southeast, respectively (fig. 2).

In this report, the term "site" refers to the approximately 80-acre tract on which the plant was located. The term "study area" refers to the geographic extent of the ground-water system that will be evaluated in this project. The study area is underlain by drift and five bedrock aquifers. The areal extent of contamination and the locations of significant hydrogeologic boundaries are different for each aquifer. Therefore, the amount and kinds of geologic, hydrologic, and chemical data required to evaluate the contamination problem vary both areally and with depth in the ground-water system.

A ground-water-flow model of the seven-county Minneapolis–St. Paul metropolitan area is at present (1979) being developed by the USGS in cooperation with the Metropolitan Council of the Twin Cities, the Minnesota Geological Survey (MGS), and the Minnesota Department of Natural Resources. Preliminary results of this project are being used to assess the location and

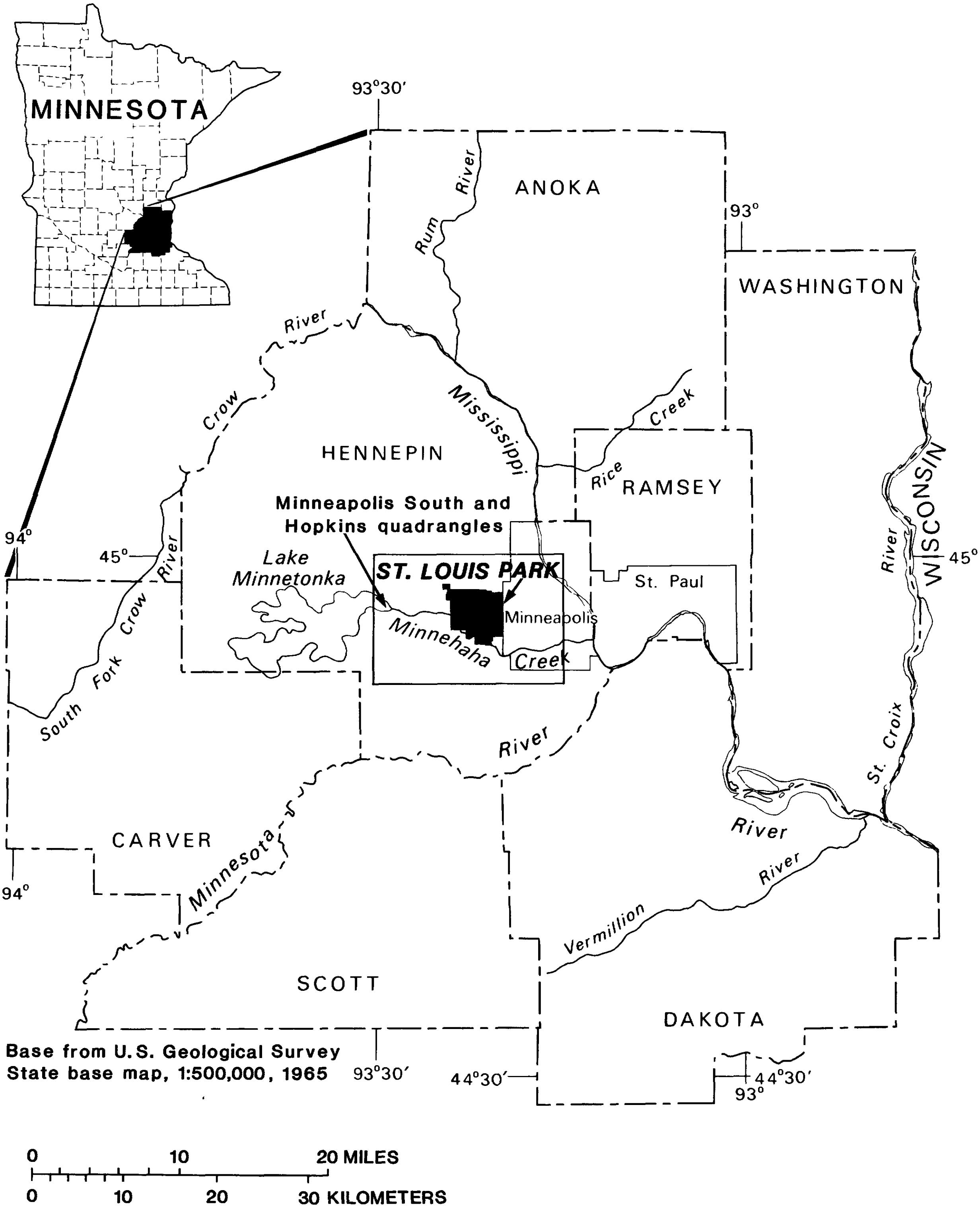


Figure 1. Locations of the city of St. Louis Park, the Minneapolis South and Hopkins quadrangles, Lake Minnetonka, and Minnehaha Creek in the Minneapolis–St. Paul metropolitan area

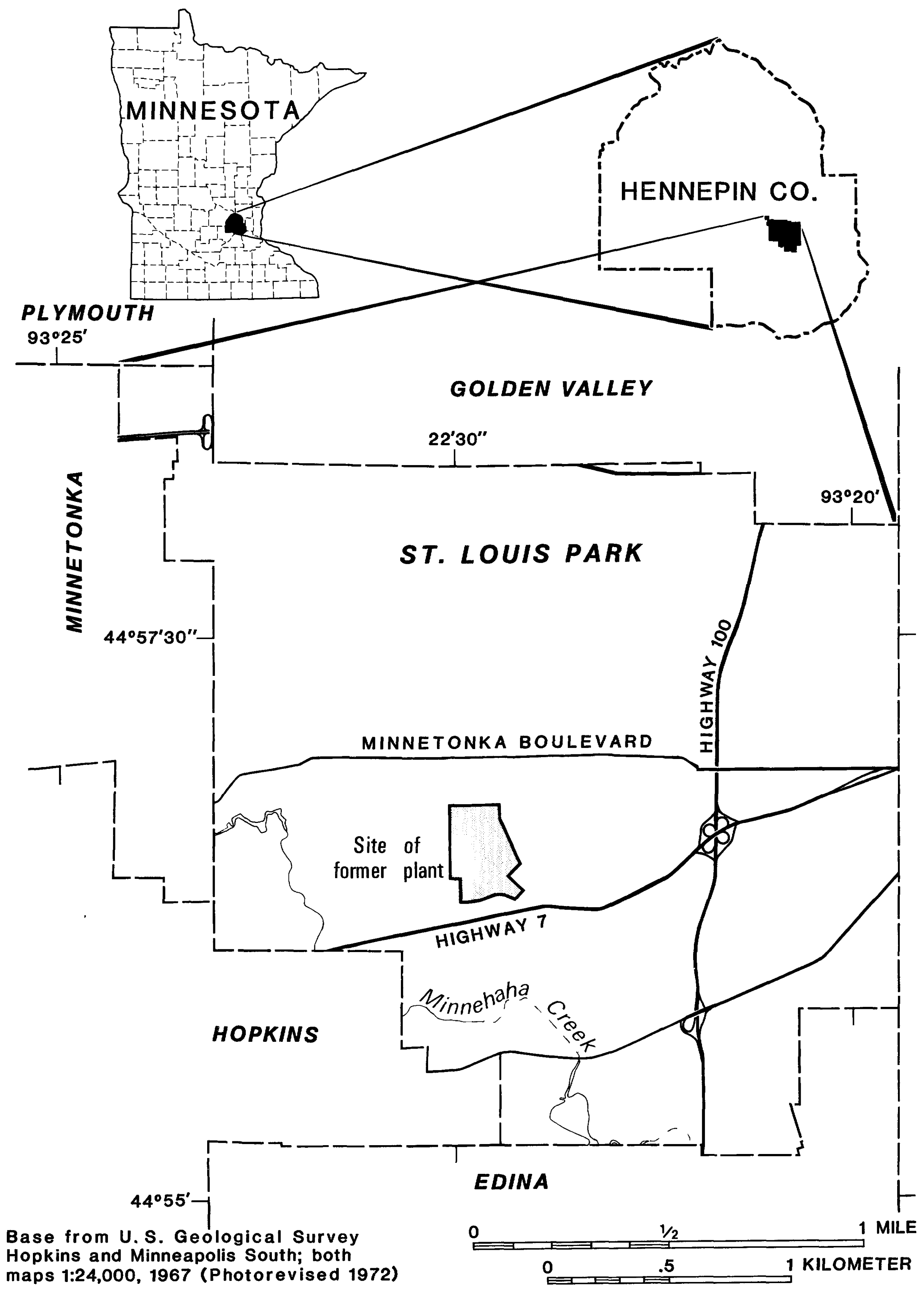


Figure 2. Location of former plant, St. Louis Park, Minn.

nature of hydrogeologic boundaries in the bedrock aquifer system that will be used to define the study area for the St. Louis Park study. Tentatively, the study area for bedrock aquifers below the Platteville aquifer is the area between Lake Minnetonka on the west, the Minnesota and Mississippi Rivers on the south and east, and approximately lat 45° on the north (fig. 1). The area being studied in the drift and uppermost bedrock aquifer is bounded by Minnehaha Creek on the west and south, Minneapolis to the east, and Minnetonka Boulevard to the north (fig. 2).

Previous Investigations and History of Reported Contamination

The coal-tar plant began operation in 1918 on the site of a former sugar-beet processing plant. In 1932, the first St. Louis Park municipal well was constructed. After several weeks of operation, complaints of a coal-tar taste to the water caused the well to be shut down. The well, St. Louis Park Old well 1 (W112; table 1, fig. 3, pl. 1) is completed in the Prairie du Chien–Jordan aquifer about 3,500 feet from the plant site. Attempts at reconstructing the well to eliminate the contamination were unsuccessful, and the well was abandoned in 1933. Water-quality changes in this well have not been monitored, but since 1953 water levels in the well have been recorded by the USGS.

An investigation by the McCarthy Well Company in 1933 (files of the USGS) concluded that the contaminants were coming from the site through "several old wells that were being used to drain creosote away into the ground." One old well on the site (W105; table 1, fig. 3) was drilled to an original depth of 940 feet (Fuller, 1904). It has also been reported (Barr Engineering Co., 1977)[1] that contamination of another well, W23 (table 1, fig. 3, pl. 1), resulted from a spill into the well. Well W23 [referred to in Barr Engineering Co. (1977) as "Hinckley well on the site"] was drilled in 1917 to an original depth of 909 feet.

A report by the Minnesota Department of Health (1938) identified nine wells that yielded water with either a phenolic or a tar-like taste. The contaminated well farthest from the site, W114 (table 1, fig. 3, pl. 1), was originally completed at a depth of 280 feet in the St. Peter aquifer (Schwartz, 1936). In 1936, the well was deepened by drilling an additional 130 feet. After reconstruction, the well was open to the Prairie du Chien–Jordan aquifer and immediately yielded water with a distinct tar-like taste.

Numerous engineering and hydrogeologic studies have been made to examine various aspects of the problem. E. A. Hickok and Associates (1969)[2] reported that the phenolic concentration in water measured in 1946 from St. Louis Park well 4, completed in the Prairie du Chien–Jordan aquifer, was 0.10 milligrams per liter (pl. 1). Measurements in 1969 indicated possible contamination of other wells, and the Hickok report suggested that additional studies be made to better evaluate the problem.

Sunde (1974),[2] in a general evaluation of the problem, concluded that contamination in the deeply buried bedrock aquifers resulted from flow through wells that connect more than one aquifer. The Minnesota Department of Health (1974) tested the water quality of private, industrial, and municipal wells in the area. Olson and others (1974)[2] compiled available geologic information for the St. Louis Park area. National Biocentric (1976a,b)[2] chemically analyzed drift materials underlying the northern part of the site for organic contaminants.

Barr Engineering Co. (1976, 1977) installed 3 piezometers and 14 drift and 2 bedrock monitoring wells. Cores from 14 borings were analyzed for phenolic and benzene-extractable compounds. Data from the borings were used to estimate that removal of drift contaminated with more than 1,000 milligrams per kilogram of benzene-extractable constituents would require excavation of 400,000 cubic yards of soil. Water samples were analyzed for phenolic compounds, oil and grease, and selected inorganic constituents. Water in the drift was found to be contaminated at least 1,000 feet from the site. Specific remedial actions were recommended to control ground-water contamination in the drift. Barr Engineering Co. (1977) concluded that the low but detectable levels of phenolic compounds in municipal wells completed in the Prairie du Chien–Jordan aquifer could not be explained by the available data.

The Minnesota Department of Health (1977, 1978)[3] measured the concentration of polynuclear aromatic hydrocarbons (PAH) in municipal water supplies, assessed the health-risk implications, and outlined major additional data needs. Plate 1 shows the locations of contaminated municipal wells in the Prairie du Chien–Jordan aquifer and bar graphs of the concentration of individual PAH constituents.

In February 1979, the USGS concluded an initial field study and evaluation of the effect of multiaquifer wells. Data on the location and construction of wells in the area were provided to the Minnesota Department of Health. These data were used by the department to design and implement a well-abandonment program.

[1]Available for inspection at the Minnesota Pollution Control Agency, Roseville, Minn.

[2]See footnote 1.

[3]Available for inspection at the Minnesota Department of Health, Minneapolis, Minn., and Minnesota Pollution Control Agency, Roseville, Minn.

Table 1. Data on selected wells in the St. Louis Park area, Minnesota

Township and range: First three (or two) digits indicate township north of the baseline; next two digits indicate range north of the principal meridian; last digit(s) indicate(s) section in which well is located. Letters indicate well location in section: first letter denotes the 160-acre tract; second letter denotes the 40-acre tract; third letter denotes the 10-acre tract. Letters are assigned counterclockwise beginning with the northeast quarter. Consecutive numbers beginning with 1 are added as suffixes to distinguish wells within a given 10-acre tract.

Site identification (lat and long): First six digits are latitude of well location in degrees, minutes, and seconds; next seven digits are longitude in degrees, minutes, and seconds; last two digits are arbitrarily assigned to distinguish wells within a given 1-second by 1-second area.

Reported log: Qd, drift, undifferentiated; Opl, Platteville Limestone; Ogl, Glenwood Shale; Osp, St. Peter Sandstone, undifferentiated; Ospl, St. Peter Sandstone, lower siltstone beds; Opc, Prairie du Chien Group; €j, Jordan Sandstone; €sl, St. Lawrence Formation; €f, Franconia Sandstone; €ig, Ironton and Galesville Sandstones; €e, Eau Claire Sandstone; €m, Mount Simon Sandstone; p€h, Hinckley Sandstone.

Altitude: When MP is given, altitude is for measuring point, not land surface.

Field measurement status: A, well field located and permanently sealed or reconstructed; AH, well field located and permanently sealed by MDH; AR, well reported permanently sealed; BR, well reported filled; D, well field located and contains debris; F, well field located; G, well field located and geophysically logged; M, mass-measurement well (measured 2 to 3 times per year); O, observation well (measured every 2 to 3 weeks); P, well field located and has pump; X, well destroyed.

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.17 AAB1.	445654093215501	216030	W1	Monitoring well	E. H. Renner	-03-76	0–102 Qd 102–107 Opl	922.76 MP	107	4 in. 0–102	Opl	43.67	11-28-78	O
117.21.17 BAC1.	445651093222901	216031	W2	do	do	03-76	0–36 Qd	897.14 MP	36	4 in. 0–32	Qd	10.40	11-28-78	O
117.21.17 BDB1.	445637093222401	216032	W3	do	do	05-76	0–52 Qd	897	52	4 in. 0–49	Qd	7	05-10-76	D,X
117.21.17 CAD2.	445622093221901	216033	W5	do	do	02-76	0–26 Qd	891.72 MP	26	4 in. 0–21	Qd	6.59	11-28-78	O
117.21.17 CAC1.	445620093222601	216034	W6	do	do	02-76	0–26 Qd	892.74 MP	26	4 in. 0–22	Qd	7.39	11-28-78	O
117.21.17 CBD1.	445625093223601	216035	W7	do	do	03-76	0–71 Qd	930	71	4 in. 0–66	Qd	35	03-02-76	D,X
117.21.17 CDD1.	445607093222101	216036	W8	do	do	02-76	0–31 Qd	892.87 MP	31	4 in.	Qd	7.96	11-28-78	O
117.21.17 DCA1.	445614093220301	216037	W9	do	do	02-76	0–25 Qd	891.21 MP	25	4 in. 0–20	Qd	7.13	11-27-78	O
117.21.20 ABD1.	445559093220201	216038	W10	do	do	02-76	0–29 Qd	891.82 MP	29	4 in. 0–25	Qd	7.63	11-27-78	O
117.21.17 DDB2.	445614093215301	216039	W11	do	do	11-76	0–23 Qd	897.20 MP	23	4 in. 0–19	Qd	13.63	11-27-78	O
117.21.17 DDA1.	445613093214001	216040	W12	do	do	12-76	0–47 Qd	919.26 MP	47	4 in. 0–42	Qd	37.02	11-27-78	O
117.21.17 DCB1.	445615093220901	216041	W13	do	do	11-76	0–50 Qd	890.40 MP	50	4 in. 0–45	Qd	6.19	11-28-78	O

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.17 DCA2.	445614093220302	216042	W14	do	do	02-77	0–68 Qd 68–82 Opl 82–85 Ogl 85–95 Osp	891.41 MP	95	8 in. 0–69 4 in. 0–86	Osp	23.75	11–27–78	G,O
117.21.17 CAC2.	445621093222601	216043	W15	do	do	04-77	0–76 Qd	892.47 MP	76	4 in.	Qd	8.30	11–28–78	O
117.21.20 ABD2	445559093220202	216044	W16	do	do	04-77	0–73.5 Qd	892.07 MP	64	4 in. 0–61	Qd	8.56	11–27–78	O
117.21.17 DDB3.	445614093215302	216045	W17	do	do	04-77	0–69 Qd	897.07 MP	69	4 in. 0–66	Qd	14.05	11–27–78	O
117.21.17 DCA3.	445614093220303	216046	W18	do	do	1978	0–68 Qd 68–78 Opl	893.23 MP	78	4 in. 0–68	Opl	9.86	11–27–78	O
117.21.17 CDD2.	445607093222102	216047	W19	do	do	1978	0–72 Qd 71–81 Opl	894.43 MP	81	4 in. 0–81	Opl	11.22	11–28–78	O
117.21.20 AAB1.	445605093215101	216048	W20	do	do	1978	0–69 Qd 69–80 Opl	895.55 MP	80	4 in. 0–70	Opl	14.01	11–27–78	O
117.21.20 ABD3.	445559093220203	216049	W21	do	do	1978	0–87 Qd 87–92 Osp	892.60 MP	92	4 in. 0–92	Osp	24.27	11–27–78	O
117.21.17 CAA1.	445630093222101	200993	W22	Republic Creosote Washroom Well.	do	12-47	0–65 Qd 65–91 Opl 91–91 Osp	896.16 MP	91	4 in. 0–71	Originally Opl-Osp Now Opl.	11.44	11–28–78	G,O
117.21.17 CAD1.	445625093221601	216050	W23	Republic Creosote Site "Hinckley" well on site, Cooling well.	McCarthy	12-17 to 05-18.	0–60 Qd 60–95 Opl 95–195 Osp 195–258 Ospl 258–372 Opc 372–457 Ꞓj 457–507 Ꞓsl 507–835 Ꞓf–Ꞓe 835–909 Ꞓm	894.49 MP	909	12 in. 0–65 10 in. 0–257 7 in. <230–373	Originally Ꞓj,Ꞓsl,Ꞓf, Ꞓig,Ꞓe,Ꞓm Now Osp, Opc, Ꞓj,Ꞓsl,Ꞓf.	33.15	11–28–78	G,O
117.21.20 ABB1.	445604093220501	160018	W24	Monitoring well	E. H. Renner	1978	0–81 Qd 81–83 Opl 83–86 Ogl 86–90 Osp	892.92 MP	90	8 in. 0–81.5 4 in. 0–86.7	Osp	22.84	11–27–78	O

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.17 CDC2.	445610093222602	206448	W25	Lakeland Door	do	11-50	0-79 Qd 79-85 Opl	888.79 MP	85	3 in. 0-79	Opl	4.39 9	10-15-78 11-01-50	G,O
117.21.17 CDA1.	445619093221801	209344	W26	Mill City Plywood	do	08-52	0-59 Qd 59-90 Opl	891.45 MP	90	4 in. 0-76	Opl	6.90 3.5	10-13-78 08-05-52	G,O
117.21.17 DBC1.	445624093220801	216052	W27	Terry Excavating	do	1953	0-80 Qd 80-100 Opl 100-112 Osp	905	112	4 in.	Opl-Osp	30	1953	G,O
117.21.17 CDB1.	445619093222501	216053	W28	7401 Walker St.		Before 1939	---	895	---	---	---	---	---	X
117.21.20 BAA2.	445604093223801	206454	W29	Flame Industries	E. H. Renner	04-63	0-73 Qd 73-90 Opl 90-94 Ogl 94-202 Osp 202-251 Ospl 251-335 Opc	897	335	10 in. 0-77 8 in. 0-257	Opc	68	04-12-63	P
117.21.17 CCA2.	445614093223801	216054	W30	3636 Quebec Ave.	do	About 1940	---	935	200	6 in. 0-100	Opl-Osp	---	---	AH
117.21.20 BBB1.	445600093224901	216055	W31	3831 Texas Ave.		About 1949	---	905	---	---	---	---	---	---
117.21.07 DDD1.	445702093225401	203190	W32	Texatonka Shopping Center.	E. H. Renner	08-51	0-98 Qd 98-112 Opl 112-117 Ogl 117-228 Osp 228-283 Ospl 283-405 Opc 405-466 Єj	925	466	8 in. 0-283.5	Opc-Єj	80	08-00-51	F
117.21.17 DDB1.	445614093214901	206449	W33	Strand Mfg., Wayne Register, Midco Register, Robinson Rubber.	Max Renner	06-53	0-80 Qd 80-100 Opl 100-102 Ogl 102-182 Osp	906.37 MP	182	8 in.	Opl-Osp Osp (from 6-79).	23.62 45.97	11-27-78 07-10-79	P,G
117.21.16 CAA1.	445627093213601	216056	W34	Crib Diaper Service, Sterilized Diaper Service.	Bergerson-Caswell	05-67	0-93 Qd 93-107 Opl 107-113 Ogl 113-212 Osp 212-280 Ospl 280-342 Opc	918	342	6 in. 0-292	Opc	99.1	11-08-78	AH,G

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.16 DAA1.	445625093210301	216057	W35	Burdick Grain Co.		About 1910	---	912	---	4 in.	Opl(?)-Osp(?)	51.6	10-20-78	P,M
117.21.16 DBD1.	445620093211901	216058	W36	Dayton Rogers Well #1.		Before 1947	---	908	---	3 in.	Qd	31.77	10-25-78	F,O
117.21.16 DBD2.	445619093211801	216059	W37	Dayton Rogers Well #2.	Laurel Hansmann	03-73	---	910	120	6 in.	Opl	36.03	10-25-78	O,G
117.21.16 CDB1.	445618093211801	216060	W38	Milwaukee Railroad Well.		1913	0-107 Qd 107-111 Opl 111-260 Osp 260-405 Opc 405-485 €j 485-515 €sl 515-1002 €f-p€h	914	1002	---	Opl-p€h	---	---	---
117.21.16 DCA3.	445613093212201	216061	W39	3612 Alabama Ave.			---	910	---	---	Osp	---	---	X
117.21.16 CDB2.	445615093211601	206444	W40	Minnesota Rubber		1963	0-125 Qd 125-205 Osp 205-276 Ospl 276-378 Opc	910	378	8 in. 0-205	Osp-Opc	---	---	P
117.21.16 DCC3.	445611093213401	216062	W41	Hartmann #1 3700 Colorado.	E. H. Renner		---	912	160	2 in.	Osp(?)	---	---	D
117.21.16 DCC1.	445611093213401	216063	W42	Hartmann #2 3700 Colorado.			---	912	60	---	---	---	---	---
28.24.7 BBC1.	445559093210301	200541	W44	King's Inn, Lilac Lane Bowling Alley.	Max Renner	12-51	0-111 Qd 111-131 Opl 131-259 Osp	910	259	8 in. 0-111	Opl-Osp	47	1951	P
117.21.16 CDA1.	445618093210001	206445	W45	S-K Products, Inc.	Don Stodola's Well Drilling.	07-63	0-92 Qd 92-94 Opl 94-122 Ogl 122-224 Osp 224-265 Ospl 265-312 Opc	900	312	8 in. 0-? 6 in. 0-244	Ospl-Opc	84	07-25-78	P
117.21.16 CDA2.	445617093210201	216065	W46	do	do	1973	0-92 Qd 92-94 Opl 94-122 Ogl 122-224 Osp 224-265 Ospl 265-312 Opc	905	305	6 in. 0-234	Ospl-Opc	95	02-16-73	P

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
28.24.6 AAC1.	445647093195301	216066	W47	Belco; Burdick Grain Co.		Before 1942	---	891	---	8 in.	Opl-€j	16.39	12-06-78	G,A
117.21.20 ADA2.	445646093214601	216067	W48	Methodist Hospital.	McCarthy		0-85 Qd 85-94 Opl 94-257 Osp 257-377 Opc 377-466 €j 466-485 €sl	889.8	485	20 in. 0-255	Ospl(?) Opc-€sl	68.82	12-06-78	G,P
117.21.17 DDD1.	445607093214101	206540	W49	Strom Block, deep well.	E. H. Renner	-1958	0-72 Qd 72-92 Opl 92-96 Ogl 96-260 Osp 260-381 Opc 381-384 €j	900	384	8 in. 0-77 6 in. 0-241	Ospl-€j	65	09-00-58	---
117.21.17 DCD1.	445609093215801	216068	W50	Prestolite		Before 1937	---	890	---	---	---	---	---	G,AH
117.21.20 BAA1.	445605093221601	216069	W51	Androc Chemical Co.			---	892	---	4 in.	Opl	---	---	G,AH
117.21.20 BCA1.	445548093223701	216070	W52	Merit Gage Co.; Suburban Sanitary Drainage.	E. H. Renner	-09-61	0-81 Qd 81-95 Opl 95-97 Ogl 97-110 Osp	920	---	4 in. 0-82	Opl-Osp	30	09-29-61	G,AH
28.24.6 BDB2.	445638093204001	216071	W53	Northland Aluminum.			---	884	---	---	---	84.10	06-22-79	F
117.21.19 AAD1.	445553093225401	216072	W54	Old Galachirche residence.			---	920	---	6 in.	---	---	---	---
117.21.20 BBA1.	445605093223501	216073	W55	7612 Division St.	E. H. Renner	-01-59	0-99 Qd 99-118 Opl	915	118	4 in. 0-102	Opl	36	1959	---
117.21.17 CCB1.	445619093224201	216074	W56	Earlinson residence			---	935	---	4 in.	---	---	---	---
117.21.17 CCA1.	445619093223801	216075	W57	Oak Hill School		Before 1940	---	935	---	---	---	---	---	---
117.21.17 DBB1.	445628093221101	216077	W59	On site east of Louisiana Extension.			---	---	24	6 in. 0-15	Qd	---	---	AH

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.17 CCA3.	445614093224001	216078	W60	3645 Rhode Island Ave.	E. H. Renner	---	---	935	250	6 in.	Opl-Osp	---	---	AH
117.21.17 DDD3.	445607093214001	216079	W61	William V. Terry	---	---	---	905	---	---	---	---	---	---
117.21.8 CAA1.	445721093221801	206438	W62	McCourtney Plastics.	do	09-66	0-86 Qd 86-103 Opl 103-105 Ogl 105-274 Osp 274-394 Opc	910	394	12 in. 0-90 10 in. 0-246	Ospl-Opc	88	09-08-69	P
117.21.20 CBB1.	445538093224501	216080	W63	National Foods	McCarthy	09-45	---	910	285	10 in. inside 12 in.	---	75	09-00-45	P
117.21.17 DDD4.	445607093214202	206451	W65	Ace Manufacturing Strom Block.	E. H. Renner	09-58	0-77 Qd 77-93 Opl 93-95 Ogl 95-109 Osp	904	109	4 in. 0-77	Opl-Osp	24.68	12-01-78	F
117.21.19 ABA2.	445559093220502	216081	W66	Black Top Service, deep well.	do	01-56	0-65 Qd 65-86 Opl 86-87 Ogl 87-251 Osp 251-280 Opc	899	280	6 in.	---	---	---	BR
117.21.19 ABA1.	445559093220501	216082	W67	Black Top Service, shallow well.	do	12-55	0-78 Qd 78-84 Opl 84-85 Ogl 85-105 Osp	812	105	3 in. 0-84	Opl(?)-Osp	25	12-29-55	---
117.21.20 BAC1.	445604093223001	206447	W68	Bergeson Residence.	Aamot	12-61	0-95 Qd	900	110	2 in. 0-90	Qd	40	12-00-61	P
28.24.6 CAA1.	445614093203601	216083	W69	Hedberg-Friedheim Block Co.; Wolfe Lake Augmentation Well.	Max Renner	07-47	0-71 Qd 71-78 Opl 78-81 Ogl 81-246 Osp 246-327 Opc	890	327	---	---	65	1947	G
28.24.6 BAA1.	445653093202601	200539	W70	Park Theatre	do	09-39	0-74 Qd 74-104 Opl 104-229 Osp 229-358 Opc 358-398 €j	905	398	10 in. 0-74 8 in. 0-229	Opc-€j	46	1939	P

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
28.24.07 CAB1.	445535093203401	200543	W71	Cairns residence	do	03-58	0-70 Qd 70-86 Opl	880	86	4 in. 0-70	Opl	16	03-00-58	---
28.24.07 DBA1.	445533093200701	216085	W72	Harder residence	Pederson	12-58	0-138 Qd 138-153 Osp	925	153	---	Osp	---	---	---
117.21.19 ACA.	---	216086	W73	Jasperson Dairy	E. H. Renner	05-52	0-87 Qd 87-114 Opl 114-120 Ogl 120-144 Osp	915	144	6 in. 0-90.3	Opl-Osp	22	05-22-52	---
117.21.08 CAA1.	445721093221801	216087	W74	Landers Gravel	McCarthy	09-21	0-82 Qd 82-100 Opl 100-265 Osp 265-280 Opc	890	280	---	Opl(?) Osp(?)-Opc	31	09-00-21	AR
28.24.6 BDB1.	445639093203201	216089	W75	Park Pet Hosp.	Max Renner	1951	0-67 Qd 67-130 Opl-Osp	884	130	6 in. 0-67	Opl-Osp	33.51	12-11-78	P
28.24.06 ABC1.	445644093202101	216090	W76	Professional Instruments.	do	1946	---	882	184	6 in.	Opl(?)-Osp	---	---	P
117.21.19 CBD1.	445608093240301	216093	W80	Red Owl	Keys	10-46	0-99 Qd 99-117 Opl 117-279 Osp 279-397 Opc 397-502 Єj	920	502	16 in. 0-279 12 in. 0-304	Opc	70	10-03-46	---
29.24.30 BCC1.	445916093205101	201039	W82	Weldwood Nursing	Bergeson-Caswell.	10-57	0-56 Qd 56-67 Opl 67-235 Osp 235-348 Opc 348-444 Єj	878	444	12 in. 0-56 6 in. 0-348	(?)-Єj	50	11-07-57	---
29.24.29 CBC1.	445808093103901	201014	W86	Prudential Insurance Co. No. 1.	Layne	07-54	0-243 Qd 243-257 Osp 257-383 Opc 383-467 Єj 467-470 Єsl	925	470	16 in. 0-259	Opc-Єsl	78	07-00-54	---
117.21.17 BAC2.	445651093222902	149710	W100	Monitoring well	E. H. Renner	12-78	0-73 Qd 73-88 Opl	910	88	4 in. 0-73	Opl	13.03	12-26-78	O
117.21.16 CDB2.	445617093211501	149711	W101	Monitoring well	do	12-78	0-100 Qd 100-106 Opl	910	106	4 in. 0-103	Opl	52.41	12-26-78	G,O
-----------	---	216102	W104	Rice Gravel & Sand	-----------	1935	---	---	250	12 in.	Opc(?)	---	---	---

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.17 CA1.	---	200979?	W105	Minnesota Sugar Beet Co.	Swenson	1899	0–73 Qd 73–93 Opl 93–260 Osp 260–385 Opc 385–504 €j 504–950 €sl–€m	892	950	---	Opl–€m(?)	---	---	---
28.24.6 CAA2.	445614093204102	216103	W106	Hedberg, Friedheim & Co.		Before 1936	0–90 Qd 90–100 Opl 100–230 Osp	900	230	---	Opl(?)–Osp	---	---	---
28.24.06 BCD1.	445634093204101	216104	W107	Interior Elevator Co., Salem Ave. and Chicago & Milwaukee Rail Road tracks.		About 1893	0–75 Qd 75–100 Opl 100–250 Osp 250–390 Opc 390–495 €j 495–710 €l–€f 710–755 €ig	875	755	---	Opl(?)–€ig	---	---	---
117.21.21 BAB1.	445605093211201	216029	W108	5800 Goodrich	E. H. Renner	Before 1936	---	---	---	---	---	---	---	---
117.21.09 CDC1.	445658093211201	216105	W109	Max Renner's Shop.	Max Renner	Before 1936	0–93 Qd 93–113 Opl 113–118 Osp	925	118	---	Opl(?)–Osp	---	---	---
117.21.16 CCD1.	445609093212501	216107	W111	6030 Oxford St.	do	Before 1936	0–190 Qd 190–240 Osp	919	240	---	Osp	---	---	G
117.21.16 CCA1.	445615093212301	206443	W112	Old St. Louis Park Well #1.	McCarthy	05-32	0–109 Qd 109–274 Osp 274–398 Opc 398–486 €j 486–540 €sl	917.52	540	16 in. 0–212 12 in. 194–274	in 1932 Opc–€sl in 1978 Opc	77	12-21-78	G,M
117.21.8 DCB3.	445701093215803	206440	W113	St. Louis Park No. 3.	do	08-39	0–103 Qd 103–118 Opl 118–286 Osp	922	286	24 in. 0–103	Opl–Osp	60	08-00-39	P
28.24.6 CAA3.	445614093204103	216108	W114	Hedberg, Friedheim & Co.	E. H. Renner	Before 1936	0–60 Qd 60–80 Opl 80–249 Osp	887	249	---	Opl(?)–Osp	---	---	F
117.21.20 ABD1.	445554093220301	216109	W115	Monitoring well	Bergerson-Caswell.	02-79	0–65 Qd 65–78 Opl 78–78 Ogl	892.16 MP	78	4 in. 0–66	Opl	10.85	02-12-79	O

Table 1. Data on selected wells in the St. Louis Park area, Minnesota—Continued

Township and range	Site identification (lat and long)	Minnesota unique well number	USGS project well number	Owner name or other identifiers	Driller	Date drilled	Reported log, in feet	Land surface altitude, in feet	Reported depth of well, in feet	Diameter, in inches, and depth, in feet, of casing	Aquifer(s) open to well bore	Water level, in feet	Date measured	Field measurement status
117.21.16 DCB3.	445634093205903	160030	W116	do	E. H. Renner	04-79	0-67 Qd	909.59	67	0-4 in. 0-63	Qd	35.01	06-05-79	O
117.21.16 CDB3.	445617093211502	160031	W117	do	do	04-79	0-72 Qd	917.73 MP	72	4 in. 0-68	Qd	39.68	06-05-79	O
117.21.20 CDC1.	445516093222501	216088	W118	Minneapolis Park Board-Meadowbrook Golf Course.	do		0-80 Qd 80-89 Opl 89-245 Osp 245-370 Opc 370-485 €j 485-487 €sl	905	487	---	Opc-€sl	---	---	---
117.21.20 DAC1.	445527093215201	216009	W119	do		06-35	0-74 Qd 74-82 Opl 82-90 Ogl 90-252 Osp 252-375 Opc 375-465 €j 465-502 €sl	890	502	16 in. 0-77 12 in. 77-257	Opc-€sl	54.5	06-28-35	---
117.21.16 DCA2.	445014093212802	165516	W120	Monitoring well	E. H. Renner	07-79	0-95.5 Qd 95.8-98 Opl, (weathered) 98-107 Opl 107-108.6 Ogl	919.8 MP	105.7	4 in. 0-98	Opl	38.84	07-12-79	G,O
117.21.21 BBD1.	445558093212001	165577	W121	do	do	07-79	0-110 Qd 110-115 Opl, (weathered) 115-117 Ogl	918	113.25	4 in. 0-109	Opl	53.58	07-18-79	G,O
117.21.21 BAD1.	445557093210901	165578	W122	do	do	08-79	0-120 Qd 120-212 Osp 212-239 Ospl	920	239	4 in. 0-217	---	---	---	G,O
117.21.21 BBC1.	445559093213201	216129	W140	Cambridge Brick			---	---	---	4 in.	Opl?	---	---	D
117.21.17 DDD5.	445607093214203	216051	W143	6425 Oxford St.			0-70 Qd 70-90 Opl	---	---	4 in. 0-70	Opl	---	---	G
28.24.06 BCD2.	445634093204102	216128	W144	Interior Elevator			---	---	---	---	---	---	---	F

Well-Numbering System

Each well or test hole has been assigned four identifying numbers. They are (1) WATSTORE (STORET) site identification, (2) township and range location, (3) Minnesota Unique Well Number, and (4) a project number (table 1). WATSTORE and STORET are water-quality data bases maintained by the USGS and U.S. Environmental Protection Agency, respectively. Most data in WATSTORE can be obtained through STORET. The WATSTORE site identification number is identical to the STORET station number and is needed to enter data into either of these data bases. The first six numerals of the number are the latitude of the well location in degrees, minutes, and seconds. The next seven numbers are the longitude of the location. The last two numbers are arbitrary numbers, which distinguish wells within a given 1-second by 1-second area (approximately 75 by 100 feet).

The township and range method of numbering test holes and wells is based on the U.S. Bureau of Land Management's system of subdivision of public lands. The first segment of a well or test-hole number indicates the township north of the baseline; the second, the range west of the principal meridian; and the third, the section in which the well is situated. The letters A, B, C, and D, following the section number, indicate well location in the section. The first letter denotes the 160-acre tract, the second letter the 40-acre tract, and the third letter the 10-acre tract. The letters are assigned counterclockwise beginning with the northeast quarter. Consecutive numbers beginning with 1 are added as suffixes to distinguish wells within a given 10-acre tract. For example, the number 117.21.17BAC2 identifies the second well or test hole in the southwest quarter of the northeast quarter of the northwest quarter, sec. 17, T. 117 N., R. 21 W.

The Minnesota Unique Well Number is an arbitrary number assigned by the State of Minnesota to new wells when they are drilled and older wells when they are located in the field. This number is needed to identify wells in ground-water data bases maintained by the State.

The project well number is used throughout this report to identify wells and piezometers. Municipal-supply wells are numbered with the initial letters of the name of the municipality and the well number assigned to the well by the municipality. For example, St. Louis Park municipal well 4 is numbered SLP4. Other wells, piezometers, and borings are numbered with the prefix W, P, or B, respectively, and a number. Wells W1–W17 and piezometers P1–P3 are consistent with the numbering system used in Barr Engineering Co. (1976, 1977).

Glossary

The geologic, hydrologic, and chemical terms pertinent to this report are defined as follows:

Aqueous phase—water in the saturated or unsaturated zone, which may contain hydrocarbon compounds. (See "Hydrocarbon fluid phase" and "Hydrocarbon solid phase.")

Aquifer—a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs.

Confined ground water—ground water under pressure significantly greater than atmospheric. Its upper limit is the bottom of a bed of distinctly lower vertical hydraulic conductivity than that of the material in which the confined water occurs. (See "Confining bed.")

Confining bed—a body of material with low vertical permeability stratigraphically adjacent to one or more aquifers. Replaces the terms "aquiclude," "aquitard," and "aquifuge."

Constituent, coal-tar—a chemical compound identified as occurring in significant amounts in commercial coal tar. (See "Derivative, coal-tar" and "Degradation product, coal-tar.")

Degradation product, coal-tar—a chemical compound identified as being formed by chemical or biochemical reactions involving coal-tar constituents.

Derivative, coal-tar—a constituent or degradation product of coal tar. (See "Constituent, coal-tar" and "Degradation product, coal-tar.")

Desorption—the removal of contaminants from the solid matrix of the porous medium by fluids in the ground-water system.

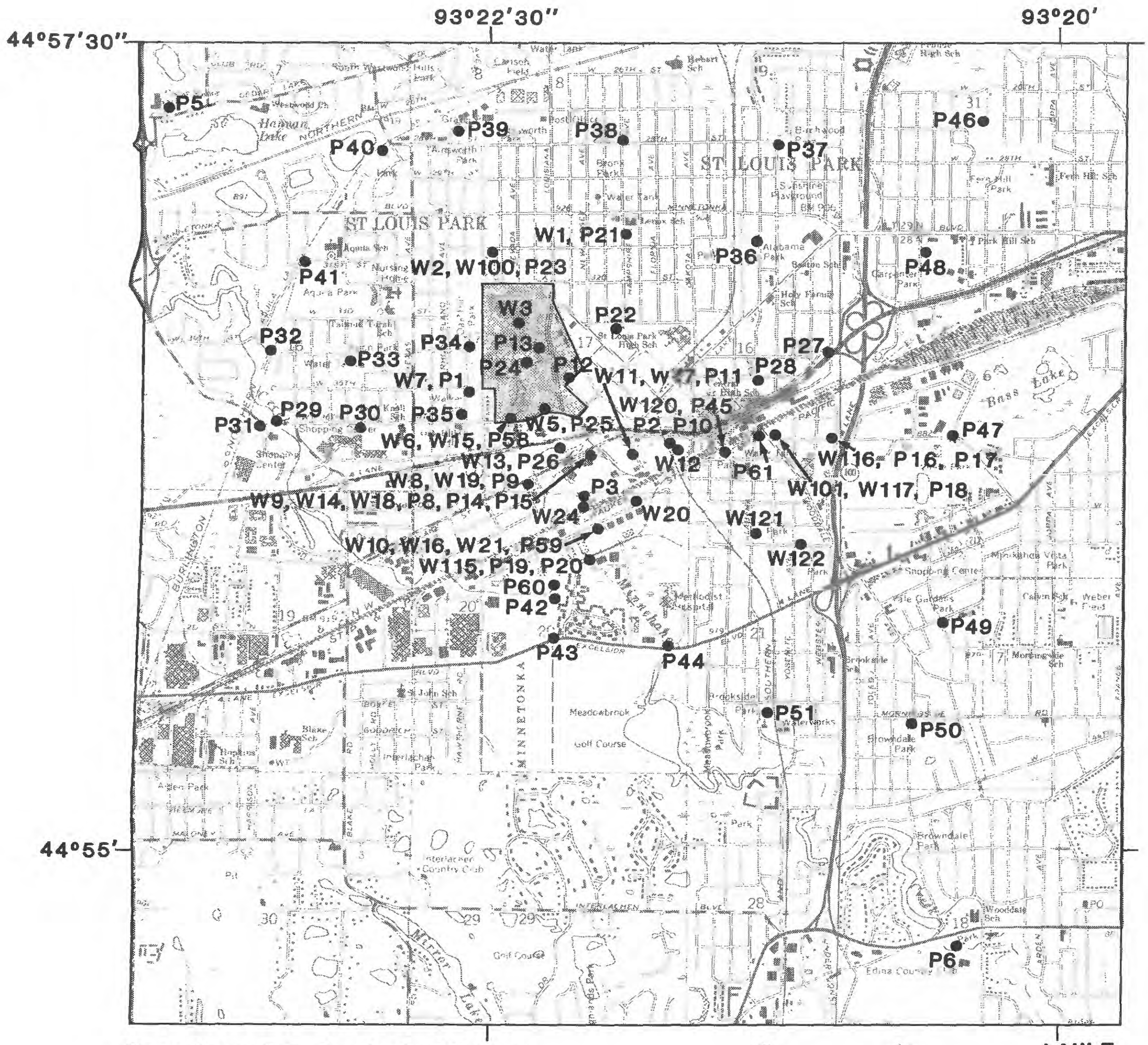
Diffusion—molecular movement of chemical constituents of ground water or hydrocarbon fluids in response to chemical-concentration gradients.

Dispersion, mechanical—differences in the rate and direction of movement of individual tracer particles owing to variations in path lengths and pore geometry or size.

Dispersion, hydrodynamic—the combined effects of "Diffusion" and "Dispersion, mechanical."

Dissolved—organic or inorganic constituents of ground water that are not removed by filtration through a 0.45-micrometer filter. (See "Suspended" and "Total.")

Drawdown—the vertical distance between the static (nonpumping) water level and the level caused by pumping.



Base from U. S. Geological Survey
Hopkins and Minneapolis South; both
maps 1:24,000, 1967 (Photorevised 1972)

0 ½ 1 MILE

0 .5 1 KILOMETER

WELLS AND PIEZOMETERS INSTALLED FOR MONITORING PURPOSES

Figure 3. Locations of wells listed in table 1 and selected piezometers

Drift—all deposits resulting from glacial activity.

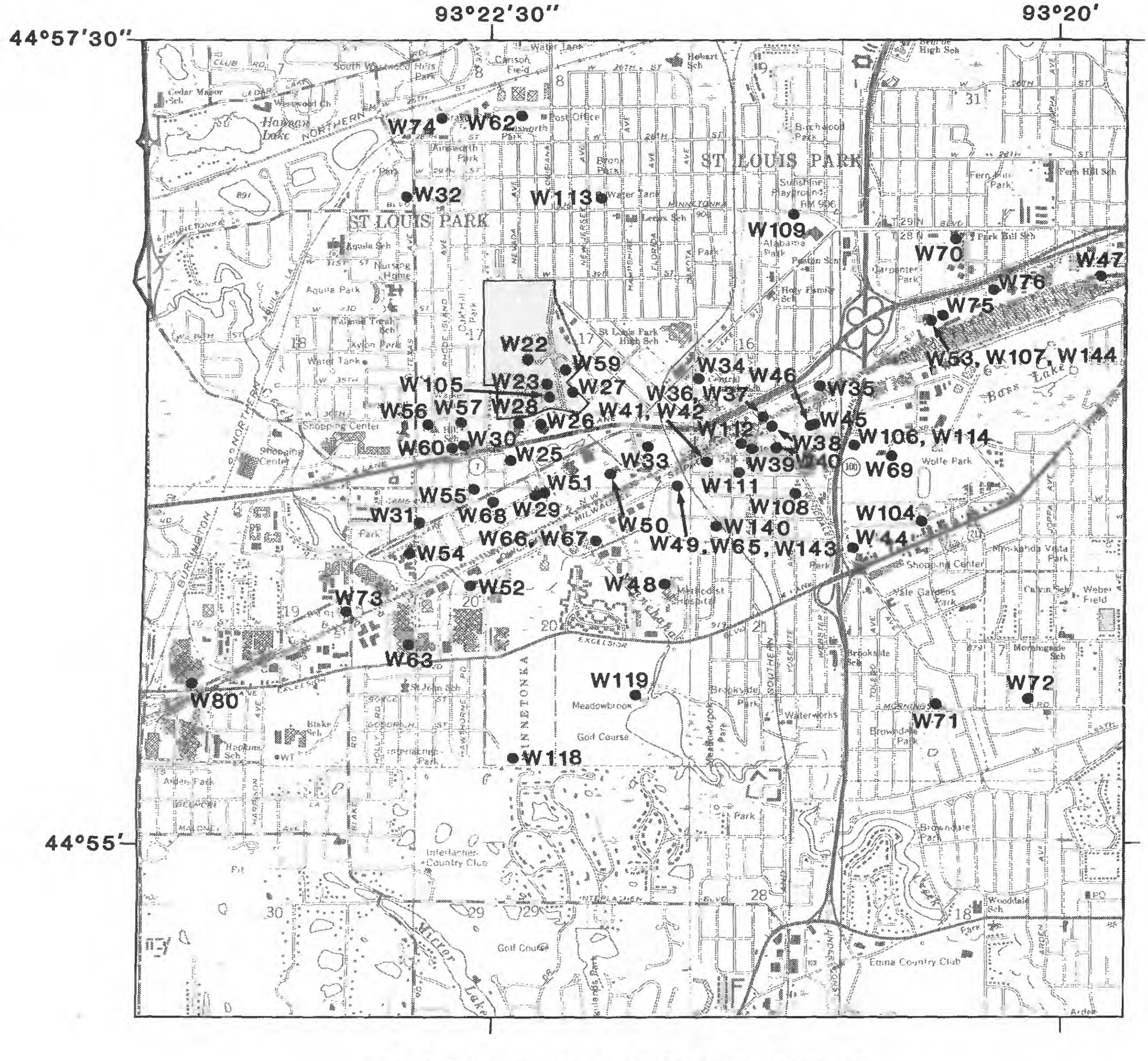
Ground water—that part of subsurface water that is in the saturated zone.

Head, static—the height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point.

Hydraulic conductivity—capacity of a rock to transmit water under pressure. It is the rate of flow of water at the prevailing kinematic viscosity passing through a unit section of area, measured at right angles to the direction of flow, under a unit hydraulic gradient. (See "Permeability, intrinsic.")

Hydrocarbon fluid phase—a liquid mixture of hydrocarbon compounds, immiscible with water, that forms a fluid phase physically distinct from the aqueous phase. It is distinctly denser and more viscous and has a higher surface tension than the aqueous phase. (See "Aqueous phase" and "Hydrocarbon solid phase.")

Hydrocarbon solid phase—hydrocarbon compounds sorbed onto the matrix of the porous medium. (See "Aqueous phase," "Hydrocarbon fluid phase," and "Sorption.")



PRIVATE AND INDUSTRIAL WELLS

EXPLANATION

LOCATION OF WELL OR PIEZOMETER

● W5, P25

"P" Prefix denotes small-diameter piezometer

"W" Prefix denotes 4-inch diameter or larger well

Numbers indicate project well or piezometer number

Site of former plant

Isopotential line—line connecting points of equal static head. (Head is a measure of the potential.)

Multiaquifer well—any well that hydraulically connects more than one aquifer. The connection may be due to original open-hole construction or to deterioration of casing or grout seal.

Outwash—sorted, stratified drift deposited beyond the ice front by melt-water streams.

Permeability, intrinsic—a measure of the relative ease with which a porous medium can transmit liquid under a potential gradient. It is a property of the medium alone, dependent upon the size and shape of the pores and independent of the nature of the liquid and of the force field causing movement.

Piezometer—a small-diameter pipe placed in the ground in such a way that the water level in the pipe represents the static head at the very point in the flow field where the piezometer terminates.

Porosity—the property of a rock or soil to contain interstices or voids. It may be expressed quantitatively as the ratio of the volume of interstices to total volume of the rock. (See "Porosity, effective.")

Porosity, effective—the amount of interconnected pore space available for fluid transmission. It is expressed as a decimal fraction or as a percentage of the total volume occupied by the interconnecting interstices.

Potentiometric surface—a surface that represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is then required to describe the distribution of head. The water table is a particular potentiometric surface. Replaces the term "Piezometric surface."

Sorption—the removal of contaminant from fluids in the ground-water system by the solid matrix of the porous medium.

Specific capacity—the rate of discharge of water from a well divided by the drawdown of water level within the well. It varies slowly with duration of discharge, which should be stated when known. If the specific capacity is constant except for time variation, it is roughly proportional to the transmissivity of the aquifer.

Specific yield—the ratio of the volume of water that a saturated rock or soil will yield by gravity to its own volume.

Storage coefficient—the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, it is virtually equal to the specific yield.

Suspended—organic or inorganic constituents of ground water that are removed by filtration through a 0.45-micrometer filter. (See "Dissolved" and "Total.")

Till—unsorted, unstratified drift deposited directly by the ice.

Total—with reference to chemical constituents in ground water, the amount of the chemical constituent in an unfiltered sample. (See "Dissolved" and "Suspended.")

Transmissivity—the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Unconfined ground water—water in an aquifer that has a water table.

Valley fill—drift or alluvial sediments deposited in an erosional depression in the bedrock surface.

Water table—that surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells that penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists.

Well field—as used in this report, any combination of wells withdrawing water from the same area and close enough to cause mutual drawdown effects.

Zone, saturated—that part of the water-bearing material in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric. The saturated zone may depart from the ideal in some respects. A rising water table may trap air in the upper part of the zone of saturation, and some parts may include accumulations of other fluids.

Zone, unsaturated—the zone between the land surface and the water table. It includes the capillary fringe. Characteristically, this zone contains liquid water under less than atmospheric pressure and water vapor and air or other gases generally at atmospheric pressure. In parts of the zone, interstices, particularly small ones, may be temporarily or permanently filled with water. Perched water bodies may exist within the unsaturated zone, and some parts may include accumulations of other fluids. Replaces the terms "zone of aeration" and "vadose zone."

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HYDROGEOLOGY

Contaminants move through the ground-water system primarily as a result of the movement of ground water. Movement of ground water is controlled by the geometry and hydraulic characteristics of rock units and the distribution of hydraulic head. The hydrogeologic system is continuously recharged in some places and discharged in others. It is always tending to adjust, sometimes in minor degrees, to climatic variations and the activities of man. As the system responds to these changes, the direction and rate of contaminant movement may change. The purpose of the hydrogeologic investigation is to develop an understanding of how the ground-water system operates and how future activities of man, including possible remedial actions, may affect contaminant movement.

Bedrock Geology

Bedrock geology maps included in this report are preliminary versions of maps that will be updated and modified for use by the USGS in constructing a numerical model of the ground-water-flow system in the seven-county Minneapolis–St. Paul metropolitan area. As part of that modeling project, the MGS, in cooperation with the USGS, is preparing structure-contour and thickness maps for 10 bedrock units.

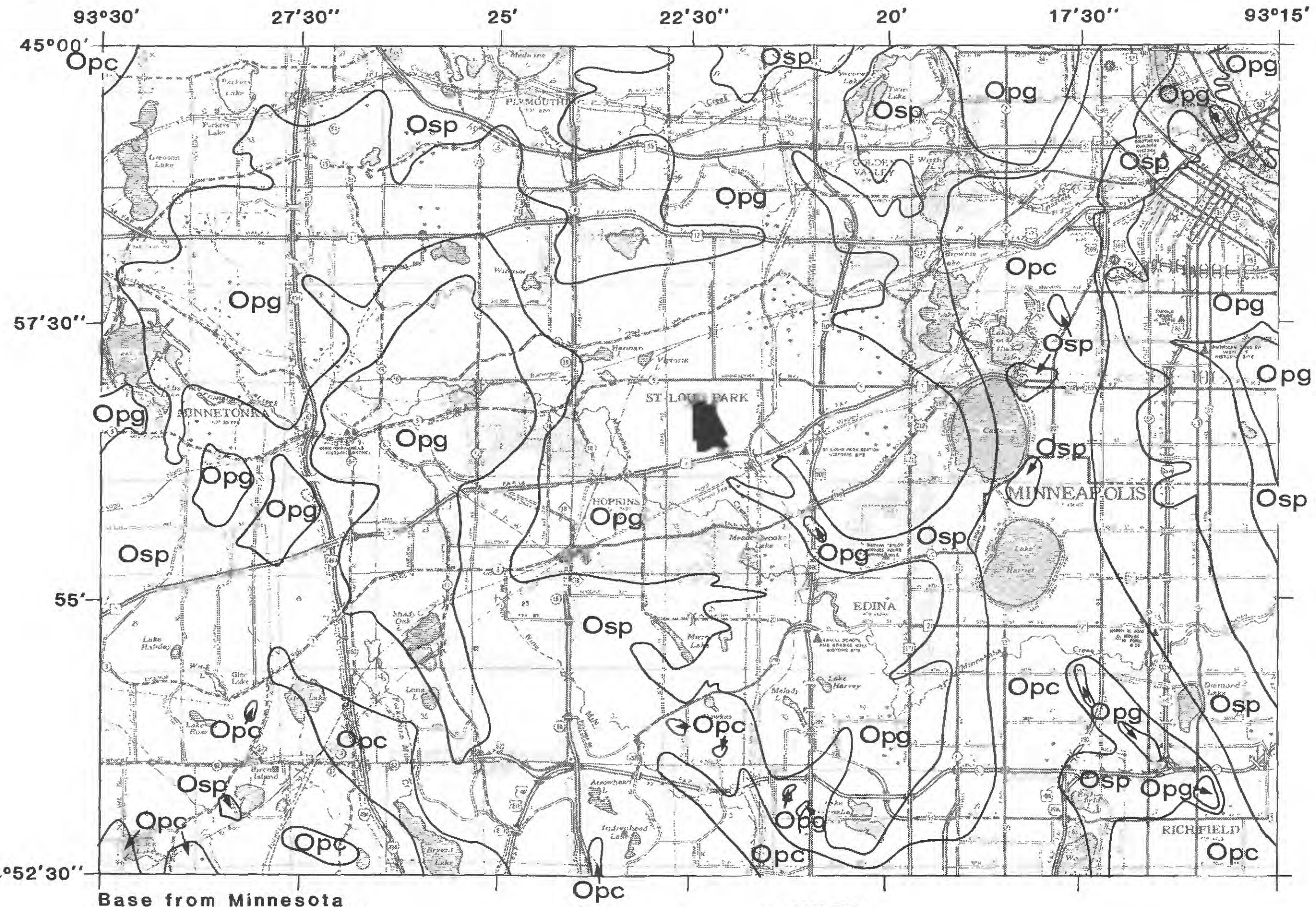
The amount of geologic detail required for the St. Louis Park study is greater than that required for the metropolitan area project. Consequently, more detailed geologic maps of the Minneapolis South and the Hopkins 7.5-minute quadrangles (fig. 1) have been prepared by the USGS for this study.

Water-well and test-hole records and data plots were obtained from the MGS and the files of the USGS and compiled at a scale of 1:24,000. The bedrock geology (fig. 4) and topography (fig. 5) maps were constructed from these data and from maps previously prepared by the USGS and MGS. The northeastern part of the mapped area is generalized from Norvitch and Walton (1979). An unpublished geologic map of the Hopkins quadrangle prepared by the MGS was updated with additional information, and a consistent map covering both quadrangles was prepared.

The bedrock geology and topography maps (figs. 4, 5) are in nearly final form, with the exception of the area near the site. Mapping subsurface geologic features requires interpolation between discrete data points, generally geologic or geophysical logs of wells or test holes. If the structure being mapped is simple, such as the top of uniformly dipping, distinct strata, relatively few data points are required to produce a map acceptable for most purposes. The structure-contour map of the top of the Mount Simon–Hinckley aquifer (pl. 2) is an example of such a map. The reliability of a map can be generally assessed by the amount of change required to make the map consistent with new or independent data. In the example of the map of the top of the Mount Simon–Hinckley aquifer, additional data will doubtless result in some changes of the contours. These refinements, however, will not be critical to understanding the contamination problem.

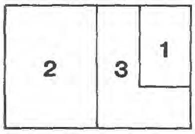
In contrast to the simple geometry of the top of the Mount Simon–Hinckley aquifer, the configuration of the bedrock surface near the site (pl. 2) is complex. Considerable detail will be required for an adequate understanding of the local hydrogeology. New data from the ongoing study may result not in minor refinements but, rather, in substantial revisions of the present interpretation. Data used in preparation of the bedrock geology map on plate 2 are from water-well and test-hole information from the files of the USGS and MGS, test holes and wells installed for this study, water-well records obtained from drillers, test holes and monitoring wells installed in conjunction with the construction of Louisiana Avenue, seismic surveys by the USGS, previous reports (principally Schwartz, 1936; Barr Engineering Co., 1977), and geophysical logging of wells by the USGS.

Because of the confusion that can be caused by incomplete well logs, wells are being geophysically logged, where possible, to confirm the reported stratigraphy. For wells at critical locations, attempts were made to obtain more complete logs than those available in the files of the MGS and USGS. For example, data on file and previously reported by Barr Engineering Co. (1977) indicate that the well at Methodist Hospital (W48) penetrated the full thickness of St. Peter Sandstone but that the Platteville Limestone and Glenwood Shale, both of Ordovician



Base from Minnesota Department of Highways General Highway Map of Hennepin County, 1977

0 1 2 MILES
0 1 2 3 KILOMETERS



1. Modified from Norvitch, R. F., and Walton, M. S., 1979, U. S. Geological Survey Miscellaneous Investigations Map I-1157
2. Modified from Minnesota Geological Survey, Unpublished Map
3. This study

INDEX TO GEOLOGIC MAPPING

EXPLANATION

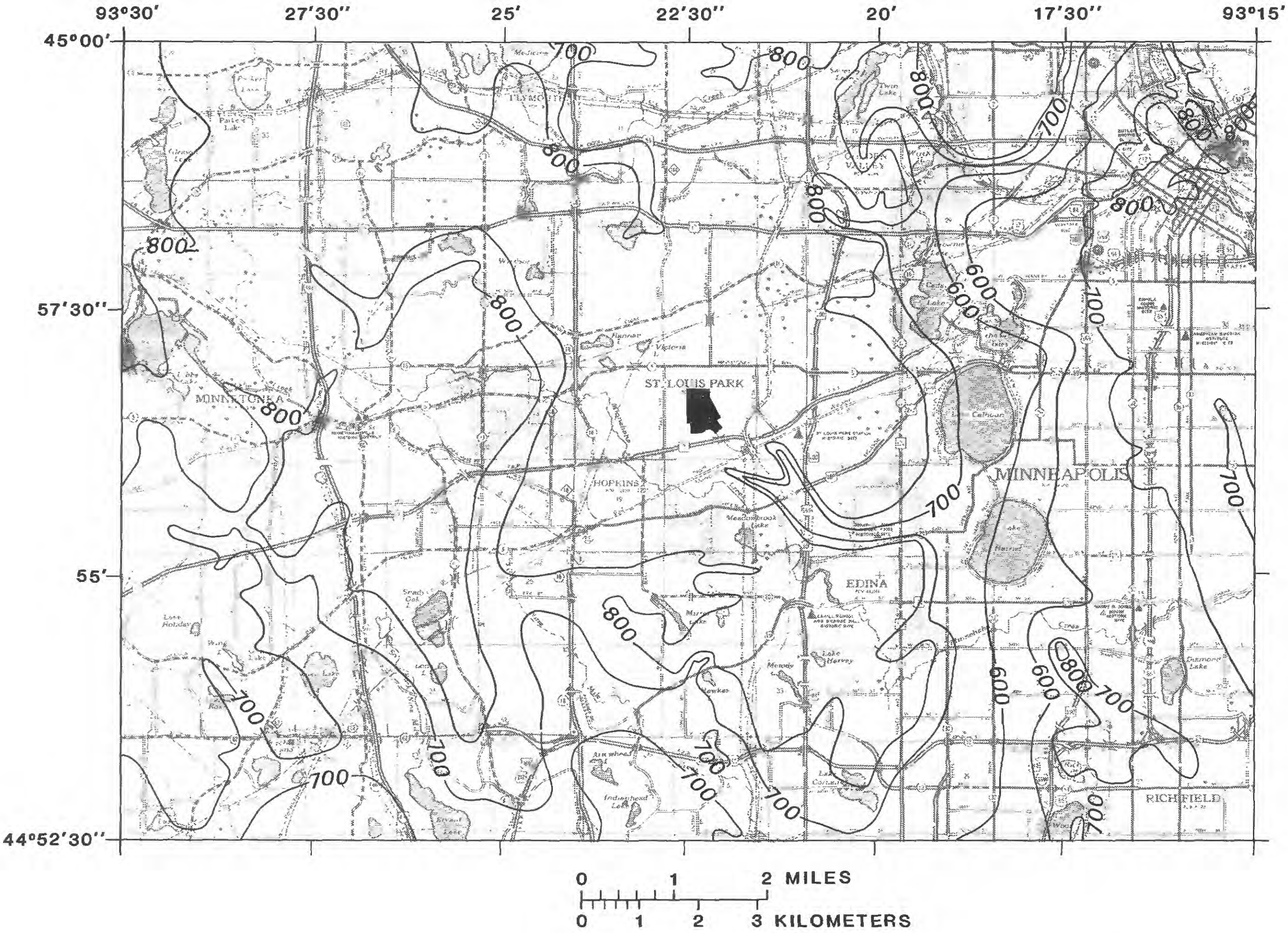
CORRELATION OF MAP UNITS

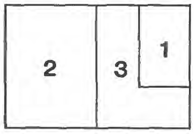
Opg	Platteville and Glenwood Formations, undivided	ORDOVICIAN
Osp	St. Peter Sandstone	
Opc	Prairie du Chien Group	

——— Approximate geologic contact

Site of former plant

Figure 4. Preliminary bedrock geology, Minneapolis South and Hopkins quadrangles





1. Modified from Norvitch, R. F., and Walton, M. S., 1979, U. S. Geological Survey Miscellaneous Investigations Map I-1157
2. Modified from Minnesota Geological Survey, Unpublished Map
3. This study

INDEX TO GEOLOGIC MAPPING

EXPLANATION

——700—— BEDROCK CONTOUR--Shows altitude of bedrock surface. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

Site of former plant

Figure 5. Preliminary bedrock topography, Minneapolis South and Hopkins quadrangles

age, were absent. Daily drilling records from the driller, however, indicate that 9 feet of "broken lime rock and gravel" (Platteville) overlies the sandstone. Similarly, the log on file for the Milwaukee Railroad well (W38) did not record the Platteville and Glenwood, but a published log for the well (Schwartz, 1936) indicates that 4 feet of limestone overlies the St. Peter.

The distribution of the Glenwood confining bed is of major importance in the transport of contaminants near the site. Regionally, leakage through the unit is significant, but locally it impedes ground-water flow and transport of contaminants. The unit separates the Platteville and St. Peter aquifers; it includes the Glenwood Shale and the upper part of the St. Peter Sandstone.

The Glenwood Shale is thin and is commonly not recorded in water-well logs. At wells where the overlying Platteville Limestone is reported as the uppermost bedrock unit, evaluation of the reported data is simple and unambiguous. However, logs for several wells indicate that the underlying St. Peter Sandstone of Ordovician age is the uppermost bedrock unit and that the altitude of the bedrock surface corresponds to that of uneroded St. Peter Sandstone. Locally, this condition may exist because of in-situ chemical weathering and subglacial scouring. In general, however, this interpretation of the bedrock surface is inconsistent with observations of the geomorphology of stream-eroded channels through these rocks where they are exposed elsewhere in the area. Typically, the Platteville Limestone forms a protective caprock, the Glenwood Shale a re-entrant in the valley wall, and the St. Peter Sandstone a near-vertical bluff. Commonly, there is a talus slope of reworked St. Peter Sandstone armored with blocks of Platteville Limestone at the base of the exposure.

Four major geomorphic processes that may be responsible for the relief on the bedrock surface near the site are stream erosion, subglacial plucking and abrasion, subglacial stream erosion, and in-situ chemical weathering. Each mechanism can produce an erosional surface having a distinctive geometry.

The bedrock geology maps (figs. 4, 5; pl. 2) are drawn on the assumption that stream erosion is responsible for the major depressions in the bedrock surface. Because streams have graded longitudinal profiles, this interpretation requires that the bedrock valleys have similar graded profiles. In southeastern Minnesota, where the Platteville Limestone is not covered by thick drift, narrow valleys having dendritic patterns have formed by waterfall recession. Olson and others (1974), however, suggested that the bedrock valleys in the St. Louis Park area were formed during glacial periods by streams that formed in front of the glacier margin (proglacial streams). Valleys that may have been eroded by preglacial or proglacial streams in the St. Louis Park area may also have been substantially modified by plucking and abrasion beneath the glaciers.

Wright (1973) has shown that moving water beneath active Pleistocene glaciers cut valleys into the bedrock surface elsewhere in Minnesota. The geometry of valleys formed by subglacial melt water may differ substantially from the geometry of those formed by preglacial or proglacial streams. Subglacial streams can flow in response to hydrostatic pressure differences beneath the glacier. The valleys eroded by subglacial streams do not necessarily have a graded longitudinal profile.

The mapped depth of the valley cut into the St. Peter Sandstone east of the site (pl. 2) is based on two data points, well W122, drilled for this study, and well W111, reported by Schwartz (1936). The latter well has been located in the field, but an obstruction in the well bore prevents complete geophysical logging to confirm the stratigraphy.

The northernmost extent shown for the eastern valley (pl. 2) is based on four test wells, driller's and (or) geophysical logs of seven other wells, and a seismic refraction survey. The Platteville Limestone in this area is deeply weathered. Inspection of the Platteville Limestone by downhole television camera in test well W101 shows weathered blocks of limestone that may indicate the edge of a valley wall. The proximity of a valley is also suggested by the low water level in the Platteville Limestone at this point (pl. 3); the low level could be caused by flow out of the Platteville if the Glenwood confining bed has been removed by erosion. Additional field data will be obtained to determine whether the valley crosses the line of section *B–B′* (pl. 3) between the data points or lies wholly south of the section.

The location of the western valley cut into the St. Peter Sandstone near the site (pl. 2) is based on soil borings, records of three wells in the vicinity of Oxford Street and Louisiana Avenue, and a seismic refraction survey along the north side of Oxford Street. Peat having a low seismic velocity underlies the area, complicating the interpretation of the seismic data. No well or test boring clearly indicates the presence of a deep bedrock valley in this area; therefore, the valley may be absent or much shallower than shown. In-situ weathering or subglacial erosion, rather than stream erosion, may have caused the relief on the bedrock surface.

Glacial Geology

The purpose of subsurface geologic mapping of the drift is to define areal extent and thickness of individual drift units and variations in their hydrogeologic characteristics. Test drilling by cable-tool, rotary, power-auger, and split-spoon coring methods will better define the glacial stratigraphy, particularly in the vicinity of the drift-filled bedrock valleys. Seismic refraction has been tried in an attempt to interpolate between drill holes. The particle-size distribution and the mineralogy of clay and selected sand-sized fractions of the drift will be determined to aid correlation between drift units.

Porosity and vertical hydraulic conductivity of selected samples are being measured in the laboratory to estimate reasonable ranges for these characteristics. Neutron and gamma-gamma logging of selected wells, in conjunction with laboratory measurements, are being used to assess variations in effective porosity. Pumping tests will provide local values for vertical and horizontal hydraulic conductivity, storage coefficient, and specific yield, but extrapolation of these values to other locations must be based on the interpretation of the stratigraphy provided by test drilling and on laboratory measurements.

Status of Water-Level Measurement and Methods Used

Water levels are being measured at about 265 wells, piezometers, and surface-water gages. The exact number of measuring sites changes continually as wells are installed, located, sealed, or reconstructed. Table 2 shows the sites organized by frequency of measurement and by hydrologic feature. Water levels at about 65 sites are measured at approximately 2-week intervals or by continuous or digital water-level recorders. These data were used to construct the detailed description of the ground-water-flow system in the area of high concentration of contamination in the drift and the Platteville aquifer (pls. 3, 4, 5). Note that the number of wells shown in table 2 may be greater than the number of values reported on potentiometric surface maps of a particular aquifer. Not all wells in the network are accessible or suitable at every measurement date. In addition, some wells in table 2 are outside the area of the maps shown.

About 200 wells and surface-water gages are measured about twice annually to evaluate the regional configuration of the water table and response of bedrock aquifers to pumping. Because water levels in the bedrock aquifers fluctuate rapidly, an attempt is made to measure all wells in a particular aquifer in a short time. The term ''mass measurement'' is used to describe this approach to collection of water-level data.

Determination of the water-level altitude in an aquifer results from two separate measurements: depth to water from a fixed measuring point and determination of the altitude above National Geodetic Vertical Datum of 1929 of the measuring point. Errors in measurement of the water level below the measuring point are small, generally less than 0.02 foot, and are seldom of significance. Errors in determination of the measuring-point altitude, however, may be substantial, depending on the method used. Because some estimates of measuring-point altitudes may be refined as part of the ongoing study, data on water-level altitudes in this report may differ from those in future reports.

Table 2. Summary of water-level-measurement network as of June 30, 1979, St. Louis Park area, Minnesota

Sites measured at twice-monthly or greater frequency	
Hydrologic feature	Number of sites
Lake or stream	6 (Including a recorder on Minnehaha Creek maintained by Watershed District)
Drift, other than water table	18
Platteville aquifer	10
St. Peter aquifer	5 (1 recorder)
Prairie du Chien-Jordan aquifer	2 (1 recorder)
Multiaquifer wells	4 (1 recorder)
Sites measured about twice annually	
Hydrologic feature	Number of sites
Lake or stream	3
Water table	72
Platteville aquifer	30
St. Peter aquifer	25
Prairie du Chien-Jordan aquifer	51
Ironton-Galesville aquifer	0
Mount Simon-Hinckley aquifer	11
Multiaquifer wells	8

Three general approaches have been used in this study. First, the measuring points of about 65 frequently measured sites have been spirit-leveled from a consistent datum; these water-level altitudes have generally been reported to the nearest 0.01 foot. The datum is derived from USGS, Minnesota Department of Transportation, and U.S. Coast and Geodetic Survey benchmarks. Each well in this network is tied in with closed loops. Closure errors in individual loops are typically less than 0.003 foot. The altitudes of the measuring points of clusters of wells and piezometers used to determine vertical head differences within and between aquifers are likely within this tolerance. Between widely separated wells, errors may accumulate to as much as 0.1 foot.

Barring computational mistakes, errors in this network are generally insignificant. One exception is possible change in measuring-point altitude owing to land subsidence. In particular, the measuring-point altitude of well W13 reported by Barr Engineering Co. (1977) is 0.6 foot higher than that measured by the USGS on September 15, 1978. This well is in the wetland south of the site and yields the most highly contaminated fluid of any well sampled for this study. One explanation of the difference in the measuring-point altitudes is that peat underlying the pond has compacted. This explanation is consistent with the observed lowering of the water table after the installation of storm sewers and cessation of plant process-water discharge. Dewatering from possible future remedial actions may cause further subsidence.

Second, many measuring-point altitudes have been determined by spirit-leveling from vertical-control-reference marks obtained from municipalities. Water-level altitudes in this network are generally reported to the nearest 0.1 foot. Most altitudes so derived are likely accurate to at least within 0.5 foot. Altitudes of all water-table piezometers not part of the consistent vertical-control network have been determined in this way, as have altitudes of several industrial and municipal wells in the mass-measurement network.

Third, measuring-point altitudes have been estimated from USGS topographic quadrangles with 10-foot contour intervals. At best, these estimates are accurate to within several feet. Most measuring-point altitudes for wells outside of St. Louis Park in the mass-measurement network have been determined in this way. As time permits and where needed, these altitudes are being refined by spirit-leveling. Water-level information is being entered into the USGS ground-water site inventory (GWSI) data base.

Bedrock Aquifer System

Water Use

Information on ground-water withdrawals was obtained from municipalities, the Minnesota Department of Natural Resources, and files of the USGS. Table 3 summarizes these data by location and aquifer. Monthly pumpage records have been compiled for all municipal wells in the area. Industrial pumpage in St. Louis Park is metered by the city, and data for recent years are nearly complete. Data on industrial withdrawals in other municipalities are based on reports to the Department of Natural Resources and are less complete and less accurate than those in St. Louis Park.

Information on ground-water withdrawals is being entered into the Minnesota Department of Natural Resources water-use data base and will be stored on the University of Minnesota computer.

Withdrawal data from multiaquifer wells do not reflect interaquifer flow through the well bore. The rate of flow into the Prairie du Chien–Jordan aquifer owing to head differences between aquifers was estimated through the use of a downhole current meter and exceeds the rate of pumping of the aquifer in at least one well (Wolfe Lake well, W69). Flow out of the St. Peter and Platteville aquifers into underlying bedrock aquifers through multiaquifer wells likely exceeds the amount of water withdrawn from the St. Peter and Platteville aquifers by pumping.

Approximately 75 percent of withdrawals are from the Prairie du Chien–Jordan aquifer. Most other withdrawals are from the Mount Simon–Hinckley aquifer. Only one high-capacity well, SLP3, is known to be in use and to yield water principally from the St. Peter aquifer. This multiaquifer well is also completed in the Platteville aquifer and may affect the potentiometric surface of both aquifers. No other high-capacity wells are known to obtain supplies from the Platteville aquifer or the drift.

Prairie du Chien–Jordan Aquifer

Withdrawals from the Prairie du Chien–Jordan aquifer have created a long-term potentiometric-surface change (fig. 6). The regional hydraulic gradient in 1979 was generally to the east. Increased pumpage during the summer causes short-term, regional decline in water level (fig. 7). Changes in water level at any individual well reflect both regional and local conditions. Figure 8 shows the relationship between the static water level in SLP Old Well No. 1 and pumpage from the five nearest pumping wells. The hydrograph of SLP Old Well No. 1 shows the regional seasonal fluctuations (fig. 8). Continuous records (1953–76) and measurements at 30-minute intervals (1977–79) indicate a cyclical weekly fluctuation of about 2 feet in addition to the seasonal fluctuations.

The combination of the regional hydrologic gradient and the effects of pumping and multiaquifer wells create a complex potentiometric surface. Figures 9, 10, and 11 show the generalized potentiometric surface of the aquifer on January 30–31 and June 20–23, 1979, and the change in water level between these two periods. Small vertical differences in head have been measured within the Prairie du Chien–Jordan aquifer at one location (Reeder and others, 1976). These differences, residual drawdown, and the effects of nearby multiaquifer and withdrawal wells account for some of the observed local variation in head between closely spaced wells in the Prairie du Chien–Jordan aquifer.

The regional hydraulic gradient shown in figures 9 and 10 generally agrees with maps compiled by Liesch (1961), Reeder (1966), and Norvitch and others (1974) from fewer water-level measurements made over a longer period of time. The eastward flow direction is supported by water-quality interpretations (Maderak, 1964, 1965). Dissolved solids increase as water moves eastward from the major recharge area near Lake Minnetonka.

Table 3. Summary of ground-water use in the St. Louis Park area, Minnesota

Site identification (lat, first 6 digits; long, next 7 digits; last 2 digits arbitrarily assigned)	Aquifer(s)	Well name and (or) number	Date of installation	Period of monthly pumpage records	Pump capacity (gal/min)	1976 total reported pumpage, summary (gal)
		Industrial Wells				
445615093211601	St. Peter-Prairie du Chien.	Minnesota Rubber (W40)	1963	1968-78	300	81,778,840
445604093223801	Prairie du Chien	Flame Industries (W29)	4/63	1968-78	100	11,923,868
445618093210001	St. Peter-Prairie du Chien.	S & K Products 1(W45)	7/63	1968-78	175	Not in use
445617093210201		2(W46)	2/73	1973-78	175	6,582,000
445646093214601	Prairie du Chien-Jordan	Methodist Hospital	1958	1973-78	---	228,170,300
445721093221801	St. Peter-Prairie du Chien.	McCourtney Plastics (W62).	9/66	1975-78	250	59,976,131
445733093214301	Prairie du Chien	Food Producer	---	1969-78	---	66,281,040
445608093240301	Prairie du Chien-Jordan	Red Owl	10/46	1973-78	---	81,752,286
		St. Louis Park Municipal Wells				
445701093215803	Platteville-St. Peter	3	8/39	1947-48, 1961-64, 1975-78	1,200	125,878,400
445548093202201	Prairie du Chien-Jordan	4	9/46	1948-64, 1975-78	1,000	91,747,970
445631093230301	do	5	8/47	1948-64, 1975-78	1,200	151,458,650
445626093211401	do	6	1/48	1948-64, 1975-78	1,200	349,558,260
445727093221701	do	7	5/52	1953-64, 1975-78	1,200	21,806,970
445806093241101	Jordan	8	10/55	1956-64, 1975-78	1,200	375,317,050
445730093222601	Prairie du Chien-Jordan	9	1955	1960-64, 1976-78	1,200	21,807,170
445701093215804	do	10	1955	1956-64, 1975-78	1,200	86,162,850
445701093215805	Mount Simon-Hinckley	11	11/60	1961-78	1,200	315,796,700
445526093211402	do	12	8/63	1964-78	1,400	108,437,660
445756093211701	Hinckley	13	7/64	1965-78	1,400	101,826,750
445756093211702	Jordan	14	2/65	1965-78	1,200	102,363,770
445701093215806	do	15	1969	1970-78	1,200	232,574,200
445750093234801	do	16	7/73	1974-78	1,200	442,279,000
445614093204101	Prairie du Chien	Wolfe Lake (W69) (Hedberg-Friedheim).	7/47	1970-79	---	None
445730093193801	St. Peter-Prairie du Chien.	Twin Lakes	5/60	---	---	None
		Edina Municipal Wells				
445442093202601	Jordan	2	1935	1958-64, 1969-77	900	426,534,700
445430093194701	Prairie du Chien-Jordan	3	1947	do	800	39,110,800
445356093203801	do	4	1950	do	700	167,694,300
445245093194001	do	5	5/54	do	1,000	86,845,700
445345093204801	do	6	6/54	do	1,000	348,150,000
445355093212201	Prairie du Chien-Jordan	7	1955	do	1,000	72,571,400
445301093213701	Jordan	8	1953	do	1,000	64,247,200
445349093222501	Mount Simon-Hinckley	9	1957	do	1,000	74,014,800
445153093195801	do	10	9/63	1964, 1969-77	1,000	256,503,900
445153093195802	Jordan	11	1963	do	1,000	397,258,000

Table 3. Summary of ground-water use in the St. Louis Park area, Minnesota—Continued

Site identification (lat, first 6 digits; long, next 7 digits; last 2 digits arbitrarily assigned)	Aquifer(s)	Well name and (or) number	Date of installation	Period of monthly pumpage records	Pump capacity (gal/min)	1976 total reported pumpage, summary (gal)
Edina Municipal Wells—Continued						
445513093231201	Hinckley	12	9/64	do	1,000	57,581,000
445513093231202	Jordan	13	9/64	do	1,000	385,594,000
445202093230201	Prairie du Chien-Jordan	14	1964	do	1,000	46,417,800
445443093222901	Prairie du Chien	15	11/67	1969–77	1,000	169,428,000
445317093225801	Prairie du Chien-Jordan	16	11/67	do	1,000	306,421,000
445345093200801	Jordan	17	1970	1971–77	1,000	117,494,200
445206093191401	do	18	1973	1974–77	1,000	49,789,000
Hopkins Municipal Wells						
445514093244301	Prairie du Chien-Jordan	1	1920	1958–78	850	268,984,400
445550093230801	do	3	1948	1958–78	1,250	71,314,500
445607093250501	do	4	5/54	1958–78	2,300	573,860,000
445607093243701	do	5	1967	1967–78	2,050	(Wells 4 & 5 combined)
445559093243501	do	6	1977	1977–78	2,200	None

Mount Simon-Hinckley Aquifer

The Mount Simon-Hinckley aquifer provides approximately 15 percent of the ground water withdrawn in the area. However, few wells are available for measurement of water levels because the aquifer is deeply buried, and only a few wells are open to the aquifer. Most water-level measurements were made in high-capacity municipal and industrial wells, and the measurements may be affected by residual drawdown. Results of water-level measurements are shown in figure 12. Pumping by municipal wells in St. Louis Park and Edina has affected water levels locally. It is not known, however, whether local drawdown effects from individual wells have coalesced to form one or more large, closed depressions in the regional potentiometric surface. It is possible that water in the Mount Simon-Hinckley aquifer moves toward the municipalities from all directions.

Multiaquifer Wells

A major effort has been made to locate and evaluate multiaquifer wells. Data on wells were initially obtained from the files of the USGS, the MGS, the St. Louis Park Department of Public Works, and previous reports (Fuller, 1904; Hall and others, 1911; Schwartz, 1936; Minnesota Department of Health, 1938; E. A. Hickok and Associates, 1969; Olson and others, 1974; Sunde, 1974; Barr Engineering Co., 1977). Additional information was obtained from discussions with area residents, employees of local businesses, and drillers. Greatest priority was given to a 2-square-mile area surrounding the site in which attempts are being made to locate and test all wells.

Data on some of these wells are presented in table 1 and (or) have been entered in the USGS GWSI data base. As wells are located in the field, logged geophysically, reconstructed, or permanently abandoned, information on them is updated.

Approximately 30 uncased or ungrouted bedrock wells have been logged with a downhole television camera by the Minnesota Department of Health and (or) geophysically logged by the USGS. Where possible, water levels and well depths were measured and the wells were geophysically logged to verify well construction and stratigraphy and to measure vertical flow. These geophysical logs, driller's logs, water-level measurements, and leveling results are available for inspection at the USGS, St. Paul, Minn.

A multiaquifer well can provide an avenue for the transport of contaminants and can locally change the potentiometric surfaces of the aquifers that are connected. Water moves from one aquifer to another through multiaquifer wells in response to differences in water levels between aquifers. In the study area, the water level in each aquifer is higher than the level in underlying

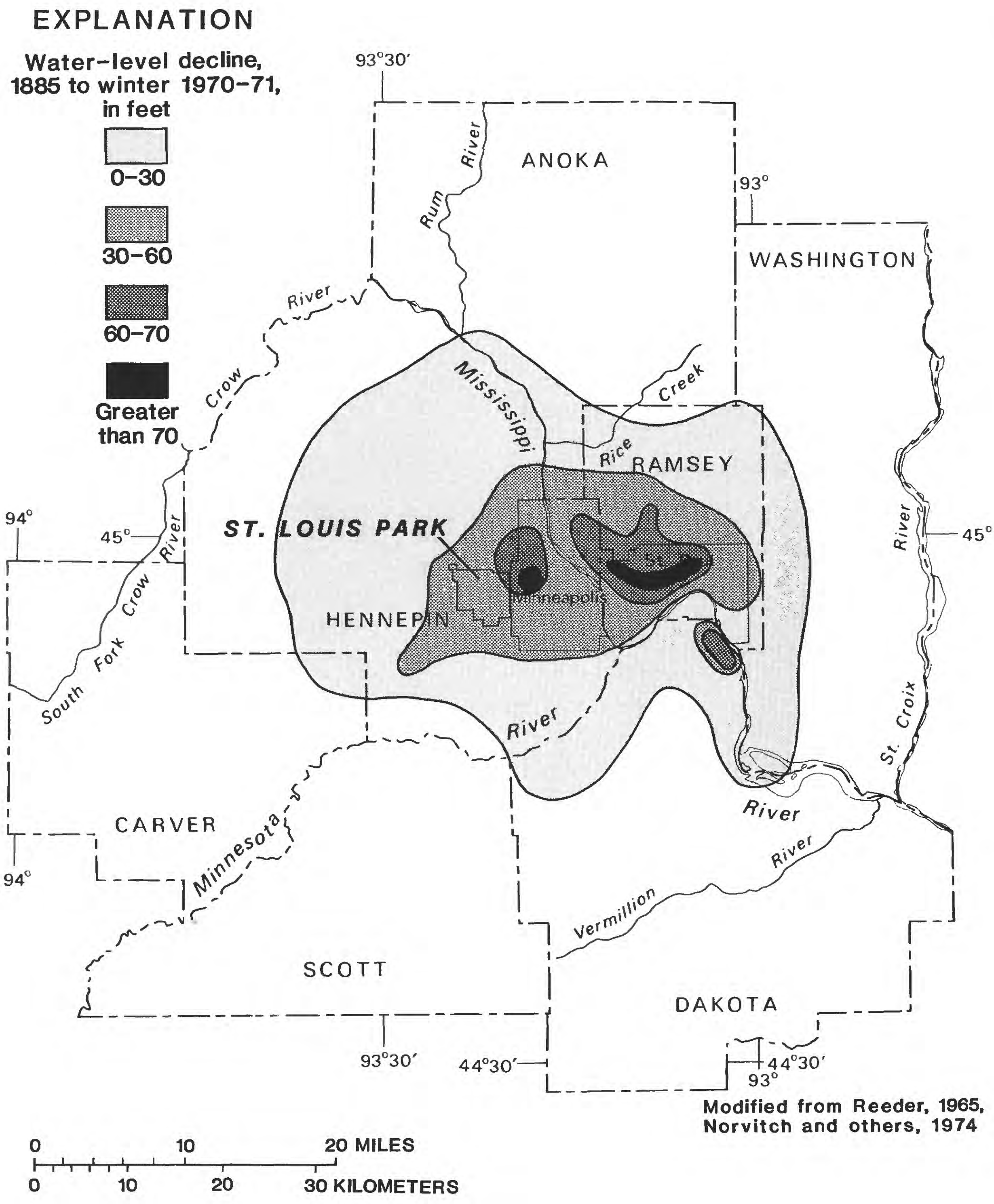


Figure 6. Long-term potentiometric-surface change in the Prairie du Chien-Jordan aquifer caused by ground-water withdrawal, 1885 to winter 1970–71

aquifers and flow through multiaquifer wells, therefore, is downward.

A multiaquifer well, as the term is used in this report, is any well that hydraulically connects more than one aquifer (see Glossary). The interconnection may be due to one or more of the following factors: original open-hole construction, leaks in the casing, or flow in the annular space between the casing and the borehole. Detecting and measuring flow in the annular space outside casings generally requires specialized techniques that

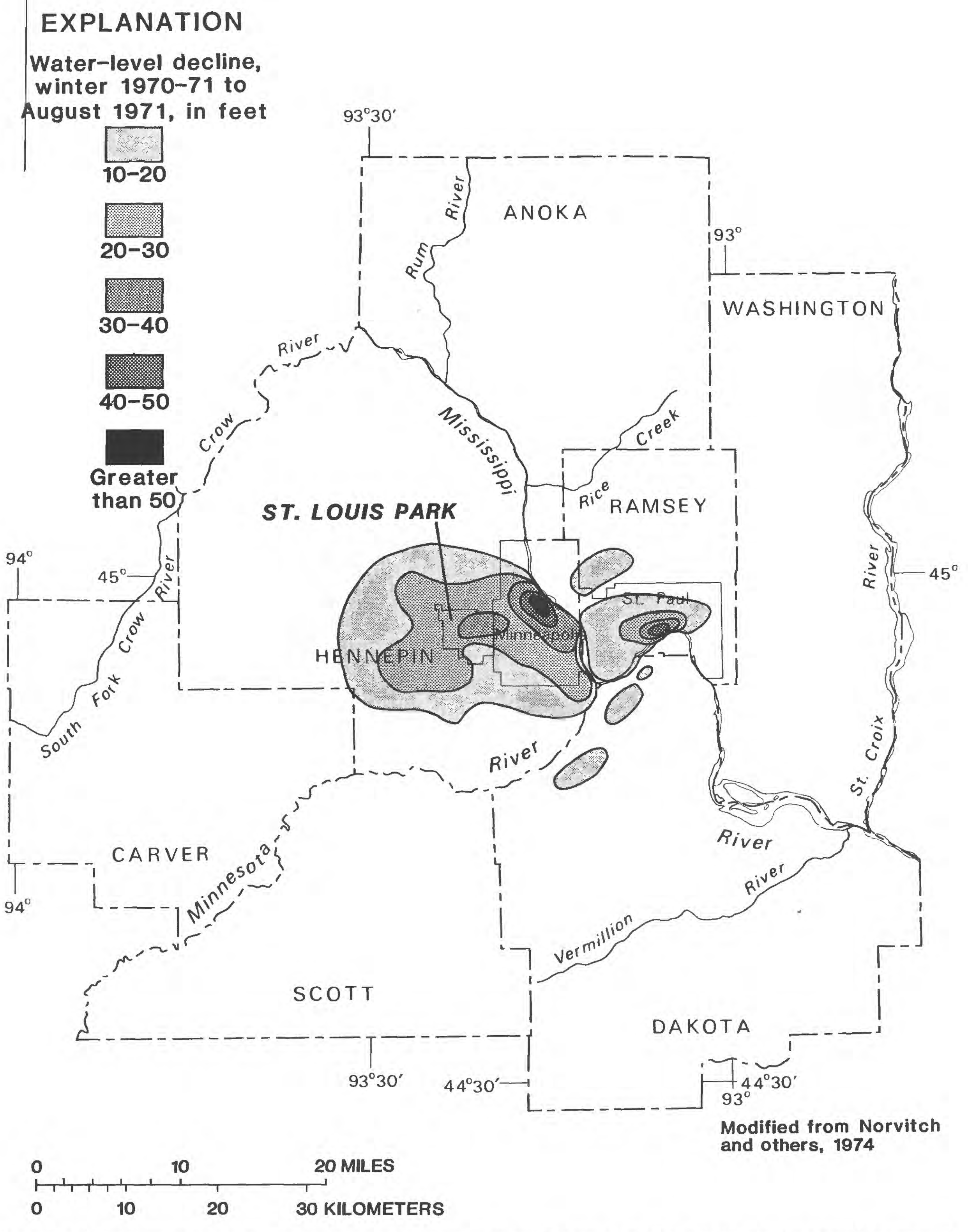


Figure 7. Short-term seasonal potentiometric-surface decline in the Prairie du Chien-Jordan aquifer caused by ground-water withdrawal, winter 1970–71 to August 1971

are beyond the scope of this study. In this report, references to flow through multiaquifer wells are to flow inside the casing or in an uncased part of the well bore.

Uncased or ungrouted wells that penetrate more than one aquifer provide avenues for the transport of contaminants. The effect of an individual well depends on the rate of flow down the well bore, local and regional ground-water flow patterns, and contaminant concentration. The rate of flow down the well bore depends primarily on the thicknesses and hydraulic conductivities of the aquifers, the head differences between them, and well construction and condition. For a given well of known original construction, the most difficult factor to estimate is present well condition because multiaquifer wells tend to be unstable and casings deteriorate with time. A phenomenon known as "skin effect" occurs when the pores of the aquifer into which water flows are clogged by sediment, biologic films, or chemical encrustation.

Well W23 ("Hinckley" well on the site; table 1, fig. 3, pl. 1) is a multiaquifer well that is particularly important because the well bore is partly filled with coal tar. When drilled in 1917, the well was 909 feet deep and may have permitted the flow of water out of the Prairie du Chien-Jordan aquifer and into the underlying Ironton-Galesville and Mount Simon-Hinckley aquifers. By early 1977, however, water was moving into the Prairie du Chien-Jordan aquifer from the overlying St. Peter aquifer. A downhole television camera survey and geophysical logging in 1978 showed that the well was 595 feet deep and visibly contaminated and that water was entering the well bore through holes in the casing adjacent to the St. Peter Sandstone (fig. 13). About 150 gallons per minute of water was leaking into the well bore, flowing downward, and entering the Prairie du Chien through another hole in the casing.

The estimate of flow was made from independent measurements through use of the television camera and an impeller-type velocity probe that was approximately calibrated in the hole. Methods of flow measurement in well bores are discussed in Patten and Bennett (1962).

Periodic water-level measurements and a second television survey confirmed that the flow was sustained. In July 1979, the city of St. Louis Park had a temporary packer installed in the well to stop the flow. The well was equipped in 1979 with digital recorders to obtain water levels above the packer (St. Peter aquifer) and below the packer (Prairie du Chien-Jordan aquifer and St. Lawrence-Franconia confining bed).

A multiaquifer well changes the direction of ground-water flow in the vicinity of the well. A cone of depression is created in the aquifer of higher head by withdrawal of water from it; conversely, a cone of impression is created in the aquifer of lower head by the flow of water into it (fig. 14). The shape and area of influence of these cones depend on the rate of flow; aquifer characteristics; head differences; stresses, such as pumping wells and flow through other multiaquifer wells; and hydrogeologic boundaries, such as drift-filled bedrock valleys. For instance, figure 15 indicates a gradient in the St. Peter aquifer toward well W23. This may be due both to a cone of depression in this aquifer caused by flow out of the aquifer through the well and to increased recharge to the St. Peter aquifer from the drift-filled valley near well W24.

The water level in a multiaquifer well reflects the cone of impression or depression in each aquifer to which it is hydraulically connected. If well loss, skin effects, and head differences needed for flow to occur within the well bore are negligible, the water-level altitude in a multiaquifer well is equal to the potentiometric head in each aquifer to which it is open.

A cone of impression caused at least in part by well W23 was formed in the Prairie du Chien-Jordan aquifer at the site. Static water levels measured by the USGS on August 23, 1977, at five St. Louis Park municipal wells (SLP5, SLP8, SLP9, SLP10, and SLP Old 1) completed in the Prairie du Chien-Jordan aquifer are shown in plate 1. The water level in well W23 is higher than the water levels measured in surrounding wells constructed in the Prairie du Chien-Jordan aquifer, indicating that a cone of impression had been created by water moving through the well bore of well W23 from the overlying St. Peter aquifer. The water level in well W23 shown on plate 1 was not measured in August 1977, but an estimate was made for this date from 18 measurements since April 1978 and a water level in the spring of 1977 inferred from Barr Engineering Co. (1977, p. III-34).

The data indicate that on August 23, 1977, water in the Prairie du Chien-Jordan aquifer was moving away from W23 in all directions but that the hydraulic gradient was steepest between W23 and the municipal well field to the north. The gradient to the north has decreased since this time, in apparent response to the interruption in use of four municipal wells in the Prairie du Chien-Jordan aquifer (figs. 9, 10; pl. 1). These wells were found to be contaminated in 1978 (Minnesota Department of Health, 1978).

Four other wells that were causing water to flow into the Prairie du Chien-Jordan aquifer from overlying aquifers (Wolfe Lake well W69; Hedberg-Friedheim, W114; Burdick Grain, W47; Prestolite, W50) have been located. These wells were sampled by the Minnesota Department of Health. Each has been permanently sealed with grout. Water pumped from wells W114 and W50 had a distinct chemical odor at the time of sampling. Chemical analysis of water pumped from well W47 did not indicate significant quantities of contaminants.

The permeability of the upper part of the Prairie du Chien-Jordan aquifer (Prairie du Chien Group) is due to solution channels and open joints (pl. 2). These openings are large compared to the intergranular pores of sandstone and are less susceptible to clogging with sediment and to other skin effects. The ability of the Prairie du Chien Group to accept large quantities of sediment entrained in the downward flow was observed in well W69. By means of downhole television, sand from the St. Peter

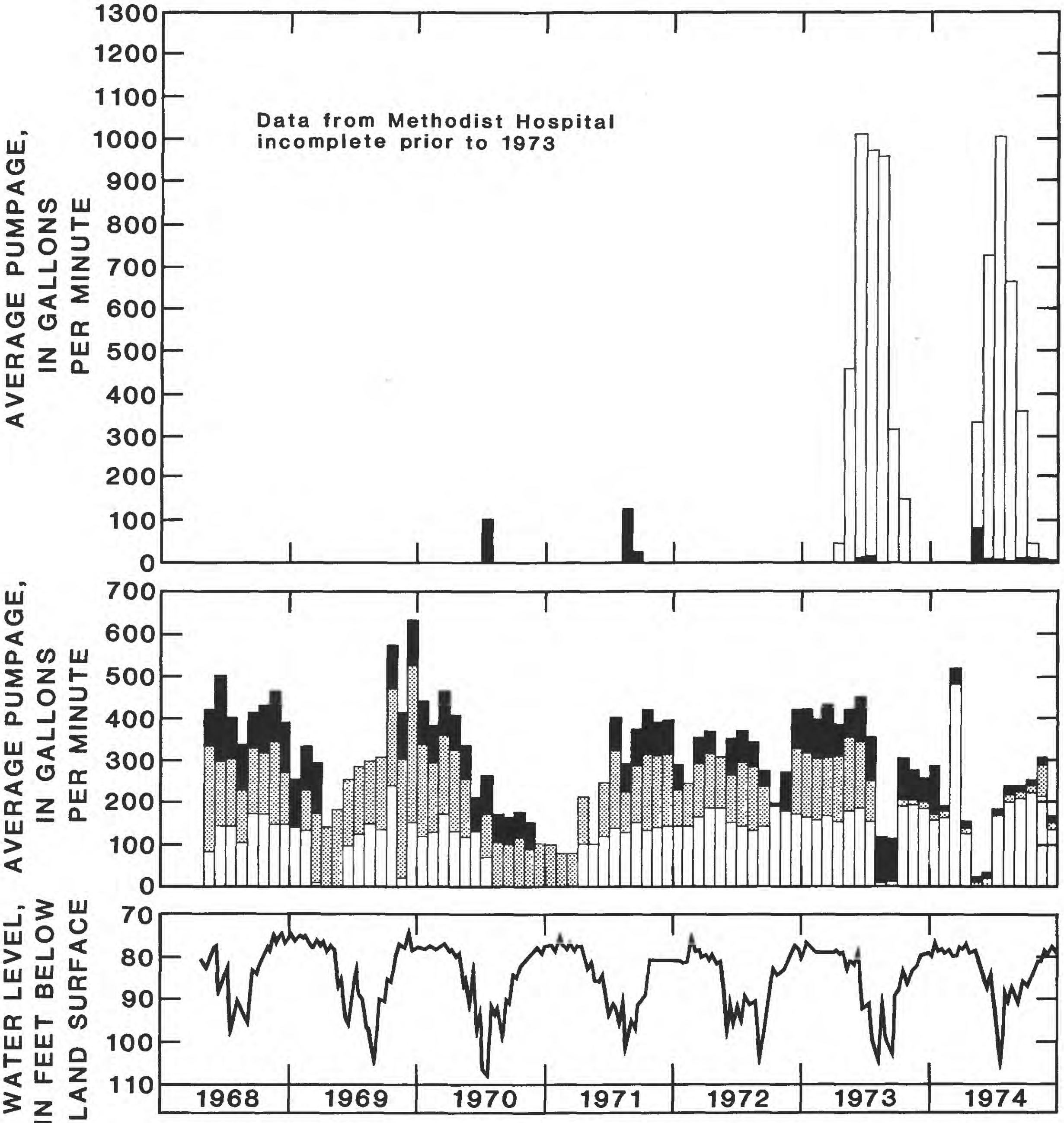
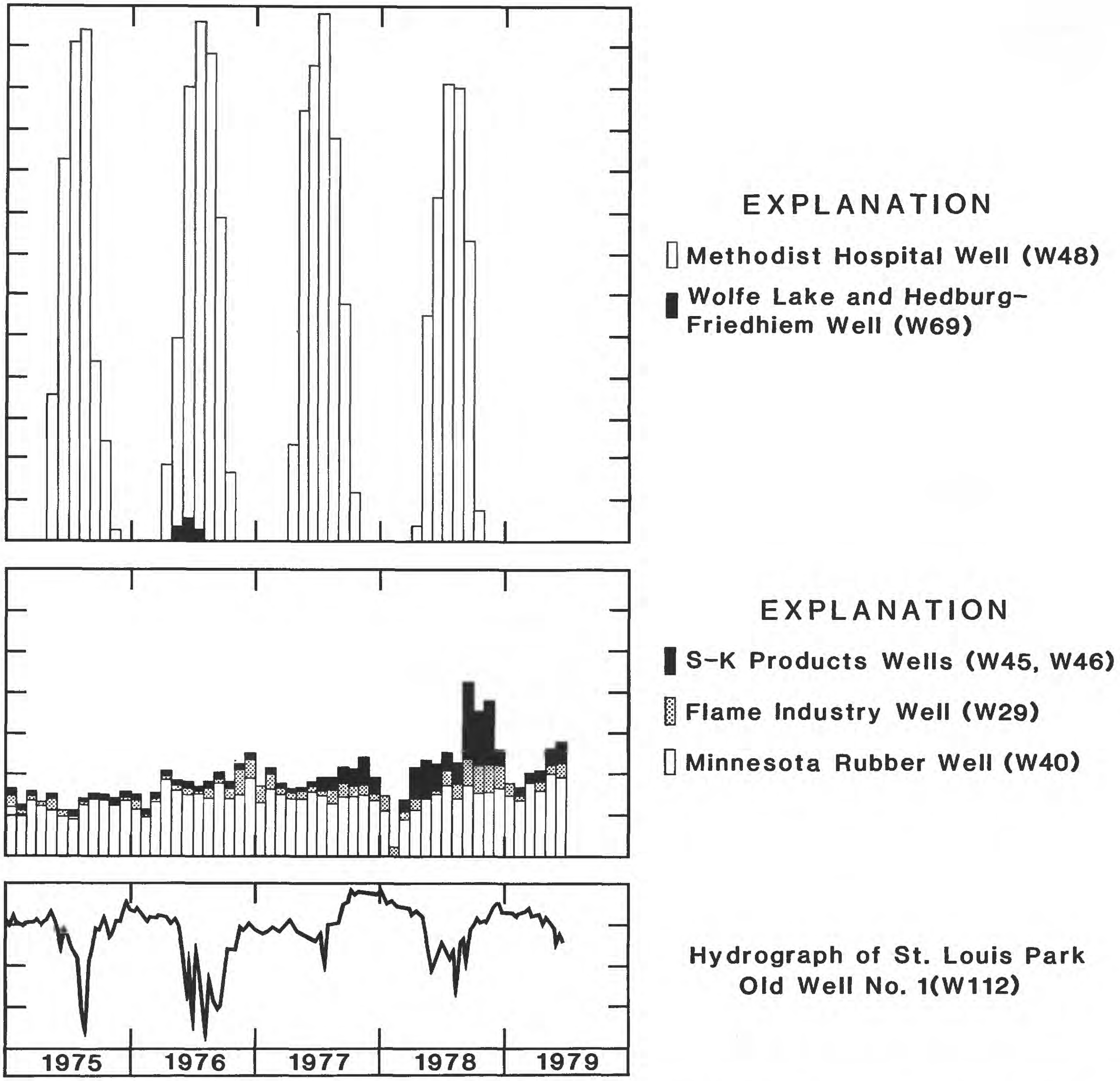


Figure 8. Relationship between water level in St. Louis Park Old Well No. 1 and pumpage from the five nearest pumping wells in the Prairie du Chien-Jordan aquifer, St. Louis Park

aquifer could be seen entering through a hole in the casing, flowing downward with the water, and moving out of the well bore through a solution channel at the bottom of the well. The well had been filled, apparently with sand from the St. Peter aquifer, to the level of the solution channel.

The head difference between the Platteville and St. Peter aquifers is generally about 20 feet. No flow was detected from the Platteville into the St. Peter aquifer in uncased wells that were geophysically logged or evaluated by downhole television camera. The lack of measurable flow is attributed to skin effects. In general, unused Platteville-St. Peter multiaquifer wells do not significantly change the potentiometric surfaces of the Platteville and St. Peter aquifers. However, the open well bore between the Platteville and St. Peter aquifers may provide a pathway for significant transport of contaminants. For instance, diluting contaminated water from the Platteville in the vicinity of well W33 (Strand Manufacturing) by a factor of 1,000 will still produce detectably contaminated water in the St. Peter aquifer. Reconstruction of well W33 was completed on July 5, 1979, by the Min-

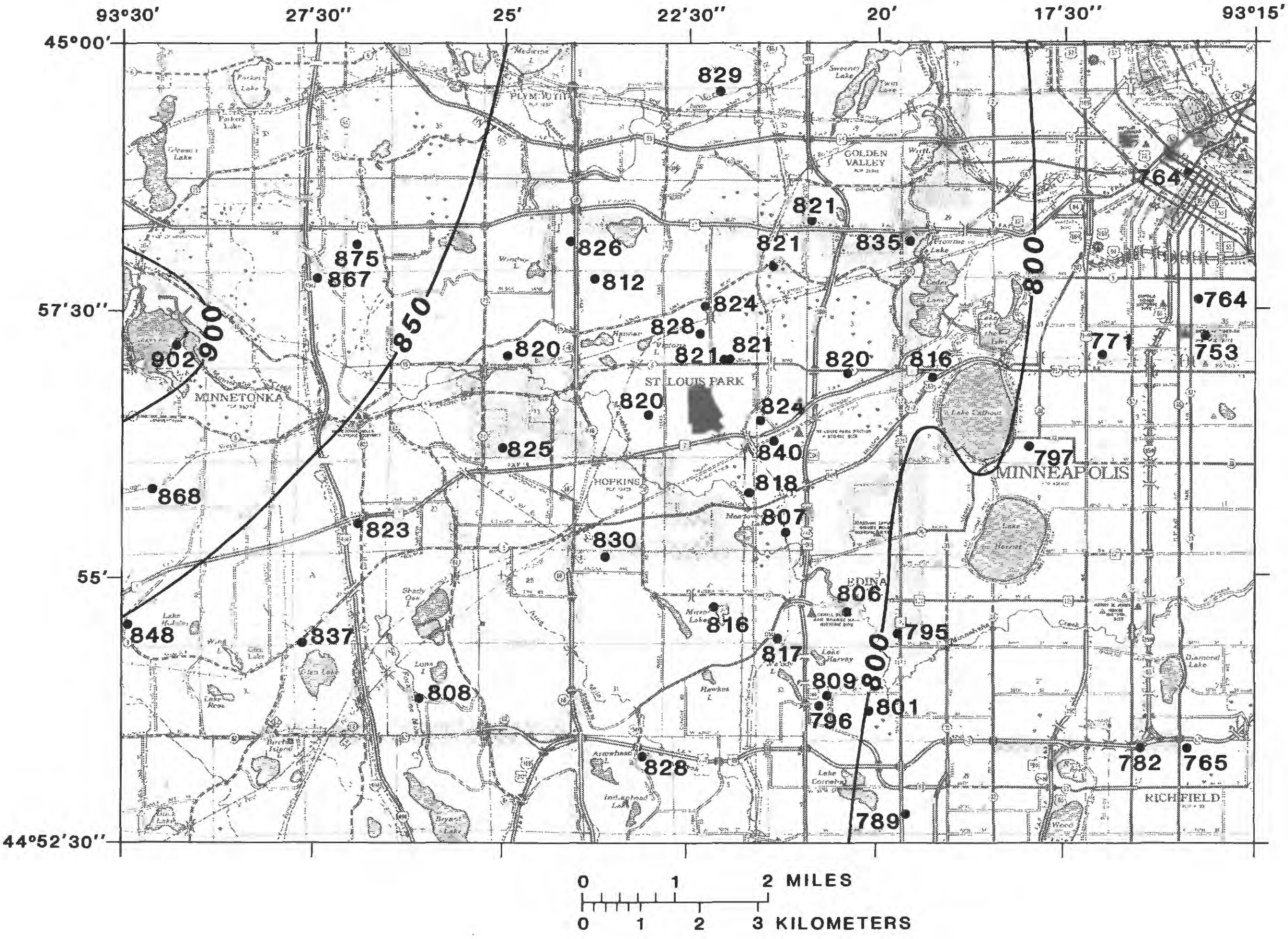


nesota Department of Health to prevent such leakage. More observation wells will be needed to clearly evaluate whether or not Platteville-St. Peter multiaquifer wells have had a measurable effect on the quality of water in the St. Peter aquifer.

Drift-Platteville Aquifer System

The upper surface of the ground-water system is the water table. The generalized configuration of the water table is shown in figure 16. The water table ranges from an altitude of 900 feet near Minnehaha Creek west of the site to 850 feet at Lake Calhoun near the east. This map (fig. 16) is in general agreement with regional maps prepared by Larson-Higdem and others (1975).

As far as is known, naturally occurring surface-water bodies in the area are surface expressions of the water table. They may also form hydrogeologic boundaries in the drift-Platteville aquifer system by controlling the altitude of the water table. The quantity of ground water entering or leaving a stream sometimes can be estimated by measuring stream discharge. Low-flow discharge measurements on November 3, 1978, at four locations on Minnehaha Creek between Cambridge Street and Louisiana Avenue indicated discharges of 10.9, 11.7, 14.1, and 12.8 cubic feet per second. Although channels are well defined at these sites, some of



EXPLANATION

771 • Location of well and static water level, in feet above sea level

—850— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour interval 50 feet. Datum is sea level

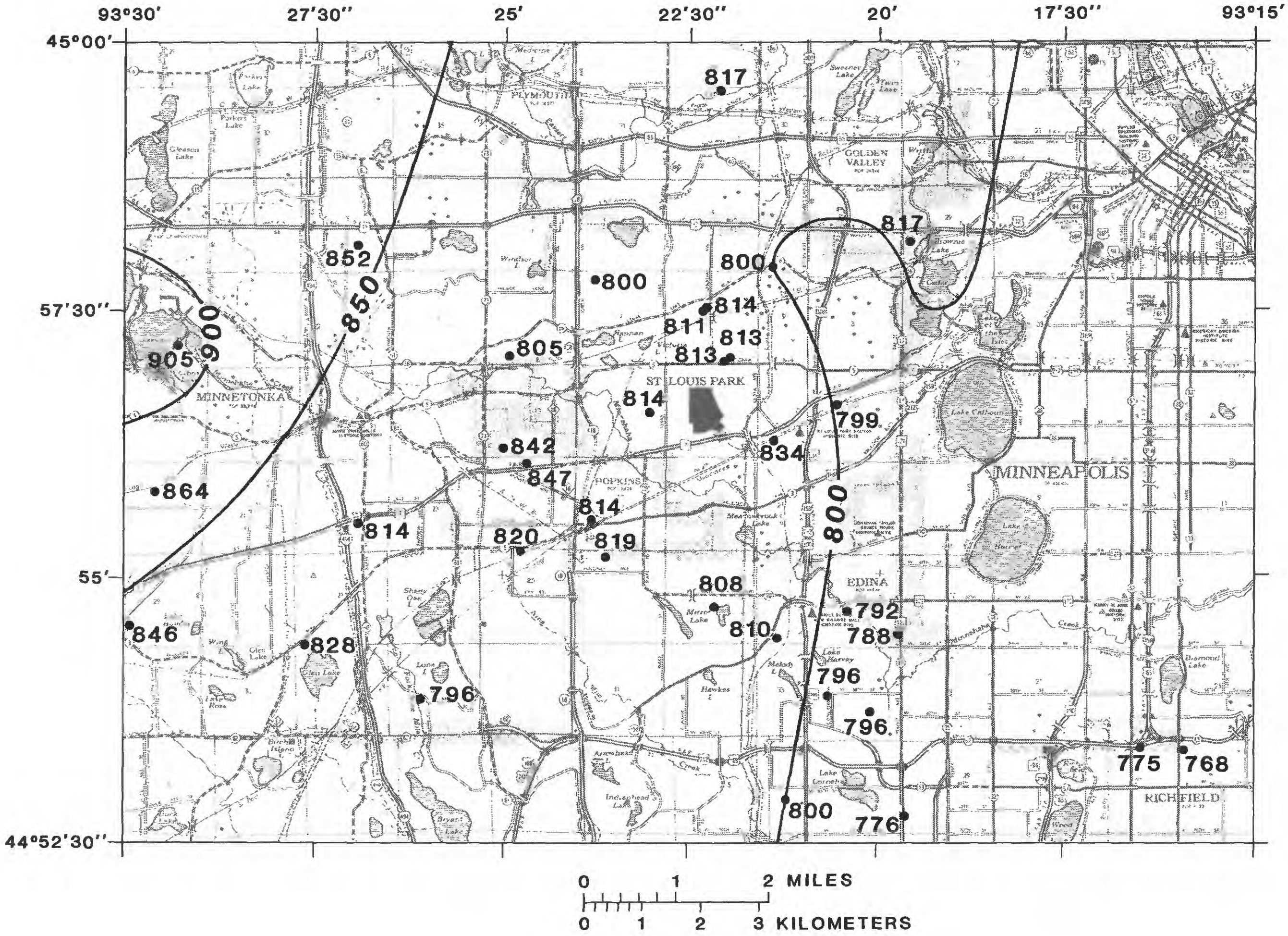
Site of former plant

Figure 9. Generalized potentiometric surface of the Prairie du Chien-Jordan aquifer, January 30–31, 1979

the observed differences may be due to measurement error rather than net gains or losses of the stream. Additional analysis of data collected to date is needed to evaluate the extent to which surface-water bodies are hydrogeologic boundaries.

The detailed stratigraphy of the drift is complex, but three areally persistent units of hydrogeologic significance have been identified (Barr Engineering Co., 1976, 1977): (1) the Middle Drift aquifer of glacial sand and gravel; (2) an overlying confining bed of lake deposits and till; and (3) the underlying basal drift complex of till, outwash, valley-fill deposits, and deeply weathered bedrock. A fourth unit, the Upper Drift aquifer, is poorly defined and is not continuous in the study area. These units are shown schematically in sections *A–A'* and *B–B'* (pl. 3).

The geometry of the Middle Drift aquifer is irregular, but its hydraulic continuity has been tentatively established by test drilling and measurements of areal and vertical variations in head (pl. 4). Measurements at



EXPLANATION

775 Location of well and static water level, in feet above sea level

—850— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour interval 50 feet. Datum is sea level

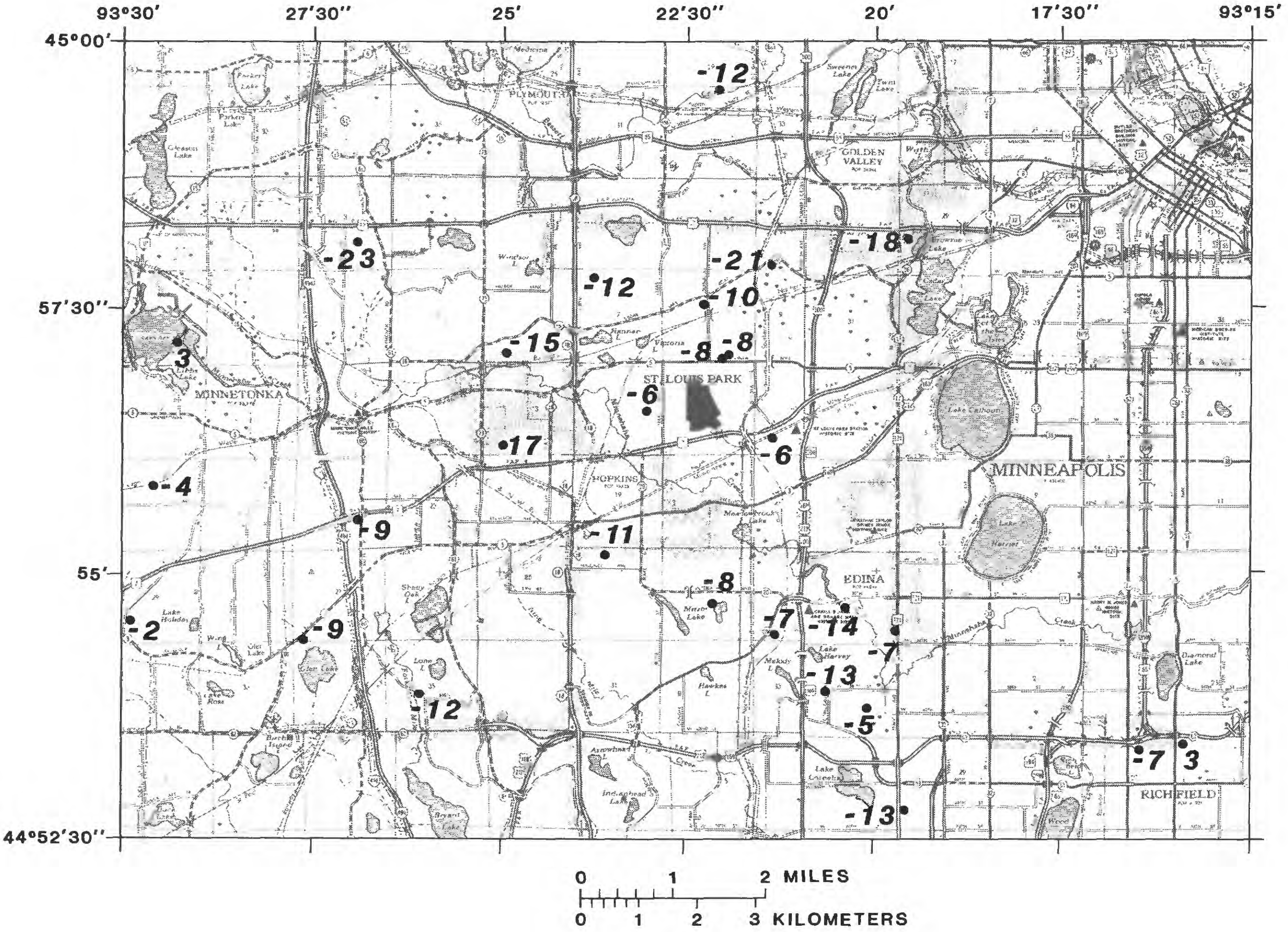
Site of former plant

Figure 10. Generalized potentiometric surface of the Prairie du Chien-Jordan aquifer, June 20-23, 1979

piezometer clusters show that vertical differences in head within the aquifer are generally less than 0.03 foot (pl. 3), indicating that the flow of water is primarily horizontal. The potentiometric surface of the aquifer generally slopes to the east (pl. 4).

The contacts between the Middle Drift aquifer, the overlying confining bed, and the underlying basal drift complex are indistinct in places. For example, observation well W10 has been previously identified as being completed in the Middle Drift aquifer (Barr Engineering Co., 1976, 1977). It is so identified on plates 4 and 6. However, logs of additional wells installed at the same location show the Middle Drift aquifer to be either very silty or absent. On the generalized hydrogeologic section *A-A′* (pl. 3), well W10 is shown to be completed in the upper confining bed because there seem to be significant changes of head with depth within this interval of drift.

The aquifer is vertically recharged through the upper confining bed from infiltration of precipitation and leakage from the Upper Drift aquifer, where present.



EXPLANATION

•-9 Location of well and change in static water level, in feet

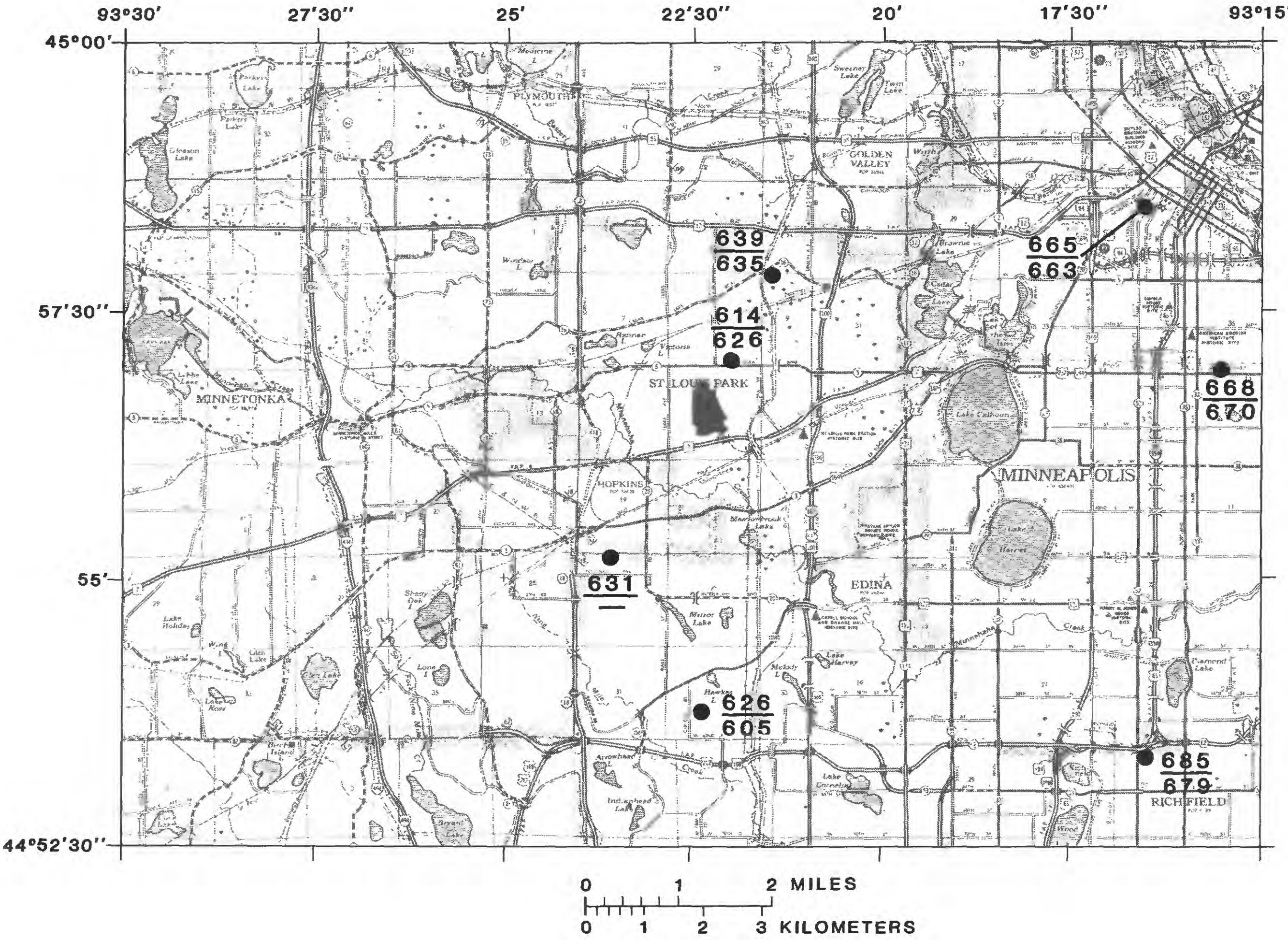
Site of former plant

Figure 11. Change in static water level, January 30–31 to June 20–23, 1979, in wells completed in the Prairie du Chien–Jordan aquifer

Evaluation of water-level measurements suggests that, during the recharge period of spring 1979, a major part of the recharge entered the area from the west and north, recharge being significant and rapid locally at and south of the site. The local recharge resulted in minor, short-term reversals in flow direction, as indicated by the intersection of the hydrographs for wells W2 and W5 (pl. 4).

In the spring of 1979, this local recharge occurred in the area that previously received plant-process water and surface-water runoff from the site. The direction of ground-water flow and contaminant transport may have changed since the plant was in operation (1918–72) owing to changes in the distribution of recharge. Surface water is now (1979) discharged to Minnehaha Creek through storm sewers.

Water from the aquifer discharges laterally to the east and southeast and vertically into the basal drift complex. Sporadic dewatering of the drift at a construction



EXPLANATION

● 626/605 — Location of well, with altitudes in feet above sea level. Upper number denotes water level measured January 30–31, 1979. Lower number denotes water level measured June 20–22, 1979

■ Site of former plant

Figure 12. Water levels in the Mount Simon-Hinckley aquifer, January 30–31 and June 20–23, 1979

site near Louisiana Avenue and Oxford Street has locally affected water levels, but the rate and timing of pumpage is poorly known. No other current water withdrawals from the drift have been identified.

Because vertical head varies appreciably with depth in the basal drift complex, meaningful areal maps of water-level altitudes in this unit cannot be drawn. However, measurements of water levels in the unit can be used to construct isopotential lines to describe the vertical and horizontal direction of flow, as shown in the hydrogeologic sections (pl. 3). Head differences between the top and bottom of the basal drift complex indicate that vertical leakage out of the Middle Drift aquifer through the basal drift complex and into the Platteville aquifer or valley fill may be appreciably greater in the vicinity of the buried valleys. Winter and Pfannkuch (1976) discussed the hydrogeologic significance of drift-filled bedrock valleys in the Minneapolis–St. Paul metropolitan area.

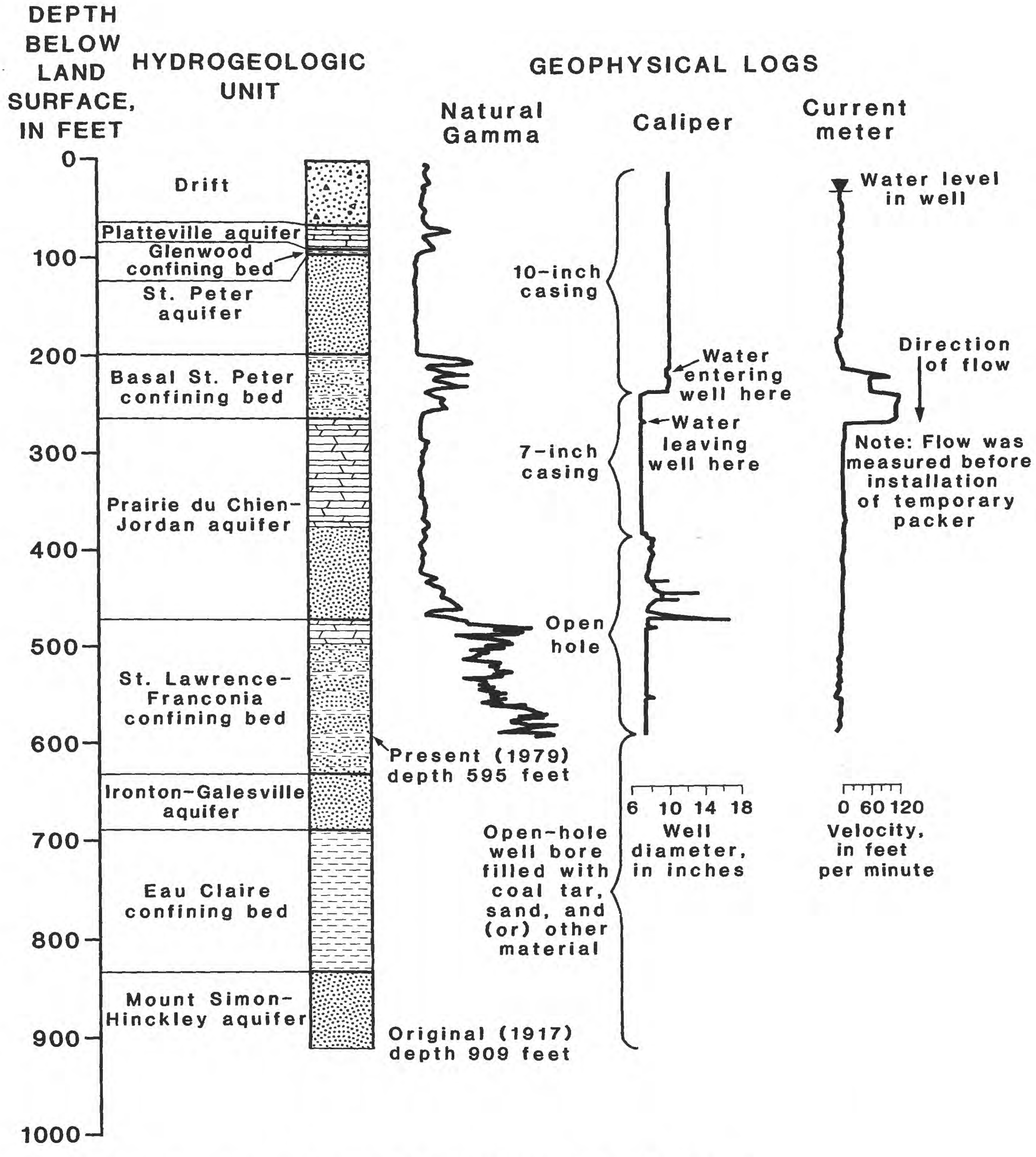


Figure 13. Hydrogeologic and geophysical logs of well W23 ("Hinckley" well on the site)

They suggested that many of these valleys may be filled with coarse-grained deposits and may provide preferential pathways for movement of contaminants.

The Platteville aquifer is nearly flat-lying, composed of limestone and dolomite, and underlain by the Glenwood confining bed. Water-level altitudes in Platteville observation wells are shown on plate 5. The water levels are not contoured because the effects on the potentiometric surface of buried bedrock valleys, multiaquifer wells, and possible vertical head differences within the aquifer are not yet sufficiently well known. The regional gradient of the potentiometric surface of the Platteville aquifer, however, is similar to that of the Middle Drift aquifer and to the configuration of the water table.

Contours of the potentiometric surface locally may

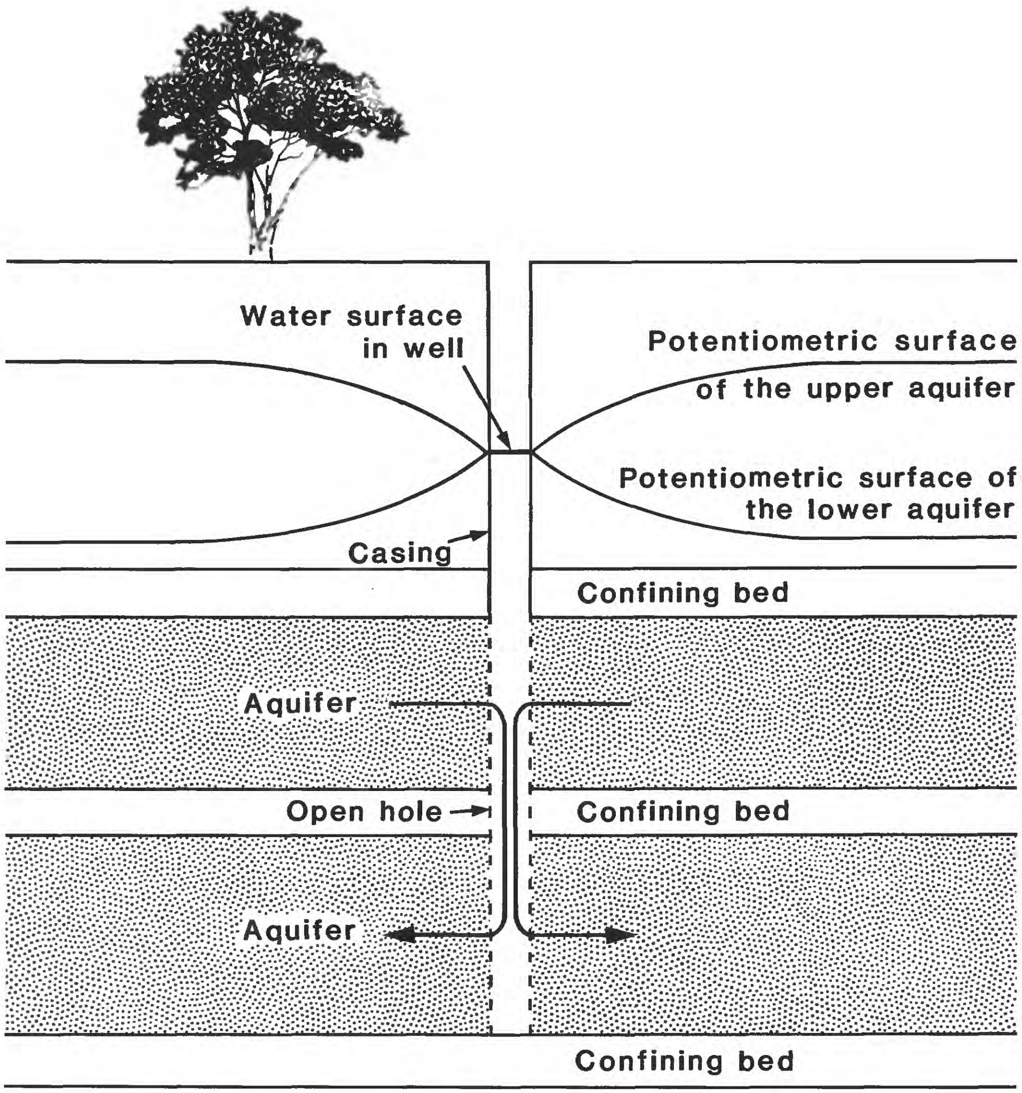


Figure 14. Schematic hydrologic section showing a well connecting two confined aquifers, flow through the well bore, and the effects of this flow on the potentiometric surfaces of the two aquifers

parallel bedrock valleys, where the Platteville and Glenwood have been removed by erosion, and water may move laterally out of the Platteville and into the valley-fill deposits contained in these bedrock valleys. This is the tentative interpretation presented on the hydrologic sections shown in plate 3. The vertical head difference between the Middle Drift and Platteville aquifers ranges from less than 0.1 foot at the observation wells farthest from the buried valleys (W2, W100) to more than 10 feet near the possible valley at the intersection of 36th Street and Wooddale Avenue (W117, P18, W101).

The hydraulic characteristics of solution-channel carbonate rocks, such as the Platteville aquifer, may differ widely from place to place. Liesch (1973) has documented large local differences in the transmissivity and storage coefficient of the Platteville aquifer near Minnehaha Creek in Minneapolis. However, short-term pumping tests (pl. 5) indicate that the hydraulic characteristics of the Platteville aquifer, particularly transmissivity, are reasonably uniform in the St. Louis Park area. The time-drawdown curve for well W101 seems anomalous and may reflect its proximity to the drift-filled valley. Well W101 is completed in the lower part of the Platteville aquifer, and the large head differences between this and adjacent Platteville wells may indicate significant vertical gradients within the aquifer. Most of this head difference is tentatively attributed to local downward flow toward the valley (pl. 3); here, and elsewhere, withdrawal through multiaquifer wells may cause local cones of depresssion.

At the well cluster near Lake and Monitor Streets (W9, W14, W18, P8, P14, P15; pl. 3), the head difference between the Platteville and St. Peter aquifers is about 20 feet. This head difference causes water to flow

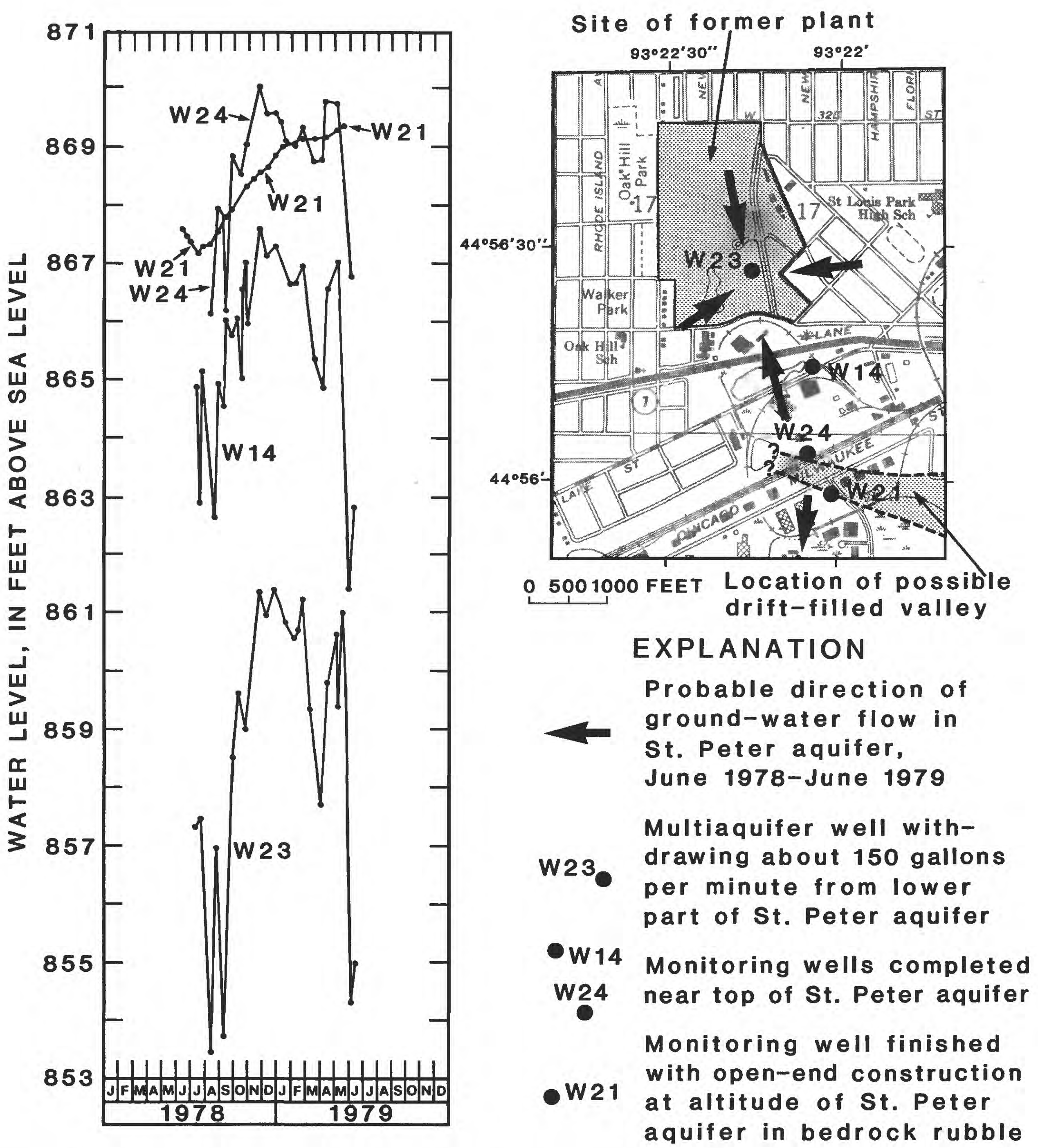
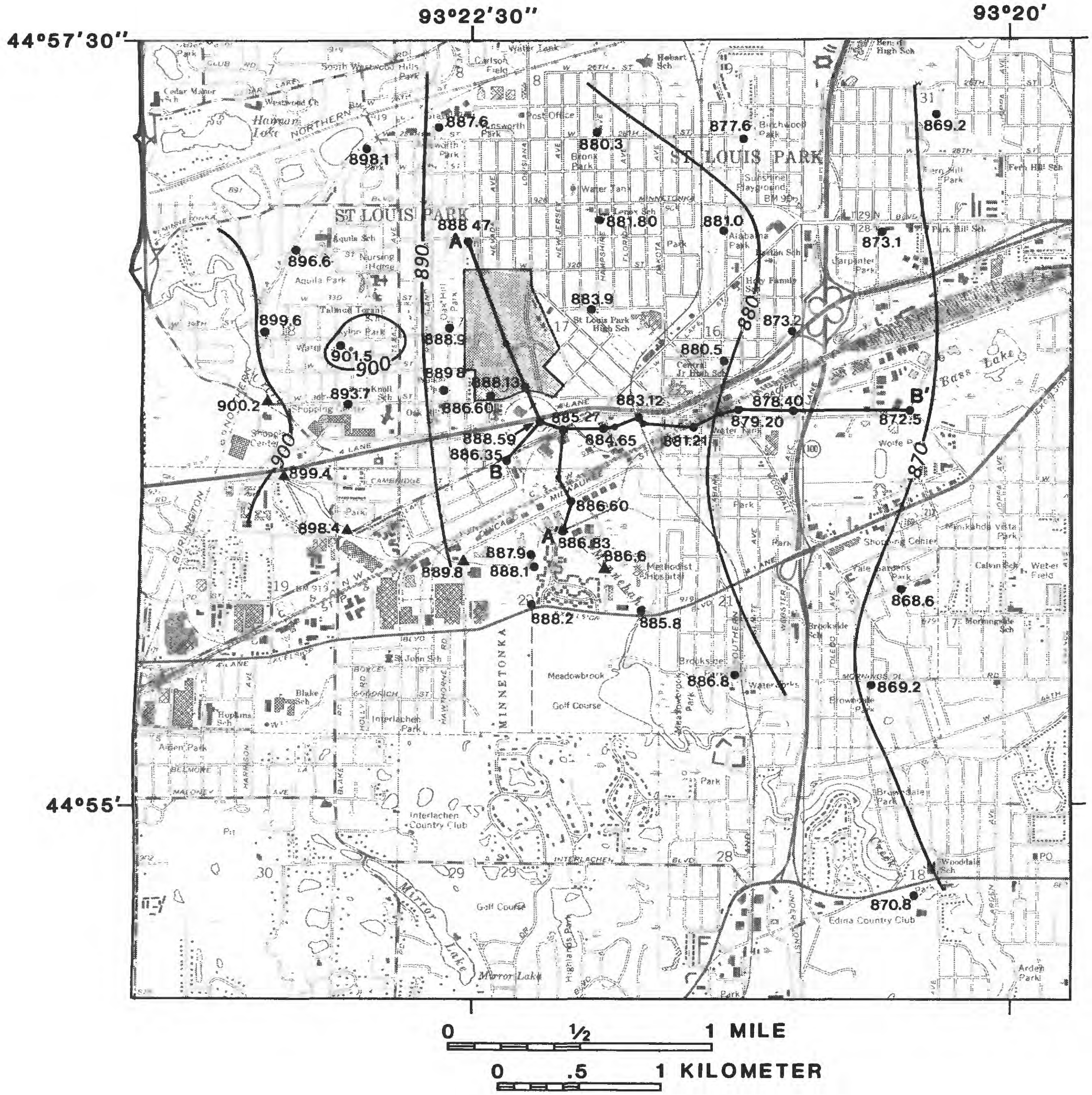


Figure 15. Relationship between water levels in multiaquifer well W23 and wells W24 and W14 completed in the St. Peter aquifer

vertically downward through the Glenwood confining bed. The water level in the Platteville aquifer at well W101 near the bedrock valley is very nearly that of the St. Peter aquifer at nearby well W111.

Five wells in the Platteville aquifer are equipped with water-level recorders (W18, W19, W20, W22, W101); the rate and magnitude of water-level fluctuations is greatest in well W101. The hydrographs shown on plate 5 were prepared from measurements made at approximately 2-week intervals and cannot show rapid changes. The water-level fluctuations in well W101 may be due to changes in flow rates from the Platteville into the buried valleys and through multiaquifer wells owing to variations in pumping from underlying bedrock aquifers. Preliminary digital-computer simulations indicate that the drift–Platteville aquifer system may be



EXPLANATION

Water-level altitude, in feet above sea level. Number of significant figures indicates reliability of measuring point altitude. (See text)

886.35● **Water-table piezometer and water-level altitude**

898.4▲ **Surface-water station and water-level altitude**

—880— **WATER-TABLE CONTOUR--Shows altitude of water table. Contour interval 10 feet. Datum is sea level**

B●——●B' **Line of section (plate 3)**

▩ **Site of former plant**

Figure 16. Generalized configuration of the water table, June 5, 1979

sensitive to such pumping stresses, depending largely on the location and effect of multiaquifer wells and the vertical hydraulic conductivity of the valley-fill material and the confining beds at the base of the St. Peter aquifer.

CHEMICAL QUALITY

Status of Data Collection and Methods Used

Organic contaminants are present in the ground-water system in three forms: the aqueous phase, the hydrocarbon fluid phase, and the hydrocarbon solid phase (see Glossary for definitions). The aqueous phase is the most mobile and the most easily sampled. Initial efforts to evaluate the areal and vertical extent of contamination focused on sampling this phase.

Fluid samples for chemical analysis were collected in March and April 1979 from 25 wells in the drift and the Platteville and St. Peter aquifers by techniques outlined by Brown and others (1970) and Wood (1976). The general procedure was as follows: The well was pumped at 10 to 15 gallons per minute by submersible pump, and the drawdown in the well was measured to evaluate well performance. Samples were taken and pH measured after the specific conductance and temperature of the water stabilized, usually within half an hour. Appropriate preservatives were added and the samples were chilled immediately and delivered the same day to the Minnesota Department of Health for analysis. Alkalinity was determined in the field, by potentiometric titration, and in the laboratory. Samples for dissolved inorganic constituents were filtered in the field through a 0.45-micrometer cellulose filter in-line with the pump discharge. Samples for dissolved and suspended organic carbon (see Glossary for definitions) were filtered in the field through a 0.45-micrometer silver filter and were analyzed by the USGS.

Data from these analyses are presented in table 4; they have also been entered into WATSTORE. Data from WATSTORE can be obtained through STORET.

The Minnesota Department of Health prepared sample bottles, extracted samples, and chemically analyzed individual organic compounds. Samples were collected in 1-gallon amber glass bottles that had been cleaned and oven-heated to remove possible contaminants. The day after sampling, organic compounds were separated from the sample by extraction with cyclohexane. Ten of the extracts were analyzed in the first year of the study by high-performance liquid chromatography for polynuclear aromatic hydrocarbon (PAH) compounds. Data for these samples are shown on plate 5. WATSTORE and STORET parameter numbers have not been assigned to these constituents, and the values have not been entered into these data bases.

In addition to the fluid samples, four core samples of drift material from a boring at the site of well W9 were chemically analyzed by the USGS in an attempt to identify as many organic compounds as possible. Each sample was split lengthwise, and the subsamples were extracted and separated into acid, neutral, and basic fractions by two different methods. The extracts were analyzed by flame-ionization gas chromatography confirmed with mass spectrometry. No contaminants were detected in the acid fraction. However, phthalate compounds were found in the basic fraction.

Nearly all the organic compounds detected were in the neutral fraction. Analysis of one core indicated that naphthalene constituted 90 percent of the contaminants detected. The Minnesota Department of Health, using high-performance liquid chromatography, analyzed fluid pumped from wells; naphthalene concentration was not measured, but the analyses identified more individual compounds than were found in the cores. Subsequent gas-chromatography analysis of fluid from well W9 by the Minnesota Department of Health has confirmed the high concentration of naphthalene relative to other compounds identified.

Efforts to isolate, identify, and quantify all major coal-tar derivatives are continuing. To date, the sum of the measured concentration of individual constituents is generally less than 10 percent of contaminant concentrations measured as TOC (total organic carbon), DOC (dissolved organic carbon), and SOC (suspended organic carbon). The USGS will continue complete characterization of the contaminants in fluid samples, rather than in core samples, to separate the problem of compound isolation, identification, and quantification from that of developing adequate techniques to extract contaminants from core samples and to provide greater contaminant mass for analysis.

As part of the project, laboratory column experiments are being made by H. O. Pfannkuch, Department of Geology and Geophysics, University of Minnesota, to evaluate the mobility of selected organic compounds in drift materials. Separate glass columns were packed with a control medium ("Ottawa sand"), whose physical properties are well known, and with drift materials. The mineralogy of the column-packing materials was determined by X-ray diffraction and point-counting. The particle-size distribution was measured and used to estimate effective grain area. The hydraulic conductivity and porosity of the column packs were determined. The columns were filled and air bubbles removed with degassed, distilled water, and the columns were sterilized. Water was circulated through the column at a known rate, a tracer injected, and the effluent concentration curve determined.

Dispersion characteristics of the columns have been determined by using an inorganic tracer (chloride) to

Table 4. Chemical analyses of fluid pumped from 25 wells completed in the drift and the Platteville and St. Peter aquifers, March–April 1979

[Township and range: First three digits indicate township north of the baseline; next two digits indicate range north of the principal meridian; last two digits indicate section in which well is located. Letters indicate well location in section: first letter denotes the 160-acre tract; second letter denotes the 40-acre tract; third letter denotes the 10-acre tract. Letters are assigned counterclockwise beginning with the northeast quarter. Consecutive numbers beginning with 1 are added as suffixes to distinguish wells within a given 10-acre tract. *, total. Site identification (lat and long): First six digits are latitude of well location in degrees, minutes, and seconds; next seven digits are longitude in degrees, minutes, and seconds; last two digits are arbitrarily assigned to distinguish wells within a given 1-second by 1-second area.]

USGS project well number	Site identification (lat and long)	Township and range	Date of sample	Aquifer	Depth of well, total (ft)	Depth to top of water-bearing zone (ft)	Depth to bottom of water-bearing zone (ft)	Flow rate, instantaneous	Pumping period prior to sampling (min)
W2	445651093222901	1172117BAC1	79-03-29	Middle Drift	36	32	36	10	15
W5	445622093221901	1172117CAD2	79-03-29	do	26	21	26	10	20
W6	445620093222601	1172117CBD1	79-04-03	do	26	22	26	10	30
W8	445607093222101	1172117CDD1	79-04-10	do	31	26	31	15	35
W9	445614093220301	1172117DCA1	79-03-27	do	25	20	25	10	20
W10	445559093220201	1172120ABD1	79-04-05	do	29	25	29	.50	5
W11	445614093215301	1172117DDB2	79-04-03	do	23	19	23	10	20
W12	445613093214001	1172117DDA1	79-04-10	do	47	42	47	3.3	30
W13	445615093220901	1172117DCB1	79-03-29	do	50	45	50	10	22
W116	445634093205903	1172116DCB3	79-04-17	do	67	63	67	15	20
W117	445617093211502	1172116CDB3	79-04-17	do	72	68	72	15	30
W16	445559093220202	1172120ABD2	79-04-05	Basal drift complex	64	61	64	2.0	55
W17	445614093215302	1172117DDB3	79-04-03	do	69	66	69	10	20
W1	445654093215501	1172117BAC1	79-03-29	Platteville	107	102	107	15	20
W18	445614093220303	1172117DCA3	79-03-27	do	78	68	78	10	40
W19	445607093222102	1172117CDD2	79-03-22	do	81	81	81	10	30
W20	445605093215101	1172120AAB1	79-03-22	do	80	70	80	10	30
W22	445630093222101	1172117CAA1	79-03-27	do	80	71	80	10	30
W26	445619093221801	1172117CDA1	79-04-17	do	90	14	90	9.1	30
W100	445651093222902	1172117BCD2	79-03-20	do	88	73	88	9.7	--
W101	445617093211501	1172116CDB2	79-03-20	do	106	103	106	8.8	30
			79-04-17	do	106	103	106	15	15
W115	445554093220301	1172120ABD1	79-03-20	do	78	66	78	10	30
			79-04-17		78	66	78	20	10
W14	445613093220302	1172117DCA2	79-04-12	St. Peter	95	90	95	15	20
W24	445604093220501	1172120ABB1	79-04-12	do	90	87	90	2.5	25

USGS project well number	Date of sample	Temperature of water (deg C)	Specific conductance (micromhos)	pH (units)	Phenolic compounds as phenol (μg/L)	Carbon, organic total (mg/L as C)	Carbon, organic dissolved (mg/L as C) (by MDH)	Carbon, organic dissolved (mg/L as C) (by USGS)	Carbon, organic suspended (mg/L as C)
W2	79-03-29	10.5	1110	7.1	5.0	3.4	--	--	.0
W5	79-03-29	11.0	900	7.3	9.4	5.3	--	5.1	.1
W6	79-04-03	10.0	780	7.4	93	16	5.8	23	6.0
W8	79-04-10	11.8	1100	7.2	9	3.3	2.4	2.4	.1
W9	79-03-27	11.0	1020	7.2	110	16	--	12	.4
W10	79-04-05	12.0	750	6.9	4.8	17	8.5	7.9	2.4
W11	79-04-03	9.0	890	7.1	3.8	8.0	9.2	8.0	.3
W12	79-04-10	12.8	900	7.3	26	14	9.0	6.5	.1
W13	79-03-29	9.5	2000	7.6	27000	6000	--	--	--
W116	79-04-17	11.4	960	7.3	2.6	4.2	2.2	2.5	.1
W117	79-04-17	11.5	1200	7.0	20	4.1	5.2	3.8	.0
W16	79-04-05	10.5	550	7.4	<2.0	8.3	8.5	7.9	.1
W17	79-04-03	10.0	1100	7.4	240	7.7	8.6	8.2	.2
W1	79-03-29	11.0	760	7.5	<2.0	3.2	--	1.7	.0
W18	79-03-27	10.0	1180	7.2	73	7.2	--	5.1	.1
W19	79-03-22	10.8	700	7.5	10	1.9	--	1.0	.0
W20	79-03-22	9.5	990	7.5	34	11	--	8.8	.0
W22	79-03-27	11.0	675	--	<2.0	2.2	--	1.5	.1
W26	79-04-17	10.5	730	7.4	2.2	2.5	2.7	1.7	.0
W100	79-03-20	10.0	730	7.4	<2.0	1.9	--	1.5	.0
W101	79-03-20	11.0	1090	7.2	--	4.4	--	--	--
	79-04-17	11.5	1074	7.2	14	--	--	4.0	.1
W115	79-03-20	11.0	900	7.4	--	4.2	--	--	.0
	79-04-17	11.0	900	7.1	9.0	--	--	5.0	.2
W14	79-04-12	9.5	535	7.5	2.7	--	--	1.0	.1
W24	79-04-12	11.8	960	7.3	13	--	--	6.3	.1

Table 4. Chemical analyses of fluid pumped from 25 wells completed in the drift and the Platteville and St. Peter aquifers, March–April 1979—Continued

USGS project well number	Date of sample	Solids, residue at 105° C dissolved (mg/L)	Solids, volatile, dissolved (mg/L)	Solids, residue at 180° C, dissolved (mg/L)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)
W2 ----------	79-03-29	760	310	620	5.2	5.2	.02	.02	.01
W5 ----------	79-03-29	560	160	560	<.01	<.01	.03	.50	<.01
W6 ----------	79-04-03	540	320	500	<.01	<.01	<.01	.11	<.01
W8 ----------	79-04-10	780	240	660	6.4	6.7	.02	.08	<.01
W9 ----------	79-03-27	620	190	--	<.01	<.01	.18	5.0	<.01
W10 ----------	79-04-05	600	200	580	<.01	<.01	1.7	5.1	<.01
W11 ----------	79-04-03	610	160	610	<.01	<.01	.12	1.2	<.01
W12 ----------	79-04-10	600	110	560	<.01	<.01	.06	.63	<.01
W13 ----------	79-03-29	4500*	1400*	1600	<.40	--	1.2	6.9	.02
W116 ----------	79-04-17	640	140	620	<.40	<.40	.11	.02	<.01
W117 ----------	79-04-17	770	150	740	<.40	<.40	.05	.16	<.01
W16 ----------	79-04-05	410	130	410	<.01	<.01	.05	.38	<.01
W17 ----------	79-04-03	720	200	730	<.01	<.01	.05	.48	<.01
W1 ----------	79-03-29	490	160	440	<.01	<.01	.03	.07	<.01
W18 ----------	79-03-27	710	220	570	<.01	<.01	.03	.46	<.01
W19 ----------	79-03-22	410	150	410	.44	.41	.02	.07	.01
W20 ----------	79-03-22	540	170	570	<.01	<.01	.05	1.1	<.01
W22 ----------	79-03-27	430	150	340	<.01	.06	.03	.06	<.01
W26 ----------	79-04-17	460	140	460	.40	<.40	.04	.06	<.01
W100 ----------	79-03-20	450	170	430	.33	.35	.04	.14	.01
W101 ----------	79-03-20	650	190	670	<.01	<.01	.07	.17	.03
	79-04-17	--	--	--	--	--	--	--	--
W115 ----------	79-03-20	550	160	570	<.01	<.01	.04	.17	<.01
	79-04-17	--	--	--	--	--	--	--	--
W14 ----------	79-04-12	320	68	300	<.01	<.01	.04	--	<.01
W24 ----------	79-04-12	620	110	600	<.01	<.01	.08	--	<.01

USGS project well number	Date of sample	Calcium dissolved (mg/L as $CaCO_3$)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Carbon dioxide dissolved (mg/L as CO_2)	Field alkalinity (mg/L as $CaCO_3$)	Lab alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)
W2 ----------	79-03-29	390	51	19	2.4	57	369	390	450
W5 ----------	79-03-29	270	29	3.9	4.9	26	320	330	390
W6 ----------	79-04-03	250	29	33	3.1	20	287	290	350
W8 ----------	79-04-10	320	44	40	3.2	31	300	370	366
W9 ----------	79-03-27	260	23	73	5.9	52	439	430	535
W10 ----------	79-04-05	320	41	22	2.4	101	431	430	525
W11 ----------	79-04-03	290	27	62	5.1	53	357	340	435
W12 ----------	79-04-10	240	34	49	5.8	26	295	300	360
W13 ----------	79-03-29	140*	18*	370*	5.4*	37	750	720	915
W116 ----------	79-04-17	310	41	36	3.5	30	324	310	395
W117 ----------	79-04-17	370	48	63	4.9	89	455	440	555
W16 ----------	79-04-05	150	19	49	3.7	17	242	260	295
W17 ----------	79-04-03	170	41	76	4.5	33	443	310	540
W1 ----------	79-03-29	270	44	6.5	2.2	21	353	380	430
W18 ----------	79-03-27	300	44	58	5.0	48	406	430	495
W19 ----------	79-03-22	220	36	7.4	2.1	15	279	290	340
W20 ----------	79-03-22	200	39	84	4.9	24	381	400	465
W22 ----------	79-03-27	230	34	4.1	1.8	--	--	350	--
W26 ----------	79-04-17	240	34	17	2.5	20	291	240	355
W100 ----------	79-03-20	240	160	6.5	2.0	.0	303	310	370
W101 ----------	79-03-20	320	180	46	4.5	55	443	500	540
	79-04-17	--	--	--	--	--	--	--	--
W115 ----------	79-03-20	240	140	46	3.1	23	295	250	360
	79-04-17	--	--	--	--	--	--	--	--
W14 ----------	79-04-12	170	29	5.2	1.6	15	275	320	335
W24 ----------	79-04-12	280	31	61	5.9	34	369	420	450

Table 4. Chemical analyses of fluid pumped from 25 wells completed in the drift and the Platteville and St. Peter aquifers, March–April 1979—Continued

USGS project well number	Date of sample	Chloride, dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as SO_4)	Arsenic total (µg/L as As)	Barium, total recoverable (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Cyanide total (mg/L as CN)
W2 ---------	79-03-29	120	50	1.9	99	<.05	.02	.6	.9	.002
W5 ---------	79-03-29	90	28	52	400	<.05	<.01	.7	1.1	.001
W6 ---------	79-04-03	78	29	--	--	--	--	--	--	--
W8 ---------	79-04-10	150	52	--	--	--	--	--	--	--
W9 ---------	79-03-27	100	<5.0	3.6	200	<.05	.18	1.5	2.2	.006
W10 ---------	79-04-05	65	7.2	--	--	--	--	--	--	--
W11 ---------	79-04-03	81	48	--	--	--	--	--	--	--
W12 ---------	79-04-10	83	79	--	--	--	--	--	--	--
W13 ---------	79-03-29	250	52	27	190	<.05	<.01	370	3.7	.021
W116 ---------	79-04-17	110	50	--	--	<.05	--	--	--	--
W117 ---------	79-04-17	160	21	--	--	.09	--	--	--	--
W16 ---------	79-04-05	69	5.0	--	--	--	--	--	--	--
W17 ---------	79-04-03	140	5.0	--	--	--	--	--	--	--
W1 ---------	79-03-29	29	45	3.0	220	<.05	<.01	.7	.5	<.001
W18 ---------	79-03-27	170	5.4	2.8	270	.07	.01	<.5	.3	.004
W19 ---------	79-03-22	33	47	1.1	82	<.05	.02	.6	.8	<.001
W20 ---------	79-03-22	93	10	1.4	230	.06	.01	<.5	.2	.005
W22 ---------	79-03-27	23	6.0	4.8	130	<.05	.03	.6	.5	<.001
W26 ---------	79-04-17	36	59	--	--	<.05	--	--	--	--
W100 ---------	79-03-20	40	43	1.7	96	<.05	.02	<.5	3.1	<.001
W101 ---------	79-03-20	110	15	2.3	310	.10	.02	.9	.3	.002
	79-04-17	--	--	--	--	--	--	--	--	--
W115 ---------	79-03-20	110	43	2.1	130	.08	<.01	<.5	<.2	<.001
	79-04-17	--	--	--	--	--	--	--	--	--
W14 ---------	79-04-12	7.8	34	--	--	--	--	--	--	--
W24 ---------	79-04-12	10	37	--	--	--	--	--	--	--

USGS project well number	Date of sample	Fluoride, dissolved (mg/L as F)	Iron, dissolved (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Mercury, total recoverable (µg/L as Hg)	Selenium, total (µg/L as Se)	Silica, dissolved (mg/L as SiO_2)
W2 ---------	79-03-29	.31	260	900	0.19	330	330	.19	4.3	26
W5 ---------	79-03-29	.20	12000	12000	1.2	1600	1500	<.1	1.0	28
W6 ---------	79-04-03	.74	2800	4700	--	1900	1600	--	--	16
W8 ---------	79-04-10	<.1	--	--	--	--	--	.13	--	23
W9 ---------	79-03-27	.41	2900	7900	3.6	430	390	<.1	1.6	23
W10 ---------	79-04-05	.16	6000	37000	--	3100	680	--	--	33
W11 ---------	79-04-03	.43	980	1400	--	430	510	--	--	21
W12 ---------	79-04-10	.39	--	--	--	--	--	<.1	--	23
W13 ---------	79-03-29	0.5*	--	2000	4.3	160	--	<.1	<5.0	33
W116 ---------	79-04-17	.10	3200	3700	--	270	270	--	--	19
W117 ---------	79-04-17	<.1	8000	8200	--	630	640	--	--	22
W16 ---------	79-04-05	.21	4000	4900	--	340	310	--	--	20
W17 ---------	79-04-03	.15	6100	6900	--	270	240	--	--	27
W1 ---------	79-03-29	.33	560	580	.19	170	190	<.1	5.1	23
W18 ---------	79-03-27	.43	2200	2200	.18	330	310	<.1	2.7	25
W19 ---------	79-03-22	.17	640	980	.51	120	110	<.1	4.6	18
W20 ---------	79-03-22	.17	1300	1400	.21	120	120	.38	2.2	24
W22 ---------	79-03-27	.26	890	1600	.53	280	250	<.1	1.2	24
W26 ---------	79-04-17	.13	500	750	--	190	180	--	--	19
W100 ---------	79-03-20	.34	680	750	1.3	130	130	<.1	4.7	18
W101 ---------	79-03-20	.17	5500	5800	.37	300	280	.33	15	19
	79-04-17	--	--	--	--	--	--	--	--	--
W115 ---------	79-03-20	.23	2100	2400	.26	160	150	.13	14	22
	79-04-17	--	--	--	--	--	--	--	--	--
W14 ---------	79-04-12	.19	2000	2400	--	37	34	--	--	18
W24 ---------	79-04-12	.24	3900	3700	--	480	450	--	--	24

assist in differentiating between hydrodynamic dispersion and sorption-desorption processes. Dispersion characteristics and tracer retention will be evaluated for naphthalene and additional coal-tar derivatives. Laboratory values for dispersion are typically several orders of magnitude lower than apparent dispersivities in real hydrologic systems. However, the differences in behavior between various combinations of tracers and column-packing materials will lend insight into field sorption-desorption processes.

Chemical and Physical Behavior of Organic Contaminants

The transport of contaminants in the ground-water system is complex. Figure 17 is a preliminary conceptual model of the overall process, including modes of introduction to and interaction between the drift–Platteville aquifer system and underlying bedrock units. Figure 18 shows in greater detail possible major physical and chemical transport processes within the drift–Platteville aquifer system.

An important distinction between the transport processes of most natural constituents of ground water and the transport of coal-tar derivatives is that many compounds in coal tar are relatively insoluble (Sutton and Calder, 1975; Schwarz, 1977; data from May and others, 1978; pl. 6). If liquid hydrocarbons are introduced into the ground-water system more rapidly than they can be dissolved and removed from the point of introduction by ground-water flow, a second fluid phase composed of hydrocarbons will develop (fig. 18). Because this second phase has physical properties that differ from those of the aqueous phase, the hydrocarbons may move at a rate and in a direction different from the rate and direction of the water. Coal-tar constituents typically have specific gravities greater than that of water (pl. 6), and a hydrocarbon-fluid phase will tend to move vertically downward with respect to water. Stallman (1964) and Bear (1972) presented reviews of the behavior of multiphase fluids in porous media.

The surface tension and viscosity of liquid coal-tar mixtures are significantly greater than those of water. With equal head gradient, degree of saturation of the pore space, and intrinsic permeability, the velocity of a coal-tar fluid phase will be very much less than that of the aqueous phase. These effects may be the cause of the anomalous time-drawdown curves of two wells, W13 and W6, in the most heavily contaminated parts of the Middle Drift aquifer (pl. 4). One hypothesis is that high-viscosity hydrocarbon fluid initially surrounds the well screen and restricts fluid movement into the well bore. As fingers of less viscous water break through the hydrocarbon front, less drawdown is required to maintain relatively constant discharge from the well. Unstable displacement of moving hydrocarbon-water fronts is a major factor in limiting the efficiency of petroleum recovery from oil reservoirs (Bear, 1972). Fluid withdrawn from wells W13 and W6 visibly decreased in hydrocarbon content during the pumping period. This fact is significant with respect both to possible future remedial action and to procedures that may be developed to monitor chemical changes within the aquifer.

Because each coal-tar compound is soluble to some extent, those in the source material will be dissolved by water moving through the source. The solubilities of common coal-tar constituents range over at least eight orders of magnitude (pl. 6). Therefore, partitioning between hydrocarbon and aqueous phases will vary widely from compound to compound.

If the hydrocarbons are dissolved, their physical properties become relatively unimportant with respect to their transport, much as the physical properties of, for instance, the solid sodium chloride are relatively unimportant in the transport of sodium and chloride ions in dilute solutions. The chemical properties of the compounds, however, are extremely important because reactions can remove or alter the compounds. Constituents that tend not to react and to remain in solution, for example chloride ions, are termed conservative. Compounds such as ammonia, which tends to be oxidized to nitrate and adsorbed onto aquifer materials, are termed nonconservative. Many organic compounds are subject to biological degradation, oxidation, reduction, reaction with other organic compounds, and sorption.

The solubility behavior of hydrocarbons is poorly understood. In this report, dissolved constituents of ground water are defined as those that are not removed by filtration through a 0.45-micrometer filter. Many coal-tar derivatives are non-ionic and tend to exist as microscopic aggregates of individual monomers known as micelles. In this report, micelles are considered to be in the aqueous phase rather than the hydrocarbon-fluid phase. The following working hypotheses relate to the behavior of micelles:

1. A critical pore size of the porous media exists that, if exceeded, permits micelles to be transported as if they were ideal solutes.
2. A critical pore size exists that, if exceeded, permits micelles to be transported as solutes are, except that if the specific gravity of an individual micelle differs from that of water, the rate and direction of the micelle's movement will differ from the rate and direction of ground water movement.
3. Micelles behave as small inclusions of hydrocarbon-fluid phase in the aqueous phase. The proportion of the pore volume that micelles occupy and their surface tension, viscosity, and specific gravity are all important factors in their transport.

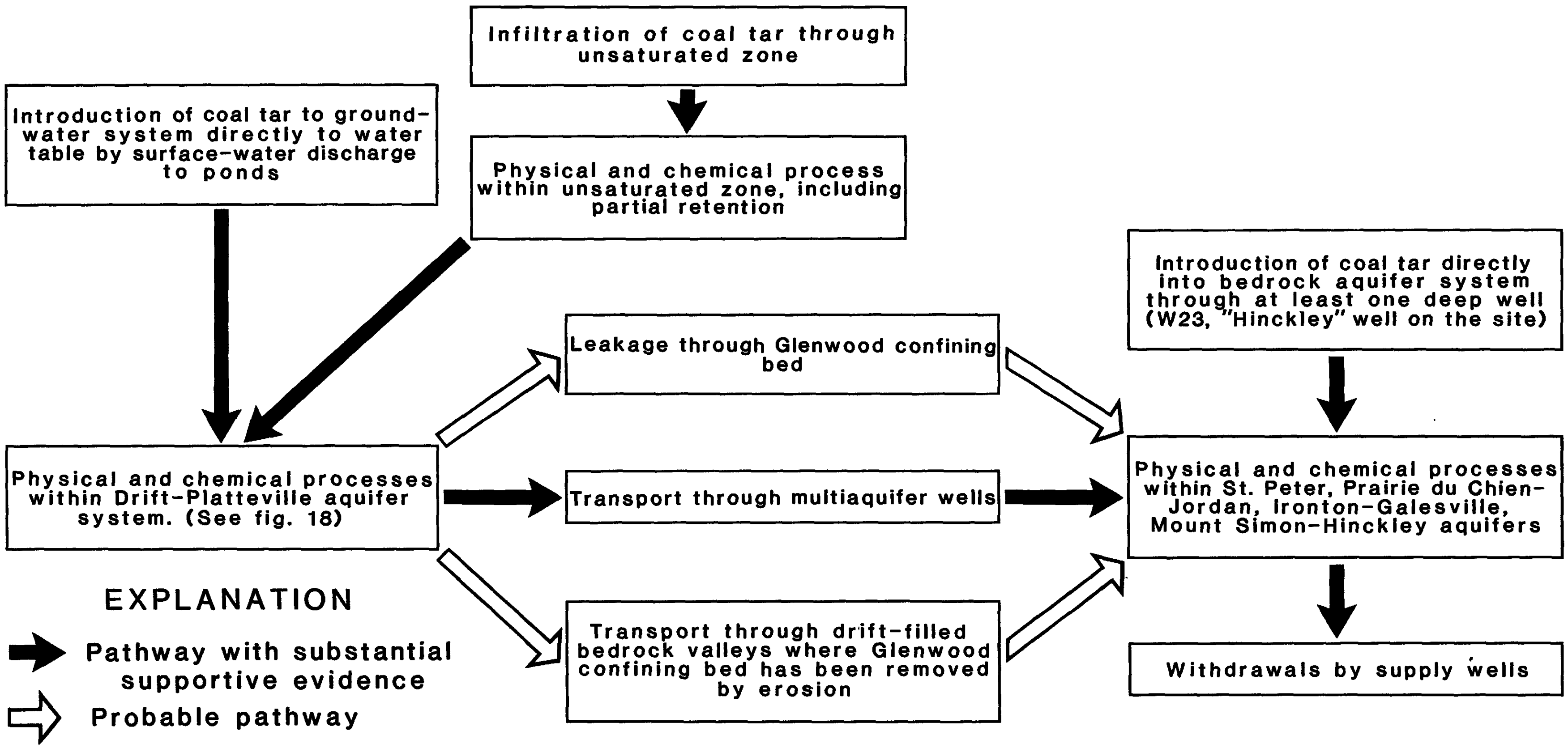


Figure 17. Tentative conceptual model of the introduction and transport of coal-tar derivatives in the ground-water system

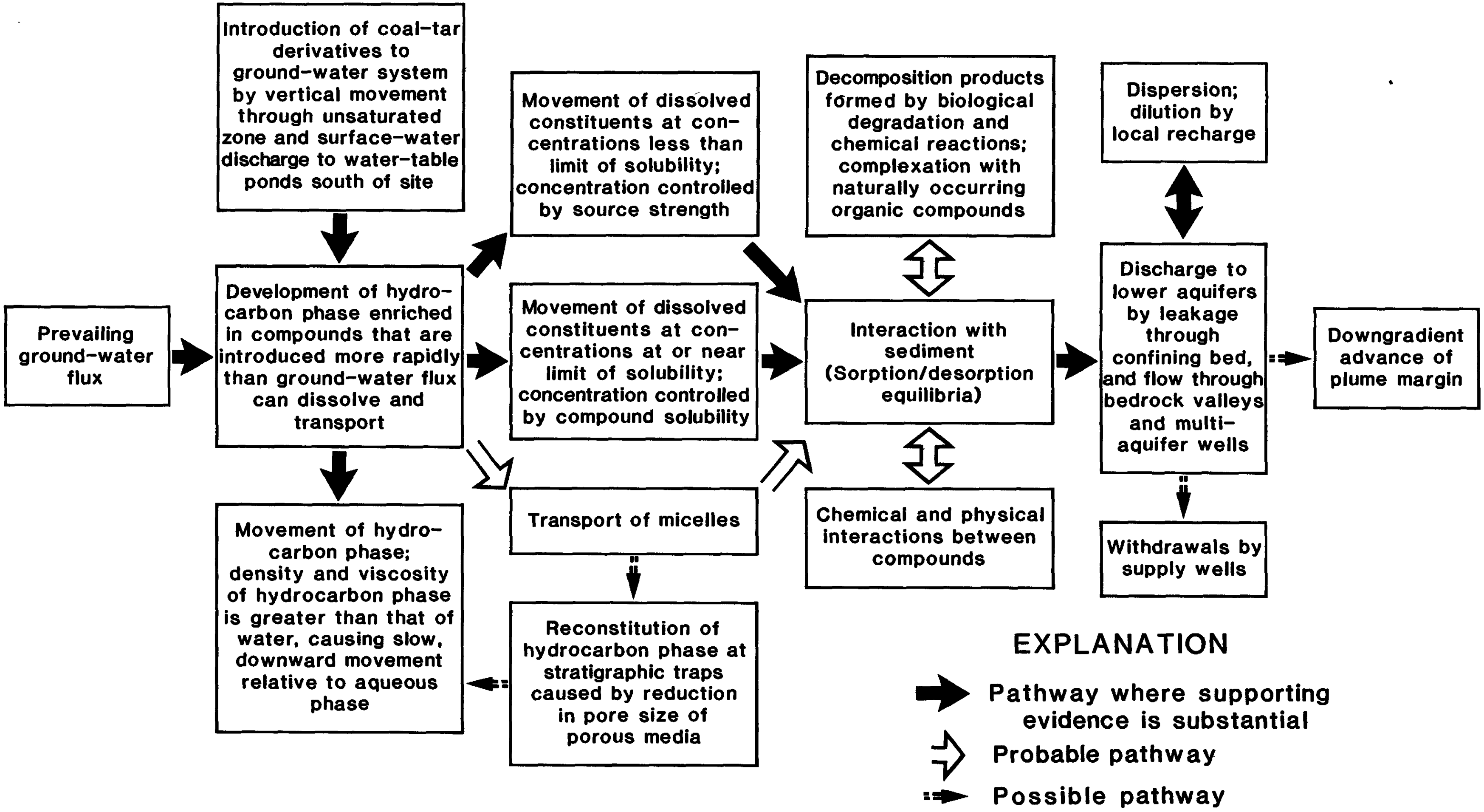


Figure 18. Tentative conceptual model of chemical, physical, and biological processes affecting transport within the drift–Platteville aquifer system

Micelles may be liberated from a hydrocarbon-fluid source and travel through porous media more rapidly than the source itself. At stratigraphic traps caused by reductions in aquifer pore size, the micelles can concentrate and reform a hydrocarbon phase (fig. 18). Both this transport mechanism and movement of hydrocarbon-fluid phase may explain the wide variations in concentration of benzene-extractable compounds reported by Barr Engineering Co. (1976) in the drift materials near the site.

A hydrocarbon-fluid phase may be developing at great distances from the site. A particularly likely location is in the valley fill adjacent to the Platteville aquifer along the walls of the buried valleys. The permeability of the Platteville aquifer is due primarily to open fractures and solution channels. These openings are large and may permit the movement of greater quantities of organic compounds than can move through the valley-fill material adjacent to the buried-valley walls. Riha (1977) has shown that some coal-tar compounds can move several miles through aquifers having secondary permeability. Solution-channel carbonate aquifers can transport large amounts of undissolved coal-tar fluids (Sisk, 1977).

Introduction of Coal-Tar Derivatives into the Ground-Water System

Coal-tar derivatives have entered the ground-water system in St. Louis Park through three major paths: (1) spills and drippings on the site, which infiltrated and percolated through the unsaturated zone to the water table (figs. 17, 18), (2) surface runoff and plant process-water discharge to depressions and wetlands on and south of the site (figs. 17, 18), and (3) movement of coal tar directly into bedrock aquifers through one or more deep wells on the site (fig. 17).

Spills and drippings from plant operations resulted in extensive contamination of the unsaturated zone on the 80-acre site. The composition of contaminants reaching the ground-water system from surface spills is the most potentially variable of the three major sources. During the 55 years of plant operation, raw coal tar was received from many different suppliers. The composition of each shipment varied. The coal tar was distilled into at least two fractions. The part having a boiling point greater than about 400°C is a heavy tar, which was sold. The part having a boiling point less than about 400°C was used for wood preservation at the site. At various times, other fractions, including naphtha and phenol, were distilled from the coal tar. Fuel oil, pentachlorophenol, zinc chloride, and possibly other materials were at times added to the fraction of the coal tar used for wood preservation. The composition of contaminants reaching the ground-water system from spills and drippings on the site likely reflects this variety of sources. Moreover, subareal decomposition of the coal-tar constituents may have produced degradation products dissimilar to those produced in the saturated zone.

Detailed evaluation of the physical, chemical, and biological processes in the unsaturated zone is beyond the scope of this study. Some of the most highly contaminated material above the water table was removed by shallow excavation on the site after the plant was closed in 1972. At times, the water table has been less than 5 feet below land surface over much of the site. The amount of contaminant remaining in the thin unsaturated zone may be small compared with that in the ground-water system.

In the saturated zone, vertical and horizontal movement of hydrocarbon mixtures having fluid properties significantly different from those of water resulted in irregular distribution of contaminated water and hydrocarbon fluid phases. Chemical analysis of drift cores (Barr Engineering Co., 1976; National Biocentric, 1976a) indicates that contaminant composition and concentration is highly variable. Visible contamination extends at least 10 feet below the water table on the site itself (Barr Engineering Co., 1976).

The second major pathway of contaminants to the ground-water system was through closed surface depressions and water-table ponds on and south of the site. The site is in a topographic low that extends south to Minnehaha Creek. Natural surface drainage was toward the site and south to the creek. Since at least 1938, however, drainage has been disrupted by roads and other structures. Surface runoff and plant-process water from the site was discharged through ditches and culverts to water-table ponds near well W13. The rate of discharge to the ponds was greater than the rate of evaporation, resulting in mounding of the water table and vertical movement of contaminated water and hydrocarbon-fluid phase into underlying, confined drift aquifers. Visible contamination extends at least 50 feet below the water table south of the site near well W13 (Minnesota Department of Health, 1974; Barr Engineering Co., 1976).

Since at least 1938, most of the surface-water inflow to the ponds was recharged to the underlying peat and Middle Drift aquifer. The inflow included 30 to 60 gallons per minute of wastewater (Minnesota Department of Health, 1938) and as much as several hundred gallons per minute of runoff during peak periods. This added inflow raised the water level in the ponds and increased vertical leakage. The water table at well W13 was at or slightly below land surface during June 1978 to June 1979, but inspection of areal photographs since 1938 shows that, previously, this area was a pond and that the water table was above the present land surface. The reduction in the water-table mound is attributed to cessation of process-water discharges from the plant and construction of storm sewers since the plant closed in 1972.

Maps in this report show the approximate extent of this pond. However, the pond on the site and the pond south of Lake Street shown on maps in this report are part of the storm-sewer system. They were constructed with plastic liners to prevent leakage.

The composition of contaminants that entered the ground-water system through the ponds may have been more consistent than the composition of spills and drippings on the site itself. Approximately 2 percent of the raw coal tar as received by the plant was water. The "2-percent cut" was removed from the coal tar and discharged. Discharge from this process may have been enriched with highly soluble compounds. In addition, sodium hydroxide and sulfuric acid were used at various times in plant processing. Between 1940 and 1943, for example, about 80,000 gallons of 70 percent sodium hydroxide was used and then discharged to the ponds.

The third major path by which contaminants reached the ground-water system was through at least one well on the site. Well W23 (fig. 13, table 1) was drilled in 1917 to an original depth of 909 feet but is now 595 feet deep and partly filled with coal tar. In 1958, a well driller attempted to remove the viscous material by bailing but was unsuccessful. A core sample of the upper 1 foot of the fill material, which was taken by the USGS in 1979, consists of sand-sized quartz grains and tar. The amount and maximum depth of the coal tar in the well are unknown.

Well W23 may have been a source of early contamination reported in the Prairie du Chien–Jordan aquifer. The effect it has had on water quality in the Ironton-Galesville and Mount Simon–Hinckley aquifers, if any, is unknown.

Chemical Quality in the Drift–Platteville Aquifer System

Samples were collected from 25 wells in March–April 1979 to define the extent and nature of contamination and the natural hydrogeochemical system on which the contamination is superposed. Data on approximately 50 chemical constituents or fluid properties are presented in table 4.

The fluid pumped from wells may contain both hydrocarbon- and aqueous-fluid phases. However, 23 of the 25 wells sampled yield fluid in which organic carbon is present almost exclusively in what is defined to be a "dissolved" form (see Glossary). The volume of drift in which a hydrocarbon-fluid phase is present is much smaller than the volume contaminated by dissolved constituents. Better criteria are needed to distinguish between DOC and organic fluids that are immiscible in water. Identification of the hydrocarbon-fluid phase was based on (1) inspection of drift cores, (2) analysis of short-term pumping tests, (3) changes in contaminant concentration in fluid yielded to a well during a single pumping period, (4) visual appearance of fluid yielded to wells, (5) measurement of DOC, SOC, and TOC of fluid samples, and (6) comparison of the measured concentration of individual organic contaminants with their respective solubilities in water. These observations have led to the working hypothesis that movement of coal-tar derivatives in the aqueous phase (whether as solutes or as micelles) is the primary mechanism for contaminant transport in most of the drift–Platteville aquifer system (fig. 18). Because the behavior of micellar coal-tar derivatives may not be critically different from that of solute, an additional working hypothesis can be made—namely, that most individual contaminant compounds in the aqueous phase behave as nonconservative solutes that react strongly with the porous media (fig. 18). A corollary to these two hypotheses is that contaminant partitioning in most of the contaminated volume of drift and the Platteville aquifer is primarily between the aqueous and the solid phases.

The direction of contaminant transport in the drift–Platteville aquifer system indicated by chemical analyses of fluid pumped from wells is in good agreement with the direction of ground-water flow based on the distribution of hydraulic head. Sodium, organic carbon, and nitrogen species can be useful indicators of chemical contamination (pls. 3–5). Sodium is a quasi-conservative, inorganic constituent that may be useful as a tracer; organic carbon is a general indicator of contamination levels; nitrogen species may indicate the influence of biologic processes. Measurement of these indicator constituents is not a substitute for measurement of the concentrations of individual coal-tar derivatives. The indicators are useful, however, in defining the areal and vertical extent of contamination and transport processes.

Contours are shown on plates 3, 4, and 5 to assist the reader in noting general trends. The values shown indicate the composition of fluid pumped from individual wells. Caution must be used in extending these data to interpretations of the relative amount of the constituent sorbed onto the porous media and in hydrocarbon- and aqueous-fluid phases. More data are needed to define the distribution of the constituents areally, vertically, and between phases. The contours are not meant to reflect concentrations in the volume of drift near wells W13 and W6 that is known to contain two fluid phases.

The discharge of sodium hydroxide along with process water from the plant has created a plume of elevated sodium concentration. This sodium may be useful in assessing the rate and direction of transport of coal-tar derivatives because it is chemically more conservative than most coal-tar derivatives. Road deicing chemicals may be an additional source of sodium, but it can be shown that they are not the major source. In the Middle

Drift aquifer in the volume of greatest contamination near well W13 (pl. 4), the ratio of sodium to chloride in milliequivalents per liter is 2.1 to 1. Road deicing chemicals currently used are typically mixtures of calcium chloride ($CaCl_2$) and sodium chloride ($NaCl$). Even if only sodium chloride were used, the ratio of sodium to chloride from this source would not exceed unity.

Plates 3 and 5 show that sodium from the plant discharge has reached the Platteville aquifer. The graphs of the percentages of reacting values of major cations (percentage of total milliequivalents per liter of each major cation) shown in plates 4 and 5 further substantiate the conclusion that sodium is being transported through the ground-water system with the organic contaminants. In the Middle Drift aquifer, the major feature of the graph is a downgradient decrease in sodium plus potassium. The potassium concentration is small, and relatively constant (table 4), and does not contribute to this effect.

Plate 3 shows the vertical distribution of sodium and the ratio of sodium to chloride. Well W12 (pls. 3, 4) is completed in the upper part of the Middle Drift aquifer, and water from the well has a low sodium concentration. The ratio of sodium to chloride, however, is consistent with the uniform downgradient trend, suggesting dilution by local vertical recharge of water that contains the low concentrations of sodium and chloride typical of uncontaminated ground water in the area.

DOC and SOC concentrations were measured to provide a general assessment of the concentration of organic contaminants in fluid pumped from wells. Hughes and others (1974) have shown that measurement of DOC can be a useful approach if the concentration of organic contaminants is significantly higher than that of natural organic compounds.

The vertical and areal distribution of DOC shown on plates 3, 4, and 5 is remarkably consistent, considering the heterogeneity of the source and the complexity of the hydrogeology and transport mechanisms. The distribution is similar to that of other indicator parameters and decreases systematically downgradient from the source area. Because the concentration of natural organic compounds seems to be 1 to 3 milligrams per liter and because the distribution of contaminants seems systematic, measurements of DOC can be used to estimate the total concentration of organic contaminants in fluid pumped from a monitoring well.

The relationship between the measurements of DOC, SOC, and TOC and the total amount of organic contaminants in the ground-water system is less clear. First, the amount of organic compounds sorbed onto the aquifer materials is not measured. Second, wells in those parts of aquifers in which two fluid phases are present may sample both phases. The amount of hydrocarbon-fluid phase pumped from these wells decreases with time as the wells are pumped. This was noted at wells W13 and W6.

During future sampling, attempts will be made to separate the two fluid phases by allowing the heavier hydrocarbon fluid to segregate from the aqueous phase after collection. Separate chemical analyses will be run on each sample. In this way, the chemistry of each of the two fluid phases may be defined, although not their relative proportions in the aquifer.

The fate of the individual coal-tar constituents (see Glossary) identified in this study is poorly known. Microbial activity may be a factor in converting the original coal-tar constituents into other compounds (see "Degradation products, coal-tar"). Sampling for microorganisms requires specialized procedures (Dunlap and others, 1977) and is beyond the scope of this study. However, the relative distribution of nitrogen species can serve as a general indicator of biologic activity (Baedecker and Back, 1979).

Water entering the general area of contamination in the Middle Drift and Platteville aquifers contains nitrogen primarily in the form of nitrate (pls. 3, 4, and 5). This nitrogen is likely both from natural sources and from septic tanks and outhouses, which were widely used before sewers were installed.

Ground water in the contaminated area contains nitrogen primarily in the form of ammonia. Microbial action, as well as purely chemical processes, is probably reducing incoming nitrate to ammonia. This hypothesis is supported by the distribution of nitrite (table 4). The ammonia from this source has mixed with ammonia in wastes discharged to the ponds from the plant. In addition, nitrogen-bearing organic compounds present in the coal tar may be degraded to ammonia.

The contours shown for ammonia can be drawn to resemble those of other constituents. Ammonia is strongly sorbed by clay and silt (Freeze and Cherry, 1979), and the downgradient decrease in concentration may reflect this sorption. Moreover, some organic compounds are known to interfere with the determination of ammonia concentration (Goerlitz and Brown, 1972). The distribution shown may be in part affected by this interference.

Extracts were prepared from 24 of the 25 samples taken for analysis of individual organic compounds. Analyses of the 10 samples collected by the USGS and completed during the first year of the study and of an additional sample collected by the Minnesota Department of Health from well W37 are shown in plate 6. The graphs were prepared by ordering the compounds in decreasing solubility from left to right. This ordering is generally consistent with increasing molecular weight, boiling point, specific gravity, and health risk associated with the compound (pl. 6). Constituents shown have been selected from those for which solubility in water is known, which are consistently present in samples, or which have been identified as of particular concern from a health-risk perspective (Minnesota Department of Health, 1977, 1978).

The data should be considered semiquantitative because the reproducibility of the analyses has not yet been established. The general shape and magnitude of the bar graphs, however, is significant.

Consider the graphs for well W6 (Middle Drift aquifer, in the volume of two-phase conditions), well W11 (Middle Drift aquifer), well W17 (basal drift complex), and well W101 (Platteville aquifer). Wells W11, W17, and W101 are located on the hydrogeologic section *B–B′*. In fluid from well W6, phenolic compounds as phenols, the most soluble constituents, are present in the smallest amounts. The ratio of benzo(a)pyrene (the compound with the lowest solubility of those shown) to phenolic compounds is slightly more than 1 to 1. In the sample from well W101, in the Platteville aquifer near the eastern bedrock valley, the ratio is less than 1 to 1,000. In these four samples, the proportion of highly soluble compounds increases relative to less soluble compounds with increasing vertical and lateral distance from the source in a downgradient direction. These observations lead to the working hypothesis that relatively soluble compounds having low molecular weights are moving preferentially through the drift–Platteville aquifer system.

The concentration of contaminants decreases downgradient, presumably owing to dilution, sorption onto the porous media, and chemical and biological decomposition of the original coal-tar constituents. This decrease is in general agreement with trends observed in TOC, DOC, and SOC concentration. The sum of individually measured coal-tar constituents is much less than the apparent contamination as estimated from the DOC concentration, except in the sample from well W6. Improvement of the mass balance will require identification and measurement of the concentration of additional coal-tar constituents and degradation products.

Wells W37 and W101 are both completed in the Platteville aquifer near 36th Street and Wooddale Avenue and have similar contaminant concentrations. A well completed in the drift, W36 (fig. 3, table 1), at the same location as W37 was abandoned in about 1972 because its water had a coal-tar taste. This well has not been sampled.

The processes of sorption and desorption onto drift materials and equilibrium concentrations of individual organic compounds are poorly known. Other physical properties of typical coal-tar constituents vary systematically with molecular weight, and their sorption characteristics may vary in a similar fashion. The working hypothesis is that the proportion of an individual compound in the solid phase, relative to the aqueous phase, increases with decreasing solubility. This hypothesis and the degree to which sorption can account for the observed concentrations can be better evaluated after comparisons of fluid and core samples and the column experiments have been completed.

The working hypothesis that most of the contaminants are moving in a virtually dissolved form may be disproved. If so, the surface tension, viscosity, and density of hydrocarbon-fluid mixtures may play major roles in transport processes outside the volume of identified two-phase flow.

SUMMARY

Operation of the coal-tar distillation and wood-preserving plant during 1918–72 resulted in a long and complex history of ground-water contamination. Coal-tar derivatives have entered the ground-water system through three major paths. Contamination of the drift resulted from (1) infiltration of spills and drippings on the site itself and (2) recharge from ponds south of the site that received surface runoff and contaminated process water. Contamination of the Prairie du Chien–Jordan and possibly deeper aquifers has resulted in part from (3) coal tar that entered well W23 on the site, which was drilled to an original depth of 909 feet.

Contaminants in the drift are moving laterally to the east and southeast and vertically into the Platteville aquifer, which directly underlies the drift in much of the affected area. On and immediately south of the site, a hydrocarbon-fluid phase is moving vertically downward with respect to the aqueous phase. Vertical movement from the Platteville aquifer to the underlying St. Peter aquifer is restricted by the Glenwood confining bed, which separates the two aquifers. The Platteville aquifer and Glenwood confining bed have been removed by erosion to the south and east, and the St. Peter aquifer directly underlies the drift. Where the Glenwood confining bed is eroded, contaminated water moves from the drift–Platteville aquifer system into the St. Peter aquifer. Multiaquifer wells and the buried valleys strongly influence the direction of ground-water flow in the Platteville and, therefore, the direction of contaminant transport.

Contaminants in the drift and Platteville aquifers have moved a minimum of 4,000 feet to the east. They reached the vicinity of 36th Street and Wooddale Avenue by 1972 at the latest. Immediately south of this area, the Platteville aquifer and Glenwood confining bed have been eroded. Fluid containing approximately 2 milligrams per liter of organic contaminants may be entering the underlying St. Peter aquifer and valley-fill materials.

Contamination in the major bedrock aquifer of the Twin Cities area, the Prairie du Chien–Jordan aquifer, reached the vicinity of 36th Street and Wooddale Avenue as early as 1932. One explanation is that contaminants moved through the aquifer from a coal-tar spill into a deep well (W23) on the site. Contaminants can move fairly rapidly through the Prairie du Chien–Jordan aquifer because the upper part of this aquifer is a

solution-channel carbonate rock of high transmissivity and low effective porosity.

The regional gradient in the Prairie du Chien–Jordan aquifer is to the east, but locally the direction of ground-water flow is affected by pumping from municipal and industrial wells and multiaquifer wells through which water flows into the Prairie du Chien. Because the rate and location of pumping is continually changing, the concentration of contaminants reaching individual wells fluctuates.

In 1978, coal-tar derivatives were found to the north of the site in five municipal wells completed in the Prairie du Chien–Jordan aquifer. The most remote of these wells is approximately 2 miles from the nearest probable source of contaminants to the aquifer, well W23 on the site. The northward direction of flow is in agreement with water levels measured in August 1977. Since November 1978, pumping patterns have been altered significantly by shutting down four of the wells that were found to be contaminated. Consequently, the direction and rate of contaminant transport may have been altered.

Five multiaquifer wells, which connect the Prairie du Chien–Jordan aquifer with the overlying aquifers, have been located and evaluated. Flow rates estimated by geophysical logging and inspection with downhole television camera ranged from 20 to 150 gallons per minute. Each of these wells may have had a significant effect on water levels near the well and, therefore, the local direction of water movement in the aquifers they interconnect. In addition, four of the wells are in areas where the bedrock aquifers are contaminated and were pathways for contaminant transport into the Prairie du Chien–Jordan aquifer. Each of these wells has been temporarily or permanently sealed.

The long history of contamination, effect of multiaquifer wells, continually changing pumping patterns, and probable high velocities of contaminant transport through solution channels and fractures in the Platteville and Prairie du Chien–Jordan aquifers combine to produce a complex distribution of contaminants in the bedrock aquifers. It is unlikely that a single distinct contaminant plume has persisted through time in the Prairie du Chien–Jordan aquifer.

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Conversion Factors

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
foot per day (ft/d)	0.3048	meter per day (M/day)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/day)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

National Geodetic Vertical Datum of 1929 (NGVD): 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."