UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ASSESSMENT OF GROUND-WATER CONTAMINATION BY COAL-TAR DERIVATIVES, ST. LOUIS PARK AREA, MINNESOTA

By M. F. Hult

Open-File Report 84-867

Prepared in cooperation with the
MINNESOTA DEPARTMENT OF HEALTH,
MINNESOTA POLLUTION CONTROL AGENCY,
CITY OF ST. LOUIS PARK, and the
U.S. ENVIRONMENTAL PROTECTION AGENCY

St. Paul, Minnesota

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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ERRATA

The following changes should be made to U.S. Geological Survey Open-File Report 84-867 (Assessment of ground-water contamination by coal-tar derivatives, St. Louis Park area, Minnesota):

page 10	(Figure 2) Well labeled " W69 " should be labeled " W114 " and the location of the well adjusted to correspond to the location shown on page 37 (figure 21).
page 12	(Figure 3) Box labeled "Mount Simon - aquifer" should be labeled " Mount Simon - Hinckley aquifer " and the dashed line connecting it to " WITHDRAWALS BY WELLS " should be queried.
page 27	Paragraph 4, sentence 2: " ... is intercepted by a multi-aquifer well, ... " should be " ... is intercepted by multiaquifer or production wells ... ".
page 35	(Figure 19) The closed contour labeled " 810 " on the potentiometric surface map for January 23-31, 1979 should be labeled " 820 ".
page 37	(Figure 21) Well labeled " W106 " should be labeled " W69 ".
page 39	(Figure 22) The labels for wells " SLP10 " and " SLP 15 " should be exchanged.
page 43	(Figure 24) The word " Fluorine " should be " Fluorene ".

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
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)	0.0003528	centimeter per second (cm/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic food per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

ASSESSMENT OF GROUND-WATER CONTAMINATION BY COAL-TAR DERIVATIVES, ST. LOUIS PARK AREA, MINNESOTA

By M. F. Hult

ABSTRACT

Operation of a coal-tar distillation and wood-preserving facility in St. Louis Park, Minnesota, during 1918-72 contaminated ground water with coal-tar derivatives and inorganic chemicals. Coal-tar derivatives entered the ground-water system through three major paths: (1) Spills and drippings that percolated to the water table, (2) surface runoff and plant process water that was discharged to wetlands south of the former plant site, and (3) movement of coal tar directly into bedrock aquifers through a multiaquifer well on the site.

In the drift, Platteville, and St. Peter aquifers, ground water flows laterally from west to east and vertically downward. Near the former plant site, creosote-like organic fluids have migrated vertically downward through the drift and are being partially dissolved by ground water. Ground water has preferentially mobilized low-molecular-weight compounds such as phenolic compounds, alkyl-benzenes, and naphthalene, although polynuclear aromatic hydrocarbons as heavy as benzo(a)pyrene have been mobilized at low concentrations. Sorption of high-molecular-weight compounds has retarded their migration down the hydraulic gradient compared to low-molecular-weight compounds in the plume. Some simple phenolic compounds are being degraded to methane and carbon dioxide by bacteria under anaerobic conditions in the drift-Platteville-St. Peter aquifer system. Other low-molecular-weight aromatic compounds are apparently being degraded by aerobic bacteria at the periphery of the plume where oxygen is available. Intermediate degradation products such as volatile fatty acids are likely present, but complete conversion of the organic contaminants to innocuous inorganic substances has not been demonstrated. Near and south of 36th and Wooddale Avenues, contaminants enter the St. Peter aquifer where the Glenwood confining unit has been eroded in a buried bedrock valley. Contaminants previously entered the Prairie du Chien-Jordan aquifer through at least one multiaquifer well (W38). Other sources of contaminants and the low concentrations of contaminants hamper delineation of the maximum areal extent of contaminants that are resistant to biologic degradation. These biorefractory compounds will probably continue to migrate down the hydraulic gradients in the drift and Platteville and St. Peter aquifers.

Of particular concern with respect to the health risk to humans are the polynuclear aromatic hydrocarbons, which are a major constituent of coal tar and are found in municipal wells near the site that are completed in the Prairie du Chien-Jordan aquifer. The Prairie du Chien-Jordan aquifer lies 250 to 500 feet below land surface and is relatively well protected from near-surface sources of contamination by overlying rocks. However, the aquifer has been contaminated since at least 1932 because coal-tar derivatives have entered the aquifer through multiaquifer wells. The most significant single source of contamination in the aquifer is a well drilled on the site in 1917 (well W23) that has contained liquid coal-tar since at least 1958. The introduction, dissolution, and movement of this coal-tar in ground water has contaminated nearby municipal wells. The composition of the tar in well W23, and the ratio of concentrations of individual compounds in water from well W23 to those in municipal well SLP15, are consistent with known hydrologic, chemical, and biologic processes, and the conclusion that contaminants in well SLP15 are due primarily to contaminants introduced at well W23. Most of the major polynuclear aromatic hydrocarbons in the tar, although slightly soluble in water and strongly sorbed by aquifer materials, have moved greater distances at higher concentrations than have the lower-molecular-weight, more soluble compounds such as phenolic compounds and naphthalene. The latter are apparently being degraded by bacteria.

The direction and rate of contaminant movement within the Prairie du Chien-Jordan aquifer changes with time because the ground-water-flow system continually adjusts to hydraulic stresses caused by ground-water withdrawals and flow through multiaquifer wells. Contaminants can move rapidly through the Prairie du Chien-Jordan because the upper part of the aquifer is a carbonate rock having fracture and solution-channel permeability, low effective porosity, and relatively small surface area for sorption. Consequently, the concentration and composition of contaminants in water pumped from individual industrial and municipal wells completed in the aquifer fluctuate with time. Although contaminants have been in the aquifer for at least 50 years and their spatial distribution is complex, concentrations remain highest near their points of introduction through multiaquifer wells near and on the site of the former plant.

Contaminants reached the Ironton-Galesville aquifer through at least two deep multiaquifer wells (W23 and W38), but the extent of contamination in this aquifer, and in the underlying Mount Simon-Hinckley aquifer, is not known.

INTRODUCTION

Operation during 1918-72 of a coal-tar distillation and wood-preserving facility in St. Louis Park, Minnesota, has contaminated ground water at and near the site. In 1978, the U.S. Geological Survey began a series of projects to obtain a detailed understanding of the transport and fate of coal-tar derivatives in ground water in the area. Results of the projects are being used by local, State, and Federal agencies to guide management decisions and to design remedial action. The projects were done by the U.S. Geological Survey both in cooperation with the Minnesota Department of Health (MDH), Minnesota Pollution Control Agency (MPCA), city of St. Louis Park (SLP), and U.S. Environmental Protection Agency (USEPA), and as research projects funded wholly by the U.S. Geological Survey.

Purpose and Scope

The purpose of this report is to summarize the major, previously published results and to update previous interpretations based on data collected since publication of some of the references cited.

The primary source of information for this report is information published by the U.S. Geological Survey and in journal articles. Two major previous publications (Ehrlich and others, 1982; and Hult and Schoenberg, 1984, (U.S. Geological Survey Water-Supply Paper 2211) provide the foundation for this report. The results in Hult and Schoenberg (1984) were first made available to the public in December 1980 as U.S. Geological Survey Open-File Report 81-72. Other publications on St. Louis Park authored by personnel of the U.S. Geological Survey include Ehrlich and others, 1983; Godsey and others, 1983; Goerlitz, 1984; and Pereira and others, 1983.

The report also relies significantly on unpublished data and information as follows:

1. The files and records of the U.S. Geological Survey including: measurements of water levels, streamflow, ground-water withdrawals, precipitation, and hydraulic properties; physical, chemical, and biologic analyses of geologic and water samples; geologic and geophysical logs of wells and test holes; sorption measurements using column and batch experiments; and geophysical and topographic surveys; and

2. Files and records of the Minnesota Pollution Control Agency and Minnesota Department of Health, particularly concerning chemical analyses, and information on abandonment and (or) reconstruction of wells (including well W23).

Location and Description of the Study Area

The city of St. Louis Park is located in the Minneapolis-St. Paul Metropolitan Area in Hennepin County. The term "site" in this report refers to the approximately 80 acres of land on which the coal-tar distillation and wood-preserving plant operated. It includes most of the NW¼ of the SW¼ of sec.17, T.117 N., R.21 W. The site is located in a topográphic depression which extends northward from the present channel of Minnehaha Creek. Local surface-water drainage is toward the site and then southward toward Minnehaha Creek.

The areal extent of the area studied by the U.S. Geological Survey in the series of studies that began in 1978 was determined by the location of hydrogeologic or other boundaries needed to evaluate the contamination problem. That area is larger than the present areal extent of contamination. The boundaries, extent of contamination, and areas studied intensively are not the same for each aquifer.

NATURE OF CONTAMINATION

Coal tar is a complex mixture of more than 1,000 individual compounds produced by heating coal in the absence of air. Although the proportion of each minor compound in coal tar varies widely, that of the major constituents is less variable. The classification scheme generally used in the coal-tar industry has been to divide the compounds into neutral, acid, and base fractions, and to distinguish between groups of compounds within each fraction on the basis of boiling point. This classification is useful because it reflects the way in which coal tar is distilled and the use made of each part. The classification also reflects the way in which environmental samples are prepared for chemical analysis by separate extraction and analysis of base, neutral, and acid fractions. Much of the data available on the composition of coal-tar fractions produced at the plant are based on boiling point. In general, the solubility in water and volatility decrease, and the density, boiling point, tendency to be sorbed on aquifer materials, and resistance to biodegradation increase with increasing molecular weight.

Of particular concern with respect to health risk to humans are a class of neutral compounds called polynuclear aromatic hydrocarbons (PAH) (Minnesota Department of Health, 1977, 1978; U.S. Environmental Protection Agency, 1979c). PAH compounds are composed of hydrogen and carbon (hydrocarbons) and consist of two or more fused benzene rings. They are a major constituent of coal tar. The fraction of coal tar known as creosote is often about 80 percent PAH. The health risk associated with individual PAH compounds generally increases with molecular weight.

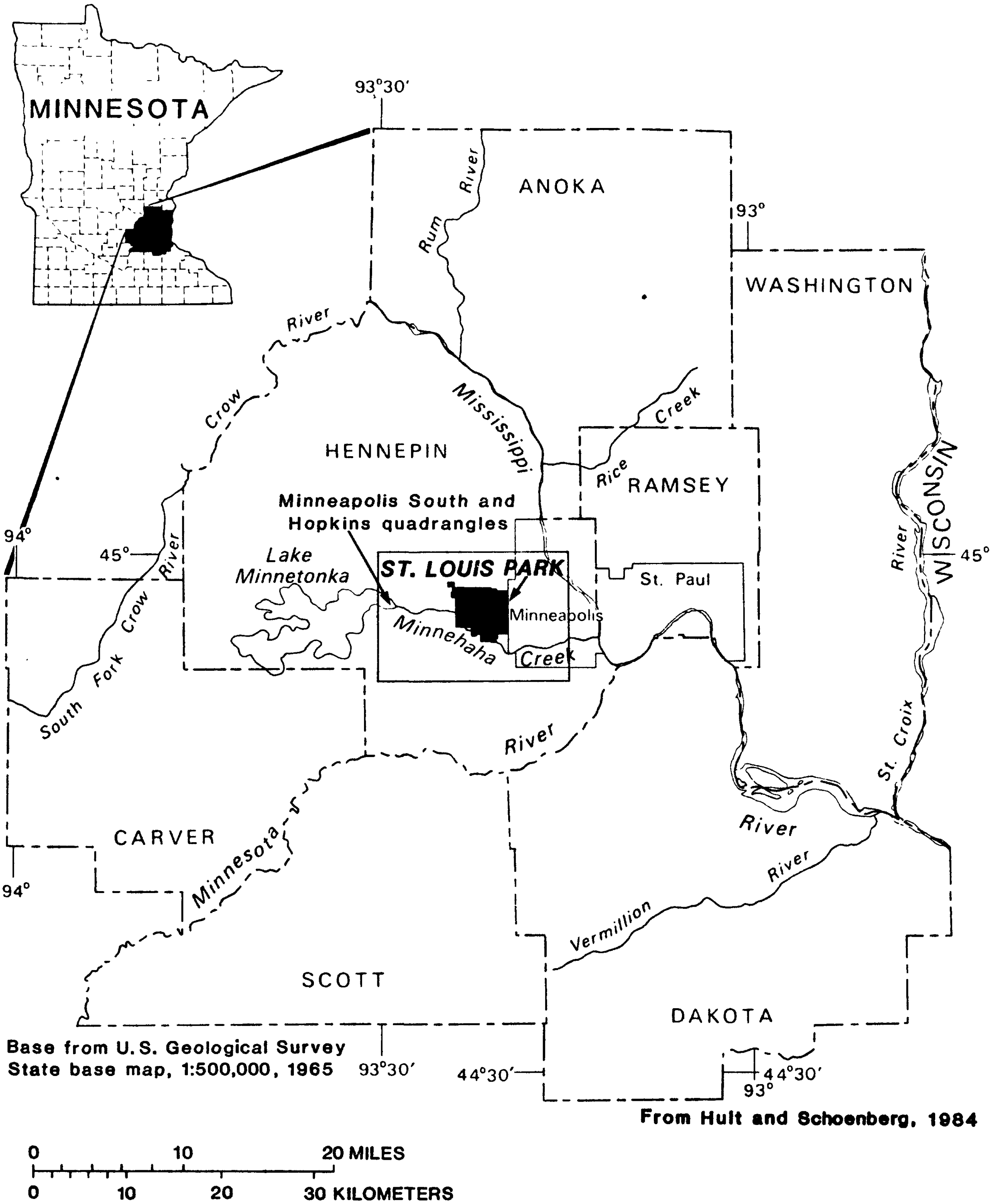


Figure 1.--Location of study area, St. Louis Park, and site of former plant in the Minneapolis-St. Paul Metropolitan Area

Phenolic compounds are the major constituents in the acid fraction, and were the first compounds identified as ground-water contaminants in the St. Louis Park area (Minnesota Department of Health, 1938). The concentration of phenolic compounds in area wells was measured for many years to assess the severity of the problem (Minnesota Department of Health, 1938, 1974; Barr, 1976, 1977). Phenolic compounds are more soluble and less strongly sorbed than PAH compounds and, therefore, are chemically more mobile in ground water than PAH. It was found, however, (Ehrlich and others, 1982, 1983; Godsey and others, 1983) that some phenolic compounds are being degraded by bacteria. This explains why PAH compounds have moved greater distances at higher concentrations than phenolic compounds.

Basic compounds in coal-tar consist primarily of heterocyclic compounds containing nitrogen. Pereira and others (1983) identified approximately 75 base compounds in a sample of creosote-like organic fluid from a well near the site (W13), but these compounds are present in lower concentration than PAH compounds in samples of organic fluids and of water.

Plant processes resulted in the discharge of inorganic substances such as sodium, chloride, and sulphate until about 1945 (Hult and Schoenberg, 1984). Measurements of these and other major cations and anions, trace metals (e.g. lead and chromium), nutrients (nitrate, nitrite, ammonia, organic nitrogen, phosphorus), dissolved gases (methane, oxygen, carbon dioxide), and physical properties (pH, specific conductance) have been used by the U.S. Geological Survey to characterize major geochemical and biologic processes that affect contaminant transport and fate.

Methods of Chemical Analysis

Methods used for well installation and sampling are described in Hult and Schoenberg (1984). Except as noted, samples for chemical analyses reported in this report were collected by the U.S. Geological Survey. Most analyses of inorganic constituents in water were done by the Minnesota Department of Health (MDH) as described in Hult and Schoenberg (1984). Fluid and core samples were chemically analyzed in order to isolate, identify, and quantify individual organic compounds by the USGS, MDH, and Midwest Research Institute (MRI) using gas chromatography with flame ionization detector (GC/FID), gas chromatography with mass spectrometry (GC/MS), probe-distillation mass spectrometry (PD/MS), and high-performance liquid chromatography (HPLC).

Methods suggested by the USEPA (method 602, purgeables by GC/MS; method 624, purge and trap by GC/MS; method 610, methylene chloride extractables using HPLC; method 625, methylene chloride extractables by GC/MS) are described by USEPA (1979b, 1979c) and method detection limits (MDL) have been evaluated statistically (Glaser and others, 1981). Modification to these methods used by MRI are described in Conrad and others (1981).

Methods used by the USGS laboratories are described in Max Nestler (1974) for methylene chloride extractables by GC/FID, American Public Health Association 1976) for methane, Pereira and Hughes (1980) for volatile compounds by GC/MS, Pereira and others (1982) for PD/MS and analysis of coal-tar bases by GC/MS, and White and others (1982) for methylene-chloride extractables by HPLC. Methods used by the MDH for analysis of cyclohexane extractables by HPLC and GC/FID are available from the Minnesota Department of Health.

Each method has advantages and disadvantages. No single method can be used to analyze all of the compounds of interest at the concentrations of concern. The purpose for collecting and analyzing the samples differed widely. Most samples analyzed by the USGS were analyzed for the purpose of isolating and identifying as many constituents as feasible. Precise quantitation of their concentrations was often a secondary consideration. Most analyses by MRI were for priority pollutants (U.S. Environmental Protection Agency, 1979a). Analyses by MDH using HPLC were primarily for about 15 PAH compounds for which the State is considering standards for potable water.

Interpretation of the data needs to recognize that data from different methods are generally not comparable, in part because methods such as GC/FID and HPLC that rely on retention time for compound identification are susceptible to compound misidentification in complex samples and matrices. Individual figures in this report contain data from a single method, laboratory, and, usually, operator.

History of Contamination

The spatial distribution of contaminants in the area's ground water is now (1984) very complex because of the long time that has elapsed since the contaminants were first introduced, the number of aquifers affected, the variety of ways in which contaminants entered and moved between aquifers, ever-changing nature of the hydraulic and chemical stresses imposed by the activities of man, and natural chemical and biologic processes that alter chemical concentrations and compositions.

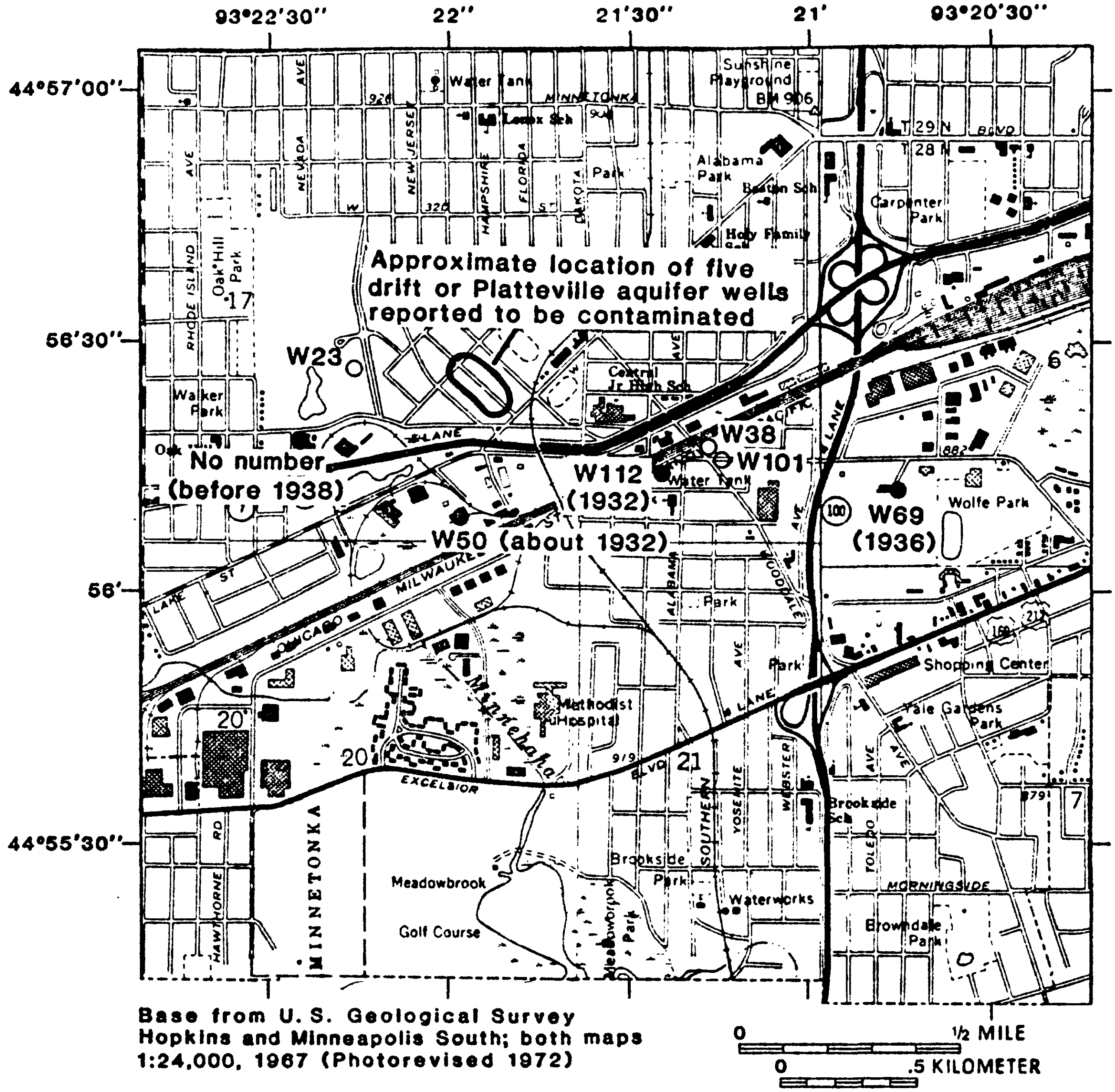
Ground water in the area was found to be contaminated as early as 1932 when the first municipal well (well W112) was drilled into the Prairie du Chien-Jordan aquifer and yielded water with a coal-tar taste [table 1; fig. 2; Hult and Schoenberg (1984)]. By 1938, contamination of other wells and aquifers up to a mile from the site had been documented [fig. 2; Minnesota Department of Health (1938)].

Table 1.—Summary of major events in history of ground-water contamination by coal-tar derivatives, St. Louis Park area, Minnesota

1899	Multiaquifer well W105 ("Sugar Beet well") was drilled to an original depth of 940 feet at the site of a sugar-beet refining plant.
1917	Coal-tar distillation and wood-preserving plant built on the site of the former sugar-beet refining plant. Multiaquifer well W23 ("Hinckley well on the site") was drilled to an original depth of 909 feet after attempts to make W105 serviceable were unsuccessful.
1918	Plant goes into operation. Surface water and plant-process water was discharged to wetlands adjacent to Minnehaha Creek.
about 1930	Discharge of surface water and plant-process water to creek disrupted, and contaminated water is ponded in wetlands south of site.
1932	The first municipal well (well W112) was drilled 3,500 feet east of the plant site. It yielded water with a coal-tar taste from the Prairie du Chien-Jordan aquifer (approximately 250 to 500 feet below land surface).
1933	Efforts to reconstruct W112 to avoid contaminated water unsuccessful, and use of well discontinued. Well W105 apparently filled to reduce liklihood that contaminants could reach the Prairie du Chien-Jordan aquifer through this pathway.
1936	Well W69 (6,000 feet east of the site) deepened by additional drilling into Prairie du Chien-Jordan aquifer. After reconstruction, well yields water with a coal-tar taste.
1938	Report by Minnesota Department of Health documents contamination of wells near the site and discharge of coal-tar derivatives and sodium-sulfate liquor to ponds south of site. City of St. Louis Park drills municipal wells (SLP1, SLP2, and SLP3) in St. Peter aquifer north of site. Water from the wells is considered to be of satisfactory quality.
by about 1945	Discharge of contaminants to ponds south of site substantially reduced compared to 1938 practices. Discharge of inorganic contaminants from by-products manufacture apparently ceased.

Table 1.—Summary of major events in history of ground-water contamination by coal-tar derivatives, St. Louis Park area, Minnesota—Continued

1946	St. Louis Park municipal well 4 (SLP4) was drilled into Prairie du Chien-Jordan aquifer. Concentration of phenolic compounds first reported to be 100 ug/L but decreases rapidly after several months of use.
1958	Well W23 found to contain coal-tar. Efforts to remove coal-tar by cable-tool drilling techniques unsuccessful. A liner was installed in the well to avoid contaminated water from the Prairie du Chien-Jordan aquifer.
1960	Minnesota Department of Health documents widespread contamination of shallow aquifers in St. Louis Park by septic tanks and outhouses. Efforts accelerate to convert all domestic water supplies to municipal system.
1965 to 1977	Various investigations are conducted on the problem of phenolic compounds in municipal and other area wells (Hickok, 1969; Sunde, 1974), and soil contamination on and near the site (National Biocentric, 1976a, 1976b; Barr Engineering Co., 1976, 1977; Minnesota Department of Health, 1972).
1972	Plant operation ceases.
1975-present	Site is graded and visibly contaminated soils excavated. Land farming and fill substantially reduce visible soil contamination. Storm-water retention ponds on and south of site are constructed and connected to storm-sewer system with discharge to Minnehaha Creek. Commercial and residential buildings and a major urban street constructed on site.
1978	Minnesota Department of Health (MDH) documents presence of polynuclear aromatic hydrocarbons (PAH) in municipal wells SLP10, SLP15, SLP7, SLP9, and SLP14. Use of the first four of these wells discontinued.
	USGS documents that well W23 contains tar, and that water is flowing (150 gallons per minute) through the well bore into the Prairie du Chien-Jordan aquifer.
1979-80	Use of three more municipal wells, SLP4, SLP5, Hopkins 3, discontinued because of presence of polynuclear aromatic hydrocarbons.
	Well abandonment program (MDH) begins to reduce movement of coal-tar derivatives between bedrock aquifers by sealing multiaquifer wells.



Approximate location of five drift or Platteville aquifer wells reported to be contaminated

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

EXPLANATION

● W112 (1932)	Location, project well number and reported date of contamination. Each well yielded contaminated water immediately after completion or deepening into Prairie du Chien–Jordan aquifer. (From Minnesota Department of Health, 1938)
○ W23	Location and project well number of other wells discussed in text.

Figure 2.--Location and reported dates of contamination of old wells near the former plant site

The flow chart in figure 3 presents a conceptual model of the introduction and transport of coal-tar derivatives through ground water in the St. Louis Park area. The geologic and water-bearing characteristics of hydrogeologic units (aquifers and confining beds) are summarized in figure 4. A more comprehensive description is presented in Hult and Schoenberg (1984).

Paths of Contaminants to Ground Water

Coal-tar derivatives have entered the ground-water system in St. Louis Park through three major paths (fig. 3): (1) Spills and drippings on the site which percolated through the unsaturated zone to the water table, (2) surface runoff and plant process-water discharge to ponds, depressions, wetlands on and south of the site, and (3) movement of coal tar directly into bedrock aquifers through a deep well on the site (well W23).

Spills and drippings from plant operations resulted in extensive contamination of the land surface and the unsaturated zone on the southern half of the site. Figure 5 shows the extent of industrial activity on the site during plant operation. 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. Figure 6 shows the redevelopment activity in progress. At times, the water table has been less than 5 feet below land surface over much of the site. Discoloration of soil and rock by coal-tar derivatives extends at least 10 feet below the water table on the site itself.

The second major path of contaminants to the ground-water system was through closed surface depressions and water-table ponds on and south of the site (fig. 3). Natural surface drainage was toward the site and south towards Minnehaha Creek. Since at least 1938, however, drainage to Minnehaha Creek has been disrupted by roads and other structures, and surface runoff and plant-process water from the site was discharged through ditches and culverts to water-table ponds south of the site that had no surface-water outflow. Creosote-like organic fluids are present at least 50 feet below the water table at the ponds south of the site.

The third major path through which contaminants entered the ground-water system was through a multiaquifer well on the site (well W23) that was drilled in 1917 to an original depth of 909 feet (table 1). When first evaluated by the U.S. Geological Survey in 1978, it was found to be only 595 feet deep and to contain coal tar (Hult and Schoenberg, 1984, p. 48). Approximately 150 gal/min of contaminated water was entering the Prairie du Chien-Jordan aquifer through a leak in the casing (Hult and Schoenberg, 1984, p. 29). This well has likely been the major source of contamination by coal-tar derivatives to the Prairie du Chien-Jordan aquifer. In 1982, it was determined that coal-tar derivatives had also entered the underlying Ironton-Galesville aquifer. The effects of the well on the water quality of the Mount Simon-Hinckley aquifer are not known although the well originally penetrated that aquifer.

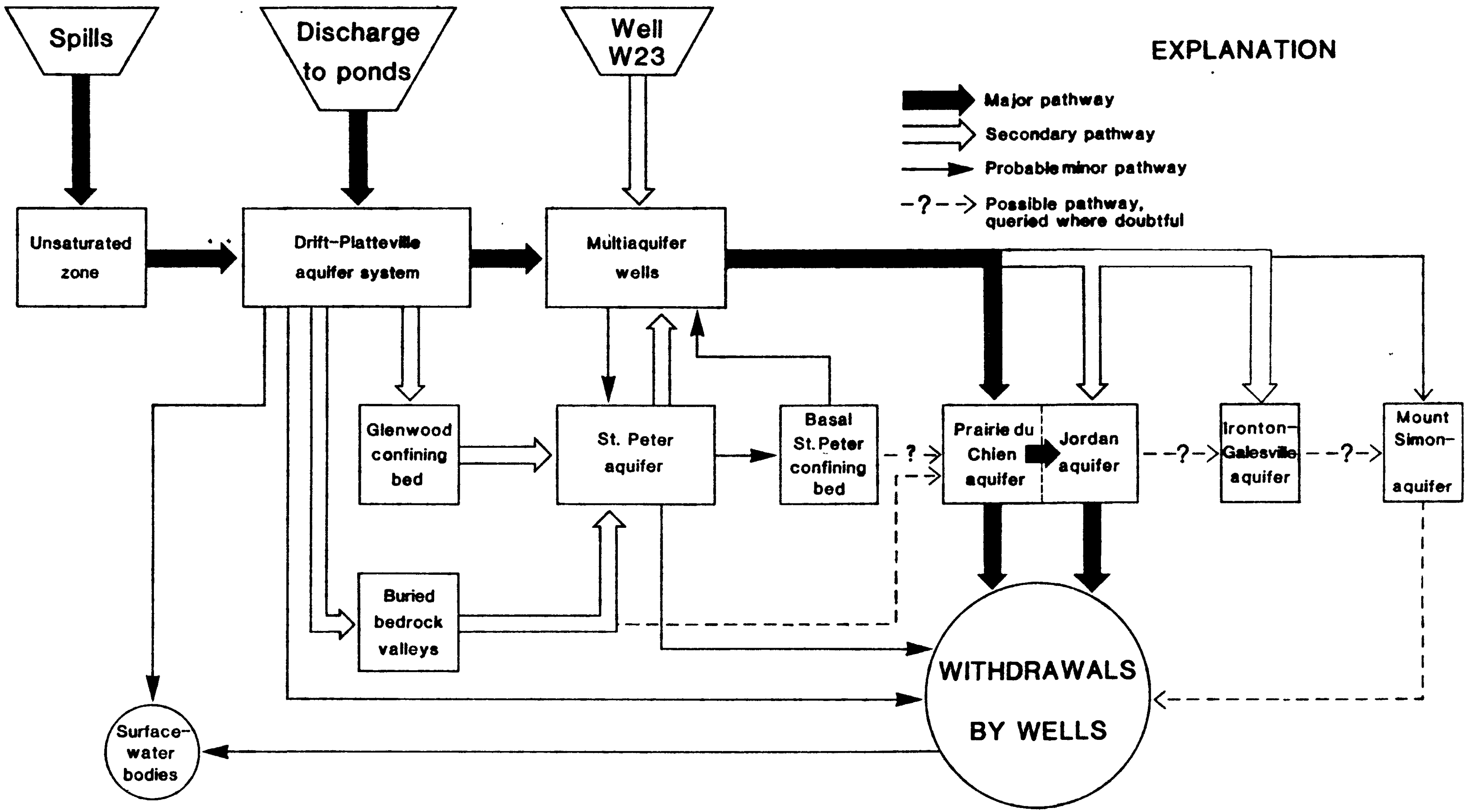
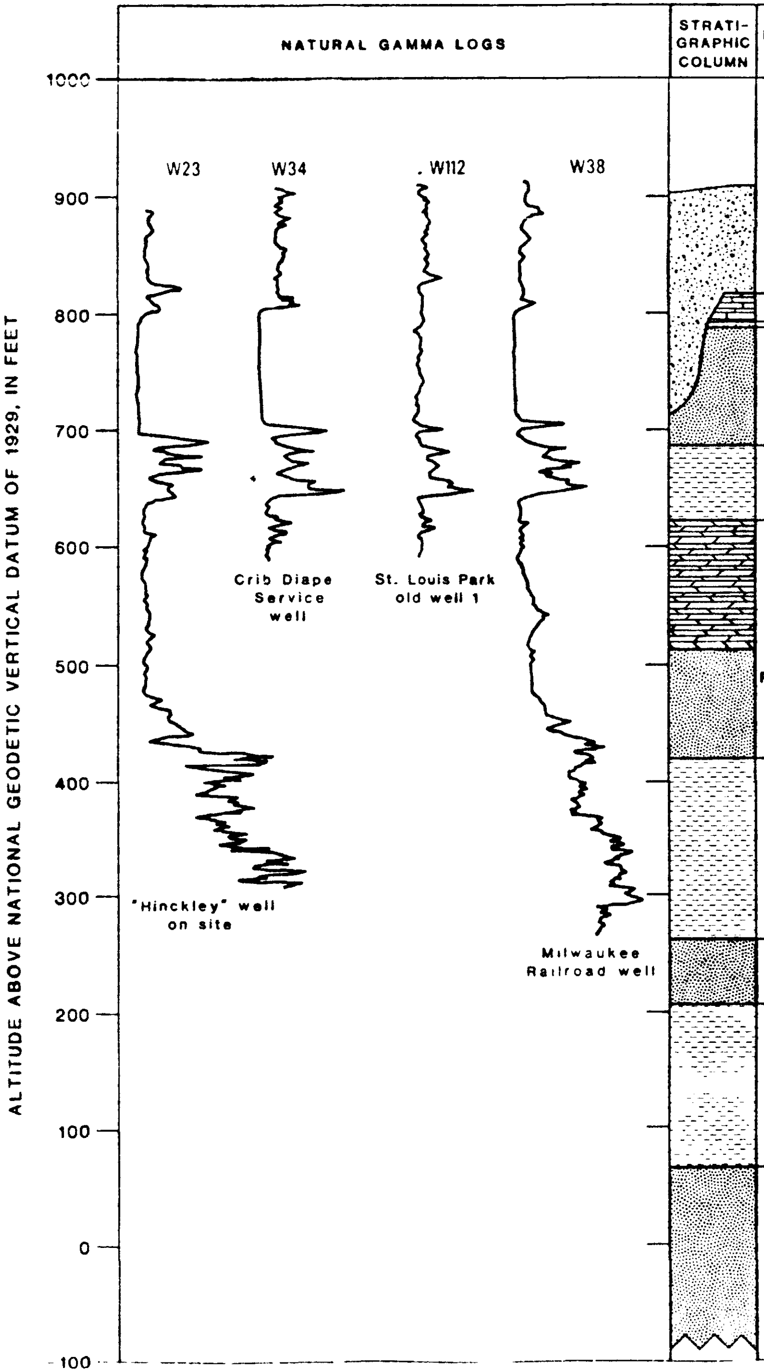


Figure 3.--Flow chart showing conceptual model of the introduction and transport of coal-tar derivatives through the ground-water system



HYDROGEOLOGIC UNIT	APPROXIMATE MAXIMUM THICKNESS, IN FEET	GEOLOGIC CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
Drift, undifferentiated	220	Till, outwash, lake clay, peat and valley fill.	**Hydraulic characteristics highly variable. Till has vertical hydraulic conductivity as low as 10^{-6} ft/s. Buried outwash aquifer has transmissivity as high as 10,000 ft^2/d.**
Platteville aquifer	35	Dolomitic limestone and dolomite, gray to buff, thin- to medium-bedded, some shale partings. Solution channels and fractures are concentrated in upper part and contain sand of glacial origin.	**Hydraulic conductivity primarily from fractures, open joints and solution channels. Specific capacities of wells are generally between 10 and 100 (gal/min)/ft of drawndown, if pumped at about 12 gal/min for one hour.**
Glenwood confining bed	7	Shale and claystone, green to buff, plastic to slightly fissil; lower 3 to 5 feet grade from claystone with disseminated sand grains to sandstone with clay matrix	Very low hydraulic conductivity. Vertical hydraulic conductivity is estimated to be about 10^{-10} ft/s based on laboratory measurements of core samples.
St. Peter aquifer	100	Sandstone, white to yellow, very well sorted, fine- to medium-grained, poorly cemented, quartzose	**Supplies about 10 percent of ground water pumped in the St. Louis Park area. Can yield more than 500 gal/min. Sandstone is poorly cemented and wells tend to pump sand or fill in.**
Basal St. Peter confining bed	65	Siltstone and claystone, red, green, and white parts are plastic in texture and poorly indurated interbedded with fine-grained quartz sandstone. Individual beds are continuous in the vicinity of the site.	Hydraulic conductivity is highly anisotropic, siltstone and claystone restrict vertical flow but sandstone may yield as much as 100 gal/min to wells
Prairie du Chien-Jordan aquifer	210	Prairie du Chien Dolomite, grayish-brown to buff, generally thickly bedded in vicinity of site Jordan Sandstone, white to pink, fine- to coarse-grained, moderately well cemented, quartzose to dolomitic	**Supplies about 75 percent of ground water pumped in the St. Louis Park and Metropolitan area. Generally yields more than 1,000 gal/min to high-capacity wells. Hydraulic conuctivity of the Prairie du Chien part of the aquifer is due to fractures, open joints, and solution channels.**
St. Lawrence-Franconia confining bed	150	Siltstone and sandstone, gray to green, poorly sorted, glauconitic and dolomitic.	Confining bed, hydraulic characteristics poorly known
Ironton-Galesville aquifer	50	Sandstone, white to light green, moderately well sorted, fine to coarse grained, quartzose.	**Regionally an aquifer, but no wells are known to yield water only from this unit in the study area.**
Eau Claire confining bed	105	Siltstone and shale, green, glauconitic	Confining bed, hydraulic characteristics poorly known
Mount Simon-Hinckley aquifer	Greater than 250	Sandstone, grayish-white to pink, silty to corse grained, well cemented, quartzose, parts are medium- to coarse grained, well sorted	Supplies about 15 percent of ground water pumped in the St. Louis Park and seven-county metropolitan area. Generally yields more than 1,000 gal/min to high-capacity wells.

From Hult and Schoenberg, 1984

Figure 4.--Geologic and water-bearing characteristics of hydrogeologic units in the St. Louis Park area

From U.S.G.S. Yearbook, 1984

Figure 5.--Vertical areal photograph of plant site during plant operation

From U.S.G.S. Yearbook, 1984

Figure 6.--Vertical areal photograph of plant site during redevelopment

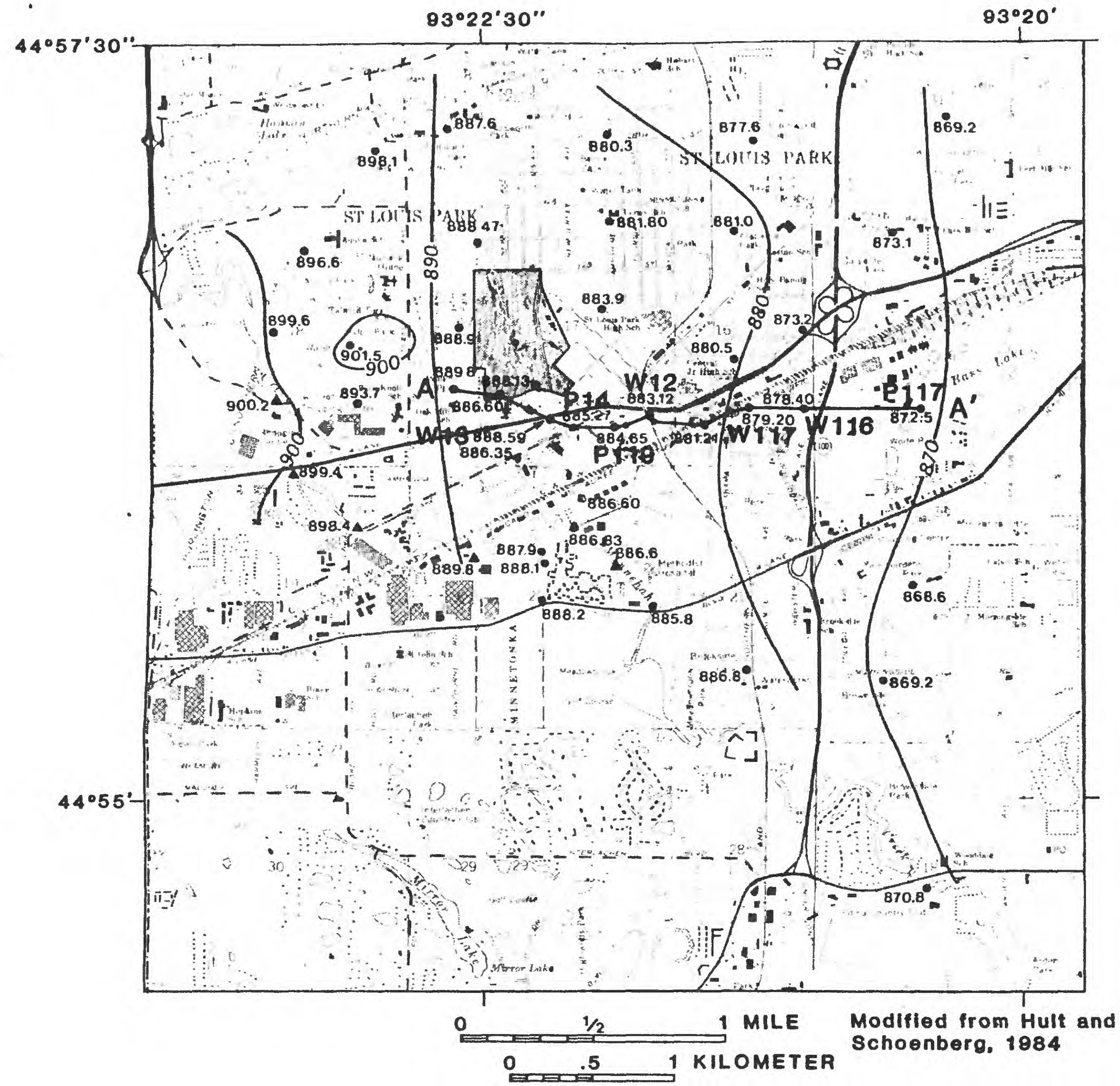
DRIFT, PLATTEVILLE, AND ST. PETER AQUIFERS

A full description of the problem in three dimensions of space might include many cross sections, and areal maps of each hydrogeologic unit at various depths. Hult and Schoenberg (1984) show water levels and concentration of major chemical constituents for the Middle Drift and Platteville aquifers, and along two different geologic sections. For the purpose of illustrating major processes in the drift and Platteville aquifer, this report presents data on geologic, hydrologic, chemical, and biologic processes along one representative hydrogeologic section. The location is consistent with the east-west section in Ehrlich and others (1982) and Hult and Schoenberg (1984) and incorporates data from 47 wells and piezometers. The section is oriented approximately parallel to the direction of ground-water flow at the water table (fig. 7), in the drift, and Platteville and St. Peter aquifers. The section extends from upgradient (west) of the site, eastward across the southwestern corner of the site, through the volume known to contain organic fluids underneath the ponds, across the buried bedrock valley (approximately 100 feet south of multiaquifer well W38), and between other known sources of petroleum-derived organic contaminants near 36th and Woodale Avenues. The section extends eastward to 36th Avenue and Beltline Drive.

Hydrogeology

Figure 8 shows the distribution of drift units, and the Platteville and St. Peter aquifers. The depth of the bedrock valley where the Platteville aquifer has been removed by erosion is exaggerated for clarity. Farther to the south, the valley is deeper than along section A-A'. Figure 9 shows that the lateral direction of ground-water flow is generally from west to east through all units. Vertically downward gradients are greatest near the site where ground water moves through peat with a low vertical hydraulic conductivity (less than 1 x 10^{-5} cm/sec), across the Glenwood confining bed (vertical hydraulic conductivity less than 1 x 10^{-8} cm/sec) and near the bedrock valley at Woodale Avenue where gray till (vertical hydraulic conductivity about 1 x 10^{-7} cm/sec) overlies the bedrock. Water moves from west of the site, through the volume containing the coal-tar fluids, and to the buried valley. Near the buried valley a component of flow is perpendicular to the line of the section down the buried bedrock valley (generally southward). East of the valley, the flow is again eastward.

The upper section (April 23, 1980) on figure 9 depicts conditions before the sealing of multiaquifer well W38 (Milwaukee Railroad well). The low water level in the Platteville aquifer at this location is due to flow out of the Platteville into the Prairie du Chien-Jordan aquifer through this well--not flow into the bedrock valley as previously interpreted in Hult and Schoenberg (1984, p. 37 and Plate 3). Contaminants moving eastward through the Platteville and St. Peter aquifers were intercepted by the multiaquifer well, but water-level measurements indicate that contaminant movement through the Middle Drift aquifer was not significantly affected.



Modified from Hult and Schoenberg, 1984

EXPLANATION

Water-level altitude, in feet above National Geodetic Vertical Datum of 1929

W13 886.35● Water-table piezometer and water-level altitude, June 6, 1979

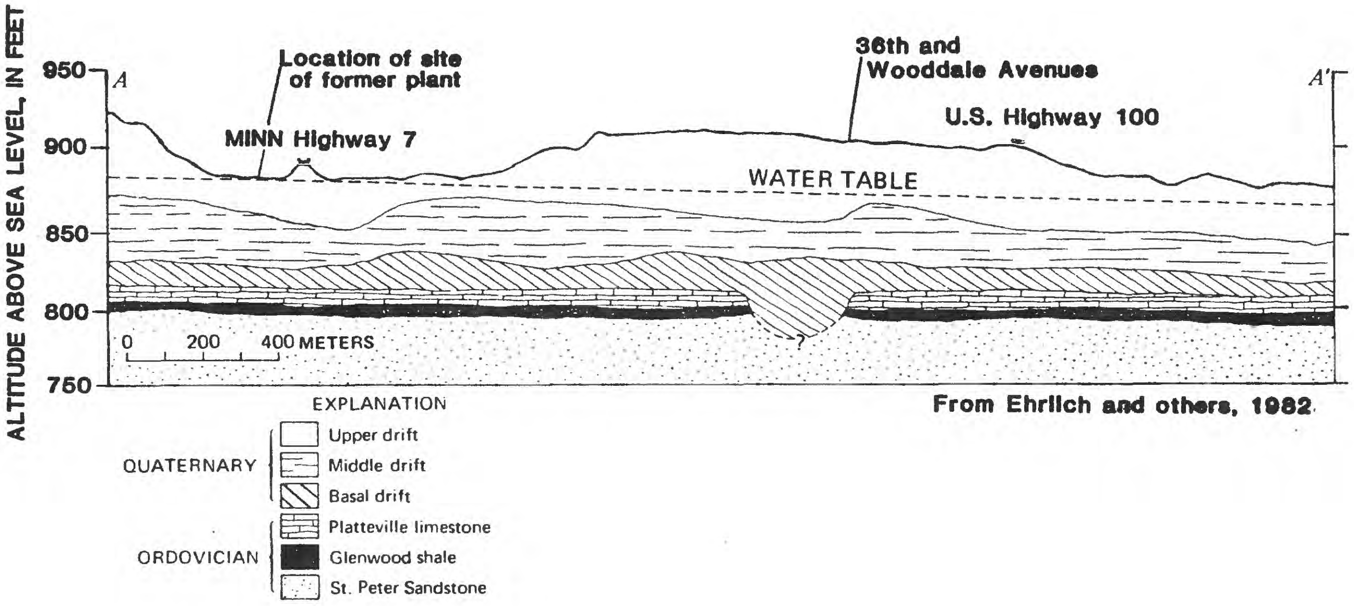
898.4▲ Surface-water station and water-level altitude, June 6, 1979

—880— WATER-TABLE CONTOUR--Shows altitude of water table. Contour interval 10 feet.

A●———●A' Line of section

▨ Site of former plant

Figure 7.--Map showing generalized configuration of the water table and location of study section A-A'



From Ehrlich and others, 1982

Figure 8.--Geologic section through drift, Platteville aquifer, Glenwood confining bed, and upper part of St. Peter aquifer in the vicinity of the former plant site

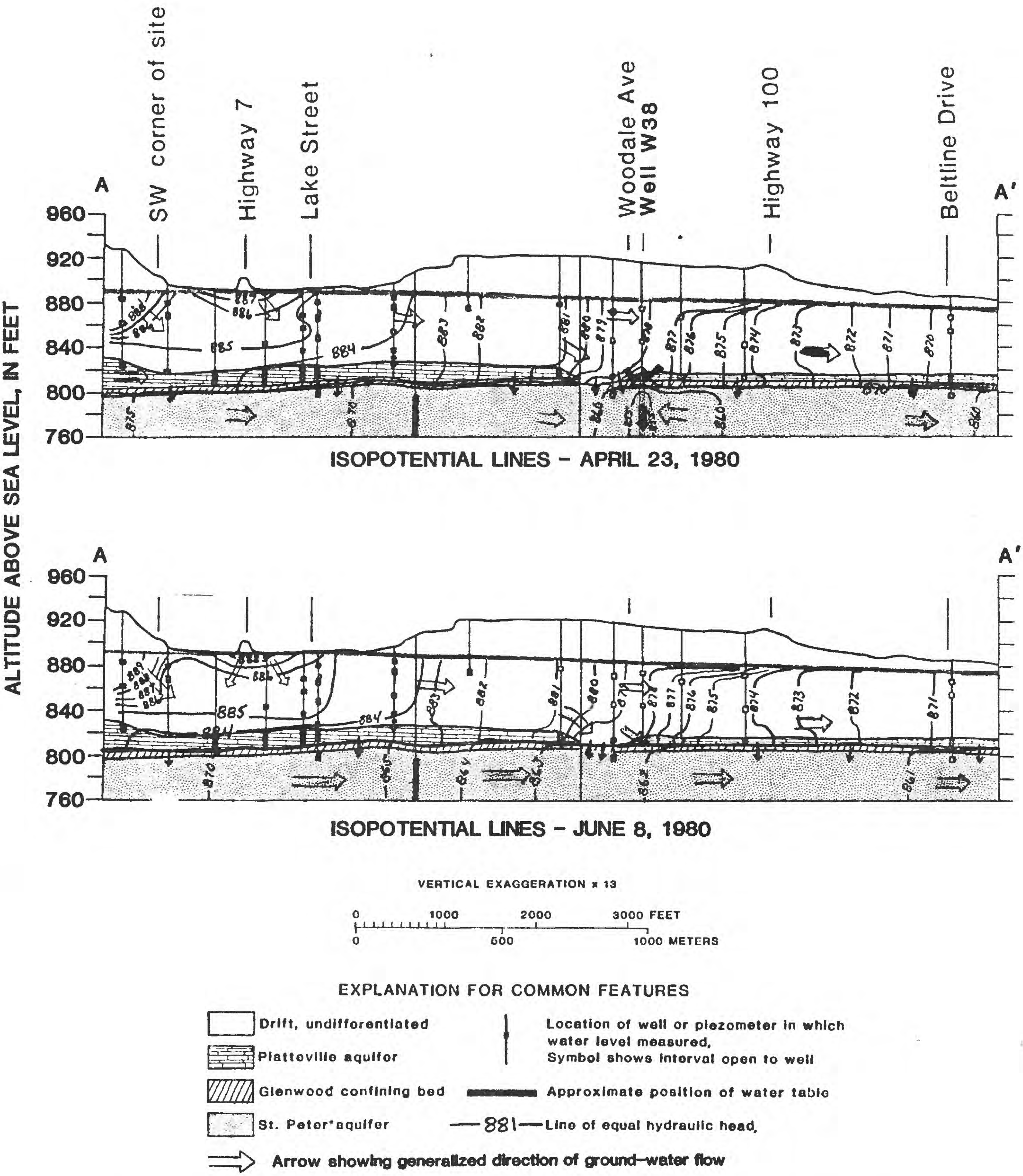


Figure 9.--Sections showing: Direction of ground-water flow, April 23, 1980, and June 8, 1980

The lower section (June 8, 1980) shows the distribution of hydraulic head after well W38 was sealed. Under these changed conditions, contaminated water in the Platteville and St. Peter aquifers previously intercepted by the well can continue migrating eastward through these aquifers.

Water Quality

Distribution and Movement of Inorganic Contaminants

The inorganic constituents of ground water in the drift-Platteville system were studied because inorganic contaminants were discharged along with the coal-tar derivatives, are useful as tracers in evaluating transport processes, and because an understanding of prevailing geochemical conditions is necessary to evaluate the chemical and biologic processes that control the fate of the contaminants.

A detailed discussion of the distribution of all inorganic constituents of the ground water is beyond the scope of this report. However, the hydrogeologic section on figure 10 shows the concentration of sodium and a general view of the geometry of the contaminant plume along the line of section. The figure shows the expected decrease in concentration down the hydraulic gradient, as well as a zone of elevated concentrations near the bedrock valley. The elevated concentrations near the valley may be due to contaminants that migrate parallel to, but north of the line section west of the valley, and then move southward towards the section because of vertical flow into the underlying St. Peter aquifer. They may also be due to a separate source of sodium (and chloride).

The distribution and concentration of inorganic nitrogen species (ammonia, nitrite, and nitrate), sulphur (sulfide and sulfate), dissolved oxygen, and manganese and iron suggest that the main body of the plume is under strongly reducing conditions and, therefore, biologic processes occur under anaerobic conditions. It has been shown that degradation of some simple phenolic compounds is now occurring even under the reducing (anaerobic) conditions that prevail in most of the plume (Ehrlich and others, 1982, 1983; Godsey and others, 1983). At the periphery of the plume, sufficient oxygen is present for aerobic biologic processes to occur. This is significant because many more coal-tar derivatives are degraded by bacteria under aerobic conditions than under anaerobic conditions. Sufficient concentrations of nutrients (nitrogen and phosphorus) are present for active aerobic degradation. Although the low ground-water temperature (about $9^{o}C$) limits biologic growth, the rate at which oxygen enters the ground-water system is most likely the primary factor limiting the rate at which the coal-tar derivatives are degraded. This suggests that artificial introduction of oxygen would stimulate more rapid degradation by enhancing naturally-occurring processes.

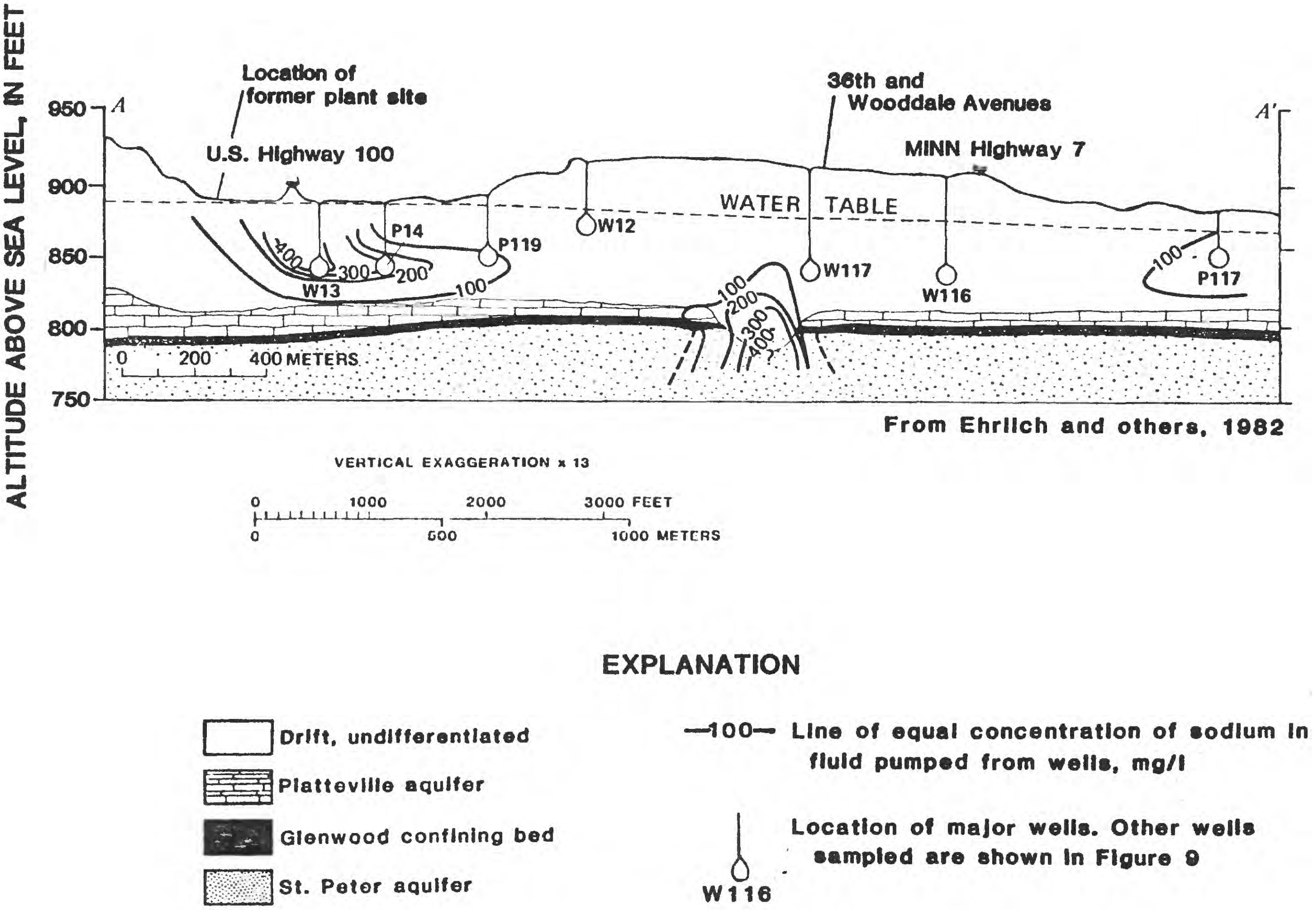


Figure 10.--Concentration of sodium, May-July, 1980

Distribution and Movement of Organic Contaminants

Discharge of coal-tar wastes to the environment resulted in the accumulation of coal-tar fluids in the drift. The fluids identified to date are more viscous and denser than water, and closely resemble creosote in chemical composition as shown by the two GC/FID chromatograms in figure 11. (Analysis by D. F. Goerlitz, U.S. Geological Survey; quantitative data for these analyses are presented in Ehrlich, 1982).

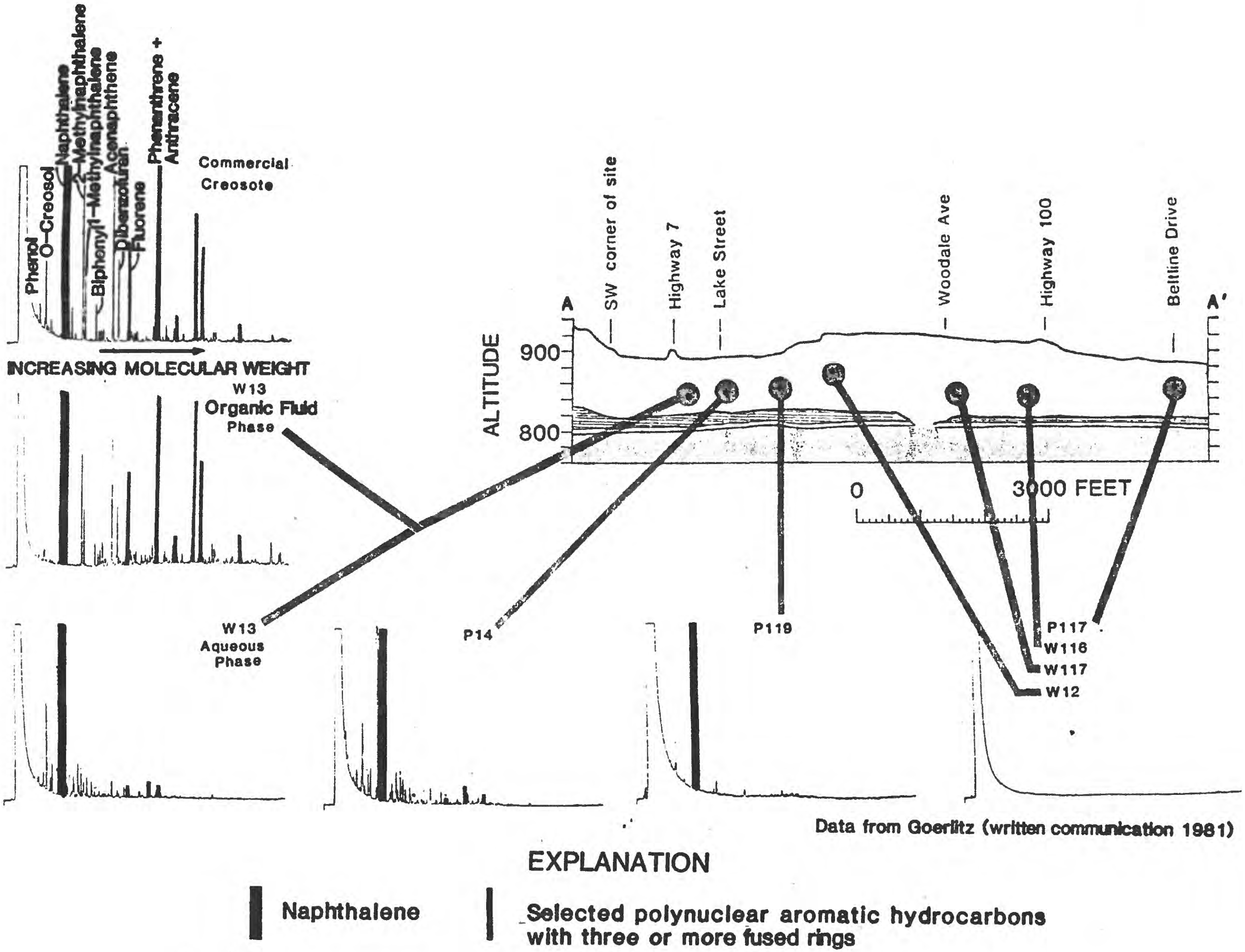
The organic fluid moves downward through the drift because it is denser than water, and moves more slowly than water because it is more viscous. As the fluid moves, some is left behind as residual saturation in the pores of the porous media through which it has migrated. This residual saturation is not mobile as a macroscopically distinct fluid phase. However, the surface area of contact between the water and the tarry fluids and the hydraulic conductivity of the porous media are both greater compared to conditions of complete saturation. Consequently, the rate of dissolution is greater compared to fully saturated conditions.

Ground water moving past the hydrocarbon fluids in the drift preferentially leaches these fluids of the more soluble constituents as shown by the chromatograms of the organic and aqueous phases of fluid pumped from well 13 (fig. 11). Because of the general, systematic relationships between the solubility, density, and molecular weight of coal-tar constituents, this weathering process will cause the fluid to become denser, more viscous, and less mobile.

The water quality in the drift and Platteville aquifer is controlled primarily by dissolution of these organic fluids. Unless isolated or removed, they will continue to dissolve into the ground water, in decreasing concentration and varying composition, for the indefinite future. The downgradient movement of chemically and biologically refractory coal-tar derivatives will continue until the source is removed or the hydraulics of the ground-water system changed.

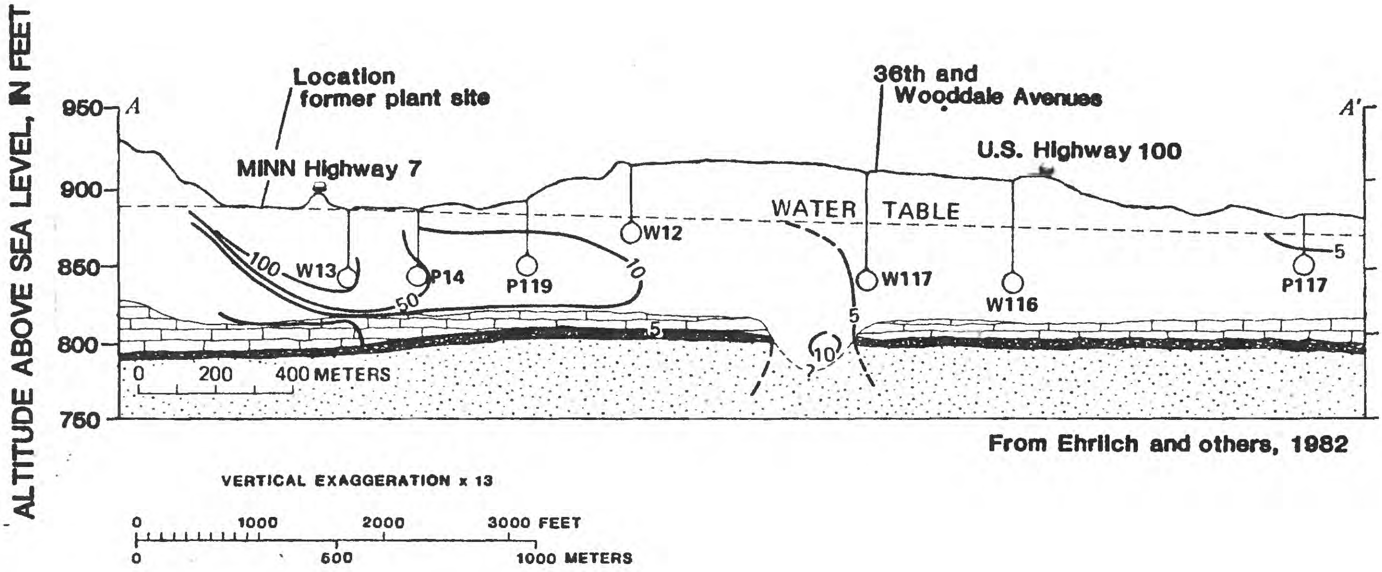
Total Organic Carbon

The geometry of the plume of organic carbon (fig. 12) is consistent with that for the inorganic indicators such as sodium. The concentrations of total organic carbon is valuable in assessing the general severity of contamination by organic compounds. Uncontaminated ground water in the area typically contains about 3 mg/L total organic carbon. Higher concentrations are due primarily to discharges from the former plant site although locally natural sources of organic carbon such as peat, and other contaminant sources such as spills of petroleum may contribute. The geometry of the plume indicates that contaminants have reached the bedrock valley near 36th and Woodale Avenues where they enter the St. Peter aquifer.



Data from Goerlitz (written communication 1981)

Figure 11.--Chromatograms of creosote and fluids pumped from wells on section A-A'



From Ehrlich and others, 1982

EXPLANATION

☐ Drift, undifferentiated

▤ Platteville aquifer

■ Glenwood confining bed

░ St. Peter aquifer

— 50 — Line of equal concentration of total organic carbon in aqueous phase of fluid pumped from wells, mg/l

W116 Location of major wells. Other wells sampled are shown in Figure 9

Figure 12.--Concentration of total organic carbon, May-July, 1980

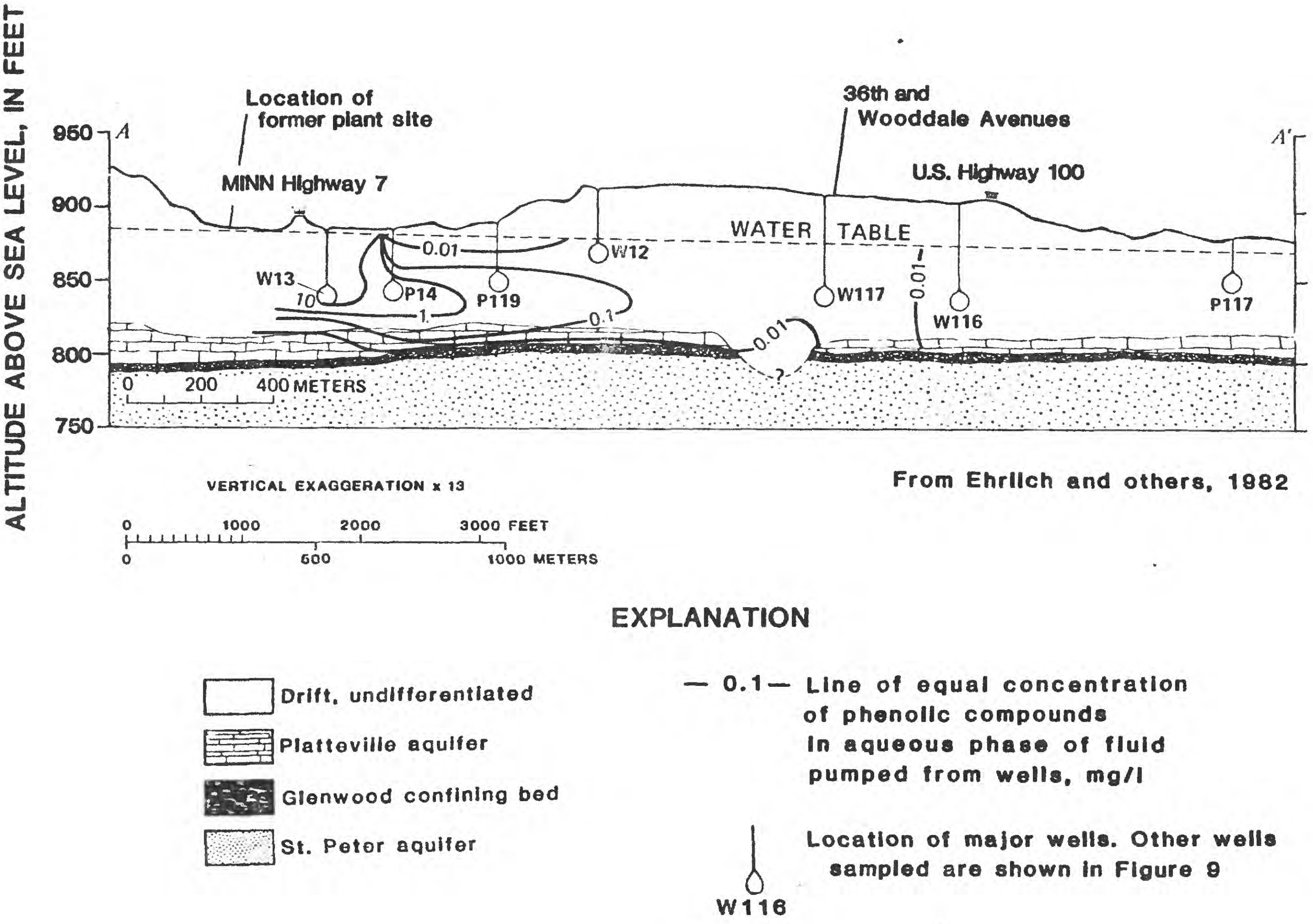
Phenolic Compounds

The distribution of phenolic compounds measured by a colorimetric method is shown in figure 13. The distribution of phenolic compounds shows much more pronounced attenuation downgradient than some other indicator parameters. Column experiments by H. O. Pfannkuch and G. Cohen (Cohen, 1983) and by D. F. Goerlitz (Goerlitz, 1984) have shown that the movement of phenol is not significantly retarded by sorption on drift materials from the area of the site. Although some mixing of contaminated water seems to be occurring near the bedrock valley, the differential attenuation of phenolic compounds seems to be due primarily to degradation of the phenols by bacteria to carbon dioxide, methane, and, probably, volatile fatty acids. Degradation of the phenols is discussed in more detail in Ehrlich and others (1982, 1983) and Godsey and others 1983).

Polynuclear Aromatic Hydrocarbons

Figure 11 shows chromatograms of a commercial creosote, the organic fluid phase of a sample pumped from well W13, the aqueous phase pumped from the same well, and samples from six downgradient wells. The chromatograms are presented to give a visual indication of the relative proportion of individual compounds between samples. Quantitative data for chromatograms of the aqueous phase samples are shown in table 2 of Ehrlich and others (1982). Other quantative, corroborating data are in Conrad and others (1981), and files of the U.S. Geological Survey.

The chromatograms show that the organic fluid yielded by well 13 is not readily distinguishable from commercial creosote by this technique. The companion chromatogram for the aqueous phase of the sample from well W13 shows the selective dissolution of the low-molecular-weight compounds (the peaks toward the left on each chromatogram). Each of the chromatograms has been normalized approximately so that the peak areas of naphthalene are the same. The chromatograms show that the proportion of low-molecular-weight compounds relative to high molecular-weight compounds increases substantially between phases, and down the hydraulic gradient in the plume. The low-molecular-weight compounds are preferentially dissolved because they are more soluble than high-molecular-weight compounds. The high-molecular-weight compounds are more strongly attenuated downgradient because they are sorbed by the aquifer.



From Ehrlich and others, 1982

Figure 13.--Concentration of phenolic compounds, May-July, 1980

Much additional detailed chemical data are available to show trends for individual compounds. The distribution of two PAH compounds of considerable interest are shown in figures 14 and 15. Acenaphthene is a major constituent of coal-tar and creosote and seems to be the lowest molecular weight PAH that has been consistently measured at high concentrations in water from municipal wells in the area. Benzo(a)pyrene is a carcinogenic PAH of major concern. The downgradient attenuation of each compound is apparent in the sections, but neither data set demonstrates the maximum eastward extent of contaminant migration because compound concentrations fall below the method-detection limits. Near 36th and Woodale Avenues, two separate spills of petroleum products have occurred that contribute organic substances to ground water. The refined products (fuel oil and lubricating oil) consist primarily of aliphatic organic compounds and contain only minor amounts of PAH. Chlorinated organic compounds used as industrial solvents are also present. Toward the eastern downgradient edge of the section, the highest concentration of benzo(a)pyrene is associated with a sample from the Platteville aquifer, presumably because sorption is less than in the drift.

Assessment of Ground-Water Contamination

The major processes in the drift, Platteville, and St. Peter aquifers are summarized in figure 16. Ground water flows laterally from west to east through the drift and Platteville aquifer. Near the site, organic fluids have migrated vertically downward through the drift and are partially dissolved by flowing ground water. The ground water preferentially mobilizes low-molecular-weight compounds such as phenols, benzenes, and naphthalene, although PAH compounds as heavy as benzo(a)pyrene are also mobilized at lower concentrations. The dissolved organic and inorganic contaminants move eastward and downward with the flowing ground water. Sorption of higher molecular-weight compounds (particularly in the drift) further increases relative differences in concentrations of organic substances.

Some individual phenolic compounds are being degraded by bacteria under anaerobic conditions; other low molecular-weight compounds are being degraded at the periphery of the plume where oxygen is available for aerobic bacterial metabolism. Near 36th and Wooddale Avenues, contaminants enter the St. Peter aquifer. East of 36th and Wooddale, ground-water flow through multiaquifer wells and into the buried bedrock valley, other sources of organic substances, and low contaminant concentrations, complicate detailed evaluation of the distribution, movement, and fate of the coal-tar derivatives.

The distribution of contaminants in the St. Peter aquifer is not known as well as in overlying aquifers because fewer wells are available for measurement purposes. However, as in the overlying drift and Platteville aquifers, and the underlying Prairie du Chien-Jordan aquifers, it is likely that PAH resistant to biologic degradation will continue to migrate until ground water in the aquifer discharges to a surface-water body, is intercepted by a multiaquifer well, or moves vertically downward through the underlying confining bed.

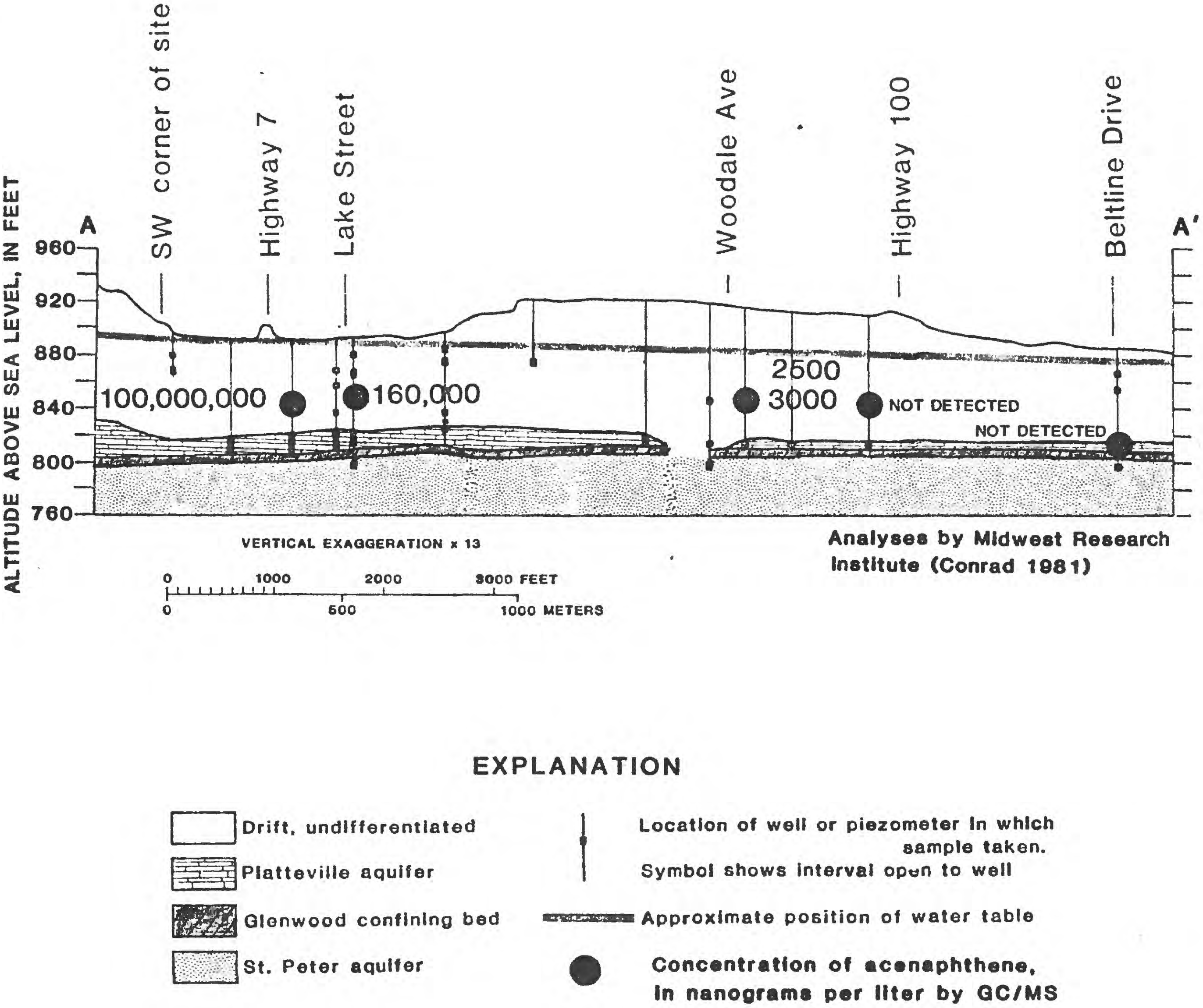
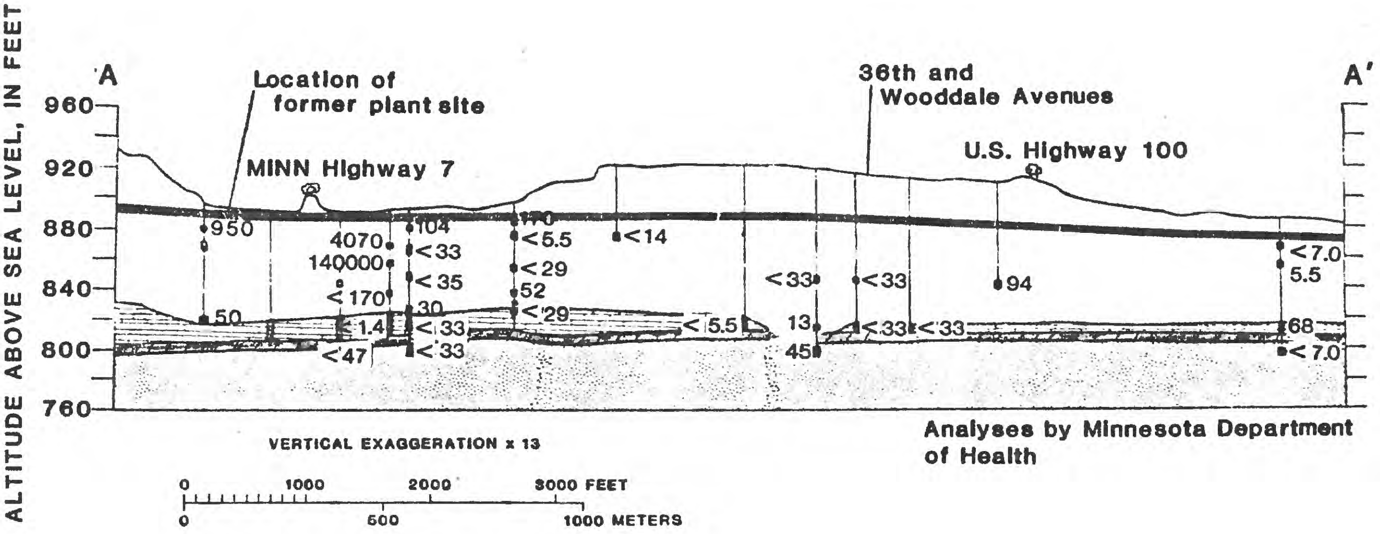


Figure 14.--Concentration of acenaphthene, February, 1981



EXPLANATION FOR COMMON FEATURES

EXPLANATION

☐ Drift, undifferentiated

▤ Platteville aquifer

▨ Glenwood confining bed

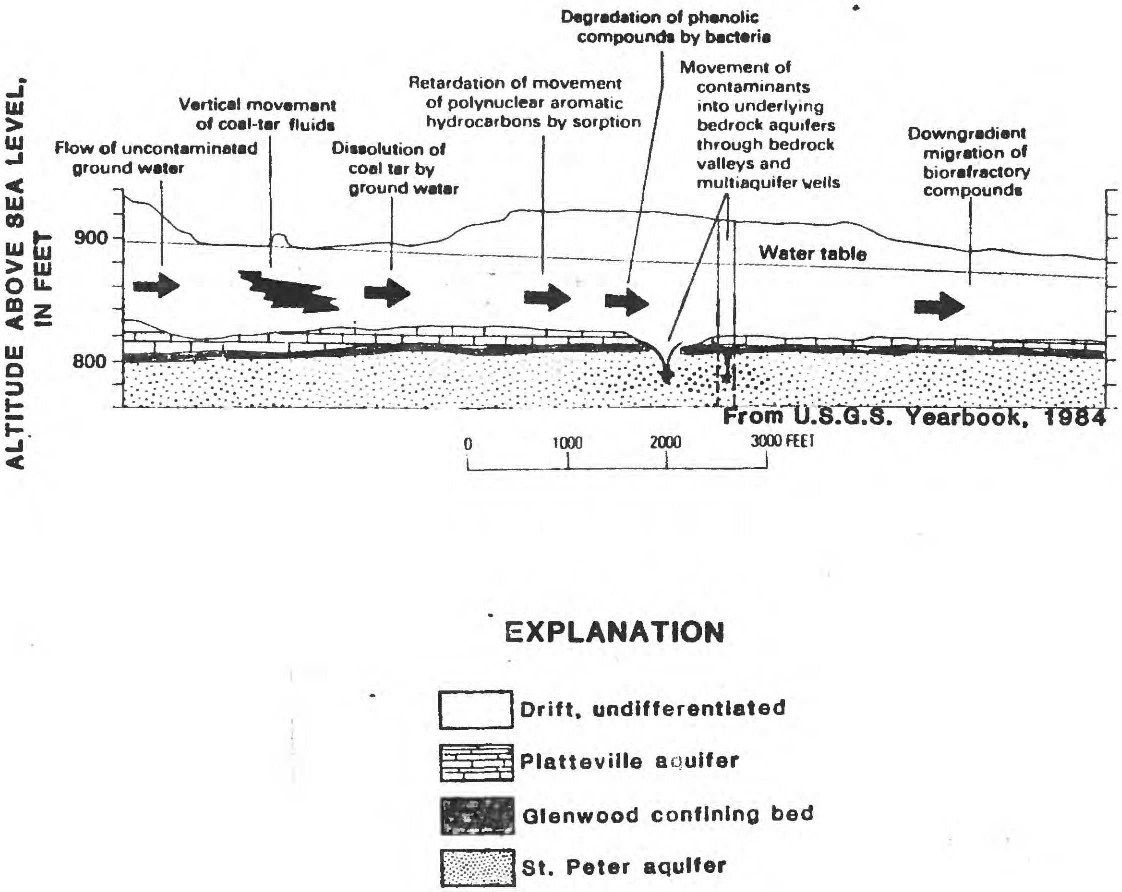
░ St. Peter aquifer

| Location of well or piezometer in which sample taken. Symbol shows interval open to well

▬ Approximate position of water table

94 Concentration of Benzo(a)pyrene, in nanograms per liter

Figure 15.--Concentration of benzo(a)pyrene, May-July, 1980



From U.S.G.S. Yearbook, 1984

Figure 16.--Zones of major processes controlling transport through groundwater and fate of coal-tar derivatives

PRAIRIE DU CHIEN-JORDAN AQUIFER

The Prairie du Chien-Jordan aquifer is the region's major ground-water resource. About 75 percent of ground-water withdrawals in the St. Louis Park and Minneapolis-St. Paul Metropolitan areas are from this aquifer (Hult and Schoenberg, 1984, p. 24). The aquifer is relatively well protected from near-surface sources of contamination. In the St. Louis Park area, it is 250 to 500 feet below land surface and is overlain by drift, two bedrock confining beds (Glenwood and basal St. Peter), and two bedrock aquifers (Platteville and St. Peter) (fig. 4). It is now contaminated because contaminants have entered the aquifer through multiaquifer wells (fig. 3). The major source of contaminants is a well (W23) drilled on the site in 1917 that has contained liquid coal tar since at least 1958 (table 1).

When the first municipal well was drilled in 1932, the Prairie du Chien-Jordan aquifer contained water having a coal-tar taste at least 3,500 feet from the plant site. During 1978-81, use of seven more municipal wells completed in this aquifer was discontinued because the wells yielded water containing trace amounts of coal-tar compounds. The long history of contamination, steep hydraulic gradients that result from the large ground-water withdrawals (pumping), and the hydrologic characteristics of the aquifer have combined to create a complex and widespread distribution of coal-tar contaminants.

Hydrogeology

The hydraulic and water-bearing characteristics of the Prairie du Chien-Jordan aquifer are important in determining how contaminants move through it. Approximately the upper half of the aquifer is the Prairie du Chien Group that consists mostly of dolomite (fig. 4). The permeability and porosity of these rocks is due primarily to jointing and enlargement of joints by dissolution of the carbonate minerals, not to intergranular permeability and porosity such as in the Jordan sandstone.

The nature of the permeability makes the Prairie du Chien particularly susceptible to contamination, and permits contaminants to move large distances rapidly once they have entered the aquifer. Hult and Schoenberg (1984, p. 29-30) note that the aquifer is vulnerable to contamination through multiaquifer wells because flow into the aquifer does not cause clogging of the pores as with sandstone aquifers, and high flows can be sustained. Areal and vertical differences in the permeability of the Prairie du Chien are at a larger and more pervasive scale than, for example, the Jordan Sandstone. These differences in permeability cause differences in flow paths of contaminants moving through the aquifer. In the Karst area of southeastern Minnesota, caves and underground streams have developed in the aquifer. These large solution channels can provide direct conduits for contaminant transport and can cause contaminants to move rapidly, and in unexpected directions.

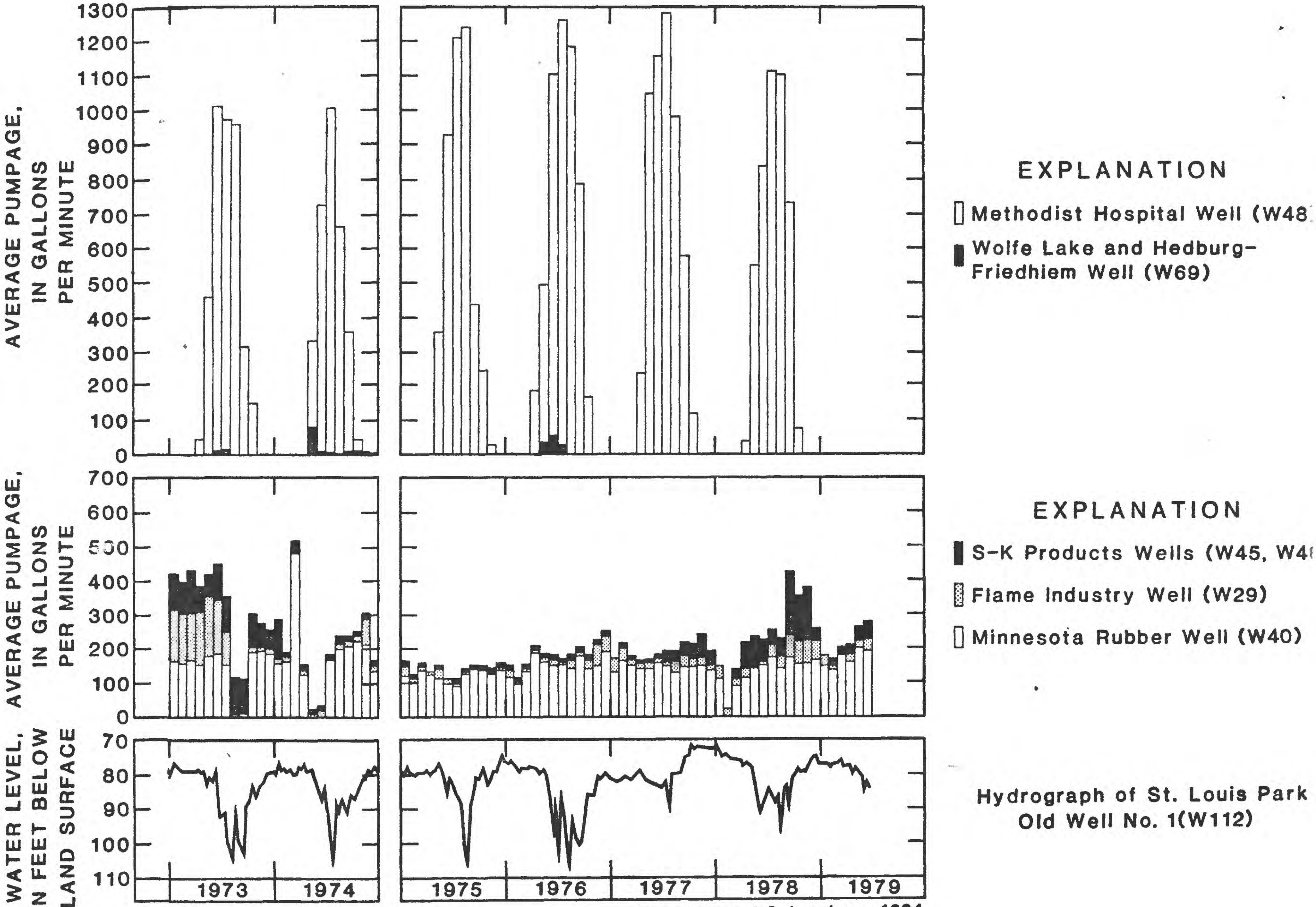
The apparent transmissivity (thickness times hydraulic conductivity) of the Prairie du Chien (about 7,000 ft^2/d) is larger than that of the Jordan (about 2,000 ft^2/d). The effective porosity of the Prairie du Chien is lower (about 4 percent) than that of the Jordan (about 20 percent). Therefore, under equal hydraulic gradients, contaminants can move much more rapidly through the Prairie du Chien than through the Jordan.

The surface area of the Prairie du Chien available for sorption is several orders of magnitude less than that of the Jordan; consequently, attenuation and retardation of contaminants is less. Because the joints and solution channels in the Prairie du Chien are large compared to the pore spaces in sandstone, organic fluid phases, if present, may move greater distances than through sandstone. As organic fluids move, they may coat surfaces of the Prairie du Chien with a thin layer that does not significantly reduce the hydraulic conductivity of the aquifer, but that provides a large surface area for dissolution of the contaminants.

Pumpage from the Prairie du Chien-Jordan aquifer is constantly changing in space and time causing ground-water gradients and the direction of contaminant transport to change. Changes in pumping occur on daily, weekly, and seasonal cycles. Figure 17 shows the relationship between the water level at well W112 (St. Louis Park old well no. 1), which is not pumped and is not itself a hydraulic stress, and pumpage from five nearby wells. Water levels change substantially between winter and summer because of a greater demand for water during the summer. At well W112, the seasonal change in water level is as much as 30 feet.

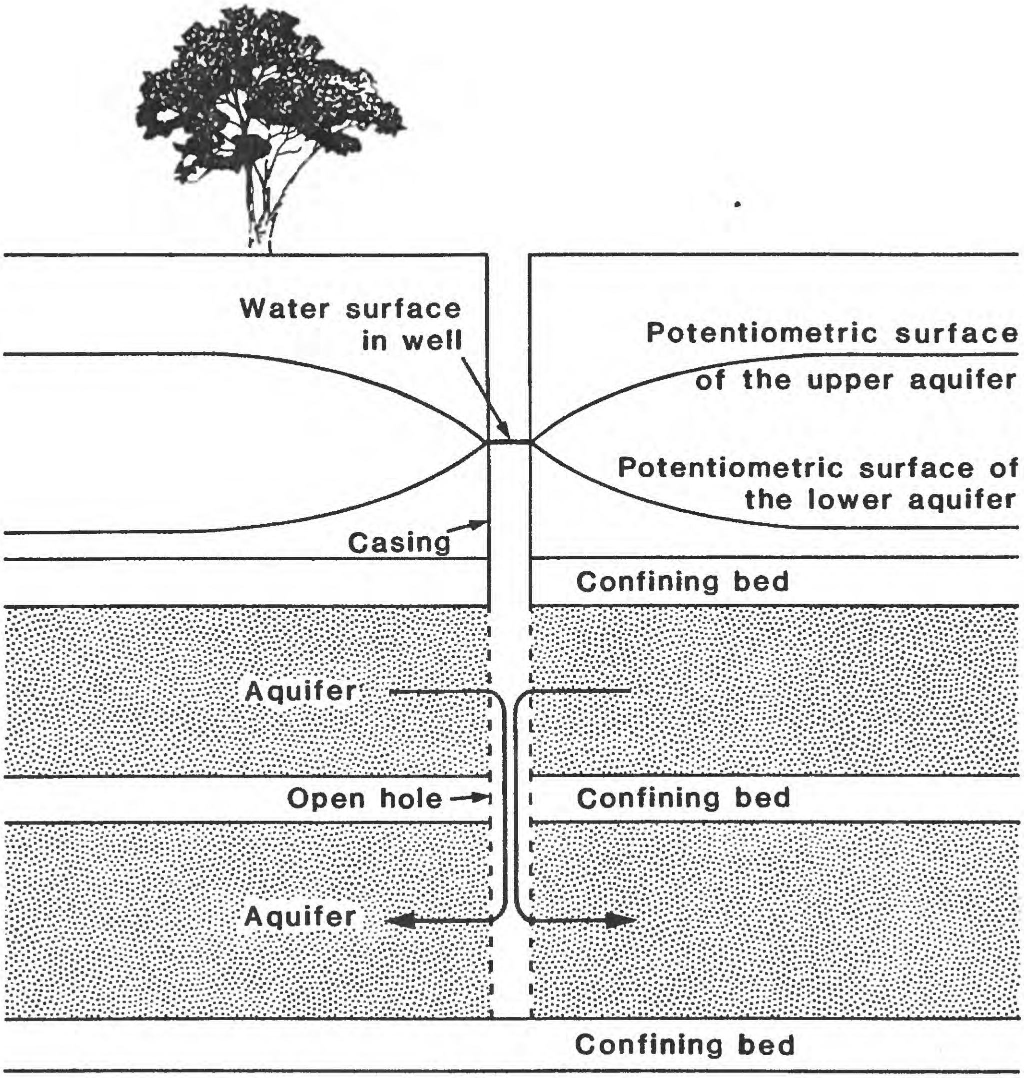
Another cause of spatial variations in the potentiometric surface of the Prairie du Chien-Jordan aquifer is flow through multiaquifer wells. A multiaquifer well hydraulically connects more than one aquifer (fig. 18). In the St. Louis Park area, the hydraulic head (potentiometric surface) of each aquifer is higher than the level in underlying rocks. Therefore, flow through the bore of a multiaquifer well is downward. This flow causes a cone of impression to form, and for water to flow radially away from the well in the lower aquifer.

A major, persistent feature of the potentiometric surface of the aquifer near the site is a mound that appears to be caused by the flow of water into the aquifer through multiaquifer wells (fig. 19). Until July 1979, approximately 150 gal/min flowed downward into the Prairie du Chien-Jordan aquifer from the St. Peter aquifer through well W23 (Hult and Schoenberg, 1984, p. 29; fig. 20). However, the flow was stopped in this and all other wells located in the field that permitted water to flow into the aquifer (fig. 21). Water from one or more multiaquifer well may still be entering the aquifer near the site because the mound in the potentiometric surface of the Prairie du Chien-Jordan has persisted (fig. 19). This is significant because if water is entering this well(s) from the drift or Platteville aquifer, the water is probably contaminated.



From Hult and Schoenberg, 1984

Figure 17.--Graph showing relationship between water levels in W112 (St. Louis Park Old Well No. 1) and pumpage in the Prairie du Chien-Jordan aquifer, 1973-1979



From Hult and Schoenberg, 1984

Figure 18.--Schematic diagram flow through a well connecting two aquifers(multiaquifer well)

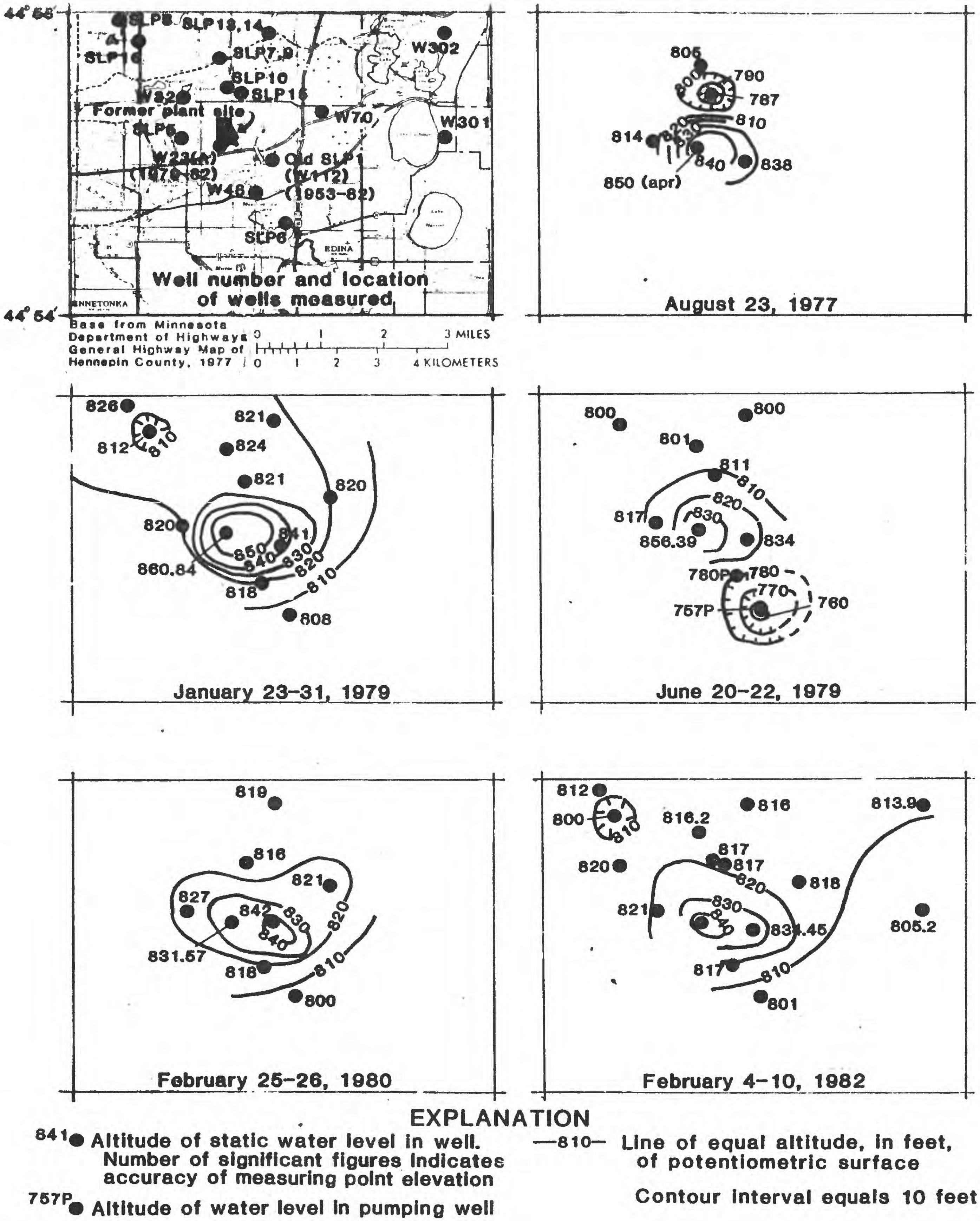
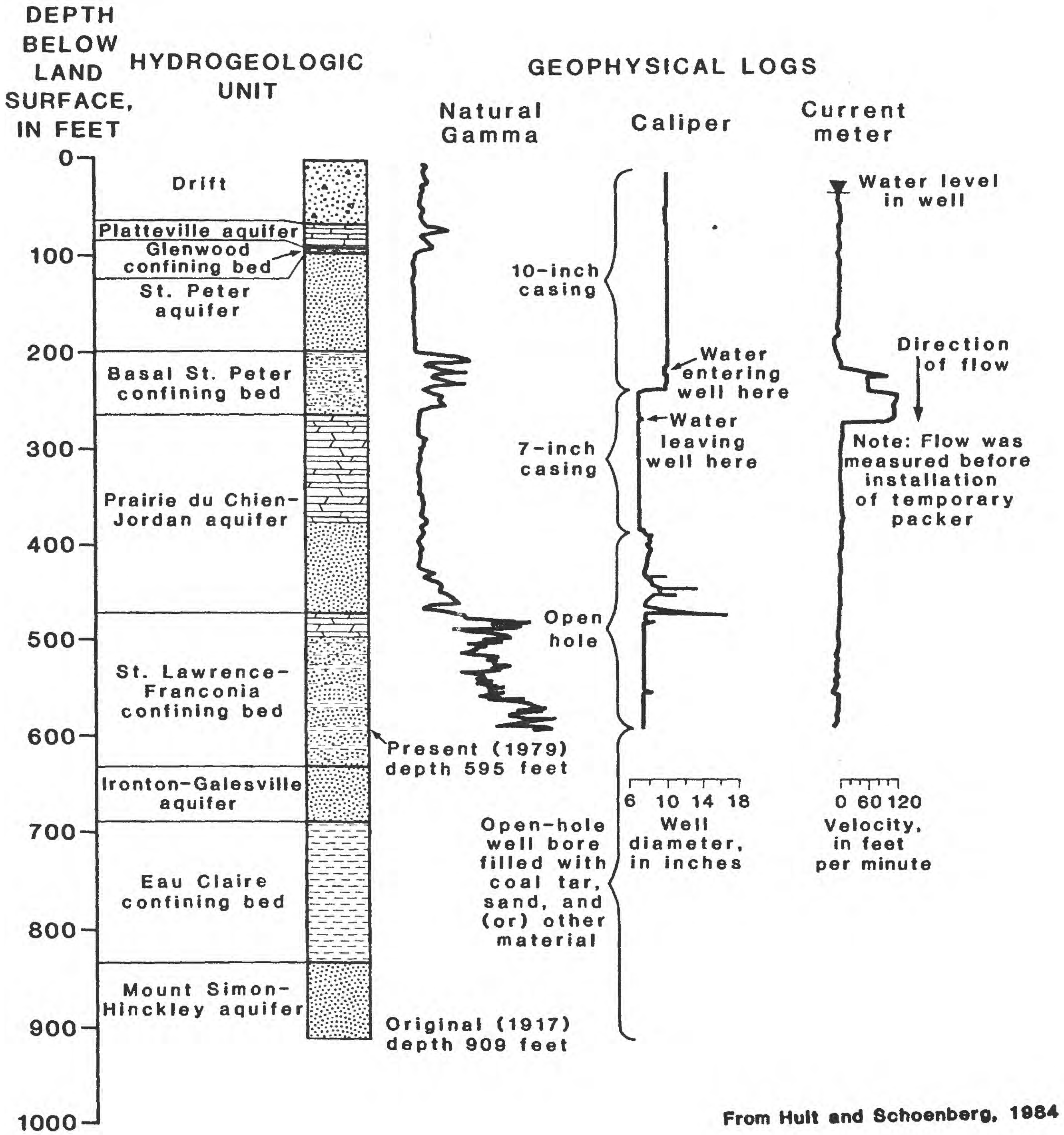
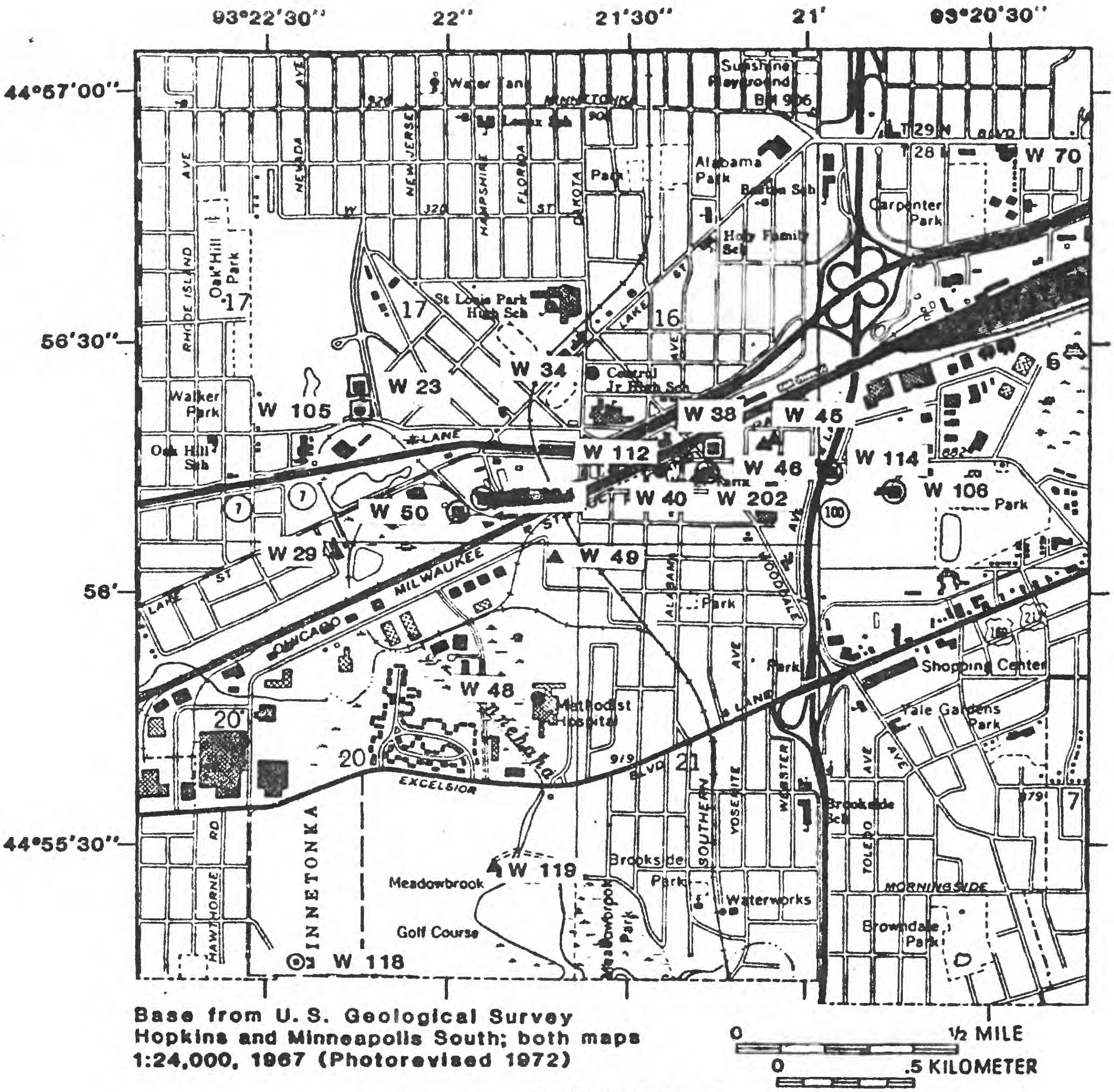


Figure 19.--Potentiometric surface of the Prairie du Chien-Jordan aquifer in the vicinity of the former plant site, August 1977-February 1982



From Hult and Schoenberg, 1984

Figure 20.--Hydrogeologic and geophysical logs of well W23 ("Hinckley" well on the site)



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

EXPLANATION

●	W112	Location and project well number
	■	Flow of water into Prairie du Chien–Jordan aquifer was detected and (or) measured
	●	No flow detected by geophysical logging and (or) inspection by down–hole T.V.
	▲	Well is known to exist, but has not been physically located or is presently (1984) not accessible
⊙	W202	Circle denotes well that was permanently sealed by MDH or well owner
▣	W38	Square denotes well that was reconstructed or fitted with temporary packer and is now (1984) used for observation purposes

Figure 21.--Location and status of wells evaluated for flow of water into the Prairie du Chien-Jordan aquifer

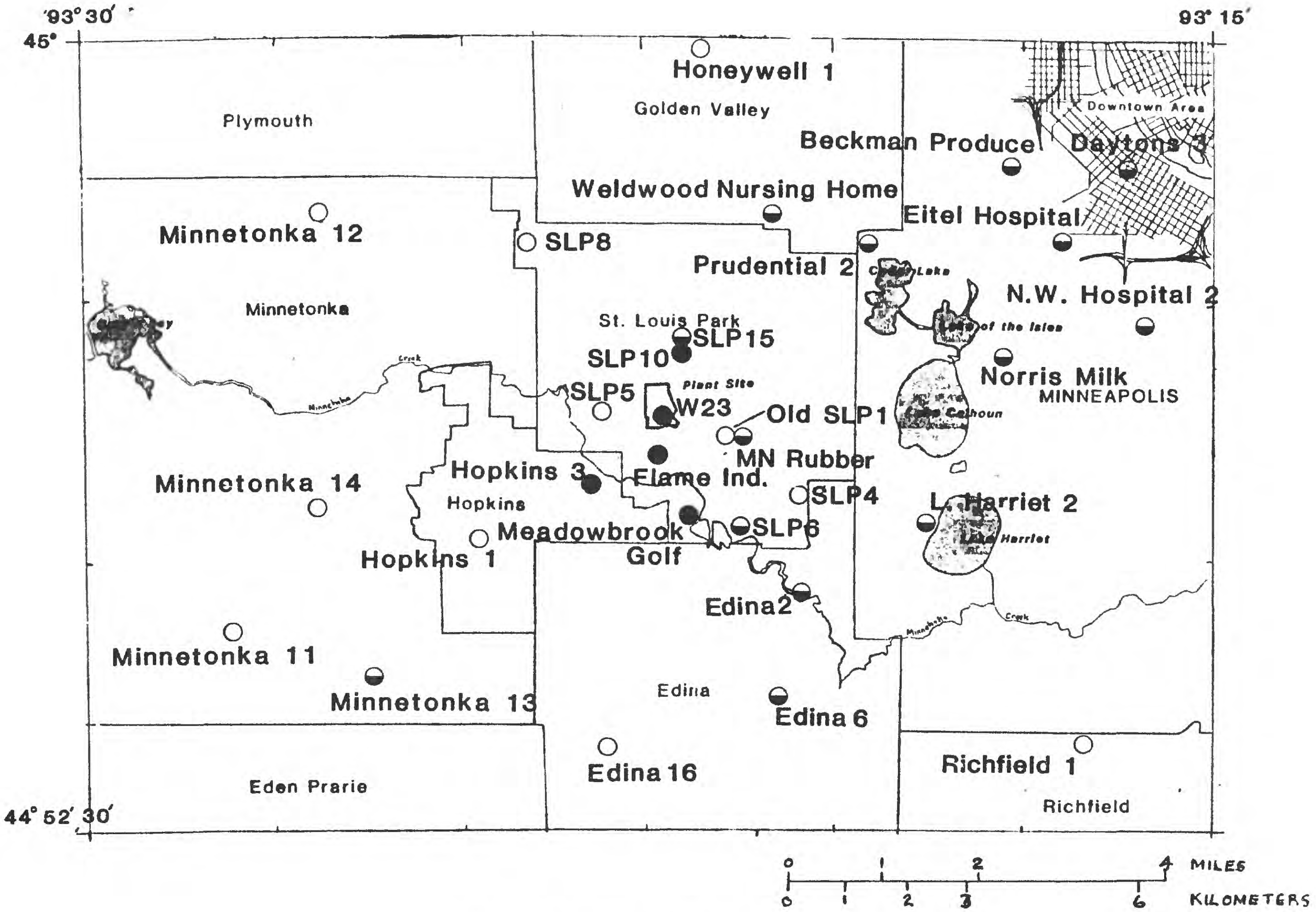
Water Quality

Since 1933, measurements of phenolic compounds have been used to assess whether or not area wells were contaminated by coal-tar from the plant. Detectable concentrations were noted, but the data were largely uninterpretable. Phenolic compounds are very soluble in water (Hult and Schoenberg, 1984) and are not significantly sorbed (Cohen, 1982; Goerlitz, 1984) and, therefore, might be expected to migrate large distances. However, they do not arrive at municipal wells in high concentrations apparently because they are degraded by bacteria under both aerobic and anaerobic conditions.

In 1978, the Minnesota Department of Health, isolated, identified, and quantified PAH in the municipal wells using newly developed methods (Minnesota Department of Health, 1978). The presence of PAH, but not phenols, is a chemically counterintuitive finding because high molecular weight PAH compounds are only slightly soluble in water and are very strongly sorbed. They are, however, biorefractory under anaerobic conditions. Apparently, the amount and concentration of contaminants in the Prairie du Chien has been sufficient to satisfy the sites available for sorption on the surface of the Prairie du Chien, and the movement through the aquifer near the site of most PAH is no longer significantly retarded by sorption.

Distribution and Movement of Organic Contaminants

A comprehensive areal survey of wells completed in the Prairie du Chien-Jordan aquifer was conducted during February-March 1981 in order to obtain temporally, spatially, and analytically consistent information on the concentration of PAH in the aquifer. Thirty wells completed in the Prairie du Chien-Jordan aquifer (fig. 22) were selected and sampled by the U.S. Geological Survey and analyzed by Midwest Research Institute (Conrad and others, 1981). Wells in the immediate vicinity of the site contained individual PAH at concentrations greater than 400 nanograms/L. The concentration in most wells east of the site exceeded 28 nanograms/L which was the definition of "contaminated" suggested by Hickok and Associates (1981) for non-carcinogenic PAH. Most wells west of the site (away from the most heavily urbanized part of the metropolitan area) were uncontaminated. The findings demonstrate that the highest concentrations are in the immediate vicinity of the site. They also provide chemical evidence for the conclusion that contaminants could have migrated many miles through the aquifer since they were first introduced into the aquifer. However, it is unlikely that all of the PAH detected in the heavily urbanized areas to the east were from the site.



EXPLANATION

○ Location of well completed in Prarie du Chien-Jordan aquifer sampled February-March 1981. All samples were analyzed using gas chromatography with mass spectrometry (GC/MS). Extracts of samples that did not contain any of 12 specific polynuclear aromatic hydrocarbons (PAH) above the method detection limits (MDL) were re-analyzed using high performance liquid chromatography (HPLC).

● Sample contained at least 400 N nanograms/liter of one or more PAH analytes as measured by GC/MS

◒ All PAH analytes below MDL for GC/MS method used. Concentration of one or more analytes greater than 28 ng/l as measured by HPLC.

○ All PAH analytes below MDL for GC/MS. Concentration of individual PAH analytes measured by HPLC below 28 ng/l

Figure 22.--Distribution of PAH analytes in the Prarie du Chien-Jordan aquifer as measured by high performance liquid chromatography and chromatography with mass spectrometry, Feb.-March 1981

The concentration of individual organic substances in the Prairie du Chien-Jordan aquifer changes with time in response to pumping stresses. For example, during 1978 chemical analysis of samples from three municipal well fields north of the site indicated that the aquifer in this area was contaminated with PAH. The use of four wells at the two closest well fields was discontinued in 1978, changing hydraulic gradients. In 1980, it was found that city of St. Louis Park wells SLP4 and SLP6 to the south and southeast of the site, which were not contaminated in 1978, contained PAH. The change in distribution of coal-tar compounds was caused in part by the change in hydraulic gradients created by discontinuing use of the wells to the north. Because contaminants have been in the aquifer since at least 1932, and because hydraulic gradients created by pumping have been significant and changing over this period, it is likely that the distribution of contaminants has been changing in a complex way through time.

The concentration of contaminants can change rapidly as shown by a comprehensive set of chemical analyses of water samples obtained from SLP4 under conditions of known hydraulic stresses and identical sampling and analytical conditions by MDH during the period January-February 1980. The well had been recently taken out of service because it had been found to be contaminated. The well was pumped only long enough to obtain a representative sample and did not impose a significant hydraulic stress on the aquifer. The only well in use in the immediate area was SLP6. The relationship between pumpage from SLP6 and concentration of selected compounds in SLP4 is shown in figure 23. Contaminant concentration in SLP4 varied inversely with pumpage in SLP6. This suggests that pumpage from SLP6 was sufficient to cause a reversal in the regional eastward gradient near SLP4 and draw uncontaminated water to the well and strongly supports the conclusions that contaminants can move rapidly through the aquifer and that the distribution of contaminants is strongly influenced by pumpage. Although additional comprehensive data are needed before accurate quantitative estimates of the effects of future pumping on contaminant distribution can be made, the findings suggest that manipulation of pumpage from area wells could be used to control and modify contaminant distribution.

Principal Source of Contamination

Well W23 is the most significant source of contamination to the Prairie du Chien-Jordan aquifer identified to date (1984). Hult and Schoenberg (1984, pl. 1) demonstrate that the hydraulic stress created by this well was consistent with ground-water flow from well W23 towards the municipal wells to the north. W23 had the greatest measured flow (150 gal/min) of any multiaquifer well evaluated, (Hult and Schoenberg, 1984, p. 29) and contains the highest concentrations of coal-tar derivatives (both in the aqueous phase and as a separate organic fluid phase) of any well open to the Prairie du Chien-Jordan aquifer. These two factors combine to make the mass flux of contaminants (contaminant concentration multiplied by flow rate) from this well at least one order of magnitude greater than any other multiaquifer well.

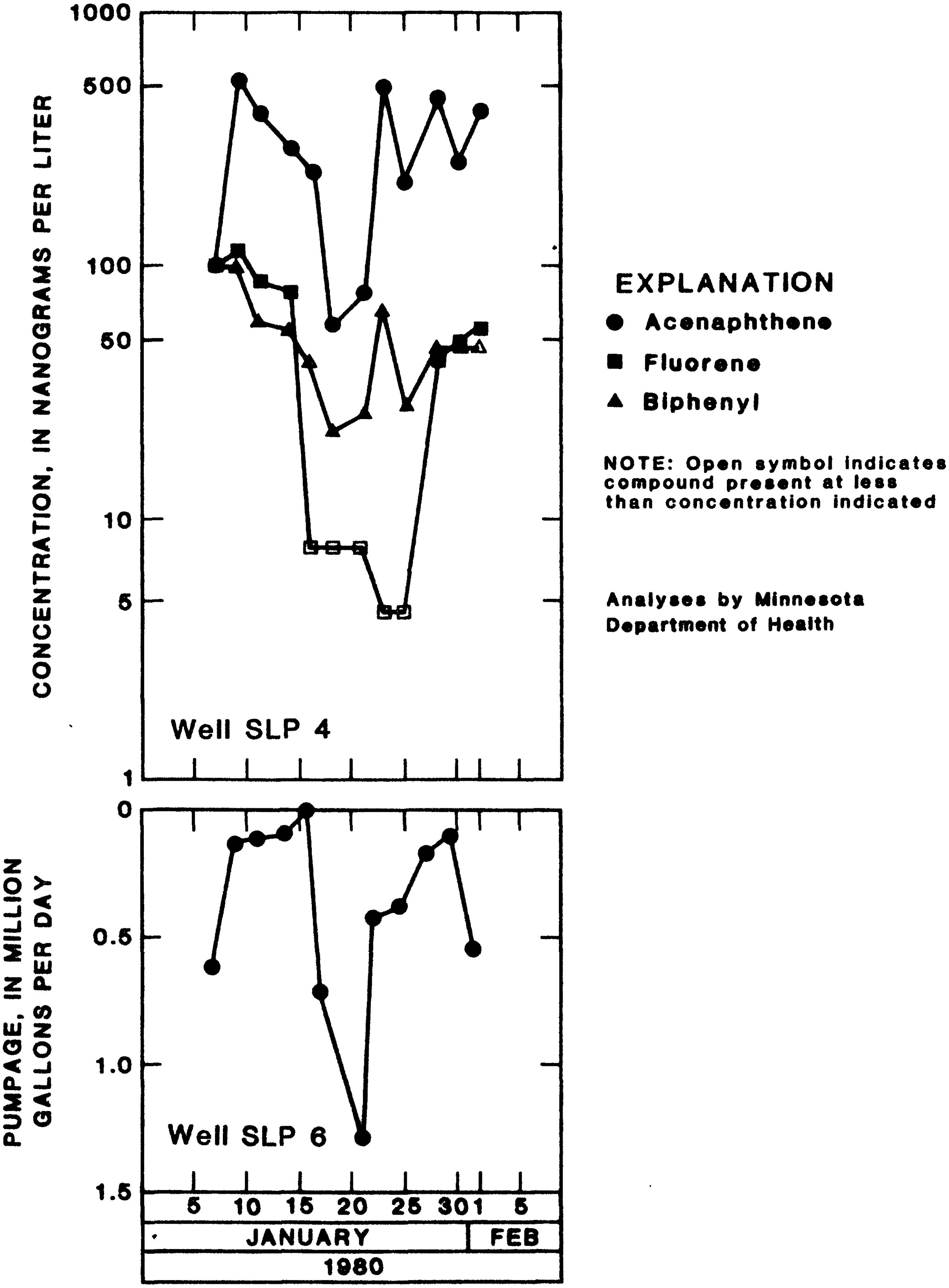


Figure 23.--Changes in concentration of selected coal-tar compounds in well SLP4 and pumpage from well SLP6, January 1980

The introduction, dissolution, and movement of coal tar in W23 is almost certainly the major source of PAH found in water from the municipal wells to the north (SLP10, SLP15). Numerous samples have been collected from these wells. At least 10 different laboratories have measured the concentration of PAH at SLP15, and their findings are in generally good agreement. A short core sample of tar from W23 and water samples from W23 and SLP15 were collected by the U.S. Geological Survey in January 1981 and analyzed for the study by MRI using GC/MS (Conrad and others, 1981). A split sample from SLP15 was also analyzed by the U.S. Geological Survey by GC/MS. As best as is known, this is the only set of data for these locations collected and analyzed in a consistent way and, at the same time, and, therefore, is used in the following discussion of the nature of the chemical stress created by well W23.

Coal tar in and around the well bore of W23 was dissolved by moving ground water (particularly the water flowing down the well bore). Dissolution is a process of partitioning between phases, in this case, two liquid phases (tar and water). Properties of individual compounds in a homologous series of compounds (such as PAH) can be predicted based on their molecular weights if the properties (for instance, octanol-water partition coefficient) of two of the members are known (fig. 24a). Tar/water partitioning for samples taken from W23 tar-water system (fig. 24b) demonstrate that the ratios of individual compounds is predictable and consistent.

Figure 24c shows that the ratio of the concentration in well W23 to that in SLP15 was approximately 20:1 for most constituents detected in both samples. The ratios do not seem to depend strongly on molecular weight, suggesting that most major constituents have arrived at the municipal wells and that retardation by sorption processes now affects only the compounds with the highest molecular weights. Naphthalene was the constituent found in highest concentration in the aqueous sample from W23 but was below the detection limit in SLP15. The concentration of naphthalene in SLP15 was at least one and one-half orders of magnitude below what would have been expected. Naphthalene is usually the PAH in highest concentrations in contaminated ground water in the drift and Platteville near the site, and was found in the highest concentration of any PAH in water from W23, but is found in anomalously low concentrations elsewhere in the Prairie du Chien-Jordan. Water in the Prairie du Chien-Jordan aquifer typically contains about 1 mg/L dissolved oxygen. Apparently naphthalene is being degraded by aerobic bacteria within the aquifer.

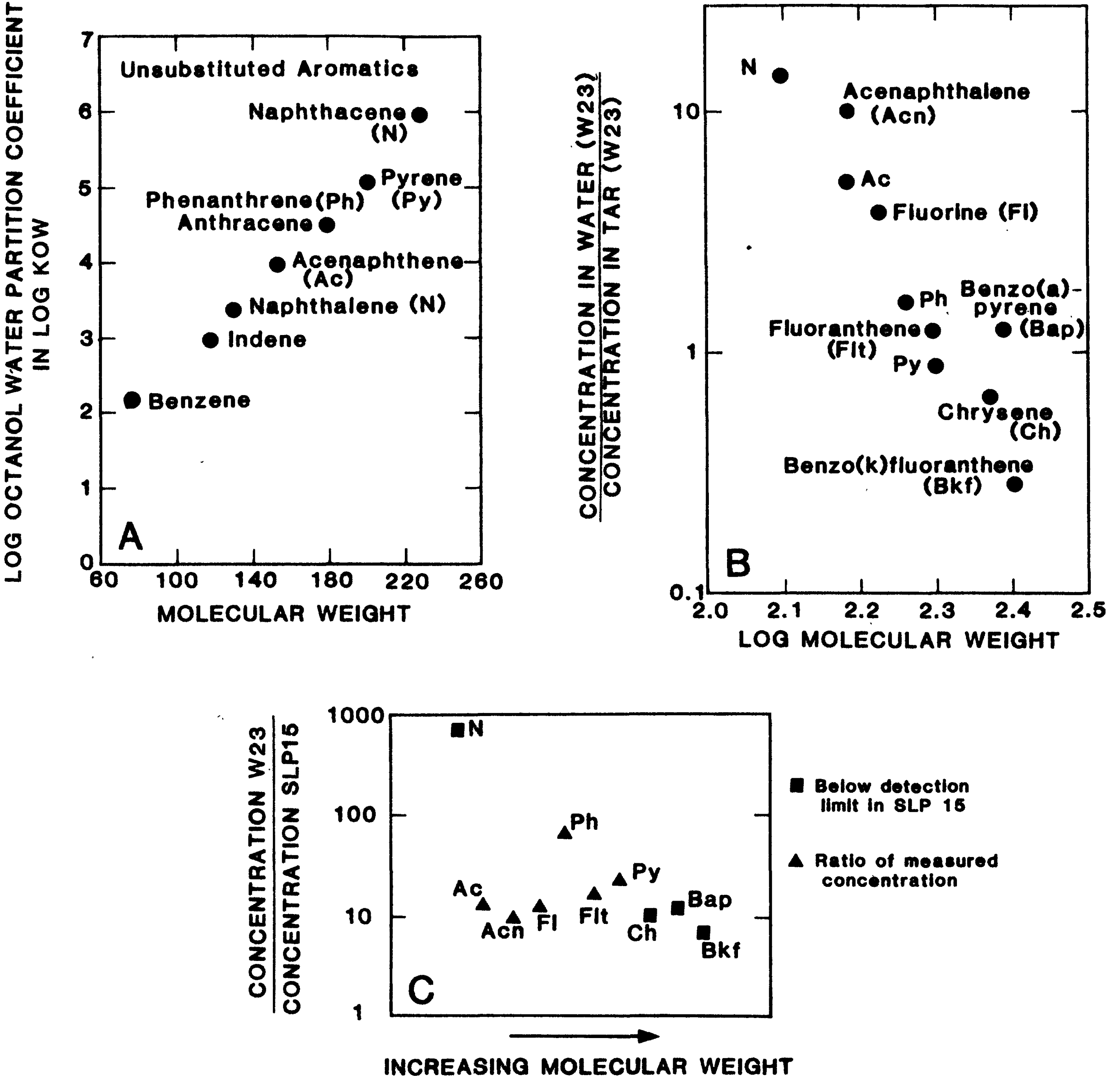


Figure 24.--Graphs showing octanol-water and tar-water partitioning for aromatic compounds found in Well23 and relationship between chemical quality in Well23 and SLP15

Assessment of Ground-Water Contamination

The Prairie du Chien-Jordan aquifer is the region's major ground-water resource. About 75 percent of ground-water withdrawals in the St. Louis Park and Minneapolis-St. Paul Metropolitan Area are from this aquifer. The aquifer is relatively well protected from near-surface sources of contamination. In the St. Louis Park area, it is 250 to 500 feet below land surface and is overlain by drift, two bedrock confining beds (Glenwood and basal St. Peter), and two bedrock aquifers (Platteville and St. Peter). It is contaminated because coal-tar derivatives entered the aquifer through multiaquifer wells. The major single source of contamination in the aquifer is a well drilled on the site in 1917 (W23) that contained liquid coal-tar since at least 1958. The introduction, dissolution, and movement of this coal tar has caused contamination of nearby municipal wells.

The direction and rate of contaminant movement changes with time because the bedrock ground-water-flow system continually adjusts to hydraulic stresses caused by ground-water withdrawals and flow through multiaquifer wells. Contaminants can move rapidly through the Prairie du Chien-Jordan because the upper part of the aquifer is a carbonate rock having fracture and solution-channel permeability, low surface area for sorption, and low effective porosity. Consequently, the concentration and composition of contaminants in water pumped from individual industrial and municipal wells completed in the aquifer fluctuates with time. Although contaminants have been in the aquifer for at least 50 years, and the present distribution of contaminants is complex, the concentrations remain highest near the points of introduction through multiaquifer wells near and on the site of the former plant.

IRONTON-GALESVILLE AND MOUNT SIMON-HINCKLEY AQUIFERS

The Ironton-Galesville and Mount Simon-Hinckley aquifers are overlain by several confining beds and aquifers (fig. 4). As with the Prairie du Chien-Jordan aquifer, contaminants can enter these aquifers through multiaquifer wells, but it is highly unlikely that contaminants have entered these aquifers in substantial amounts through natural paths (fig. 3).

Three multiaquifer wells were identified that were deep enough to penetrate the Ironton-Galesville and Mount Simon-Hinckley aquifers in areas where overlying aquifers are seriously contaminated. Each well was located in the field, and found to be partially filled with sediment. When found, the well bore adjacent to both aquifers in each well was filled, thereby preventing high flow rates into these aquifers.

Some leakage of contaminants through the wells has occurred, however. Chemical analyses of water pumped from these wells indicate that the Ironton-Galesville aquifer is contaminated. Well W23 contained a mixture of coal-tar and sand directly adjacent to the Ironton-Galesville aquifer that was removed prior to pumping. The areal extent of contamination is unknown because other wells are not available through which measurements can be made. Each well was drilled prior to or contemporaneous with the beginning of plant operations and may have had a long history of interaquifer flow.

It is not known when and where the coal-tar found in well W23 was first released to the environment, although some contaminants may have entered the well bore as early as 1932 (Barr Engineering Co., 1977; Hult and Schoenberg, 1984; files of the MPCA). Additional field work would be needed to better determine whether the tar was released through many small discharges, through large spills, or both. The upper portion of the tarry sediment in well W23 apparently entered the well bore over a period of years, probably through holes in the casing (fig. 20) and around the outside of the casing because the tarry material contains sand grains, and is interbedded with sand from both drift and bedrock sources.

The chemical quality of water in the Mount Simon-Hinckley aquifer adjacent these wells has not been measured because in each case, efforts to redrill (clean out) the wells to their original depth were unsuccessful. The amount of contamination in the aquifer is likely minor compared to that in overlying aquifers.

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