AREAL EXTENT OF PETROLEUM-RELATED COMPOUNDS FROM A GASOLINE AND DIESEL-FUEL LEAK IN GROUND WATER AT A SITE IN YAKIMA, WASHINGTON, 1984-89

By Richard J. Wagner

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	*By*	*To Obtain*
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
gallon	3.785	liter
microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C)	1.000	micromho per centimeter at 25 degrees Celsius

Temperature: To correct temperature given in this report in degrees Celsius (°C), to degrees Fahrenheit (°F), use the following equation: °F = 1.8 x °C + 32.

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

A gasoline and diesel-fuel leak was discovered in the early 1980's at a service station in Yakima, Washington, and an attempt to recover the free-floating petroleum product was unsuccessful. From 1984 through 1989, data were collected from observation wells drilled near the site of the leak and from nearby domestic wells during three separate studies. Between February 1985 and November 1986, benzene, toluene, xylenes, and other soluble compounds of petroleum origin were found at concentrations that exceeded standards for drinking water in all samples from observation wells within 300 feet of the service station. These compounds also were found in smaller concentrations in some samples from domestic wells as far as 1,500 feet downgradient of the service station. Concentrations of these soluble compounds in ground-water samples collected in March 1989 had decreased, and areal distribution of the compounds was smaller than when monitoring began in 1984.

INTRODUCTION

In 1980, 1981, and 1982, the residents of a neighborhood in the northeastern part of Yakima, Wash., reported to the State of Washington Department of Ecology (Ecology) that water from their domestic or irrigation wells, which are open to a shallow, unconfined ground-water system, had the odor and taste of gasoline. Ecology determined that the source of the odor and taste was gasoline and diesel fuel leaking near the land surface from pump delivery lines at a service station on North First Street (fig. 1). New delivery lines and storage tanks had been installed at the station in May and June 1979, and had been tested for leaks both upon installation and again in December 1980. No leaks were reported. Additional tests, made in September 1982 as a result of the complaints from private well owners, revealed leaks in the delivery lines, which were repaired immediately.

An audit of gasoline and diesel-fuel inventory records, done by representatives of the service station, indicated that about 5,970 gallons of leaded gasoline and 1,740 gallons of diesel fuel were lost between September 1981 and October 1982. This represents an average leakage rate of 550 gallons of product per month. If the leak began shortly after the December 1980 test and was constant, then about 12,000 gallons could have been lost during the 22-month period from the time of the test to the repair of the leaks. If the December 1980 test was invalid and the system leaked at a constant rate during the entire 40-month period from the time of installation, then the product loss could have been as much as 22,000 gallons.

An insurance company representing the service station began to recover the lost gasoline and diesel fuel in 1982-83 to prevent further contamination of drinking water. As part of the recovery, at least 13 observation wells and 2 recovery wells were installed on or adjacent to the service station property. Three of the observation wells contained several inches of free product—pure gasoline or diesel fuel—floating on top of the water. The recovery operation was discontinued because only 40 gallons of free product were recovered. All but three of the wells subsequently were destroyed. In the summer of 1985, most homes with affected wells were connected to alternative water supplies. As part of the U.S. Geological Survey Ground-Water Toxic Substances Hydrology Program (hereafter referred to as the ground-water toxics study), the gasoline and diesel-fuel leak site in Yakima was selected for an interdisciplinary research study of petroleum hydrocarbons in soil and ground water. Research was discontinued in 1987 and no results or data were published. The U.S. Geological Survey, in cooperation with Ecology, investigated the distributions and concentrations of petroleum-related compounds in ground water during March 1989 and compared the results with previous data.

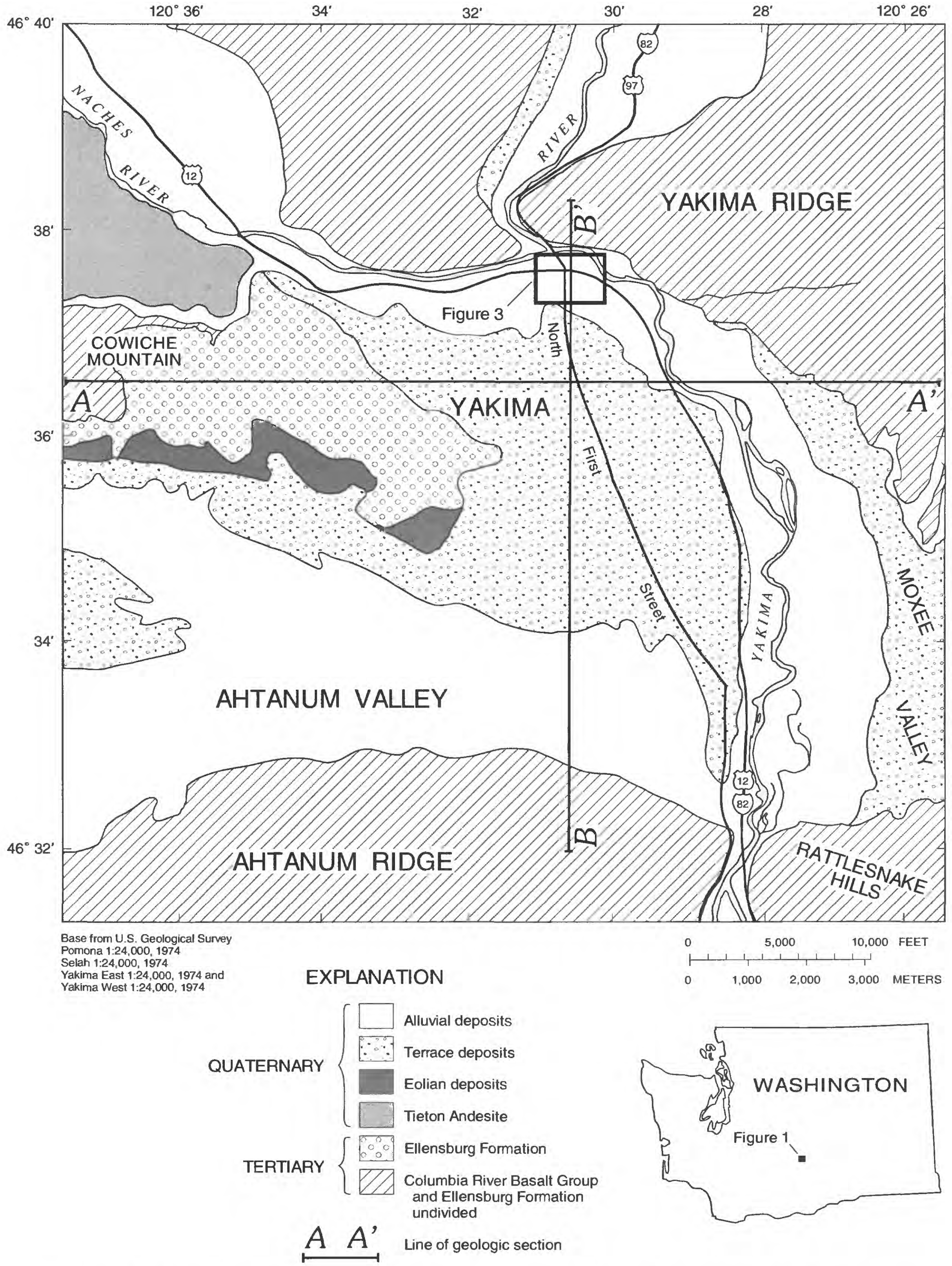

Figure 1.--Location of study site at Yakima, Washington, and the surficial geology in the area (Modified from Bentley and Campbell, 1983a, b; and Foxworthy, 1962). Geologic sections A-A´ and B-B´ are shown on figure 2.

Purpose and Scope

This report presents and compares changes in the concentrations and areal extent of petroleum-related compounds in ground water collected during three studies near the site of the gasoline and diesel-fuel leak on North First Street in Yakima, Wash., between 1984 and 1989, and presents data and describes methods of collection for soil-gas and aquifer-material samples. The report includes data from ground-water samples collected during three separate investigations: in March 1989 by the U.S. Geological Survey (USGS) as part of the current 1989 study; from 1985 to 1987 as part of the ground-water toxics study; and from October 1984 through November 1986 during a study by an insurance company. Data collected in the three sampling studies are presented in tables in this report, and comparisons between studies and changes in time are made by presenting distributions of selected compounds on maps. Sampling procedures and laboratory methods that were used in the three studies also are described.

Description of the Study Area

The city of Yakima is the commercial center for the Yakima River valley, a major agricultural area in south-central Washington. The service station on North First Street, where the gasoline and diesel-fuel leak occurred, is approximately 2,000 feet southwest of the Yakima River (fig. 1). The area around the service station consists of some orchards and vacant lots interspersed among commercial and residential properties.

The general direction of ground-water flow is eastward from the service station to the river. The subsurface geologic materials immediately underlying the area are predominantly coarse-grained alluvial deposits. The water table is approximately 10 feet below land surface. Additional information on the geohydrology is given in the section "Geohydrologic Setting".

Annual precipitation in the valley is about 8 inches (U.S. Department of Commerce, 1987), more than half occurring during the winter months as snow. Potential evapotranspiration, determined using a modified Blaney-Criddle calculation (U.S. Department of Agriculture, 1970), is approximately 38 inches annually. Consequently, crops require extensive irrigation. Most irrigation water is diverted surface water, but some is pumped ground water. The main municipal water supply for the city of Yakima is surface water; however, some individual residences and small water purveyors rely on ground water.

Hydrogeologic Setting

The study area in Yakima, Wash., is located in the Ahtanum-Moxee subbasin (fig. 1), which lies along an east-west-oriented alluvial valley between two similarly oriented basalt ridges: Cowiche Mountain and Yakima Ridge to the north and Ahtanum Ridge and Rattlesnake Hills to the south. The valley lies along a broad structural syncline, is approximately 7 miles wide and 40 miles long, and has a relatively flat alluvial surface that ranges between 1,000 and 1,500 feet in altitude. The basalt ridges on either side of the valley were formed by anticlinal upwarp, are much narrower than the valley, and range between 2,000 and 3,000 feet in altitude. Perennial east-west-oriented streams flow along the valley from both directions toward the valley center and empty into the perennial north-south, through-flowing Yakima River. A significant summer inflow of water into the higher parts of the valley comes by way of irrigation canals fed by dam-regulated flow along the Yakima River and its tributaries upstream of the study area.

Folded and faulted basalts are exposed along the anticlinal ridges (fig. 1) and are found at depths of 300 to 1,000 feet beneath the synclinal valley. The basalt flows belong to the Columbia River Basalt Group (table 1), and they are interbedded with and underlie a thick section of clastic rocks of debris-flow, lacustrine, and fluvial origin located along the valley axis. The oldest of these clastic units, the Ellensburg Formation (table 1), is from 100 to perhaps 1,000 feet thick in the valley and is dominated by semi-consolidated fine to coarse clastics of volcanic debris-flow origin. Above these beds lie about 100 to 500 feet of Pleistocene fine-grained lake-deposited and coarser-grained river-deposited clastics of glaciofluvial origin. Above these, and composing much of the surficial material at and near the study site, are 50 to 75 feet of Holocene unconsolidated alluvial sands and gravels laid down beneath the present flood plain by the Yakima River and beneath adjacent terraces by streams older, and perhaps larger, than the present Yakima River. The clasts within these two recent alluvial deposits are dominantly of volcanic (andesitic and basaltic) composition.

Table 1.--*Major hydrogeologic units in the Ahtanum-Moxee subbasin, Washington*

System	Series	Group	Formation	Hydrologic description
Quaternary	Holocene			Alluvium and terrace deposits consisting principally of unconsolidated stream deposits of silt, sand, and gravel, with cobbles throughout. Clasts are dominantly of andesite and basaltic composition. Locally, lacustrine paludal and eolian deposits occur. Generally, deposit is a thin mantle less than 50 feet thick, but known to reach 165 feet thick at one point in subbasin. Estimates of porosity range from 15 to 25 percent and from 0.4 to 86 feet per day hydraulic conductivity.
	Pleistocene			Coarse sand and gravel deposits including large amounts of cemented mixture of gravel, sand, silt, and clay. Clasts are dominantly of andesitic and basaltic composition, and locally contain discontinuous and unconsolidated bodies of glacial fluvial and lacustrine deposits. Up to 500 feet in thickness. In general, unit has low permeability except in unconsolidated sections.
			Tieton Andesite	Single intracanyon flow confined to the Naches River drainage.
Tertiary	Miocene to Pliocene		Ellensburg Formation	A thick sequence of stream- and lake-deposited silt, sand, and gravel which is composed chiefly of volcanic ash, pumice, and hornblende andesite. Thickness exceeds 1,000 feet in some parts of subbasin. It has moderate to high porosity and low to medium permeability, and provides a large amount of effective storage. Permeable strata form important aquifers. Unit includes all conformably underlying sediments of similar lithology that intertongue with flows of the Columbia River Basalt Group.
		Columbia River Basalt Group	Saddle Mountains Basalt Wanapum Basalt Grande Ronde Basalt	Sequence of dark lava flows which contains some inter-bedded lake- and stream-deposited materials. Individual lava flows range from less than 20 to over 200 feet in thickness. The maximum thickness of the Columbia River Basalt Group exceeds 4,000 feet in the Yakima River Basin. Water generally moves along the interflow zones, which are more permeable than the massive centers of the flow. The porosity of this formation probably ranges from 5 to 10 percent, and its permeability ranges from low to very high. Provides a large quantity of effective ground-water storage and includes some important aquifers.

The shallow stratigraphy of the study site was determined by descriptive geologic logs from recent drilling of observation wells (fig. 2). In general, the lithologic descriptions show an upper 15- to 20-foot-thick depositional unit beneath the present flood plain with about 5 feet of clay, silt, and sand at the surface (overbank deposits) and 10 feet of sandy, coarse gravels and cobbles below the overbank deposits. The lower contact of this upper unit is indistinct, but it overlies 30 to 50 feet of older gravels and sands, probably deposited in similar environments. At normal stages of flow, the Yakima River is flowing within the upper fluvial unit and perhaps within the top of the gravel layer of these fluvial deposits. There is a highly permeable connection between the Yakima River and the adjacent water-table aquifer within these recent fluvial deposits. The ground-water-quality data at the site indicate that the leaked gasoline and diesel fuel and the dispersed dissolved compounds downgradient of the leak are wholly contained within the upper and lower Holocene alluvial deposits.

There is upward ground-water flow from the basalts through the Ellensburg Formation clastics into Holocene alluvium and into the perennial drainages (Henry Bauer, U.S. Geological Survey, oral commun., 1990), including the Yakima River. Regionally, the ground-water flow is generally eastward from the leak site toward the Yakima River. During the study, the general direction of local ground-water movement was from west to east-southeast (fig. 3), and the velocity was estimated at between 0.2 and 1.2 feet per day, on the basis of water-level measurements and interpretation of geologic well logs (J. Pankow, Oregon Graduate Center, written commun., 1986). In general, the water table lies 7 to 12 feet below land surface. The upper sand, silt, and clay of the alluvium is unsaturated, and the lower coarser-grained part of the alluvium is saturated.

Continuous hydrographs of two water-table wells document annual water-level fluctuations of 2 to 3 feet, and there are two unequal annual peaks. One peak is in late spring, coincident with maximum vertical recharge from precipitation, and the other is in the late summer and early fall, coincident with upgradient recharge from irrigation returns and canal leakage (figs. 4 and 5, and table 2).

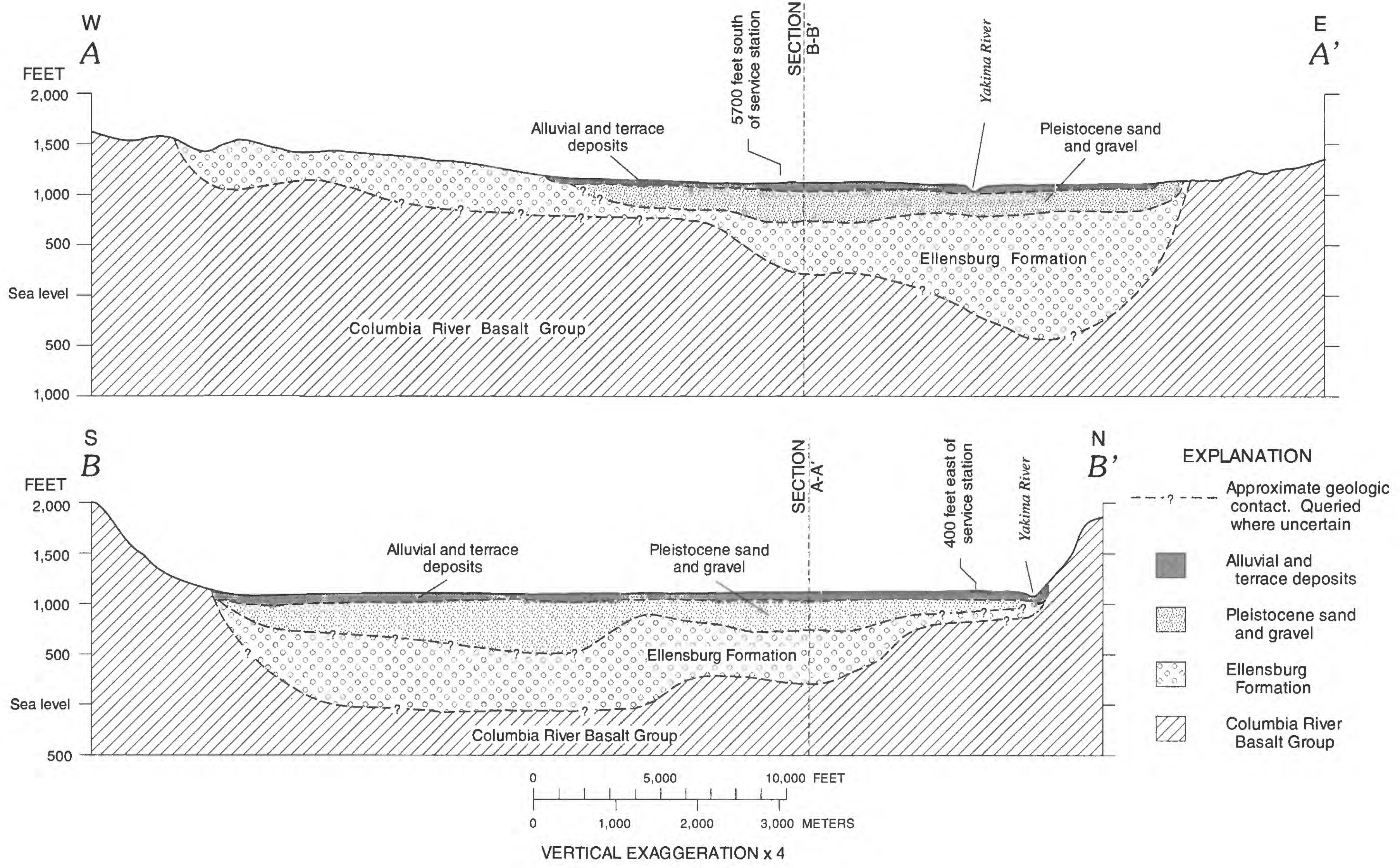

Figure 2.--Geological sections near study site. Geology is based on well logs. Pleistocene sand and gravel shown on sections only. See figure 1 for locations of sections.

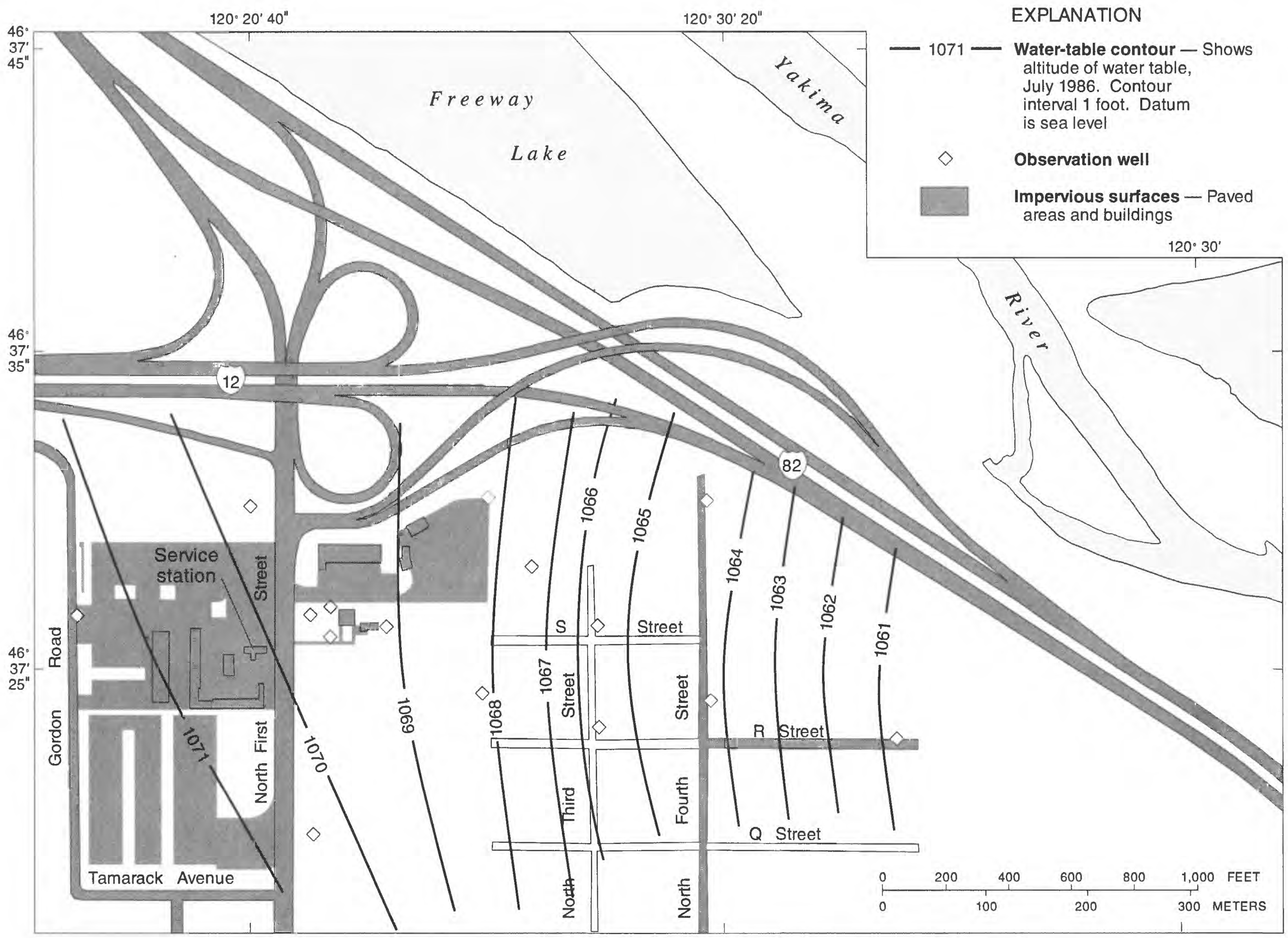

Figure 3.--Water-table altitudes for July 1986 at the study site.

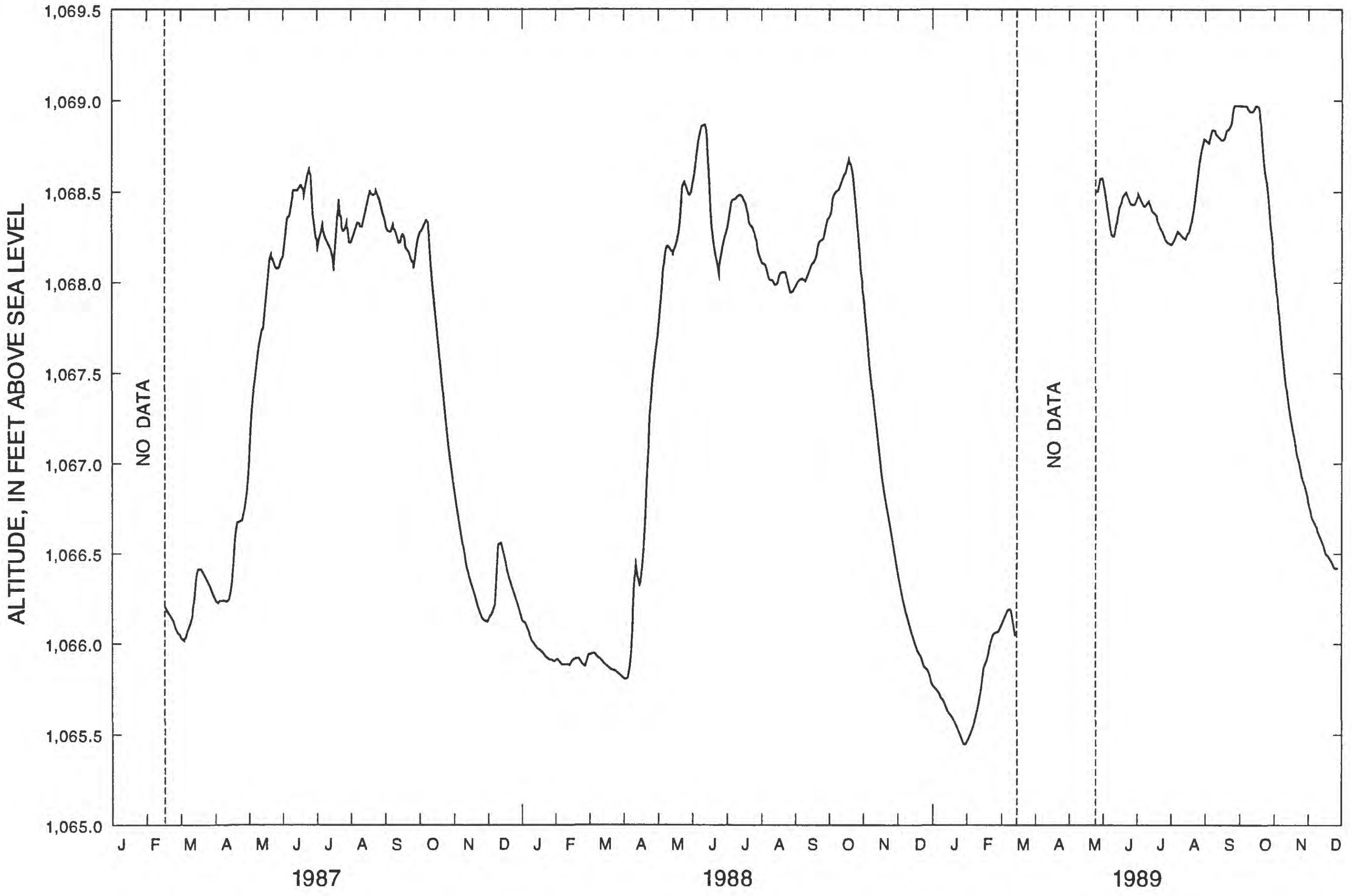

Figure 4.--Daily mean observed water levels in well M14, 1987 through 1989. Land surface altitude is 1,076.14 feet above sea level.

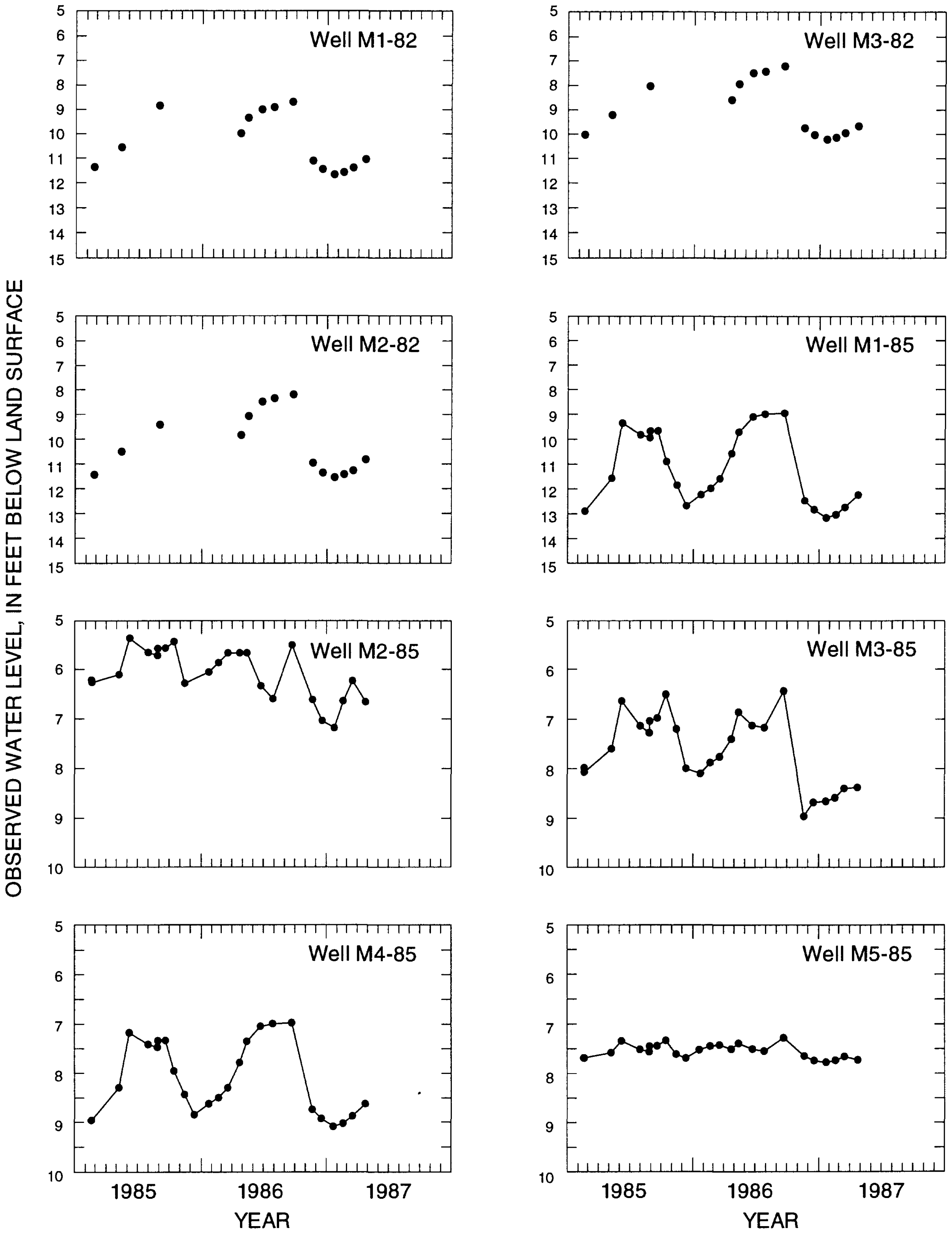

Figure 5.--Observed water levels in observation wells with a 2-year period of record collection. (For wells where water-level measurements were made at intervals greater than 2 months, points are shown without connecting line.)

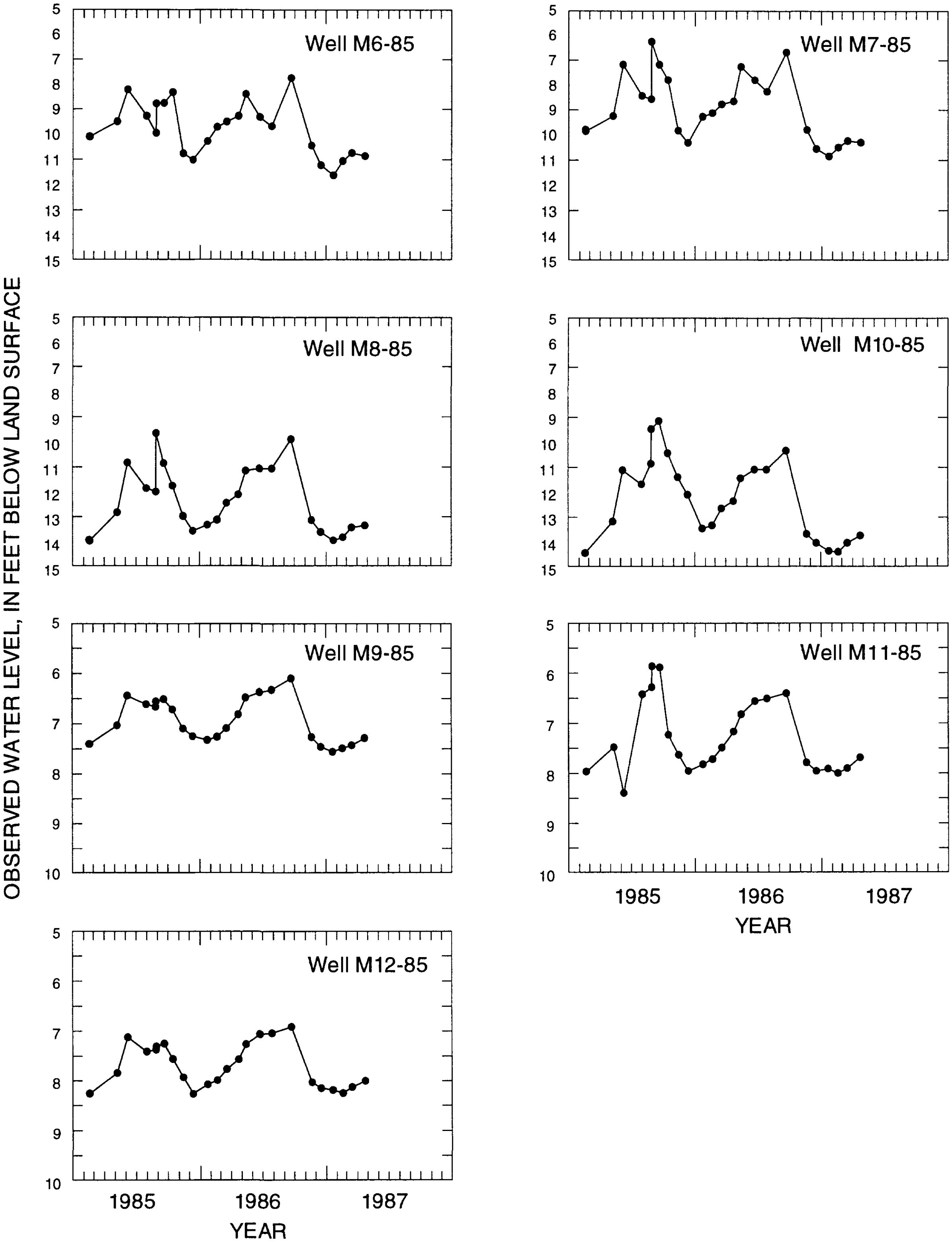

Figure 5.--Continued.

Table 2.--*Observed water levels in observation and domestic wells*

Well identifier	Date	Water level (feet below land surface)	Well identifier	Date	Water level (feet below land surface)	Well identifier	Date	Water level (feet below land surface)
M1-82	Feb 21, 1985	11.37	M2-82	Feb 21, 1985	11.48	M3-82	Feb 21, 1985	10.05
	May 11	10.57		May 11	10.55		May 11	9.23
	Aug 29	8.84		Aug 29	9.47		Aug 29	8.05
	Apr 23, 1986	10.00		Apr 23, 1986	9.88		Apr 23, 1986	8.61
	May 14	9.36		May 14	9.12		May 14	7.96
	Jun 23	9.00		Jun 23	8.54		Jun 23	7.51
	Jul 28	8.91		Jul 28	8.40		Jul 28	7.45
	Sep 22	8.69		Sep 22	8.25		Sep 22	7.23
	Nov 19	11.12		Nov 19	11.01		Nov 19	9.76
	Dec 17	11.46		Dec 17	11.40		Dec 17	10.03
	Jan 20, 1987	11.67		Jan 20, 1987	11.60		Jan 22, 1987	10.23
	Feb 17	11.58		Feb 17	11.46		Feb 17	10.15
	Mar 16	11.39		Mar 16	11.32		Mar 16	9.96
	Apr 22	11.05		Apr 22	10.86		Apr 22	9.67
				Mar 18, 1989	11.65		Mar 18, 1989	10.16
M1-85	Feb 21, 1985	12.90	M2-85	Feb 20, 1985	6.22	M3-85	Feb 20, 1985	7.98
	May 10	11.58		21	6.27		21	8.07
	Jun 09	9.37		May 10	6.11		May 11	7.60
	Aug 02	9.84		Jun 09	5.37		Jun 09	6.64
	29	9.95		Aug 02	5.66		Aug 02	7.14
	30	9.69		29	5.72		29	7.28
	Sep 21	9.68		30	5.58		30	7.04
	Oct 16	10.91		Sep 21	5.57		Sep 21	6.98
	Nov 15	11.86		Oct 16	5.44		Oct 16	6.51
	Dec 13	12.69		Nov 15	6.29		Nov 15	7.20
	Jan 24, 1986	12.24		Jan 24, 1986	6.06		Dec 13	8.00
	Feb 21	11.99		Feb 21	5.87		Jan 24, 1986	8.10
	Mar 20	11.59		Mar 20	5.67		Feb 21	7.88
	Apr 23	10.58		Apr 23	5.67		Mar 20	7.76
	May 14	9.72		May 14	5.67		Apr 23	7.40
	Jun 23	9.11		Jun 23	6.34		May 14	6.86
	Jul 28	9.00		Jul 28	6.60		Jun 23	7.13
	Sep 22	8.96		Sep 22	5.51		Jul 28	7.17
	Nov 20	12.48		Nov 20	6.62		Sep 22	6.44
	Dec 17	12.85		Dec 18	7.04		Nov 20	8.96
	Jan 21, 1987	13.17		Jan 22, 1987	7.18		Dec 17	8.68
	Feb 18	13.05		Feb 17	6.64		Jan 22, 1987	8.66
	Mar 16	12.75		Mar 16	6.24		Feb 18	8.59
	Apr 23	12.25		Apr 23	6.66		Mar 16	8.40
	Mar 13, 1989	13.33		Mar 14, 1989	9.14		Apr 23	8.38

Table 2.--*Observed water levels in observation and domestic wells--Continued*

Well identifier	Date	Water level (feet below land surface)
M4-85	Feb 20, 1985	8.95
	21	8.95
	May 11	7.91
	Jun 09	5.83
	Aug 02	6.12
	29	6.31
	30	6.07
	Sep 21	6.04
	Oct 16	7.10
	Nov 15	8.09
	Dec 13	8.90
	Jan 24, 1986	8.69
	Feb 21	8.58
	Mar 20	8.15
	Apr 23	6.96
	May 14	6.07
	Jun 23	5.40
	Jul 28	5.07
	Sep 22	4.94
	Nov 20	8.55
	Dec 17	8.98
	Jan 21, 1987	9.26
	Feb 17	9.04
	Mar 16	8.92
	Apr 23	8.27
M5-85	Feb 20, 1985	5.39
	21	5.38
	May 10	5.17
	Jun 09	4.69
	Aug 02	5.04
	29	5.13
	30	4.91
	Sep 21	4.89
	Oct 16	4.67
	Nov 15	5.23
	Dec 13	5.39
	Jan 21, 1986	5.05
	Feb 21	4.90
	Mar 20	4.85
	Apr 23	5.02
	May 14	4.79
	Jun 23	5.02
	Jul 28	5.10
	Sep 22	4.56
	Nov 20	5.30
	Dec 18	5.49
	Jan 22, 1987	5.56
	Feb 18	5.48
	Mar 16	5.32
	Apr 23	5.46
	Mar 13, 1989	5.64
M6-85	Feb 20, 1985	7.55
	21	7.55
	May 10	7.25
	Jun 09	6.61
	Aug 02	7.14
	29	7.48
	30	6.89
	Sep 21	6.88
	Oct 16	6.66
	Nov 15	7.88
	Dec 13	8.01
	Jan 24, 1986	7.64
	Feb 21	7.36
	Mar 20	7.25
	Apr 23	7.14
	May 14	6.70
	Jun 23	7.16
	Jul 28	7.34
	Sep 22	6.37
	Nov 20	7.72
	Dec 17	8.11
	Jan 22, 1987	8.31
	Feb 18	8.03
	Mar 16	7.87
	Apr 23	7.93
	Mar 13, 1989	8.52
M7-85	Feb 20, 1985	7.40
	21	7.43
	May 11	7.13
	Jun 09	6.09
	Aug 02	6.72
	29	6.79
	30	5.63
	Sep 21	6.09
	Oct 16	6.40
	Nov 15	7.42
	Dec 13	7.66
	Jan 24, 1986	7.14
	Feb 21	7.07
	Mar 20	6.89
	Apr 23	6.83
	May 14	6.13
	Jun 23	6.40
	Jul 28	6.63
	Sep 22	5.84
	Nov 20	7.40
	Dec 17	7.78
	Jan 22, 1987	7.93
	Feb 18	7.75
	Mar 16	7.62
	Apr 23	7.65
	Mar 14, 1989	8.05
M8-85	Feb 20, 1985	9.47
	21	9.49
	May 11	8.92
	Jun 09	7.92
	Aug 02	8.43
	29	8.50
	30	7.33
	Sep 21	7.93
	Oct 16	8.38
	Nov 15	8.99
	Dec 13	9.29
	Jan 24, 1986	9.17
	Feb 21	9.07
	Mar 20	8.73
	Apr 23	8.56
	May 14	8.08
	Jun 23	8.04
	Jul 28	8.04
	Sep 22	7.45
	Nov 20	9.07
	Dec 17	9.31
	Jan 22, 1987	9.48
	Feb 18	9.42
	Mar 16	9.22
	Apr 23	9.18
	Mar 14, 1989	9.59
M9-85	Feb 20, 1985	9.81
	21	9.81
	May 11	9.07
	Jun 09	7.88
	Aug 02	8.22
	29	8.32
	30	8.11
	Sep 21	8.02
	Oct 16	8.43
	Nov 15	9.19
	Dec 13	9.50
	Jan 24, 1986	9.65
	Feb 21	9.52
	Mar 20	9.18
	Apr 23	8.63
	May 14	7.96
	Jun 23	7.75
	Jul 28	7.65
	Sep 22	7.20
	Nov 20	9.53
	Dec 17	9.92
	Jan 20, 1987	10.12
	Feb 17	9.98
	Mar 16	9.86
	Apr 22	9.58
	Mar 15, 1989	10.37

Table 2.--*Observed water levels in observation and domestic wells--Continued*

Well identifer	Date	Water level (feet below land surface)	Well identifer	Date	Water level (feet below land surface)	Well identifer	Date	Water level (feet below land surface)
M10-85	Feb 20, 1985	9.72	M11-85	Feb 20, 1985	10.94	M12-85	Feb 20, 1985	11.52
	21	9.72		21	10.94		21	11.52
	May 11	9.09		May 11	9.96		May 10	10.68
	Jun 09	8.06		Jun 09	11.81		Jun 09	9.24
	Aug 02	8.34		Aug 02	7.83		Aug 02	9.82
	29	7.93		29	7.56		29	9.73
	30	7.24		30	6.72		30	9.61
	Sep 21	7.08		Sep 21	6.76		Sep 21	9.50
	Oct 16	7.72		Oct 16	9.47		Oct 16	10.12
	Nov 15	8.20		Nov 15	10.27		Nov 15	10.86
	Dec 13	8.55		Dec 13	10.92		Dec 13	11.52
	Jan 24, 1986	9.23		Jan 24, 1986	10.65		Jan 24, 1986	11.15
	Feb 21	9.17		Feb 21	10.44		Feb 21	10.98
	Mar 20	8.83		Mar 20	9.98		Mar 20	10.53
	Apr 23	8.68		Apr 23	9.34		Apr 23	10.13
	May 14	8.22		May 14	8.64		May 14	9.53
	Jun 23	8.05		Jun 23	8.11		Jun 23	9.13
	Jul 28	8.05		Jul 28	8.01		Jul 28	9.08
	Sep 22	7.67		Sep 22	7.79		Sep 22	8.83
	Nov 20	9.34		Nov 19	10.58		Nov 20	11.06
	Dec 17	9.52		Dec 17	10.92		Dec 17	11.30
	Jan 22, 1987	9.68		Jan 20, 1987	10.83		Jan 20, 1987	11.38
	Feb 18	9.70		Feb 17	11.01		Feb 18	11.50
	Mar 16	9.52		Mar 16	10.81		Mar 16	11.26
	Apr 22	9.37		Apr 22	10.38		Apr 23	11.01
				Mar 18, 1989	11.10			
M1	Nov 19, 1986	12.01	M2	Nov 20, 1986	10.55	M3	Nov 20, 1986	10.73
	Dec 17	12.69		Dec 17	10.84		Dec 17	11.02
	Jan 20, 1987	12.72		Jan 20, 1987	11.01		Jan 20, 1987	11.22
	Feb 17	12.55		Feb 17	10.94		Feb 17	11.16
	Mar 16	12.39		Mar 16	10.76		Mar 16	10.96
	Apr 22	12.08		Apr 22	10.48		Apr 22	10.67
M4	Nov 20, 1986	10.91	M5	Nov 19, 1986	10.94	M6.1	Nov 20, 1986	10.51
	Dec 17	11.07		Dec 17	11.27		Dec 17	10.89
	Jan 20, 1987	11.28		Jan 20, 1987	11.50		Jan 20, 1987	11.04
	Feb 17	11.19		Feb 17	11.40		Feb 17	10.95
	Mar 16	11.01		Mar 16	11.20		Mar 16	10.76
	Apr 22	10.68		Apr 22	10.72		Apr 22	10.48
	Mar 17, 1989	11.2						
M6.2	Nov 20, 1986	10.53	M7.1	Nov 19, 1986	11.16	M7.2	Mar 16, 1987	11.33
	Dec 17	10.79		Dec 17	11.42		Apr 22	10.82
	Jan 20, 1987	10.98		Jan 20, 1987	11.67			
	Feb 17	10.89		Feb 17	11.56			
	Mar 16	10.72		Mar 16	11.38			
	Apr 22	10.38		Apr 22	10.97			
	Mar 17, 1989	11.03						

Table 2.--*Observed water levels in observation and domestic wells--Continued*

Well identifier	Date	Water level (feet below land surface)	Well identifier	Date	Water level (feet below land surface)	Well identifier	Date	Water level (feet below land surface)
M8	Nov 20, 1986	11.32	M9	Nov 20, 1986	11.28	M10	Nov 20, 1986	11.03
	Dec 17	11.75		Dec 17	11.62		Dec 17	11.41
	Jan 20, 1987	11.92		Jan 20, 1987	11.70		Jan 20, 1987	11.61
	Feb 17	11.81		Feb 19	11.71		Feb 17	11.50
	18	11.82		Mar 16	11.53		Mar 16	11.32
	Mar 16	11.64		Apr 22	11.13		Apr 22	10.95
	Apr 22	11.14						
M11	Nov 20, 1986	10.89	M12	Nov 19, 1986	11.13	M13	Nov 19, 1986	11.15
	Dec 17	11.23		Dec 17	11.46		Dec 17	11.58
	Jan 20, 1987	11.45		Jan 20, 1987	11.63		Jan 20, 1987	11.83
	Feb 17	11.35		Feb 17	11.57		Feb 17	11.72
	Mar 16	11.19		Mar 16	11.40		Mar 16	11.53
	Apr 22	10.87		Apr 22	11.05		Apr 22	11.17
	Mar 17, 1989	11.56		Mar 18, 1989	11.69		Mar 16, 1989	11.90
M14	Nov 20, 1986	9.58	M16	Nov 19, 1986	10.99	M17	Nov 20, 1986	11.35
	Dec 17	9.88		Dec 17	11.42		Dec 17	11.73
	Jan 20, 1987	10.09		Jan 20, 1987	11.63		Jan 20, 1987	11.97
	Feb 17	9.92		Feb 17	11.52		Feb 17	11.86
	18	9.93		Mar 16	11.34		Mar 16	11.64
	Mar 16	9.76		Apr 22	10.80		Apr 22	11.12
	Apr 22	9.43		Mar 18, 1989	11.59		Mar 17, 1989	12.02
	Mar 16, 1989	10.14						
M18	Nov 20, 1986	10.99	M19	Nov 20, 1986	11.38	M20	Nov 20, 1986	11.21
	Dec 17	11.36		Dec 17	11.69		Dec 17	11.62
	Jan 20, 1987	11.58		Jan 20, 1987	11.90		Jan 20, 1987	11.88
	Feb 17	11.46		Feb 17	11.77		Feb 17	11.75
	Mar 16	11.26		Mar 16	11.61		Mar 16	11.53
	Apr 22	10.84		Apr 22	11.16		Apr 22	10.92
	Mar 17, 1989	11.70		Mar 15, 1989	12.08		Mar 17, 1989	12.00
M21	Nov 20, 1986	11.49	M22	Nov 20, 1986	10.79	M23	Nov 20, 1986	10.10
	Dec 17	11.88		Dec 17	11.03		Dec 17	10.39
	Jan 20, 1987	12.15		Jan 21, 1987	11.33		Jan 22, 1987	10.60
	Feb 17	11.90		Feb 17	11.13		Feb 18	10.53
	Mar 16	11.71		Mar 16	10.95		Mar 16	10.32
	Apr 22	11.31		Apr 22	10.47		Apr 22	10.02
							Mar 16, 1989	10.64
M24	Nov 20, 1986	9.11	M25	Nov 20, 1986	9.35	M26	Nov 20, 1986	9.38
	Dec 17	9.40		Dec 17	9.66		Dec 17	9.65
	Jan 22, 1987	9.66		Jan 22, 1987	9.94		Jan 22, 1987	9.91
	Feb 18	9.58		Feb 18	9.81		Feb 18	9.84
	Mar 16	9.54		Mar 16	9.58		Mar 16	9.63
	Apr 22	9.05		Apr 22	9.26		Apr 22	9.33

Table 2.--*Observed water levels in observation and domestic wells--Continued*

Well identifier	Date	Water level (feet below land surface)
M27	Nov 20, 1986	9.73
	Dec 17	9.91
	Jan 22, 1987	10.20
	Feb 18	10.14
	Mar 16	9.92
	Apr 22	9.67
	Mar 16, 1989	9.21
M28	Nov 20, 1986	13.69
	Dec 17	14.24
	18	14.19
	Jan 22, 1987	14.19
	Feb 18	14.13
	Mar 16	13.88
	Apr 22	13.35
	Mar 15, 1989	13.97
M29	Nov 20, 1986	10.19
	Dec 17	10.37
	Jan 22, 1987	10.72
	Feb 18	10.65
	Mar 16	10.56
	Apr 22	10.24
	Mar 15, 1989	10.84
M30	Nov 20, 1986	9.94
	Dec 17	10.20
	Jan 22, 1987	10.32
	Feb 18	10.33
	Mar 16	10.23
	Apr 22	9.90
	Mar 14, 1989	10.47
M31	Nov 20, 1986	10.74
	Dec 17	10.99
	Jan 22, 1987	11.19
	Feb 18	11.14
	Mar 16	10.92
	Apr 22	10.65
	Mar 15, 1989	11.31
M33	Nov 20, 1986	9.15
	Dec 18	9.46
	Jan 22, 1987	9.64
	Feb 18	9.59
	Mar 16	9.44
	Apr 23	9.27
M34	Nov 20, 1986	8.19
	Dec 18	8.37
	Jan 22, 1987	8.51
	Feb 18	8.52
	Mar 16	8.33
	Apr 23	8.24
	Mar 14, 1989	8.65
M35	Nov 20, 1986	11.22
	Dec 17	11.47
	Jan 22, 1987	11.71
	Feb 18	11.41
	Mar 16	11.44
	Apr 23	11.17
D32	Jul 28, 1986	8.15
	Sep 22	8.07
	Nov 20	11.61
	Dec 17	12.04
	Jan 21, 1987	12.36
	Feb 18	12.23
	Mar 16	11.94
	Apr 23	9.09
M36	May 14, 1986	9.46
	Jun 23	9.08
	Jul 28	9.01
	Sep 22	8.71
	Nov 19	10.64
	Dec 17	11.17
	18	11.17
	Jan 20, 1987	11.36
	Feb 17	11.29
	Mar 16	12.28
	Apr 22	11.94
M37	May 14, 1986	9.05
	Jun 23	8.78
	Jul 28	8.76
	Sep 22	8.45
	Nov 20	11.34
	Dec 17	10.82
	Jan 22, 1987	10.78
	Feb 18	10.73
	Mar 16	10.56
	Apr 22	10.35
M38	Nov 20, 1986	8.17
	Dec 17	9.41
	Jan 22, 1987	8.80
	Feb 18	9.34
	Mar 16	9.13
	Apr 23	9.11
M39	Jan 20, 1987	11.02
	Feb 18	11.07
	Mar 16	10.81
	Apr 23	10.69
M40	Jan 21, 1987	12.85
	Feb 18	11.89
	Mar 16	11.73
	Apr 23	11.70

Data Collection

Three studies have been done since the gasoline and diesel fuel recovery program was discontinued in 1983. The first study, under the general direction of the insurance company, consisted of several phases with different contractors. In October 1984, selected domestic wells were sampled for the analysis of soluble aromatic compounds in ground water. Three wells from the original recovery program still remained at the end of 1984 (M1-82 through M3-82, pl. 1), but the wells were not sampled during the insurance company study. In December 1984, 12 new observation wells (M1-85 through M12-85, pl. 1) were drilled. Beginning in February 1985, water levels were measured and selected observation and domestic wells were sampled for the insurance-company study at 3-month intervals to determine the direction of ground-water flow and the concentrations of petroleum-related compounds in ground water.

The second study, which started in 1985, was conducted by the USGS and the Oregon Graduate Center (OGC) as part of the ground-water toxics study. The purpose of the study was to determine the transport and fate of gasoline and diesel fuel in a subsurface environment. The study was discontinued in 1987, and no data or results were published. During this study, the USGS and OGC collected ground-water samples three times, soil-gas samples twice, and samples of aquifer material once. Soil-gas samples and volatile samples were analyzed by OGC, and inorganic samples were analyzed by the USGS National Water Quality Laboratory (NWQL). In August 1985, water samples were analyzed for petroleum-related hydrocarbons. In November 1985, soil-gas samples were collected by using driven probes, and were analyzed for petroleum-related hydrocarbons. From April through June 1986, water samples were collected from selected domestic and observation wells and from temporary wells driven to the water table and pulled out after sampling. In late summer and early fall of 1986, 32 observation wells and 8 multilevel soil-gas sampling tubes were installed. In November 1986, water samples were collected from the new, larger network of observation wells. All ground-water samples were analyzed for volatile hydrocarbons and dissolved oxygen, and selected samples were analyzed for trace metals and common ions. In November 1986, samples of ground water and aquifer material were collected from selected observation wells and analyzed for lead. During the ground-water toxics study, water levels were measured monthly from February 1985 to April 1987. Water-level recorders, which were installed in M8 and M14, operated continuously from January 1987 to 1991.

The third study was done in cooperation with Ecology to determine the 1989 distributions and concentrations of petroleum-related compounds in ground water. In March 1989, ground-water samples were collected from 27 observation wells and were analyzed for volatile hydrocarbons. Samples from six wells were analyzed for trace metals and common ions. Water levels were measured at the time the samples were taken.

Samples collected for the analysis of volatile hydrocarbons during all three studies were preserved by chilling them to 4°C. It has been observed, however, that significant biodegradation can occur in some samples if analyses are not made within 7 days (Brooke Connor, U.S. Geological Survey, oral commun., 1989).

The results and additional information on the procedures used during this and the other two sampling programs are given in the sections "Sampling Studies, Field Techniques, and Laboratory Procedures," and "Chemistry of Ground Water, Soil Gas, and Aquifer Materials".

Processes that Affect the Fate and Distribution of Petroleum Hydrocarbons in a Subsurface Environment

Both gasoline and diesel fuel are refined petroleum products that are mixtures of numerous organic compounds with different physical and chemical properties. The fate and distribution of the individual compounds in a subsurface environment are governed to a large extent by these properties. For example, the aromatic hydrocarbons are the most water-soluble components of gasoline and diesel fuel and are relatively easily dissolved and transported in ground water. Selected properties of some of the major aromatic compounds in gasoline and diesel fuel are given in table 3.

After a liquid petroleum product spills or leaks, some of it will flow through the unsaturated zone to the water table by gravity, and some of it will be held in the unsaturated zone by surface tension. The petroleum that reaches the water table will float and spread on top of the water table because it is less dense than water. Initially, only those hydrocarbon compounds that can be dissolved in ground water at the petroleum-water interface would be transported by ground water. Once dissolved in ground water, compounds can be transported by advection and dispersed horizontally and vertically in the ground water.

Table 3.--*Physical properties of selected aromatic hydrocarbons. (From Weast, 1982; Verschueren, 1983; and MacKay and Shiu, 1982)*

[Solubilities at 20°C unless otherwise indicated; mg/L, milligrams per liter; mm, millimeters; (K_{ow}), octanol-water partition coefficients]

Compound	Aqueous solubility (mg/L)	Vapor pressure (mm of mercury)	Log K_{ow}	Molecular weight
Benzene	1,780	76	2.13	78.11
Toluene	515	22	2.69	92.13
o-Xylene	175	5	2.77	106.17
m-Xylene	196	6	3.20	106.17
p-Xylene	198 (at 25°C)	6.5	3.15	106.17
Ethylbenzene	152	7	3.15	106.17
Naphthalene	34.4	.05	3.37	128.17

Seasonal variations in the water-table altitude can increase dispersion and dissolution of hydrocarbon compounds in the ground water. When the water table rises, some of the petroleum will remain trapped in the interstitial pores of the soil by surface tension below the rising interface (Schwille, 1981). When the water table falls, some water is trapped above the falling interface. This sequence of events substantially increases the vertical distance over which the petroleum is dispersed and provides additional surface area for the dissolution of hydrocarbon compounds into ground water. During periods of ground-water recharge, downward percolating ground water can dissolve hydrocarbons from the petroleum trapped in the unsaturated zone.

The relative proportions of various petroleum hydrocarbons dissolved in the ground water also are affected by volatilization, biodegradation, and sorption. The low-molecular-weight hydrocarbon compounds can volatilize from the petroleum product or from the ground water and can diffuse into the unsaturated zone. The presence of hydrocarbon gases in the unsaturated zone sometimes is used to indicate the presence of petroleum hydrocarbons in ground water.

Some hydrocarbons preferentially sorb to soil particles. These compounds are not as readily transported as those in the gas phase or in the ground water. Some sediment characteristics that affect sorption are grain size, moisture, and organic content.

A variety of naturally occurring soil microbes can, under favorable conditions, degrade hydrocarbon compounds found in gasoline and diesel fuel. Biodegradation is most efficient under aerobic conditions with sufficient supplies of nitrogen and phosphorus, a near-neutral pH, and warm soil temperatures. Under these conditions, some hydrocarbon compounds can be completely degraded into carbon dioxide and water (Atlas, 1981). Anaerobic biodegradation of petroleum hydrocarbons also has been observed, but generally at lower rates than aerobic biodegradation (Healy and Daughton, 1986).

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Clar Pratt, Alan Newman, and William Meyers of the State of Washington Department of Ecology provided much background information about the Yakima site. James F. Pankow, professor at the Oregion Graduate Center (OGC) and director of the OGC Water Research Laboratory in Portland, Oreg., provided technical advice, as well as planning and executing much of the reconnaissance sampling. J.R. McPherson and Lorne M. Isabelle of OGC analyzed the volatile organic compounds in the 1985-86 ground-water toxics study, and William Fish of OGC coordinated the program for the analysis of lead in the aquifer material and in water. Mark S. Mason, of Soil Exploration Company, St. Paul, Minn., provided information about the drilling and monitoring program during the insurance study.

Appreciation also is extended to the many property owners who granted access to land, private wells, and monitoring wells during the samplings.

Well-Identification System

Wells in this report are referenced by identification numbers that are listed in table 4. Their locations are shown on plate 1. The table cross-references these identification numbers with the station name stored in WATSTORE, the USGS computer data base, and with identifiers used in correspondence and progress reports during previous studies. The identification numbers in this report are prefixed by an M for observation wells, D for domestic wells, T for temporary wells installed for the collection of water samples, SG for multidepth soil-gas wells, and SGT for temporary wells installed for the collection of soil-gas samples. The temporary water wells and soil-gas wells were removed immediately after sample collection.

Table 4.--*Wells and well identifiers used in this report*

[N/A, not available; letters in well identifiers in this report signify the following: M, observation well; T, temporary well; D, domestic well; SG, multidepth soil-gas well; SGT, temporary soil-gas well. All domestic wells were sampled at an outside spigot unless suffixed with a K (sampled at kitchen sink) or I (irrigation well, sampled at wellhead); N/A, not applicable]

Well identifiers			Land surface altitude (feet above sea level)	Depth (feet below land surface[1])	Comments
This report	WATSTORE	Other reports			
M1-82	13N/18E-12R01	1	1,078.06	6.0 - 15.6	
M2-82	13N/18E-12R02	2	1,077.93	6.6 - 16.1	Identified as 3-82 (Fish, 1987)
M3-82	13N/18E-12R03	3	1,076.86	6.0 - 15.8	
M1-85	13N/18E-12R04	1-85, MW-1	1,080.48	6.0 - 21.0	
M2-85	13N/19E-07N01	2-85, MW-2	1,067.51	3.5 - 18.5	
M3-85	13N/19E-07N02	3-85, MW-3	1,072.62	4.1 - 19.1	
M4-85	13N/18E-12R05	4-85, MW-4	1,075.66	4.1 - 19.1	
M5-85	13N/19E-07N03	5-85, MW-5	1,069.66	1.8 - 16.8	
M6-85	13N/19E-07N04	6-85, MW-6	1,071.52	4.3 - 19.4	
M7-85	13N/19E-07N05	7-85, MW-7	1,072.48	4.2 - 19.2	
M8-85	13N/19E-07N06	8-85, MW-8	1,075.70	5.0 - 20.0	
M9-85	13N/18E-12R06	9-85, MW-9	1,075.48	4.8 - 19.8	
M10-85	13N/18E-12R07	10-85, MW-1	1,076.37	4.3 - 19.3	
M11-85	13N/18E-12R08	11-85, MW-11	1,077.67	5.5 - 20.5	
M12-85	13N/18E-12R09	12-85, MW-12	1,078.49	6.4 - 21.4	
M1	13N/18E-12R12	T1	1,077.43	55.0 - 58.0	
M2	13N/18E-12R13	T2	1,077.65	28.0 - 30.0	SG1 also in same borehole
M3	13N/18E-12R14	T3	1,077.65	28.0 - 30.0	SG2 also in same borehole
M4	13N/18E-12R15	T4	1,077.02	3.8 - 12.0	
M5	13N/18E-12R16	T5	1,078.39	13.9 - 15.9	SG3 also in same borehole
M6.1	13N/18E-12R17	T6.1	1,077.39	44.6 - 46.6	Piezometers M6.1 and M6.2 are in the same hole
M6.2	13N/18E-12R18	T6.2	1,077.11	7.6 - 13.6	
M7.1	13N/18E-12R19	T7.1	1,078.11	30.3 - 32.3	Piezometers M7.1 and M7.2 are in the same hole
M7.2	13N/18E-12R20	T7.2	1,078.11	7.3 - 13.3	
M8	13N/18E-12R21	T8	1,078.22	8.4 - 14.4	
M9	13N/18E-12R22	T9	1,078.07	7.0 - 13.0	
M10	13N/18E-12R23	T10	1,077.81	8.3 - 14.3	
M11	13N/18E-12R24	T11	1,077.65	8.4 - 14.2	
M12	13N/18E-12R25	T12	1,078.09	7.4 - 13.4	
M13	13N/18E-12R26	T13	1,078.09	30.5 - 32.3	SG4 also in same borehole
M14	13N/18E-12R27	T14	1,076.14	6.8 - 12.8	
M16	13N/18E-12R28	T16	1,078.09	7.9 - 13.9	
M17	13N/18E-12R29	T17	1,078.36	7.7 - 13.7	
M18	13N/18E-12R30	T18	1,077.70	7.1 - 13.1	
M19	13N/18E-12R31	T19	1,078.12	7.8 - 13.8	
M20	13N/18E-12R32	T20	1,078.26	7.2 - 13.2	
M21	13N/18E-12R33	T21	1,077.70	56.3 - 58.3	

Table 4.--*Wells and well identifiers used in this report--Continued*

Well identifiers			Land surface altitude (feet above sea level)	Depth (feet below land surface[1])	Comments
This report	WATSTORE	Other reports			
M22	13N/18E-12R34	T22	1,077.50	6.7 - 12.7	
M23	13N/18E-12R39	B1	1,077.10	6.5 - 12.5	
M24	13N/18E-12R40	B2	1,076.16	7.6 - 13.6	
M25	13N/18E-12R41	B3	1,076.08	30.3 - 32.3	SG6 also in same borehole
M26	13N/18E-12R42	B4	1,076.58	8.0 - 14.0	
M27	13N/18E-12R43	B5	1,076.79	9.0 - 18.0	
M28	13N/18E-12R35	S1	1,077.03	54.0 - 56.5	SG7 also in same borehole
M29	13N/18E-12R36	S2	1,076.99	7.7 - 16.8	
M30	13N/18E-12R37	S3	1,076.89	7.8 - 16.8	
M31	13N/18E-12R38	S4	1,077.74	8.6 - 17.4	
M33	13N/19E-07N08	H1	1,075.13	55.0 - 57.0	
M34	13N/19E-07N09	H2	1,075.02	8.6 - 14.6	
M35	13N/18E-12R11	WS1	1,078.63	57.0 - 59.0	
M36	13N/18E-12R44	T1, GS1	1,077.85	6.0 - 13.0	Estimated screen interval
M37	13N/18E-12R45	B1, GS2	1,077.53	6.0 - 13.0	Identified as GS1 (Fish, 1987)
M38	13N/19E-07N07	3/R	1,072.58	54.2 - 56.2	
M39	13N/18E-12J03	HWY1	1,078.22	N/A	
M40	13N/19E-07M01	HWY2	1,078.35	N/A	
T1	13N/19E-07M04	8T1-1	N/A	N/A	
T2	13N/19E-07N10	8T1-2	N/A	N/A	
T3	13N/19E-07N11	8T1-3	N/A	N/A	
T4	13N/18E-12R46	8T1-4	N/A	N/A	
T5	13N/18E-12R47	8T1-5	N/A	N/A	
T6	13N/18E-12R48	8T1-6	N/A	N/A	
T7	13N/19E-07N12	8T2-2	N/A	N/A	
T8	13N/19E-07N13	8T2-3	N/A	N/A	
T9	13N/19E-07N14	8T2-4	N/A	N/A	
T10	13N/19E-07N15	8T2-5	N/A	N/A	
T11	13N/19E-07N16	8T2-6	N/A	N/A	
T12	13N/19E-07N17	8T2-7	N/A	N/A	
T13	13N/19E-07N18	8T2-8	N/A	N/A	
T14	13N/18E-12R51	7-5	N/A	N/A	
T15	13N/18E-12R52	8-5	N/A	N/A	
T16	13N/18E-12R53	9-7.5	N/A	N/A	
T17	13N/18E-12R54	8-4	N/A	N/A	
T18	13N/18E-12R55	9-4	N/A	N/A	
T19	13N/18E-12R56	1.5-1.5	N/A	N/A	
T20	13N/18E-12R57	8-3	N/A	N/A	
T21	13N/18E-12R58	7-4	N/A	N/A	
T22	13N/18E-12R59	5-3	N/A	N/A	
T23	13N/18E-12R60	5-2	N/A	N/A	
T24	13N/18R-12R61	4-2	N/A	N/A	

Table 4.--*Wells and well identifiers used in this report--Continued*

Well identifiers			Land surface altitude (feet above sea level)	Depth (feet below land surface[1])	Comments
This report	WATSTORE	Other reports			
T25	13N/18E-12R62	4-3	N/A	N/A	
T26	13N/18E-12R63	3-2	N/A	N/A	
T27	13N/18E-12R64	3-3	N/A	N/A	
T28	13N/18E-12R65	6-7	N/A	N/A	
T29	13N/18E-12R66	1-8	N/A	N/A	
T30	13N/18E-12R67	1-9	N/A	N/A	
T31	13N/18E-12R68	1-10	N/A	N/A	
T32	13N/18E-12R69	6-8	N/A	N/A	
T33	13N/18E-12R70	6-9	N/A	N/A	
T34	13N/18E-12R71	4-8	N/A	N/A	
T35	13N/18E-12R72	4-9	N/A	N/A	
T36	13N/18E-12R73	11-8.5	N/A	N/A	
T37	13N/18E-12R74	11-9.5	N/A	N/A	
T38	13N/18E-12R75	11-7.5	N/A	N/A	
T39	13N/18E-12R76	9-8.5	N/A	N/A	
T40	13N/18E-12R77	9-9.5	N/A	N/A	
T41	13N/18E-12R89	(1 m north of M36)	1,078	N/A	
T42	13N/18E-12R90	(1.3 m south of M36)	1,078	N/A	
D1	13N/19E-07M03	H1-01	N/A	25	
D2	13N/19E-07N19	H4-03-(I)	N/A	20	
D3	13N/19E-07N20	H4-06-(K)	N/A	28	
D4	13N/19E-07N21	H4-06-(I)	N/A	13	
D5	13N/19E-07N22	H4-01	N/A	N/A	
D6	13N/19E-07N23	H3-08-(I), H3-07-(I)	N/A	70	
D7	13N/19E-07N24	H3-10-(I), H3-09-(I)	N/A	20	
D8	13N/19E-07N25	H3-11-(I)	N/A	20	
D9	13N/19E-07N26	H4-07	N/A	20	
D10	13N/19E-07N27	H4-08	N/A	80	
D11	13N/19E-07N28	H4-11	N/A	65	
D12	13N/19E-07N29	H6-05	N/A	18	
D13	13N/19E-07N30	H6-04-(I)	N/A	25	
D14	13N/19E-07N31	H6-03-(I)	N/A	N/A	
D15	13N/19E-07N32	H6-01	N/A	N/A	
D16	13N/19E-07N33	H5-06	N/A	N/A	
D17	13N/19E-07N34	H5-05-(I)	N/A	28	
D18	13N/19E-07N35	H5-04-(I)	N/A	28	
D19	13N/19E-07N36	H5-02	N/A	N/A	
D20	13N/19E-07N02	IK6-06-(I)	N/A	30	
D21	13N/19E-07N37	B2-05	N/A	N/A	
D22	13N/19E-07N38	B2-03	N/A	21	
D23	13N/19E-07N39	B2-01	N/A	N/A	
D24	13N/19E-07N40	B1-04	N/A	36	

Table 4.--*Wells and well identifiers used in this report--Continued*

Well identifiers			Land surface altitude (feet above sea level)	Depth (feet below land surface[1])	Comments
This report	WATSTORE	Other reports			
D25	13N/19E-07N41	B1-01	N/A	26	
D26	13N/19E-07N42	B3-05	N/A	N/A	
D27	13N/19E-07N43	B3-03	N/A	N/A	
D28	13N/19E-07N44	B3-01	N/A	30	
D29	13N/19E-07N45	B4-06	N/A	38	
D30	13N/19E-07N46	B4-05	N/A	N/A	
D31	13N/19E-07N47	B4-01	N/A	N/A	
D32	13N/18E-12R97	Mesa	1,079.47	N/A	Water levels only
SG1	13N/18E-12R91	T2	1,077.43	N/A	Sampling tubes installed above the well screen (M2)
SG2	13N/18E-12R92	T3	1,077.65	N/A	Sampling tubes installed above the well scrren (M3)
SG3	13N/18E-12R93	T5	1,078.02	N/A	Sampling tubes installed above the well screen (M5)
SG4	13N/18E-12R94	T13	1,078.09	N/A	Sampling tubes installed above the well screen (M13)
SG5	13N/18E-12R87	T15	1,078.19	N/A	Multidepth soil-gas sampler only
SG6	13N/18E-12R95	B3	1,076.08	N/A	Sampling tubes installed above the well screen (M25)
SG7	13N/18E-12R96	S1	1,077.03	N/A	Sampling tubes installed above the well screen (M28)
SG8	13N/18E-12R88	S5	1,077.65	N/A	Multidepth soil-gas sampler only
SGT1	13N/18E-12R81	1-9	N/A	5.67	
SGT2	13N/18E-12R81	1-7	N/A	3.46	
SGT3	13N/18E-12R79	1-4	N/A	3.59	
SGT4	13N/18E-12R78	1-2	N/A	4 to 5 (estimated)	
SGT5	13N/18E-12R82	2-5	N/A	3.47	
SGT6	13N/18E-12R83	3-2	N/A	4.58	
SGT7	13N/18E-12R84	4-6	N/A	4.10	
SGT8	13N/18E-12R85	4-2	N/A	5.35	
SGT9	13N/18E-12R86	5-5	N/A	4.96	

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[1] Screened interval or bottom depth of an open-ended casing.

SAMPLING STUDIES, FIELD TECHNIQUES, AND LABORATORY PROCEDURES

Field and laboratory methods used during the three studies were generally similar and are discussed in detail for comparison—field and laboratory methods in this section and quality-assurance procedures and results in Appendix A.

Ground-Water Sampling

Insurance Company Study

Twelve observation wells were installed using a cable-tool drilling rig. Wells were constructed with 2-inch-diameter, flush-threaded PVC (polyvinyl chloride) casing and 15 feet of PVC screen, 10 feet of which extended below the water table. Water samples were collected from the wells using bottom-filling Teflon bailers. A minimum of three casing volumes of water was pumped from a well before a ground-water sample was collected. Water samples from domestic wells were collected from cold-water faucets that were allowed to run at a rate of about 1 gallon per minute for 30 minutes prior to sampling. The samples were from untreated sources that were non-filtered and non-aerated. All samples were preserved on ice and transported to a private laboratory for analysis.

Ground-Water Toxics Study

The ground-water toxics study included three water-sampling periods with different objectives. The first sampling (August 1985) was done to determine the farthest extent of dissolved hydrocarbon movement in the ground water. The second sampling (April through June 1986) included 29 additional temporary wells to better delineate the extent of dissolved hydrocarbons and to determine appropriate sites for 34 additional observation wells. In the third sampling period (November 1986), samples were collected from some of the new observation wells.

The additional 34 observation wells were drilled using the air-rotary method. The wells were constructed of 2-inch PVC casing, with 3- to 5-foot lengths of 0.10-inch slotted PVC screen at the bottom. Most screens were set so that the middle part of the screen was close to the surface of the water table at the time of drilling. Sections of PVC casing were welded together rather than cemented, to prevent contamination by solvents used in the cement. The annulus around each screen was packed with sand to a depth of several feet above the screen and then sealed to the surface with bentonite or a bentonite and cement mix. Several deeper wells that were drilled below the water table were packed with sand several feet above the screen, backfilled with clean cuttings, and then surface sealed with a bentonite and cement mix. The wells were developed by pumping.

In the spring of 1985, staff of the OGC collected ground-water samples from 29 temporary wells. The wells were installed by jackhammering a steel drive tube to a depth 2 feet below the water table and then removing the tube with a railroad jack. A 3-foot length of 3/8-inch flexible tubing was attached to the top of a 3/8-inch stainless steel pipe and lowered down the hole to collect a sample. A vacuum was applied when the pipe was a few inches below the water table, the flexible tubing was then bent and clamped, and the pipe was lifted out of the hole. Two 14-mL (milliliter) sample vials were filled by slowly releasing the clamp, and the vials were stored on ice for later analysis. Some modifications to this sample collection procedure were made during the course of the study. To prevent borehole collapse upon removal of the steel drive tube, the tube was fitted with a perforated tip and left in the hole during sample collection. Also, some samples were collected by securing the sample vial at the end of a thin stainless steel rod and lowering the vial to the water table directly through the driven hollow tube. All downhole tools that were used in this phase were cleaned with a methanol solution and dried with an electric hair dryer.

Bottom-filling glass bailers were used to collect water samples from observation wells for the analysis of volatile hydrocarbons. Before each sample was collected, five casing volumes were pumped from the well. Before each well was sampled, the bailer was rinsed with a 10-percent methanol solution and an acetone-hexane mixture (60 to 40, by volume). Remaining solvent residues then were removed from the bailer by baking in an oven, by heating with an electric hair dryer, or by aspirating with a vacuum pump.

The cleaned sampler then was rinsed by bailing three times from the well. A sample vial was filled from the fourth bailing and packed in ice until analysis. The technique used to collect samples from domestic wells was similar to that used during the insurance company study. All volatile hydrocarbon water samples collected were analyzed by the staff from the OGC.

1989 Study

The procedure used to sample observation wells in the 1989 study was nearly identical to that used during the ground-water toxics study. One difference was that the bailer was rinsed with organic-free water after the acetone-hexane rinse. Also, the bailer was routinely baked in an oven at 105°C for one-half hour after the organic-free water rinse. Results of tests to check the adequacy of the cleaning procedure are given in Appendix A.

Samples were analyzed by the NWQL in Arvada, Colo. Field quality-assurance procedures included duplicate samples, field blanks, and field-spiked samples with known amounts of target compounds. These procedures are described in Appendix A.

Ground-Water Analysis Methods

Similar gas-chromatographic techniques were used for all three studies to determine concentrations of volatile hydrocarbons in ground-water samples. Differences in techniques are noted below and references are given for more details. Analyses made by OGC produced concentrations that were blank-corrected, as referenced in Appendix A. Analyses made by the other studies were not blank-corrected.

Insurance Company Study

Samples were analyzed for benzene, toluene, and total xylenes (the sum of the meta, para, and ortho isomers), and a value was calculated for total hydrocarbons expressed as gasoline. Samples were analyzed using a Tekmar LSC-2 liquid sample concentrator linked to a Perkin-Elmer Sigma 300 gas chromatograph with flame ionization detection (FID), on a 6-foot stainless steel column with SP-1000 100/120 mesh packing. Total xylenes, benzene, and toluene were identified by retention time and quantified by comparison with known standards using an SP-4000 data system. Total gasoline concentrations were calculated by comparing total peak area with a gasoline standard total peak area.

Ground-Water Toxics Study

The analytical method used by the OGC was purge and trap with whole-column cryotrapping. This method was employed with fused-silica, capillary-column gas chromatography (GC), as developed by Pankow and Rosen (1984) and modified by Pankow (1986). Both FID and mass spectrometric (MS) detection were used. The purge and trap device was a Chemical Data Systems Model 320 concentrator. The GC/MS was a Hewlett-Packard 5790A GC interfaced to a Finnigan 4000 MS/DS (data system). The carrier flow from the capillary column exiting the GC was split, approximately half of the flow directed into the MS source and the remainder to a FID housed in a Hewlett-Packard 5700A GC.

Normally, a 5.0-mL aliquot of sample was loaded into the sparging vessel and each aliquot was spiked with 10 µL (microliter) of an internal standard solution in methanol. If samples were highly contaminated, smaller sample aliquots were loaded into the sparging vessel and organic-free water was added to produce 5.0 mL of diluted sample for analysis. Samples were analyzed for a set of 18 target compounds (table 5) known to be components of gasoline and diesel fuel. During sample analysis, standards containing known concentrations of target and internal standards compounds were run routinely. Replicates of the samples were run back to back, a day apart, and in one case 6 days apart.

Sample concentrations were computed on the basis of the appropriate sample and standard peak areas, and were blank-corrected using replicate values of blanks, duplicates, and standards. The internal-standard compounds served to compensate for any variations in the purging efficiencies and the system response. The response factors were assumed to be linear over the concentration range of interest.

1989 Study

The method used by the NWQL to analyze samples was purge and trap. This method was employed with gas chromatography and electron impact mass spectrometry (GC/MS) as per EPA Method 524.2 (U.S. Environmental Protection Agency, 1988a), and the list of volatile organic compounds targeted by this analytical method was modified by adding standards for the quantification of five compounds in addition to those targeted by EPA Method 524.2 (table 5). The purge and trap device was a Tekmar LSC 2000 with an ALS 2016 and ALS 2032. The 25-mL sample was purged for 11 minutes at ambient temperature with a gas flow of 40 mL per minute, desorbed at 180°C for 4 minutes onto a 30-meter x 0.53-mm ID (inside diameter) DB-624 megabore column, and baked at 225°C for 15 minutes. Temperature of the Finnigan Incos 50 MS/DS was held at 10°C for 1 minute, then increased to 160°C at

5°C per minute, and held at 160°C for 1 minute. The megabore column was coupled directly to the mass spectrometer, which was set to analyze from 45 to 300 atomic mass units with a scan time of 1 second. A Hewlett-Packard HP5996A MS/DS was used for those samples on which a computer library search was performed. Ten percent of the samples were run in duplicate, and 10 percent of the less-contaminated samples were spiked with a solution containing six matrix spike compounds. Additional quality-assurance measures included daily blanks, daily standards, daily instrument tuning, and quality-control check samples.

For selected analyses, a computer library search was used to compare mass spectra from corresponding GC peak maximums with National Bureau of Standards Library Reference Standards. The best library matches were selected according to a "reliability factor"—a parameter used by the library search algorithm to quantify the match between the sample and library spectra. The best computer matches were compared with the sample spectrum manually to attempt the best possible tentative identification.

Soil Gas

Samples of soil gas, the gas in the pore spaces in the soils and sediments above the water table, were collected from temporary-driven sampling tubes and from permanent wells in which multidepth sampling tubes were installed. Samples from the temporary-driven wells were taken from locations with the smallest expected concentrations and then from locations where larger concentrations were expected. A 6-foot-long, 3/4-inch OD (outside diameter), 1/4-inch ID stainless steel casing tube was driven to a depth of 5.5 feet below land surface and then backed out a few inches. Then, a 7-foot stainless steel sampling tube was inserted 1 inch beyond the bottom of the casing tube. Two hundred mL of soil gas, an amount that was greater than 5 times the volume of the sampling system, was drawn through the sampling tube with a vacuum pump. A Tenax-GC sample cartridge then was placed in line and the system was pumped for about 12 minutes at a rate of about 40 mL per minute. The sample cartridge was removed, the ends were capped, and the sample was stored in an organic-free environment at ambient temperature prior to analysis.

Sampling techniques and analytical methods for multidepth wells were the same as for the temporary driven wells. The stainless steel sampling tubes each extended to a specified depth, were surrounded with sand, and were sealed from each other with concrete.

Soil-gas analysis was done by adsorption onto a Tenax cartridge, and subsequent thermal desorption with whole-column cryotrapping on the GC and FID and MS detection. The Tenax cartridges needed no sample preparation prior to desorption. The cartridge was placed in the desorption apparatus and purged for 10 minutes with a backflow of helium to remove the oxygen and most of the methanol. The Tenax cartridge was desorbed at 250°C for 10 minutes at 30 pounds per square inch (psi) and the released compounds were readsorbed onto the GC column, which was held at a temperature of -80°C. After desorption, the GC column temperature was raised rapidly to 0°C, and then programmed to increase at 10°C per minute to 250°C. Additional details are given by Ligocki and Pankow (1985).

Aquifer Materials

In November 1986, samples of both solid aquifer material and water were collected from selected observation wells. Concentrations of lead dissolved in water and lead adsorbed onto the surface of the less-than-63-µm (micrometer) fraction of the aquifer material were determined. Samples of aquifer material could not be obtained easily by coring because of the cobbly nature of the deposits, therefore samples of fine-grained aquifer materials that had passed through well screens after installation of the well were obtained by placing a pump intake near the bottom of the well. Approximately 5 gallons of sediment-laden water was pumped from each undeveloped well and collected in a clean plastic bucket. The sediment was allowed to settle, dewatered by filtering into a firm cake, placed in a polyethylene bag, and stored on ice. The firm cake was then processed by mixing with water and wet-sieving through a 63-µm polypropylene sieve. The less-than-63-µm fraction was filtered to a moist cake, subsampled, and digested with a solution composed of 6-percent Ultrex nitric acid and 1-molar reagent-grade ammonium acetate. The samples then were analyzed in the same manner as the filtered ground water (Fish, 1987). After the well was pumped at 10 gallons per minute for 20 to 30 minutes, ground-water samples were collected by pumping through acid-washed Tygon tubing and filtering through acid-washed 0.1-µm (pore-size) membrane filters into acid-washed polypropylene bottles.

Table 5.--*Target compounds in water analyzed for volatile organic compounds by the purge and trap method*

Compound	Chemical Abstract Services registry number
Ground-water toxics study	
1,2-Dibromoethane	106-93-4
1,3-Dimethyl-4-ethylbenzene	874-41-9
1,4-Dimethyl-2-ethylbenzene[1]	175-88-89
2-Ethyl-1-methylbenzene	611-14-3
1-Isopropyl-4-methylbenzene	99-87-6
1,2,3-Trimethylbenzene	526-73-8
1,2,4-Trimethylbenzene	95-63-6
1,3,5-Trimethylbenzene	108-67-8
1,2,3,4-Tetramethylbenzene	488-23-3
1,2,3,5-Tetramethylbenzene	527-53-7
Benzene	71-43-2
n-Butylbenzene	104-51-8
sec-Butylbenzene	135-98-8
tert-Butylbenzene	98-06-6
Ethylbenzene	100-41-4
Isobutylbenzene	538-93-2
Naphthalene	91-20-3
n-Propylbenzene	105-65-1
Toluene	108-88-3
m-Xylene	108-38-3
o-Xylene	95-47-6
p-Xylene	106-42-3
March 1989 study	
2-Chlorotoluene	95-49-8
4-Chlorotoluene	106-43-4
1,2-Dibromoethane	106-93-4
1,2-Dichlorobenzene	95-50-1
1,3-Dichlorobenzene	541-73-1
1,4-Dichlorobenzene	106-46-7
1,1-Dichloroethane	75-34-3
1,1-Dichloroethene	75-35-4
1,2-Dichloroethane	107-06-2
cis-1,2-Dichloroethene	156-59-2
trans-1,2-Dichloroethene	156-60-5
1,2-Dichloropropane	78-87-5
1,3-Dichloropropane	142-28-9
2,2-Dichloropropane	594-20-7
1,1-Dichloropropene	563-58-6
cis-1,3-Dichloropropene	100-61-015
trans-1,3-Dichloropropene	100-61-026
1,3-Dimethyl-2-ethylbenzene	2870-04-4
1,4-Dimethyl-2-ethylbenzene[1,2]	175-88-89
2-Ethyl-1-methylbenzene[2]	611-14-3
1,1,1-Trichloroethane	71-55-6
1,1,2-Trichloroethane	79-00-5
March 1989 study--continued	
1,2,3-Trichlorobenzene	87-61-6
1,2,4-Trichlorobenzene	120-82-1
1,2,3-Trichloropropane	96-18-4
1,2,3-Trimethylbenzene[2]	526-73-8
1,2,4-Trimethylbenzene	95-63-6
1,3,5-Trimethylbenzene	108-67-8
1,1,1,2-Tetrachloroethane	630-20-6
1,1,2,2-Tetrachloroethane	79-34-5
1,2,3,4-Tetramethylbenzene[2]	488-23-3
1,2,3,5-Tetramethylbenzene[2]	527-53-7
Benzene	71-43-2
Bromobenzene	108-86-1
Bromodichloromethane	75-27-4
Bromoform	75-25-2
Bromomethane	74-83-9
n-Butylbenzene	104-51-8
sec-Butylbenzene	135-98-8
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroethane	75-00-3
Chloroform	67-66-3
Chloromethane	74-87-3
Chlorodibromomethane	124-48-1
Dibromomethane	74-95-3
Dichlorodifluoromethane	75-71-8
Ethylbenzene	100-41-4
Isopropylbenzene	98-82-8
p-Isopropyltoluene	99-87-6
Methylene chloride	75-09-2
Naphthalene	91-20-3
n-Propylbenzene	105-65-1
Styrene	100-42-5
Tetrachloroethene	127-18-4
Trichlorofluoromethane	75-69-4
Toluene	108-88-3
Trichloroethene	79-01-6
Vinyl chloride	75-01-4
m-Xylene	108-38-3
o-Xylene	95-47-6
p-Xylene	106-42-3

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[1] This compound co-elutes with 1,3-dimethyl-4-ethylbenzene (Chemical Abstract Services registry number 874-41-9).

[2] Standards for the quantification of this compound were added to the laboratory procedure of EPA Method 524.2

CONCENTRATIONS AND AREAL EXTENT OF PETROLEUM-RELATED PRODUCTS

Ground water, soil gas, and aquifer materials have been sampled during the course of the three studies since the recovery of leaked gasoline and diesel fuel was discontinued.

Ground-water samples were analyzed for volatile organic compounds and inorganic compounds that were used as indicators of reduced conditions. Several methods were used in sampling soil gas in the unsaturated zone near the leak site, and initial results were used to help determine the placement of observation wells. Samples of the aquifer materials were analyzed in an attempt to correlate lead concentrations in the soil with the movement of dissolved gasoline in ground water.

Volatile Organic Compounds in Ground Water

Insurance Company Study

At least one of the three target compounds of the insurance study (benzene, toluene, and total xylenes) was detected at least once in 4 of the 23 wells (figs. 6 to 10 and table 6). Target compounds were detected consistently and at relatively large concentrations in water from well M11-85, located about 150 feet from the leak site. Target compounds were detected consistently in only one domestic well, D10, located about 1,200 feet downgradient of the site, but concentrations were smaller than in M11-85. Target compounds were detected in wells M8-85 and M10-85, located about 900 feet downgradient of the leak site, but the occurrences were sporadic and concentrations were small. The wells used in this study were too widely separated to allow a detailed definition of the distributions of hydrocarbon compounds in ground water.

Ground-Water Toxics Study

During the ground-water toxics study, ground-water samples were analyzed for as many as 23 aromatic hydrocarbons, primarily alkylated-benzenes (table 5). All but six of the compounds were found in ground water. Concentrations of compounds found during the different sampling periods of this study are given in table 7. Because analytical methods changed during the course of the study, not all of the target compounds were analyzed in each of the sampling periods. Furthermore, the method for reporting analytical results when concentrations were near background or detection levels differed among sampling periods.

Distributions of concentrations of data for benzene, toluene, naphthalene, and total xylenes are shown on figures 6 through 9. These four compounds are among the more water-soluble aromatic compounds in gasoline (table 3), and lines of equal concentration of 5 µg/L are used to compare changes in concentration and areal extent of ground-water contamination. A value of 5 µg/L was chosen as the line of equal concentration because it is an order of magnitude greater than the level of detection for most compounds, and consequently there is a high certainty of detection at this concentration, eliminating any doubt of trace detections at or near the detection level. The 5-µg/L concentration is also the drinking water Maximum Contaminant Level (MCL) for benzene (U.S. Environmental Protection Agency, 1988c). There is no MCL for naphthalene, but the MCL for toluene is 2,000 µg/L, and the MCL for total xylenes is 10,000 µg/L.

During the first sampling period in August 1985, detectable concentrations of benzene, toluene, naphthalene, and total xylenes were found in samples from 5 of 15 insurance company observation wells, 1 of 13 temporary wells, and 2 of 31 domestic wells (table 7). Although petroleum-related compounds were detected as far as 1,000 feet from the service station, concentrations of individual compounds exceeded 500 µg/L only in samples from the three wells closest to the service station (figs. 6 to 9). A petroleum sheen was noted on samples from two of these three wells (M3-82 and M11-85), indicating the presence of free product.

During the second sampling, from April through June 1986, detectable concentrations of benzene, toluene, naphthalene, or total xylenes were found in the samples from 5 of 6 insurance company observation wells and at all 29 temporary wells. Observed concentrations of benzene, toluene, naphthalene, and total xylenes (figs. 6 to 9) indicate that some of the dissolved compounds had migrated in an east north-easterly direction.

During the third sampling in November 1986, benzene, toluene, naphthalene, or total xylenes were detected in samples from 5 of 8 insurance company observation wells and in 18 of the 23 observation wells installed during this study (table 4; see plate 1 for well locations). Concentrations of some of these four compounds exceeded 500 µg/L at 8 of the observation wells within 400 feet of the service station (figs. 6 to 9).

The vertical distribution of hydrocarbons dissolved in ground water was also investigated. Observation wells that penetrated deeper into the aquifer than wells that were screened at the water table (M2, M6.1, M7.1, and M13; pl. 1 and table 4) were sampled in November 1986. Observation wells M6.1 and M6.2 were installed in the same hole about 1,300 feet downgradient of the service station; M6.1 extended to 46 feet below land surface, and M6.2 was screened at the water table. Observation wells M7.1 and M7.2 are a similar pair installed in a hole about 500 feet downgradient from the service station, M7.2 screened at the water table, and M7.1 extended to 32 feet below land surface. Benzene, toluene, napthalene, total xylenes, ethyl benzene, and other alkyl benzenes were detected in all the deeper observation wells that were sampled. Concentrations of dissolved hydrocarbons in the ground water from observaton wells M2 and M6.1 were less than 1 µgL, whereas observation well M7.1 had a concentration of 3.2 µg/L total xylenes. Concentrations of dissolved hydrocarbons in ground water from observation well M13 ranged from 0.5 to 47 µg/L. The concentrations of dissolved hydrocarbons in ground water from deeper wells were from one to more than three orders of magnitude smaller than those from observation wells at the water-table surface. The major part of the leaked gasoline and diesel fuel dissolved in the ground water appears to be near the surface of the water table. Further, the migration of dissolved hydrocarbons in the ground water is preferentially in a horizontal downgradient direction.

1989 Study

Analyses of ground-water samples collected in 1989 indicate that there were still dissolved components of gasoline and diesel fuel in the ground water (table 8, figs. 6 to 9). Concentrations of benzene, toluene, naphthalene, and total xylenes greater than the detection limit of 0.2 µg/L were found in ground-water samples from 11 of the 27 sampled wells. Only concentrations of total xylenes exceeded 500 µg/L, at two wells, M3-82 and M16. Large amounts of toluene or other alkyl benzenes also were found at these two wells and at well M11-85, but concentrations for these compounds were less than 500 µ/L. Concentrations of volatile hydrocarbons were less than 5 µg/L at distances more than 400 feet from the source of the leak.

In March 1989, concentrations of petroleum-related compounds in ground water were less than in 1985 and 1986 and the areal extent of ground-water contamination was less than in 1985 and 1986 (tables 6 and 7, figs. 6 to 9). Consequently, the concentrations of petroleum-related products dissolved in ground water appear to be decreasing, and the area where concentrations are at 5 µg/L or greater also appears to be decreasing. However, this conclusion is based on a single sampling in 1989.

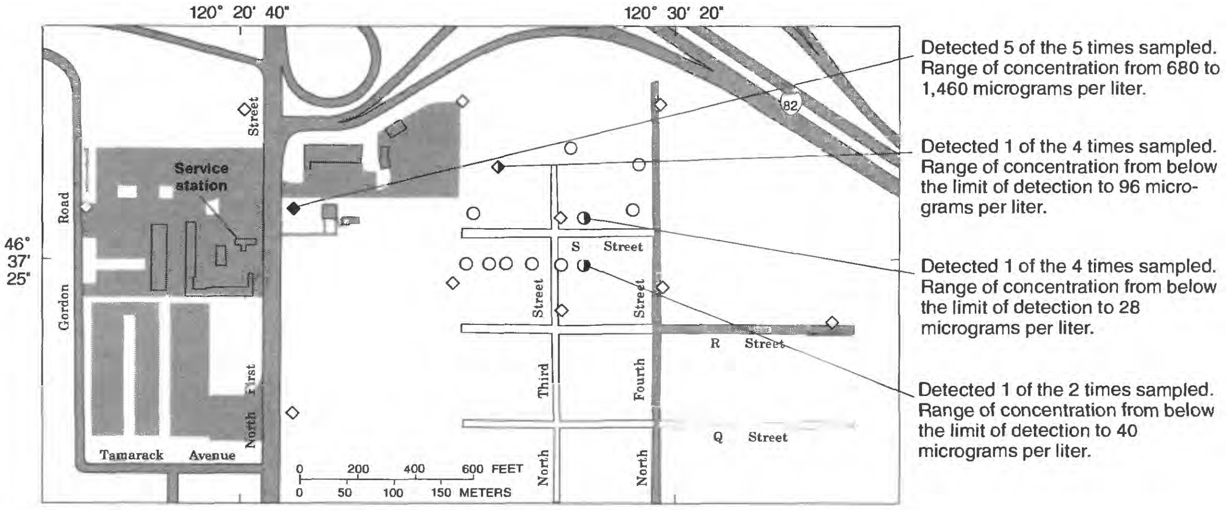
Table 6.--*Concentrations of volatile organic compounds in ground water, October 1984 through June 1986. (Data from the insurance company study, analyzed by a private laboratory)*

[ND, below the detection limit of 1 microgram per liter unless otherwise indicated; --, not analyzed for]

		Concentrations (milligrams per liter)			
Well identifier	Date	Benzene	Toluene	Total xylenes	Total hydrocarbons (as gasoline)
M1-85	02-21-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
M2-85	02-21-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
M3-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	ND	ND	ND
M4-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	ND	ND	ND
M5-85	02-21-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
M6-85	02-21-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
M7-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	ND	ND	ND
	08-27-85	ND	ND	ND	ND
	12-16-85	ND	ND	ND	ND
	06-20-86	ND	ND	ND	ND
M8-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	ND	ND	ND
	08-27-85	96	1	9	230
	06-20-86	ND	ND	ND	ND
M9-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	ND	ND	ND
	12-16-85	ND	ND	ND	ND
	06-20-86	ND	ND	ND	ND
M10-85	02-21-85	ND	ND	ND	ND
	05-11-85	ND	2	5	17
	08-27-85	ND	ND	ND	ND
	12-16-85	ND	ND	ND	ND
	06-20-86	ND	ND	ND	ND
M11-85	02-21-85	1,460	5,300	6,260	23,400
	05-11-85	[1]1,240	[1]5,850	[1]13,940	[1]33,000
	08-27-85	920	1,100	6,300	12,000
	12-16-85	710	1,100	750	28,000
	06-20-86	680	7,000	18,000	45,000
M12-85	02-21-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
D3	02-19-85	ND	ND	ND	ND
	03-25-85	ND	ND	ND	ND
	05-10-85	ND	ND	ND	ND
	06-25-85	ND	ND	ND	ND
	07-25-85	ND	ND	ND	ND
	12-16-85	ND	ND	ND	ND
	06-20-86	ND	ND	ND	ND
D5	02-19-85	ND	ND	ND	ND
D6	10-02-84	<0.5	<0.5	0.9	--
	02-19-85	ND	ND	ND	ND
D10	10-02-84	<0.5	<0.5	<0.5	--
	02-19-85	ND	ND	5	14
	03-25-85	28	680	980	3,120
	05-10-85	ND	1	4	17
D11	10-02-84	<.5	<.5	<.5	--
D12	02-19-85	ND	ND	ND	ND
D13	02-19-85	ND	ND	ND	ND
D14	02-19-85	ND	ND	ND	ND
D15	10-02-84	<0.5	<0.5	<0.5	--
D16	02-19-85	ND	ND	ND	ND
D17	10-02-84	40	70	45	--
	02-19-85	ND	ND	ND	ND

---

[1] Average of two values.



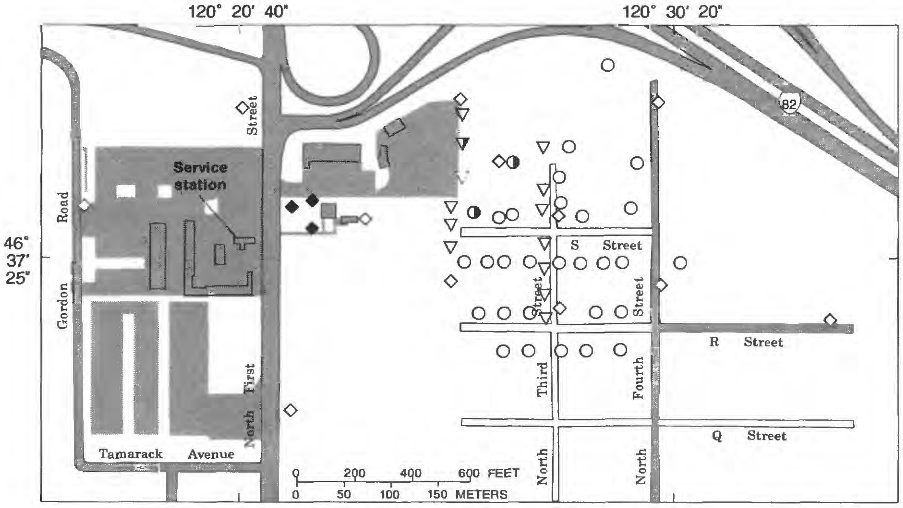
Detected 5 of the 5 times sampled. Range of concentration from 680 to 1,460 micrograms per liter.

Detected 1 of the 4 times sampled. Range of concentration from below the limit of detection to 96 micrograms per liter.

Detected 1 of the 4 times sampled. Range of concentration from below the limit of detection to 28 micrograms per liter.

Detected 1 of the 2 times sampled. Range of concentration from below the limit of detection to 40 micrograms per liter.

a. October 1984 through May 1986



b. August 1985

EXPLANATION

▨ **Impervious surface** — Paved areas and buildings.

Sampled well and benzene concentrations in micrograms per liter — Symbols indicates well type. Open symbol indicates near or below detection limits. Half-shaded symbol indicates detected but less than 500 micrograms per liter. Solid symbol indicates concentrations of 500 micrograms per liter or greater.

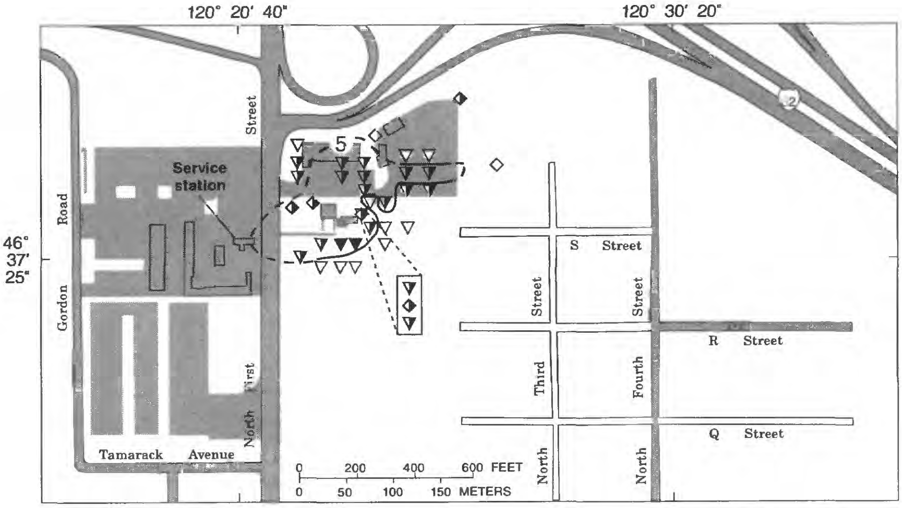
- - - - 5 ——— **Line of equal benzene concentration (5 micrograms per liter)** — Dashed where approximately located.

◇ **Observation well**

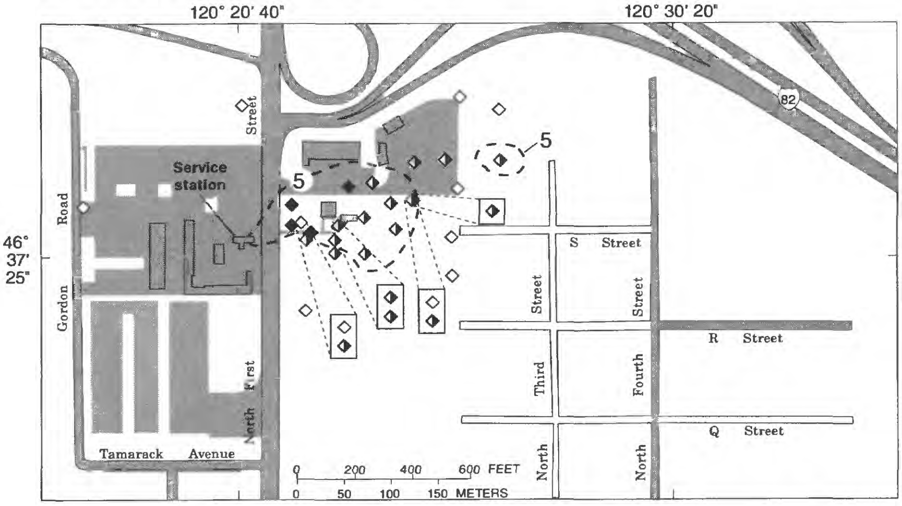
▽ **Temporary well**

○ **Domestic well**

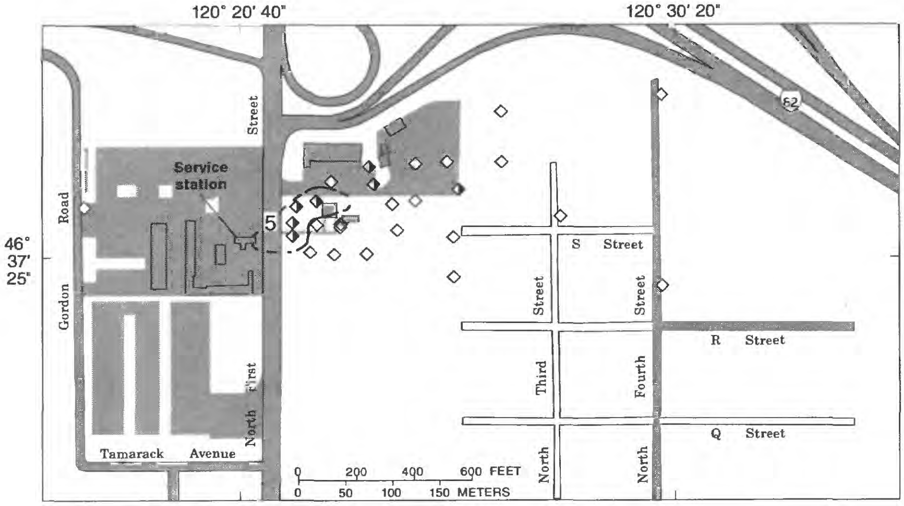
Figure 6.--Concentrations of benzene in ground water, October 1984 through March 1989. (Data are from (a) the insurance company study, (b-d) the ground-water toxics study, and (e) the 1989 study).



c. April through June 1986

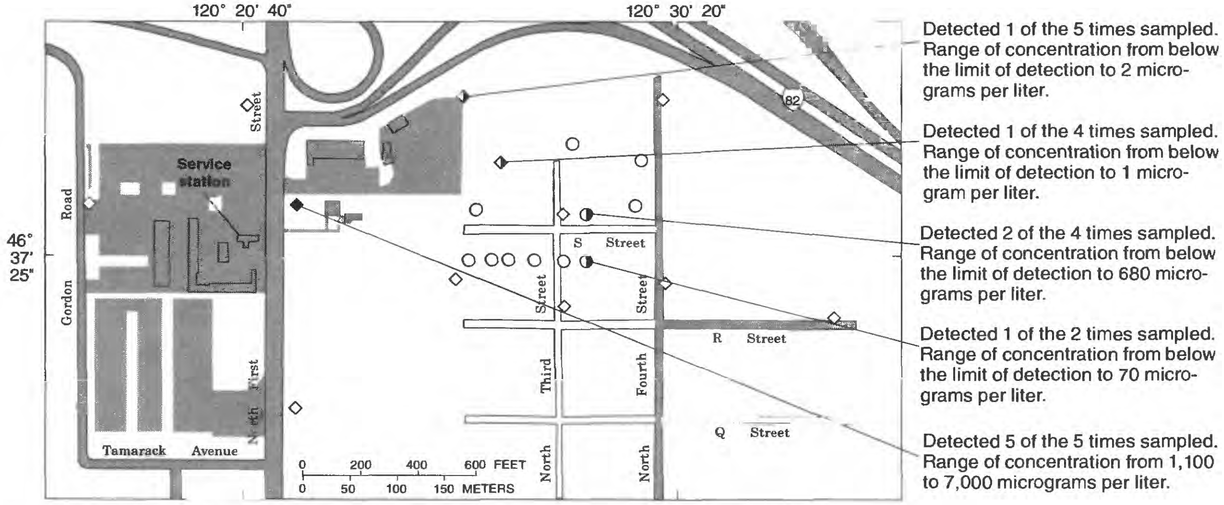


d. November 1986



e. March 1989

Figure 6.--Continued.



Detected 1 of the 5 times sampled. Range of concentration from below the limit of detection to 2 micrograms per liter.

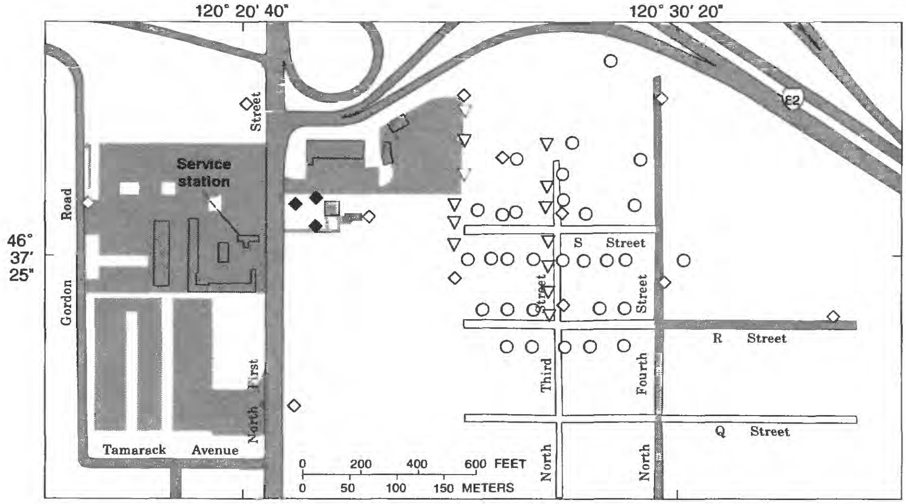
Detected 1 of the 4 times sampled. Range of concentration from below the limit of detection to 1 microgram per liter.

Detected 2 of the 4 times sampled. Range of concentration from below the limit of detection to 680 micrograms per liter.

Detected 1 of the 2 times sampled. Range of concentration from below the limit of detection to 70 micrograms per liter.

Detected 5 of the 5 times sampled. Range of concentration from 1,100 to 7,000 micrograms per liter.

a. October 1984 through June 1986



b. August 1985

EXPLANATION

▨ **Impervious surface** — Paved areas and buildings.

Sampled well and benzene concentrations in micrograms per liter — Symbols indicates well type. Open symbol indicates near or below detection limits. Half-shaded symbol indicates detected but less than 500 micrograms per liter. Solid symbol indicates concentrations of 500 micrograms per liter or greater.

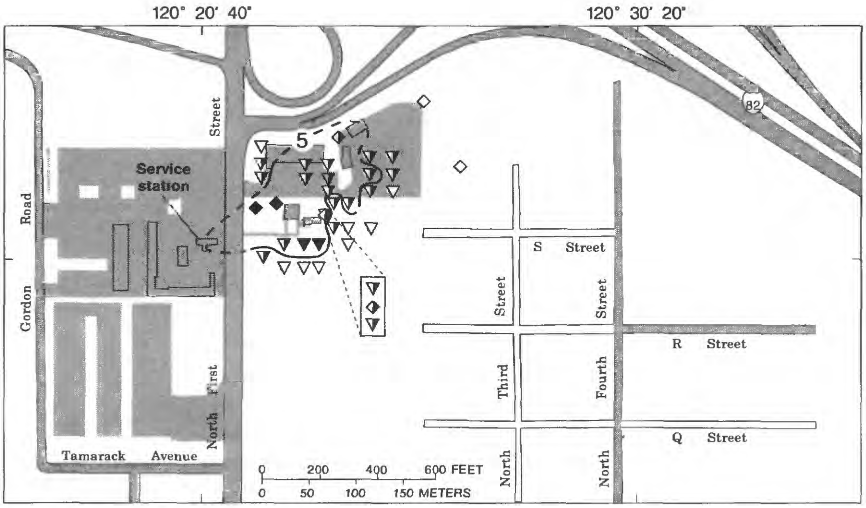
- - - - 5 ——— **Line of equal benzene concentration (5 micrograms per liter)** — Dashed where approximately located.

◇ **Observation well**

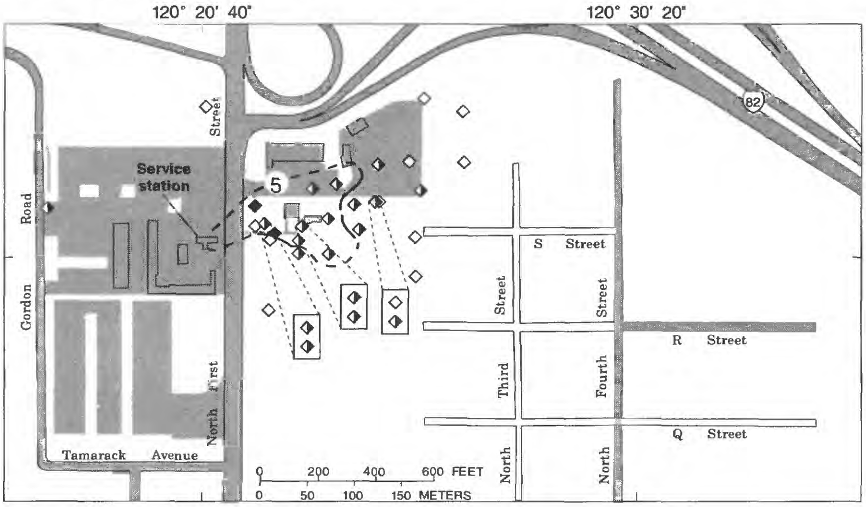
▽ **Temporary well**

○ **Domestic well**

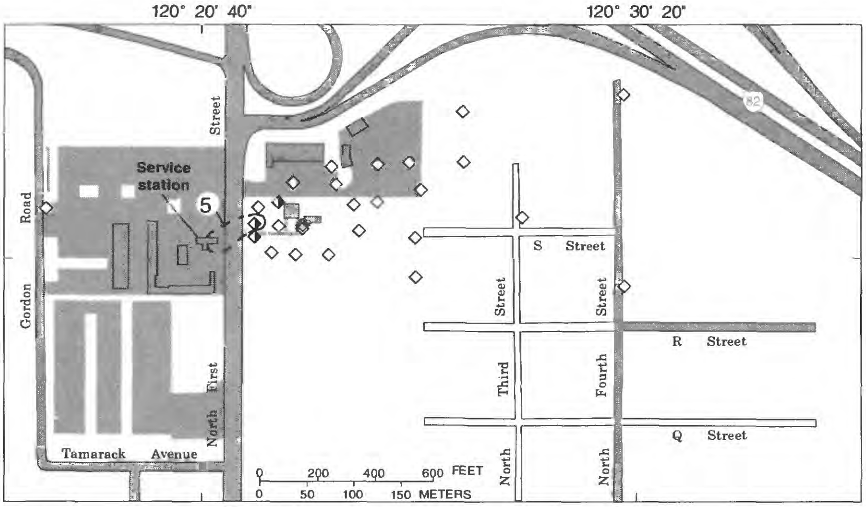
Figure 7.--Concentrations of toluene in ground water, October 1984 through March 1989. (Data are from (a) the insurance company study, (b-d) the ground-water toxics study, and (e) the 1989 study).



c. April through June 1986

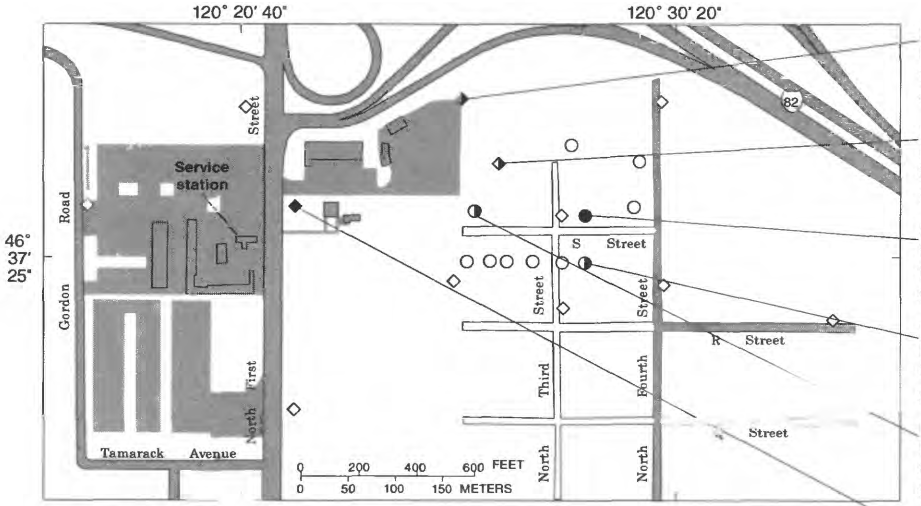


d. November 1986



e. March 1989

Figure 7.--Continued.



Detected 1 of the 5 times sampled. Range of concentration from below the limit of detection to 5 micrograms per liter.

Detected 1 of the 4 times sampled. Range of concentration from below the limit of detection to 9 micrograms per liter.

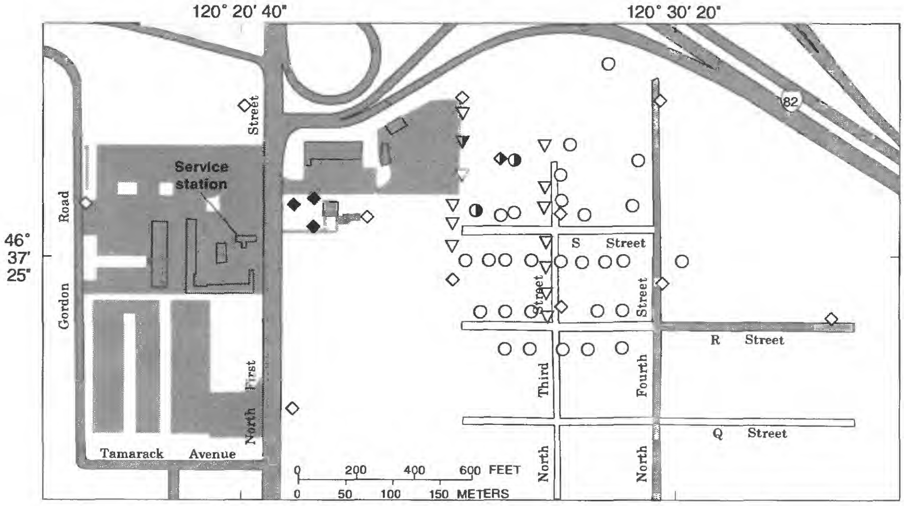
Detected 3 of the 4 times sampled. Range of concentration from below the limit of detection to 980 micrograms per liter.

Detected 1 of the 2 times sampled. Range of concentration from below the limit of detection to 45 micrograms per liter.

Detected 1 of the 2 times sampled. Range of concentration from below the limit of detection to 0.9 micrograms per liter.

Detected 5 of the 5 times sampled. Range of concentration from 750 to 18,000 micrograms per liter.

a. October 1984 through June 1986



b. August 1985

EXPLANATION

▨ **Impervious surface** — Paved areas and buildings.

Sampled well and benzene concentrations in micrograms per liter — Symbols indicates well type. Open symbol indicates near or below detection limits. Half-shaded symbol indicates detected but less than 500 micrograms per liter. Solid symbol indicates concentrations of 500 micrograms per liter or greater.

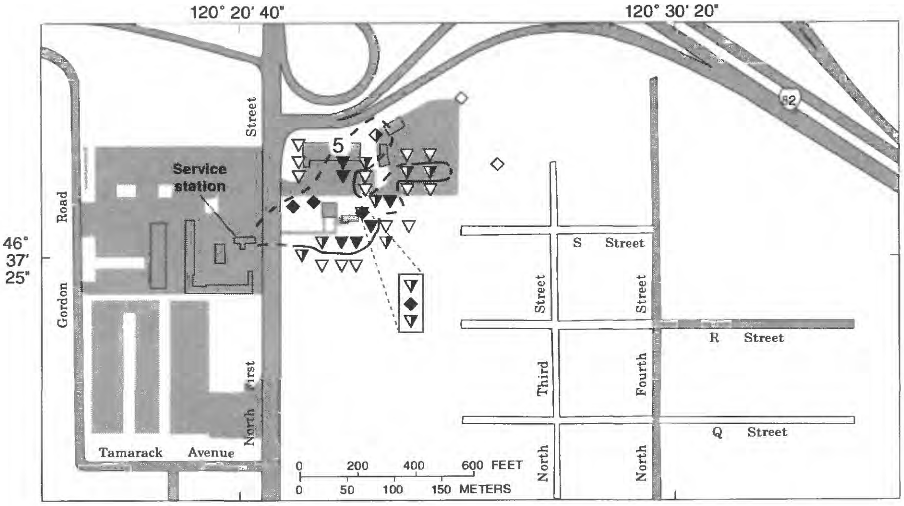
- - - - 5 ——— **Line of equal benzene concentration (5 micrograms per liter)** — Dashed where approximately located.

◇ **Observation well**

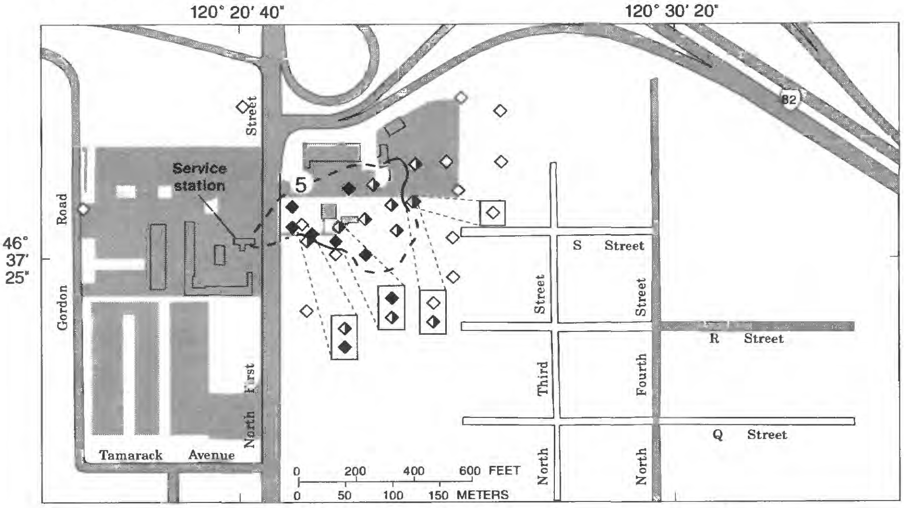
▽ **Temporary well**

○ **Domestic well**

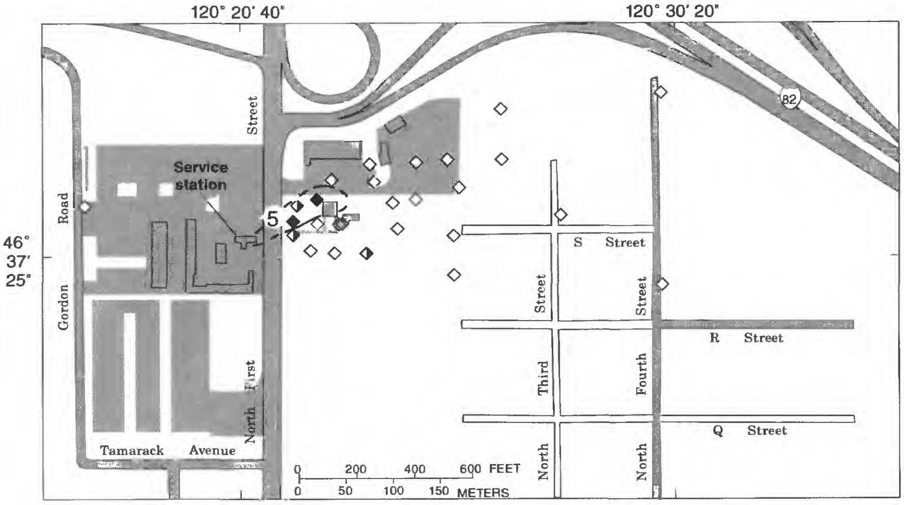
Figure 8.--Concentrations of total xylenes in ground water, October 1984 through March 1989. (Data are from (a) the insurance company study, (b-d) the ground-water toxics study, and (e) the 1989 study).



c. April through June 1986

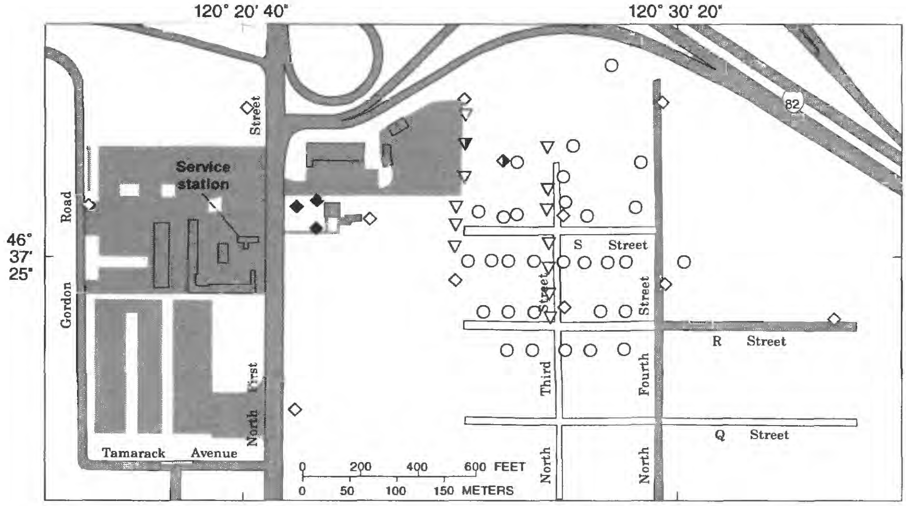


d. November 1986

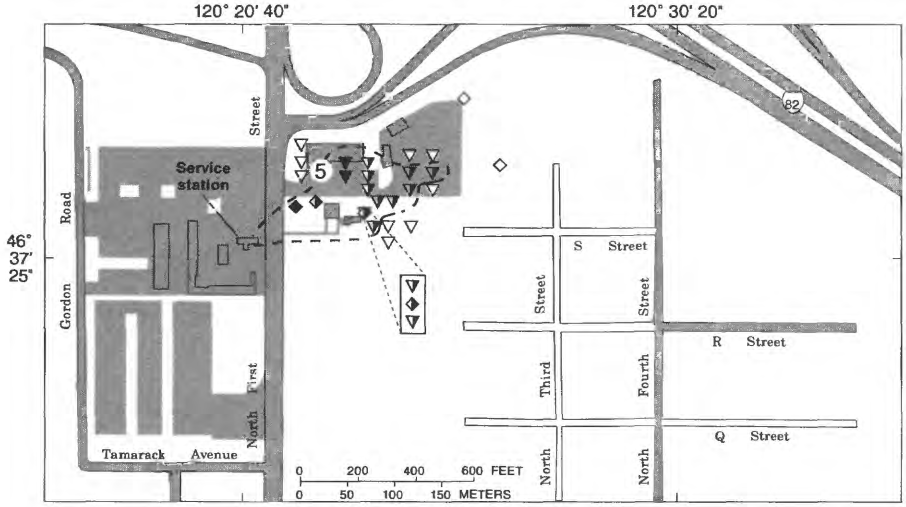


e. March 1989

Figure 8.--Continued.



a. August 1985



b. April through June 1986

EXPLANATION

▨ **Impervious surface** — Paved areas and buildings.

Sampled well and benzene concentrations in micrograms per liter — Symbols indicates well type. Open symbol indicates near or below detection limits. Half-shaded symbol indicates detected but less than 500 micrograms per liter. Solid symbol indicates concentrations of 500 micrograms per liter or greater.

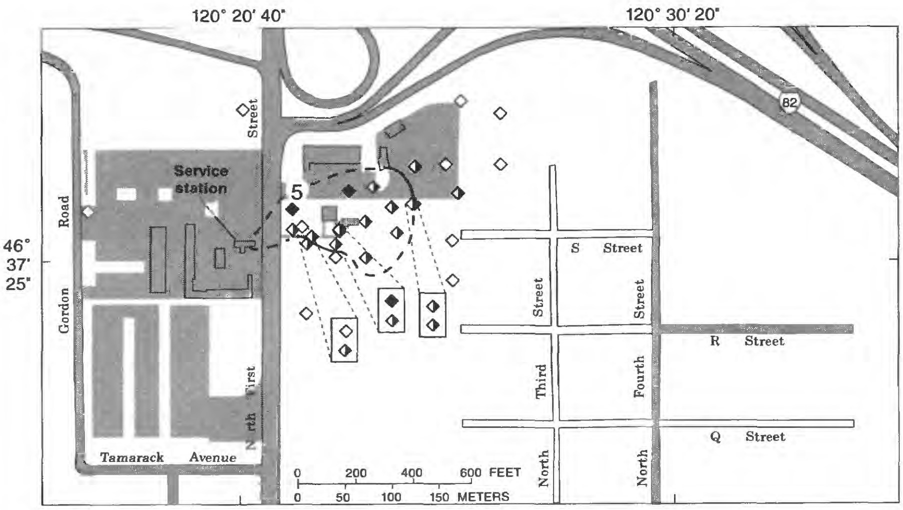
- - - - 5 ——— **Line of equal benzene concentration (5 micrograms per liter)** — Dashed where approximately located.

◇ **Observation well**

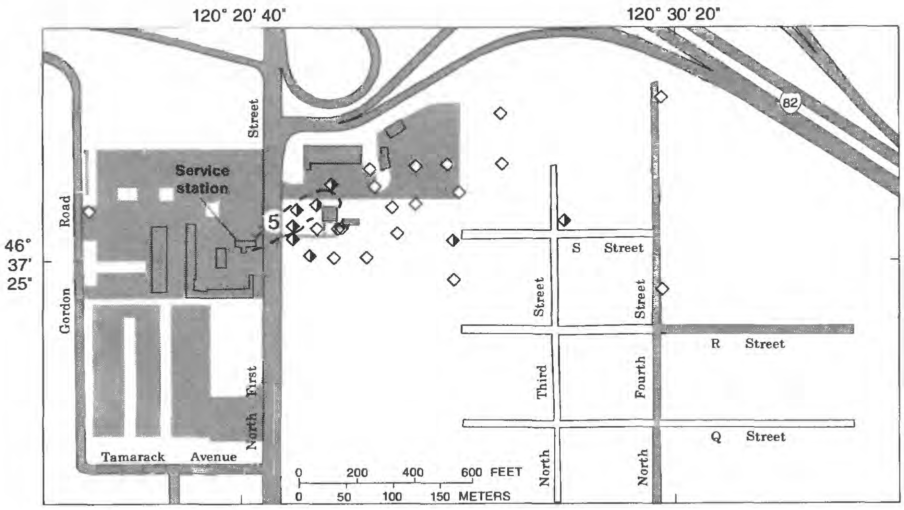
▽ **Temporary well**

○ **Domestic well**

Figure 9.--Concentrations of naphthalene in ground water, August 1985 through March 1989. (Data are from (a-c) the ground-water toxics study, and (d) the 1989 study).

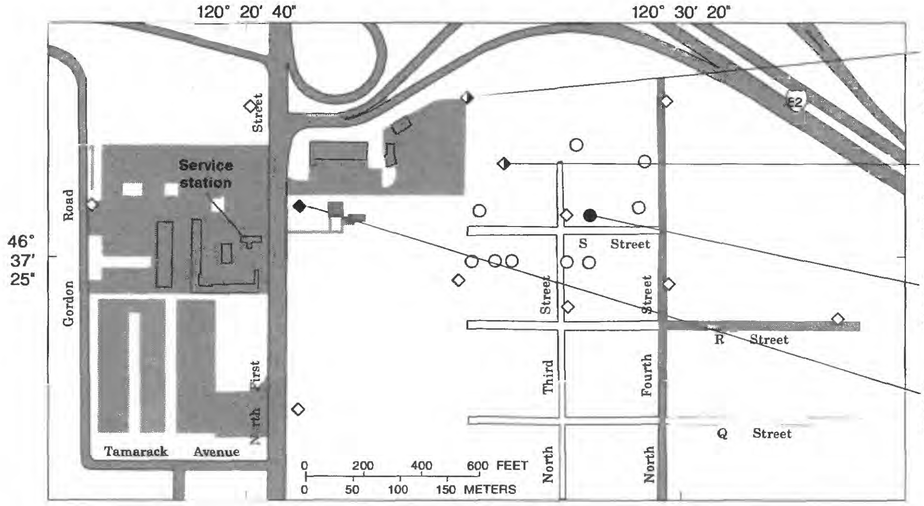


c. November 1986



d. March 1989

Figure 9.--Continued.



Detected 1 of the 5 times sampled. Range of concentration from below the limit of detection to 17 micrograms per liter

Detected 1 of the 4 times sampled. Range of concentration from below the limit of detection to 30 micrograms per liter

Detected 3 of the 3 times sampled. Range of concentration from 14 to 3,120 micrograms per liter

Detected 5 of the 5 times sampled. Range of concentration from 12,000 to 45,000 micrograms per liter

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

Sampled well and gasoline concentration calculated by comparison of total peak area to a gasoline standard total peak area, in micrograms per liter — Symbol indicates near or below detection limits. Half-shaded symbol indicates detected but less than 500 micrograms per liter or greater.

◇ **Observation well**

▽ **Temporary well**

○ **Domestic well**

Figure 10.--Concentrations of total gasoline in ground water, February 1985 through May 1986. (Data are from the insurance company study).

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the gorund-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected)*

[ND, concentration is below limit of detection, see text, p. 73 and table A3; 0 indicates compound detected, but not above blank levels; --, compound not specifically analyzed for; NQ, compound peak present at proper retention time, but only one or two characteristic ions were present; NAB, concentration not above background (compound's characteristic ions were identified, but quantitative level was not greater than the average of travel blanks plus three standard deviations of the travel blanks); T, concentration is more than twice blank level, but less than twice the blank level plus three blank level standard deviations]

Well identifier	Date	Concentrations (micrograms per liter)									
		Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene	1,2,3.5-Tetramethylbenzene
M1-82	08-28-85	ND	ND	ND	ND	2.8	--	ND	25	5.6	8.6
	11-18-86	170	6.5	530	110	130	13	97	53	--	28
M2-82	08-27-85	3,300	11,000	910	10,500	400	--	1,500	620	55	130
	11-18-86	1,100	3,200	1,700	4,400	230	180	830	210	--	65
M3-82	08-28-85	800	2,600	150	8,200	740	--	2,400	930	180	380
	05-13-86	280	1,500	240	3,800	280	230	990	310	82	180
M1-85	08-26-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
	11-19-86	NAB	.2	NQ	NQ	ND	ND	NQ	ND	--	ND
M2-85	08-26-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M3-85	08-26-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M4-85	08-26-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M5-85	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M6-85	08-26-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M7-85	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
M8-85	08-27-85	ND	ND	ND	1.0	3.0	--	.13	ND	.2	.66
	06-25-86	0	ND	0	0	ND	T	ND	ND	--	ND
	11-20-86	6.5	NAB	.1	NQ	NQ	ND	ND	NQ	--	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Concentrations (micrograms per liter)									
	1,2-Dibromoethane	1,3-Dimethyl, 4-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl 1-methylbenzene	1-Isopropyl-4-methylbenzene	Isobutylbenzene	*n*-Butylbenzene	*sec*-Butylbenzene	*tert*-Butylbenzene	*n*-Propylbenzene
M1-82	ND	--	--	--	ND	ND	1.2	ND	ND	ND
	--	--	45	110	--	--	--	--	--	--
M2-82	ND	--	--	--	ND	ND	ND	ND	ND	130
	--	--	97	190	--	--	--	--	--	--
M3-82	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	--	76	250	--	--	--	--	--	--
M1-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	--	ND	ND	--	--	--	--	--	--
M2-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M3-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M4-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M5-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M6-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M7-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M8-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	ND	ND	.8	--	--	--	--	--	--
	--	--	ND	NQ	--	--	--	--	--	--

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identi-fier	Date	Concentrations (micrograms per liter)									
		Benzene	Toluene	Ethyl-benzene	Total xylenes	Naph-thalene	1,2,3-Tri-methyl-benzene	1,2,4-Tri-methyl-benzene	1,3,5-Tri-methyl-benzene	1,2,3,4-Tetra-methyl-benzene	1,2,3,5-Tetra-methyl-benzene
M9-85	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
	11-19-86	NAB	NAB	ND	NQ	ND	ND	NQ	ND	--	ND
M10-85	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
	06-25-86	.4	ND	0	0	ND	ND	ND	ND	--	ND
	11-19-86	NAB	NAB	ND	NAB	NAB	ND	ND	NAB	--	ND
M11-85	08-27-85	1,000	3,400	220	7,300	440	--	1,200	420	46	81
	05-13-86	240	5,500	1,600	11,900	950	780	2,500	780	94	190
	11-17-86	570	5,000	2,700	7,900	530	320	1,400	330	--	88
M12-85	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
	11-20-86	NAB	NAB	NQ	NQ	NQ	ND	NQ	ND	--	ND
M2	11-20-86	.7	NAB	NQ	NQ	NQ	NQ	.1	.01	--	NQ
M4	11-18-86	23	1.0	90	15	32	1.9	17	20	--	7.2
M6.1	11-20-86	NAB	NAB	NQ	NQ	.8	NQ	.02	NQ	--	NQ
M6.2	11-20-86	16	2.9	70	2.5	8.6	0.9	3.4	NQ	--	2.1
M7.1	11-20-86	NAB	.32	NQ	3.2	NQ	.52	.1	.32	--	NQ
M7.2	11-17-86	1,700	7,100	3,000	8,500	480	340	1,600	390	--	110
M8	11-17-86	1.3	NQ	.1	.05	.4	NQ	.1	NQ	--	.02
M9	11-17-86	130	51	180	500	58	55	190	51	--	18
M11	11-18-86	100	2.2	190	53	110	4.4	45	20	--	14
M12	11-18-86	380	490	1,900	5,900	550	450	2,100	640	--	260
M13	11-20-86	34	.5	47	7.3	7.9	4.1	5.9	.5	--	1.5
M14	11-20-86	NAB	NAB	NQ	NQ	NQ	ND	ND	ND	--	ND
M16	11-17-86	1,500	980	1,400	4,000	180	100	460	100	--	24
M18	11-18-86	150	17	430	500	94	66	320	100	--	52

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Concentrations (micrograms per liter)									
	1,2-Dibromoethane	1,3-Dimethyl, 4-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl 1-methylbenzene	1-Isopropyl-4-methylbenzene	Isobutylbenzene	*n*-Butylbenzene	*sec*-Butylbenzene	*tert*-Butylbenzene	*n*-Propylbenzene
M9-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	--	ND	NQ	--	--	--	--	--	--
M10-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	--	ND	ND	--	--	--	--	--	--
	--	--	ND	ND	--	--	--	--	--	--
M11-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
	--	--	120	680	--	--	--	--	--	--
	--	--	120	300	--	--	--	--	--	--
M12-85	ND	--	--	--	ND	ND	ND	ND	ND	ND
M2	--	--	NQ	.2	--	--	--	--	--	--
M4	--	--	14	19	--	--	--	--	--	--
M6.1	--	--	NQ	NQ	--	--	--	--	--	--
M6.2	--	--	4.4	19	--	--	--	--	--	--
M7.1	--	--	ND	.44	--	--	--	--	--	--
M7.2	--	--	160	340	--	--	--	--	--	--
M8	--	--	.05	.05	--	--	--	--	--	--
M9	--	--	31	66	--	--	--	--	--	--
M11	--	--	23	56	--	--	--	--	--	--
M12	--	--	380	500	--	--	--	--	--	--
M13	--	--	2.3	8.7	--	--	--	--	--	--
M14	--	--	ND	NQ	--	--	--	--	--	--
M16	--	--	37	110	--	--	--	--	--	--
M18	--	--	76	110	--	--	--	--	--	--

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

		Concentrations (micrograms per liter)									
Well identi-fier	Date	Benzene	Toluene	Ethyl-benzene	Total xylenes	Naph-thalene	1,2,3-Tri-methyl-benzene	1,2,4-Tri-methyl-benzene	1,3,5-Tri-methyl-benzene	1,2,3,4-Tetra-methyl-benzene	1,2,3,5-Tetra-methyl-benzene
M19	11-18-86	.4	.02	.05	.01	NQ	ND	.02	ND	--	ND
M22	11-20-86	NAB	NAB	NQ	NQ	NQ	ND	NQ	ND	--	ND
M23	11-18-86	250	17	490	200	160	30	180	33	--	44
M24	11-18-86	1,600	280	3,000	9,600	770	520	2,200	660	--	220
M29	11-19-86	NAB	.1	NQ	NQ	1.1	NQ	.1	NQ	--	NQ
M30	11-20-86	1.5	NAB	NQ	NQ	NAB	ND	NQ	NQ	--	ND
M31	11-19-86	.4	.1	.2	.11	.5	ND	NQ	ND	--	NQ
M34	11-20-86	NAB	NAB	NQ	NQ	ND	ND	NQ	ND	--	ND
M36	04-30-86	150	210	220	590	--	100	130	260	210	110
	06-25-86	370	320	ND	4,800	460	490	1,700	720	--	200
M37	04-30-86	T	6	7	46	--	3	14	5	T	T
T1	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T2	08-29-85	2.3	ND	ND	.17	ND	--	ND	ND	ND	ND
T3	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T4	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T5	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T6	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T7	08-29-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T8	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T9	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T10	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T11	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T12	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
T13	08-30-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identi-fier	Concentrations (micrograms per liter)									
	1,2-Di-bromo-ethane	1,3-Di-methyl, 4-ethyl-benzene	1,4-Di-methyl-2-ethyl-benzene	2-Ethyl 1-methyl-benzene	1-Iso-propyl-4-methyl-benzene	Iso-butyl-benzene	*n*-Butyl-benzene	*sec*-Butyl-benzene	*tert*-Butyl-benzene	*n*-Propyl-benzene
M19	--	--	ND	NQ	--	--	--	--	--	--
M22	--	--	ND	ND	--	--	--	--	--	--
M23	--	--	59	140	--	--	--	--	--	--
M24	--	--	280	550	--	--	--	--	--	--
M29	--	--	NQ	NQ	--	--	--	--	--	--
M30	--	--	ND	ND	--	--	--	--	--	--
M31	--	--	ND	.2	--	--	--	--	--	--
M34	--	--	ND	ND	--	--	--	--	--	--
M36	--	--	60	140	--	--	--	--	--	--
	--	110	130	560	--	--	--	--	--	--
M37	--	--	T	3	--	--	--	--	--	--
T1	ND	--	--	--	ND	ND	ND	ND	ND	ND
T2	ND	--	--	--	ND	ND	ND	ND	ND	ND
T3	ND	--	--	--	ND	ND	ND	ND	ND	ND
T4	ND	--	--	--	ND	ND	ND	ND	ND	ND
T5	ND	--	--	--	ND	ND	ND	ND	ND	ND
T6	ND	--	--	--	ND	ND	ND	ND	ND	ND
T7	ND	--	--	--	ND	ND	ND	ND	ND	ND
T8	ND	--	--	--	ND	ND	ND	ND	ND	ND
T9	ND	--	--	--	ND	ND	ND	ND	ND	ND
T10	ND	--	--	--	ND	ND	ND	ND	ND	ND
T11	ND	--	--	--	ND	ND	ND	ND	ND	ND
T12	ND	--	--	--	ND	ND	ND	ND	ND	ND
T13	ND	--	--	--	ND	ND	ND	ND	ND	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

		Concentrations (micrograms per liter)									
Well identifier	Date	Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene	1,2,3,5-Tetramethylbenzene
T14	05-13-86	T	0.2	ND	120	13	20	39	59	6.5	14
T15	05-13-86	100	24	78	630	150	67	310	200	27	62
T16	06-25-86	1.2	.06	.1	T	1.6	T	T	0	--	.4
T17	05-13-86	T	0	ND	0	ND	ND	0	ND	ND	ND
T18	05-13-86	T	0	T	.04	0	ND	0	ND	ND	ND
T19	04-30-86	15	.6	T	.8	--	0	0	0	T	0
T20	05-13-86	T	T	.03	.12	0	ND	T	ND	ND	ND
T21	05-13-86	170	2.8	38	970	300	39	820	420	47	94
T22	04-27-86	670	1,600	260	4,900	--	370	1,600	720	410	330
T23	04-30-86	0	T	T	T	--	0	T	T	T	0
T24	04-30-86	0	0	0	T	--	T	T	T	T	T
T25	04-30-86	850	2,100	2,200	11,300	--	660	3,800	1,400	760	410
T26	04-30-86	0	0	0	T	--	0	T	T	T	T
T27	04-30-86	75	4	2	7	--	0	0	8	7	14
T28	06-25-86	.9	.05	.05	T	.4	0	0	0	--	T
T29	06-25-86	1.0	.1	T	0	0	0	0	0	--	0
T30	06-25-86	1.5	.08	T	0	T	ND	0	ND	--	ND
T31	06-25-86	0	T	0	0	T	ND	ND	ND	--	ND
T32	06-25-86	3.1	.2	.3	0	2.1	0	0	0	--	.2
T33	06-25-86	31	.3	.09	36.2	2	11	11	.9	--	15
T34	06-25-86	240	92	280	4,200	970	820	3,400	1,100	--	930
T35	06-25-86	110	43	13	2,620	770	420	1,900	590	--	230
T36	06-25-86	31	1	8.7	8	63	7.3	49	ND	--	15
T37	06-25-86	0	.05	0	0	0	ND	ND	ND	--	ND
T38	06-25-86	.7	T	T	0	0	ND	0	ND	--	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Concentrations (micrograms per liter)									
	1,2-Dibromoethane	1,3-Dimethyl, 4-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl 1-methylbenzene	1-Isopropyl-4-methylbenzene	Isobutylbenzene	*n*-Butylbenzene	*sec*-Butylbenzene	*tert*-Butylbenzene	*n*-Propylbenzene
T14	--	--	7.8	50	--	--	--	--	--	--
T15	--	--	49	170	--	--	--	--	--	--
T16	--	.1	.2	.4	--	--	--	--	--	--
T17	--	--	ND	ND	--	--	--	--	--	--
T18	--	--	ND	.03	--	--	--	--	--	--
T19	--	--	0	18	--	--	--	--	--	--
T20	--	--	ND	.03	--	--	--	--	--	--
T21	--	--	77	320	--	--	--	--	--	--
T22	--	--	120	830	--	--	--	--	--	--
T23	--	--	0	T	--	--	--	--	--	--
T24	--	--	T	0	--	--	--	--	--	--
T25	--	--	280	1,400	--	--	--	--	--	--
T26	--	--	0	0	--	--	--	--	--	--
T27	--	--	0	170	--	--	--	--	--	--
T28	--	T	.02	T	--	--	--	--	--	--
T29	--	ND	0	0	--	--	--	--	--	--
T30	--	ND	ND	0	--	--	--	--	--	--
T31	--	ND	ND	ND	--	--	--	--	--	--
T32	--	0.06	ND	2	--	--	--	--	--	--
T33	--	36	--	110	--	--	--	--	--	--
T34	--	530	510	740	--	--	--	--	--	--
T35	--	130	140	470	--	--	--	--	--	--
T36	--	4.6	12	77	--	--	--	--	--	--
T37	--	ND	ND	0	--	--	--	--	--	--
T38	--	ND	ND	ND	--	--	--	--	--	--

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Date	Concentrations (micrograms per liter)									
		Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene	1,2,3,5-Tetramethylbenzene
T39	06-25-86	120	43	110	420	280	76	350	81	--	97
T40	06-25-86	T	.2	T	T	0	0	0	0	--	ND
T41	06-25-86	30	.4	.1	22.2	74	2.4	T	36	--	10
T42	06-25-86	16	.8	.6	.5	66	19	T	.5	--	.8
D1	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D2	08-27-85	10	ND	ND	1.2	1.0	--	1.4	ND	ND	.26
D3	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D4	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D5	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D6	08-27-85	26	ND	4.7	3.53	12	--	ND	ND	.4	1.5
D7	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D8	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D9	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D10	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D11	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D12	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D13	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D14	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D15	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D16	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D17	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D18	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D19	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D20	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D21	08-27-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Concentrations (micrograms per liter)									
	1,2-Dibromoethane	1,3-Dimethyl, 4-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl 1-methylbenzene	1-Isopropyl-4-methylbenzene	Isobutylbenzene	*n*-Butylbenzene	*sec*-Butylbenzene	*tert*-Butylbenzene	*n*-Propylbenzene
T39	--	39	55	170	--	--	--	--	--	--
T40	--	0	ND	0	--	--	--	--	--	--
T41	--	8.0	1.8	56	--	--	--	--	--	--
T42	--	5.5	0	110	--	--	--	--	--	--
D1	ND	--	--	--	ND	ND	ND	ND	ND	ND
D2	ND	--	--	--	ND	0.38	0.29	0.93	ND	0.11
D3	ND	--	--	--	ND	ND	ND	ND	ND	ND
D4	ND	--	--	--	ND	ND	ND	ND	ND	ND
D5	ND	--	--	--	ND	ND	ND	ND	ND	ND
D6	ND	--	--	--	ND	.32	.45	.70	ND	1.7
D7	ND	--	--	--	ND	ND	ND	ND	ND	ND
D8	ND	--	--	--	ND	ND	ND	ND	ND	ND
D9	ND	--	--	--	ND	ND	ND	ND	ND	ND
D10	ND	--	--	--	ND	ND	ND	ND	ND	ND
D11	ND	--	--	--	ND	ND	ND	ND	ND	ND
D12	ND	--	--	--	ND	ND	ND	ND	ND	ND
D13	ND	--	--	--	ND	ND	ND	ND	ND	ND
D14	ND	--	--	--	ND	ND	ND	ND	ND	ND
D15	ND	--	--	--	ND	ND	ND	ND	ND	ND
D16	ND	--	--	--	ND	ND	ND	ND	ND	ND
D17	ND	--	--	--	ND	ND	ND	ND	ND	ND

Table 7.--*Concentrations of volatile organic compounds in ground water, August 1985 through November 1986. (Data from the ground-water toxics study, analyzed by Oregon Graduate College; concentrations are blank-corrected).--Continued*

Well identifier	Date	Concentrations (micrograms per liter)									
		Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene	1,2,3,5-Tetramethylbenzene
D22	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D23	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D24	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D25	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D26	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D27	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D28	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D29	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D30	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND
D31	08-28-85	ND	ND	ND	ND	ND	--	ND	ND	ND	ND

Well identifier	Concentrations (micrograms per liter)									
	1,2-Dibromoethane	1,3-Dimethyl, 4-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl 1-methylbenzene	1-Isopropyl-4-methylbenzene	Isobutylbenzene	*n*-Butylbenzene	*sec*-Butylbenzene	*tert*-Butylbenzene	*n*-' Propylbenzene
D22	ND	--	--	--	ND	ND	ND	ND	ND	ND
D23	ND	--	--	--	ND	ND	ND	ND	ND	ND
D24	ND	--	--	--	ND	ND	ND	ND	ND	ND
D25	ND	--	--	--	ND	ND	ND	ND	ND	ND
D26	ND	--	--	--	ND	ND	ND	ND	ND	ND
D27	ND	--	--	--	ND	ND	ND	ND	ND	ND
D28	ND	--	--	--	ND	ND	ND	ND	ND	ND
D29	ND	--	--	--	ND	ND	ND	ND	ND	ND
D30	ND	--	--	--	ND	ND	ND	ND	ND	ND
D31	ND	--	--	--	ND	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)*

[ND, below the detection limit of 0.2 micrograms per liter, unless otherwise noted]

	Concentration (micrograms per liter)								
Well identifier	Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene
M2-82	ND	ND	ND	ND	ND	1.7	ND	ND	0.9
M3-82	17	1.6	ND	1,500	19	200	300	280	58
M1-85	ND	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	.2	.2	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85	ND	ND	ND	ND	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11-85	23	ND	3.6	320	62	95	150	160	50
M4	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	.2	ND	ND	ND	ND
M16	68	15	ND	820	130	86	49	60	14
M17	75	.3	ND	.5	44	.3	.5	ND	4.0
M18	ND	ND	.2	.2	ND	.3	ND	ND	ND
M19	ND	ND	ND	ND	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	.3	ND	ND	ND	ND
M23	.3	ND	ND	ND	ND	ND	ND	ND	ND
M26	ND	ND	ND	ND	.2	ND	ND	ND	ND
M27	.3	ND	ND	ND	ND	ND	ND	ND	ND
M29	1.0	ND	ND	ND	ND	ND	ND	ND	ND
M30	ND	ND	ND	ND	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	ND	ND	ND	ND	ND
M34	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Concentration (micrograms per liter)									
	1,2,3,5-Tetramethylbenzene	2-Chlorotoluene	4-Chlorotoluene	1,2-Dibromoethane	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,1,-Dichloroethane	1,1,-Dichloroethene	1,2,-Dichloroethane
M2-82	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.7
M3-82	150	ND	ND	ND	ND	ND	ND	ND	ND	ND
M1-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11-85	140	ND	ND	ND	ND	ND	ND	ND	ND	ND
M4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M16	36	ND	ND	ND	ND	ND	ND	ND	ND	ND
M17	ND	ND	ND	ND	ND	ND	ND	ND	ND	.3
M18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

	Concentration (micrograms per liter)									
Well identifier	1,2-Dichloroethene (total)	1,2-Dichloropropane	1,3-Dichloropropane	2,2-Dichloropropane	1,1-Dichloropropene	*cis*-1,3-Dichloropropene	*trans*-1,3-Dichloropropene	1,3-Dimethyl-2-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl-1-methylbenzene
M2-82	ND	ND	ND	ND	ND	ND	ND	0.8	ND	5.7
M3-82	ND	ND	ND	ND	ND	ND	ND	4.7	100	240
M1-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11-85	ND	ND	ND	ND	ND	ND	ND	2.0	13	130
M4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M16	ND	ND	ND	ND	ND	ND	ND	1.1	20	79
M17	ND	ND	ND	ND	ND	ND	ND	2.0	3.1	49
M18	ND	ND	ND	ND	ND	ND	ND	.8	ND	3.2
M19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M23	ND	ND	ND	ND	ND	ND	ND	.4	ND	.4
M26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M27	ND	ND	ND	ND	ND	ND	ND	.3	ND	.4
M29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Concentration (micrograms per liter)									
	1,1,1-Trichloroethane	1,1,2-Trichloroethane	1,2,3-Trichloropropane	1,1,1,2-Tetrachloroethane	1,1,2,2-Tetrachloroethane	Bromobenzene	Bromodichloromethane	Bromoform	Bromomethane	*n*-Butylbenzene
M2-82	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M3-82	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M1-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M17	ND	ND	ND	ND	ND	ND	ND	ND	ND	.5
M18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Concentration (micrograms per liter)									
	sec-Butylbenzene	Carbon tetrachloride	Chlorobenzene	Chloroethane	Chloroform	Chloromethane	Chlorodibromomethane	Dibromomethane	Dichlorodifluoromethane	Isopropylbenzene
M2-82	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M3-82	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M1-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	.2	ND	ND	2.5	ND	ND	ND	ND	ND
M8-85	ND	.3	ND	ND	5.3	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	.8	ND	ND	ND	ND	ND
M11-85	.8	ND	ND	ND	ND	ND	ND	ND	ND	2.3
M4	ND	ND	ND	ND	82	ND	ND	ND	ND	ND
M6.2	ND	ND	ND	ND	27	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	.2	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	.4	ND	ND	ND	ND	ND
M16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M17	1.4	ND	ND	ND	4.5	ND	ND	ND	ND	7.5
M18	ND	ND	ND	ND	.5	ND	ND	ND	ND	ND
M19	ND	ND	ND	ND	.8	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	1.4	ND	ND	ND	ND	ND
M23	ND	ND	ND	ND	1.8	ND	ND	ND	ND	ND
M26	ND	ND	ND	ND	.7	ND	ND	ND	ND	ND
M27	ND	ND	ND	ND	.4	ND	ND	ND	ND	ND
M29	ND	ND	ND	ND	1.4	ND	ND	ND	ND	ND
M30	ND	ND	ND	ND	.9	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	2.4	.6	ND	ND	ND	ND
M34	ND	ND	ND	ND	2.2	ND	ND	ND	ND	ND

Table 8.--*Concentrations of volatile organic compounds in ground water, March 1989. (Data from the 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

	Concentration (micrograms per liter)							
Well identifier	*p*-Isopropyltoluene	Methylene chloride	*n*-Propylbenzene	Styrene	Tetrachloroethene	Trichlorofluoromethane	Trichloroethene	Vinyl chloride
M2-82	ND	ND	ND	ND	ND	ND	ND	ND
M3-82	2.1	ND	ND	ND	ND	ND	ND	ND
M1-85	ND	ND	ND	ND	ND	ND	ND	ND
M5-85	ND	ND	ND	ND	ND	ND	ND	ND
M6-85	ND	ND	ND	ND	ND	ND	ND	ND
M7-85	ND	ND	ND	ND	ND	ND	ND	ND
M8-85	ND	ND	ND	ND	ND	ND	ND	ND
M9-85	ND	ND	ND	ND	ND	ND	ND	ND
M11-85	11	ND	ND	ND	ND	ND	ND	ND
M4	ND	6.3	ND	ND	ND	ND	ND	ND
M6.2	ND	.8	ND	ND	ND	ND	ND	ND
M11	ND	ND	ND	ND	ND	ND	ND	ND
M12	ND	ND	ND	ND	ND	ND	ND	ND
M13	ND	ND	ND	ND	ND	ND	ND	ND
M14	ND	ND	ND	ND	ND	ND	ND	ND
M16	3.5	ND	ND	ND	ND	ND	<.3	ND
M17	.2	ND	.2	ND	ND	ND	ND	ND
M18	ND	ND	ND	ND	ND	ND	ND	ND
M19	ND	ND	ND	ND	ND	ND	ND	ND
M20	ND	ND	ND	ND	ND	ND	ND	ND
M23	ND	ND	ND	ND	ND	ND	ND	ND
M26	ND	ND	ND	ND	ND	ND	ND	ND
M27	ND	ND	ND	ND	ND	ND	ND	ND
M29	ND	ND	ND	ND	ND	ND	.3	ND
M30	ND	ND	ND	ND	ND	ND	ND	ND
M31	ND	ND	ND	ND	ND	ND	ND	ND
M34	ND	ND	ND	ND	ND	ND	ND	ND

Common Constituents, Trace Metals, and Dissolved Organic Carbon in Ground Water

The shallow ground water within the study area is predominantly of the calcium-magnesium bicarbonate type (table 9 and fig. 11). Specific conductance values ranged from 208 to 390 μS/cm (microsiemens per centimeter at 25°C), and values of pH ranged from 6.3 to 6.9. Dissolved-oxygen concentrations were small, with a median value of 0.6 mg/L (milligrams per liter). Dissolved oxygen concentrations upgradient of the leak area at observation well M1-85 ranged from 6.3 to 6.8 mg/L whereas the ground water contained little or no oxygen at sites M2-82, M3-82, M11-85, M12, M16, and M18 in the leak area. Concentrations of dissolved nitrate plus nitrite ranged from less than the detection limit of 0.1 mg/L to 1.8 mg/L, with a median value less than the limit of detection. Concentrations of dissolved ammonium ranged from less than the detection limit of 0.01 mg/L to 0.18 mg/L, with a median value of 0.03 mg/L. Concentrations of metals were generally less than 0.10 mg/L and did not exceed the MCL for drinking water, except for dissolved manganese, which exceeded the secondary MCL at 15 sites, and dissolved iron, which exceeded the secondary MCL at 12 sites (U.S. Environmental Protection Agency, 1988b). The median concentration of dissolved organic carbon was 1.9 mg/L, with values ranging from 0.6 to 81 mg/L.

Samples analyzed during the ground-water toxics study and the 1989 study show a strong relation between the detection of volatile hydrocarbons in the ground water and large concentrations of iron and manganese, detectable ammonium, and nitrate values at or near the level of detection. The oxidation of organic compounds in the gasoline and diesel fuel caused small dissolved-oxygen concentrations in ground water and affected concentrations of iron, manganese, and the speciation of nitrogen compounds in ground water at the site. Small concentrations of dissolved oxygen commonly indicate the biological oxidation of carbon and consumption of oxygen. Under these reducing conditions, iron and manganese are more soluble and concentrations of iron and manganese in ground water are generally larger than under oxidizing conditions. Reduced forms of nitrogen, particularly ammonia, are also found in low-oxygen ground water. Samples analyzed for dissolved organic carbon generally showed a relation between elevated concentrations of dissolved organic carbon in the ground water and the detection of volatile hydrocarbons. Elevated concentrations of dissolved organic carbon were detected in samples from observation wells M7-85 and M6.2; however, petroleum-related volatile hydrocarbons were not detected in samples from these wells. This anomaly could be due to contamination of the ground water from non-volatile forms of petroleum hydrocarbons or by contamination during processing and handling of the samples.

During the November 1986 sampling, enough samples were analyzed for inorganic constituents to allow clear differentiation between areas of reducing conditions and areas of oxidizing conditions. The number of samples from 1989 was smaller, but still indicates generally an area of reduced conditions immediately downgradient of the leak site and areas of oxidizing conditions upgradient of the leak site and downgradient beyond the area of reduced conditions (fig. 12). There were exceptions to this relation in both studies. Samples from observation well M29 also indicated reduced conditions, but the concentrations of volatiles were small. During the ground-water toxics study, samples from observation well M1-82 contained large concentrations of volatile hydrocarbons and dissolved manganese, but the concentrations of ammonium, nitrate, and iron were small. During the ground-water toxics study and the 1989 study, results from observation well M18 indicated reduced conditions, but concentrations of volatile samples during the 1989 study were much smaller than in November 1986. These exceptions to the relation of volatiles indicating an area of reduced conditions could be caused by the oxidation of non-volatile hydrocarbons or poor well construction and seepage of oxygenated surface water. As the leak products age, non-volatile forms of carbon will prevail and the oxidation of these species will also cause reduced conditions. It is unlikely that reduced conditions in the leak area are a natural phenomenon. The permeable soils and the relatively large influx of freshly oxygenated ground water that flows past the leak area toward the river strongly support biodegradation of the leaked diesel and gasoline as the cause of the reduced conditions of ground water immediately downgradient of the leak site.

Table 9.--*Concentrations of inorganic compounds and dissolved organic carbon in ground water, November 1986 and March 1989. (Data are from ground-water toxics study and 1989 study, analyzed by the National Water Quality Laboratory)*

[μS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; μg/L, micrograms per liter; --, not analyzed for]

Well identifier	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Turbidity (NTU)	Oxygen, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)
M1-82	11-18-86	1215	280	6.8	15.0	--	<0.5	120	0
M2-82	11-18-86	1430	320	6.7	14.0	--	< .3	130	0
	03-18-89	1630	323	6.8	14.0	--	.0	--	--
M3-82	03-18-89	1030	389	6.3	13.5	--	.0	--	--
M1-85	11-19-86	1230	238	6.7	14.5	--	5.7	100	0
	03-13-89	1015	208	6.9	11.5	1.7	8.5	88	0
M5-85	03-13-89	1715	252	6.7	9.5	27	3.1	110	0
M6-85	03-13-89	1500	262	6.7	12.5	--	1.8	--	--
M7-85	03-14-89	0930	278	6.7	10.5	--	1.2	--	--
M8-85	03-14-89	1500	235	6.6	13.5	--	1.6	--	--
M9-85	11-19-86	1130	254	6.5	14.0	--	.4	100	0
	03-15-89	1515	249	6.5	13.0	5.2	.2	100	0
M10-85	11-19-86	1000	298	6.6	14.5	--	2.2	120	5
M11-85	11-17-86	1155	264	6.6	16.0	--	.0	100	0
	03-18-89	1530	292	6.6	15.0	19	.2	120	0
M4	11-18-86	1110	313	6.6	15.5	--	1.2	110	0
M6.2	03-17-89	1610	258	6.6	13.5	--	1.2	--	--
M7.2	11-17-86	0945	352	6.4	15.5	--	.0	140	0
M8	11-17-86	1450	247	6.6	14.5	--	1.7	100	0
M9	11-17-86	1555	279	6.6	15.0	--	.0	110	0
M11	11-18-86	1000	307	6.6	15.0	--	.3	120	0
	03-17-89	1330	265	6.6	13.5	--	.2	--	--
M12	11-18-86	1345	323	6.5	16.0	--	.0	130	0
	03-18-89	0900	280	6.4	13.0	--	.0	--	--
M13	03-16-89	1200	252	6.6	13.5	--	1.2	--	--
M14	03-16-89	0915	246	6.6	11.5	--	.2	--	--
M16	11-17-86	1115	342	6.7	16.0	--	.0	140	0
	03-18-89	1215	259	6.7	15.0	--	.0	--	--
M17	03-17-89	1200	282	6.5	13.0	--	1.0	--	--
M18	11-18-86	0930	292	6.6	15.0	--	.7	120	0
	03-17-89	1030	319	6.7	13.0	40	.0	130	0
M19	11-18-86	0805	257	6.6	15.0	--	2.7	100	0
	03-15-89	1800	236	6.6	10.5	--	3.5	--	--
M20	03-17-89	0845	328	6.5	12.5	--	3.5	--	--
M23	11-18-86	1630	390	6.7	16.0	--	.7	170	0
	03-16-89	1700	280	6.8	12.0	--	.4	--	--
M24	11-18-86	1430	365	6.5	15.0	--	.0	140	0
M26	03-16-89	1600	268	6.6	12.0	--	2.2	--	--
M27	03-16-89	1450	248	6.6	13.0	--	.2	--	--
M29	11-19-86	0830	259	6.6	14.5	--	.3	110	0
	03-15-89	1100	250	6.6	9.5	--	1.1	--	--
M30	03-14-89	1730	268	6.6	12.0	.4	.8	120	0
M31	11-19-86	0930	261	6.5	15.0	--	.3	110	0
M34	03-14-89	1130	242	6.7	13.0	--	2.5	--	--

Table 9.--*Concentrations of inorganic compounds and dissolved organic carbon in ground water, November 1986 and March 1989. (Data are from ground-water toxics study and 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium (percent)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
M1-82	31	10	13	19	0.5	3.3	131	8.5
M2-82	34	11	12	16	.5	3.3	156	5.8
	--	--	--	--	--	--	160	--
M3-82	--	--	--	--	--	--	206	--
M1-85	26	8.5	11	19	.5	2.3	103	12
	23	7.5	12	22	.6	2.4	89	11
M5-85	29	9.5	13	20	.6	2.2	113	12
M6-85	--	--	--	--	--	--	117	--
M7-85	--	--	--	--	--	--	122	--
M8-85	--	--	--	--	--	--	109	--
M9-85	27	8.9	12	20	.5	2.6	108	12
	27	8.9	12	20	.5	2.5	112	12
M10-85	32	10	14	20	.6	2.6	116	15
M11-85	27	8.9	11	18	.5	2.7	125	19
	31	10	12	18	.5	2.3	140	11
M4	30	9.6	17	24	.7	3.7	151	16
M6.2	--	--	--	--	--	--	116	--
M7.2	37	12	13	16	.5	3.4	185	2.3
M8	27	8.9	12	19	.5	3.3	105	13
M9	29	9.6	12	18	.5	3.2	133	13
M11	33	10	14	19	.6	3.5	148	8.3
	--	--	--	--	--	--	124	--
M12	35	11	13	17	.5	3.5	164	4.0
	--	--	--	--	--	--	118	--
M13	--	--	--	--	--	--	113	--
M14	--	--	--	--	--	--	115	--
M16	38	12	14	17	.5	3.8	172	7.6
	--	--	--	--	--	--	131	--
M17	--	--	--	--	--	--	144	--
M18	30	9.8	12	18	.5	3.3	149	5.5
	32	11	12	17	.5	2.6	132	34
M19	26	8.7	13	21	.6	2.7	105	14
	--	--	--	--	--	--	91	--
M20	--	--	--	--	--	--	113	--
M23	45	14	15	16	.5	3.9	193	8.4
	--	--	--	--	--	--	135	--
M24	38	12	15	18	.6	3.7	190	2.9
M26	--	--	--	--	--	--	110	--
M27	--	--	--	--	--	--	115	--
M29	28	8.8	13	20	.6	3.5	120	14
	--	--	--	--	--	--	114	--
M30	31	10	13	19	.5	2.7	128	11
M31	28	9.1	12	19	.5	2.6	113	12
M34	--	--	--	--	--	--	109	--

Table 9.--*Concentrations of inorganic compounds and dissolved organic carbon in ground water, November 1986 and March 1989. (Data are from ground-water toxics study and 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Chloride, dissolved (mg/L as Cl)	Fluorride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus ortho, dissolved (mg/L as P)
M1-82	6.2	0.2	0.026	37	--	190	<0.10	<0.01	0.03
M2-82	6.9	.2	.032	40	--	213	<.10	.09	<.01
	--	--	--	--	--	--	--	--	--
M3-82	--	--	--	--	--	--	--	--	--
M1-85	5.4	.2	.034	26	--	157	.68	<.01	.02
	6.2	.2	--	25	136	145	.91	<.01	.02
M5-85	6.5	.2	--	33	166	176	.64	<.01	.02
M6-85	--	--	--	--	--	--	--	--	--
M7-85	--	--	--	--	--	--	--	--	--
M8-85	--	--	--	--	--	--	--	--	--
M9-85	5.8	.2	.033	33	--	169	.49	<.01	.02
	6.7	.2	--	32	168	171	.50	<.01	.06
M10-85	8.6	.2	.039	30	--	190	1.8	<.01	.02
M11-85	6.1	.2	.039	40	--	196	<.10	.06	.02
	7.1	.2	--	36	186	200	.10	.08	.06
M4	7.2	.2	.037	43	--	227	<.10	.15	<.01
M6.2	--	--	--	--	--	--	--	--	--
M7.2	7.1	.2	.019	44	--	242	<.10	.16	<.01
M8	5.6	.2	.034	32	--	170	1.1	<.01	.02
M9	6.1	.2	.027	34	--	190	<.10	.03	<.01
M11	6.7	.2	.031	39	--	210	<.10	.03	.02
	--	--	--	--	--	--	--	--	--
M12	6.4	.2	.020	43	--	224	<.10	.13	<.01
	--	--	--	--	--	--	--	--	--
M13	--	--	--	--	--	--	--	--	--
M14	--	--	--	--	--	--	--	--	--
M16	7.9	.2	.030	44	--	242	<.10	.12	<.01
	--	--	-	--	--	--	--	--	--
M17	--	--	--	--	--	--	--	--	--
M18	6.0	.2	.026	41	--	208	<.10	.11	<.01
	7.0	.2	--	38	209	227	<.10	.10	.05
M19	5.6	.2	.028	32	--	171	1.3	<.01	.04
	--	--	--	--	--	--	--	--	--
M20	--	--	--	--	--	--	--	--	--
M23	10	.2	.029	50	--	274	<.10	.07	<.01
	--	--	--	--	--	--	--	--	--
M24	7.7	.2	.019	48	--	255	<.10	.18	<.01
M26	--	--	--	--	--	--	--	--	--
M27	--	--	--	--	--	--	--	--	--
M29	6.3	.2	.033	34	--	183	<.10	.01	.02
	--	--	--	--	--	--	--	--	--
M30	6.9	.2	--	32	172	188	.93	<.01	.05
M31	6.7	.2	.033	32	--	174	.54	<.01	<.01
M34	--	--	--	--	--	--	--	--	--

Table 9.--*Concentrations of inorganic compounds and dissolved organic carbon in ground water, November 1986 and March 1989. (Data are from ground-water toxics study and 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Barium, dissolved (μg/L as Ba)	Beryllium, dissolved (μg/L as Be)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)	Cobalt, dissolved (μg/L as Co)	Copper, dissolved (μg/L as Cu)	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Lithium, dissolved (μg/L as Li)
M1-82	11	<0.5	<1	--	<3	<10	65	<10	5
M2-82	16	<.5	<1	--	<3	<10	4,000	<10	5
	--	--	--	--	--	--	--	--	--
M3-82	--	--	--	--	--	--	--	--	--
M1-85	7	<.5	<1	--	<3	<10	3	<10	5
	8	<.5	<1	<5	<3	<10	15	<10	<4
M5-85	9	<.5	<1	<5	<3	<10	14	<10	<4
M6-85	--	--	--	--	--	--	--	--	--
M7-85	--	--	--	--	--	--	--	--	--
M8-85	--	--	--	--	--	--	--	--	--
M9-85	8	<.5	<1	--	<3	<10	<3	<10	5
	9	<.5	<1	<5	<3	<10	11	<10	<4
M10-85	10	<.5	<1	--	<3	<10	<3	<10	6
M11-85	13	<.5	<1	--	<3	<10	3,400	<10	<4
	16	<.5	<1	<5	<3	<10	3,700	10	<4
M4	16	<.5	1	--	<3	<10	6,200	<10	4
M6.2	--	--	--	--	--	--	--	--	--
M7.2	17	<.5	1	--	<3	<10	9,100	<10	5
M8	8	<.5	<1	--	<3	<10	12	<10	4
M9	12	<.5	<1	--	<3	<10	1,500	<10	4
M11	21	<.5	<1	--	<3	<10	1,700	<10	4
	--	--	--	--	--	--	--	--	--
M12	14	<.5	<1	--	<3	<10	6,400	10	5
	--	--	--	--	--	--	--	--	--
M13	--	--	--	--	--	--	--	--	--
M14	--	--	--	--	--	--	--	--	--
M16	11	<.5	1	--	<3	<10	7,400	<10	6
	--	--	--	--	--	--	--	--	--
M17	--	--	--	--	--	--	--	--	--
M18	12	<.5	<1	--	<3	<10	8,100	<10	4
	18	<.5	<1	<5	4	<10	7,300	<10	6
M19	10	<.5	<1	--	<3	<10	7	<10	5
	--	--	--	--	--	--	--	--	--
M20	--	--	--	--	--	--	--	--	--
M23	22	<.5	<1	--	<3	<10	5,800	<10	5
	--	--	--	--	--	--	--	--	--
M24	20	<.5	<1	--	<3	<10	9,700	<10	5
M26	--	--	--	--	--	--	--	--	--
M27	--	--	--	--	--	--	--	--	--
M29	15	<.5	<1	--	<3	<10	1,300	<10	4
	--	--	--	--	--	--	--	--	--
M30	10	<.5	<1	<5	<3	<10	7	<10	<4
M31	11	<.5	<1	--	<3	<10	10	<10	5
M34	--	--	--	--	--	--	--	--	--

Table 9.--*Concentrations of inorganic compounds and dissolved organic carbon in ground water, November 1986 and March 1989. (Data are from ground-water toxics study and 1989 study, analyzed by the National Water Quality Laboratory)--Continued*

Well identifier	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Na)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Carbon, organic dissolved (mg/L as C)
M1-82	1,600	<10	--	--	120	<6	5	1.6
M2-82	1,900	<10	--	--	140	<6	8	2.1
	--	--	--	--	--	--	--	4.1
M3-82	--	--	--	--	--	--	--	7.5
M1-85	<1	<10	--	--	95	<6	8	1.2
	16	<10	<10	<1	87	<6	130	.9
M5-85	2	<10	<10	<1	110	<6	52	1.0
M6-85	--	--	--	--	--	--	--	.9
M7-85	--	--	--	--	--	--	--	11
M8-85	--	--	--	--	--	--	--	.6
M9-85	28	<10	--	--	100	<6	<3	1.1
	85	<10	<10	<1	100	<6	100	1.1
M10-85	<1	<10	--	--	120	<6	<3	1.2
M11-85	2,400	<10	--	--	110	<6	6	2.9
	1,900	<10	<10	<1	130	<6	5	2.8
M4	3,400	<10	--	--	140	<6	7	2.3
M6.2	--	--	--	--	--	--	--	81
M7.2	2,300	<10	--	--	150	<6	10	3.4
M8	3	<10	--	--	100	<6	10	1.2
M9	1,300	<10	--	--	120	<6	10	1.6
M11	4,700	<10	--	--	140	<6	11	1.8
	--	--	--	--	--	--	--	--
M12	2,500	<10	--	--	150	<6	9	3.4
	--	--	--	--	--	--	--	4.7
M13	--	--	--	--	--	--	--	2.2
M14	--	--	--	--	--	--	--	1.5
M16	3,000	<10	--	--	170	<6	6	3.0
	2.4							
M17	--	--	--	--	--	--	--	5.5
M18	2,300	<10	--	--	130	<6	5	2.0
	2,800	<10	<10	<1	150	<6	69	1.9
M19	26	<10	--	--	100	<6	<3	1.8
	0.8							
M20	--	--	--	--	--	--	--	2.4
M23	5,600	<10	--	--	200	<6	7	3.7
	--	--	--	--	--	--	--	9.8
M24	3,700	<10	--	--	170	<6	4	3.4
M26	--	--	--	--	--	--	--	2.8
M27	--	--	--	--	--	--	--	2.1
M29	1,900	<10	--	--	120	<6	7	1.2
	--	--	--	--	--	--	--	.9
M30	14	<10	<10	2	120	<6	5	.8
M31	840	<10	--	--	110	<6	<3	1.2
M34	--	--	--	--	--	--	--	1.0

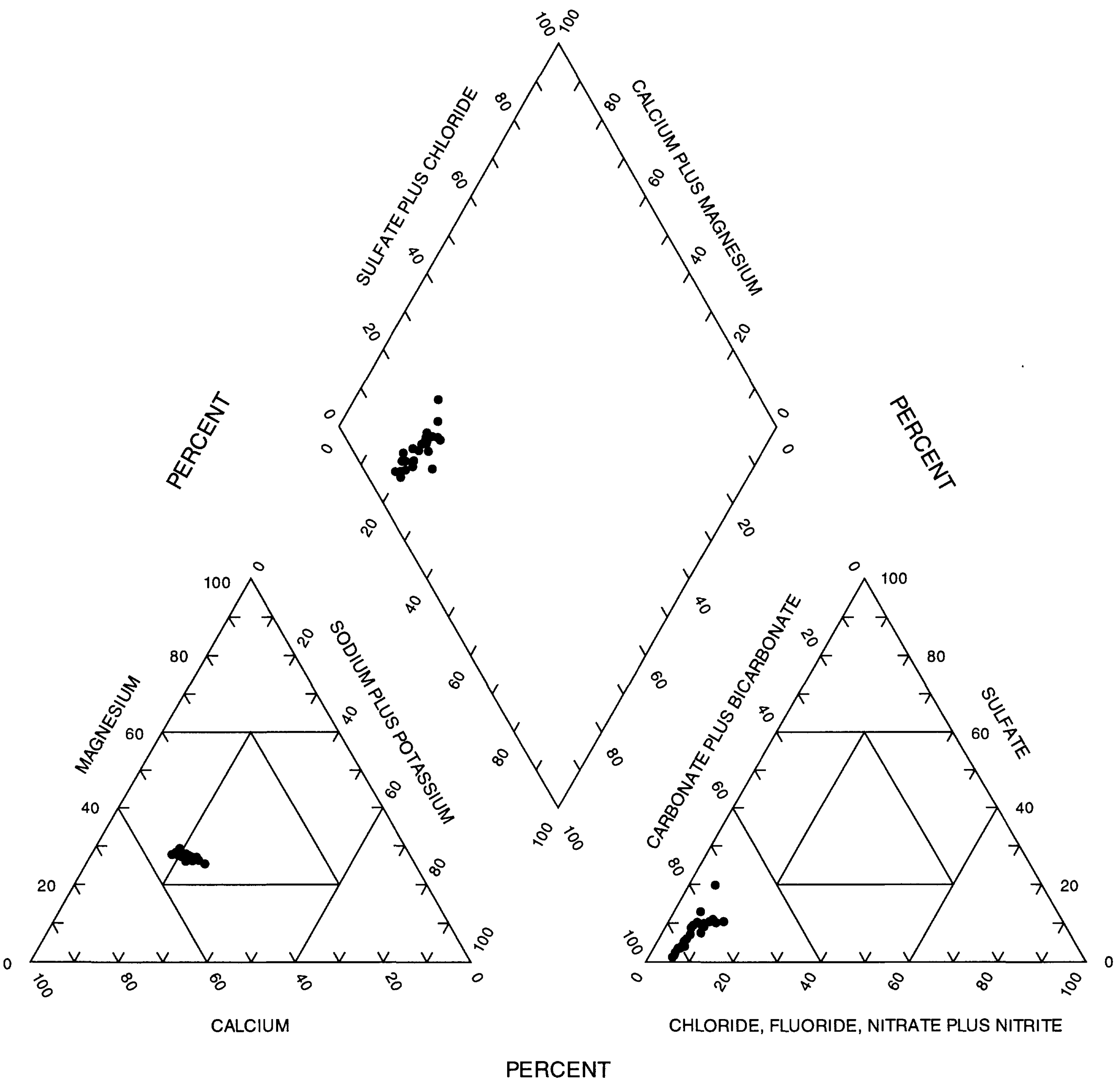
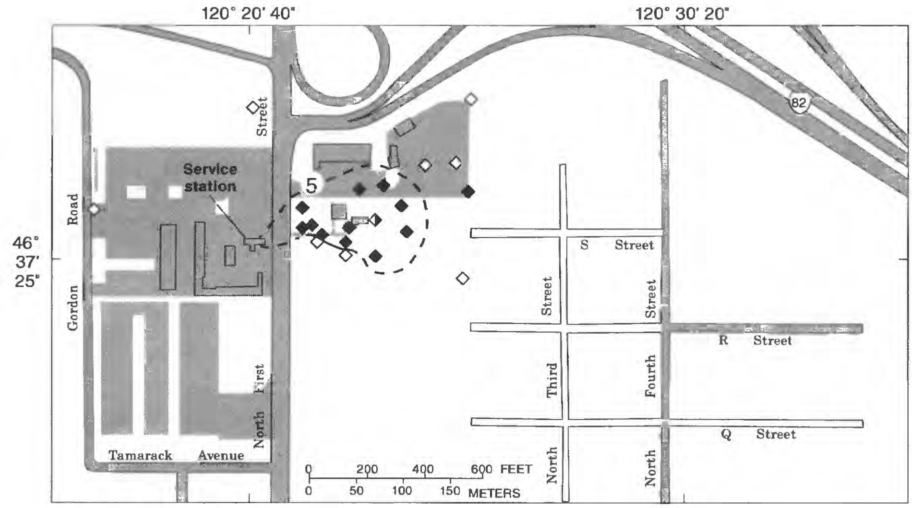
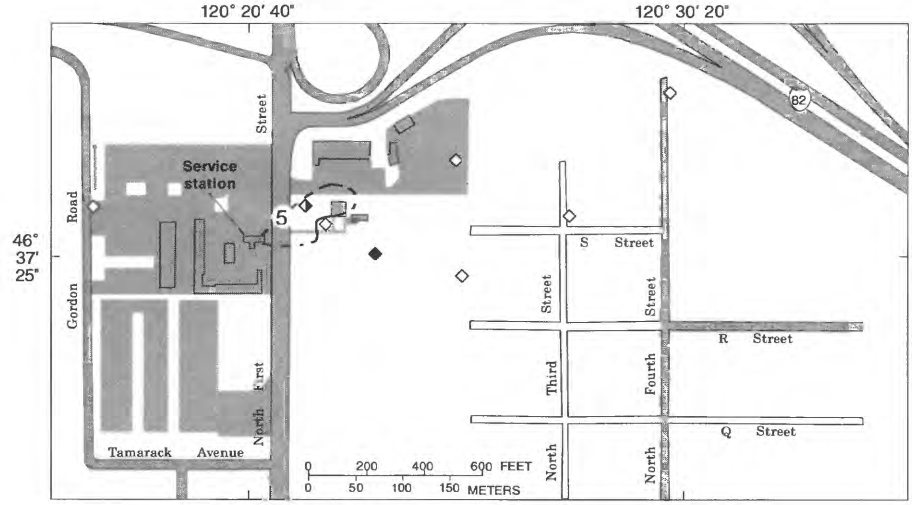


Figure 11.--Percentage of major ions in ground water, November 1986 and March 1989. (Data are from the ground-water toxics study and 1989 study).



a. November 1986



b. March 1989

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

- - - - 5 ——— **Line of equal benzene concentration (5 micrograms per liter)** — Dashed where approximately located.

◇ **Observation well and concentrations** — Nitrate plus Nitrite as Nitrogen (NO3+NO2-N) in milligrams per liter. Ammonia as Nitrogen (NH3-N) in milligrams per liter. Iron as Fe (Fe) in micrograms per liter. Manganese as Mn (Mn) in micrograms per liter.

Symbols indicate the following concentrations:

◆ **Solid symbol**		◇ **Open symbol**		⬗ **Half-shaded symbol**	
NO_3+NO_2-N	< 0.10	NO_3+NO_2-N	> 0.10	NO_3+NO_2-N	< 0.10
NH_3-N	> 0.01	NH_3-N	< 0.01	NH_3-N	< 0.01
Fe	> 50	Fe	< 50	Fe	> 50
Mn	> 500	Mn	< 500	Mn	> 500

Figure 12.--Concentrations of nitrate plus nitrite, ammonia, iron, and manganese in ground water, November 1986 through March 1989. (Data are from (a) the ground-water toxics study and (b) the 1989 study).

Lead in Ground Water and Aquifer Materials

Concentrations of lead in the filtered ground-water samples ranged from 1.4 to 10.1 µg/L (table 10). These concentrations are less than the EPA drinking-water MCL of 50 µg/L (U.S. Environmental Protection Agency, 1988c). Samples of aquifer material contained lead in concentrations 30 to 10,000 times greater than in ground-water samples on a per-weight basis (table 9). Because of the large affinity of the divalent lead ion for sediment, it is not unusual to find small concentrations of lead in ground water and large concentrations of lead in sediments. As a result of this affinity, inorganic lead is relatively immobile in ground water.

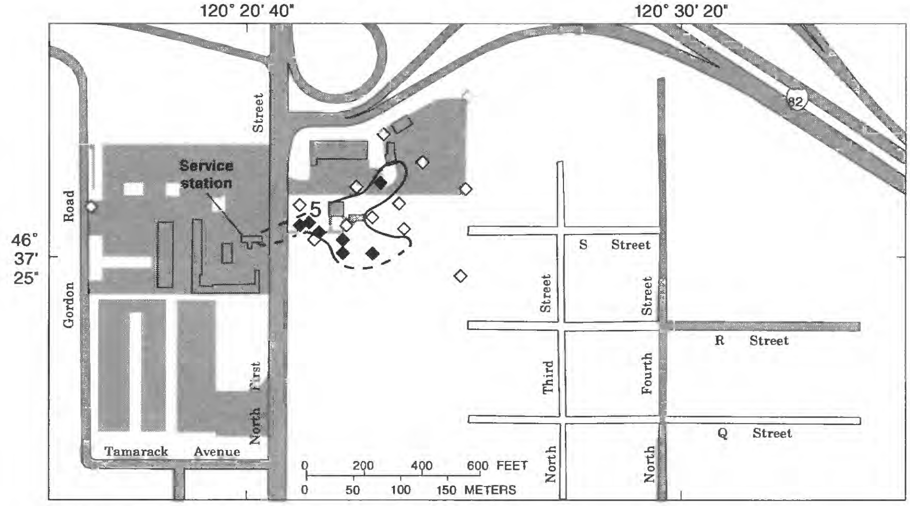
There is little or no correlation between concentrations of lead in soil and in ground water (correlation coefficient = -0.19). Fish (1987) concluded that for the Yakima site, a simple adsorption or ion-exchange model does not explain the distribution of lead between the solid and aqueous phases. Calculations indicated that the observed concentrations of lead in the ground water were near the limit of solubility for $PbCO_3$. Therefore, precipitation of $PbCO_3$ may control the concentration of lead in ground water. Because the areal extent of aquifer materials with elevated concentrations of lead is similar to the areal extent of ground water with elevated levels of dissolved aromatic hydrocarbons (fig 13), the source of the lead is probably lead additives in gasoline, tetraethyl and tetramethyl lead.

The similarity between spatial distributions of lead in the aquifer materials and of some of the aromatic compounds dissolved in ground water suggests that some of the lead has moved in approximately the same direction as some of the aromatic compounds dissolved in the ground water (Fish, 1987). Consequently, Fish concluded that the lead is, or has been, more mobile than implied by the average ground-water velocity and nature of the aquifer materials and that there are several possible modes of transport (see, for example, Freeze and Cherry, 1979, p. 404). Shortly after the gasoline leak, the lead could have been transported as part of the free product. It could have been transported by ground water when in the more soluble alkyl lead phase, which subsequently degraded to inorganic lead that precipitated out of solution. The lead in the aquifer materials also could have been transported by colloidal-size particles.

Table 10.--*Concentrations of extractable lead in aquifer materials and dissolved lead in ground water, November 1986. (Data from ground-water toxics study, analyzed by Oregon Graduate College)*

[µg/L, microgams per liter; µg/kg, micrograms per kilogram; soil extracts are for the size fraction less than 63 micrometers; NS, not sampled]

Well identifier	Dissolved lead in ground water (µg/L)	Extractable lead in aquifer materials (µg/kg)
M1-82	1.8	310
M2-82	2.8	7,610
M1-85	1.4	270
M9-85	1.8	310
M10-85	1.5	40
M11-85	5.3	590
M4	6.0	410
M7	7.2	6,100
M8	9.3	540
M9	5.3	4,870
M11	1.8	200
M12	3.9	890
M16	3.4	20,270
M18	2.4	6,890
M19	1.4	19,150
M23	9.2	4,360
M24	10.1	340
M29	7.4	520
M31	2.4	330
M37	NS	890



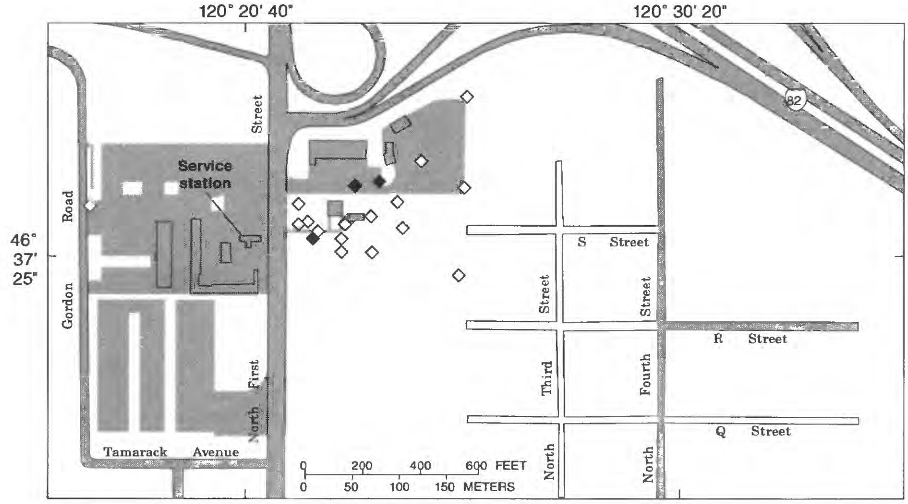
Total extractable lead in aquifer materials

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

- - - - 5 ——— **Line of equal total xylenes concentration in ground-water (100 micrograms per — liter)** — Dashed where approximately located.

◇ **Observation well and concentration of total-extractable lead in aquifer material** — Open symbol indicates detected, but less than 1,000 micrograms per kilogram. Solid symbol indicates concentrations of 1,000 micrograms per liter or greater.



Dissolved lead in ground water

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

◇ **Observation well and concentrations of dissolved lead in ground-water** — Open symbol indicates detected, but less than 9 micrograms per liter. Solid symbol indicates concentration of 9 micrograms per liter or greater.

Figure 13.--Concentrations of total-extractable lead in aquifer material and dissolved lead in ground water, November 1986. (Data are from the ground-water toxics study).

Soil Gas

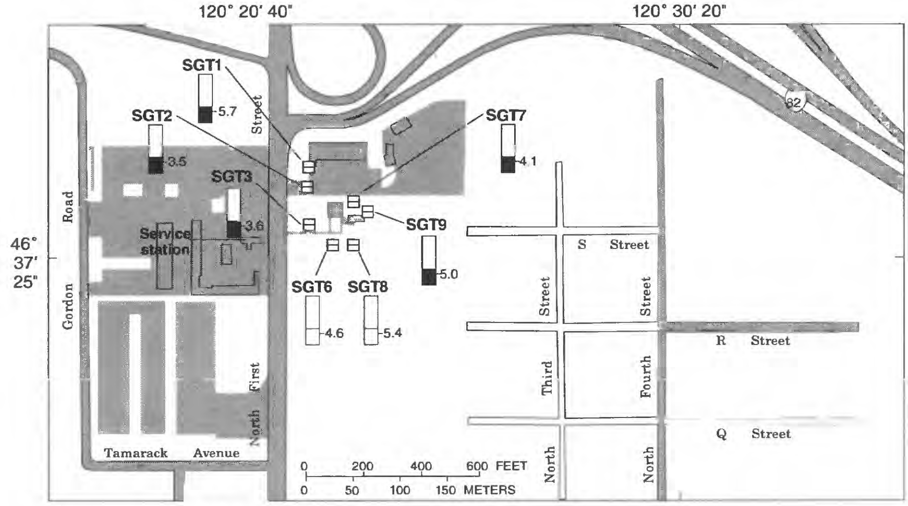
In November 1985, soil-gas samples were collected from seven temporary wells, SGT1 through SGT3 and SGT6 through SGT9 (fig. 14). Originally, 25 wells were to be sampled, but frozen ground and cobbly soil reduced the selection to 7. Also, because of analytical calibration problems, the determination of concentrations of compounds detected in the soil-gas samples was qualitative and not quantitative.

Target compounds (table 11) were detected in samples from wells SGT2 and SGT7. Also, chromatographs for samples from wells SGT1, SGT3, and SGT9 contained peaks that are indicative of likely degradation products of aromatic hydrocarbon compounds (J.R. McPherson, Oregon Graduate Center, oral commun., 1989). Soil gas from wells SGT6 and SGT8 did not contain detectable amounts of hydrocarbon compounds. Although gas samples were collected from wells SGT4 and SGT5, difficulties with collection and analyses of the samples preclude determining the presence or absence of hydrocarbon compounds in soil gas at these two sites. These two wells are not shown on figure 14.

In November 1986, soil-gas samples were collected from multidepth soil-gas tubes in six wells (fig. 14, table 12). Target compounds (listed in table 11) and mixed alkanes were detected at some depths at three of the six wells—SG3, SG5, and SG8 (fig. 14). With the exception of toluene and several alkyl benzenes that were found at depths of 3 to 6 feet below land surface in SG8, most compounds were detected only close to the water table at the deepest levels from which samples were withdrawn (table 11). This is consistent with the steep concentration gradients of concentrations in soil gas near the water table that have been found in other studies (see, for example, Hult and Grabbe, 1985).

Table 11.--*Target compounds for the analysis of volatile organic compounds in soil gas, November 1985*

Compound	Chemical Abstract Service registry number
Benzene	71-43-2
Toluene	108-88-3
n-Octane	111-65-9
Ethylbenzene	100-41-4
m-Xylene	108-38-3
o-Xylene	95-47-6
1,3,5-Trimethylbenzene	108-67-8
n-Decane	124-18-5
1,2,4-Trimethylbenzene	95-63-6
1,2,3,5-Tetramethylbenzene	527-53-7
1,2,3,4-Tetramethylbenzene	488-23-3
n-Dodecane	112-40-3
Naphthalene	91-20-3



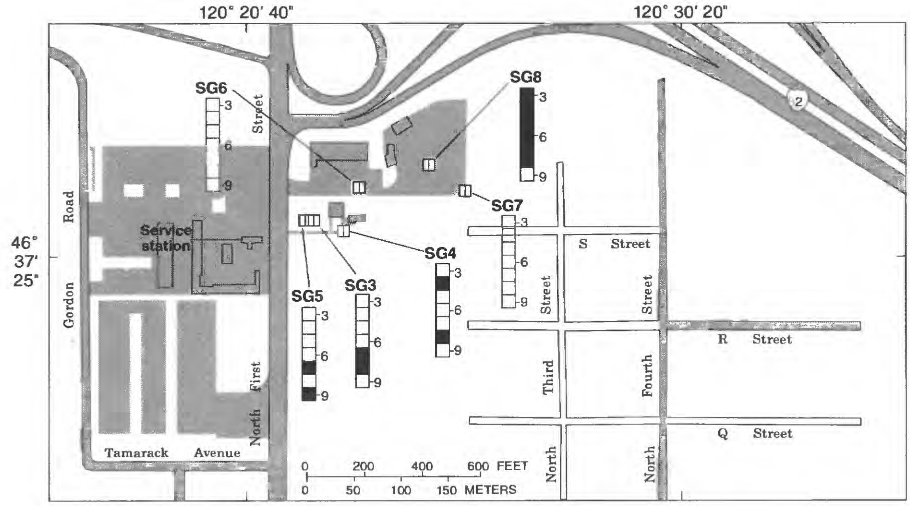
November 1985

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

⊟ **Temporary soil-gas well**

SGT9 -5.0 **Detection symbol and well identifier** — Solid area indicates where volatile hydrocarbons were detected. Numbers indicate depth of sample in feet below land surface. (Well identifiers shown on table 4).



November 1986

EXPLANATION

▨ **Impervious surfaces** — Paved areas and buildings.

◫ **Multidepth soil-gas well.**

SG5 -3 -6 -9 **Detection symbol and well identifier** — Solid area indicates where volatile hydrocarbons were detected. Numbers indicate depth of sample in feet below land surface.

Figure 14.--Locations where soil-gas samples from temporary wells were collected in November 1985 and where multidepth soil-gas samples were collected in November 1986. (Data are from the ground-water toxics study).

Table 12.--*Concentrations of volatile organic compounds in soil gas, November 1986. Data from ground-water toxics study, analyzed by Oregon Graduate College)*

[ND, below detection; NQ, not quantified due to high background noise; L, low concentrations of alkanes, not quantified; H, high concentrations of alkanes, not quantified, applies to target compound *n*-Octane]

Well identifier	Depth of soil-gas sample tubes (feet below land surface)[1]	Concentrations (parts per billion by volume)						Water level (feet below land surface)[1]
		Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1.3.5-Trimethylbenzene	
SG3	7	ND	ND	ND	ND	6,500	ND	10.94
	8	5,340	4,470	610	9,960	14,600	2,970	
SG4	2	ND	ND	ND	ND	ND	ND	11.15
	4	ND	ND	ND	ND	360	ND	
	6	ND	ND	ND	ND	ND	ND	
	8	410	ND	ND	450	750	460	
SG5[2]	1	ND	ND	ND	ND	ND	ND	10.99
	2	ND	ND	ND	ND	ND	ND	
	3	ND	ND	ND	ND	ND	ND	
	4	ND	ND	ND	ND	ND	ND	
	5	ND	ND	ND	ND	ND	ND	
	6	ND	ND	ND	ND	ND	ND	
	7	ND	ND	ND	210	ND	430	
	9	230,000	300,000	83,000	460,000	ND	26,000	
SG6	5	ND	ND	ND	ND	ND	ND	9.35
SG7	6	ND	ND	ND	ND	ND	ND	13.69
	7	ND	ND	ND	ND	ND	ND	
SG8	1	ND	ND	ND	ND	ND	ND	
	2	ND	ND	ND	ND	ND	ND	
	3	ND	230	ND	ND	ND	ND	
	4	540	ND	ND	ND	ND	ND	
	5	ND	ND	ND	ND	ND	ND	
	6	ND	570	ND	ND	ND	ND	
	7	ND	ND	ND	ND	ND	ND	
	8	ND	ND	ND	ND	ND	ND	
	9	***(Sample tube clogged/in water)***						

Table 12.--*Concentrations of volatile organic compounds in soil gas, November 1986 Data from ground-water toxics study, analyzed by Oregon Graduate College)--Continued*

Well identifier	Depth of soil-gas sample tubes (feet below land surface)[1]	Concentrations (parts per billion by volume)						
		2-Ethyl-1-methylbenzene	1,2,4-Trimethylbenzene	1,2,3-Trimethylbenzene	1,2,3,5-Tetramethylbenzene	1,4-Dimethyl-2-ethylbenzene	1,3-Dimethyl, 4-ethylbenzene	Mixed alkanes (or *n*-Octane)
SG3	7	ND	ND	ND	580	790	ND	ND
	8	1,720	7,030	2,470	5,920	8,620	ND	940
SG4	2	ND	ND	ND	ND	ND	ND	ND
	4	ND	30	130	750	1,260	ND	ND
	6	ND	ND	ND	ND	ND	ND	ND
	8	ND	ND	ND	ND	ND	ND	ND
SG5	1	D	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND	ND	ND
	3	ND	ND	ND	ND	ND	ND	ND
	4	ND	ND	ND	ND	ND	ND	ND
	5	ND	ND	ND	ND	ND	ND	ND
	6	ND	ND	ND	ND	ND	ND	ND
	7	ND	ND	ND	ND	ND	ND	ND
	9	5,820	56,500	25,200	3,950	9,180	ND	NQ
SG6	5	ND	ND	ND	ND	ND	ND	L
SG7	6	ND	ND	ND	ND	ND	ND	ND
	7	ND	ND	ND	ND	ND	ND	ND
SG8	1	ND	ND	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND	ND	ND
	3	ND	ND	ND	390	320	ND	L
	4	ND	ND	ND	120	ND	ND	H
	5	ND	ND	ND	160	ND	ND	H
	6	ND	ND	ND	150	ND	ND	L
	7	ND	ND	ND	ND	ND	ND	L
	8	ND	ND	ND	ND	ND	ND	L
	9	*** (Sample tube clogged/in water)***						

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[1] See table 2 for land surface altitudes.

[2] Water level from M16 is used for SG5.

SUMMARY AND CONCLUSIONS

An estimated 12,000 to 22,000 gallons of gasoline and diesel fuel were leaked to unsaturated sediments and shallow ground water from delivery lines at a service station in Yakima, Washington. Data indicate that the fuel leak is contained within unconsolidated sediments and shallow ground water 7 to 12 feet below land surface.

After unsuccessful attempts in 1982-83 to recover fuel in the ground, an insurance company directed a study in 1984-85 to monitor the presence of dissolved hydrocarbons in ground water. From August 1985 through November 1986, in a separate study by the U.S. Geological Survey, ground-water samples were analyzed for dissolved hydrocarbons and lead, and soil gas was sampled in the unsaturated sediments. Fine-grained sediments in the aquifer also were analyzed for lead. The gasoline leak in Yakima was selected to be a part of the USGS Ground-Water Toxic Substances Hydrology Program, but the study was discontinued before an interpretive phase was completed. In a follow-up study, data were collected in March 1989 to determine the concentrations and areal extent of dissolved hydrocarbons in ground water and to compare results with those of the two previous studies.

Similar gas-chromatographic techniques were used in all three studies to determine concentrations of benzene, toluene, naphthalene, and total xylenes in shallow ground water for five sampling periods beginning in 1985. Large concentrations of toluene (680 µg/L) and of total xylenes (980 µg/L) were found in one domestic well about 1,200 feet downgradient from the leak, but water in all other domestic wells sampled beginning in 1984 had hydrocarbon concentrations that were less than 500 µg/L. Samples collected from 1985 to 1986 indicate that volatile hydrocarbons in observation wells commonly exceeded 500 µg/L at distances of 150 to 500 feet downgradient from the gasoline leak. Soil-gas samples taken in November 1986 indicated that volatile hydrocarbons were detected only close to the water table.

By March 1989, concentrations of volatile hydrocarbons had decreased and the areal extent over which they were present in shallow ground water was smaller. Only concentrations of total xylenes exceeded 500 µg/L, at two wells near the source of the leak. Concentrations of volatile hydrocarbons generally were less than 500 µg/L near the source of the leak and generally were less than 5 µg/L at distances more than 400 feet from the source of the leak. In contrast, during the sample periods of November 1986 and earlier, volatile hydrocarbon concentrations exceeded 5 µg/L at distances of as much as 1,200 feet from the source of the leak. The decrease in volatile dissolved hydrocarbons in the shallow ground water between 1984-86 and 1989 could be due to natural dispersal, volatilization, or biodegradation.

Concentrations of dissolved lead in ground water were small for the sample periods from 1986-89. These concentrations were 1.4 to 10.1 µg/L and less than the U.S. Environmental Protection Agency Maximum Contaminant Level of 50 µg/L for drinking water. Lead has a high affinity for soils and is relatively immobile in ground water. However, elevated concentrations of lead in aquifer sediments suggest lead has moved in the aquifer in the same direction that the dissolved hydrocarbons have moved.

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APPENDIX A: QUALITY ASSURANCE

The quality of the data from all three studies cited in this report appears to be good enough to allow interlaboratory comparison among the three studies. Differences between concentrations in duplicate samples generally were small, and concentrations of standards, spiked samples, and blank samples were within the stated goals of each study (see tables A1 to A6).

Insurance Company Study

The quality-assurance part of the insurance company study consisted of field blanks, lab blanks, and duplicate samples. Concentrations of benzene, toluene, and total xylenes in field and laboratory blanks were less than the detection limit of 1 microgram per liter (table A1). Sample results for the insurance company study were not blank corrected. Replicate analyses of a sample from observation well M11-85 indicate good precision for all compounds except toluene. On August 27, 1985, personnel from the insurance company study and the ground-water toxics study independently collected samples from four wells, and the samples were analyzed by their respective laboratories (see table A2). Differences between the two sets of results are small, except for the concentration of benzene in the samples from well M8-85 and perhaps the concentration of toluene in the samples from M11-85. Differences between other concentrations can be attributed to variabilities in sample collection and analysis.

Table A1.--*Concentrations of volatile organic compounds in quality-assurance samples, May 1985 through June 1986. (Data are from the insurance compnay study and were analyzed by a private laboratory)*

[ND, below the detection limit of 1 microgram per liter; D, duplicate sample]

Sample or well identifer	Date	Concentrations (in micrograms per liter)		
		Benzene	Toluene	Total xylenes
Field blank	05-10-85	ND	ND	ND
Field blank	05-11-85	ND	ND	ND
M11-85	05-11-85	1,380	7,700	12,900
M11-85 (D)	05-11-85	1,090	4,000	14,900
Lab blank	12-16-85	ND	ND	ND
Lab blank	06-27-86	ND	ND	ND

Table A2.--*Comparison of concentrations of volatile organic compounds analyzed during the insurance company study and ground-water toxics study, August 27, 1985*

[ICS, insurance company study, GWTS, Ground-Water Toxics Study; ND, below the limit of detection of 1 microgram per liter for ICS; see p. 26 for discussion of detection limits for GWTS]

Well identifier	Concentrations, in micrograms per liter					
	Benzene		Toluene		Total xylenes	
	ICS	GWTS	ICS	GWTS	ICS	GWTS
M7-85	ND	ND	ND	ND	ND	ND
M8-85	96	ND	1	ND	9	ND
M10-85	ND	ND	ND	ND	ND	ND
M11-85	920	1,000	1,100	3,400	6,300	7,300

Ground-Water Toxics Study

The quality assurance during the ground-water toxics study consisted of collecting duplicate samples, doing replicate analysis, and analyzing trip-blank samples. Organic-free blank water for trip blanks and sample dilutions was prepared in the Oregon Graduate Center laboratory. The replicate analyses of trip blanks and duplicate samples were used to calculate the statistical limits of detection. Mean and standard deviation of concentrations detected in the trip blanks for the August 1985 sampling are listed in table A3. Sample results were correspondingly blank corrected. Concentrations determined for mixtures of standard solutions supplied by the U.S. Environmental Protection Agency are compared with concentrations in the standards (table A4).

Table A3.--*Mean and standard deviations of volatile organic compounds detected in trip blanks, August 26-30, 1985 [Data are from the Ground-Water Toxics Study, analyzed by the Oregon Graduate Center]*

[n, number of replicates; concentrations are in micrograms per liter]

Parameter	Benzene	Toluene	Ethyl benzene	*m*+*p*- Xylene	*o*- Xylene	*n*-Propyl- benzene	1,3,5-Tri- methyl- benzene
Mean (n = 6)	0.87	0.49	0.032	0.041	0.025	0.0024	0.017
Standard deviation	±.11	±.10	±.015	±.015	±.0071	±.0047	±.0096

Parameter	1,2,4- Tri- methyl- benzene	Iso- butyl- benzene	*sec*- Butyl- benzene	*n*-Butyl- benzene	1,2,3,5- Tetra- methyl- benzene	1,2,3,4- Tetra- methyl- benzene	Naph- thalene
Mean (n = 6)	0.053	0.0046	0.006	0.019	0.009	0.014	0.20
Standard deviation	±.017	±.0082	±.0089	±.011	±.014	±.016	±.29

Table A4.--*Comparison of means and standard deviations of standard hydrocarbon compound concentrations, November 1985. (Data from the ground-water toxics study, analyzed by Oregon Graduate Center; standard solutions prepared from materials supplied by the U.S. Environmental Protection Agency-Environmental Monitoring Services Laboratory, Cincinnati, Ohio)*

[µg/L, micrograms per liter; EPA, U.S. Environmental Protection Agency; GWTS, Ground-Water Toxics Study]

		EPA	GWTS	
Standard solution	Compound	Concentration (µg/L)	Concentration (µg/L)	One standard deviation
I	Benzene	10,000	12,000	± 1,800
	Toluene	10,000	11,000	± 540
	m+*p*-Xylene	10,000	9,700	± 680
	o-Xylene	5,000	5,100	± 320
II	Benzene	10,000	12,000	± 800
	o-Xylene	10,000	9,500	± 560
III	Toluene	10,000	11,000	± 480
	m+*p*-Xylene	10,000	10,000	± 720

1989 Study

Organic Constituents

The quality assurance during the 1989 study consisted of collecting duplicate samples and equipment-rinse samples, using blank-water samples and trip-blank samples, and spiking samples with identical concentrations of target compounds in the field and in the laboratory. The blank water used during the 1989 study was commercially available Burdick & Jackson HPLC water. Equipment-rinse samples consisted of 40 mL of this water that was passed through the sampler after cleaning. Tests were made to check the adequacy of the cleaning procedure prior to field sampling and also during the sampling period.

Samples of the blank water, blank water from an equipment rinse, and blank water from an equipment rinse after baking the sampler were analyzed for volatile hydrocarbon compounds (table A5). The blank water contained relatively small concentrations of methylene chloride and chloroform. Compounds tentatively identified using a National Institute of Standards Technology computer search were hexane and methylcyclopentane. Equipment-rinse blanks contained small concentrations of benzene, toluene, total xylenes, and larger concentrations of methylene chloride and chloroform. The equipment-rinse blanks also contained relatively large concentrations of compounds that were tentatively identified as hexane, methylcyclopentane, 3-methylpentane, and acetone. Equipment-rinse blanks that were passed through the sampler after it was baked at 105 °C contained only small concentrations of chloroform, bromodichloromethane, chlorodibromomethane, and 1,2-dichloropropane. This could complicate the identification of bromide- or chloride-substituted methane compounds used as fuel additives, but does not interfere with the interpretation of other petroleum-related hydrocarbons in the ground-water samples.

Trip blanks were collected with the intention of analyzing the samples only if a problem was suspected in collection or processing techniques. Because no anomalous results were found, the trip blanks were not analyzed. Sample results for the 1989 study are not blank corrected.

One set of replicate samples from observation well M8-85 was spiked in the field with target compounds to check the effective recovery of compounds from a field-matrix sample. Supelco VOC Standard Mixture 2, containing target compounds at a concentration of 2,000 ng/µL (nanograms per microliter), was diluted at the National Water Quality Laboratory to 4-ng/µL. One hundred µL of the 4-ng/µL solution was added to the sample in the field to give a spike concentration of 10 µg/L. An extra sample, unspiked, also was sent to the laboratory for spiking in the laboratory (table A5). The difference in recovery between the field spikes and the lab spikes ranged from +25 to -7 percent, with an average difference for FS1 of 4 percent and an average for FS2 of 12 percent. These differences are considered to be normal, but differences between some of the field and laboratory spike values suggest a partial loss of some compounds that could be due to biodegradation (Brooke Connors, U.S. Geological Survey, oral commun., 1989).

Inorganic Constituents

Various sums, differences, and ratios, based on aquatic chemistry principles, were computed for each inorganic sample. These computations check the consistency between constituent concentrations in a sample and provide a gross check of the accuracy and completeness of the analysis. Two of the most useful computations are the cation-anion balance and calculated dissolved-solids concentration, which are defined in the following paragraphs.

The cation-anion balance is the difference, in percent, between the sums of the concentrations of cations and anions, expressed in milliequivalents. Ideally, this value is zero, but non-zero values occur when a cation or anion concentration is in error or when the concentration of a significant ion (often a metal) is not determined. The acceptable difference varies with the total sum of cations and anions. The differences ranged from 0.0 to 5.97 percent.

Calculated solids is the dissolved-solids concentration determined by summing the concentrations of cations, anions, silica, and other major dissolved constituents. This value is theoretically equal to the dissolved-solids concentration determined in the laboratory by residue upon evaporation. Differences usually are due to errors in analyses of the various cations or anions (which may be verified by the cation-anion balance) or errors in the laboratory-determined dissolved-solids concentration. In analyses at the study site, differences between the calculated and analyzed dissolved solids ranged from 2 to 9 percent.

Table A5.--*Concentrations of volatile organic compounds in quality-assurance samples, February 23 through March 17, 1989. (Data analyzed by National Water Quality Laboratory)*

[Equivalent spikes FS1 and FS2 are field spikes and LS is a laboratory spike containing benzene, toluene, ethylbenzene, m-xylene, napthalene, 1,3,5-trimethylbenzene, *p*-isopropyltoluene, 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, *n*-butylbenzene, styrene, and bromobenzene; D, duplicate sample; BL, blank-water sample; ER, equipment-rinse sample; ERB, baked-equipment rinse sample; ND, below the detection limit of 0.2 micrograms per liter; --, not analyzed]

Sample or well identifier	Date	Concentrations (micrograms per liter)									
		Benzene	Toluene	Ethylbenzene	Total xylenes	Naphthalene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,2,3,4-Tetramethylbenzene	1,2,3,5-Tetramethylbenzene
M8-85	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (FS1)	03-14-89	6.6	6.9	7.6	7.4	9.8	ND	7.6	7.7	ND	ND
M8-85 (FS2)	03-14-89	5.2	5.2	5.9	5.8	9.4	ND	6.4	6.5	ND	ND
M8-85 (LS)	03-14-89	8.6	8.2	8.7	8.3	9.4	ND	8.5	8.7	ND	ND
M18	03-17-89	ND	ND	.2	.2	ND	0.3	ND	ND	ND	ND
M18 (D)	03-17-89	.4	ND	.4	.3	ND	.4	ND	ND	ND	ND
BL1	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL2	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL3	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL5	03-13-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER1	02-23-89	.2	.2	ND	[1].1	ND	ND	ND	ND	ND	ND
ER2	02-23-89	.4	.4	ND	.3	ND	ND	ND	ND	ND	ND
ER3	02-23-89	.2	.2	ND	ND	ND	ND	ND	ND	ND	ND
ERB4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB5	03-13-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sample or well identifier	Date	Concentrations (micrograms per liter)									
		2-Chlorotoluene	4-Chlorotoluene	1,2-Dibromoethane	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	1,1-Dichloroethane	1,1-Dichloroethene	1,2-Dichloroethane	1,2-Dichloroethene (total)
M8-85	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (FS1)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (FS2)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (LS)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M18	03-17-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M18 (D)	03-17-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL1	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL2	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL3	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL5	03-13-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER1	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER2	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER3	03-13-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB4	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB5	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table A5.--*Concentrations of volatile organic compounds in quality-assurance samples, February 23 through March 17, 1989. (Data analyzed by National Water Quality Laboratory)--Continued*

Sample or well identifier	Date	Concentrations (micrograms per liter)									
		1,2-Dichloropropane	1,3-Dichloropropane	2,2-Dichloropropane	1,1-Dichloropropene	*cis*-1,3,-Dichloropropene	*trans*-1,3,-Dichloropropene	1,3,-Dimethyl-2-ethylbenzene	1,4-Dimethyl-2-ethylbenzene	2-Ethyl-1-methylbenzene	1,2,3-Trichlorobenzene
M8-85	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
M8-85 (FS1)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.4
M8-85 (FS2)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.2
M8-85 (LS)	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.1
M18	03-17-89	ND	ND	ND	ND	ND	ND	0.8	ND	3.2	--
M18 (D)	03-17-89	ND	ND	ND	ND	ND	ND	.9	ND	5.4	--
BL1	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
BL2	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
BL3	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
BL4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
BL5	03-13-89	0.3	ND	ND	ND	ND	ND	ND	ND	ND	--
ER1	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
ER2	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
ER3	02-23-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
ERB4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
ERB5	03-13-89	.3	ND	ND	ND	ND	ND	ND	ND	ND	--

Sample or well identifier	Date	Concentrations (micrograms per liter)									
		1,2,4-Trichlorobenzene	1,1,1-Trichloroethane	1,1,2-Trichloroethane	1,2,3-Trichloropropane	1,1,1-2-Tetrachloroethane	1,1,2,2-Tetrachloroethane	Bromobenzene	Bromodichloromethane	Bromoform	Bromomethane
M8-85	03-14-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (FS1)	03-14-89	8.8	ND	ND	ND	ND	ND	8.7	ND	ND	ND
M8-85 (FS2)	03-14-89	7.1	ND	ND	ND	ND	ND	7.1	ND	ND	ND
M8-85 (LS)	03-14-89	7.9	ND	ND	ND	ND	ND	7.7	ND	ND	ND
M18	03-17-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
M18 (D)	03-17-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL1	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL2	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL3	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL4	03-06-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL5	03-13-89	--	ND	ND	ND	ND	ND	ND	0.5	ND	ND
ER1	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER2	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
ER3	02-23-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB4	03-06-89	--	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB5	03-13-89	--	ND	ND	ND	ND	ND	ND	.5	ND	ND

Table A5.--*Concentrations of volatile organic compounds in quality-assurance samples, February 23 through March 17, 1989. (Data analyzed by National Water Quality Laboratory)--Continued*

Sample or well identifier	Date	Concentrations (micrograms per liter)									
		n-Butylbenzene	*sec*-Butylbenzene	Carbon tetrachloride	Chlorobenzene	Chloroethane	Chloroform	Chloromethane	Chlorodibromomethane	Dibromomethane	Dichlorodifluoromethane
M8-85	03-14-89	ND	ND	0.3	ND	ND	5.3	ND	ND	ND	ND
M8-85 (FS1)	03-14-89	6.2	ND	ND	ND	ND	1.4	ND	ND	ND	ND
M8-85 (FS2)	03-14-89	5.4	ND	ND	ND	ND	1.4	ND	ND	ND	ND
M8-85 (LS)	03-14-89	8.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
M18	03-17-89	ND	ND	ND	ND	ND	.5	ND	ND	ND	ND
M18 (D)	03-17-89	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BL1	02-23-89	ND	ND	ND	ND	ND	1.4	ND	ND	ND	ND
BL2	02-23-89	ND	ND	ND	ND	ND	1.5	ND	ND	ND	ND
BL3	02-23-89	ND	ND	ND	ND	ND	1.6	ND	ND	ND	ND
BL4	03-06-89	ND	ND	ND	ND	ND	1.3	ND	ND	ND	ND
BL5	03-13-89	ND	ND	ND	ND	ND	3.7	ND	0.2	ND	ND
ER1	02-23-89	ND	ND	ND	ND	ND	61	ND	ND	ND	ND
ER2	02-23-89	ND	ND	ND	ND	ND	148	ND	ND	ND	ND
ER3	02-23-89	ND	ND	ND	ND	ND	57	ND	ND	ND	ND
ERB4	03-06-89	ND	ND	ND	ND	ND	1.3	ND	ND	ND	ND
ERB5	03-13-89	ND	ND	ND	ND	ND	3.2	ND	.2	ND	ND

Sample or well identifier	Date	Concentrations (micrograms per liter)								
		Isopropylbenzene	*p*-Isopropyltoluene	Methylene chloride	*n*-Propylbenzene	Styrene	Tetrachloroethene	Trichlorofluoromethane	Trichloroethene	Vinyl chloride
M8-85	03-14-89	ND	ND	ND	ND	ND	ND	ND	ND	ND
M8-85 (FS1)	03-14-89	ND	6.6	ND	ND	8.6	ND	ND	ND	ND
M8-85 (FS2)	03-14-89	ND	5.8	ND	ND	7.0	ND	ND	ND	ND
M8-85 (LS)	03-14-89	ND	7.9	ND	ND	8.8	ND	ND	ND	ND
M18	03-17-89	ND	ND	ND	ND	ND	ND	ND	ND	ND
M18 (D)	03-17-89	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL1	02-23-89	ND	ND	0.4	ND	ND	ND	ND	ND	ND
BL2	02-23-89	ND	ND	.6	ND	ND	ND	ND	ND	ND
BL3	02-23-89	ND	ND	.5	ND	ND	ND	ND	ND	ND
BL4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND
BL5	03-13-89	ND	ND	.2	ND	ND	ND	ND	ND	ND
ER1	02-23-89	ND	ND	2.6	ND	ND	ND	ND	0.2	ND
ER2	02-23-89	ND	ND	5.3	ND	ND	ND	ND	.5	ND
ER3	02-23-89	ND	ND	2.7	ND	ND	ND	ND	.2	ND
ERB4	03-06-89	ND	ND	ND	ND	ND	ND	ND	ND	ND
ERB5	03-16-89	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table A5.--*Concentrations of volatile organic compounds in quality-assurance samples, February 23 through March 17, 1989. (Data analyzed by National Water Quality Laboratory)--Continued*

Sample or well identifier	Tentatively identified organic compounds[2]			
	Hexane	Methyl-cyclo-pentane	3-Methyl-pentane	Acetone
M8-85	ND	ND	ND	ND
M8-85 (FS1)	ND	ND	ND	ND
M8-85 (FS2)	ND	ND	ND	ND
M8-85 (FS3)	ND	ND	ND	ND
M18	ND	ND	ND	ND
M18 (D)	ND	ND	ND	ND
BL1	0.7	1.2	ND	ND
BL2	1.0	.9	ND	ND
BL3	.9	1.0	ND	ND
BL4	ND	ND	ND	ND
BL5	ND	ND	ND	ND
ER1	6	57	2.4	0.5
ER2	18	166	5.9	.6
ER3	57	57	2.5	.7
ERB4	ND	ND	ND	ND
ERB5	ND	ND	ND	ND

[1] Laboratory quantified compound detection, even though below the reported detection limit of 0.2 microgram per liter.

[2] Tentatively identified organic compound; the reported concentration generally is accurate to one order of magnitude.

The primary controls on field values of pH, specific conductance, dissolved oxygen, and temperature are proper instrument calibration and field procedures. However, pH and specific conductance also are determined in the laboratory. Differences between laboratory and field specific conductances were less than 5 percent in all cases (table A6).

Field and laboratory pH differed by more than 0.2 unit for only 3 out of 18 samples, and none of these differences are more than 0.5 unit. Because pH and specific conductance can change during the time between the field and laboratory determinations, these comparisons must be considered approximations at best, but the good agreement generally serves to confirm the field values.

Field determinations of bicarbonate concentrations were checked by calculating alkalinities from them and comparing the results with laboratory-determined alkalinities. Field and laboratory alkalinities differed by more than 5 percent for only one of six samples.

Duplicate samples were collected and analyzed for both inorganic and organic constituents during the 1989 study (table A7). Dissolved zinc is the only constituent for which duplicate sample results do not agree. Results were verified by reruns of split samples. The differences could be explained as contamination during handling or natural variability in the water. The ground water sampled at the site contained particulate matter that could vary from one sample to another (see turbidity values, table A6). Upon acidification, colloidal zinc would be transformed to the dissolved state.

Table A6.--*Comparison of field and laboratory determinations of specific conductance, pH, and alkalinity, November 1986 and March 1989. (Data from ground-water toxics study and 1989 study, laboratory data analyzed by the National Water Quality Laboratory)*

[µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; --, not analyzed]

Well identifier	Date	Specific conductance (µS/cm)		pH (standard units)		Alkalinity (mg/L as $CaCO_3$)	
		Field	Lab	Field	Lab	Field	Lab
M1-82	11-18-86	280	279	6.8	6.9	131	--
M2-82	11-18-86	320	303	6.7	6.8	156	--
M1-85	11-19-86	238	239	6.7	6.9	103	--
	03-13-89	208	222	6.9	7.0	89	90
M5-85	03-13-89	252	265	6.7	6.8	113	114
M9-85	11-19-86	254	254	6.5	6.9	108	--
	03-15-89	249	260	6.6	6.7	112	111
M10-85	11-19-86	298	293	6.6	6.8	116	--
M11-85	11-17-86	264	251	6.6	6.8	125	--
	03-18-89	292	295	6.6	6.8	140	134
M4	11-18-86	313	295	6.6	6.8	151	--
M7.2	11-17-86	352	336	6.4	6.6	185	--
M8	11-17-86	247	245	6.6	6.8	105	--
M9	11-17-86	279	272	6.6	6.9	133	--
M11	11-18-86	307	298	6.6	6.9	148	--
M12	11-18-86	323	303	6.5	6.7	164	--
M16	11-17-86	342	329	6.7	6.8	172	--
M18	11-18-86	292	271	6.6	6.8	149	--
	03-17-89	319	307	6.7	6.9	132	113
M19	11-18-86	257	251	6.6	6.9	105	--
M23	11-18-86	390	385	6.7	6.8	193	--
M24	11-18-86	365	332	6.5	6.7	190	--
M29	11-19-86	259	258	6.6	6.8	120	--
M30	03-14-89	268	284	6.6	6.6	128	122
M31	11-19-86	261	261	6.5	6.8	113	--

Table A7.--*Concentrations of inorganic and dissolved-organic carbon quality-assurance samples, March 1989. (Data from 1989 study, laboratory data analyzed by the National Water Quality Laboratory)*

[ER, equipment-rinse blank, deionized water; D, duplicate sample; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; NTU, nephelometric turbidity units; --, not analyzed]

Well or sample identifier	Date	Specific conductance (µS/cm)	Lab specific conductance (µS/cm)	pH (stanfard units)	Lab pH (stanfard units)	Temperature water (°C)	Turbidity (NTU)	Oxygen, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)
M18	03-17-89	319	307	6.7	6.9	13.0	40	0.0	130	0
M18 (D)	03-17-89	--	307	--	6.7	--	33	--	130	0
ER4	03-15-89	--	--	--	7.2	--	.3	--	0	0

Sample or well identifier	Date	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium (percent)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
M18	03-17-89	32	11	12	17	0.5	2.6	132	113	34
M18 (D)	03-17-89	32	11	12	17	.5	2.6	--	113	34
ER4	03-15-89	.03	.05	<.2	--	--	.1	--	2	<.2

Sample or well identifier	Date	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2 +NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus ortho, dissolved (mg/L as P)	Barium, dissolved (mg/L as Ba)
M18	03-17-89	7.0	0.2	38	209	227	<0.10	0.10	0.05	18
M18 (D)	03-17-89	7.0	.2	38	208	227	<.10	.11	.05	19
ER4	03-15-89	<.1	.1	<.01	<1	--	<.10	<.01	<.01	<2

Table A7.--*Concentrations of inorganic and dissolved-organic carbon quality-assurance samples, March 1989. (Data from 1989 study, laboratory data analyzed by the National Water Quality Laboratory)--Continued*

Sample or well identifier	Date	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)
M18	03-17-89	<0.5	<1	<5	4	<10	7,300	<10	6	2,800
M18 (D)	03-17-89	<.5	<1	<5	<3	<10	7,200	<10	5	2,800
ER4	03-15-89	<.5	<1	<5	<3	<10	5	<10	<4	<1

Sample of well identifier	Date	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Carbon, dissolved organic (mg/L as C)
M18	03-17-89	<10	<10	<1	150	<6	69	1.9
M18 (D)	03-17-89	<10	<10	<1	150	<6	230	2.0
ER4	03-15-89	<10	<10	<1	<1	<6	<3	.3

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