Water-Quality and Hydrologic Conditions at a Site of Ground-Water Contamination by Volatile Organic Compounds, South Grafton, Massachusetts, September and October 1994

U.S. GEOLOGICAL SURVEY
Open-File Report 95-425

Prepared in cooperation with
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION,
BUREAU OF WASTE SITE CLEANUP

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

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By LESLIE A. DESIMONE and PAUL M. BARLOW

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	2.54	millimeter
mile (mi)	1.609	kilometer

Concentrations of major inorganic constituents and dissolved organic carbon (DOC) are given in milligrams per liter (mg/L), which is equivalent to parts per million. Concentrations of volatile organic compounds (VOCs) are given in micrograms per liter (µg/L), which is equivalent to parts per billion.

Vertical Datum

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.

Water-Quality and Hydrologic Conditions at a Site of Ground-Water Contamination by Volatile Organic Compounds, South Grafton, Massachusetts, September and October 1994

By Leslie A. DeSimone *and* Paul M. Barlow

Abstract

Ground-water quality and hydrologic data were collected at a site contaminated by volatile organic compounds (VOCs) in South Grafton, Massachusetts, during September and October 1994. The VOCs have formed a plume of contaminated ground water at an abandoned textile mill adjacent to the Blackstone River. Concentrations of total VOCs in the plume ranged from less than 1 to more than 40,000 micrograms per liter. Trichloroethylene (TCE) was the primary chlorinated contaminant, comprising as much as 98 percent of the total VOCs. The highest concentration, 43,000 micrograms per liter, was higher than any previously measured concentration at the site; however, the maximum extent and distribution of concentrations in the VOC plume in September 1994 was similar to that found in July 1993 and in earlier rounds of sampling. In addition to TCE, 1,2-dichloroethene (1,2-DCE) and vinyl chloride were detected at most sites. Spatial and temporal changes in concentrations of TCE, 1,2-DCE, and vinyl chloride are consistent with the hypothesis that TCE biodegradation was the source of 1,2-DCE and vinyl chloride. Ground water at the site contained low to moderately high concentrations of dissolved solids (44 to 406 milligrams per liter), had a moderately high specific conductance (155 to 670 microsiemens per centimeter at 25 degrees Celsius), and was slightly acidic (pH=5.9 to 7.0). Concentrations of the major ions—calcium, sodium, chloride, and sulfate—were not related to VOC concentrations. Dissolved-oxygen concentrations were low (0 to 2 milligrams per liter) throughout most of the aquifer. Distribution of nitrogen species, iron, and manganese indicates that zones of varying oxidation-reduction potential were present in the aquifer. Concentrations of trace metals other than iron or manganese, including arsenic, cadmium, chromium, and copper, generally were less than analytical detection limits.

Stream stage in the Blackstone River at the site during September and October 1994 fluctuated by about 1 to 2 feet within 24-hour periods. These rapid fluctuations resulted from sudden release of impounded water at a hydroelectric-generating facility downstream from the site. In addition to the daily fluctuations, rapid small changes in stream stage also occurred that were related to storms. Fluctuations in ground-water levels in four observation wells at the site were similar in amplitude and timing to the rapid fluctuations in stream stage; the daily fluctuations of ground-water levels were greatest in an observation well within 100 feet of the river and least in an observation well about 300 feet from the river. Because ground-water levels at the study site seem to be affected by fluctuations in stage of the Blackstone River, transport of the VOC plume in ground water also is likely to be affected by the fluctuations in stage.

INTRODUCTION

The Massachusetts Department of Environmental Protection, Bureau of Waste Site Cleanup (BWSC) has been monitoring a plume of volatile organic compounds (VOCs) at the site of an abandoned textile mill adjacent to the Blackstone River in South Grafton, Massachusetts (fig. 1) for several years (HMM Associates, Inc., 1994). The site may be within the zone of contribution of existing and proposed public-supply wells in South Grafton (fig. 1) and therefore has been of concern to the BWSC. The BWSC is considering remedies that will eliminate, reduce, or control risks to human health and the environment posed by this VOC plume. However, several aspects of the ground-water-flow system and geochemical environment at the site that are essential to evaluating remedial strategies require further investigation. Data needed to determine the ground-water quality and hydrologic conditions at the site were collected during September and October 1994 by the U.S. Geological Survey (USGS), in cooperation with the BWSC. This report describes (1) methods of data collection, (2) water-quality conditions of the aquifer, and (3) hydrologic conditions at the site during the period of investigation. Water-quality characteristics measured included physical properties and concentrations of dissolved organic carbon (DOC), major inorganic constituents, trace metals, and several VOCs. Stream stage of the Blackstone River and ground-water levels in four observation wells were measured during the investigation. Precipitation measured at a nearby weather station and ground-water pumping rates measured at a nearby public-supply well were reported to the USGS and are included in this report.

METHODS OF DATA COLLECTION

Water-Quality Sampling and Analysis

Twenty-one existing 2-inch inside-diameter (i.d.) monitoring wells were sampled (table 1). The sampling order was based on previously measured (July 1993) VOC concentrations (HMM Associates, Inc., 1994), proceeding from least to most heavily contaminated wells. Wells were purged using a peristaltic pump (about 0.4 gal/min), with dedicated 0.25-inch outside-diameter FEP Teflon[1] and Norprene tubing (pump head). Samples were collected after at least three well volumes had been removed and field measurements of specific conductance and pH had stabilized. Dissolved-oxygen concentrations were measured colorimetrically (Chemetrics, Inc.) with water collected from the pump discharge line. In-line filtration [capsule filters, 0.45 μm (micrometer)] and preservation of major-ion, trace-metal, and nutrient samples was done in a portable clean box to prevent contamination by airborne particles. Ground-water samples for analysis of DOC concentration were collected into a combusted glass bottle and filtered using a stainless-steel filter holder (silver filters, 0.45 μm). Ground water for analysis of VOCs

Table 1. Well depths and water levels in wells sampled for water-quality analysis, South Grafton, Massachusetts, September 1994

[Altitudes of measuring points are from HMM Associates, Inc., 1994. Altitudes are given in feet above sea level. ft, foot. Depth of well is given in feet below land surface]

Well No. (fig. 1)	Depth of well (ft)	Altitude of measuring point	Depth to water (ft)	Altitude of water level
MW1	12.2	285.05	5.05	280.00
MW1D	49.5	285.27	5.22	280.05
MW2	14.3	283.95	4.00	279.95
MW2D	49.1	283.94	4.65	279.29
MW3	22.0	283.72	3.47	280.25
MW7B	21.6	290.78	9.11	281.67
MW7C	35.8	290.47	7.58	282.89
MW17A	12.7	285.01	5.18	279.83
MW17C	40.8	284.92	4.76	280.16
MW25S	17.6	289.10	8.54	280.56
MW25D	50.6	288.55	8.40	280.15
MW29S	14.8	285.29	5.27	280.02
MW29D	60.2	285.31	5.17	280.14
MW30D	42.2	284.75	4.57	280.18
MW31D	62.0	284.10	3.91	280.19
MW32	26.8	284.59	6.29	278.30
MW33S	22.6	295.00	10.90	284.10
MW33D	48.9	295.16	13.92	281.24
MW34	46.1	292.68	12.72	279.96
MW35	52.6	292.90	12.50	280.40
MW36	51.9	293.88	12.95	280.93

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[1] Use of trade names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

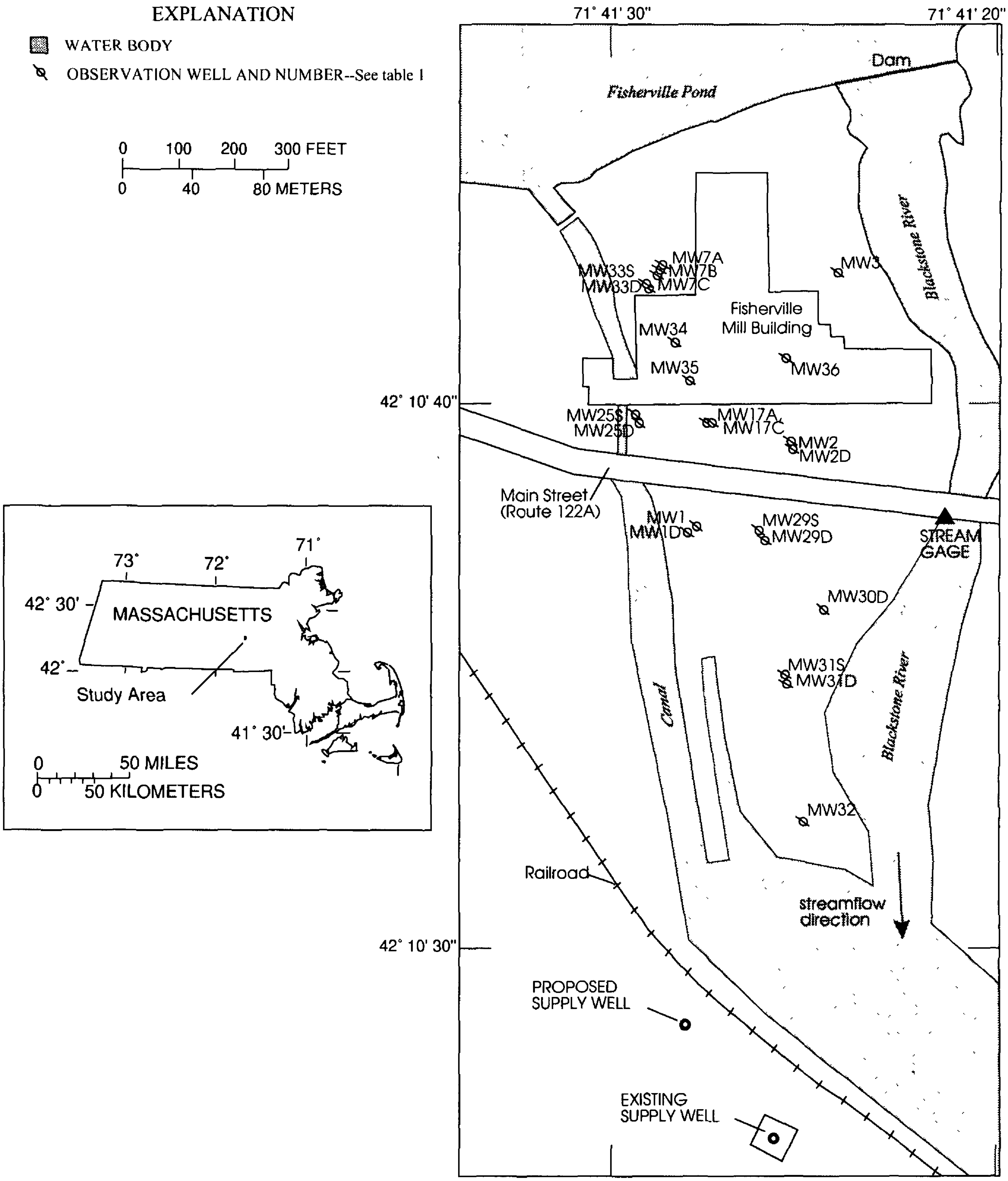

Figure 1. Locations of observation wells, proposed and existing public-supply wells, and stream gage at the contamination site, South Grafton, Massachusetts. (Modified from HMM Associates, Inc., 1994, fig. 2-2.)

was collected with a FEP Teflon bailer equipped with a point-source top and controlled-flow bottom valve. The bailer was lowered into the well using dedicated polypropylene line after all other samples were collected and rinsed once with well water before sampling. The bailer was cleaned between wells with sequential deionized-water, detergent (0.1 percent Liquinox), methanol, and deionized-water rinses. Samples were shipped on ice within 12 hours to the analyzing laboratory (Quanterra Environmental Services, Arvada, Colo). Quality-assurance and quality-control samples consisted of two equipment blanks, one bottle blank, four replicates, and two laboratory spikes (spiked samples for trace metals and VOCs only). Methods approved by the U.S. Environmental Protection Agency were used to analyze samples and chain of custody was maintained. Depths of wells and water levels also were measured at the time of sampling (table 1).

Ground-Water-Level and Stream-Stage Monitoring

Ground-water levels were measured in four existing 2-inch i.d. observation wells with downhole water-level sensors and recorders (Johnson and Rorabaugh, 1988). The observation wells—MW29D, MW31S, MW31D, and MW32—are in a north-south-trending line south of the Fisherville Mill Building between Route 122A and the canal (fig. 1). Wells MW29D, MW31S, and MW31D were located within the areal extent of the VOC plume, and well MW32 was located outside of the areal extent of the contaminated zone. Water levels were measured by pressure transducers at 15-minute intervals. Pressure-transducer measurements were converted to feet of water using the pre-set instrument calibration and electronic-tape measurements at the beginning, middle, and end of the measurement period. Stream stage was measured with a pressure transducer that was affixed to the downstream side of the bridge on Route 122A over the Blackstone River. Measurements were made at 15-minute intervals and were recorded with an electronic data logger. The pressure transducer was calibrated in the field to convert millivolt measurements to feet of water and checked with steel-tape measurements.

WATER-QUALITY CONDITIONS

Physical Properties, Major Inorganic Constituents, and Dissolved Organic Carbon

Ground water at the site contained low to moderately high concentrations of dissolved solids (44 to 406 mg/L, median 193 mg/L) and had a moderately high specific conductance (155 to 670 µS/cm, median 347 µS/cm) relative to ground water elsewhere in the Blackstone River Basin and was slightly acidic (pH=5.9 to 7.0, median 6.6; table 2). Calcium (median 26 mg/L), sodium (median 29 mg/L), chloride (47 mg/L), and sulfate (median 21 mg/L) were the major ions (table 2). Concentrations of major ions were not related to VOC concentrations. Dissolved-oxygen concentrations were low (0 to 2 mg/L) throughout most of the aquifer (table 2). Dissolved-oxygen concentrations were greater than 3 mg/L at three wells only—wells MW1, MW1D, and MW32, which were near the canal and river (fig. 1). Dissolved-oxygen concentrations in ground water directly beneath the Fisherville Mill Building in the center of the VOC plume were similar to dissolved-oxygen concentrations in ground water outside of the VOC plume (except for ground water from well MW35, which contained no dissolved oxygen). However, the colorimetric method used for dissolved-oxygen measurement was relatively insensitive to small differences in dissolved-oxygen concentrations.

The distribution of nitrogen species, nitrate (oxidized form) and ammonium (reduced form), suggested that zones of varying oxidation-reduction potential were present in the aquifer (table 2). Ammonium concentrations were high (5.6 to 12.6 mg/L as N) beneath and north of the Fisherville Mill Building (wells MW3, MW7C, MW33D, MW34, MW36). DOC concentrations also were relatively high (3.9 to 8.6 mg/L) in several wells (MW7B, MW33D, and MW36) in this area. The highest ammonium concentrations in ground water from the deep wells northeast of the main building (wells MW7C and MW33D) may be related to on-site sewage disposal. A septic system was located between these wells and the pond (BSC Engineering, 1986). Nitrate was not detected in ground water from these wells or in any wells north of Route 122A, but was detected in low concentrations (1.3 to 2.7 mg/L as N) in ground water south of Route 122A (wells MW1D, MW29D, MW30D, MW31D, and MW32). Nitrate in this area may originate from nitrification of ammonium from sewage disposal and(or) infiltration of water from the Blackstone River and the canal.

Trace Metals

Concentrations of selected trace metals, including arsenic, cadmium, chromium, and copper, generally were less than analytical detection limits (table 3). High concentrations of iron (0.35 to 37 mg/L) and manganese (3.7 to 7.1 mg/L) were detected beneath and north of the main building (wells MW3, MW7C, MW33S, MW33D, MW34, MW35, and MW36). The high dissolved iron and manganese concentrations indicate reducing conditions in these areas, because iron and manganese oxides and hydroxides are soluble under these conditions.

Volatile Organic Compounds

Concentrations of total VOCs in ground water ranged from less than 1 to more than 10,000 µg/L (fig. 2). Trichloroethylene (TCE) was the primary chlorinated contaminant, comprising as much as 98 percent of the total VOCs (table 4). At sites where two wells screened at different depths were sampled, total VOC concentrations were higher in the deep well than in the shallow well, except near the source area, as found in previous investigations (HMM Associates, Inc., 1994). The highest concentration, 43,000 µg/L at MW35, was higher than any previously measured concentration at the site (HMM Associates, Inc., 1994). However, the maximum extent and distribution of concentrations in the VOC plume in September 1994 were similar to that found in July 1993 and in earlier rounds of sampling (fig. 2; HMM Associates, Inc., 1994). In addition, temporal changes in total VOC concentrations in ground water from individual wells show no consistent pattern indicating transport. Concentrations near the source area (MW7A[2], fig. 3*A*) may be decreasing (fig. 3*A*). At well MW17C, south of the main building, total VOC and TCE concentrations greatly increased from April 1991 to January 1992 and decreased from July 1993 to September 1994 (fig. 3*B*). This pattern might suggest transport of the VOC plume past wells MW17A and MW17C; however, at the same time, concentrations at well MW35, between well MW17C and the source area, increased from about 35,000 to 43,000 µg/L (HMM Associates, Inc., 1994). At wells MW3 and MW29D near the northeastern and southern boundaries of the VOC plume, respectively, total VOC concentrations fluctuated erratically (figs. 3*C* and *D*).

In addition to TCE, 1,2-dichloroethene (1,2-DCE) and vinyl chloride were detected at several wells (table 4). 1,2-DCE and vinyl chloride are biodegradation products of TCE. Under anaerobic conditions, TCE (electron acceptor) can be reduced by dechlorination reactions to 1,2-DCE and subsequently to vinyl chloride in conjunction with oxidation of an organic-carbon electron donor (Kleopfer and others, 1985; Bouwer, 1992; Chapelle, 1993). High concentrations of 1,2-DCE and vinyl chloride near the source area in ground water from wells MW7B and MW33S (table 4) may be related to organic-carbon oxidation in the septic-system area. Concentrations of 1,2-DCE and vinyl chloride also were high in ground water from well MW2D. Temporal changes in concentrations of TCE, 1,2-DCE, and vinyl chloride are consistent with the hypothesis that TCE biodegradation was the source of these compounds. For example, decreases in TCE or 1,2-DCE concentrations were accompanied by increases in 1,2-DCE concentrations at well MW3 and increases in vinyl chloride concentrations at well MW7A (figs. 3*A* and 3*C*) in many instances.

Vinyl chloride, 1,2-DCE, and TCE also may be biodegraded in the presence of oxygen and methane (Semprini and others, 1990, 1991; Bouwer, 1992). However, under anaerobic conditions such as apparently occur at the study site, vinyl chloride can accumulate because the dechlorination reaction reducing vinyl chloride proceeds more slowly than reactions reducing TCE and 1,2-DCE (Wood and others, 1985; Bouwer, 1992).

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[2] Well MW7A was not sampled in September 1994 as part of the present study. Data shown are from HMM Associates, Inc. (1994) and represent the longest water-quality data set of all wells near the source area.

Table 2. Physical properties and concentrations of major inorganic constituents and dissolved organic carbon in ground water, South Grafton, Massachusetts, September 1994

[Specific conductance is in microsiemens per centimeter at 25 degrees Celsius. pH is in standard units. All other concentrations are given in milligrams per liter. Total alkalinity is reported as $CaCO_3$ at pH 4.5. Significant figures are as reported by the analyzing laboratory. nd, not detected; ~, about; --, not determined; ≤, actual value is less than or equal to value shown]

Well No.	Specific conductance	pH	Oxygen, dissolved	Calcium	Magnesium	Sodium	Potassium	Alkalinity, total	Sulfate
MW1	611	7.0	10-12	50.5	nd	87.8	nd	180	3.0
MW1D	218	6.6	6-10	21.4	nd	21.0	nd	42.5	15.7
MW2	186	6.3	<1.0	8.9	nd	19.6	nd	56.3	5.4
MW2D	670	6.1	≤1.0	12.6	nd	15.3	nd	33.7	21.6
MW3	480	6.6	<0.05	27.9	nd	36.3	nd	72	15.1
MW7B	249	6.3	0-1	12.3	nd	28.3	nd	43.1	21.2
MW7C	488	6.7	≤1.0	29.3	9.2	29.4	nd	89.0	39.9
MW17A	210	6.6	0-2	25.5	nd	14.3	nd	67.3	20.7
MW17C	418	6.7	0.8-1.0	52.2	11.7	34.1	5.2	114	67.6
MW25S	329	6.3	~1.0	24.8	nd	32.2	5.6	34.5	31.0
MW25D	329	7.0	~1.0	49.9	10.0	21.8	nd	124	31.2
MW29S	228	6.6	~1.0	20.5	nd	33.4	nd	130	3.6
MW29D	364	6.5	0-1	25.6	nd	27.5	5.4	45.0	20.2
MW30D	295	6.6	~2.0	23.3	nd	27.2	nd	46.0	17.8
MW30D duplicate	297	6.6	~2.0	23.2	nd	27.8	nd	46.0	17.8
MW31D	204	6.0	0.8-1.0	15.5	nd	27.9	nd	13.8	15.0
MW32	195	5.9	7-10	11.6	nd	28.5	nd	7.9	11.4
MW33S	155	6.5	0-1	64.4	12.6	42.4	8.2	127	133
MW33D	492	6.6	≤1.0	30.5	nd	30.4	7.7	139	43.5
MW34	449	6.5	1-3	40.3	6.0	32.4	7.5	79.2	55.6
MW35	445	6.9	0	64.2	9.9	30.0	nd	138	70.6
MW35 duplicate	450	6.9	0	64.5	10.1	31.5	nd	137	70.9
MW36	512	6.5	1-2	46.6	8.0	35.1	6.2	121	76.5
MW35 duplicate	513	6.5	1-2	45.9	8.0	34.9	6.5	122	76.6
Equip blank #1	1.4	8.0	nd	nd	nd	nd	nd	nd	nd
Equip bland #2	1.3	8.3	nd	nd	nd	nd	nd	nd	nd
Bottle blank	nd	5.3	nd	nd	nd	nd	nd	6.0	nd
Reporting limit	1.0	--	--	5.0	5.0	5.0	5.0	--	.50
EPA analysis method	120.1	9,040	--	6,010	6,010	6,010	6,010	310.1	300.0

Table 2. Physical properties and concentrations of major inorganic constituents and dissolved organic carbon in ground water, South Grafton, Massachusetts, September 1994—*Continued*

Well No.	Chloride	Fluoride	Bromide	Dissolved solids, total	Nitrogen, nitrate plus nitrite, dissolved (as N)	Nitrogen, ammonium, dissolved (as N)	Phosphorus, dissolved, ortho-phosphate (as P)	Carbon, organic, dissolved (as C)
MW1	116	nd	nd	406	nd	0.71	nd	2.3
MW1D	38.7	nd	nd	152	1.3	.12	nd	1.1
MW2	6.8	nd	0.51	44	nd	.40	nd	2.1
MW2D	10.6	nd	nd	67	nd	2.5	nd	3.0
MW3	49.9	nd	nd	246	nd	7	nd	3.2
MW7B	31.1	nd	nd	156	nd	1.9	nd	3.9
MW7C	69.9	nd	nd	249	.059	12.6	nd	--
MW17A	9.3	nd	nd	101	.23	nd	nd	1.4
MW17C	53.5	nd	nd	270	nd	.50	nd	2.0
MW25S	56.1	nd	nd	152	.40	1.4	nd	1.2
MW25D	40.4	nd	nd	210	nd	.30	nd	nd
MW29S	17.6	nd	nd	202	nd	1.3	nd	3.4
MW29D	44.7	nd	nd	183	1.8	.38	nd	nd
MW30D	42.0	nd	nd	161	1.9	.20	nd	1.1
MW30D duplicate	43.1	nd	nd	170	1.9	.20	nd	nd
MW31D	51.4	nd	nd	139	2.7	nd	nd	nd
MW32	52.6	nd	nd	128	2.4	.11	nd	nd
MW33S	48.8	nd	nd	367	nd	.16	nd	2.1
MW33D	69.3	nd	nd	257	nd	9.0	nd	8.6
MW34	59.1	nd	nd	252	nd	6.3	nd	nd
MW35	52.2	0.55	nd	302	nd	1.3	nd	2.8
MW35 duplicate	52.0	.54	nd	305	nd	1.3	nd	2.8
MW36	38.9	nd	nd	312	nd	5.6	nd	4.7
MW36 duplicate	38.6	nd	nd	300	nd	5.9	nd	4.8
Equip blank #1	nd	nd	nd	nd	nd	nd	nd	nd
Equip blank #2	nd	nd	nd	nd	nd	nd	nd	nd
Bottle blank	nd	nd	nd	nd	nd	nd	nd	nd
Reporting limit	.50	.50	.20	10	.050	.10	0.50	.10
EPA analysis method	300.0	300.0	300.0	160.3	353.2	350.1	300.0	9,060

Table 3. Concentrations of trace metals in ground water, South Grafton, Massachusetts, September 1994

[Concentrations in milligrams per liter. Significant figures are as reported by the analyzing laboratory. nd, not detected; --, not determined]

Well No.	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron
MW1	nd	nd	nd	0.22	nd	nd	nd	nd	nd	13.6
MW1D	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.2
MW2	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.2
MW2D	nd	nd	nd	nd	nd	nd	nd	nd	nd	.11
MW3	nd	nd	nd	nd	nd	nd	nd	nd	nd	37.0
MW7B	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.3
MW7C	nd	nd	nd	nd	nd	nd	nd	nd	nd	25.9
MW17A	nd	nd	nd	nd	nd	nd	nd	nd	nd	.06
MW17C	nd	nd	nd	nd	nd	nd	nd	nd	nd	.073
MW25S	nd	nd	nd	nd	nd	nd	nd	nd	nd	.057
MW25D	nd	nd	nd	nd	nd	nd	nd	nd	nd	.3
MW29S	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MW29D	nd	nd	nd	nd	nd	nd	nd	nd	nd	30.2
MW30D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MW30D duplicate	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MW31D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MW32	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MW33S	nd	nd	nd	nd	nd	nd	nd	nd	nd	.35
MW33D	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.4
MW34	nd	nd	nd	nd	nd	nd	nd	nd	nd	24.8
MW35	nd	nd	nd	.22	nd	nd	nd	nd	nd	3.6
MW35 duplicate	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.4
MW36	nd	nd	nd	nd	nd	nd	nd	nd	nd	9.5
MW36 duplicate	nd	nd	nd	nd	nd	nd	nd	nd	nd	9.5
Equip blank #1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Equip blank #2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Bottle blank	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Reporting limit	0.20	0.20	0.30	.10	0.0020	0.0050	0.030	0.040	0.20	.040
EPA analysis method	6,010	6,010	6,010	6,010	6,010	6,010	6,010	6,010	6,010	6,010

Table 3. Concentrations of trace metals in ground water, September 1994—*Continued*

Well No.	Lead	Manganese	Molybdenum	Nickel	Selenium	Sliver	Vanadium	Zinc
MW1	nd	0.77	nd	nd	nd	nd	nd	nd
MW1D	nd	.98	nd	nd	nd	nd	nd	nd
MW2	nd	1.0	nd	nd	nd	nd	nd	nd
MW2D	nd	.092	nd	nd	nd	nd	nd	0.11
MW3	nd	5.0	nd	nd	nd	nd	nd	nd
MW7B	nd	.2	nd	nd	nd	nd	nd	.022
MW7C	nd	3.7	nd	nd	nd	nd	nd	nd
MW17A	nd	.038	nd	nd	nd	nd	nd	.032
MW17C	nd	1.8	nd	nd	nd	nd	nd	nd
MW25S	nd	1.9	nd	nd	nd	nd	nd	nd
MW25D	nd	.57	nd	nd	nd	nd	nd	nd
MW29S	nd	1.6	nd	nd	nd	nd	nd	nd
MW29D	nd	.51	nd	nd	nd	nd	nd	nd
MW30D	nd	.27	nd	nd	nd	nd	nd	nd
MW30D duplicate	nd	.27	nd	nd	nd	nd	nd	nd
MW31D	nd	nd	nd	nd	nd	nd	nd	nd
MW32	nd	.042	nd	nd	nd	nd	nd	nd
MW33S	nd	7.1	nd	nd	nd	nd	nd	nd
MW33D	nd	4.4	nd	nd	nd	nd	nd	nd
MW34	nd	4.3	nd	nd	nd	nd	nd	nd
MW35	nd	9.9	nd	nd	nd	nd	nd	nd
MW35 duplicate	nd	4.0	nd	nd	nd	nd	nd	nd
MW36	nd	4.1	nd	nd	nd	nd	nd	nd
MW36 duplicate	nd	4.0	nd	nd	nd	nd	nd	nd
Equip blank #1	nd	nd	nd	nd	nd	nd	nd	nd
Equip blank #2	nd	nd	nd	nd	nd	nd	nd	nd
Bottle blank	nd	nd	nd	nd	nd	nd	nd	nd
Reporting limit	0.20	.010	0.040	0.040	0.40	0.030	0.040	.010
EPA analysis method	6,010	6,010	6,010	6,010	6,010	6,010	6,010	6,010

Table 4. Concentrations of volatile organic compounds in ground water, South Grafton, Massachusetts, September 1994

[Concentrations in micrograms per liter. Reporting limit for volatile organic compounds is 1.0 micrograms per liter for undiluted samples. EPA analysis method was a modified 624 method. Significant figures are as reported by the analyzing laboratory. nd, not detected; --, not determined]

Well No.	Acetone	Chloro-methane	1,1-dichloro-ethane	1,2-dichloro-ethene (total)	1,1-dichloro-ethene	Methylene chloride	Tetra-chloro-ethene	1,1,1-Trichloro-ethane	Trichloro-ethylene	Vinyl chloride	Total VOCs
MW1	nd	nd	nd	[1]0.30	nd	nd	nd	nd	nd	nd	0.3
MW1D	nd	nd	nd	[1]0.46	nd	nd	[1]0.41	42	nd	nd	42.9
MW2	nd	nd	nd	8.1	nd	nd	[1]0.22	nd	4.7	[1]0.47	13.5
MW2D	nd	nd	nd	2,800	nd	nd	nd	nd	1,000	[1]47	3,850
MW3	nd	nd	[1]0.40	20	[1]0.49	nd	nd	4.7	[1]0.44	14	40.0
MW7B 9/19	nd	nd	nd	840	nd	[1]6.4	nd	nd	37	410	1,290
MW7B 9/29	nd	nd	nd	730	nd	[1]13	nd	nd	15	[1]390	1,140
MW7C	nd	[1]0.53	[1].38	37	nd	[1]0.37	nd	nd	11	2.3	51.4
MW17C	nd	nd	nd	600	nd	[1]77	nd	nd	5,600	nd	6,280
MW25S	nd	nd	nd	150	nd	nd	[1]2.6	nd	220	[1]1.9	375
MW25D	nd	nd	nd	[1]140	nd	nd	[1]110	nd	16,000	nd	16,250
MW29S	nd	nd	nd	[1]0.45	nd	nd	nd	nd	1.7	nd	2.15
MW29D	nd	nd	nd	2.9	nd	nd	[1]0.82	[1].34	48	nd	52.1
MW30D	14	nd	nd	[1]0.44	nd	nd	[1]0.47	nd	8.8	nd	9.7
MW30D duplicate	[1]8.4	nd	nd	[1]0.49	nd	nd	[1]0.47	nd	9.0	nd	10.0
MW31D	nd	nd	nd	nd	nd	nd	nd	[1].44	[1]0.72	nd	1.16
MW32	nd	nd	nd	nd	nd	nd	nd	[1].44	nd	nd	0.44
MW33S	nd	nd	[1]46	1,600	160	nd	nd	[1]22	4,700	nd	6,530
MW33D	nd	nd	[1].31	3.4	nd	nd	nd	nd	[1]0.26	[1].32	4.29
MW34	nd	nd	nd	220	nd	nd	nd	nd	23	12	255
MW35	nd	nd	nd	[1]840	nd	nd	[1]500	nd	41,000	nd	42,340
MW35 duplicate	nd	nd	nd	[1]760	nd	nd	[1]520	nd	43,000	nd	44,280
MW36	nd	nd	nd	70	[1]12	nd	nd	[1]15	540	[1]16	653
MW36 duplicate	nd	nd	nd	68	[1]10	nd	nd	[1]14	550	[1]16	658
Equip blank #1	nd	nd	nd	nd	nd	[1]0.58	nd	nd	nd	nd	
Equip blank #2	nd	nd	nd	nd	nd	1.0	nd	nd	nd	nd	
Bottle blank	[1]1.3	nd	nd	nd	nd	[1]0.79	nd	nd	nd	nd	

[1] Concentration is less than the analytical reporting limit.

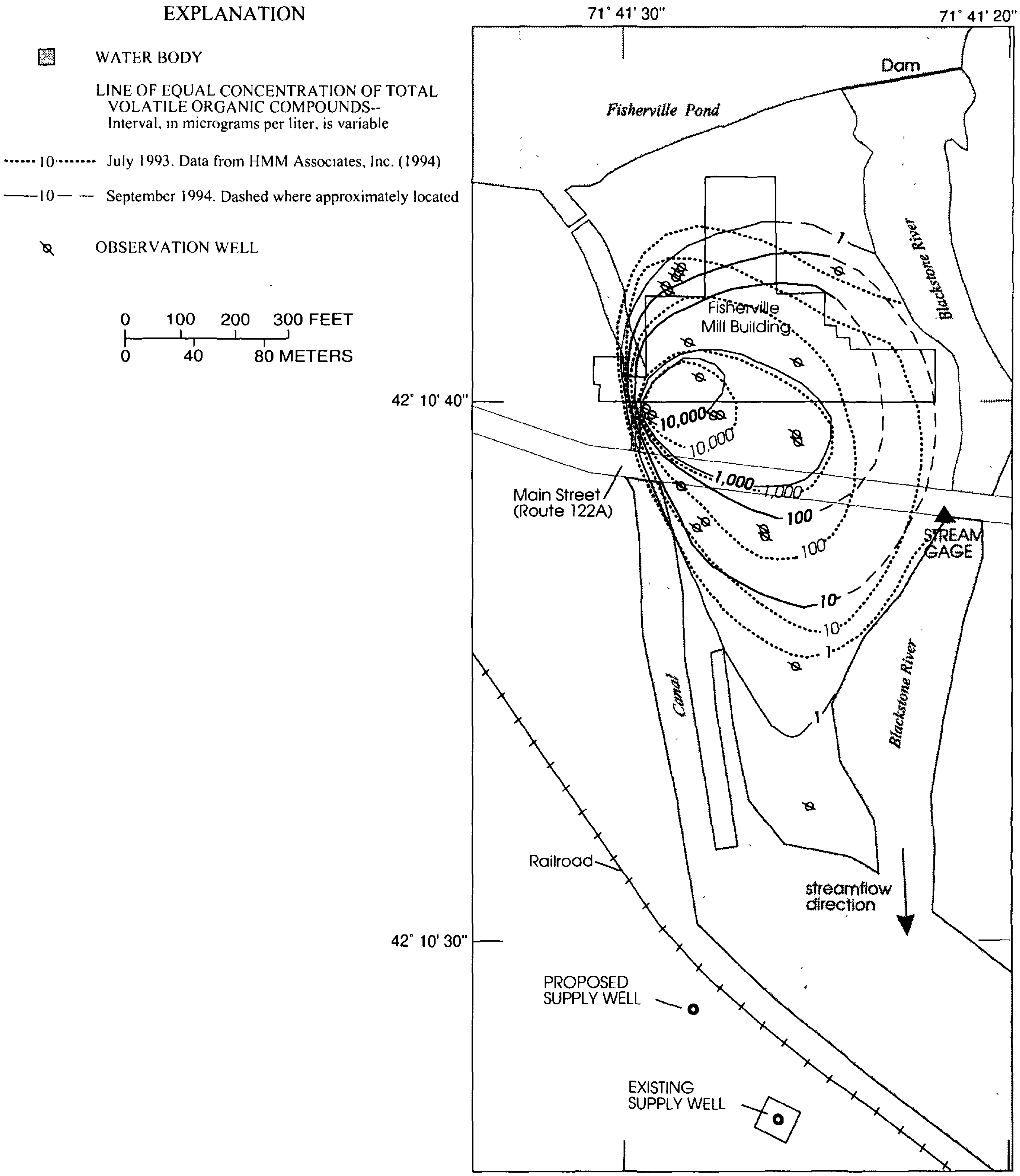

Figure 2. Areal distribution of total volatile organic compounds in ground water at the contamination site, South Grafton, Massachusetts, July 1993 and September 1994. (Modified from HMM Associates, Inc., 1994, fig. 6-1.)

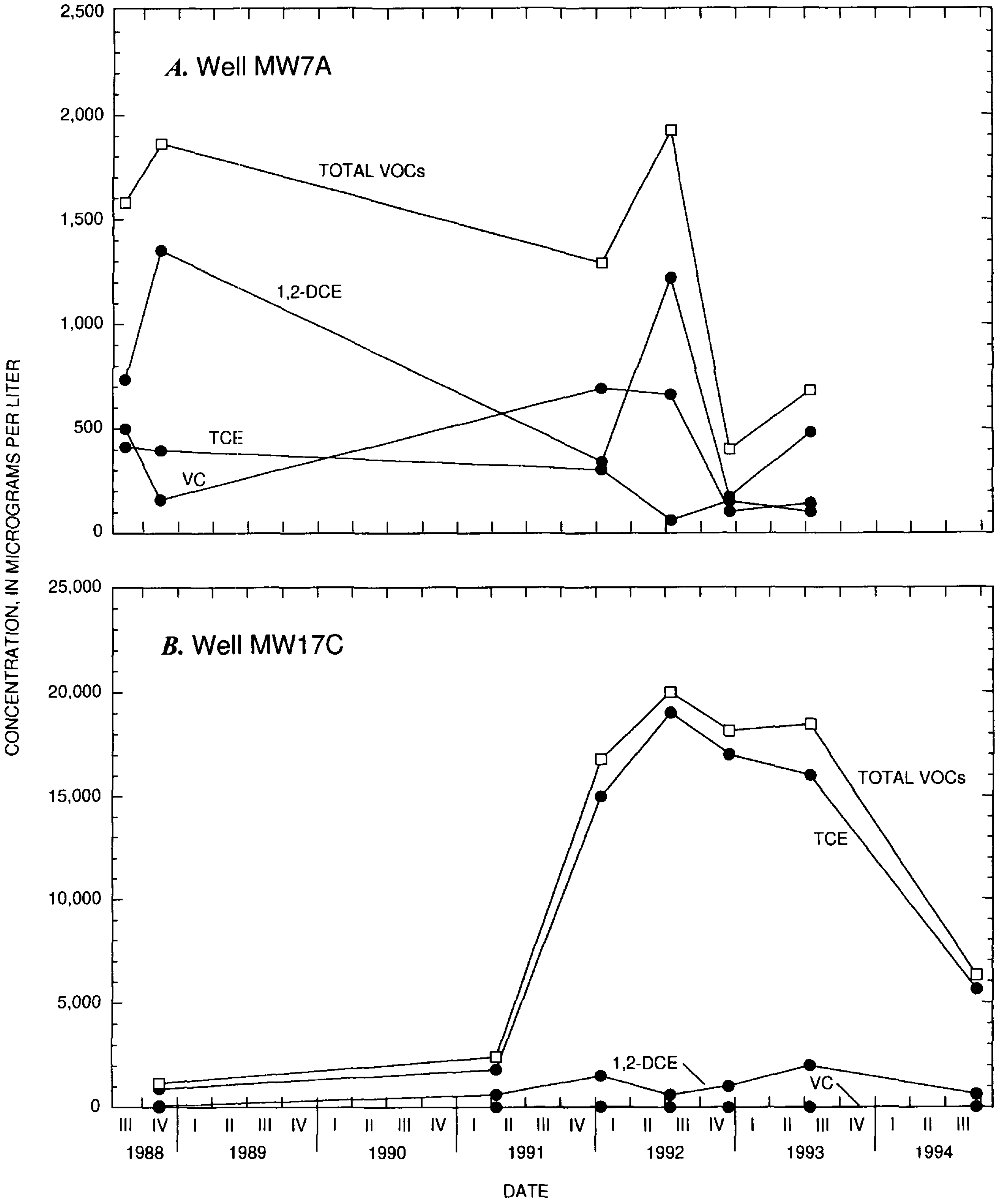

Figure 3. Concentrations of trichloroethylene (TCE), 1,2-dichloroethene (1,2-DCE), vinyl chloride (VC), and total volatile organic compounds (VOCs) in ground water from four observation wells with time, South Grafton, Massachusetts. Data prior to September 1994 and all data from well MW7A are from HMM Associates, Inc. (1994).

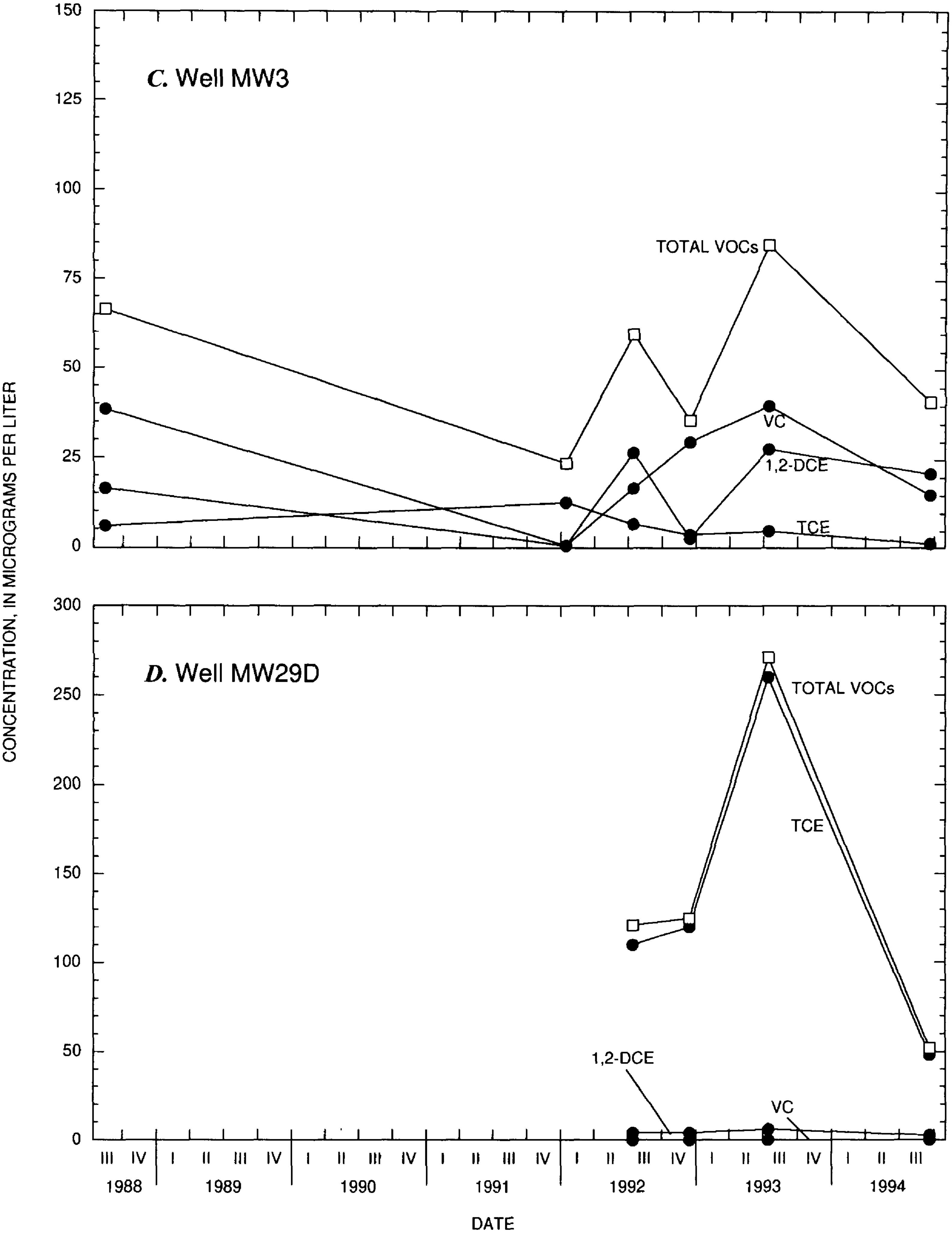

Figure 3. Concentrations of trichloroethylene (TCE), 1,2-dichloroethene (1,2-DCE), vinyl chloride (VC), and total volatile organic compounds (VOCs) in ground water from four observation wells with time, South Grafton, Massachusetts. —*Continued.*

HYDROLOGIC CONDITIONS

Stream stage in the Blackstone River at the site fluctuated by about 1 to 2 ft within 24-hour periods (fig. 4). These rapid fluctuations resulted from sudden release of impounded water at the hydroelectric-generating facility downstream from the site. Releases occurred almost daily during midweek. In addition to the daily fluctuations, rapid small changes in stream stage also occurred that were related to storms. Precipitation, which was below normal during September and October 1994, was minimal during the period of record, except for a storm on September 23, 1994 (fig. 4). This storm, in which 2.45 in. of precipitation was recorded at a nearby station in Worcester, Mass. (Northeast Regional Climate Center, Cornell University, written commun., November 1994) resulted in a stream-stage increase of about 1.2 ft.

Ground-water levels in wells MW29, MW31S, MW31D, and MW32 appeared to be strongly affected by stream stage (fig. 5). Fluctuations in ground-water levels measured in these wells were similar in amplitude and timing to the rapid fluctuations in stream stage. Daily fluctuations were greatest in well MW32 within 100 ft of the river, and least in well MW29D about 300 ft from the river. Ground-water levels also rose about 1 ft after the heavy precipitation on September 23, 1994 and did not appear to immediately return to prestorm levels. The sustained rise in ground-water levels may have been related to an increase in stage in Fisherville Pond, where water was ponded after the storm. Ground-water pumping rate at the existing public-supply well near the site from September 3 through October 29, 1994, is shown in figure 6 (Steven Lemoyne, South Grafton Water District, written commun., November 1994). Pumping was nearly continuous through September 26, 1994 and cycled on and off at about 0.5- to 1-day intervals through the rest of the study period.

Because ground-water levels in the aquifer appear to be affected by fluctuations in stage of the Blackstone River, transport of the VOC contamination plume also is likely to be affected by these fluctuations in stage. An improved understanding of how fluctuations in stream stage affect stream/aquifer interaction and plume transport would assist in the development of optimal remediation strategies at the site. Potential changes in operating procedures of the hydroelectric facility downgradient from the site could substantially alter ground-water and surface-water interaction. An improved understanding of ground-water and surface-water interaction could be attained by continued monitoring of fluctuations in stream stage and ground-water levels as well as stage in Fisherville Pond for a time period that would include prolonged periods of ground-water recharge.

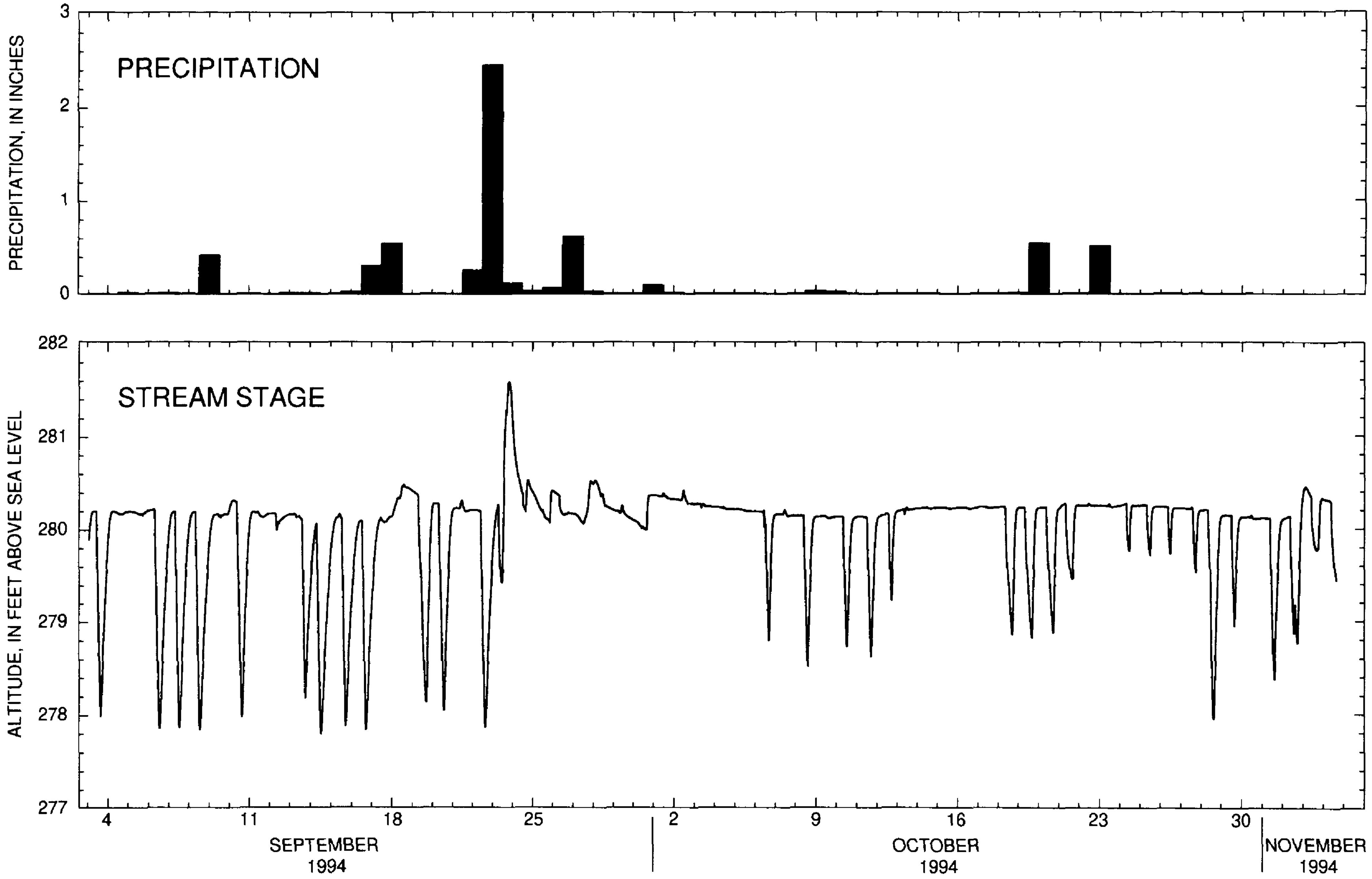

Figure 4. Precipitation at Worcester, Massachusetts, and stream stage in the Blackstone River at the contamination site in South Grafton, Massachusetts, September and October 1994. (Precipitation data from Northeast Regional Climate Center, Cornell University, written commun., November 1994.)

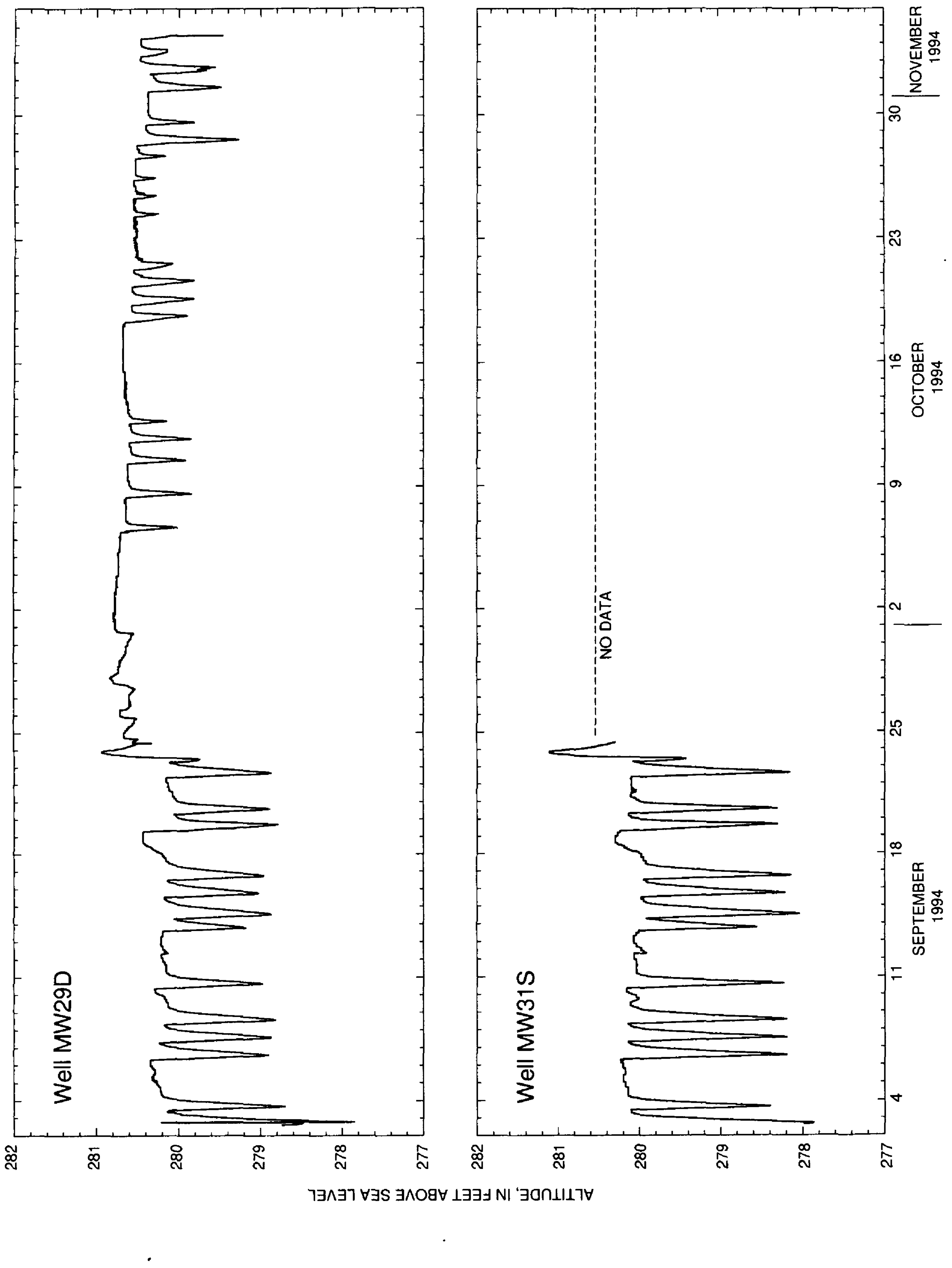

Figure 5. Ground-water levels in four observation wells, South Grafton, Massachusetts, September and October 1994.

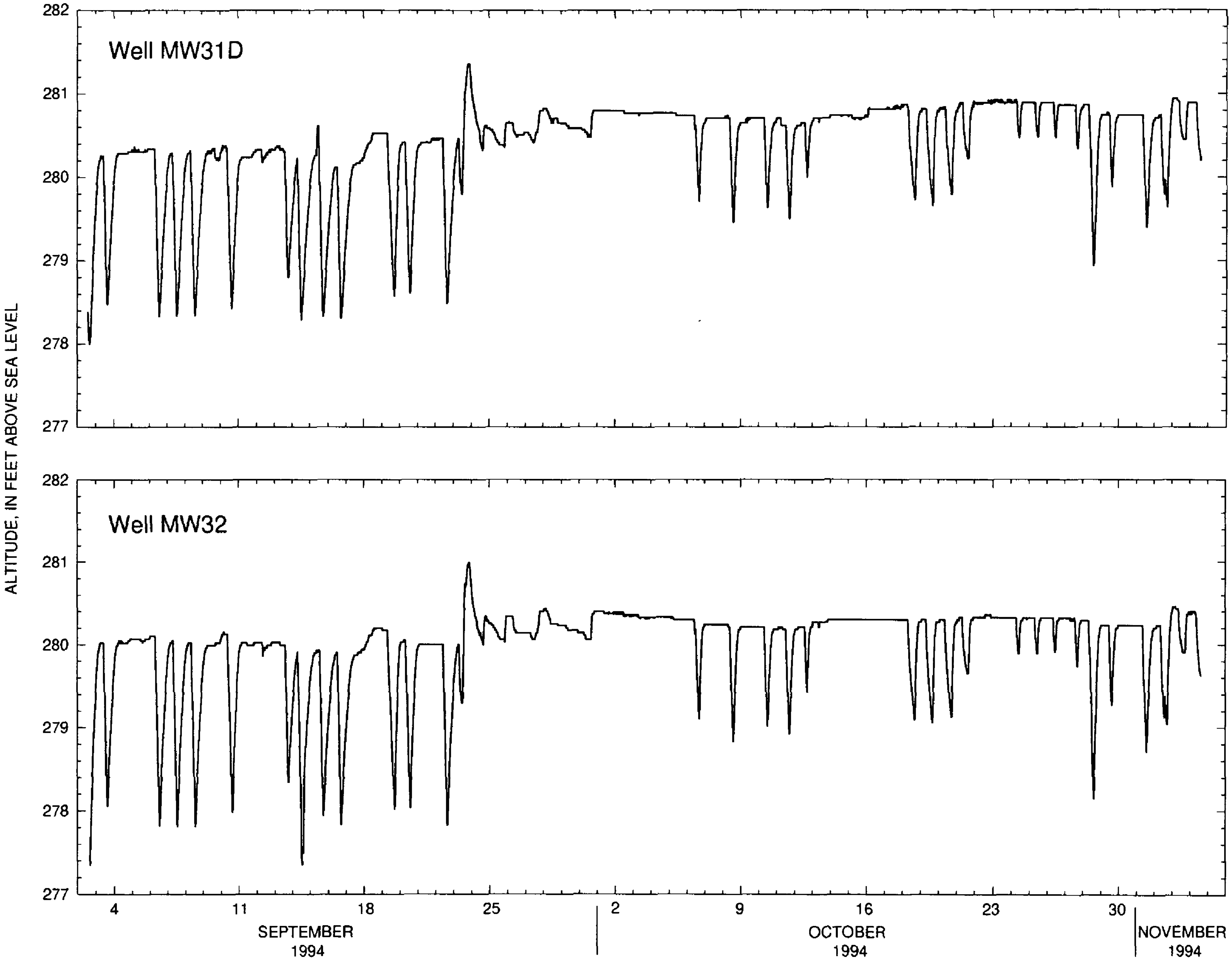

Figure 5. Ground-water levels in four observation wells, South Grafton, Massachusetts, September and October 1994—*Continued.*

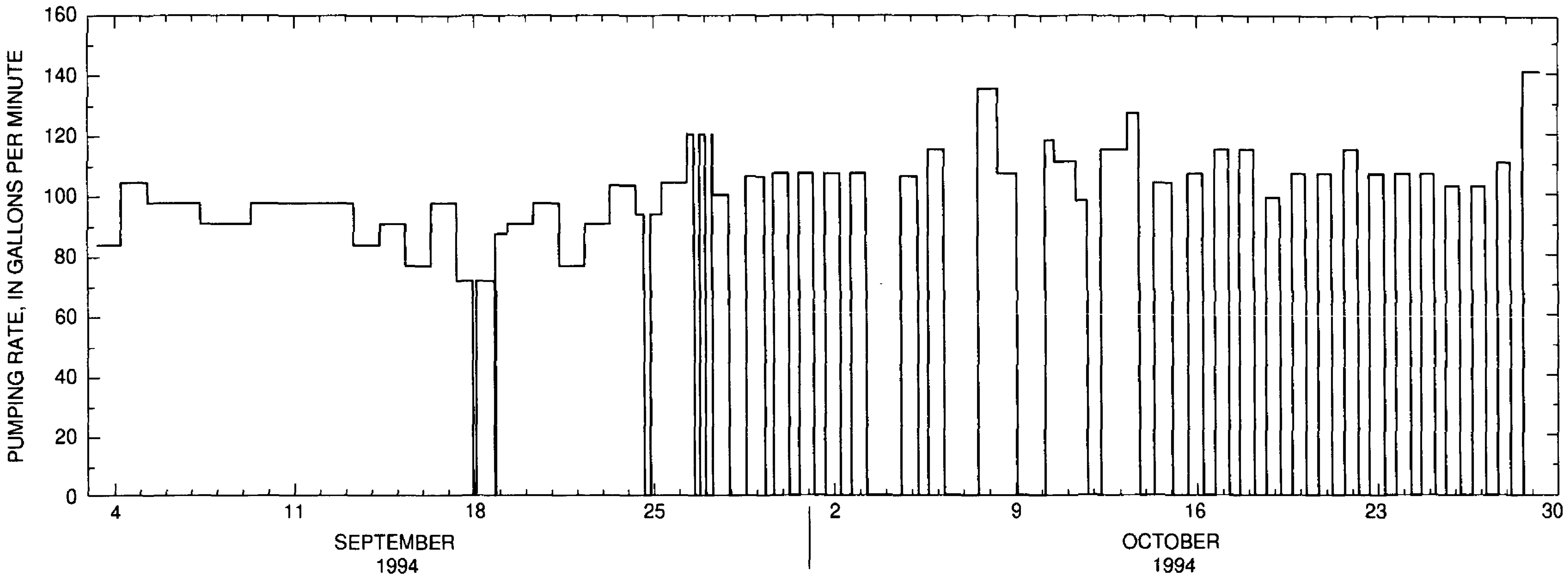

Figure 6. Pumping rate at the existing public-supply well near the contamination site, South Grafton, Massachusetts, September and October 1994. (Data from Steven Lemoyne, South Grafton Water District, written commun., November 1994.)

SUMMARY

The USGS collected ground-water-quality and other hydrologic data during September and October 1994 in South Grafton, Massachusetts, at a site where ground water has been contaminated by VOCs. The VOC plume is at the site of an abandoned textile mill adjacent to the Blackstone River.

Concentrations of total VOCs in ground water ranged from less than 1 to more than 40,000 μg/L. TCE was the primary chlorinated contaminant, comprising as much as 98 percent of the total VOCs. The highest concentration, 43,000 μg/L, was higher than any previously measured concentration at the site; however, the maximum extent and distribution of concentrations in the VOC plume in September 1994 was similar to that detected in July 1993 and in earlier rounds of sampling. In addition to TCE, 1,2-DCE and vinyl chloride were detected at most sampling locations. Temporal changes in concentrations of TCE, 1,2-DCE, and vinyl chloride are consistent with the hypothesis that TCE biodegradation was the source of these compounds.

Ground water at the site contained low to moderately high concentrations of dissolved solids, had a moderately high specific conductance, and was slightly acidic. Calcium, sodium, chloride, and sulfate were the major ions and were not related to VOC concentrations. Dissolved-oxygen concentrations were low (0 to 2 mg/L) throughout most of the aquifer, although concentrations were greater than 3 mg/L at three wells that were near the canal and river. The distribution of nitrogen species, iron, and manganese also indicate that zones of varying oxidation-reduction potential were present in the aquifer. Reducing conditions were indicated beneath and north of the main building. High ammonium concentrations in ground water from deep wells northeast of the main plant building may be related to on-site sewage disposal. Concentrations of selected trace metals other than iron and manganese, including arsenic, cadmium, chromium, and copper, generally were less than analytical detection limits.

Stream stage in the Blackstone River at the site fluctuated by about 1 to 2 ft within 24-hour periods. These rapid fluctuations resulted from sudden release of impounded water at the hydroelectric-generating facility downstream from the site. In addition to the daily fluctuations, rapid small changes in stream stage also occurred that were related to storms.

Fluctuations in ground-water levels in four observation wells at the site appeared to be strongly affected by fluctuations in stream stage. Fluctuations in ground-water levels measured in these wells were similar in amplitude and timing to the rapid fluctuations in stream stage. Daily fluctuations were greatest in an observation well within 100 ft of the river and least in an observation well about 300 ft from the river. Because ground-water levels at the study site appear to be affected by fluctuations in stage of the Blackstone River, transport of the VOC plume also is likely to be affected by these fluctuations in stage. An improved understanding of how fluctuations in stream stage affect stream/aquifer interaction and plume transport would assist in the development of optimal remediation strategies at the site.

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