Effects of a Remedial System and its Operation on Volatile Organic Compound-Contaminated Ground Water, Operable Unit 1, Savage Municipal Well Superfund Site, Milford, New Hampshire, 1998–2004

Scientific Investigations Report 2006–5083

**U.S. Department of the Interior
U.S. Geological Survey**

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By Philip T. Harte

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
Pressure		
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
Specific capacity		
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per foot (ft/ft)	0.3048	meter per meter (m/m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), approximately equivalent to parts per million (ppm), or micrograms per liter (µg/L), approximately equivalent to parts per billion (ppb).

ABBREVIATIONS AND EXPLANATIONS OF TERMS USED IN THIS REPORT:

cis-1,2-DCE	cis-1,2-dichloroethene
DCE	dichloroethene
DNAPL	Dense Non-Aqueous Phase Liquid
MSGD	Milford-Souhegan Glacial-Drift aquifer
OU1	Operable Unit 1 of the Savage Municipal Well Superfund site
OU2	Operable Unit 2 of the Savage Municipal Well Superfund site
PCE	tetrachloroethylene
TCE	trichloroethylene
TOC	total organic carbon
VOC	volatile organic compound

UNITS OF MEASUREMENT

g	grams
min	minute
yr	year

WELL IDENTIFICATION, ABBREVIATIONS, AND EXPLANATION

Well names used in this report, including appendix 1, are typically designated based on previous studies. In some cases, well names are designated after the owner's name.

<u>Prefix for remedial wells</u>

EW	exterior barrier wall extraction well
IW	interior barrier wall extraction well
RW	recharge wells
SP	air sparge well (used for remedial technology that reduces concentrations of volatile contaminants adsorbed to soils and dissolved in ground water in the saturated zone; involves the injection of air into the saturated zone)
SVE	soil vapor extraction well (used for remedial technology that reduces concentrations of volatile contaminants adsorbed to soils in the unsaturated zone; involves the extraction of air from the unsaturated zone)

<u>Miscellaneous</u>

VP	vertical profile
INEEL	well located in INEEL well field (Idaho National Engineering and Environmental Laboratory)

<u>Prefix for observation wells</u>

P	piezometer
PW, B, MI, and MW	observation wells

<u>Suffix for observation wells</u>

D or C	deep cluster well; typically set at depths greater than 70.1 feet below land surface
M or B	medium cluster well; typically set at depths between 40.1 and 70.1 feet below land surface
R	bedrock well
S or A	shallow cluster well; typically set at depths less than 40.1 feet below land surface

<u>Lithology abbreviations</u>

c	coarse
f	fine
m	medium
Wx	weathered

Acknowledgments

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By Philip T. Harte

Abstract

The Savage Municipal Well Superfund site in the Town of Milford, N.H., is underlain by a 0.5-square mile plume of volatile organic compounds (VOCs), mostly tetrachloroethylene (PCE). The plume occurs mostly within a highly transmissive sand and gravel layer, but also extends into underlying till and bedrock. The plume has been divided into two areas called Operable Unit 1 (OU1), which contains the primary source area, and Operable Unit 2 (OU2), which is defined as the extended plume area.

PCE concentrations in excess of 100,000 parts per billion (ppb) had been detected in the OU1 area in 1995, indicating a likely Dense Non-Aqueous Phase Liquid (DNAPL) source. In the fall of 1998, the New Hampshire Department of Environmental Services (NHDES) and the U.S. Environmental Protection Agency (USEPA) installed a remedial system in OU1 to contain and capture the dissolved VOC plume. The OU1 remedial system includes a low-permeability barrier wall that encircles the highest detected concentrations of PCE, and a series of injection and extraction wells to contain and remove contaminants. The barrier wall likely penetrates the full thickness of the sand and gravel; in most places, it also penetrates the full thickness of the underlying basal till and sits atop bedrock. Remedial injection and extraction wells have been operating since the spring of 1999 and include a series of interior (inside the barrier wall) injection and extractions wells and exterior (outside the barrier wall) injection and extraction wells. A recharge gallery outside the barrier wall receives the bulk of the treated water and reinjects it into the shallow aquifer.

From 1998 to 2004, PCE concentrations decreased by an average of 80 percent at most wells outside the barrier wall. This decrease indicates (1) the barrier wall and interior extraction effectively contained high PCE concentrations inside the wall, (2) other sources of PCE did not appear to be outside of the wall, and (3) ambient ground-water flow in conjunction with the exterior remedial wells effectively remediated most of the dissolved PCE plume outside the wall.

The overburden at middle depths (40 to 70 ft below land surface) downgradient from exterior extraction wells showed relatively slow decreases in PCE concentrations compared to other areas outside the barrier wall. Numerical simulation shows extraction caused the formation of a small downgradient slow-velocity zone. Because the ambient ground-water velocities are high (approximately 1 foot per day), temporary termination of extraction at the exterior wells may increase dilution downgradient from the exterior extraction wells. Extraction can also be optimized on the basis of seasonal hydrologic conditions to facilitate exterior well capture from upgradient areas outside of the barrier wall where PCE concentrations are highest.

Reductions in concentrations of PCE inside the barrier wall from 1998 to 2003 were minimal near suspected source areas, indicating that the operation of interior remedial wells had not been effective in remediating dissolved PCE or the DNAPL source. Capture of the dissolved PCE plume within the barrier wall by interior extraction wells could be enhanced if operation (injection rates) increased at underutilized interior injection wells, thereby increasing hydraulic gradients.

Introduction

The Savage Municipal Well Superfund site (Savage site), named after a former municipal water-supply well (the Savage well) for the Town of Milford, N.H., is underlain by a 0.5-mi^2 plume of volatile organic compounds (VOCs), consisting primarily of tetrachloroethylene (PCE) (fig. 1). The VOC plume occurs mostly within a highly transmissive sand and gravel layer but also extends to underlying till and bedrock. The sand and gravel layer, part of the Milford-Souhegan-Glacial-Drift aquifer (MSGD), is an important source of water for a New Hampshire State Fish Hatchery, which uses more than 2 Mgal/d. Before contamination with VOCs, the aquifer also supplied more than 1 Mgal/d to two municipal water-supply wells (the Savage well and a well outside of the study area).
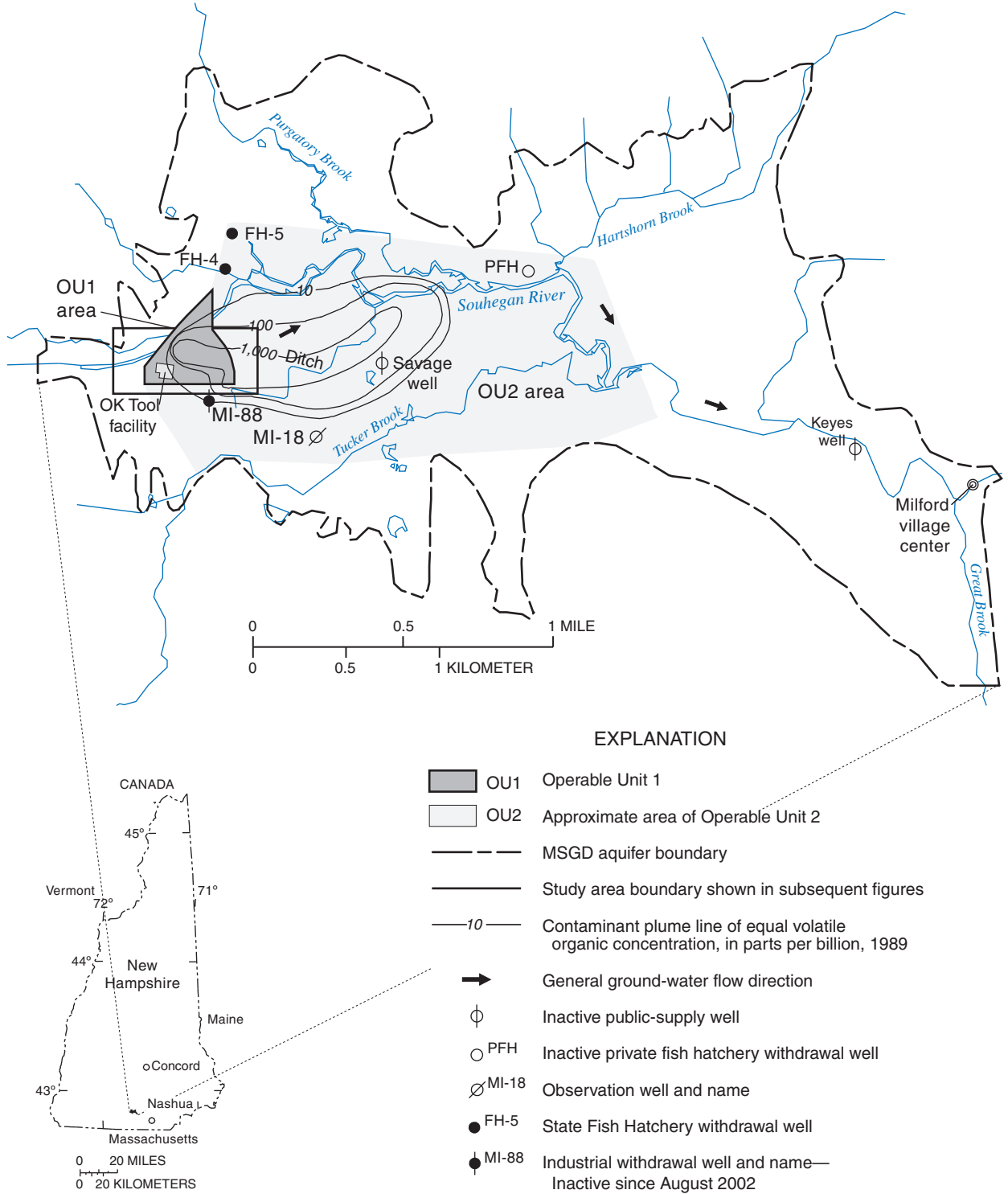
Figure 1.   Location of the Milford-Souhegan Glacial-Drift (MSGD) aquifer, Savage well, and Operable Units 1 (OU1) and 2 (OU2) of the Savage Municipal Well Superfund site, Milford, N.H.

A discontinued tool manufacturing facility, the OK Tool facility, in Operable Unit 1 (OU1), has been identified as the primary source (HMM Associates, Inc., 1989 and 1991) of PCE that led to the contamination of the Savage well. The contaminant plume downgradient from OU1 is designated Operable Unit (OU2), also called the extended plume area.

The State of New Hampshire Department of Environmental Services (NHDES) and the U.S. Environmental Protection Agency (USEPA) Region 1 have constructed a remedial system for the OU1 area (fig. 2). The remedial system consists of a low-permeability barrier wall, which surrounds the highest concentrations of dissolved PCE and most likely some Dense Non-Aqueous Phase Liquid (DNAPL), and includes various injection and extraction wells (vapor and water) to capture and treat the dissolved contaminant plume. The barrier wall was constructed from July to November 1998. Remedial operations of wells were tested from December 1998 to March 1999, and full operation started in May 1999.

The U.S. Geological Survey (USGS), in cooperation with the NHDES and the USEPA, Region 1, is studying the solute transport of VOCs (primarily PCE) in contaminated ground waters of the unconsolidated sediments (overburden) of the Savage site. Specific objectives of the cooperative study include the following:

1. Evaluate effectiveness of remedial operations in the OU1 area,

2. Help improve long-term (more than 1 year) forecasting of PCE decreases in the overburden on the basis of current (1999–2004) remedial operations,

3. Identify important processes that affect contaminant transport, and

4. Improve upon long-term (more than 1 year) monitoring strategies by helping to design a cost-effective monitoring network.

Previous studies by the USGS of the study site include construction and calibration of two ground-water-flow models (Harte and others, 1999; Harte and Mack, 1992), evaluation of effects of ground-water withdrawals on advective transport of contaminated ground waters (Harte and Willey, 1997), analysis of PCE trends for pre- and post-barrier conditions (Harte and others, 2001), and description of results of a monitoring program of continuous water levels from water years 1997–2003 (Brayton and Harte, 2001; Harte, 2005). Furthermore, solute transport of PCE was investigated and a transport model calibrated for the OU1 and OU2 areas (Harte, 2004).

Purpose and Scope

This report describes the remedial system of OU1 and includes an evaluation of the effectiveness of the remedial system from 1998 to 2004 in terms of efficient capture of VOCs and reduction of their concentrations. Included in the evaluation is an integration of hydrologic, geophysical, and chemical data. Simulations of ground-water flow and transport of PCE were performed to assist in the evaluation process. Possible options to enhance remedial effectiveness are also discussed.

Description of Study Area

The MSGD aquifer is defined as the entire sequence of unconsolidated sediments (overburden) overlying the bedrock in the Souhegan River Valley of Milford, N.H. This section of the report includes a description of the MSGD aquifer area, which includes the river valley shown in figure 1, and of the OU1 area that is in the western part of the MSGD aquifer.

The river valley slopes gently to the east at approximately 12 ft/mi along the Souhegan River. Land-surface elevations range from 230 to 280 ft in the valley and water drains to the Souhegan River and its tributaries (fig. 1), including Tucker, Purgatory, Great, and Hartshorn Brooks, and a number of small, unnamed streams. A discharge ditch drains processed waters from a manufacturing company in the southwestern part of the study area. Discharge to the ditch was reduced in August 2002.

Land use in the MSGD aquifer area is predominantly industrial in the southwestern part, agricultural in the central and northwestern parts, and residential and commercial elsewhere. The contaminant plume (fig. 2) underlies a large agricultural area in the center of the plume (not shown on any figures) and abuts a commercial-industrial area to the south.

Ground-water withdrawals in 2001 were primarily used for commercial and industrial purposes. Withdrawal wells include two wells for the State Fish Hatchery in the northwestern part of the study area (wells FH-4 and FH-5, fig. 1) that withdraw more than 2 Mgal/d. Consumptive use is small because most of the withdrawn water is returned to Purgatory Brook (fig. 1). A discontinued withdrawal well at a private fish hatchery (PFH, fig. 1) in the eastern part of the study area withdrew 0.14 Mgal/d until the late 1990s. A discontinued (as of August 2002) withdrawal well (MI-88, fig. 1) at an industrial complex in the southwestern part of the study area withdrew about 0.25 Mgal/d as reported in 1995. The effluent from this well was formerly discharged to the aforementioned drainage ditch.

The former OK Tool facility in OU1 had been identified as the primary source of VOCs to the Savage well (HMM Associates, Inc., 1989, 1991) and is in the western part of the MSGD aquifer (figs. 1 and 2). Solvents were discharged into the subsurface at this facility for many years until the early 1980s. Although discharges have ceased, the underlying contaminant-soaked sediments and immiscible solvents (most likely DNAPLs) continued to contaminate ground water flowing easterly underneath the site until a barrier wall was constructed in 1998.

The barrier wall (referred to as "barrier" in this report) is constructed of low-permeability materials (bentonite clay) and is designed to contain the highest concentrations of contaminants. The barrier encircles a 0.008-mi^2 area and generally
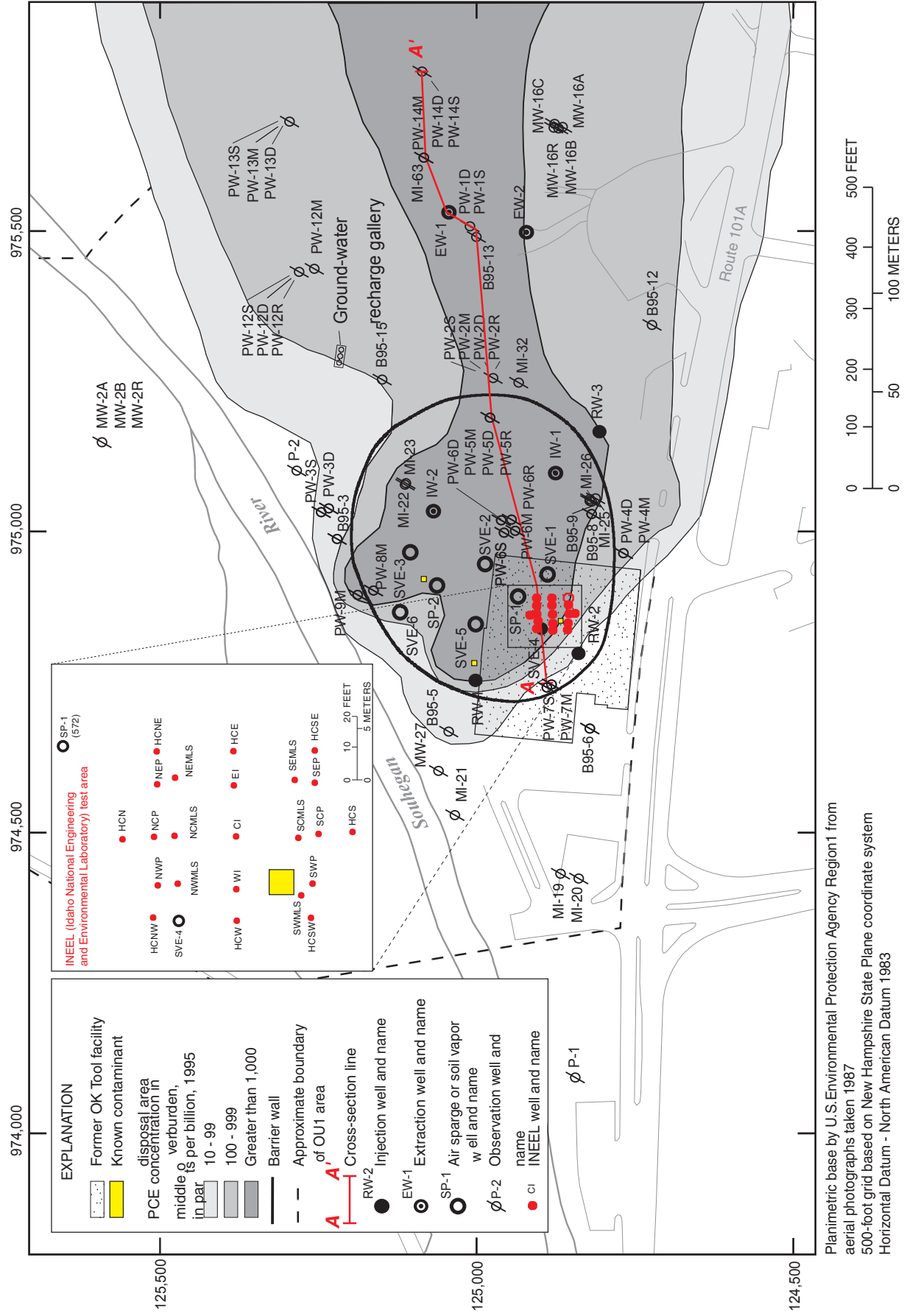
Figure 2. Operable Unit 1 (OU1) remedial system, PCE concentration in ground water (1995), and wells, Savage Municipal Well Superfund site, Milford, N.H.

Planimetric base by U.S.Environmental Protection Agency Region1 from
aerial photographs taken 1987
500-foot grid based on New Hampshire State Plane coordinate system
Horizontal Datum - North American Datum 1983

fully penetrates the overburden (sand and gravel layers and underlying till); it sits atop the bedrock in most cases. The barrier was designed to at least penetrate 3 ft into the basal till but in many locations this minimum depth was exceeded. In the eastern part of the barrier, till thickness is less than 3 ft and the barrier sits atop bedrock. Various injection and extraction wells (fig. 2, appendix 1) were installed within and outside the barrier to insure hydraulic isolation, reduce contaminant mass inside the barrier wall, and to capture and treat contaminants outside the barrier.

Maximum concentrations of PCE, the primary contaminant, ranged from 100,000 ppb inside the wall to 10,000 ppb outside the wall in 1995 (Camp, Dresser, and McKee, Inc., Federal Programs Corporation, 1995). Secondary VOCs (TCE and *cis*-1,2-DCE) concentrations were typically one to two orders of magnitude less than those of PCE (Harte and others, 2001).

Overview of the Remedial System and its Operation

The remedial extraction wells in OU1 help capture VOC-contaminated (primarily PCE) ground water, which is then piped to an onsite treatment plant for decontamination and injection back into the aquifer. Extraction wells include soil vapor extraction (SVE) wells and water wells. SVE wells are inside the barrier and are used to remediate the VOC plume by extracting volatilized VOC from the vadose zone. SVE wells have been sporadically used from 1998 to 2004. Ground-water extraction wells inside the barrier include wells IW-1 and IW-2 (fig. 2). These wells capture PCE and maintain inward hydraulic gradients, which reduce outflow of PCE from within the barrier area. Two ground-water extraction wells (EW-1 and EW-2, fig. 2, table 1) outside and downgradient from the barrier are used to capture PCE outside the barrier. Injection wells include two wells inside of the barrier on the upgradient end (RW-1 and RW-2, fig. 2). These wells are used to prevent inflow of uncontaminated waters from outside the barrier and to induce hydraulic gradients within the barrier. Another injection well (RW-3, fig. 2) is outside of, and downgradient from, the barrier. A recharge gallery outside the barrier on the northern flank of the plume (fig. 2) receives most of the treated water and injects water into the shallow (less than 20 ft) subsurface. Air sparging (SP) wells (SP-1 and SP-2, fig. 2) inside the barrier are used to inject air into the deep overburden to facilitate transfer of VOCs that are adhered onto soils into the vapor phase. SP wells were primarily inactive from 1998 to 2004.

From 1999 to 2003, the net amount of water extracted (extraction minus injection) inside the barrier was increased in an attempt to decrease heads inside the barrier to maintain inward hydraulic gradients around the barrier and allow the efficient use of the soil vapor extraction (SVE) wells. SVE wells work most efficiently when water levels inside the barrier are less than 255 ft. Continuously monitored water levels

from well B95-9 inside the barrier (fig. 2, table 1) showed that water levels generally did not decrease below 257 ft (Harte, 2005) although the net extraction inside the barrier increased by a factor of six from 1999 to 2003.

Hydrogeology

The MSGD aquifer (fig. 1) is defined as the entire sequence of unsaturated and saturated alluvium, glacial drift, and other unconsolidated deposits overlying the bedrock surface in the Souhegan River Valley in Milford. The aquifer consists primarily of stratified sand and gravel with some basal till, and is overlain in places by recent alluvium. The maximum saturated thickness of the aquifer exceeds 80 ft, but generally ranges from 0 to 60 ft. The aquifer is bounded laterally by till-covered bedrock uplands.

Two bedrock types underlying the aquifer have been identified in rock cores. These types include a white to pink, medium to coarse-grained granite, and a gray biotite-rich diorite gneiss (HMM Associates, Inc., 1989, 1991). Lyons and others (1997) identified several bedrock units in the Milford area including the Massabesic Gneiss Complex of Late Proterozoic age, an unnamed intrusive gray biotite granite of Permian age, and biotite quartz diorite of early Devonian age (Spaulding Tonalite). A high-angle strike-slip fault called the Campbell Hill Fault traverses the study area in a southwest-northeast trend. The degree of fracturing of the bedrock is unknown, but wells set in bedrock yield water. Because the primary porosity of the underlying bedrock in the study area is negligible, fractures are the principal mechanism to transmit ground-water flow.

Till forms the basal unit of unconsolidated sediments and discontinuously overlies bedrock (Harte and Mack, 1992). The till has a sandy to silty matrix and can contain pebbles, cobbles, and boulders. The till is thickest (greater than 20 ft thick) in the westernmost part of the valley.

Stratified-drift deposits represent the most transmissive units underlying the site. Estimates of hydraulic conductivity exceed 100 ft/d (Camp, Dresser, and McKee, Inc., 1996) in the gravel and sand layers of the stratified-drift deposits. Stratified drift was deposited in ice-contact, fluvial deltas, and outwash environments (Koteff, 1970). During the late stages of Pleistocene glaciation, a west-to-east drainage pattern that was similar to present drainage patterns caused coarser sediments to be deposited in the western part of the valley. Specifically, glacial drainage occurred through the channel occupied by Purgatory Brook (fig. 1) and through the channel occupied by the Souhegan River west of OU1. These glacial-drainage channels transported coarse-grained sediments into the present-day Souhegan River Valley.

The unconsolidated sediments beneath the Savage site consist of up to 100-ft-thick deposits of predominantly sand and gravel. In OU1, lithologic logs show that sand and gravel sequences are interspersed with discontinuous finer grained

Table 1.   Location, well screen data, and geology for selected wells in Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[All data in feet; NGVD 29, altitude in feet above mean sea level; Aquifer code: S&G, sand and gravel; f-c, fine to coarse; G&S, gravel and sand; rk, bedrock; --, no data available; site type names explained in abbreviation section of report; locations of all wells shown in figure 2; E, outside barrier; I, inside barrier]

Well name	Well number	Easting	Northing	Site type	Location code	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface	Aquifer code at screen interval
MI-32	46	975247.20	124933.70	Observation	E	270.2	30	75	--	95	S&G
MW-2A	310	975148.90	125591.30	Observation	E	266.6	29	39	--	--	S&G
P-1	335	974088.30	124847.50	Observation	E	276.6	13.9	14.9	--	--	S&G
P-2	336	975100.90	125281.90	Observation	E	268.6	17	18	--	--	S&G
MW-16A	233	975671.20	124863.10	Observation	E	267.5	16.9	26.9	--	--	S&G
MW-16B	321	975671.00	124868.60	Observation	E	267.6	39.6	49.6	--	--	Sand, f-c
MW-16C	344	975678.10	124877.10	Observation	E	267.4	73.2	83.2	--	87.5	S&G
MW-16R	345	975670.80	124875.20	Observation	E	266.5	100	138	--	87.5	Rock
B95-9	404	975039.81	124825.60	Observation	I	270.31	10	20	--	--	S&G
B95-12	407	975343.81	124724.70	Observation	E	269.45	55	60	--	76	G&S
B95-13	408	975490.63	125002.00	Observation	E	267.01	60	65	--	90.5	S&G
B95-15	409	975254.00	125149.40	Observation	E	269.61	85	95	--	96.5	G&S
PW-1D	531	975507.10	125010.99	Observation	E	266.88	84.48	94.48	--	94	Till/rk
PW-2R	535	975254.74	124973.56	Observation	E	268.92	113.93	133.93	--	102	Rock
PW-12S	555	975427.31	125256.36	Observation	E	265.73	18.1	28.1	--	--	S&G
PW-12M	556	975437.19	125255.65	Observation	E	265.81	57.8	68	--	--	S&G
PW-12D	557	975427.88	125266.19	Observation	E	265.69	87	97	--	--	Sand
PW-12R	558	975437.63	125267.37	Observation	E	265.66	113.9	134	--	100	Rock
PW-13S	559	975692.00	125287.51	Observation	E	267.68	20.3	30.3	--	--	S&G
PW-13M	560	975699.94	125292.84	Observation	E	267.86	59.8	70	--	--	S&G
PW-13D	561	975691.69	125297.73	Observation	E	267.55	94.3	104.35	--	103	Gravel/rk
PW-14S	562	975756.44	125094.57	Observation	E	266.76	20.03	30.03	--	--	S&G
PW-14M	563	975757.31	125104.17	Observation	E	266.76	60	70	--	--	Sand, c-f
PW-14D	564	975764.88	125098.02	Observation	E	266.77	102.71	112.71	--	111.5	Sand, c-f/rk
EW-1	565	975535.23	125046.05	Extraction (OU1)	E	266.88	63.55	93.55	--	--	S&G
EW-2	566	975492.89	124936.25	Extraction (OU1)	E	267.05	51.22	81.22	--	81.5	S&G
IW-1	567	975105.37	124871.14	Extraction (OU1)	I	272.4	73.75	103.75	--	103.75	Sand, till, rk
IW-2	568	975037.83	125068.37	Extraction (OU1)	I	277.03	67.8	87.8	--	--	S&G
RW-1	569	974751.80	125000.52	Injection (OU1)	I	273.67	31.65	41.65	--	--	Gravel
RW-2	570	974799.44	124838.74	Injection (OU1)	I	273.38	22.04	32.04	--	--	S&G

Table 1. Location, well screen data, and geology for selected wells in Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All data in feet; NGVD 29, altitude in feet above sea level; Aquifer code: S&G, sand and gravel; f-c, fine to coarse; G&S, gravel and sand; rk, bedrock; --, no data available; site type names explained in abbreviation section of report; locations of all wells shown in figure 2; E, outside barrier; I, inside barrier]

Well name	Well number	Easting	Northing	Site type	Location code	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface	Aquifer code at screen interval
SVE-1	574	974927.14	124888.11	Airwell	I	274.99	8.37	23.36	--	--	--
SVE-2	575	974946.49	124988.03	Airwell	I	276.25	9.41	24.41	--	--	--
SVE-3	576	974966.91	125106.60	Airwell	I	273.38	12.34	27.34	--	--	--
SVE-4	577	974828.74	124901.85	Airwell	I	274.02	12.66	27.66	--	--	--
SVE-5	578	974846.81	125001.08	Airwell	I	274.76	12	27	--	--	--
SVE-6	579	974870.28	125128.88	Airwell	I	273.7	12.39	27.39	--	--	--
INEEL-NCP	612	974856.96	124907.38	INEELwell	I	--	15	62	--	60	--
INEEL-NWP	613	974842.08	124906.24	INEELwell	I	--	15	62.5	--	59	--
INEEL-NEP	614	974873.14	124906.38	INEELwell	I	--	15	62.5	--	59	--
INEEL-SCP	615	974857.90	124856.79	INEELwell	I	--	--	--	--	--	--
INEEL-SWP	616	974842.57	124858.68	INEELwell	I	--	15	62.5	--	--	--
INEEL-SEP	617	974873.60	124858.01	INEELwell	I	--	--	--	--	--	--
INEEL-EI	618	974872.78	124882.94	INEELwell	I	--	15	62	--	--	--
INEEL-WI	619	974840.93	124882.09	INEELwell	I	--	15	62.5	--	62	--
INEEL-HCN	620	974856.16	124917.14	INEELwell	I	--	--	--	--	--	--
INEEL-HCNW	621	974832.22	124907.67	INEELwell	I	--	--	--	--	--	--
INEEL-HCW	623	974831.23	124882.02	INEELwell	I	--	17	62	--	--	--
INEEL-HCSW	624	974832.09	124859.16	INEELwell	I	--	--	--	--	--	--
INEEL-SCMLS	641	974857.34	124863.31	INEELwell	I	--	--	--	--	--	--
INEEL-SEMLS	642	974873.68	124864.23	INEELwell	I	--	--	--	--	--	--
INEEL-NEMLS	643	974873.85	124900.95	INEELwell	I	--	--	--	60	--	--
INEEL-NCMLS	644	974857.27	124901.59	INEELwell	I	--	--	--	--	--	--
INEEL-NWMLS	645	974842.22	124901.08	INEELwell	I	--	--	--	--	--	--
INEEL-SWMLS	640	974842.13	124864.87	INEELwell	I	--	--	--	--	--	--
MW-0312	629	975227.26	125335.06	Observation	E	--	92.7	97.7	--	--	--
Gallery	639	975284.18	125247.99	Gallery	E	--	--	--	--	--	S&G
INEEL-HCS	625	974858.48	124846.42	INEELwell	I	--	17	62	--	--	--
INEEL-HCSE	626	974883.47	124857.95	INEELwell	I	--	--	--	--	--	--
INEEL-HCE	627	974883.28	124883.03	INEELwell	I	--	--	--	--	--	--
INEEL-HCNE	628	974883.24	124906.56	INEELwell	I	--	--	--	--	--	--

sands at depths of 40 and 70 ft. Coarse-grained deposits (cobbles and gravels) occur at the uppermost layer near the water table (at a depth of 6–18 ft), at around 60 ft, and near the base of the unconsolidated sediments at 90 ft.

The stratigraphy of the study area was apparently created by a sequence of multiple glacial advances. The deep, coarse-grained deposits at 85–90 ft below land surface indicate that subglacial meltwater eroded deeply into the potentially weakened bedrock near the Campbell Hill Fault Zone. According to Randall (2001), many subglacial channels persisted throughout later stages of deglaciation and deposited sand and gravel atop bedrock near the retreating ice margin. The remaining deposits in OU1 indicate meltwater deposition in the form of deltas, outwash, and a glacial outburst deposit, which deposited a coarse cobble zone near the uppermost sequence. The extent of the glacial outburst deposit is limited to the western part of the aquifer. Farther east, in the upper strata, the predominant depositional unit is outwash.

Borehole geophysical (natural gamma) logs and lithologic logs from a west-east cross section (fig. 3) through the OU1 area illustrate the complex stratigraphic pattern of the overburden. The natural gamma logs show high gamma count readings in boulder and cobble layers and low gamma count readings in well-sorted sand layers with few clay particles (fig. 3A). Interpolated gamma values between borehole logs are provided to help map the subsurface. The lithology from the site is difficult to interpret because of different standards in lithologic log interpretations from drillers (fig. 3B). Nevertheless, some general patterns are visible. Stratigraphic interpretations based on natural gamma logs and lithologic logs are shown in fig. 3C. An upper sand and gravel layer that contains the cobble layer extends through the OU1 area to approximately a 30-ft depth below land surface. In the west, a thick till deposit pinches out to the east. A middle fine-to-medium sand layer extends from PW-2R to EW-1. It appears to pinch out between EW-1 and former (sealed) well MI-63. An underlying gravel and sand layer extends beyond the middle fine sand layer. Two discontinuous coarse-grained layers occur at depths of approximately 65 and 80 ft below land surface.

A partially penetrating river, the Souhegan River, bounds the northwestern part of OU1, and is the major source of recharge in this area (Harte and others, 1999). Farther downstream in OU2, the Souhegan River is a discharge sink for ground water. In areas near the Souhegan River, the ground-water-flow system responds quickly to variations in river stage, recharge from the river, or infiltration from precipitation; therefore, the flow system is highly transient.

Ground water flows to the east at velocities of up to several feet per day in the MSGD aquifer. Ground-water-flow directions can vary daily because of transient hydrologic conditions, which are induced by oscillations in river stage and variations in rates of recharge and discharge (Harte and others, 1997). In the MSGD aquifer, ground-water-flow velocities are highest (greater than 1.5 ft/d) in the cobble zone deposit in OU1 and lowest (less than 0.5 ft/d) in the basal till throughout the study area.

In OU1, the hydraulic connection between the overburden and fractured bedrock is thought to be high in areas where till is absent. A computed water budget of the net extraction of water inside the barrier indicated bedrock upflow was a large percentage (approximately 50 percent) of the source of water to IW-1 and IW-2 extraction wells (Harte, 2004). Monitoring of continuous water levels in the overburden and bedrock wells showed that net extraction of overburden water from inside the barrier caused bedrock water levels to decrease (Harte, 2005). The presence of PCE in bedrock wells may indicate contaminant transport between the PCE source in the overburden and underlying bedrock.

The transmissive capabilities of the overburden are assumed to exceed that of the fractured bedrock based on limited hydraulic testing of the bedrock. Data on hydraulic properties of the bedrock are limited to a few wells, whereas data on hydraulic properties of the overburden include numerous wells in the study area. Estimates of bedrock hydraulic conductivity from a few bedrock wells indicate a value similar (about 1 ft/d) to that of the basal till (HMM Associates, Inc. 1989).

Previous Investigations of Contaminant Sources and Previous Remediation Efforts

This section focuses on the results of investigations that characterized contaminant source and remediation at OU1. From 1983, when contamination was first detected by NHDES and USEPA, until 2004, ground-water quality of the primarily PCE plume was monitored. Prior to 1999, when the remedial system began operating, PCE concentrations in ground water at OU1 showed modest decreases from 1983 to 1999 (Harte, 2004) probably from a shrinkage in the DNAPL pool from the continuing dissolution of DNAPL into the ground water. After 1999, PCE concentrations decreased at double the rate of pre-remedial conditions (Harte, 2004).

Three primary source locations have been identified at the former OK Tool facility (Camp, Dresser, and McKee, Inc., 1996) in OU1. They include a floor drain inside the former building near a degreasing tank (called abandoned pit area), a leach field north of the former building, and an area northwest of the former building near a former degreasing tank. The abandoned pit area (southernmost location on fig. 2 and identified as contaminant disposal location in figure inset) is thought to be the primary source input location on the basis of soil concentrations of PCE and ground-water concentrations from nearby vertical profile points (not shown on any figure) and observation wells.

The abandoned pit has been the focus of most investigations of source characterization. Vertical profiling of ground water by use of a direct-push profiler has been performed on multiple occasions by University of Waterloo in 1994, 1995,
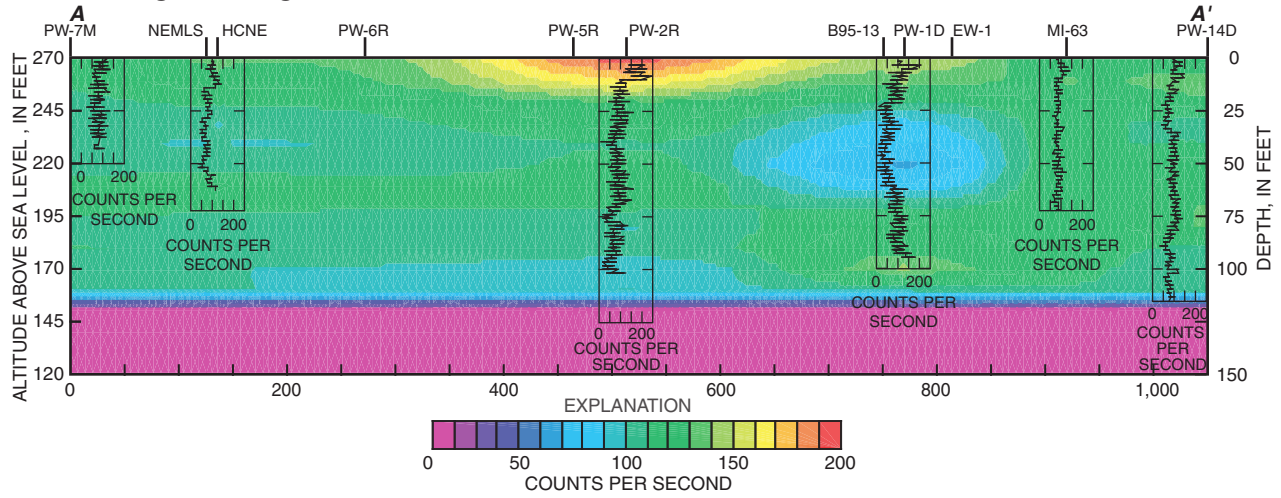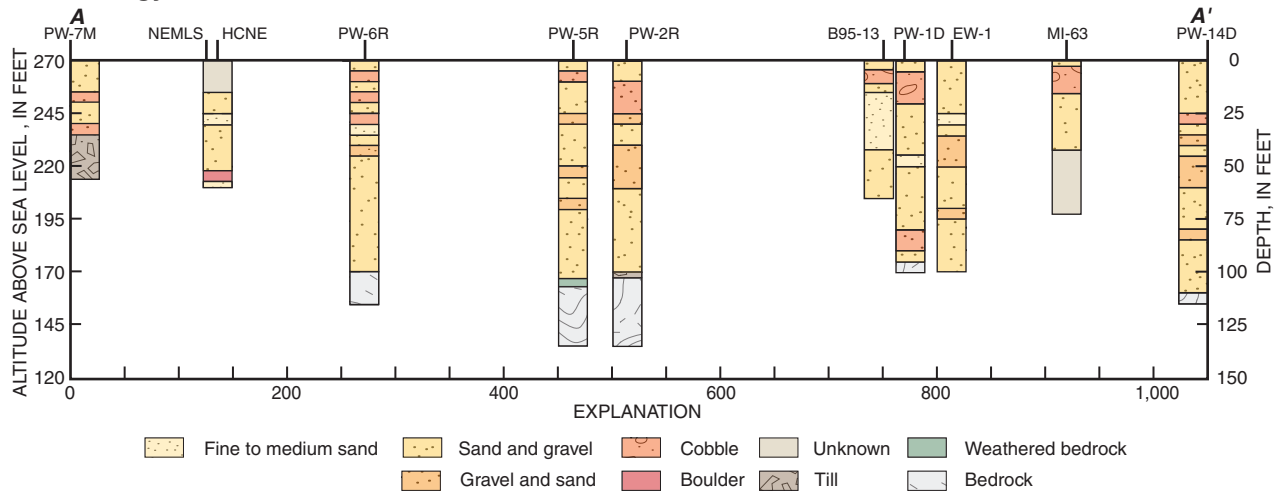
Figure 3. Cross section A-A' through Operable Unit 1 (OU1) showing *A*, natural gamma log results, *B*, lithology, and *C*, interpretation of stratigraphy, Milford, N.H. Location of cross section and wells are shown on figure 2.

1997, and 1998 (Guilbeault and others, 1997, 1998) to map subsurface contamination. High-resolution (close spacing) profiling near the pit was done in 1997 and 1998. In 1994–95, profiling detected PCE concentrations exceeding 100,000 ppb at shallow depths (19 ft below land surface) approximately 20 ft south of the abandoned pit (Camp, Dresser, and McKee, Inc., Federal Programs Corporation, 1995). In 1997, a line of profile points was done about 17 ft downgradient (east) of the pit location where the profiling detected maximum PCE concentrations of approximately 70,000 ppb. Maximum concentrations at any profile location appear to be in 3 to 15-ft-thick intervals at depths of 15 to 50 ft below land surface. The depths of maximum PCE concentrations slope to the northeast with the primary ground-water-flow direction but also are controlled by heterogeneity of the subsurface. In 1998, vertical profile points were done upgradient, lateral, and downgradient to the pit. Profile points to the north and northeast (lateral and downgradient) of the pit detected maximum PCE concentrations exceeding 100,000 ppb at depths less than 40 ft below land surface (Guilbeaut and others, 1998).

Based on profiling results, 17 long-screened (45-ft) wells were installed near the abandoned pit (fig. 2 insert; appendix 1). The assembly of wells is referred to as the INEEL (Idaho National Engineering and Environmental Laboratory) well field, named after the lead agency responsible for installation. In addition to the 17 long-screened wells (fig. 2 insert), 6 multi-level sampler wells (not shown in fig. 2) were also installed. Multi-level samplers had sample intakes at depths of 22, 28, 42, 48, 58.5, and 60.5 ft below land surface.

The well installation near the pit location was part of a demonstration study by INEEL to test Surfactant-Enhanced Aquifer Remediation at Neutral Buoyancy (SEAR-NB) technology to help reduce DNAPL volume (Tetra Tech EM, Inc., 2003). SEAR-NB mobilizes DNAPL through horizontal transport without vertical migration because of the two-step process of surfactant mobilization with neutral buoyancy. The study included collection of two core holes, slug tests of INEEL wells, and a series of primarily conservative interwell tracers tests (CITT) in three zones of the overburden (shallow, middle, and deep). Results of the tracer tests showed significant horizontal and vertical heterogeneity (more than a factor of 10 in hydraulic conductivity) within the well field. Estimates of hydraulic conductivity ranged from 28 to 574 ft/d (Tetra Tech EM, Inc., 2003) with an average porosity of 0.25. A partioning interwell tracer test (PITT) also was performed to measure residual DNAPL saturation. Results showed a maximum DNAPL saturation of 15 percent within several layers. Numerical simulations of CITT, PITT, and the planned SEAR-NB, were done with a finely discretized transport model. The actual SEAR-NB demonstration was not conducted because of problems with the disposal, after extraction from the subsurface, of the mobilized DNAPL and surfactant, which contains high biological oxygen demand (BOD) concentrations.

A review of the OU1 remedial system by U.S. Environmental Protection Agency (2001) identified the following two problems with the effectiveness of the current (2004) remedial

system: (1) uncertainty in the delineation of capture areas of the exterior extraction wells, and (2) inability to reduce DNAPL quantities inside the barrier. The latter is identified on the basis of trends in PCE concentrations inside the barrier at observation wells (PW-6 cluster, fig. 2) between the source area at the INEEL field and interior extraction wells (IW-1 and IW-2). PCE concentrations at PW-6 cluster wells (PW-6S, 6M, 6D, and 6R; fig. 2), as collected and analyzed by New Hampshire Department of Environmental Services (Leah Desmarais, New Hampshire Department of Environmental Services, written commun., 2004), increased after barrier installation. This trend is consistent with a continuous DNAPL source, reduced dilution inside the barrier, and a decrease in ambient ground-water flow.

A review of a 5-year (1998–2003) post-remedial time period of OU1 remedial construction and operation was done by New Hampshire Department of Environmental Services (2003). Data on system operation, aquifer response, and contamination clean-up were synthesized, including the testing and monitoring of the SVE and SP systems in 2002.

The SVE system operated between February 16 through March 19, 2002, and adjacent observation wells were monitored to assess the effect of SVE on the ground water of the overburden and bedrock. The SVE wells are shallow screened (12–27 ft below land surface) and are capable of delivering a maximum negative pressure output of 5 pounds per square inch (psi) by extracting air from the unsaturated zone. One psi is equivalent to 2.3 ft of water. For the test, negative pressure output averaged 2 psi. A maximum pressure response, indicated by a decrease in water level of 2.2 ft, was measured at observati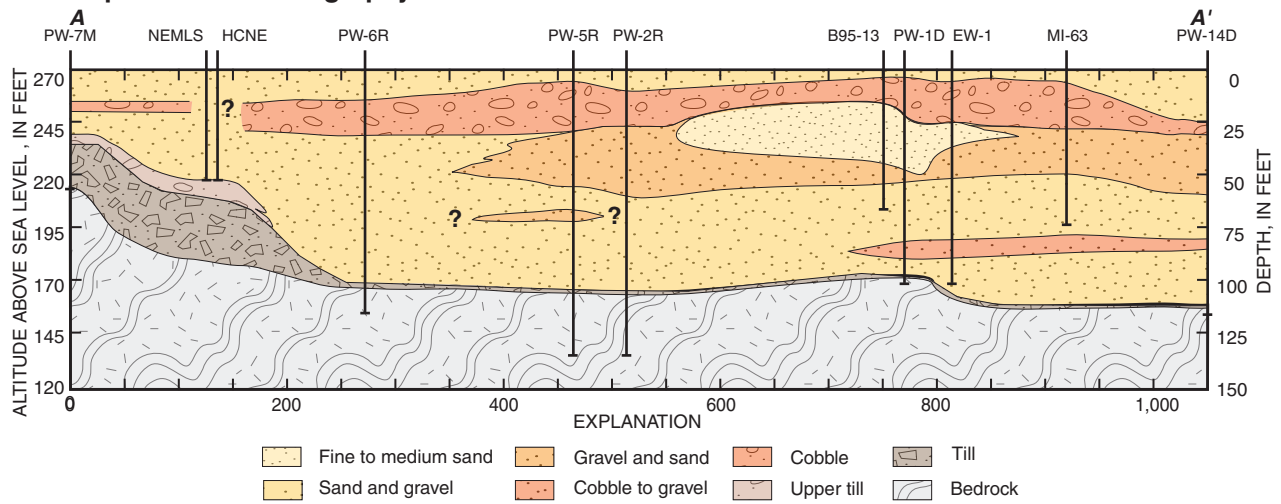on well PW-8M. In general, pressure changes increased at most interior shallow wells and decreased slightly (by about 20 percent) with depth (New Hampshire Department of Environmental Services, 2003) during the test. However, shallow well B95-9 screened near the water-table surface and within the cobble zone showed water-level decreases of only 1 ft. This change indicates a lateral and vertical decrease in pressure in the cobble layer because of the high permeability of this layer. Wells outside the barrier showed the greatest decrease in water level at depth, converse to wells inside the barrier, which indicates a ground-water connection inside and outside the barrier beneath the barrier wall. Water-level decreases at well clusters PW-5 (inside) and PW-2 (outside) showed similar responses in bedrock wells indicating a connection beneath the barrier through the bedrock, whereas overburden wells showed a muted response in the exterior overburden wells. At the PW-8M (inside) and PW-9M (outside) overburden wells straddling the barrier, the water level decreased by 2.2 ft at PW-8M while decreases at PW-9M were negligible.

The two air sparge wells (SP-1, SP-2) were operated for 2 days (August 15–16, 2002) and observation wells were monitored to measure the response of water levels to air pressure. The air sparge wells increase pressure by adding air to the aquifer. The SP wells are capable of a maximum positive pressure of 25 psi each well. The air sparge wells are report-

edly screened at 59 to 64 ft below land surface (Peter Borowiec, Camp, Dresser, and McKee, Inc., written commun., 1999). The results of the test show water-level rises of up to 3 ft in deep observation wells and about 1 ft in shallow wells. Interior wells responded the most; exterior wells responded about 30 percent of the interior wells. These results indicate the barrier is hydraulically isolating the interior flow system. Results also showed the greatest responses of water levels to injection at SP-2 and less at SP-1 (New Hampshire Department of Environmental Services, 2003). Well SP-1 is screened near the bedrock surface and probably partially screened in the till, which has a lower permeability than the sand and gravel units of the overburden. The driller log for SP-1 shows a 3-ft sump penetrating the bedrock below the well screen, which could cause a partial loss of air into the bedrock, making SP-1 less efficient in delivering injected air into the overburden.

In September 2003, an insitu chemical oxidation (ISCO) pilot test (U.S. Filter, Inc., 2005) was done in the INEEL text array (fig. 2) to help reduce dissolved VOC concentrations. The ISCO test included injection of 8,400 pounds of potassium permanganate through the targeted DNAPL source zones. Research is ongoing, but as of 2004, decreases in PCE concentration were not detected at nearby PW-6 wells (fig. 2).

Effects of the Remedial System and its Operation on Ground-Water Quality and Flow

Effectiveness of VOC (primarily PCE) remediation at OU1 is discussed on the basis of monitoring data including water levels and water quality. Selected construction data for the barrier wall are also included to assess the potential for lateral transport in the overburden between interior and exterior barrier areas in OU1.

Hydrogeologic Responses

This section discusses remedial operation and ambient conditions that affect ground-water flow, solute transport of VOCs, and abatement of VOCs. Ground-water-flow conditions for pre-barrier wall construction, but prior to operation of the remedial system, were discussed in Brayton and Harte (2001). Post-construction ground-water-flow patterns due to the barrier produce an area of focused recharge (river loss) from the Souhegan River to the aquifer in OU1 near well P-2 (fig. 2). In contrast, pre-construction flow patterns show diffuse recharge along the entire Souhegan River reach of OU1. Therefore, ground-water velocities in the shallow overburden where most river loss occurs have increased to accommodate the focused recharge.

Remedial operation affects ground-water flow and solute transport. The extraction of contaminated ground water, treatment, and reinjection alters ground-water flow and solute

transport. The distribution and rate of extraction and injection at interior and exterior barrier locations is the primary factor affecting flow and transport. Inside the barrier, different rates of extraction occurred from 1999 to 2003 and reinjection of treated water inside the barrier decreased during that same time. The net rate (extraction minus injection) of extraction inside the barrier generally increased as a result of decreases in interior injection.

Ambient hydrologic conditions affect ground-water levels, gradients, and flow in OU1. Ambient hydrologic conditions include precipitation, evapotranspiration, and river-stage fluctuations from the Souhegan River. Additionally, stresses from ground-water withdrawal wells outside of OU1 also affect ground water in OU1.

Water table (shallow overburden[1]) and potentiometric (middle[2] and deep overburden[3]) head maps indicate ground-water-flow patterns in OU1 become complex after the completion of the barrier wall and particularly during the operation of the remedial system. Heads are controlled by ambient recharge boundaries (Souhegan River), flow into discharge areas (OU2 area), seasonal and long-term (more than 1 year) climate trends, the barrier wall, and remedial operations. Under non-operating conditions in January 2002 (fig. 4), flow, assumed orthogonal to head contours, diverges on the upgradient side of the barrier and converges on the downgradient side of the barrier. Inside the barrier, head gradients are small because of the low rates of horizontal flow into and out of the barrier. When the remedial system is not operating, the horizontal gradient inside the barrier is 0.0011 ft/ft, and outside is 0.0069 ft/ft. Vertical gradients also are small (less than 0.001 ft/ft) when the system is not operating.

When the remedial system is operating, as in November 2001, the most prominent water-table-surface feature is the mound created from injection at the recharge gallery outside the barrier in the shallow overburden (fig. 5A). The exact dimensions and elevation of the mound are unknown because of a lack of shallow water-table wells near the gallery but it is likely the gallery raises the water-table surface by several feet. Cones of depression from extraction at EW-1 and EW-2 are small because of the small rates of extraction (typically 25 gal/min each). Inside the barrier, horizontal gradients increase slightly from 0.0011 ft/ft (non-operating conditions) to 0.0016 ft/ft (operating conditions). Similar to EW-1 and EW-2, cones of depression at IW-1 and IW-2 are small because of the small rates of extraction (37 gal/min total), high hydraulic conductivity (exceeding 25 ft/d), and lack of data points near the wells.

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[1] Shallow overburden is defined in this report as depths equal to or less than 40 ft below land surface.

[2] Middle overburden is defined in this report as depths greater than 40 ft and less than or equal to 70 ft below land surface.

[3] Deep overburden is defined in this report as depths greater than 70 ft below land surface.
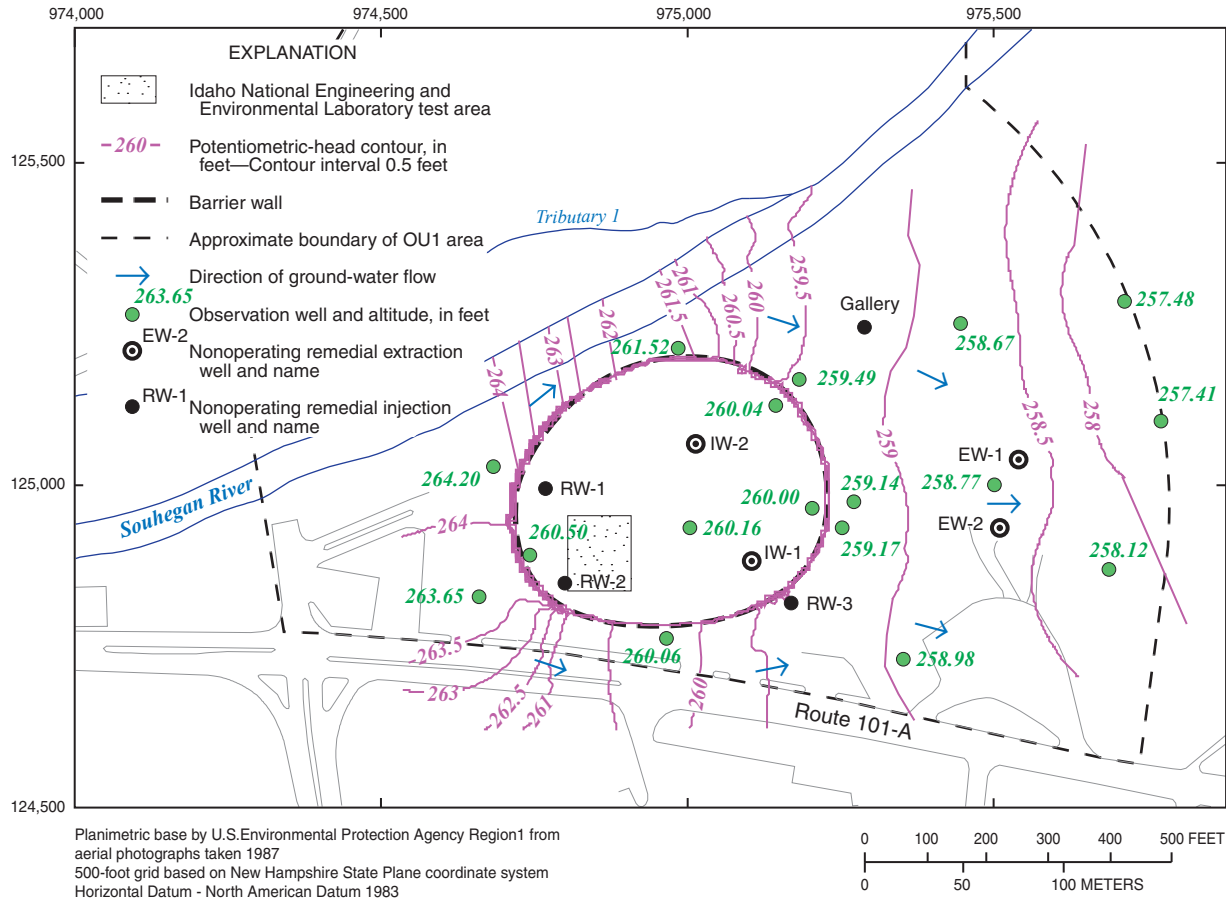
Figure 4. Potentiometric-head contours of middle overburden after barrier construction but under non-operating conditions during low recharge, January 2002, Operable Unit 1 (OU1), Milford, N.H.

Small stagnation areas form on the upgradient side of the recharge gallery, and the downgradient side of the extraction wells at EW-1 and EW-2 whenever the remedial system is operating. The stagnation areas are areas of slow velocity that are problematic for flushing of contaminants in ground water. If concentrations of PCE are high in these areas, PCE transport decreases and high concentrations remain for extended periods of time.

In the middle of the overburden in November 2001 (fig. 5B), the mound from the recharge gallery is not observable because of a lack of data points in that area. Flow is from the gallery area to the extraction wells. Inside the barrier, horizontal gradients are flat in the area between IW-1 and IW-2 from PW-6 to PW-5 well clusters (fig. 2) indicating a slow velocity zone.

In the deep overburden in November 2001 (fig. 5C), flow from the gallery area is more easterly than southerly unlike the middle overburden; this deep ground water in this area is less likely to be captured by EW-1 and EW-2 than ground water in the middle overburden. Inside the barrier, the horizontal gradient between IW-1 and IW-2 is greater in the deep overburden

than in the middle overburden, thus indicating a stagnation area is likely to be more prevalent in the middle overburden.

The ambient hydrologic conditions for the head maps shown in figures 4 and 5 are of low recharge periods when water levels were low. Low recharge can be the result of low rates of precipitation and(or) high rates of evapotranspiration. In figures 4 and 5, low recharge is caused exclusively by low rates of precipitation. To better quantify hydrologic conditions for the periods shown in figures 4 and 5, water levels were evaluated based on water-level statistics from long-term (from 1962) monitoring well MI-18 in OU2 (fig. 1). Water levels were ranked from low to high from 1997 to 2004 to provide exceedance rankings for each daily average water level recorded at M-18. Referencing the daily average water level of MI-18 from the day that head data were mapped in OU1 provides an exceedance ranking and insight into recharge conditions. Water-level exceedance was low (less than 18 percent) for January 2002 and November 2001.

A head map of the middle overburden during remedial operations in May 2002 (fig. 6A) represents a high recharge period when water levels were high; water-level exceedance
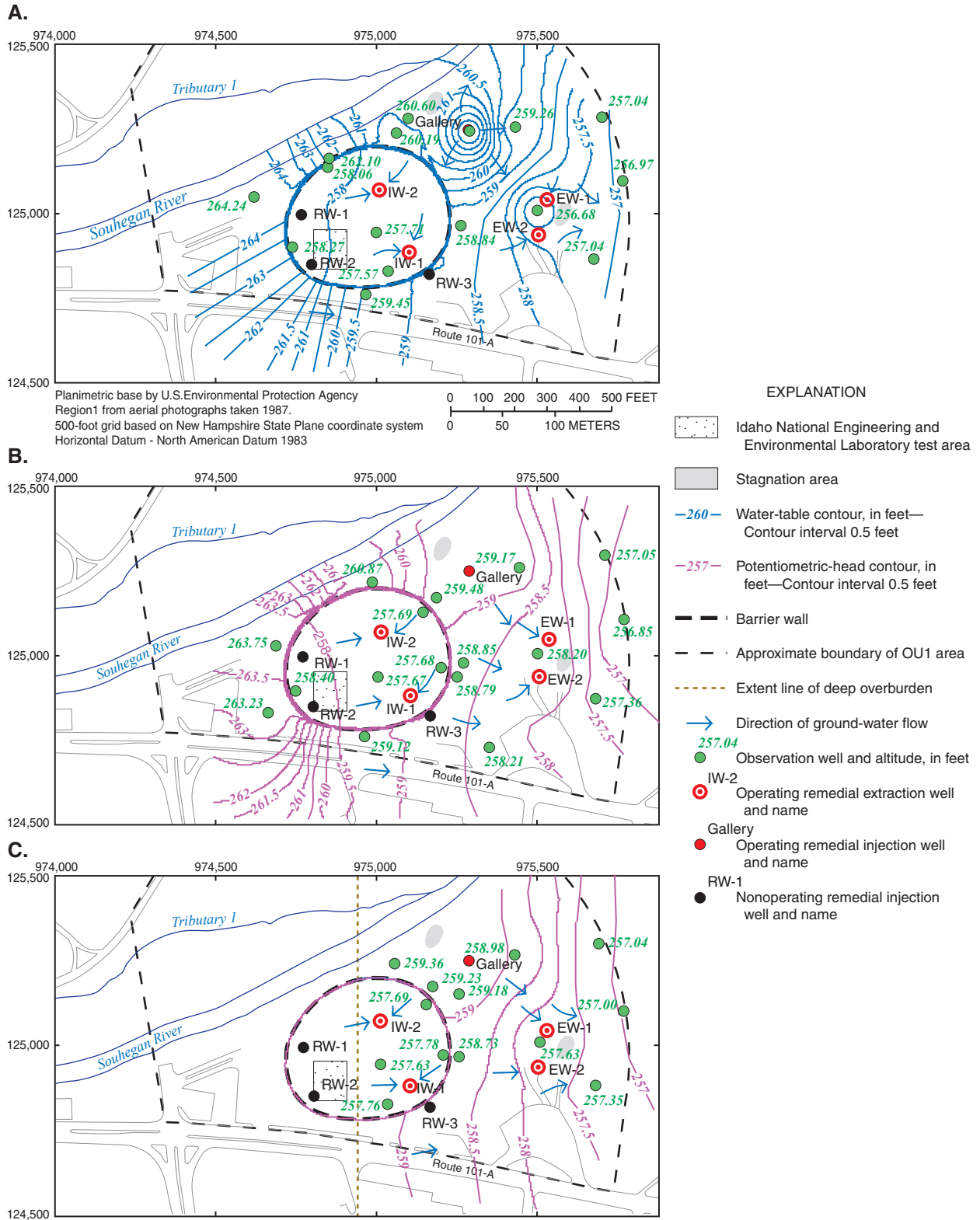
Figure 5. Water-table and potentiometric-head contours for *A*, shallow, *B*, medium, and *C*, deep overburden under operating conditions during low recharge, November 2001, Operable Unit 1 (OU1), Milford, N.H.
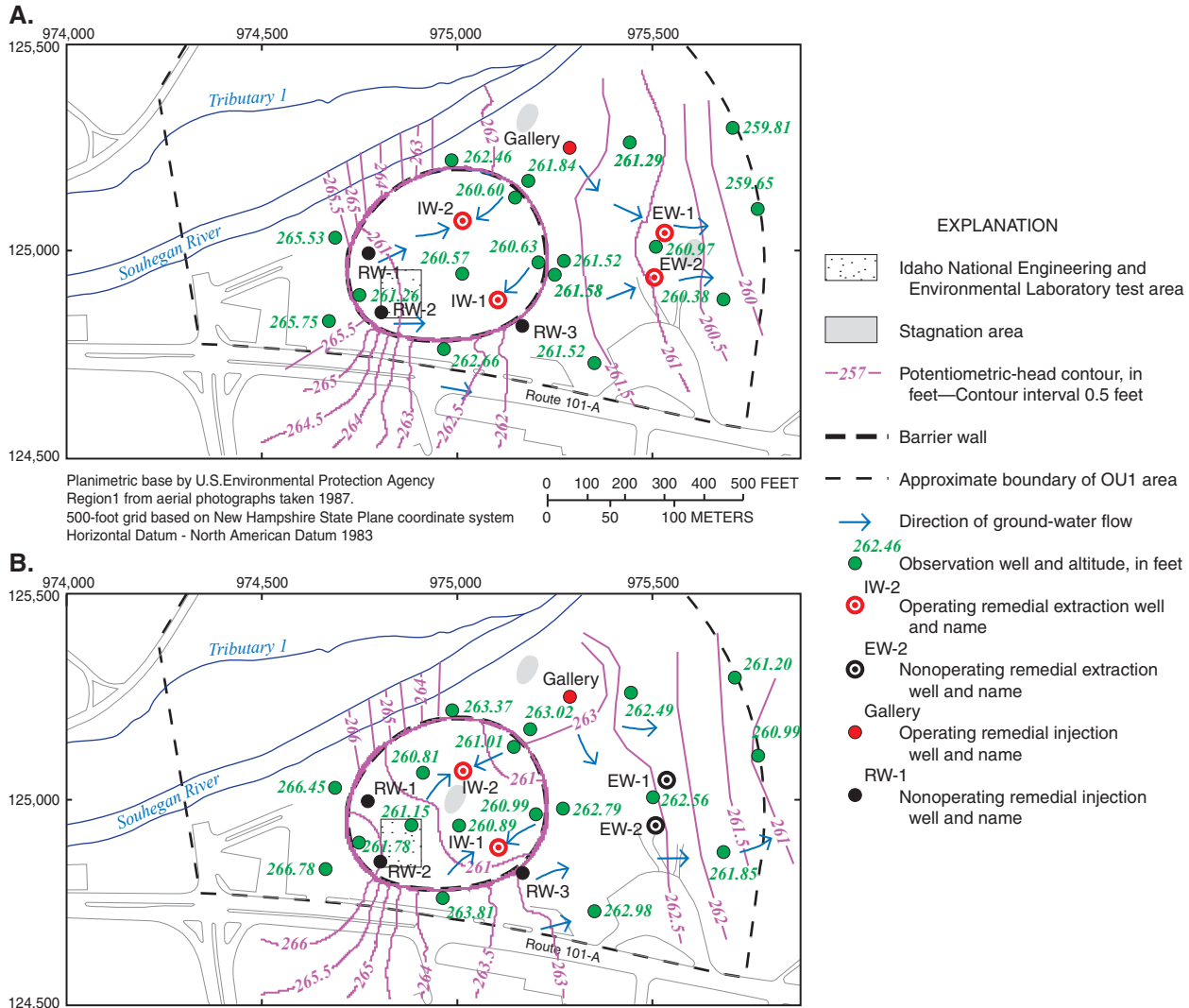
Figure 6.   Potentiometric-head contours of middle overburden in a high recharge period under *A*, operations in May 2002, and *B*, partial operating conditions in April 2004, Operable Unit 1 (OU1), Milford, N.H.

was 83 percent at well MI-18. Outside the barrier, the horizontal hydraulic gradients in the middle overburden are less in May 2002 during a high recharge period than in November 2001 during a low recharge period. *This process occurs at OU1 because maximum river loss occurs during low recharge periods as documented in Harte and others (1999). High recharge periods, therefore, correspond with slower ground-water velocities than low recharge periods and larger stagnation areas east of EW-1 and EW-2.* Inside the barrier, horizontal gradients are similar between May 2002 and November 2001.

A head map of the middle overburden under partial remedial operation in April 2004 (fig. 6B) represents a high recharge period when water levels were high; water-level exceedance was 91 percent at well MI-18. In April 2004, EW-1 and EW-2 were not operating and interior extraction at

IW-1 and IW-2 increased from 37 to 60 gal/min. Injection at the gallery continued as in November 2001 but at lower injection rates; 60 gal/min in April 2004 compared to 110 gal/min in November 2001. Outside the barrier, the horizontal hydraulic gradients in the middle overburden are less in April 2004 than in May 2002 and in November 2001 because extraction ceased. Stagnation areas are eliminated downgradient of EW-1 and EW-2 but still occur upgradient of the gallery. Inside barrier, horizontal gradients increase because of increased extraction at IW-1 and IW-2. A stagnation area is visible inside the barrier near PW-6 well cluster at the bend in the 261-ft contour (fig. 6B). The stagnation area is not visible in November 2001 (fig. 5B) and May 2002 (fig. 6B) likely because fewer measurement points were available for these periods than the other periods.

Precipitation effects on ground water in OU1 were examined in Brayton and Harte (2001). Findings from that study showed that the land-surface crown inside the barrier area decreases infiltration of precipitation and recharge to ground water. A 50-percent reduction of recharge was attributed to the crown based on water-level responses to precipitation (water-level accretion method; Rasmussen and Andreason, 1959) after construction of the barrier wall in the fall of 1998. Simulations of ground-water flow and solute transport (Harte, 2004) of transient recharge events indicate that the reduction of recharge from the crown is likely less than 50 percent. Water-level rises in water years 2000–01, correlated to specific precipitation events during stable remedial operation periods (no variation in extraction or injection for several days), indicate that the crown reduces recharge by 15 to 45 percent (mean value of 30 percent) based on the water-level accretion method. The crown likely increases runoff (overland or interflow) and decreases infiltration into ground water from precipitation. Water mounding in the 2.5-ft-deep trench where B95-9 (fig. 2) is located have been observed after precipitation. The water seems to travel laterally as interflow, and seeps into cracks in the concrete culvert that supports the trench. The base of the trench represents the original land surface before the crown was constructed.

The response of ground-water levels to changes in ambient conditions is useful in assessing connectivity of the aquifer inside and outside the barrier. The proximity of the barrier to the Souhegan River is an important ambient boundary condition to assess connectivity. Fluctuations in river stage and ground-water levels were compared, with daily precipitation data, to identify periods when river-stage fluctuations (specifically increased stage) were measured with no corresponding precipitation event. By excluding periods of snowmelt or thaw, river-stage fluctuations during these periods probably indicate changes in flow from regulations upstream. At the same time, ground-water level rises during this time would indicate that ground-water levels in a well are affected by the river. The purpose of diagnosing ground-water-level changes during this period is to (1) allow for evaluation of barrier wall integrity by comparing whether river-stage fluctuations cause ground-water-level fluctuations inside the barrier, and (2) provide insight into the analyses of ground-water recharge by identifying wells with water levels that are highly correlated with river stage. Several periods were identified, including December 26–29, 1999, December 26–29, 2000, and January 12–19, 2003. All periods had air temperatures below freezing and thus experienced no thawing in the vadose zone. In general, water-level responses indicate that the barrier is generally effective in hydraulically isolating the flow through the overburden inside the barrier but the fractured bedrock provides a flowpath from outside to inside the barrier.

From December 26–29, 1999, the remedial system was operating and continuous water-level data were being monitored at wells P-2 (outside barrier, adjacent to river), B95-9 (inside barrier), MI-32 (outside barrier), and MW-16A (outside barrier). Water levels at P-2 rose 0.67 ft from a cor-

responding river stage increase. Water levels at MI-32 rose 0.15 ft, whereas water levels at B95-9 rose about 0.09 ft. Wells MI-32 and B95-9 are similar distances from the river but are outside and inside the barrier, respectively.

From December 26–29, 2000, the remedial system was not operating (shutdown on December 22) and continuous water-level data were being monitored at wells P-2, B95-9, MI-32, and PW-5R (inside barrier, bedrock well). Water levels at well P-2 rose 0.98 ft from a corresponding 1.2 ft river stage increase. Water levels at MI-32 rose 0.32 ft, whereas water levels at B95-9 and PW-5R were affected by recovery from remedial system shutdown on December 22.

From January 12–19, 2003, the remedial system was operating (start-up on December 31) and continuous water-level data were being monitored at wells P-2, B95-9, PW-5D (inside barrier), PW-5R, PW-2D (outside barrier, opposite of PW-5D), PW-2R (outside barrier, bedrock well, opposite of PW-5R), PW-8M (inside barrier), and PW-9M (outside barrier, opposite of PW-8M). Water levels at well P-2 rose 1.3 ft from a corresponding 1.7 ft river stage increase, as did water levels at PW-9M, which indicates a similar response of the aquifer at P-2 and PW-9M since they are at similar distances from the river. Water levels inside the barrier at PW-8M, opposite PW-9M, show no increase. Water levels at PW-2D, PW-2R, and PW-5R show a slight increase of 0.29, 0.25, and 0.10 ft, respectively.

Continuous monitoring of water levels during remedial system changes, particularly when extraction or injection begins after periods (days to weeks) of no operation, provides information on ground-water flow and implications for solute transport and remediation. Examination of remedial operations and the response of ground-water levels to remediation also support the conclusion that the low-permeability barrier restricts ground-water flow in the overburden but that the fractured bedrock provides a path of flow from outside to inside the barrier.

Extraction at interior wells IW-1 and IW-2 cause water-level drawdowns in descending priority from greatest to least (1) interior overburden wells (B95-9, PW-8M, and PW-5D), (2) interior bedrock wells (PW-5R), (3) exterior bedrock wells (PW-2R), and (4) exterior overburden wells (PW-2D). This priority indicates effective hydraulic containment in the overburden. A uniform drawdown inside the barrier also indicates little horizontal inflow into the interior barrier area through the overburden. Several periods are discussed in the next section to further illustrate flow processes in OU1.

In June 2001, a total net extraction rate of 31 gal/min from the two interior extraction wells (IW-1 and IW-2) caused a 2-ft decrease at B95-9, and similar decreases at PW-8M, and PW-5D (fig. 7). In contrast, water-level drawdown at PW-9M was negligible indicating the barrier wall effectively retards flow at this location. Water-level drawdown was measurable, about 0.5 ft., at exterior overburden well PW-2D, before precipitation and subsequent recharge increased water levels. However, the decrease at PW-2D is less than the decrease at interior bedrock well PW-5R (1.1 ft), and was less than the
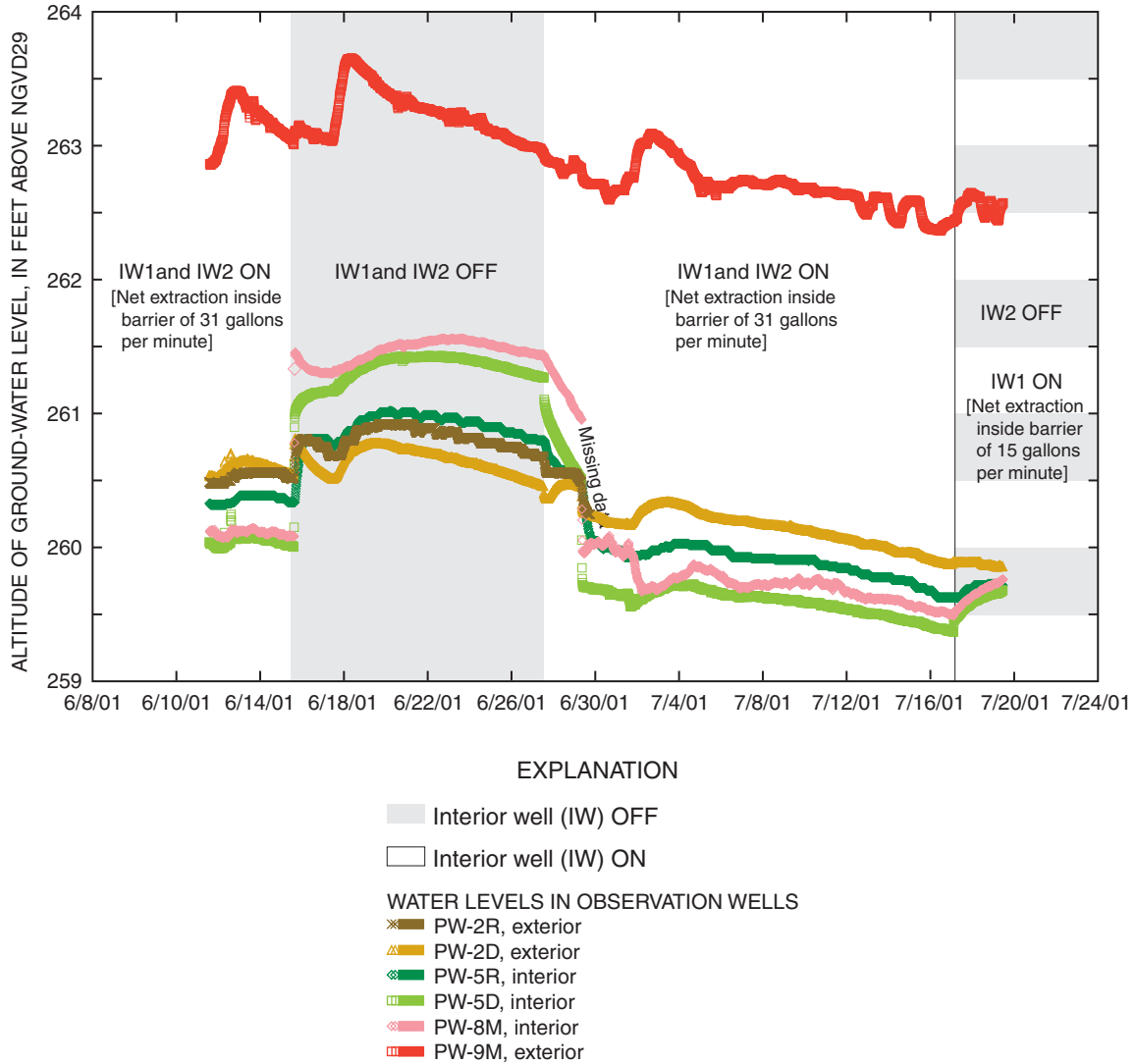
Figure 7.   Water-level drawdowns from interior extraction at continuously monitored observation wells, Operable Unit 1 (OU1), Milford, N.H. Well locations are shown on figure 2.

initial decrease at exterior bedrock well PW-2R. This decrease in water-level drawdown indicates that the mechanism for flow between interior and exterior areas is likely through the fractured bedrock, and that the bedrock is hydraulically connected to the overburden. Head, vertical gradient, and potential flow direction between the bedrock and overburden are affected by the interior extraction. Before extraction, downward vertical gradients exist between the overburden and bedrock inside the barrier. After extraction begins, upward vertical gradients exist indicating recharge from the bedrock to the overburden. A schematic diagram of this process is shown in figure 8.

From December 31, 2002 to January 20, 2003, a total net extraction of 60 gal/min from the two interior extraction wells (IW-1 and IW-2) caused water levels to decrease 3.9 ft at B95-9, with similar decreases at PW-8M, and PW-5D. Water-

level drawdown at PW-9M was again negligible indicating the barrier wall effectively slows flow at this location. Water-level drawdown was about 0.5 ft. at exterior overburden well PW-2D, which was similar to drawdown observed in June 2001. Water levels decreased at interior bedrock well PW-5R by 2.5 ft and at exterior bedrock well PW-2R by 1.1 ft. The increased drawdowns in both bedrock wells (PW-5R and PW-2R compared to exterior overburden well PW-2D) indicate that the increased internal extraction is being supplied by increased flow from the bedrock.

Water-level decreases from exterior extraction wells EW-1 and EW-2 are negligible at exterior monitored wells PW-2D and PW-2R. Total extraction rates are typically 30–50 gal/min. Because of the high rate of ground-water flow in the exterior area and high hydraulic conductivity, extraction

A. Nonoperating with no extraction
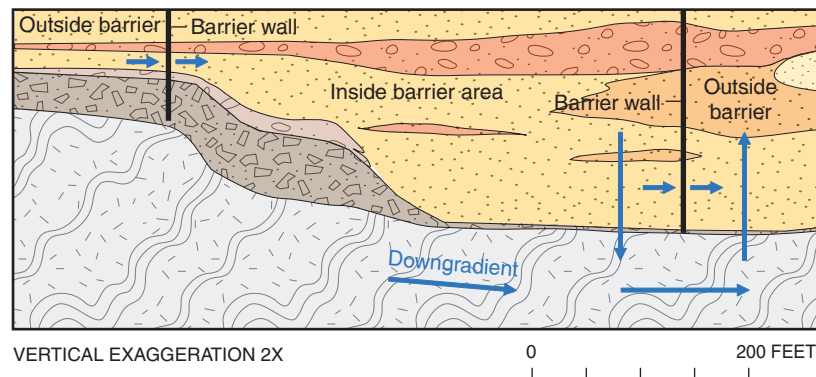
B. Operating with extraction
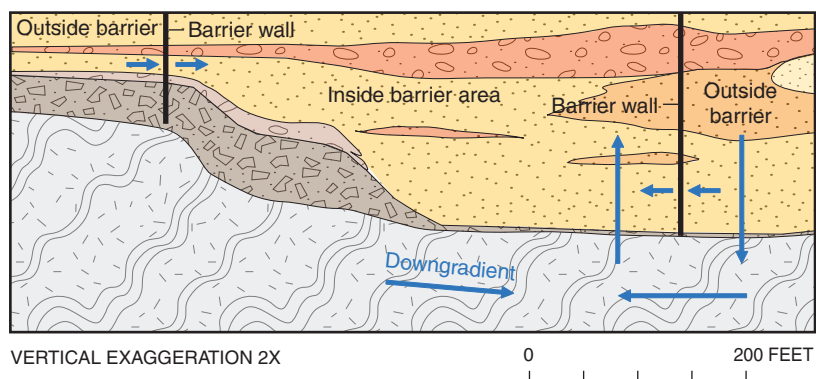
Figure 8. Schematic diagram of ground-water flow patterns between the overburden and bedrock inside and outside the barrier area for *A*, non-operating extraction conditions, and *B*, operating conditions, Operable Unit 1 (OU1), Milford, N.H.

at exterior wells intercepts flow rather than induces large drawdown. These conditions help to maintain inward gradients across the barrier.

An inward horizontal gradient across the barrier is important to contain solute transport of VOCs inside the barrier. When there is no net extraction (net extraction of zero), the mean horizontal gradients are outward in the overburden and bedrock from the barrier area. Small net extraction rates (less than 10 gal/min) also can produce conditions with outward gradients during medium to high recharge periods (Harte, 2004).

Extraction rates inside the barrier of 30 gal/min and greater are effective in maintaining inward horizontal hydraulic gradients toward the interior barrier area and reducing the potential for transport of PCE outside the barrier. For example,

during water year 2001 and 2003, (between PW-5 (inside) and PW-2 (outside) cluster wells), the mean horizontal head gradient between PW-5D (inside) and PW-2D (outside) was -0.00160 ft/ft or a head difference of -0.77 ft (negative means inward) for water year 2001 and -0.0401 ft/ft or a head difference of -1.92 ft for water year 2003. The increased inward gradient for water year 2003 was a result of increased extraction (specifically net extraction) inside the barrier from 18.5 gal/min in 2001 to approximately 62 gal/min in 2003.

Horizontal-head gradients in the bedrock between interior and exterior barrier areas are less than gradients in the overburden and, consequently, are more sensitive to variations in interior net extraction rates. Outward horizontal-head gradients in the bedrock between PW-5R and PW-2R occurred when interior extraction took place on 35 days in water year

2001 (net extraction rate of 18.5 gal/min) but only 3 days in water year 2003 (net extraction of 62 gal/min). The mean horizontal head gradient between PW-5R and PW-2R was -0.0025 ft/ft or a head difference of -0.12 ft for water year 2001 and -0.0079 ft/ft or a head difference of -0.36 ft for water year 2003.

Injection at the recharge gallery creates a water-table mound several feet high that spreads towards the river. This localized mounding affects local ground-water flow by reducing the flushing of river water into this part of the aquifer. Water-level increases from injection into the recharge gallery (fig. 2) are noticeable at P-2 well during low-recharge conditions. Injection rates of 90 gal/min at the gallery caused a water-level rise of 0.3 ft at well P-2 during low-recharge conditions in September 2002. Well P-2 is 190 ft from the gallery.

Injection at well RW-3 has little affect on ground-water levels. Water-level increases from injection at shallow (less than 30 ft deep) injection well RW-3 (fig. 2) is negligible at PW-2D located about 200 ft away. The rate of injection at RW-3 ranges from 5 to 25 gal/min.

Ground-Water Quality

Ground-water quality in OU1 is affected by natural and anthropogenic factors. The primary anthropogenic factor is the remedial system. The remedial system and other factors affect the overall ground-water chemistry and contaminant distribution. In this section, the general ground-water chemistry is discussed first and VOC distribution and trends is discussed second. Ground-water chemistry includes a discussion of major ions, metals, and total organic carbon. The VOC discussion focuses on the primary VOCs detected in OU1.

Water Chemistry

The general chemistry of ground water in the OU1 area is affected by the chemistry of the Souhegan River water that recharges the aquifer, infiltration of precipitation through the soils, road salting activities along Route 101, the geology of the subsurface materials, and remedial operation of wells and construction materials of the barrier wall. Ground-water residence time and flowpath length and direction are also a major factor in water chemistry. At several wells, well-construction materials, such as grout, in the annulus space of the well borehole also affect water chemistry.

The general chemistry of sampled water from remedial extraction wells was analyzed in spring 2004 to identify if there are major differences in chemistry of waters between interior extraction wells (IW) wells and exterior extraction (EW) wells given the different capture areas[4] of the wells. Water samples were analyzed for major cations, anions, metals, total organic carbon, and VOCs by USEPA, Region 1 Laboratory. On April 28, 2004, water samples were collected

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[4] The term capture areas used in this report refers to the three-dimensional volume of aquifer contributing water to extraction wells.

at the OU1 plant. The water collected from the OU1 plant was derived from individual active remedial extraction wells (IW-1, IW-2, EW-1, and EW-2), called influent water, and from the combined processed water, remediated for VOCs, and subsequently injected into the recharge gallery, called effluent water. The effluent water was sampled to determine whether water being injected into the aquifer has a different chemical signature than ambient water in the area of the recharge gallery.

Specific conductance of water samples from remedial wells except IW-2 are generally high (greater than 300 µS/cm) and exceed the mean concentrations of specific conductance from shallow overburden, deep overburden, and bedrock observation wells (table 2) in OU1. The cause of elevated specific conductance in water samples from remedial wells is likely because of location. Remedial wells IW-1 and EW-2 are close to Route 101 and capture the highest amount of water affected by road-salting, whereas most samples from observation wells are from wells north of EW-1 that receive along flowpaths emanating from the river area that are less affected by road salting. Of the 611 samples analyzed for specific conductance, 466 samples (76 percent of samples) had concentrations less than 337 µS/cm, which was the concentration measured at EW-2, and 398 samples (65 percent of samples) had concentrations less than 252 µS/cm, the concentration measured at EW-1. Most samples from observation wells with concentrations exceeding 337 µS/cm are from wells near Route 101 that receive flowpaths from that area.

Some samples with high specific conductance are from wells farther away from the road, which should be less affected by road salting. These samples are affected by grout contamination at the well and have anomalously high pH (greater than 8.5). One additional well (PW-2S) had high specific conductance values (exceeding 600 µS/cm) from samples in 1999. Well PW-2S is a shallow well and constructed with no cement grout in the annulus spacing of the borehole. It is possible, given this well is less than 50 ft from the barrier, that the water chemistry is affected by the slurry of the barrier. The pH of samples from PW-2S were all less than 7, and indicate the specific conductance is unaffected by grout contamination but potentially affected by slurry contamination from the barrier because samples showed no corresponding increase in pH with high specific conductance. The pH of the slurry, when mixed with ambient water from the site, was approximately 7 (Camp, Dresser, and McKee, Inc., written commun., 1998). Specific conductance of the slurry was not directly measured but values of specific conductance of water in contact with bentonite (the material comprising the slurry) were measured at approximately 470 µS/cm.

The specific conductance of effluent water injected into the recharge gallery (303 µS/cm) exceeds the ambient specific conductance from the river (90.5 µS/cm) and ground water upgradient from the gallery (120 µS/cm). Therefore, the relatively high specific conductance of injected water is identifiable in ground water as a tracer at locations downgradient of the gallery.

Table 2.   Summary of inorganic and selected volatile organic compounds, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[USGS, U.S. Geological Survey; site type names explained in abbreviation section of report; locations of all wells shown in figure 2; IW, interior extraction well; EW, exterior extraction well; --, no data; source of data: U.S. Environmental Protection Agency, Region 1 (1999); wells affected by grout contamination excluded from statistical summary; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; >, greater than; <, less than; ~, approximate]

Constituent and unit of measurement	Mean concentration			Well name and date of sample collection					
	Shallow overburden wells	Deep overburden wells	Bedrock wells	River	IW-2	IW-1	EW-2	EW-1	Gallery
	pre-1999	pre-1999	pre-1999	12/4/2003	4/28/2004	4/28/2004	4/28/2004	4/28/2004	4/28/2004
Number of samples	25	17	8	1	1	1	1	1	1
Specific conductance (µS/cm)	232	237	195	91	168	448	337	252	303
pH	5.8	5.8	8.5	--	--	--	--	--	--
Calcium (mg/L)	8.7	12	17	3.7	11	19	19	14	16
Magnesium (mg/L)	1.5	2.3	2.5	0.84	2.2	2.6	2.8	2.4	2.4
Sodium (mg/L)	31	26	17	12	14	60	38	26	36
Potassium (mg/L)	2	2	3.5	0.81	1.6	2.8	2.6	2	2.1
Alkalinity, bicarbonate (mg/L)	13.2	14.6	65	5.9	22	23	14	12	17
Alkalinity, carbonate (mg/L)	0	0	0	0	0	0	0	0	0
Sulfate (mg/L)	12	14	8.5	6.4	20	35	34	26	28
Chloride (mg/L)	52	52	13	18	26	99	73	52	64
Flouride (mg/L)	--	--	--	.05	.25	0.25	0.25	0.25	0.25
Bromide (mg/L)	.5	0.5	0.4	<.5	<.5	<.5	<.5	<.5	<.5
Nitrate (mg/L)	.5	0.5	0.2	.05	2.7	8.3	6.9	3.4	4.1
Aluminum (mg/L)	--	--	--	<.2	<.1	<.1	<.1	<.1	<.1
Arsenic (mg/L)	--	--	--	--	<.1	<.1	<.1	<.1	<.1
Barium (mg/L)	--	--	--	<.03	<.03	.042	.032	<.03	<.03
Iron (mg/L)	0.6	0.4	1.1	0.43	0.11	<.1	<.1	<.1	<.1
Manganese (mg/L)	0.2	0.3	0.1	0.05	0.021	.057	.058	.2	.13
Zinc (µg/L)	--	--	--	<.03	0.42	.44	<.03	<.03	.42
Total organic carbon, (mg/L)	1.6	0.7	1	~3.4	<.5	<.5	<.5	<.5	
cis-1,2-dichloroethene (µg/L)	84	58	45	--	10	25	1	1	1
Tetrachloroethylene (µg/L)	507	979	682	--	1,020	374	45	24	1
Trichloroethylene (µg/L)	100	70	80	--	44	33	1	1	1

Specific-conductance values (fig. 9) from samples from cluster wells (PW-12 and PW-13) downgradient from the recharge gallery show large increases in specific conductance since the barrier construction in November 1998, and start of remedial operations in March 1999. Samples from wells B95-3 (fig. 9B), PW-3S (fig. 9A) and PW-3D (fig. 9C) upgradient from the gallery show little increase. The specific conductance of samples from the PW-12 well cluster steadily increases from the early spring of 1999 for PW-12S (fig. 9A), the fall of 1999 for PW-12M (fig. 9B), and the late spring of 2000 for PW-12D and PW-12R (fig. 9C). The lag time in specific conductance increases with depth is controlled by increased travel times because the injected water enters at the water-table surface and must travel increasingly long distances to intersect the deeper wells. The specific conductance of samples from the PW-13 cluster steadily increase from the early spring of 2000 for PW-13S (fig. 9A), PW-13M (fig. 9B), and PW-13D (fig. 9C) indicating vertical mixing of ground water between the gallery and these wells. The increase in specific conductance is greatest at PW-13S (fig. 9A), less at PW-13M (fig. 9B), and the least at PW-13D (fig. 9C) indicating dilution occurs with depth.

Ground-water seepage velocities were estimated by identifying increases in specific-conductance at downgradient wells from injection in the gallery. By use of a simple average seepage velocity calculation (Zheng and Bennett, 1995, p. 6, eq. 1–6), given the timing of increases in specific conductance and the travel distances, an approximate ground-water (seepage) velocity of 1 ft/d was computed for all PW-12 and PW-13 wells except PW-12S, which had a computed velocity of 5 ft/d.

The specific conductance of water from well PW-14M shows negligible increase in specific conductance since 1999. A possible cause for this negligible increase is that travel times to PW-14M from the gallery exceed 4 years.

Total organic carbon (TOC) is an important constituent to examine because anaerobic degradation of aliphatic organic compounds, such as PCE, are electron-donor limited and TOC is the primary source of carbon in the absence of anthropogenic carbon sources (U.S. Environmental Protection Agency, 1999). TOC concentrations at remedial wells were all below USEPA detection levels (0.5 mg/L). TOC concentrations are generally low in OU1 from subsurface sediments (Camp, Dresser, and McKee, Inc., 1996) and ground water (Harte and others, 2001). TOC concentrations are slightly higher (approximately 3 mg/L) in the river and some shallow wells adjacent to the river than in other wells. Historically, the river and PW-6 well cluster have had the highest TOC concentrations, exceeding 2 mg/L.

Metal concentrations (aluminum, barium, iron, manganese, and zinc) were typically low (below detection levels) for most constituents from remedial well water samples. Iron concentrations from remedial well samples are less than mean concentrations from shallow overburden, deep overburden, and bedrock observation wells (table 2).

Major cations and anion concentrations of remedial wells indicate lowest concentrations in samples from IW-2 (table 2). Specific conductance was also the lowest at IW-2. In contrast, the highest concentrations of cations, anions, and specific conductance occurred in samples from IW-1.

The dominant cation of water from remedial wells is sodium, and the dominant anion is chloride. Sodium and chloride concentrations from remedial well samples closely correlate (coefficient of determination of 0.97). The likely reason for the strong relation between sodium and chloride concentrations is that these constituents are derived from road-salt dissolution.

Linear regression of sodium and chloride concentrations shows that the slope of the regression line (0.60) is similar to the ratio of molecular weight of sodium and chloride (0.65) found in salt. This relation indicates that even for low concentrations, such as that found at IW-2, salt affects the water chemistry. Sodium and chloride concentrations for shallow and deep overburden, bedrock, river, and remedial wells (table 2) indicate that the ratio of the mean concentration for sodium and chloride are near 0.65 except for samples from bedrock. Bedrock water samples show proportionally higher sodium to chloride concentrations indicating dissolution of sodium-bearing bedrock minerals contributes to the increase in sodium concentrations.

The proportional (percent) concentration of major cations and anions, in milliequivalents per liter, are shown in trilinear plots (figs. 10 and 11). Milliequivalents per liter are obtained from the product of the constituent (cation or anion) concentration and its ionic charge, divided by the formula weight of the cation or anion. The percentage of a specific cation concentration to total cation concentration is plotted on the left triangle, and the percentage of a specific anion concentration to total anion concentration is plotted on the right triangle. The middle triangle combines the percent cation or anion concentration. Trilinear plots are useful in characterizing water chemistry (type) because the dominant cation or anion is easily distinguishable.

Water types of the remedial wells are similar and indicative of a sodium-chloride water type for wells IW-1, EW-1, and EW-2 and calcium-sodium chloride water type for IW-2. The most dissimilar water chemistry is between IW-1 and IW-2 because the percentage of sodium varies the most between these samples. Water samples from IW-1 have the highest percentage of sodium, whereas IW-2 samples have the lowest (table 2).

The remedial well water chemistry is most similar to the water chemistry from the deep overburden (fig. 11) and the water chemistry from some shallow overburden (fig. 10) wells based on trilinear plots. However, the water chemistry of the overburden observation wells shows greater variation than the water chemistry from the remedial wells (fig. 10). Samples from some deep overburden wells (PW-6D and PW-10D) contain high calcium, sulfate, and bicarbonate concentrations (relative to other cation or anion concentrations) and are likely contaminated by grout. Samples from some shallow
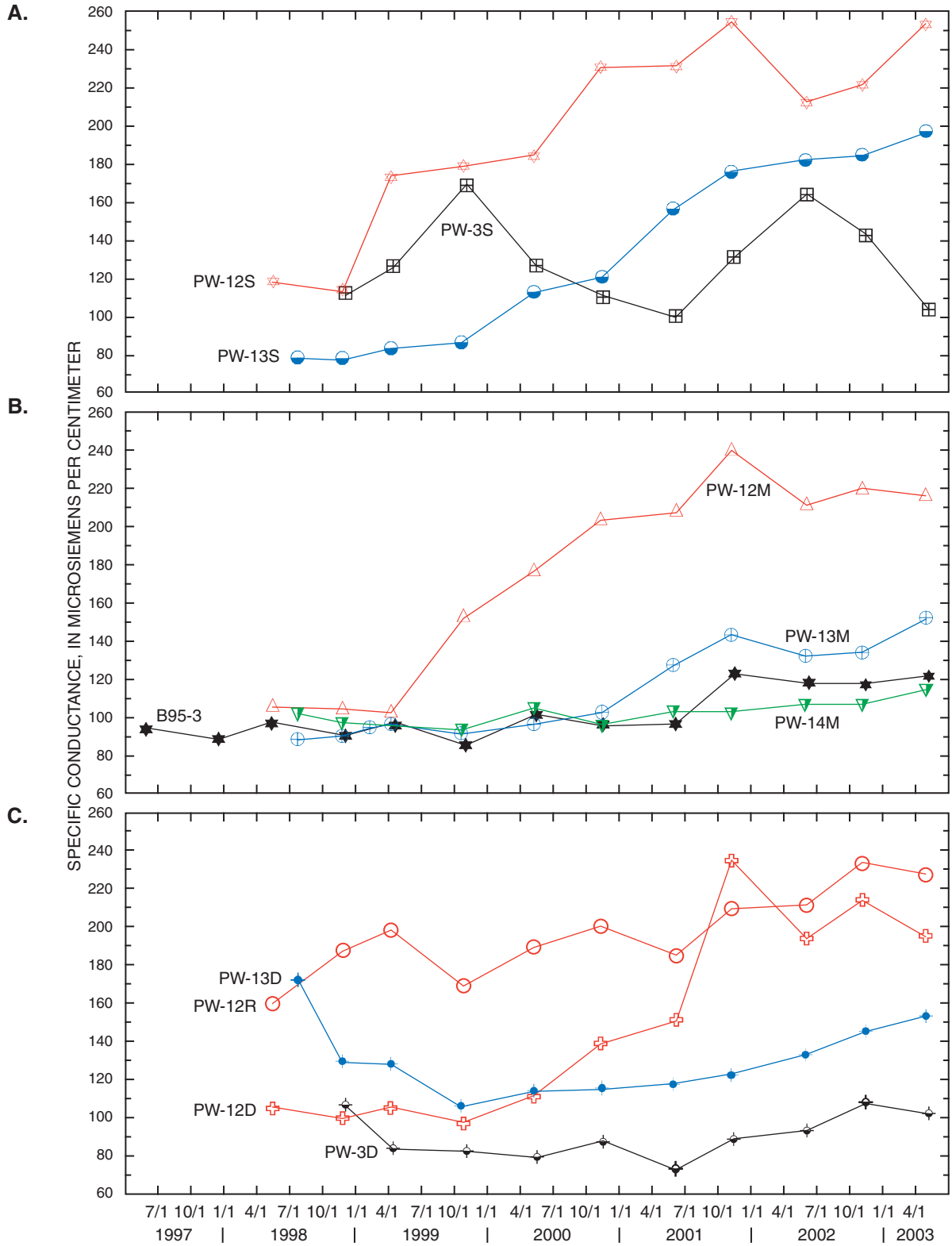
Figure 9.   Specific conductance for selected observation-well clusters in Operable Unit 1 (OU1), Milford, N.H. *A*, shallow (S) overburden wells; *B*, middle (M) overburden wells and B95-3; and *C*, deep (D) overburden and bedrock (R) wells. Lines color coded by well cluster. Location of wells shown on figure 2.
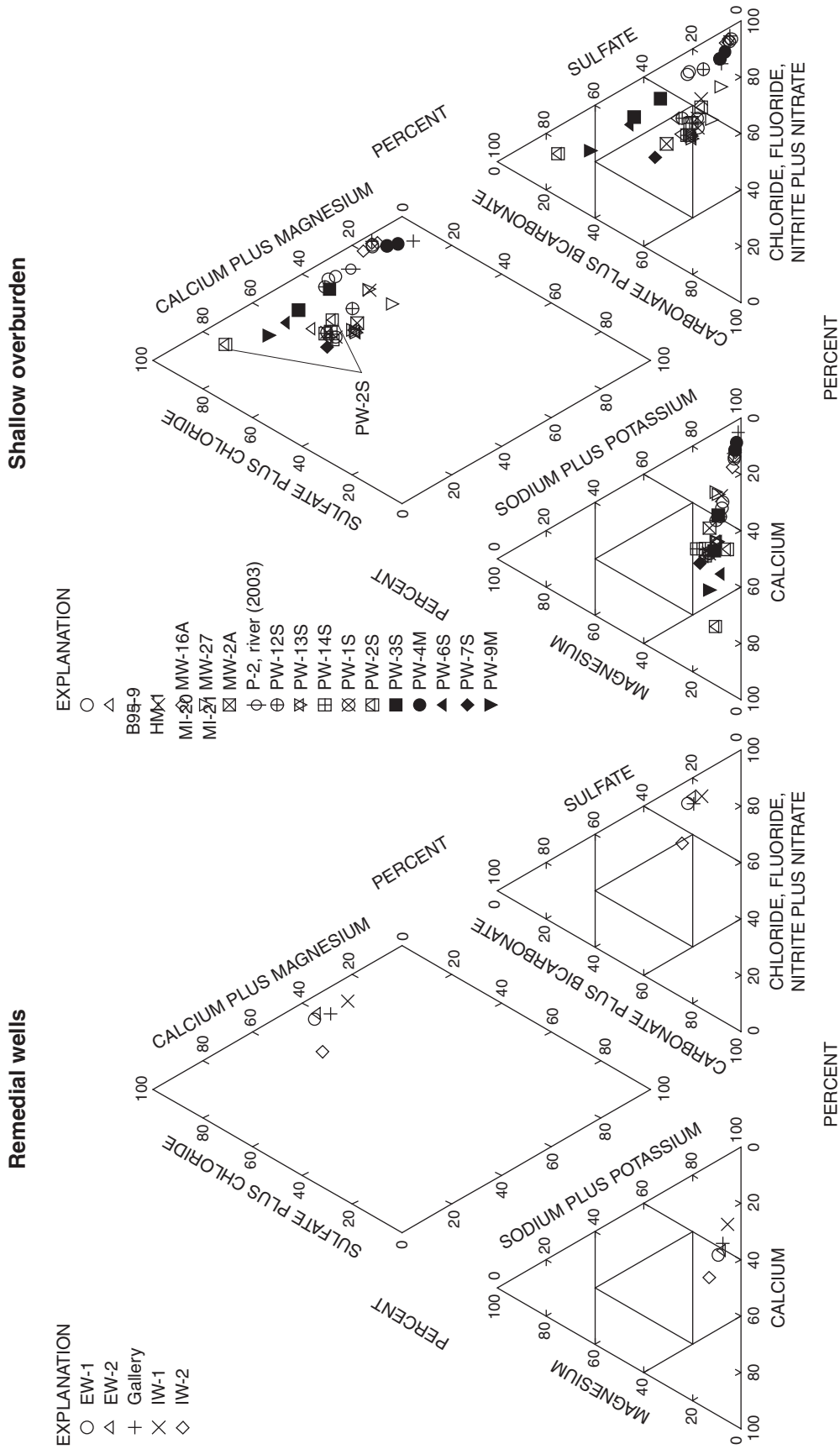
Figure 10.   Trilinear diagrams of major anion and cation chemistry for remedial wells (2004) and shallow overburden wells (1998), Operable Unit 1 (OU1), Milford, N.H. Location of wells shown on figure 2.
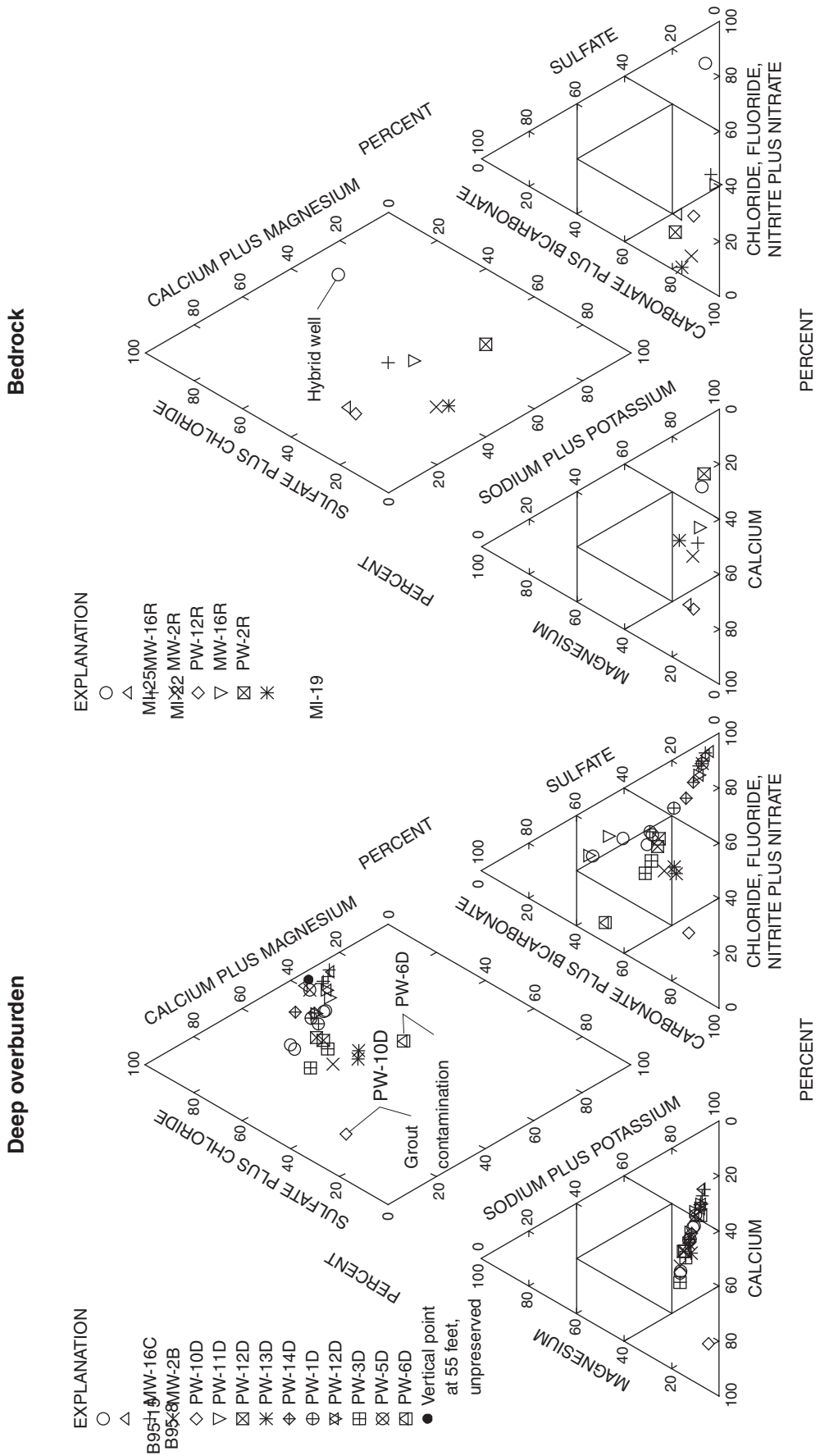
Figure 11. Trilinear diagrams of major anion and cation chemistry for deep overburden wells and bedrock samples (1998), Operable Unit 1 (OU1), Milford, N.H. Location of wells shown on figure 2.

overburden wells contain higher percentages of sodium and chloride than remedial wells, while others (PW-2S) contain some higher calcium concentrations (relative to other cation concentrations) and could be affected by slurry from the barrier.

Bedrock water chemistry has the highest percentage of bicarbonate concentrations to total anion concentrations, and bicarbonate concentrations from bedrock well samples (mean concentration of 65 mg/L) exceed bicarbonate concentrations of samples from remedial and overburden wells. Differences in the vertical distribution of bicarbonate concentrations between overburden and bedrock are useful to help quantify the amount of bedrock water being captured by extraction of remedial wells.

Bicarbonate concentrations of interior wells IW-1 (23 mg/L) and IW-2 (22 mg/L) exceed concentrations of exterior wells EW-2 (14 mg/L) and EW-1 (12 mg/L) and indicate interior wells capture more bedrock waters than the exterior wells. Bicarbonate concentrations are highest in bedrock waters (mean concentration of 65 mg/L), whereas bicarbonate concentrations of samples from overburden wells are low (mean concentration of 13.2 mg/L and 14.6 mg/L for shallow and deep overburden, respectively). The bicarbonate concentrations of the exterior remedial wells are similar to shallow and deep overburden wells and indicate negligible recharge from bedrock waters to the exterior wells (table 2). The bicarbonate concentrations of the interior remedial wells are higher than that of the shallow and deep overburden wells and indicate some recharge from bedrock waters to the internal wells. By use of a mass-balance equation to solve for two sources (bedrock and deep overburden) of water to the interior wells, and solving for the bicarbonate concentration of 23 mg/L (IW-1), a percent contribution of bedrock recharge to IW-1 of 17 percent is computed. This number is probably a minimum value of bedrock recharge because as bedrock water upflows into the interior barrier area and travels in the deep overburden to the IW-1 well, some bicarbonate reaction to carbonic acid probably takes place given the lower pH of ground water in the overburden, which would tend to reduce bicarbonate concentrations en route to the well.

Volatile Organic Compound Trends

The distribution of PCE concentrations in the middle overburden from 1995 is shown in figure 2. Concentrations in the middle overburden typically rank between the shallow (low concentrations) and deep (high concentrations) overburden except near source areas. The area containing concentrations at or above 1,000 ppb is extensive and continuous from the suspected source zones; source zones are shown on figure 2. In December 1998, PCE concentrations were similar to 1995 as shown in figure 12. In December 1998, the barrier was just completed but remedial extraction had yet to start.

Pre-remedial VOC trends were examined in Harte (2004) who showed that a first-order exponential decay equation could describe bulk decreases of VOC concentrations in OU1.

An exponential rate constant of 0.13 was computed (Harte, 2004, p. 14). Given a rate constant of 0.13, for the 3 years between 1995 and 1998, a reduction of PCE concentrations of less than a third would occur, which is supported by the similarity in concentrations shown on figure 12 and figure 2. The reductions in VOCs are probably from a decrease in the amount of dissolution from the DNAPL as a result of a mass decrease in the DNAPL pool size.

In November 2001 (fig. 13), remedial operation of the extraction wells, partial operation of the SVE wells inside the barrier, and containment by the barrier help reduce and limit transport of PCE as indicated by the reduction in size of the area covered by the 1,000 ppb contour. In November 2001, the 1,000 ppb contour terminates at the barrier wall unlike in 1998 (fig. 12) when it extends into OU2. Remedial rates of PCE decrease were shown by Harte (2004) to increase from an exponential rate constant of 0.13 to 0.26. For the 3-year period from 1998 to 2001, a reduction of PCE concentrations of more than 50 percent would occur, as supported by the reduction in area covered by the 1,000 ppb contour (figs. 12–13).

In November 2000, chlorinated solvents were accidentally released to the recharge gallery because of a problem with the treatment system (U.S. Environmental Protection Agency, 2001). The exact mass of VOCs released is unknown but estimated PCE concentrations ranged from 13,000 to 260,000 ppb. PCE concentrations increased in adjacent shallow and medium wells (PW-12S and PW-12M) in the spring of 2001 (Leah Desmarais, New Hampshire Department of Environmental Services, written commun., 2004). In June 2001, exploratory vertical profiles were installed to help map the release (Camp, Dresser, and McKee, Inc., 2001). A revised November 2001 PCE concentration map (fig. 14) with the incorporated vertical profile data (appendix 2) shows a distinct PCE plume expanding from the recharge gallery in the deep overburden (fig. 14C).

Comparison of PCE concentration over time to initial PCE concentration at the start of remediation in December 1998 allows for identification of areas where PCE decreases are static or show little change. Concentrations from April 2004 indicate that most exterior barrier wells had concentrations about one-fifth of the initial concentrations (table 3). Well samples with slow or negligible decreases include PW-14M in the middle overburden and PW-2R in the bedrock. PW-14M is located downgradient from the EW-1 and EW-2 wells and ground-water velocities are slowed from extraction. Bedrock well PW-2R is just outside of the barrier and remedial extraction inside the barrier probably decreases dilution in the bedrock because of induced bedrock upflow into the overburden.

Decreases in PCE concentration show large variability in interior wells. Wells east of interior extraction wells IW-1 and IW-2 and away from the direct path of suspected source zones and extraction wells show large decreases (table 4 and fig. 2). Wells located between source zones and interior extraction wells show no decrease. PW-6 cluster wells generally show large increases (PW-6D, table 4). This indicates that the
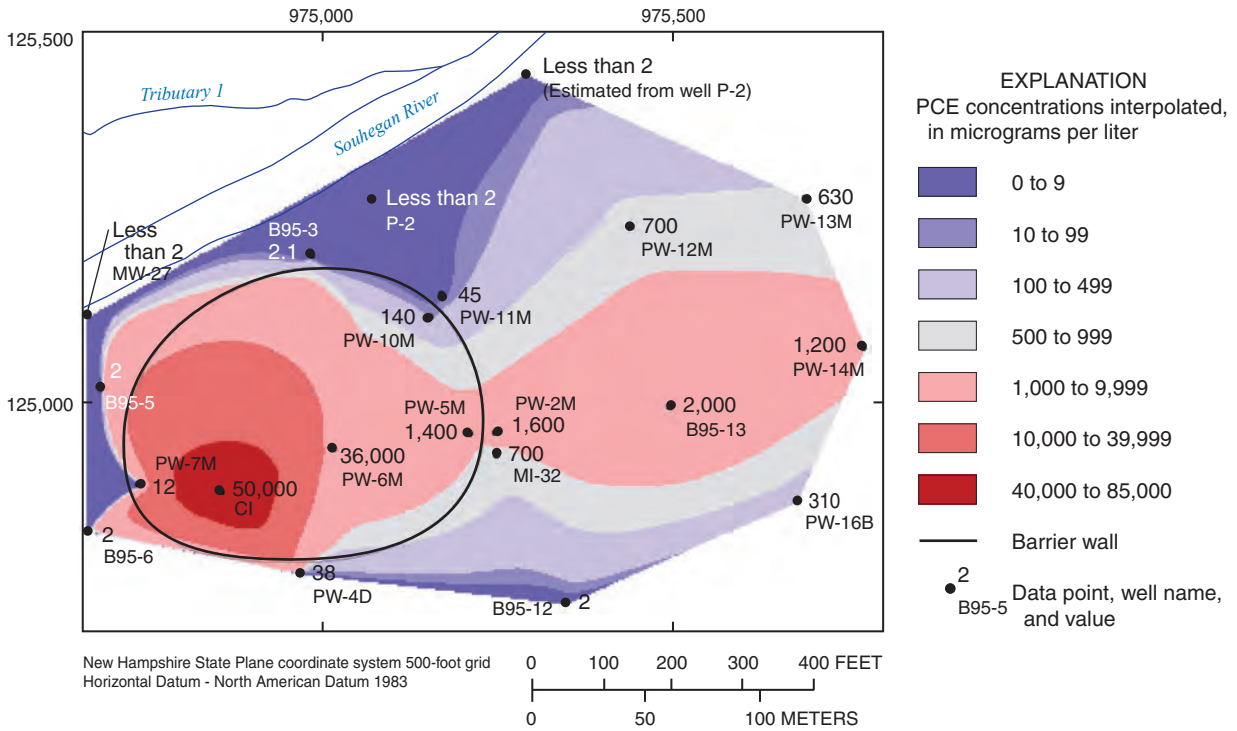
Figure 12. Concentrations of tetrachloroethylene (PCE) in middle overburden, December 1998, Operable Unit 1 (OU1), Milford, N.H.
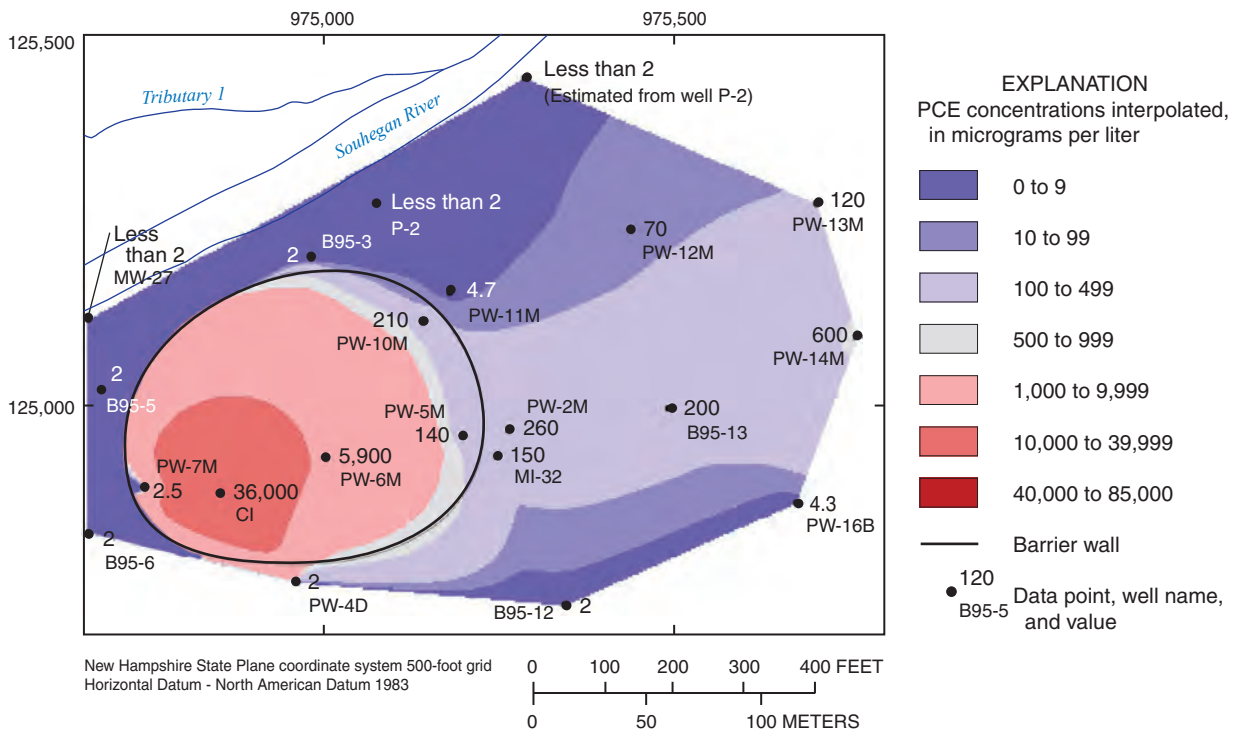
Figure 13. Concentrations of tetrachloroethylene (PCE) in middle overburden, November 2001, Operable Unit 1 (OU1), Milford, N.H.

A. Shallow overburden from shallow-depth samples, 0 to 40 feet deep

New Hampshire State Plane coordinate system 500-foot grid
Horizontal Datum - North American Datum 1983
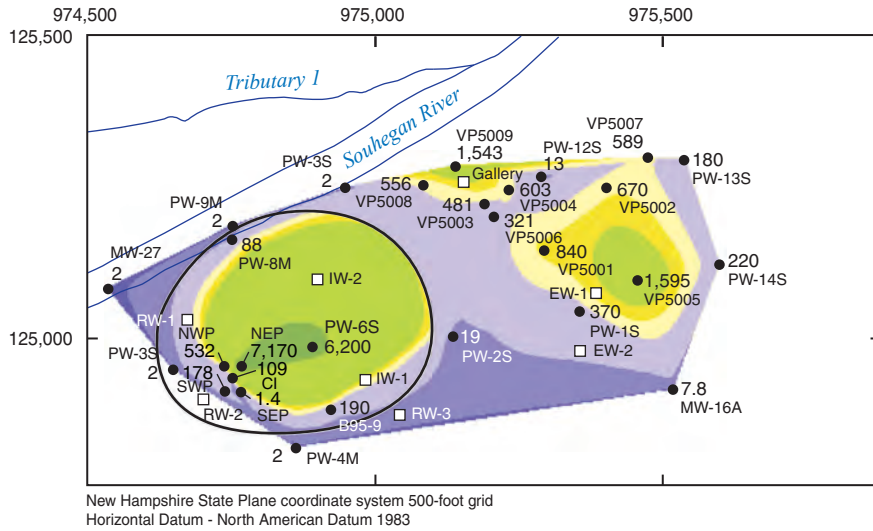
B. Middle overburden from medium-depth samples, 40 to 70 feet deep
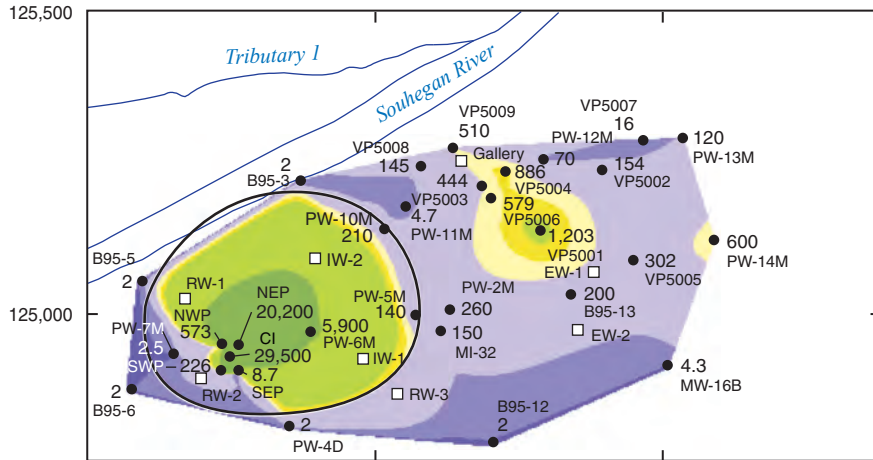
C. Deep overburden from deep samples, 70 to 105 feet deep
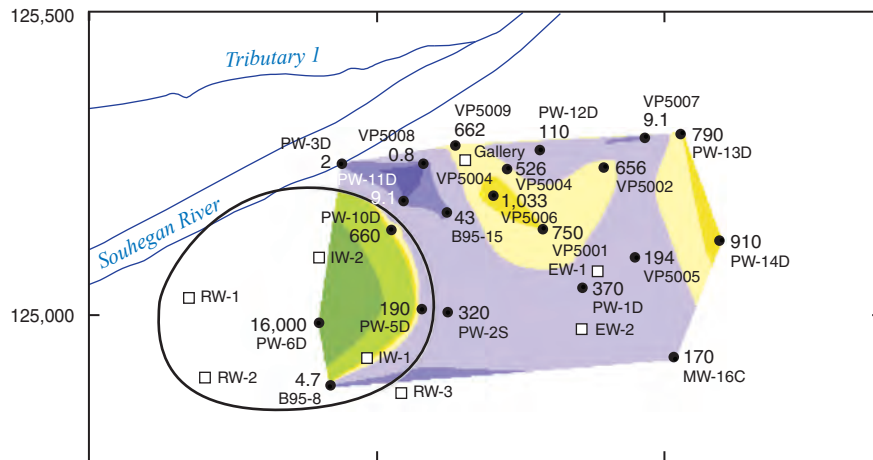
EXPLANATION
PCE concentrations interpolated,
in micrograms per liter

0 to 9
10 to 99
100 to 499
500 to 749
750 to 999
1,000 to 4,999
5,000 to 30,000

Barrier wall

310 Data point, well name
PW-3S and value

IW-2 Remedial well and
name

0   100   200   300   400 FEET

0   50   100 METERS
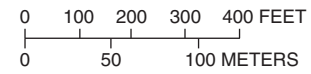
Figure 14.   Maximum concentrations of tetrachloroethylene (PCE) in November 2001 for *A*, shallow, *B*, middle, and *C*, deep overburden, Operable Unit 1 (OU1), Milford, N.H.

Table 3.   Observed PCE concentrations of exterior barrier wells for December 1998, May 2000, November 2001, and April 2004 in Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[PCE, tetracholorethylene; C/Co, ratio of current to initial concentration; Concentrations in parts per billion (ppb); --, no data; Wells sorted by depth: S, shallow (less than 40.1 feet below land surface); M, medium (40.1–70 feet depth); D, deep (greater than 70 feet); R, bedrock; Well locations shown on figure 2]

Well name	Well number	Easting, State Planar (in feet)	Northing, State Planar (in feet)	Code, depth of well	Concentration of PCE (observed)				Relative PCE change (C/Co)			Comments
					December 1998	May 2000	November 2001	April 2004	May 2000	November 2001	April 2004	
MW-16C	344	975678.1	124877.1	D	1,500	380	170	40	0.25	0.11	0.03	
B95-15	409	975254.0	125149.4	D	410	12	43	2	.03	.10	.00	
PW-1D	531	975507.1	125011.0	D	2,400	320	370	52	.13	.15	.02	
PW2D	534	975245.2	124965.2	D	1,700	1,000	320	80	.59	.19	.05	
PW-3D	537	975059.1	125239.1	D	2	2	2	2	--	--	--	
PW12D	557	975432.2	125281.2	D	700	190	110	16	.27	.16	.02	
PW-13D	561	975682.2	125294.2	D	1,100	1,100	790	320	1.00	.72	.29	
PW-14D	564	975765.2	125085.2	D	1,750	2,700	910	507	1.54	.52	.29	
MW-16R	345	975670.8	124875.2	R	300	70	120	128	.23	.40	.43	
PW-2R	535	975254.7	124973.6	R	20	9	52	242	.45	2.60	12.10	
PW-12R	558	975437.6	125267.4	R	870	650	190	282	.75	.22	.32	
MI-32	46	975247.2	124933.7	M	700	435	150	--	.62	.21	--	
MW-16B	321	975671.0	124868.6	M	310	51	4	2	.16	.01	.01	
B95-12	407	975343.8	124724.7	M	2	2	2	2	--	--	--	
B95-13	408	975490.6	125002.0	M	2,000	100	200	12	.05	.10	.01	
PW2M	533	975245.1	124965.1	M	1,600	210	260	5	.13	.16	.00	
PW12M	556	975437.2	125255.7	M	700	41	70	2	.06	.10	.00	
PW-13M	560	975682.1	125294.1	M	560	71	120	156	.13	.21	.28	
PW-14M	563	975765.1	125085.1	M	1,250	730	600	1,260	.58	.48	1.01	
MW-16A	233	975671.2	124863.1	S	60	38	8	2	.63	.13	.03	
PW-1S	530	975498.5	125008.0	S	3,000	540	370	67	.18	.12	.02	
PW2S	532	975245.0	124965.0	S	1,400	27	19	2	.02	.01	.00	
PW-3S	536	975059.0	125239.0	S	2	2	2	2	--	--	--	
PW-12S	555	975432.0	125281.0	S	10	2	13	8	.21	1.30	.78	
PW-13S	559	975682.0	125294.0	S	94	89	180	52	.95	1.91	.55	
PW-14S	562	975765.0	125085.0	S	950	230	220	39	.24	.23	.04	
				Mean	900	346	204	131	0.4	0.4	0.7	All wells.
				Median	700	95	135	39	.2	.2	.0	All wells.
				Mean	965	360	214	120	.4	.3	.2	Overburden wells only.
				Median	700	100	150	14	.2	.2	.0	Overburden wells only.

Table 4.   Observed PCE concentrations of interior barrier wells for December 1998, May 2000, November 2001, and April 2004 in Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[PCE, tetracholorethylene; C/Co, ratio of current to initial concentration; concentrations in parts per billion (ppb); wells sorted by depth: S, shallow (less than 40.1 feet midpoint depth of screen below land surface); M, medium (40.1–70 feet depth); D, deep (greater than 70 feet); R, bedrock; well locations shown on figure 2]

Well name	Well number	Easting, State Planar (in feet)	Northing, State Planar (in feet)	Code, depth of well	Concentration of PCE (observed)				Relative PCE change (C/Co)		
					December 1998	May 2000	November 2001	April 2004	May 2000	November 2001	April 2004
B95-8	403	975035.4	124825.8	D	65	10	5	2	0.15	0.07	0.03
PW-5D	541	975206.8	124969.2	D	1,500	420	190	57	.28	.13	.04
PW-6D	545	975014.3	124943.8	D	610	11,000	16,000	18,400	18.03	26.23	30.16
PW-10D	552	975149.6	125118.0	D	6,300	1,800	660	587	.29	.10	.09
PW-5M	540	975198.9	124963.3	M	1,400	690	140	17	.49	.10	.01
PW-6M	544	975005.4	124932.2	M	3,600	3,100	5,900	4,780	.86	1.64	1.33
PW-7M	548	974748.6	124890.1	M	12	2	3	2	.20	.21	.17
PW-10M	551	975142.3	125124.8	M	140	180	210	112	1.29	1.50	.80
PW-5R	542	975206.9	124959.1	R	95	37	44	45	.39	.46	.47
PW-6R	546	975015.9	124934.2	R	940	230	320	565	.24	.34	.60
B95-9	404	975039.8	124825.6	S	610	230	190	158	.38	.31	.26
PW-6S	543	975004.8	124942.1	S	3,100	4,600	6,200	3,000	1.48	2.00	.97
PW-7S	547	974747.6	124900.1	S	40	2	2	2	.06	.05	.05
				Mean	**1,416**	**1,715**	**2,297**	**2,133**	**1.9**	**2.5**	**2.7**
				Median	**610**	**230**	**190**	**112**	**.4**	**.3**	**.3**

DNAPL source has not been effectively remediated and that less dilution occurs inside the barrier than originally estimated for pre-remedial conditions. As a result, NHDES and USEPA have instituted aggressive treatment at this location as discussed in the section titled "Previous Investigations of Contaminant Source and Remediation."

Secondary VOC concentrations followed trends in PCE concentrations (figs. 15–16) inside and outside the barrier from 1998 to 2004. Concentrations of secondary VOCs (TCE, and *cis*-1,2DCE) are typically one-tenth to one-fifth the concentrations of PCE. Several interesting results are visible in the graphs in figures 15 and 16. First, a spike in PCE concentration occurs in January 2001 at PW-12S (fig. 15) that corresponds to the release in the fall of 2000 from the gallery. This spike in PCE concentration is not associated with a corresponding spike in secondary VOC concentrations. VOC concentrations from vertical profile points in 1995 compared to points collected in June 2001 indicate that PCE concentration comprised 99 percent of the total VOC concentration in 2001, whereas in 1995, it was 92 percent. Second, large decreases in PCE and secondary VOC concentrations are observed in overburden wells outside the barrier (fig. 15, PW-12S, 12M, and 12D) but not in overburden wells inside the barrier (fig. 16, PW-6S, 6M, and 6D). Third, only small decreases in PCE and

secondary VOC concentrations are detectable in the bedrock well outside of the barrier (fig. 15, PW-12R).

Effects of Barrier Construction and Trench Depths on Lateral Inflow

Examination of barrier wall construction and trench depths is useful to assess the amount of lateral inflow in the overburden between the interior and exterior barrier areas. Quantification of lateral inflow rates contribute to the development of water budgets for the interior overburden area. The interior water budget is then used to help develop conceptual models of flow to the interior extraction wells.

The barrier was constructed from June to November 1998. During construction, trench depths were recorded (appendix 3) and confirmed depths to bedrock and till contacts were noted. The coordinate system used to identify barrier and trench locations is given in figure 17. The barrier was designed and installed to fully penetrate the sand and gravel units of the overburden, and in most places, the basal till so as to sit atop bedrock. Where hard refusal or till was encountered, the barrier was set at least 3 ft into it (Richard Goehlert, U.S. Environmental Protection Agency, oral commun., 1999).
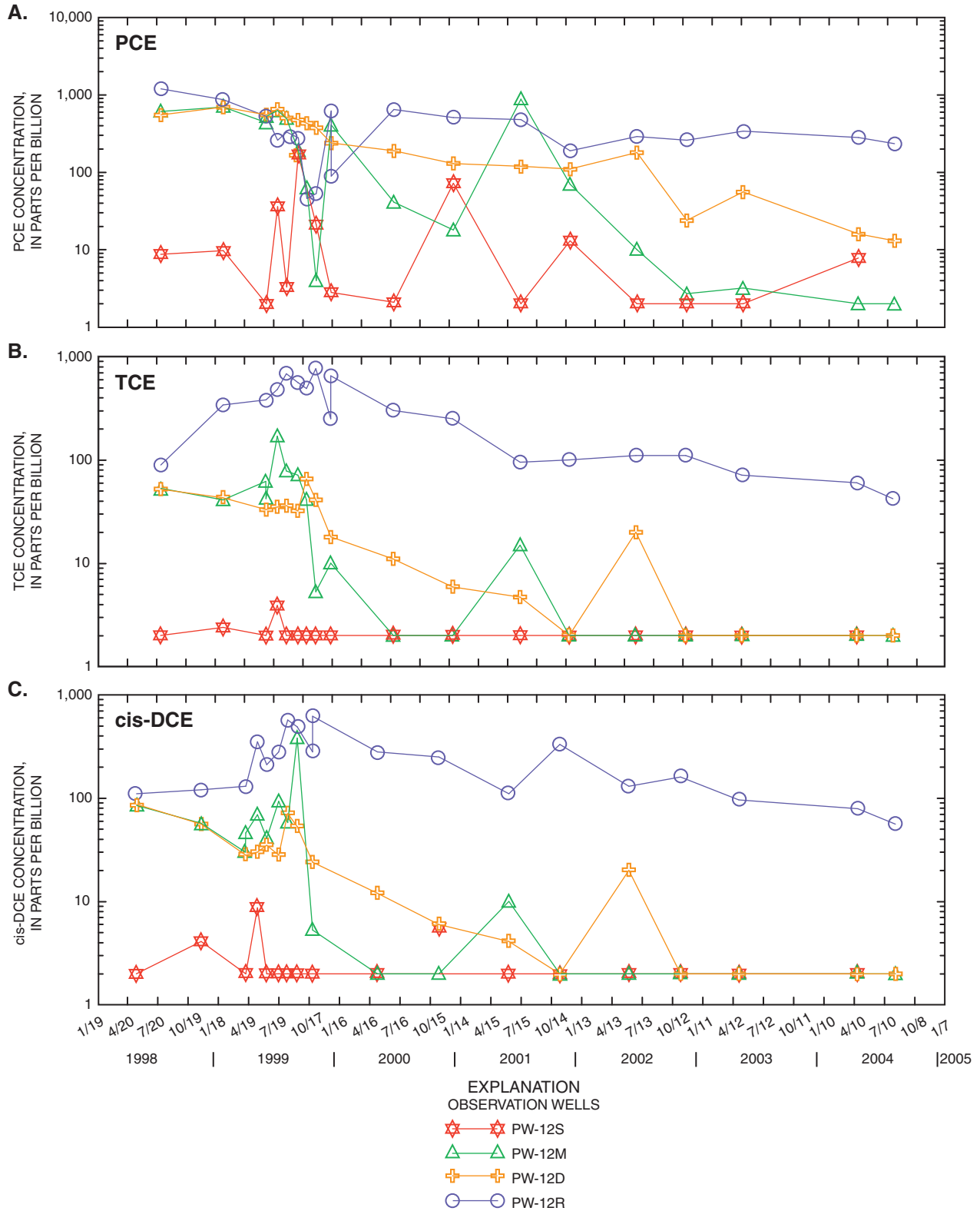
Figure 15. Concentrations of *A*, tetrachloroethylene (PCE), *B*, trichloroethylene (TCE), and *C*, *cis*-1,2 dichloroethylene (*cis*-DCE) for PW-12 cluster wells, Operable Unit 1 (OU1), Milford, N.H., 1998–2004. Location of wells shown on figure 2.
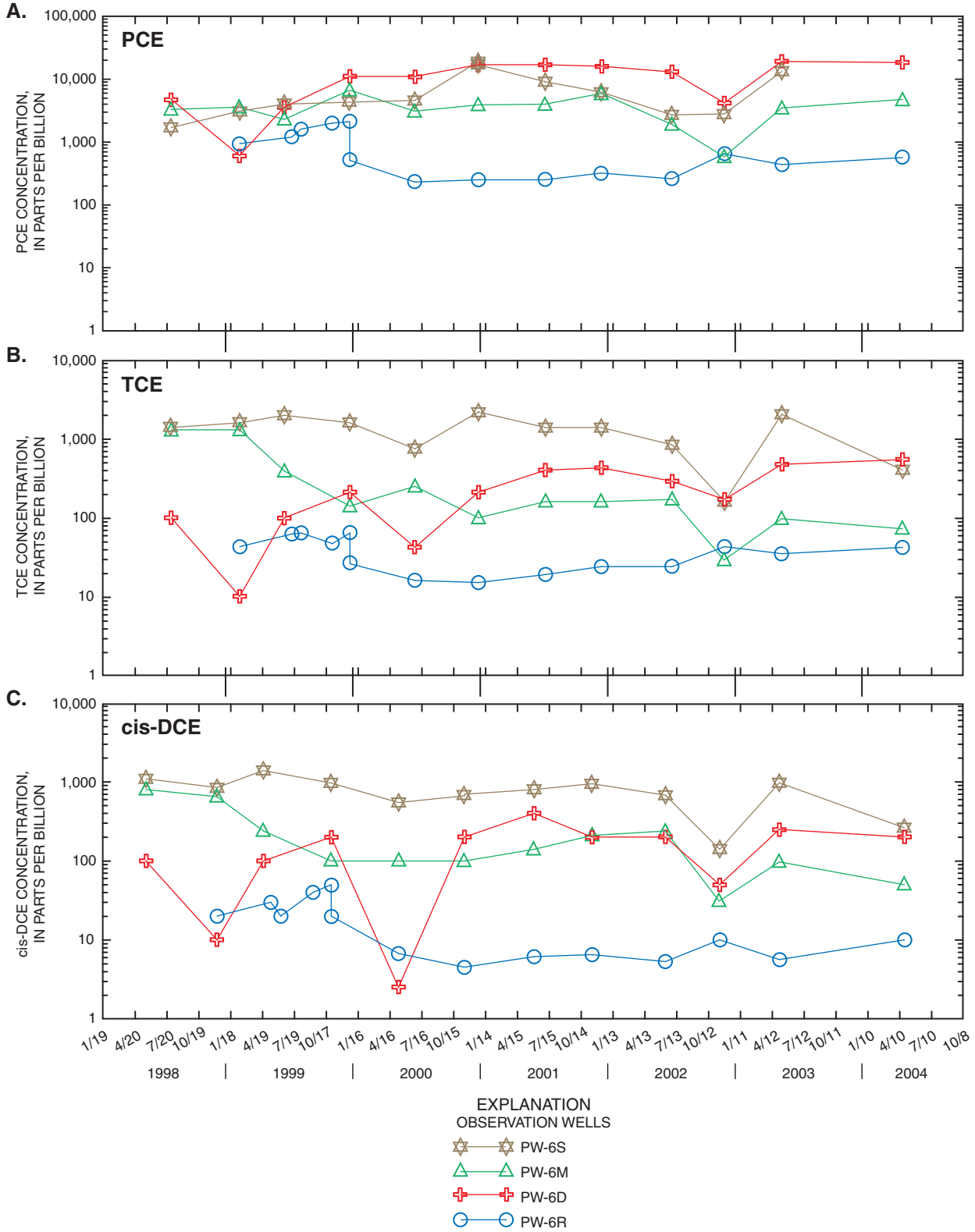
Figure 16. Concentrations of *A*, tetrachloroethylene (PCE), *B*, trichloroethylene (TCE), and *C*, *cis*-1,2 dichloroethylene (*cis*-DCE) for PW-6 cluster wells, Operable Unit (OU1), Milford, N.H., 1998–2004. Location of wells shown on figure 2.
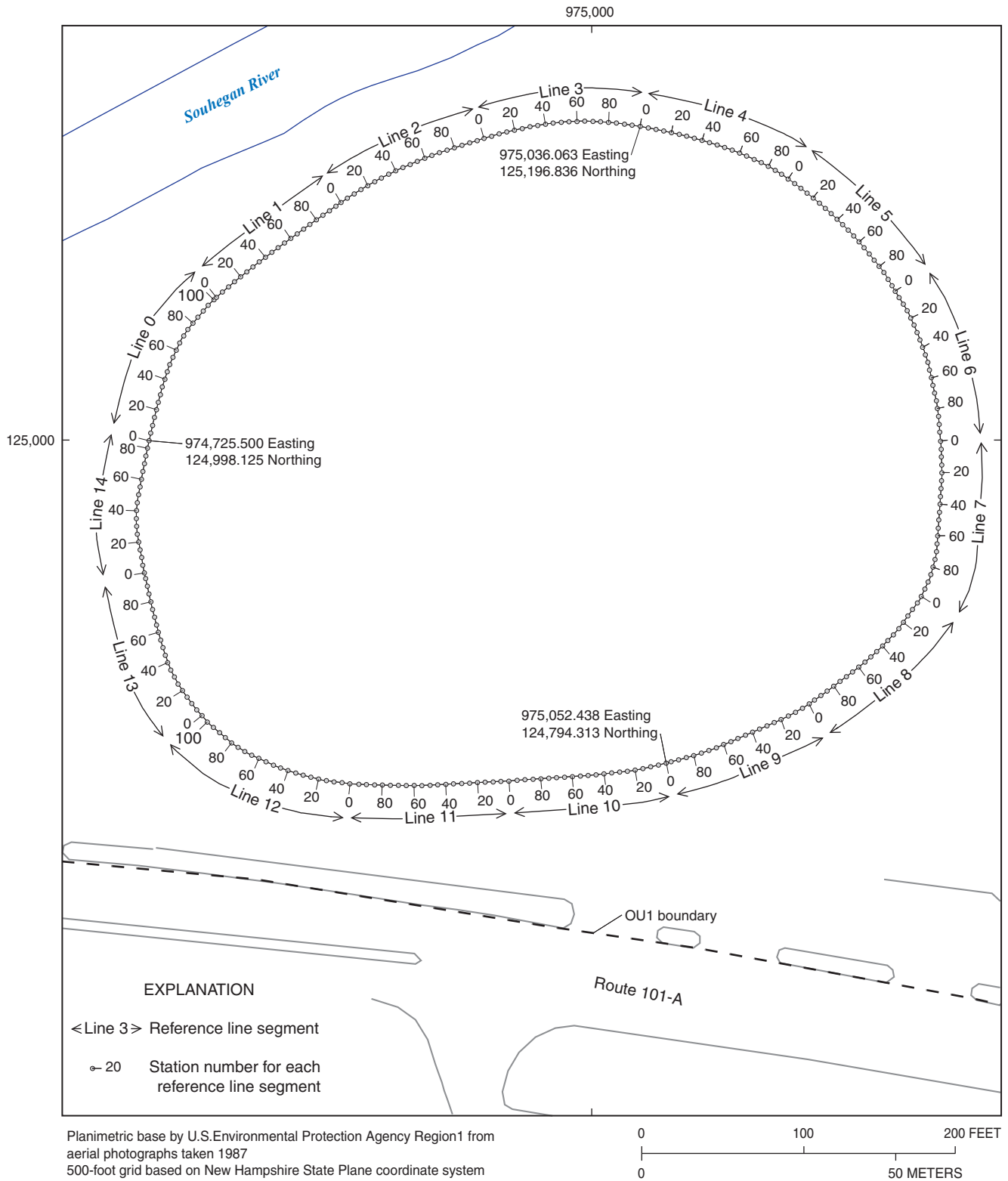
Figure 17.   Location, reference lines, and station numbers for completed (as built) barrier-trench system, Operable Unit 1 (OU1), Milford, N.H.

Recorded trench depths from barrier construction were compared to interpolated bedrock surface depths that were generated from borehole logs. The interpolated bedrock surface was from a previously used ground-water-flow and solute-transport model by Harte (2004). The comparison helps identify areas where premature trench depths may occur because incomplete penetration into the overburden would allow lateral flow of water in the overburden under the barrier.

Most of the barrier trench depths (called "as built" depths) match the interpolated bedrock surface and small differences of less than 5 ft (the assumed reasonable match criteria) occur. In other areas where trench depths are more than 5 ft shallower than the interpolated surface, confirmed bedrock was noted during construction, which indicates that the interpolated surface is too deep. In a small area near lines 12 (fig. 17) and 5, trench depths exceeded the interpolated bedrock surface by more than 5 ft indicating the interpolated surface is too shallow.

Trench depths along one area of the barrier were identified as potentially being too shallow (by more than 5 ft), which can allow horizontal flow into the overburden under the barrier. This area is from line 13 station 50 to line 0 station 50. Given the subsurface lithology at that location and reported trench depths, it is surmised that potentially up to 10 ft of till is not penetrated by the barrier.

No appreciable (greater than 5 ft thick) layers of sand and gravel were identified as incompletely (not fully) penetrated by the barrier. This indicates that horizontal ground-water flow in the overburden under the barrier area is small because incomplete penetration was only identified in the till. A calculation of one-dimensional ground-water flow using a Darcy-flow equation was done and a potential inflow of 0.7 gal/min was computed for the identified incomplete penetration area in the till. A flow rate of 0.7 gal/min was calculated assuming a horizontal hydraulic conductivity of 5 ft/d for the till, an average thickness of 10 ft, a length of 100 ft, and a horizontal gradient of 0.033 ft/ft for that area of the barrier. Harte (2004) found that bedrock upflow is likely to be a much more important component of the interior water budget (about 10 times greater in magnitude) than the estimated rate of lateral inflow through the till.

Thin (thickness less than 5 ft) permeable layers that are not fully penetrated by the barrier (permeable windows) are potentially unidentifiable. The likelihood of these layers existing is probably greatest in areas where the permeable layer directly overlies the bedrock in areas without till. Such areas may occur along the eastern perimeter of the barrier; however, data resolution is high in these areas and currently (2004), no permeable windows have been identified.

Simulation of the Remedial System and its Operation

Ground-water simulations of the remedial injection/extraction system were done to (1) understand sources of water and the water budget to extraction wells, (2) evaluate effectiveness of injection/extraction system to capture contaminated ground water within the overburden, (3) examine the relative importance of flow processes on capture of contaminated ground water, and (4) evaluate effectiveness of containment of the low-permeability barrier. A numerical ground-water flow and solute transport model was used to simulate the remedial ground-water system. Only the results of the flow simulations are presented in this report. A detailed description of the flow and transport model used for this study is presented in Harte (2004). The model consists of five layers approximately vertically discretized into 20-ft-thick model layers with horizontal discretization approximately 25 by 50 ft in OU1 (appendix 4). Model layers 1 and part of 2 correspond to the shallow overburden, layer 3 corresponds primarily to the medium overburden, and layers 4 and 5 correspond to the deep overburden.

For this report, most of the model simulations were done with a steady-state version of the remedial-transport model (Harte, 2004, p. 34). This steady-state model uses average rates of recharge and river stage as reported in Harte (2004, p. 25) but varies withdrawals based on simulated remedial operations. Hydraulic properties and other model-input values used in this report were the same as those presented in Harte (2004) unless otherwise noted. Simulations used the computer code MODFLOW-2000 (Harbaugh and others, 2000) and included tracking of advective transport of ground-water flow with ground-water particles to discern flow direction, velocity, and capture areas by use of MODPATH (Pollack, 1994).

The transient and steady-state remediation model used the MODFLOW Horizontal-Flow Barrier Package (HFB) (Hsieh and Freckleton, 1993) to simulate the barrier. The wall was set at a hydraulic conductivity value of 1.64e-09 ft/s based on permeability tests of the barrier slurry (Camp, Dresser, and McKee, Inc., written commun., 1998). The barrier-wall thickness is 3 ft and extends from above the water table to the bedrock or 3 ft into the till. A computer program ARGUS MODFLOW GUI (Winston, 2000) was used to assign barrier-wall hydraulic properties.

An important component of the remediation model is the solution of the interior area ground-water-flow budget for inside the barrier. The ground-water budget for inside the barrier wall is summarized as follows:

Net extraction = direct recharge ± net storage ± net flow through the barrier ± net flow under the barrier ± bedrock upflow   (1)

The net extraction term is controlled by the amount of extraction at IW-1 and IW-2 minus any injection at RW-1 and RW-2.

Information on net extraction rates from 1999–2003 is listed in table 5.

The transient-remedial model solves for the right-hand side of equation 1. The steady-state model version assumes that net storage changes are negligible. Harte (2004) found that annual storage changes are likely less than 1.2 gal/min or less than 10 percent of the 1999 annual ground-water budget for the interior barrier area.

Direct recharge inside the barrier from infiltration of precipitation was estimated at a yearly rate of 1.75 gal/min (Brayton and Harte, 2001). This rate is 50 percent less than the rate for outside the barrier. Brayton and Harte (2001) found that recharge rates inside the barrier area decreased by as much as a half from pre-construction periods because of the addition of a semiconical land-surface crown during barrier construction. Analysis of additional data subsequent to that reported in Brayton and Harte (2001) indicates that a recharge rate of 2.45 gal/min also may be appropriate (about a 30-percent reduction from outside the barrier). Therefore, simulated ranges in direct recharge varied from 1.75 to 2.45 gal/min.

The amount of inflow and outflow either through (throughflow) or under (underflow) the barrier in the overburden is considered a small part of the water budget for the interior barrier area. The barrier hydraulic conductivity (1.64e-9 ft/s) is low (Harte, 2004); therefore, the maximum inflow through the barrier is small. Furthermore, the analysis of trench depths indicates that only a small area in the till may not be penetrated by the barrier. An inflow rate from underflow into the interior barrier area (containment area) of 0.7 gal/min was calculated. Simulated ranges for underflow and throughflow are solved in the model but are constrained by the depth of penetration of the barrier assumed in the model.

Examination of the ground-water budget (eq. 1) for the interior barrier area shows that most of the annual budget is likely derived from bedrock upflow. In 1999, for the minimum rate of net extraction (9.6 gal/min) and assuming no storage changes, bedrock upflow is at least 57 percent (5.45 gal/min) of the interior ground-water budget, assuming inflow through or under the barrier of 1.7 gal/min and a recharge rate of 2.45 gal/min, or at the most 82 percent of the budget (7.85 gal/min), assuming no inflow through or under the barrier and a recharge rate of 1.75 gal/min. Simulated ranges in bedrock upflow, therefore, varied from 5.45 to 7.85 gal/min for 1999 conditions but increased, as discussed in the following paragraphs, for other conditions. Because bedrock upflow is calculated as a residual term in the ground-water budget for the interior barrier area, the accuracy of values calculated for bedrock upflow relies on the accuracy of the other calculated terms. Nevertheless, the importance of bedrock upflow in sustaining the net extraction rates inside the barrier is supported by water-budget calculations and by water-level monitoring.

To simulate upflow from the bedrock, a series of hypothetical injection wells were assigned to the model at the base of the overburden in layer 5 of the model because the bedrock is not simulated in the model and the bottom model boundary is treated as a no-flow boundary. Injection wells were simulated in areas where the till is thin or absent in the eastern half of the interior barrier area.

Initial model simulations assumed the barrier is fully penetrating with the barrier wall in the lowermost (5th) layer slightly more permeable (by a factor of 10) than the upper layers. This adjustment allows for some increased lateral inflow into the interior barrier area to account for the difficulty of constructing the barrier at the lowest depths of the overburden. Although the hydraulic conductivity of the barrier wall is increased by a factor of 10 in layer 5, the barrier is still relatively impermeable and inflow into the interior barrier area is restricted. In this report, a primary modification to the simulations of the barrier is the depth of penetration in the overburden. To accommodate the increase in net extraction inside the barrier from 1999 to 2003, model-simulation scenarios included adjusting the depth of penetration of the

Table 5. Remedial wells and operational rates for selected wells 1999–2003, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[All units in gallons per minute; rates represent mean rates while operating; *, combined mean rate; site type names explained in abbreviation section of report; location of all wells shown in figure 2; RW, injection well; IW, interior extraction well; EW, exterior extraction well; --, no data; Source of data: Camp, Dresser, and McKee, Inc., written commun. 2002; U.S. Filter, Inc. (2004 and 2005)]

Water year	Inside barrier				Outside barrier				Comments
	Net extraction rates	RW-1,2*	IW-1	IW-2	RW-3	Gallery	EW-1	EW-2	
1999	9.6	9.4	10.0	9.0	0.0	59.6	25.0	25.0	--
2000	28.9	0.0	13.5	15.4	.0	62.6	14.5	15.5	--
Early 2001	18.5	.0	9.9	8.6	.0	62.9	30.1	18.8	Estimated rates.
Late 2001	27.3	3.1	14.9	15.5	.0	62.9	30.1	18.8	--
2002	37.0	.0	11.0	26.0	.0	67.0	15.0	15.0	Estimated rates.
2003	62.0	.0	31.0	31.0	17.0	75.0	15.0	15.0	Estimated rates.

barrier and the amount of ground-water upflow from the bedrock. An alternative approach to simulating increased net extraction would be to simulate increased barrier throughflow by specifying hypothetical permeable holes in the barrier. This was not done because permeameter testing of the barrier bentonite material showed consistently low hydraulic conductivity values (range of 3.0e-9 to 3.0e-11; Camp, Dresser, and McKee, Inc., written commun., 1998).

Effects of Operational Variations on Ground-Water Flow and Solute Transport

This section includes a discussion on the effect of various remedial operational schemes, specifically, varying extraction and injection rates that were used, from 1999 to 2003 in OU1, on ground-water flow and solute transport. From 1999 to 2003, the net amount of water extracted inside the barrier (net extraction) increased in an attempt to decrease heads inside the barrier for the purpose of maintaining inward hydraulic gradients around the barrier and allowing the efficient use of the SVE wells; the SVE wells work most efficiently when water levels inside the barrier are less than 255 ft. Continuously monitored water levels from well B95-9 show that water levels generally did not decrease below 257 ft (Harte, 2005), although the net extraction inside the barrier increased from 9.6 to 62 gal/min from 1999 to 2003 (table 5).

The steady-state simulations discussed in this report were run with different rates of extraction and injection, as observed in the field at wells IW-1, IW-2, RW-1, RW-2, and at the recharge gallery. Rates were initially kept constant (25 gal/min) at EW-1 and EW-2, located outside the barrier, to simplify the analysis.

To facilitate the analysis of flow through the barrier (throughflow), assigned rates of recharge and bedrock upflow were initially kept constant (table 6; simulation type—"Evaluation of maximum barrier throughflow"). In addition, the barrier was assumed initially to fully penetrate the overburden with no openings in the till or sand and gravel layers. There-

fore under these scenarios, the model calculates the maximum potential horizontal inflow in the overburden through the low-permeability barrier wall. Interior barrier area ground-water budget terms per simulation are summarized in table 6.

Assuming a fully penetrating barrier wall, as the simulated net extraction inside the barrier increased from 9.6 (1999 rate) to 18.5 gal/min (early 2001 rate), model cells inside the barrier dewatered as a result of insufficient inflow. Therefore, the maximum potential inflow through the barrier is less than 9.52 gal/min, which was determined by adding the throughflow value computed by the model of 0.62 gal/min for the 1999 net extraction rate to the additional 8.9 gal/min (18.5 minus 9.6) needed for the 2001 net extraction rate. The throughflow rate of 0.62 gal/min for 1999 net extraction is equal to the net extraction rate of 9.6 gal/min minus an assigned bedrock upflow rate of 7.23 gal/min (calibrated value for 1999 conditions; Harte, 2004) and an assigned recharge rate of 1.75 gal/min (calibrated value for 1999 conditions; Harte, 2004).

To accommodate the increased net extraction rate while comparing to observed heads, it was necessary to simulate either incomplete penetration of the barrier or increase rates of bedrock upflow. The following discussion describes simulation results for the various rates (1999, 2001, 2002, and 2003) of net extraction after either adjusting the (1) depth of barrier penetration or (2) increasing assigned rates of ground-water upflow from the bedrock.

Sensitivity of Inside Barrier Area to Lateral Inflow

One of the primary reasons in simulating the remedial system and operation was to evaluate sources of water and their effect on capture areas to interior extraction wells (IW-1 and IW-2). One source of water to interior extraction wells is lateral inflow from underflow (eq. 1; term "net flow under the barrier"). The effect of varying the amount of lateral inflow as a result of net extraction inside the barrier for an assigned

Table 6.   Model ground-water budget terms evaluated during simulations of interior barrier area remedial system, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[gal/min, gallons per minute; Codes used: F, fixed value during simulation; C, calculated in simulation; V, variable adjusted between simulations; values in parentheses represent simulated rates]

Simulation type	Simulated ground-water budget terms (All values in gal/min)				
	Net extraction	Direct recharge	Barrier throughflow	Barrier underflow	Bedrock upflow
Evaluation of maximum barrier throughflow	F (9.6–18.5)	F (1.75)	C	F (0)	F (7.85)
Evaluation of barrier underflow	F (9.6–62.0)	F (1.75–2.45)	C	C	F (5.45–7.85)
Evaluation of bedrock upflow	F (9.6–62.0)	F (1.75–2.45)	C	F (0)	V (7.85–58)

constant rate of assigned recharge and upflow from bedrock (eq. 1) is discussed in this section and shown in table 6 (simulation type—"Evaluation of barrier underflow"). To allow for increased rates of lateral inflow in the overburden into the interior barrier area, the hydraulic conductivity of barrier cells in the HFB package were increased to rates exceeding the aquifer (from 1.64e-9 ft/s or 1.4e-4 ft/d to 1.0e-1 ft/s or 8.6e+3 ft/d). This procedure essentially assumes no barrier at these locations because it allows the horizontal hydraulic conductivity of the overburden, either the till (5 ft/d) or the sand and gravel (60 ft/d), to be the controlling factor of ground-water flow into the barrier.

Model results indicate it is unlikely that inflow into the interior barrier area is sufficient in the till if the barrier incompletely penetrates the till in small areas around the perimeter because interior model cells dewatered (excessive drawdown) with increased net extraction associated with 2001 conditions. In contrast, field-observation data indicate small (less than 6 ft) drawdowns. Initially, the hydraulic conductivity of the barrier was increased for one cell set in the till in layer 5, 50-by-10-ft along the southern barrier by the PW-4 well cluster (fig. 2). In this scenario, model cells also dewatered inside the barrier. Two additional barrier cells in layer 5 (all in the till) were then increased. In this scenario, heads inside the barrier dewatered in layer 1 only, and model-computed heads were about 248 ft at well B95-9. Because model-computed heads were still 9 ft below minimum observed heads, three additional barrier cells in layer 4 (tapping the sand and gravel layer) were increased. This hypothetical scenario is called a breach wall because the barrier incompletely penetrates the sand and gravel layer. In a breach-wall scenario, inflow was sufficient and model-computed heads increased to observed heads.

Although a formal calibration was not performed, model-computed heads were checked against observed heads of interior extraction wells to assess model performance before and after allowing for the increased lateral inflow. Model[5] drawdowns at IW-1 and IW-2 were similar to observed drawdowns before increasing lateral inflow, indicating the hydraulic properties of the overburden in the interior barrier area are appropriate. Model-computed heads are generally insensitive to varying the amount of allowable lateral inflow given that the amount of lateral inflow exceeds the net extraction inside the barrier. Model-computed heads were also checked against observed heads from selected, continuously monitored, water-level observation wells to guide sensitivity tests. A detailed discussion of model calibration is presented in Harte (2004, p. 36–53).

Heads from layer 1 (not shown) and layer 4 (fig. 18), ground-water-flow vectors, and particle pathlines were ana-

[5] Model-computed drawdown was not adjusted in the comparison to correct for differences between cell size and well diameter. This correction is important for wells with large extraction rates. For OU1 extraction wells, differences between model-computed heads and heads at the interior wells, IW-1 and IW-1, are small (less than 0.5 ft), because of their low rates of extraction, according to Trescott and others (1976).

lyzed to assess ground-water flow into OU1. Interval contours of 0.5 ft for model-computed head in layer 4 of the model are shown in figure 18 for 1999, 2001, and 2002 net extraction rates. The 1999 simulation (fig. 18A) assumes a fully penetrating barrier. The 2001 (fig. 18B) and the 2002 (fig. 18C) simulations assume a hypothetical breach wall in the sand and gravel layer near the PW-4 cluster wells (fig. 2). The extent of layer 4 ends to the west as the bedrock surface rises in this direction and layer 4 does not underlie the full perimeter of the barrier. The bottom of layer 4 corresponds to depths greater than 70 ft below land surface (deep overburden).

Model-computed head contours are gentle within the barrier, sharp across the barrier, and more uniform outside of the barrier (fig. 18). Ground-water recharge from river seepage is prominent in all simulations (shown by upward bending head contours across the river). On the eastern, downgradient side of the barrier, a slow velocity zone is created from the shadow of the barrier. The increased injection rates in 2002 (fig. 18C) at the gallery causes head gradients to increase between the gallery and exterior extraction wells EW-1 and EW-2.

Ground-water velocity vectors are shown in figure 19 for 1999, 2001, and 2002 net extraction rates. The 1999 simulation (fig. 19A) assumes a fully penetrating barrier. The 2001 (fig. 19B) and 2002 (fig. 19C) simulations assume a hypothetical breach wall in the sand and gravel layer near PW-4 cluster wells (fig. 2). Velocity vectors represent the magnitude and direction of the average linear velocity across the cell. Vectors are drawn from the cell midpoint as a small square with a line segment extending outward toward the predominant flow direction. A minimum velocity of 1e-5 ft/s or 0.84 ft/d was used. Vectors from all model layers are shown and are projected to the surface for visualization purposes. In general, most of the vectors are from model layer 1. Slow velocity zones are delineated by the absence of vectors. The barrier creates a slow velocity zone outside the barrier to the west (upgradient) and east (downgradient). Inside the barrier, velocity is slow (less than 0.84 ft/d) except in the simulation for 2002, where hypothetically high rates of inflow under the barrier occur for the breach-wall scenario and because extraction rates were increased at IW-2. The mounding of the water-table surface at the recharge gallery creates a slow velocity zone upgradient between the river and gallery for all simulations. The slow velocity zone increases at the gallery as a result of an increase in rates of injection for 2002; therefore, solute transport of any contaminated ground water upgradient of the gallery decreases with an increase in gallery injection.

One-year capture zones in the overburden are shown in figure 20 as capture areas for IW-1 and IW-2 for 1999, 2001, and 2002 net extraction rates. The 1999 simulation (fig. 20A) assumes a fully penetrating barrier scenario. The 2001 (fig. 20B) and 2002 (fig. 20C) simulations assume a hypothetical breach-wall scenario in the sand and gravel layer near PW-4 cluster wells (fig. 2).

One-year capture areas were developed by backward-tracking particle pathlines from the extraction wells and terminated after 1 year of advective transport. Pathlines are

Figure 18.   Model-computed head contours in layer 4 for remedial-operation rates in *A*, 1999, *B*, 2001, and *C*, 2002, Operable Unit 1 (OU1), Milford, N.H.
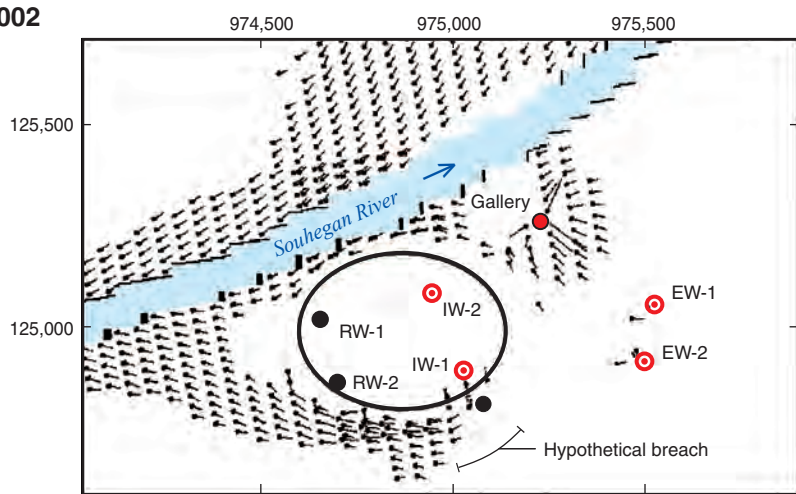
Figure 19. Model-computed horizontal ground-water velocity vectors for velocities above 0.84 feet per day for *A*, 1999, *B*, 2001, and *C*, 2002, Operable Unit 1 (OU1), Milford, N.H.
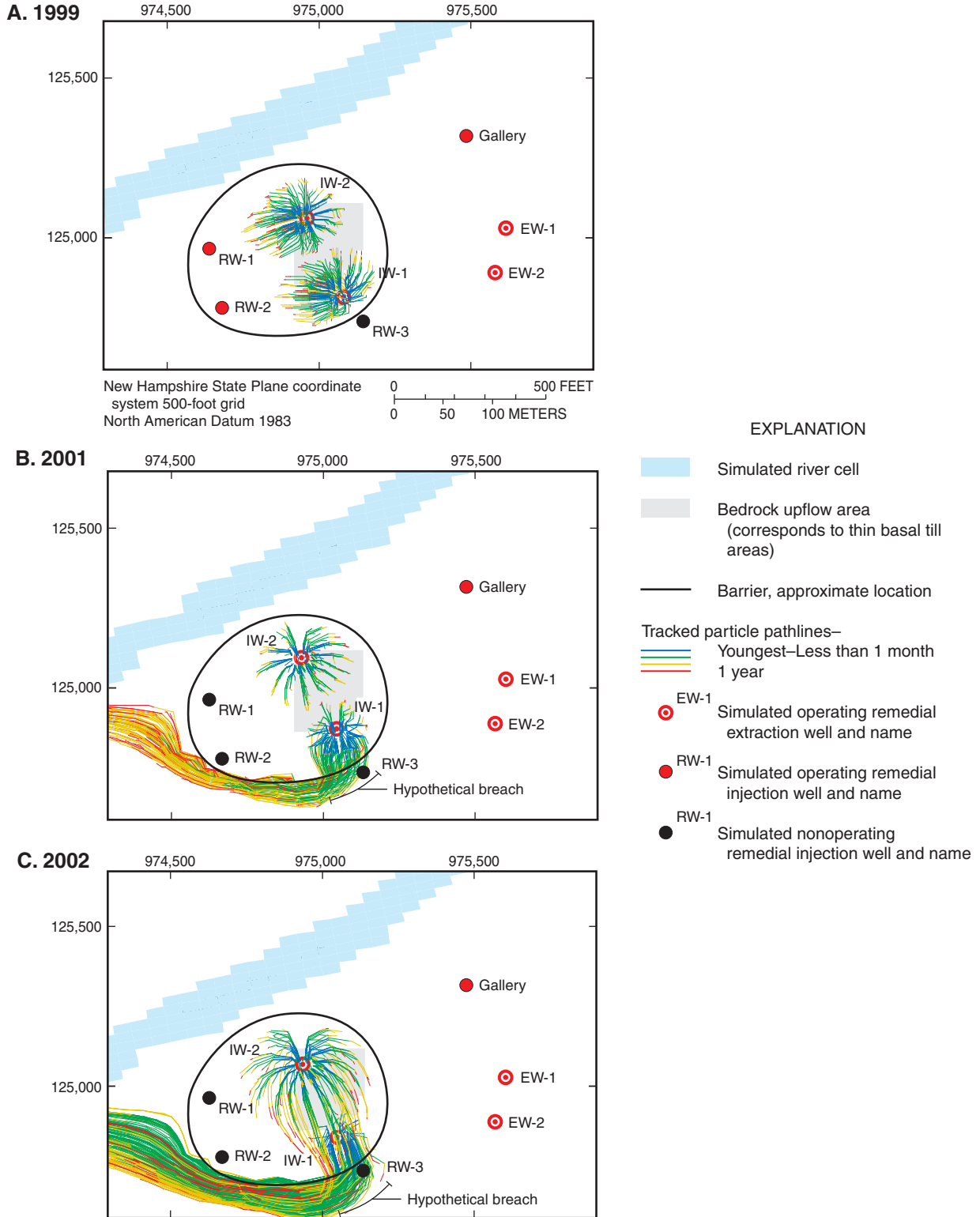
Figure 20.   Backward-tracked particles showing capture areas to IW-1 and IW-2 in *A*, 1999, *B*, 2001, and *C*, 2002, Operable Unit 1 (OU1), Milford, N.H.

projected onto a two-dimensional surface, called capture area, but represent the projection of a three-dimensional capture zone. Therefore, for consistency purposes in this report, the term capture area will be used to describe the two-dimensional area or three-dimensional volume of water contributing to an extraction well. Colors denote ranges in travel times; blue lines represent less than 1 month and red lines represent approximately 1 year.

Results show that simulated inflow through the barrier from the breach barrier wall is clearly visible by particle pathlines that breach the barrier in the model (fig. 20B–C). The capture area for IW-1 and IW-2 are relatively small for 1999 rates (fig. 20A) because of the small extraction rates (less than 25 gal/min) and because a part of the captured water is derived from ground-water upflow from the bedrock. For 1999 rates, the capture areas are skewed to the west because of the injection of water at RW-1 and RW-2. In the absence of injected water during 2001 and 2002, the capture area for IW-2 is more cylindrical and centered around the well (fig. 20B–C). For 2001 and 2002, the capture area for IW-1 extends past the barrier because of the arbitrary location of the assigned barrier breach.

Capture of contaminated PCE waters within the barrier is important for the long-term (greater than 10 years) success of remediation. PCE concentrations are high in the INEEL field (fig. 2) and concentrations are found in two distinct high PCE concentration layers, one shallow and one deep. Particle paths were forward tracked from shallow and deep locations to simulate advective transport from the INEEL field to their final discharge locations so as to evaluate the effectiveness of different internal net-extraction rates.

For the three net-extraction rates (1999, 2001, and 2002) and the simulated underflow conditions, the time-to-discharge of particles (or capture) by the IW-1 and IW-2 wells varied. Advective transport from the INEEL field, and capture by one of the two interior extraction wells, is fastest for 2002 and slowest for 2001. Although capture is quickest in 2002, the simulation results indicate a more efficient remedial operation in 1999 considering that 2002 extraction rates are doubled that of 1999. For 1999 rates, the shallow plume is captured in 2 years and flows to IW-1, whereas the deep plume is captured in 5 years to the same well. For 2001, the shallow plume is captured in 5 years and flows to IW-2, whereas the deep plume is captured in 10 years and also flows to IW-2. For 2002, the shallow plume is captured in 2 years and flows to IW-2, whereas the deep plume is captured in 4 years to the same well.

Sensitivity of Inside Barrier Area to Upflow from Bedrock

Another source of water to interior extraction wells is bedrock upflow (eq. 1). Whereas the previous simulations tested the effects of horizontal lateral inflow in the overburden into the interior barrier area, analysis of available monitoring

data indicates a more likely scenario that interior extractions are augmented by increased vertical ground-water upflow from the bedrock. The effect of varying the amount of bedrock upflow is discussed in this section (table 6; simulation type—"Evaluation of bedrock upflow").

Available monitoring data indicate bedrock upflow is an important component of the interior barrier area ground-water budget. Continuously monitored ground-water levels at cluster wells show that the bedrock ground-water levels respond quickly to variations in net extraction inside the barrier (fig. 7). This quick response indicates that variations in bedrock upflow occur with variations in net extraction and increases in net extraction inside the barrier induce increases in bedrock upflow. Observed head gradients within the barrier in the overburden are low (head differences less than 0.5 ft; Harte 2005) between well B95-9 and PW-5D (fig. 2). The low observed gradients inside the barrier indicate recharge is diffuse and likely from upward flow from the bedrock. In contrast, steep gradients (head differences greater than 0.5 ft; Harte, 2005) in the overburden across the barrier from wells that straddle the barrier indicate the barrier penetrates the overburden in those locations. This is additional evidence indicating upflow from bedrock is an important factor in the overburden water budget of the interior barrier area.

Unlike the simulations testing variations in the amount of allowable lateral inflow, model-computed heads are sensitive to variations in rates of upflow from the bedrock. If there is too much upflow, heads become too high; if too little upflow, heads dewater inside the barrier.

For 2002 conditions and complete penetration in the overburden by the barrier (no breach), a bedrock upflow rate of up to 35.25 gal/min is required to maintain the net extraction rate of 37 gal/min, which is equal to the net extraction rate of 37 gal/min minus the minimum aerial recharge rate of 1.75 gal/min. In this scenario, the capture areas for IW-1 and IW-2 are entirely within the barrier (fig. 21). However, because of the relatively high rates of upflow from the bedrock, the capture areas do not extend throughout the interior barrier area and are limited to the eastern part of the interior barrier area.

An important condition to consider when examining capture areas is that the capture areas are limited to the overburden because the model does not directly simulate the underlying bedrock. The model indirectly simulates the contribution of bedrock as an assigned upward flow rate at the base of the overburden. If the source volume of the bedrock upflow was simulated, particle pathlines would extend into the bedrock in areas possibly outside the barrier.

In March 2003, rates of extraction at interior wells IW-1 and 2 were increased to 60 gal/min total (30 each) and injection was distributed outside the barrier to the gallery and a small amount (less than 20 gal/min) to the exterior injection well RW-3 (fig. 2). Because of the large rate of bedrock upflow (approximately 58 gal/min) needed to augment interior extraction under a no-breach condition, the heads in layer 5 became too high when the hypothetical injection-well rates
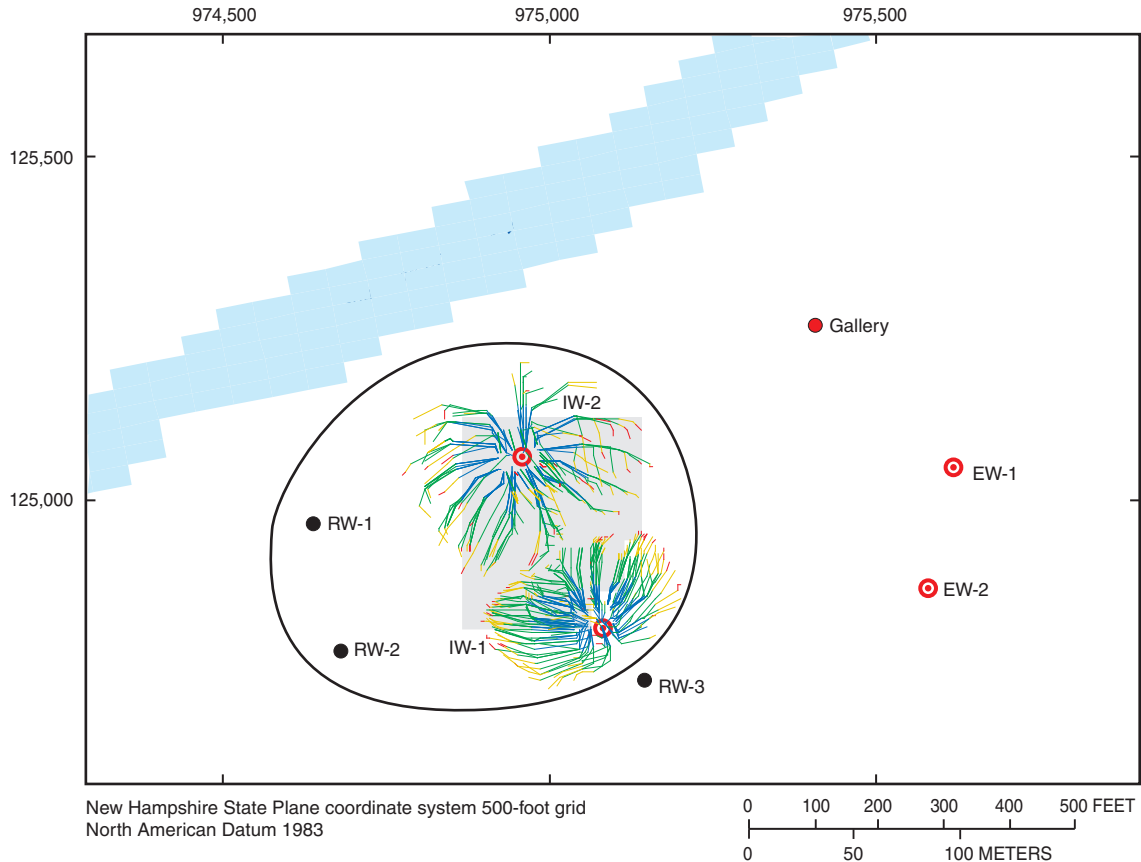
Figure 21.   Backward-tracked particles showing capture areas to IW-1 and IW-2 with no horizontal inflow under the barrier in layer 5, 2002 rates, Operable Unit 1 (OU1), Milford, N.H.

were increased to 58 gal/min because of the low hydraulic conductivity assigned to some of this layer (5 ft/d in the till). Therefore, it was necessary to simulate bedrock upflow under a breach-barrier condition to allow some additional inflow to augment net extraction. A reasonable simulation was achieved with a maximum bedrock upflow rate of 49 gal/min. Model results are constrained by the limitations of the current boundary conditions and model, and more realistic model results may be achieved by adding the bedrock as a new layer in the model.

Sensitivity of Outside Barrier Area on Capture Areas to Exterior Extraction Wells

The capture areas to the exterior extraction wells (EW-1, and EW-2) are examined in this section. The capture areas for EW-1 and EW-2 are affected by the barrier wall, recharge from the adjacent Souhegan River and by injection at the gallery, and stresses (extraction) from wells located outside of OU1. These factors were simulated in the model. RW-3 was not simulated because of sporadic operations.

For the study periods (1999, 2001, and 2002), variation in extraction was minimal at EW-1 and EW-2 (fig. 22); therefore, extraction rates for EW-1 and EW-2 were kept constant at 25 gal/min. The amount of injection at the gallery increased from 59.6, to 62.9, to 90 gal/min in 1999, 2001, and 2002, respectively. The simulated head from the increased injection at the gallery is less than 1 ft because of the high horizontal hydraulic conductivity (450 ft/d) assigned to layer 1 of the model to simulate the cobble layer. Yet, even with this small head change, the capture areas for EW-1 and EW-2 are affected by the rate of injection at the gallery.

The 1-year capture areas are shown for EW-1 and EW-2 in figure 22. Particle paths were backward-tracked from the extraction wells and ended after 1 year of advective transport. Capture areas are from 1999 (fig. 22A), 2001 (fig. 22B), and 2002 (fig. 22C). The barrier and the Souhegan River bound the capture areas of EW-1 and EW-2. The most important difference in simulated capture areas is the amount of recirculated water from the gallery that is captured by EW-1. As injection rates increase at the gallery, so does the amount of injected water captured by EW-1. As a result, the extent of the two capture areas (EW-1 and EW-2) varies particularly to the south.

Only a percentage of gallery-injected water is captured by EW-1. Simulated forward-tracking of particles from the gallery (not shown in any figure) indicates that gallery-injected water covers a lateral area from EW-1 to 200 ft north of the PW-13 cluster (fig. 2). The percent of particles tracked from the gallery that is captured by EW-1 increases from 11 percent in 1999, to 16 percent in 2001, and to 18 percent in 2002.

Exterior stresses in the aquifer affect the capture areas of EW-1 and EW-2 (fig. 23). Termination of withdrawals at an industrial well (MI-88, fig. 1) to the south of OU1 affects the capture areas of EW-1 and EW-2. This relation indicates that the northern edge of the capture area for MI-88 bounds the southern edge of capture areas for EW-1 and EW-2. When withdrawals are terminated at MI-88 (fig. 23B), the capture area of EW-1 and EW-2 spreads further south by approximately 150 ft.

Effects of Transient Flow on Capture Areas to Exterior Extraction Wells

Differences in capture areas between steady-state and transient models were examined to assess the effect of transient conditions on capture to EW-1 and EW-2 because variations in transient seasonal capture areas could affect remedial effectiveness. Unlike the steady-state model, the transient model incorporates storage and monthly variation in recharge and river stage and follows seasonal trends described in Harte (1999, table 6, medium recharge rate). The starting condition for the transient model is the steady-state simulation of 1999 (fig. 18A), which provides an appropriate initial condition of head. Extraction rates at EW-1 and EW-2 were kept constant at 25 gal/min for the steady-state and transient simulations.

The capture areas to EW-1 and EW-2 are dynamic in that 1-year travel times to these wells cover a large area. Travel times to EW-1 and EW-2 are young (less than 1 month) because of the high hydraulic conductivity of the aquifer and location of the wells near the river. The river is a major source of recharge for the aquifer with an average recharge of several cubic feet per second. One-year travel times to the wells cover more than 90 percent of the capture area, therefore, annual capture areas were used to assess the affect of transient conditions.

The annual capture area is 30 percent larger for the transient simulation than for the steady-state simulation. The major differences between the simulations are that the transient capture area extends farther to the south than the steady-state capture area. This area of the aquifer, as of 2004, has low to non-detectable levels of VOCs (Leah Desmarais, New Hampshire Department of Environmental Services, written commun., 2004); therefore, increased ground-water capture of water south of the barrier decreases efficiency of remediation (contaminant mass removed per gallon of water extracted).

To estimate the effect of capture of contaminated ground water as a result of transient conditions, further testing was done to identify differences between capture areas under steady-state and transient conditions. A line source of particles were placed directly downgradient from the barrier wall, from west of the recharge gallery to RW-3 (fig. 2), to simulate the advective transport of contaminated ground water outside the barrier. Particles were released semi-annually in the middle layer (layer 3 of the solute-transport model). Two different start dates were used, June and December. Simulations starting in June begin during a low precipitation-recharge period. Simulations starting in December begin during a high precipitation-recharge period. Ranges of simulation periods included 4 months (June–September, and December–March), 6 months (June–November, and December–May), 8 months
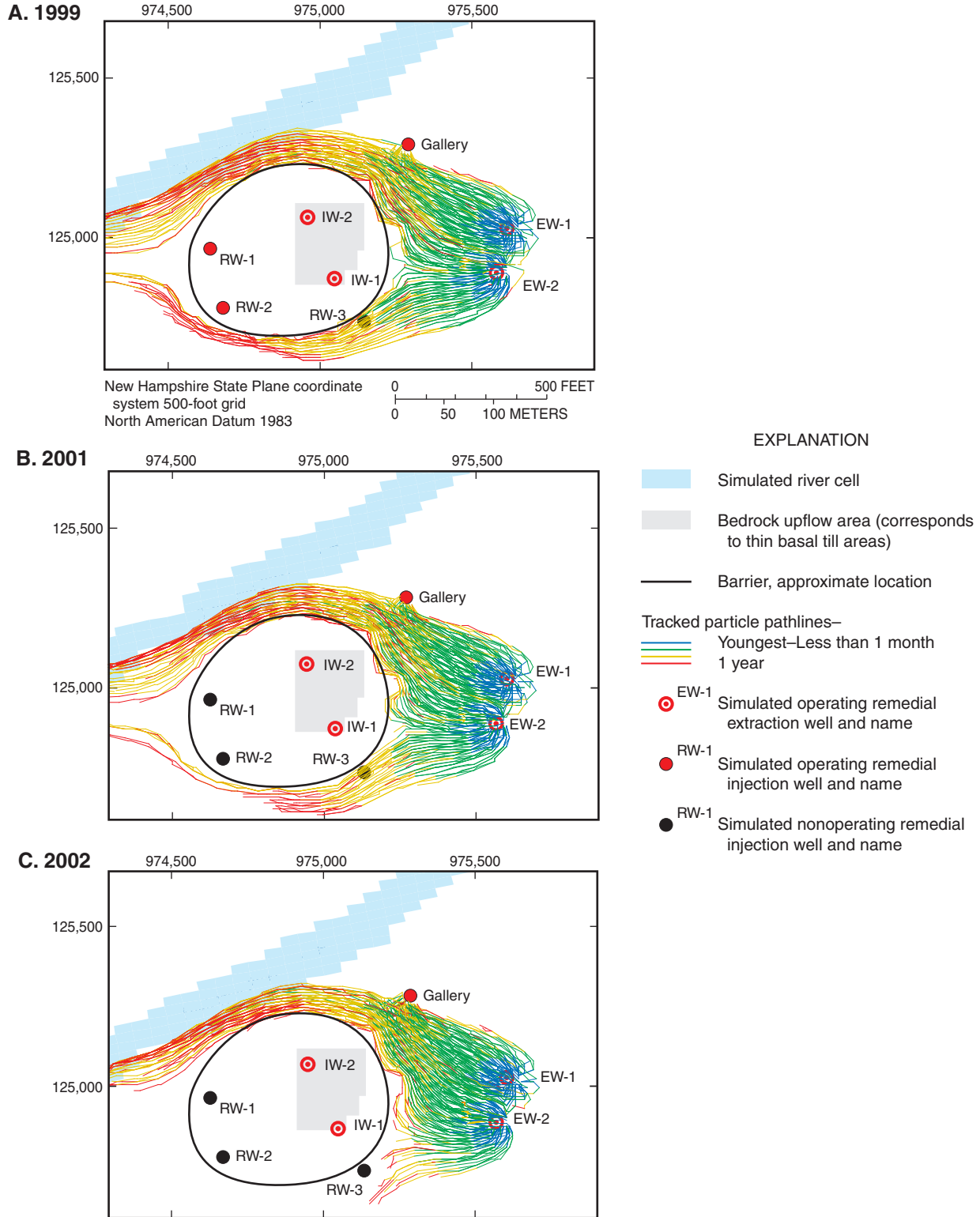
Figure 22.   Backward-tracked particles showing capture areas to EW-1 and EW-2 in *A*, 1999, *B*, 2001, and *C*, 2002, Operable Unit 1 (OU1), Milford, N.H.
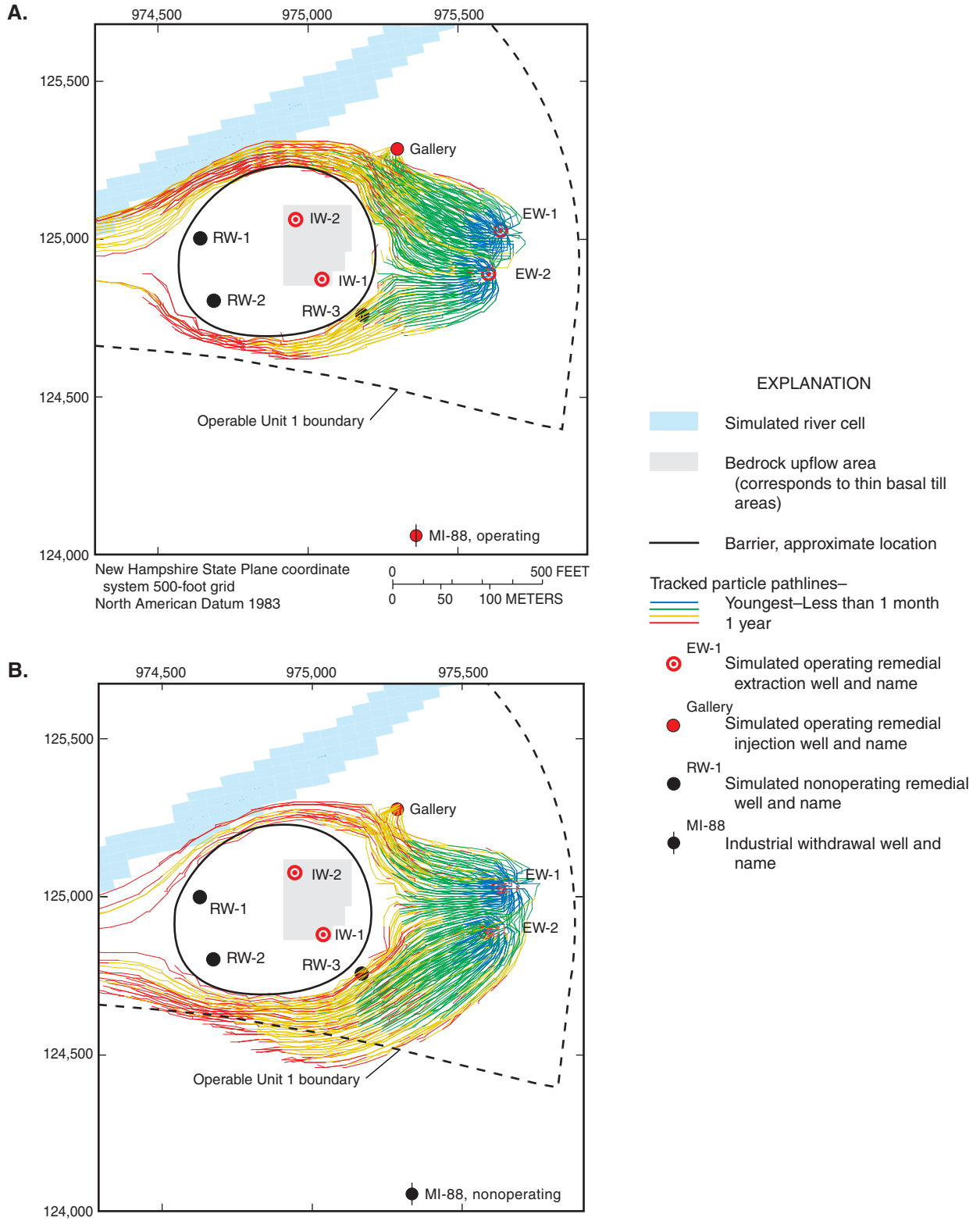
Figure 23. Backward-tracked particles showing capture areas to EW-1 and EW-2 for 2002 rates *A*, with, and *B*, without withdrawals from MI-88, Operable Unit 1 (OU1), Milford, N.H.

(June–January, and December–July), and 1 year (June–June, December–December).

Over the annual cycle, less than a 2-percent difference in capture of particles resulted between transient and steady-state simulations (table 6). During shorter periods of time (4 months), up to a 29-percent difference in capture resulted. Simulations starting in December captured more particles than those starting in June. The steady-state simulation captures an equal number of particles for any 4-month period because velocity and flow direction is constant throughout the year. Capture of particles in the transient simulations brackets the results of the steady state indicating that the steady-state model represents an average capture condition. The differences in capture between the June and December transient simulations are a function of variations in flow direction and particle velocity.

Ground-water gradients and flow direction in OU1 are affected by surface- and ground-water interactions. The amount of aquifer recharge from the losing river reach in OU1 affects ground-water-flow direction outside the barrier. Harte (1999) showed that maximum gradients occur during low water-table conditions in the aquifer because aquifer recharge from the river reach in OU1 is highest during this period. When recharge is highest from the river, more flow occurs from the river area toward EW-1 and EW-2.

Less particles from in front of the barrier are captured in the summer because more water is being captured by EW-1 and EW-2 from the river area north of the barrier, away from areas where particles were placed. In particles starting in December, a high direct-infiltration recharge period, river loss and gradients from the river are at their lowest and less water is captured by EW-1 and EW-2 from the river area. In particles starting in June, a low direct-infiltration recharge period, river loss and gradients from the river are at their highest and more water is captured from the river area.

Extraction rates at EW-1 and EW-2 (25 gal/min each) adequately capture contaminants during high recharge periods because more particles are being captured from outside the barrier than during low recharge periods. Optimization of capture would improve if withdrawals were modified on the basis of seasonal climate trends to more effectively capture contaminants from outside the barrier. For example, reduced extraction at EW-1 and EW-2 during the summer captured less uncontaminated water from the river area. Increased extraction at EW-1 and EW-2 during the winter captured more contaminated water outside the barrier.

Alternative Operational Schemes to Accelerate Flushing of Contaminants

PCE-concentration decreases from 1998 to 2004 (table 3) outside the barrier in OU1 at PW-14M were potentially small as a result of the formation of a small stagnant area down-gradient from EW-1 and EW-2 caused by low ground-water velocities. Alternative operational schemes at EW-1 and EW-2 were investigated to determine whether ground-water velocities at PW-14M could be increased by modifying injection rates. PCE-concentration decreases at PW-14M from 1999 to 2004 were small (table 3). Increased ground-water velocities near PW-14M accelerated flushing of contaminated ground water in this area.

The flushing of pore volume by ground water can be increased by modifying the existing injection operation. The base and current (2004) operation has most of the water at OU1 being injected into the recharge gallery. Under this operation, one model-computed pore volume is flushed every 46 days at the model cell containing PW-14M (layer 4; table 7). Relocating the gallery approximately 100 ft east of EW-2 caused an increase in flushing of one pore volume of

Table 7. Advective transport and capture of a line-source of ground-water particles from steady state and transient models, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[June 1 and December 1 start dates for tracking with transient model; --, no data]

Simulation	Four months		Six months		Eight months		One year	
	Total particles captured	Percent of particles captured (out of 128)	Total particles captured	Percent of particles captured (out of 128)	Total particles captured	Percent of particles captured (out of 256)	Total particles captured	Percent of particles captured (out of 256)
Steady state	28	22	105	82	113	44	220	86
Transient								
June 1	24	19	102	80	110	43	216	84
December 1	32	25	109	85	116	45	224	88
Difference	8	--	7	--	6	--	4	--
Percent difference from steady state	29	--	6	--	5.3	--	1.8	--

Table 8. Simulations testing alternative injection locations outside the barrier wall for Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[Location of wells shown on figure 2; site type names explained in abbreviation section of report; EW, exterior extraction well; ft, feet]

Description of simulation testing location of injection	OU1 operational rates[1]	Volumetric flow into model cell at well PW-14M, in gallons per minute	Number of days to flush one pore water volume for model cell at well PW-14M	Injection model layer
Existing gallery location	March 2003	0.71	46	1
100 ft east of EW-2 in layer 1	March 2003	.95	34	1
100 ft east of EW-2 in layer 4	March 2003	1.04	31	4
100 ft east and 50 ft north of EW-2 in layer 4	March 2003	1.51	22	4
In EW-1	March 2003	.81	40	4

[1]March 2003 rates include wells EW-1 and EW-2 at 15 gallons per minute (gal/min) each, wells IW-1 and IW-2 at 31 gal/min each, well RW-3 at 17 gal/min, and 75 gal/min in injection gallery or new well. Source of data: U.S. Filter, Inc., written commun., 2003.

water near PW-14M from 46 to 34 days compared to the previous simulation (table 7). Converting the injection at a gallery in layer one to an injection well screened in layer 4 at this same location modestly increases flushing from 34 to 31 days (table 7). If the injection well is moved approximately 50 ft north, flushing increases dramatically (22 days in table 7) indicating the horizontal changes in injection location are more important than vertical placement.

Utilizing an existing exterior extraction well as an injection well does little to increase flushing at PW-14M. Switching EW-1 from an extraction well to an injection well causes the flushing rate to decrease by only 5 days (table 7) from the base rate of 45 days.

Simulations were used to evaluate the feasibility of increased flushing of ground water near the small PCE stagnant zone. These simulations indicate that enhanced flushing can be achieved by optimal horizontal placement of injection downgradient from EW-1 and EW-2 in layer 1. Only a slight additional benefit was achieved from varying vertical placement. Not shown in any figure, but tested as a simulation, was the effect of increased flushing at PW-14M when all extraction was discontinued at EW-1 and EW-2. A 15-percent increase in flushing was achieved when extraction was discontinued.

Evaluation of Effectiveness of Remediation

From 1998 to 2004, PCE concentrations decreased by an average of 80 percent at most wells outside the barrier. This decrease indicates (1) the barrier and interior extraction have effectively contained high PCE concentrations within the barrier, (2) other sources of PCE did not appear to be present outside of the barrier, and (3) ambient ground-water fluxes and velocities in conjunction with the exterior remedial wells

effectively continued to remediate most of the dissolved PCE plume outside the barrier.

The middle overburden downgradient of exterior (to barrier) extraction wells shows slow (less than 50 percent) decreases in PCE concentrations, at least partly because of the formation of a small downgradient slow-velocity zone based on numerical simulations. Because the ambient ground-water velocities are high (1 ft/d), discontinuing extraction at the exterior wells may increase flushing by 15 percent in this area. An alternative approach is to relocate the injection gallery or locate a new injection well to an area east of the exterior wells.

If the existing exterior remedial system is maintained, adjusting extraction at EW-1 and EW-2 based on seasonal trends in recharge would increase the efficiency of capture of contaminated ground water. Seasonal trends in direct infiltration recharge from precipitation and recharge from river leakage cause directional variations in flow that affect capture of the contaminated ground water by the existing exterior extraction wells as shown by numerical simulations of transient hydrologic conditions. Monitoring data indicate that maximum gradients and recharge from the losing river reach in OU1 are generally during low water-table conditions (Harte, 1999). Therefore, if exterior extraction at EW-1 and EW-2 is turned off during low recharge periods (summer), then less, relatively clean ground water from the river area is captured. Conversely, increasing extraction during high recharge periods (early spring) would capture more contaminated ground water from outside the barrier.

PCE-concentration decreases inside the barrier from 1998 to 2003 (before ISCO treatment) were slow near suspected source areas, which indicate that the existing remedial system is inefficient in remediating either dissolved PCE or the DNAPL source within the barrier. Operation of soil-vapor-extraction wells and air-sparge wells has been limited by factors such as the inability to lower the water-table surface inside the barrier. Large amounts of ground-water upflow

from the underlying fractured bedrock allow water to enter the barrier area in the overburden and prevent dewatering, which compromises the effectiveness of capture of contaminants in the overburden. Capture of the dissolved PCE plume may be increased by using existing injection wells to increase the hydraulic gradient inside the barrier. As the gradient increases, contaminated ground water would move more quickly toward the interior extraction wells.

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the New Hampshire Department of Environmental Services (NHDES) and the U.S. Environmental Protection Agency (USEPA), Region 1, has investigated the effectiveness of the remediation system at Operable Unit No. 1 (OU1), which contains the primary source area of volatile organic compounds (VOCs), at the Savage Municipal Well Superfund site (Savage site) in Milford, N.H. This project is one of several continuing evaluations of the site by NHDES and USEPA.

The OU1 remedial system includes a low-permeability (bentonite) barrier wall (barrier) that encircles the highest detected concentrations of tetrachloroethylene (PCE), which is the primary VOC, and a series of injection and extraction wells. The barrier likely penetrates the full thickness of the sand and gravel; in most places, it also penetrates the full thickness of the underlying basal till and sits atop bedrock.

The overburden stratigraphy of the OU1 site from land surface downwards includes a shallow cobble layer, a sand lens, several coarse-grained sand and gravel layers, and discontinuous till that thickens to the west. The sand and gravel has complex stratigraphy and it is laterally and vertically discontinuous.

Ground-water flow is from west to east and includes significant recharge (several cubic feet per second) from the Souhegan River, which is primarily a losing river reach in OU1. The construction of the barrier has focused river loss to an area northeast of the barrier. During remedial operation of injection and extraction wells, ground-water flow is complex and several stagnation areas (relatively slow velocity zones) form. Outside the barrier, small stagnation areas are upgradient from injection at a recharge gallery, and downgradient from extraction at exterior remedial wells EW-1 and EW-2. Inside the barrier, extraction at interior remedial wells IW-1 and IW-2 causes flowpaths to diverge, which contributes to the formation of zones of slow ground-water velocity or stagnation zones.

Continuously monitored water-level responses to remedial extraction inside the barrier show that (1) bedrock is hydraulically connected to the overburden, and (2) extraction at interior overburden wells IW-1 and IW-2 induces ground-water upflow from the fractured bedrock. A water budget for the interior barrier area indicates bedrock upflow contributes

greater than 50 percent of the source of water for the interior extraction wells.

Numerical simulations show that ground-water upflow from the bedrock reduces the size of the capture areas to the interior extraction wells. For this reason, interior extraction capture areas are small and less effective in inducing transport of high PCE concentrations dissolved from overburden DNAPL source zones inside the barrier. Use of existing injection wells inside the barrier can increase the existing shallow horizontal gradients and promote flow of high PCE concentrations toward extraction wells.

Simulations show that capture areas of the exterior extraction wells EW-1 and EW-2 are affected by the Souhegan River, injection at the recharge gallery, the barrier wall, and a neighboring capture area from an industrial well to the south. Increased injection at the gallery increases the amount of water recirculated and captured by the exterior extraction wells.

Based on simulations of transient capture areas of the exterior extraction wells, the Souhegan River affects capture. During low direct-infiltration recharge periods in the summer, recharge from the river is at a maximum causing the exterior extraction wells to capture additional water from areas north of the barrier by the river. During high direct-infiltration recharge periods in late fall, recharge from the river is at a minimum causing additional water to be captured by the exterior extraction wells from outside the barrier on the downgradient side. Because PCE concentrations are greatest in front of the barrier, optimizing capture from in front of the barrier area would be advantageous.

From 1998 to 2004, large decreases (80 percent reduction) in PCE concentrations have been measured at many observation wells outside the barrier. However, there are several areas where PCE concentrations decrease slowly, including an area downgradient from the exterior extraction wells outside the barrier and in areas near source zones inside the barrier. Velocities in slow-velocity zones downgradient from the exterior extraction wells can be increased by modifying the existing injection system or terminating extraction during periods of low direct recharge when horizontal head gradients are greatest from the river. Slow decreases in PCE concentrations inside the barrier are more problematic and require more aggressive source treatment. Interior barrier areas with high PCE concentration would also benefit from increased flushing by operating existing interior injection wells and by increasing horizontal head gradients.

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Appendixes 1–4

Appendix 1. Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
106	--	969943.6	115997.7	--	--	--	--	--	--	--
105	--	972221.4	119573.1	--	--	--	--	--	--	--
63	--	973226.9	124779.4	--	--	282.4	--	--	--	--
118	--	974663.4	117151.1	--	--	--	--	--	--	--
120	--	974826.1	117243.0	--	--	--	--	--	--	--
622	--	974829.0	124902.3	272.94	TPVC	--	--	--	--	--
119	--	975143.4	117530.1	--	--	--	--	--	--	--
66	--	975354.0	124548.9	--	--	270.0	--	--	--	--
79	--	975782.3	119504.9	--	--	350.0	--	--	--	--
80	--	975917.3	119166.0	--	--	--	--	--	--	--
68	--	976054.9	124695.2	--	--	267.9	--	--	--	--
64	--	976086.6	124426.6	--	--	265.3	--	--	--	--
69	--	976146.7	124676.0	--	--	266.3	--	--	--	--
71	--	976275.6	124553.6	--	--	264.0	--	--	--	--
70	--	976282.6	124669.8	--	--	264.1	--	--	--	--
364	--	976295.6	125521.0	264.93	--	262.5	--	--	--	--
121	--	976507.9	117660.4	--	--	--	--	--	--	--
111	--	976843.4	115878.6	--	--	--	--	--	--	--
117	--	977035.0	115723.0	--	--	--	--	--	--	--
67	--	979957.1	124233.7	--	--	250.0	--	--	--	--
360	--	981136.4	126667.9	251.03	TSC	247.1	--	34.5	--	--
358	--	981191.1	126524.6	250.03	TSC	247.2	--	20.5	--	--
356	--	981217.3	126573.6	250.05	--	247.4	--	--	--	--
357	--	981218.6	126572.1	249.97	--	247.4	--	--	--	--
83	--	982062.2	125393.9	--	--	240.9	--	--	--	--
82	--	982214.8	125347.6	--	--	240.0	--	--	--	23
107	--	982412.5	131350.5	--	--	349.2	--	--	--	--
109	--	982510.9	130710.2	--	--	349.3	--	--	--	--
192	--	984005.2	123305.5	--	--	266.7	--	--	--	12
84	#226inSurv	975999.6	127234.7	262.51	TSC	261.7	51	66	--	60
376	2ftHitchPW1	975620.1	124005.9	--	--	--	--	--	--	--
377	3ftHitchPW1	975608.9	124010.1	--	--	--	--	--	--	--
412	A01	975851.3	124173.6	--	--	--	--	--	--	--
413	A02	975826.8	124285.6	--	--	--	--	--	--	--
414	A03	975766.3	124433.6	--	--	--	--	--	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
415	A04	975663.9	124453.7	--	--	--	--	--	--	--
416	A05	975549.3	124477.4	--	--	--	--	--	--	--
417	A06	975407.3	124511.0	--	--	--	--	--	--	--
418	A07	975266.9	124527.1	--	--	--	--	--	--	--
419	A08	975081.1	124581.5	--	--	--	--	--	--	--
420	B02	976040.8	124216.3	--	--	--	--	--	--	--
421	B03	976012.1	124285.5	--	--	--	--	--	--	--
422	B04	975987.0	124364.6	--	--	--	--	--	--	--
97	B1	974473.7	125037.5	--	--	269.9	--	43	43	--
103	B11	974370.3	125169.7	--	--	275.0	--	--	--	--
104	B12	974471.9	125190.8	--	--	275.4	--	--	--	--
98	B3	974360.1	124970.2	--	--	269.3	--	33.8	33.8	--
99	B4	974211.6	124942.2	--	--	270.0	--	54.5	54.5	--
100	B6	974327.4	125036.1	--	--	269.0	--	--	26.2	--
101	B8	974392.9	125051.0	--	--	269.7	--	26	--	--
102	B9	974212.3	125172.5	--	--	275.3	--	--	--	--
396	B95-01	975177.4	124917.1	--	--	269.8	--	--	--	107
397	B95-02	975120.7	125077.4	--	--	269.7	--	--	--	99.8
398	B95-03	974985.3	125214.8	274.44	TPVC	269.7	61.5	71.5	--	86
399	B95-04	974848.7	125108.9	--	--	270.4	--	--	--	69
400	B95-05	974688.2	125027.7	275.10	TPVC	273.1	37	47	--	73.5
401	B95-06	974669.0	124826.0	272.12	TPVC	272.8	41.5	51.5	--	--
402	B95-07	974914.3	124802.5	273.64	TPVC	271.7	46	56	--	58
403	B95-08	975035.4	124825.8	276.26	TPVC	270.1	72	82	--	88
404	B95-09	975039.8	124825.6	273.07	TPVC	270.3	10	20	--	--
405	B95-10	974816.7	124997.5	274.68	TPVC	272.1	61	66	--	--
406	B95-11	974969.1	124987.0	274.58	TPVC	272.4	73	78	--	80
407	B95-12	975343.8	124724.7	272.32	TSC	269.5	55	60	--	76
408	B95-13	975490.6	125002.0	266.35	TSC	267.0	60	65	--	90.5
409	B95-15	975254.0	125149.4	268.23	TSC	269.6	85	95	--	96.5
410	B95-16	974827.3	124995.7	274.48	TPVC	272.0	10	20	--	--
411	B95-17	974980.4	124985.1	274.50	TPVC	272.1	40	50	--	--
368	BMc821934	978403.9	123964.9	--	--	--	--	--	--	--
423	C01	976256.1	124044.3	--	--	--	--	--	--	--
424	C02	976230.6	124189.2	--	--	--	--	--	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
425	C03	976190.0	124344.9	--	--	--	--	--	--	--
426	C05	976169.6	124514.3	--	--	--	--	--	--	--
427	C06	976100.7	124649.9	--	--	--	--	--	--	--
428	C07	976004.9	124868.5	--	--	--	--	--	--	--
429	C08	975946.1	125071.3	--	--	--	--	--	--	--
430	C09	975816.7	125270.9	--	--	--	--	--	--	--
431	C10	975918.7	125457.1	--	--	--	--	--	--	--
432	C11	975949.1	125669.0	--	--	--	--	--	--	--
249	Cassarino	975491.4	127480.1	--	--	267.9	--	12.5	--	--
433	D01	977181.0	123965.6	--	--	--	--	--	--	--
434	D02	977047.1	124350.6	--	--	--	--	--	--	--
435	D03	976969.2	124522.3	--	--	--	--	--	--	--
436	D04	976926.2	124651.9	--	--	--	--	--	--	--
437	D05	976816.8	124924.6	--	--	--	--	--	--	--
438	D06	976751.4	125088.4	--	--	--	--	--	--	--
439	D07	976690.2	125251.6	--	--	--	--	--	--	--
440	D08	976551.7	125609.5	--	--	--	--	--	--	--
441	D10	976363.6	126104.4	--	--	--	--	--	--	--
442	D11	976033.8	126246.6	--	--	--	--	--	--	--
443	D21	976616.5	125429.2	--	--	--	--	--	--	--
444	E01	978145.9	124145.0	--	--	--	--	--	--	--
445	E02	978218.4	124455.1	--	--	--	--	--	--	--
446	E03	978112.3	124704.9	--	--	--	--	--	--	--
447	E04	978005.2	124898.1	--	--	--	--	--	--	--
448	E05	977928.1	125053.3	--	--	--	--	--	--	--
449	E06	977852.8	125221.0	--	--	--	--	--	--	--
450	E07	977768.1	125414.4	--	--	--	--	--	--	--
451	E08	977698.5	125714.6	--	--	--	--	--	--	--
452	E09	977575.0	126168.8	--	--	--	--	--	--	--
453	E10	977468.0	126394.4	--	--	--	--	--	--	--
454	E11	977542.1	126522.2	--	--	--	--	--	--	--
599	ESE-EWA	977303.1	125074.5	260.79	--	257.5	36.4	51.7	--	--
605	ESE-EWB	979262.3	126082.9	256.10	--	254.0	38.9	56	--	--
600	ESE-PZA1	977301.3	125087.4	260.06	--	257.4	10	15	--	--
601	ESE-PZA2	977317.0	125042.6	260.14	--	257.5	10	15	--	--

Appendix 1. Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
602	ESE-PZA3	977314.0	124043.9	260.12	--	258.0	44.75	49.75	55.5	--
603	ESE-PZA4	977358.8	125206.6	261.59	--	258.9	10	15	--	--
604	ESE-PZA5	977354.8	125204.7	261.45	--	258.8	45	55	--	--
606	ESE-PZB1	979246.9	126084.3	256.72	--	254.3	12	17	--	--
607	ESE-PZB2	979248.4	126086.4	256.98	--	254.3	50	55	--	--
608	ESE-PZB3	979199.6	126069.1	256.26	--	254.1	11.5	16.5	61	--
609	ESE-PZB4	979201.8	126071.2	256.21	--	254.3	45	50	--	--
610	ESE-PZB5	979442.6	125971.7	253.81	--	251.7	10	15	--	--
565	EW-1	975535.2	125046.1	265.09	TSC	266.9	63.55	93.55	--	--
566	EW-2	975492.9	124936.3	265.81	TSC	267.1	51.22	81.22	--	81.5
359	FH-?	981138.8	126516.3	249.86	TSC	248.5	--	24.8	--	--
240	FH-10(OBS)	975991.4	127198.4	268.01	TSC	267.3	58	63	--	--
208	FH-10(PUMP)	975988.3	127199.9	267.89	TINRSC	268.0	50	65	--	--
301	FH-11	975989.9	127199.8	268.08	TSC	267.4	--	62	--	--
86	FH-13(OBS)	975717.7	126524.2	269.03	TPVC	260.0	33	43	--	--
87	FH-14	975867.0	126592.8	263.53	VENT	262.2	32	42	--	--
85	FH-15	976951.6	126886.4	265.72	AHPUMP	265.1	18	38	--	--
88	FH-16	977174.8	126706.3	262.99	--	261.0	--	--	--	--
353	FH-17	978711.3	127671.8	272.44	BOLT HEAD	--	--	--	--	--
305	FH-18	978724.8	126549.2	255.01	--	--	--	--	--	--
302	FH-19	978898.8	126408.4	256.17	TSC	--	--	--	--	--
96	FH1974	978905.3	126519.5	--	--	254.5	--	--	--	--
94	FH-21	978928.6	126400.6	251.63	TPVC	252.1	21	26	--	--
90	FH-22	978953.0	126400.0	255.10	TPVC	253.1	24	29	--	--
93	FH-23	979002.6	126401.5	253.70	TPVC	252.0	22	25	--	--
91	FH-24	979035.9	126403.9	253.27	TPVC	251.6	24	29	--	--
92	FH-25	979102.5	126406.5	254.04	TSC	252.1	23	28	--	--
374	FH-26	979100.8	126405.4	254.35	TPVC	--	--	--	--	--
89	FH-27	978957.5	126176.8	251.45	TPVC	251.3	36	41	--	--
378	FH27-SG1	978965.1	126137.3	248.05	BOLT HEAD	--	--	--	--	--
379	FH27-SG2	978965.0	126143.6	245.48	SG2	--	--	--	--	--
288	FH-28	981031.7	126543.6	248.85	TSC	248.1	--	23	--	--
289	FH-29	981063.3	126519.2	250.07	TSC	247.8	--	33.9	--	--
292	FH-30	981104.8	126341.0	250.69	TSC	248.3	--	23	--	--
95	FH85-8A	975813.9	126532.9	--	--	260.0	20	26	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
242	FH-9	975997.3	127233.1	269.83	TSC	268.3	--	52	--	--
369	FHwoods	976854.1	127069.3	266.46	TSC	266.1	--	--	--	--
455	G03	979635.0	124972.0	--	--	--	--	--	--	--
456	G04	979755.0	125132.0	--	--	--	--	--	--	--
457	G05	979735.0	125352.0	--	--	--	--	--	--	--
458	G06	979635.0	125491.7	--	--	--	--	--	--	--
459	G07	979475.0	125626.0	--	--	--	--	--	--	--
460	G08	979474.7	125812.3	--	--	--	--	--	--	--
461	G09	979440.9	125972.7	--	--	--	--	--	--	--
462	G10	979160.1	126039.3	--	--	--	--	--	--	--
463	G11	978953.7	126217.3	--	--	--	--	--	--	--
464	G12	978791.4	126327.7	--	--	--	--	--	--	--
465	G13	978584.8	126507.3	--	--	--	--	--	--	--
124	GW-01D	982862.3	127876.4	--	--	256.5	60	70	--	56
125	GW-01M	982953.4	127904.3	--	--	256.7	30	40	--	--
123	GW-01S	982781.1	127851.5	--	--	256.1	6	16	--	--
155	GW-02S	983400.8	127487.9	--	--	255.1	6	16	--	--
156	GW-03S	984191.2	126042.6	--	--	252.4	8.4	18.4	--	--
157	GW-04S	983770.6	127239.5	--	--	255.6	5.4	15.4	--	--
158	GW-05S	984189.9	127055.1	--	--	264.2	7	17	--	--
466	H02	979042.0	126437.2	--	--	--	--	--	--	--
179	H10-71	981819.4	126331.6	--	--	250.9	18	28	--	34
174	H11-71	981478.2	125561.4	--	--	241.6	25	35	--	39
173	H12-71	981352.5	124815.3	--	--	250.0	36	36	--	36
180	H5-71	981751.4	126415.0	--	--	250.5	23	28	--	31
177	H6-71	981885.6	126032.0	--	--	249.5	16	16	--	16
178	H7-71	981841.0	125953.9	--	--	246.9	15	15	--	15
176	H8-71	981881.9	126202.3	--	--	250.0	20	25	--	32
175	H9-71	981665.1	126217.4	--	--	250.8	20	25	--	28.5
127	HAYWOOD	981163.8	124370.3	--	--	256.3	--	--	--	--
380	HitchWlHs	975651.6	124010.8	--	--	--	--	--	--	--
299	HM-1	975363.0	125252.3	269.05	TSC	269.2	3	83	--	--
273	HP-1	978832.7	125303.4	254.51	--	252.3	1	6	--	--
274	HP-2	979099.7	125374.2	253.24	--	251.0	1.5	6.5	--	--
275	HP-3	979343.9	125403.5	253.53	--	251.1	1.5	6.5	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
611	INEL-CI	974857.1	124882.2	270.40	TPVC	--	15	62	--	63.8
618	INEL-EI	974872.8	124882.9	270.69	TPVC	--	15	62	--	--
627	INEL-HCE	974883.3	124883.0	270.51	TPVC	--	--	--	--	--
620	INEL-HCN	974856.2	124917.1	271.09	TPVC	--	--	--	--	--
628	INEL-HCNE	974883.2	124906.6	271.67	TPVC	--	--	--	--	--
621	INEL-HCNW	974832.2	124907.7	270.82	TPVC	--	--	--	--	--
625	INEL-HCS	974858.5	124846.4	270.47	TPVC	--	17	62	--	--
626	INEL-HCSE	974883.5	124858.0	270.31	TPVC	--	--	--	--	--
624	INEL-HCSW	974832.1	124859.2	270.38	TPVC	--	--	--	--	--
623	INEL-HCW	974831.2	124882.0	270.38	TPVC	--	17	62	--	--
612	INEL-NCP	974857.0	124907.4	270.89	TPVC	--	15	62	--	60
614	INEL-NEP	974873.1	124906.4	271.16	TPVC	--	15	62.5	--	59
613	INEL-NWP	974842.1	124906.2	270.29	TPVC	--	15	62.5	--	59
615	INEL-SCP	974857.9	124856.8	270.31	TPVC	--	--	--	--	--
617	INEL-SEP	974873.6	124858.0	270.78	TPVC	--	--	--	--	--
616	INEL-SWP	974842.6	124858.7	270.49	TPVC	--	15	62.5	--	--
619	INEL-WI	974840.9	124882.1	270.50	TPVC	--	15	62.5	--	62
567	IW-1	975105.4	124871.1	269.91	TSC	272.4	73.75	103.75	--	103.75
568	IW-2	975037.8	125068.4	268.44	TSC	277.0	67.8	87.8	--	--
467	J02	980936.7	124496.2	--	--	--	--	--	--	--
468	J03	980935.1	124692.0	--	--	--	--	--	--	--
469	J04	981371.5	124939.3	--	--	--	--	--	--	--
470	J05	981370.2	125136.7	--	--	--	--	--	--	--
471	J06	981367.5	125313.4	--	--	--	--	--	--	--
472	J07	981307.1	125716.7	--	--	--	--	--	--	--
473	J08	981224.7	125972.8	--	--	--	--	--	--	--
474	K02	980485.2	126513.0	--	--	--	--	--	--	--
475	K04	980675.5	126332.7	--	--	--	--	--	--	--
476	K06	981000.1	126333.8	--	--	--	--	--	--	--
477	L01	978613.0	126138.0	--	--	--	--	--	--	--
478	L01R	978397.0	126271.5	--	--	--	--	--	--	--
479	L02	979290.6	126300.6	--	--	--	--	--	--	--
480	L03	979520.8	126351.7	--	--	--	--	--	--	--
481	L04	979734.1	126310.9	--	--	--	--	--	--	--
148	LW-01M	984856.9	125418.5	--	--	265.1	42.6	52.6	--	--

Appendix 1. Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
149	LW-01S	984856.9	125419.5	--	--	265.2	25.6	35.6	--	--
150	LW-02S	984495.9	124860.8	245.91	--	243.4	4	14	--	--
151	LW-03S	984876.2	124673.4	250.44	--	250.0	9	19	--	--
152	LW-04S	985003.8	124625.3	246.46	--	244.8	5	15	--	--
367	M261942	973138.9	124764.6	--	--	--	--	--	--	--
23	MI-10	979677.4	124853.9	255.12	TPVC	252.2	44	47	--	58.5
24	MI-11	979580.1	125310.7	254.52	TSC	252.1	40	56	63	--
25	MI-12	979476.4	125858.7	253.26	TSC	251.5	43	49	50	--
204	MI-13	984325.5	123765.2	251.42	--	249.6	12	18	33	--
170	MI-14	977619.8	123760.4	--	--	260.0	--	--	--	--
26	MI-15	976242.8	123624.9	265.17	TSC	264.7	--	--	--	--
27	MI-16	976813.6	123543.9	--	--	269.1	--	--	--	--
29	MI-18	977625.4	123963.1	264.34	TCONC	262.7	--	--	--	--
30	MI-19	974416.4	124870.3	277.42	TPVC	275.6	65	80	--	63.5
163	MI-2	978827.6	124764.7	253.94	TSC	252.9	42	47	--	--
31	MI-20	974416.4	124870.3	277.40	TPVC	275.6	10	40	--	63.5
32	MI-20A	974565.1	124758.4	--	TPVC	274.7	--	14.8	--	--
33	MI-21	974566.7	125043.3	275.31	TSC	272.1	15	40	--	53
34	MI-21A	974696.4	124790.3	272.61	TPVC	272.5	--	--	--	--
35	MI-22	975053.7	125123.5	278.75	TPVC	269.1	99	114	--	94
36	MI-22A	974976.6	125182.6	--	--	270.1	--	11.7	--	--
37	MI-23	975053.7	125123.5	278.75	TPVC	269.1	10	75	--	94
38	MI-24	975050.2	124966.3	272.63	TPVC	269.8	10	85	--	96
39	MI-24A	975092.1	124891.9	--	--	272.0	--	14	--	--
40	MI-25	975089.2	124821.7	272.18	TPVC	269.3	101.8	111	--	105
41	MI-26	975089.2	124821.7	271.31	TPVC	269.3	8	88	--	105
42	MI-27	975064.8	124731.3	272.58	TSC	269.9	13	78	--	88
43	MI-28	974962.8	124603.6	271.85	TPVC	270.3	35	55	56	--
171	MI-29	975306.9	123808.1	269.93	TPVC	268.5	31.5	51.5	51.5	--
164	MI-3	978692.7	124915.0	257.28	TSC	254.5	44	49	--	--
44	MI-30	975877.3	124347.0	269.35	TPVC	265.7	27	72	75	--
45	MI-31	975786.4	124591.9	267.23	TPVC	266.1	36	54	--	--
46	MI-32	975247.2	124933.7	273.88	Shelter	270.2	30	75	--	95
47	MI-33	975651.3	124011.3	265.90	WELLCVR	268.0	50	60	60	--
48	MI-34	975833.6	122797.6	278.84	TPVC	278.8	--	17.7	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
49	MI-35	976578.5	124150.8	263.20	PWMC	262.2	--	55	--	--
50	MI-36	974900.8	123429.2	270.51	TPVC	269.9	--	12.5	--	--
51	MI-37	975299.5	123330.9	272.60	TPVC	270.4	--	12.5	--	--
52	MI-38	975116.9	123948.1	--	--	270.0	--	--	--	--
165	MI-4	978596.4	124892.5	257.49	TSC	255.0	39	49	--	--
172	MI-40	977391.3	124739.2	257.40	TPVC	256.1	--	--	--	--
54	MI-41	977561.6	124774.2	260.12	TPVC	258.7	--	20	--	--
55	MI-42	977567.3	124958.1	258.51	TPVC	257.2	--	20	--	--
56	MI-43	977583.8	125123.0	258.82	TPVC	257.3	--	20	--	--
58	MI-44	977514.1	125199.4	260.60	TPVC	259.2	--	20	--	--
59	MI-45	975909.3	125772.4	--	--	264.9	--	--	--	--
60	MI-46	975970.8	125598.0	--	--	267.3	--	--	--	--
61	MI-47	975825.5	125094.2	--	--	270.0	--	--	--	--
62	MI-48	976556.3	124678.9	--	TCONC	264.1	--	--	--	--
166	MI-5	978717.7	124920.5	255.89	TSC	255.2	39	49	--	--
167	MI-6	978717.1	124918.6	255.66	TSC	255.1	--	--	--	--
72	MI-62	977408.8	125554.8	--	--	260.0	17	58	60.58	--
203	MI-63	975636.8	125076.6	267.75	TSC	265.1	24	64	--	--
73	MI-64	979161.5	123887.2	--	--	259.9	--	--	--	--
168	MI-6A	978830.1	124812.8	--	--	259.5	--	--	--	--
21	MI-7	978642.4	125263.6	256.68	TSC	253.2	--	31	--	--
22	MI-8	976549.9	125251.5	264.93	TINRSC	262.6	--	13.5	--	--
169	MI-9	976255.7	125936.0	265.05	TCONC	263.8	--	--	--	--
188	MOA-25	975839.7	125937.0	--	--	262.0	50	60	72	--
189	MOA-35	975554.9	125804.9	--	--	265.2	--	--	12	--
190	MOA-37	975737.6	126314.6	--	--	260.0	--	--	13	--
191	MOA-38	975295.4	125590.6	--	--	270.0	--	--	14	--
78	MOA-4	978318.2	124603.5	--	--	249.5	33	38	54	--
193	MOW-15	977255.8	127892.7	--	--	260.0	--	--	--	--
202	MOW-19	976722.5	125725.6	--	--	260.8	--	--	--	--
200	MOW-25	977668.8	122997.3	--	--	259.7	--	--	4	--
201	MOW-26	977661.4	122551.6	--	--	260.0	--	--	14	--
154	MOW-32	976679.8	124466.7	--	--	261.8	6	16	20	--
74	MOW-35	979010.1	124641.8	--	--	260.0	--	--	59	--
153	MOW-38	975574.2	128320.7	--	--	262.7	30	40	41	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measurement point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
194	MOW-58	975647.0	125574.5	--	--	268.7	54	63	76	--
57	MOW-63	975248.2	125062.1	--	--	270.0	53	62	65	--
195	MOW-64	976832.4	126380.5	--	--	260.0	41	49	76	--
196	MOW-65	976555.4	126488.7	--	--	260.0	54	62	73	--
197	MOW-66	982904.6	124297.2	--	--	252.8	27	33	37	--
198	MOW-67	983164.5	124318.2	--	--	249.8	37	43	45	--
199	MOW-68	983417.4	124322.2	--	--	245.0	36	42	53	--
580	MW-101A	975981.9	125600.9	266.55	TPVC	--	9	19	--	--
581	MW-101B	975984.5	125594.2	266.33	TPVC	--	45	55	--	--
582	MW-101C	975985.1	125588.7	265.73	TSC	--	93	103	102.9	102.9
316	MW-10A	976221.5	124928.6	263.77	TPVC	262.2	19	29	--	--
317	MW-10B	976218.5	124928.4	263.55	TPVC	262.2	44	54	--	--
218	MW-10C	976215.0	124930.6	264.74	TPVC	262.8	81.5	91.5	--	91.6
318	MW-11A	976433.3	125888.7	262.78	TPVC	260.9	20.5	30.5	--	--
319	MW-11B	976435.2	125885.3	262.83	TPVC	261.0	52.3	64.3	--	65
219	MW-11R	976435.0	125881.6	262.47	TINRSC	261.0	70	100.5	--	65
220	MW-12A	978133.3	124280.7	265.96	TPVC	264.0	25	35	--	--
320	MW-12B	978134.3	124287.4	265.61	TPVC	264.0	56	66	--	66
308	MW-13A	977298.8	125084.8	258.04	TPVC	257.9	23.9	33.9	--	--
221	MW-13B	977300.6	125081.1	259.35	TPVC	257.9	48	58	--	64
349	MW-14A	978695.9	125654.9	254.85	TSC	253.4	19	29	--	--
341	MW-14B	978696.6	125651.1	255.14	TSC	253.3	50	60	--	60
222	MW-14R	978696.0	125647.0	255.50	TINRSC	253.8	73	110	--	60
223	MW-15A	982006.4	125915.3	258.53	TPVC	256.8	12.5	27.5	--	--
342	MW-15B	982001.4	125914.5	258.61	TPVC	257.0	29.4	36.4	--	27.5
233	MW-16A	975671.2	124863.1	269.98	TPVC	267.5	16.9	26.9	--	--
321	MW-16B	975671.0	124868.6	269.84	TPVC	267.6	39.6	49.6	--	--
344	MW-16C	975678.1	124877.1	269.73	TPVC	267.4	73.2	83.2	--	87.5
345	MW-16R	975670.8	124875.2	268.96	TSC	266.5	100	138	--	87.5
258	MW-17A	976216.5	124754.0	265.66	TPVC	264.4	19.8	29.8	--	--
322	MW-17B	976212.0	124755.5	265.67	TPVC	264.6	52.4	62.4	--	--
323	MW-17C	976212.8	124757.9	265.27	TPVC	264.7	85	95	--	99.3
231	MW-18A	975824.8	124273.4	269.78	TPVC	267.9	44.5	54.5	--	--
324	MW-18B	975824.1	124279.1	270.30	TPVC	268.0	72	82	--	82
326	MW-19A	977289.2	124123.2	263.68	TPVC	261.6	23.5	33.5	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
327	MW-19B	977294.8	124124.8	263.44	TPVC	260.9	39	49	30	35
307	MW-1A	974929.8	122712.2	281.26	TPVC	279.7	5	17	--	--
309	MW-1B	974926.7	122718.3	281.38	TPVC	279.5	35.4	45.4	--	--
209	MW-1C	974922.8	122726.7	281.28	TPVC	279.5	51.1	61.1	--	62
264	MW-20A	977472.9	124629.1	263.23	TPVC	260.8	15.2	25.2	--	--
328	MW-20B	977476.1	124622.3	263.03	TPVC	260.7	35	45	--	47.5
278	MW-21A	979001.3	124463.6	261.27	TPVC	259.2	3.8	13.8	--	--
329	MW-21B	979001.2	124469.8	261.77	TPVC	259.3	20	30	--	--
330	MW-21C	979001.5	124474.0	261.34	TPVC	259.4	44.1	54.1	--	63.75
293	MW-22A	981102.3	126204.0	252.52	TPVC	250.2	13.8	23.8	--	--
294	MW-22B	981098.7	126201.3	252.77	TPVC	250.1	33.5	43.5	--	47
237	MW-23A	975835.1	125944.3	267.51	TPVC	265.4	20	30	--	--
331	MW-23B	975802.8	125947.1	267.40	TPVC	265.3	48	58	--	--
332	MW-23C	975840.8	125954.0	267.34	TPVC	265.3	84.3	94.3	--	106
381	MW23-SG1	975803.8	125915.3	261.09	BOLT HEAD	--	--	--	--	--
382	MW23-SG2	975805.7	125912.7	265.52	USGS disc	--	--	--	--	--
255	MW-24A	977644.9	126373.3	259.67	TPVC	257.1	19.5	29.5	--	--
333	MW-24B	977649.7	126372.3	259.39	TPVC	256.8	31	41	--	40.5
226	MW-25	975168.9	123046.5	273.12	TPVC	270.5	4	12	--	--
225	MW-26	975206.2	123141.4	271.11	TPVC	268.7	3	13	--	--
235	MW-27	974627.7	125049.4	275.64	RIM	273.8	5	15	--	--
234	MW-28	974374.9	124929.3	275.53	TSC	275.6	5	15	--	--
262	MW-29	977125.3	124080.3	260.90	TPVC	261.0	2.5	12.5	--	--
310	MW-2A	975148.9	125591.3	269.32	TPVC	266.6	29	39	--	--
210	MW-2B	975151.8	125599.9	269.19	TSC	266.4	70.7	80.7	--	--
311	MW-2R	975145.0	125587.7	267.67	TSC	266.2	134	164	--	115.5
228	MW-3	975915.6	123237.1	270.54	TPVC	268.7	11.5	21.5	--	21.5
366	MW-30	975228.8	125893.3	267.96	TSC	--	--	--	--	--
334	MW-31	978979.1	126191.9	251.87	TSC	250.1	60	273	--	49
296	MW-32A	981366.6	125490.0	250.46	TPVC	247.9	7	17	--	--
297	MW-32B	981369.8	125487.1	251.23	TPVC	248.3	31.8	41.8	--	43.5
306	MW-33	979070.9	126468.1	254.52	TSC	251.8	41.5	51.5	--	52.5
281	MW-34	979987.0	126490.7	260.91	TPVC	258.5	9.5	19.5	--	20.5
312	MW-4A	975307.9	123586.4	268.34	TPVC	266.5	19.7	29.7	--	--
212	MW-4B	975303.5	123583.8	268.59	TPVC	266.7	45.8	55.8	--	43.2

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
347	MW-4R	975299.9	123581.5	268.47	TSC	266.4	64	98	--	45
313	MW-5A	975414.6	123981.8	269.71	TPVC	267.6	28	38	--	--
213	MW-5B	975408.3	123982.6	269.61	TPVC	267.6	50.4	60.4	--	61.35
348	MW-6A	975521.4	124481.8	269.11	TPVC	267.0	8	20	--	--
214	MW-6B	975521.2	124486.8	268.95	TPVC	267.1	56.8	66.8	--	69.4
314	MW-7A	976267.6	123912.6	264.40	TPVC	262.3	3.2	13.2	--	--
215	MW-7B	976263.3	123908.4	264.29	TPVC	262.5	45.6	55.6	--	58.6
315	MW-8A	976511.8	124151.8	263.91	TPVC	262.0	4.5	16.5	--	--
216	MW-8B	976524.9	124151.4	263.80	TPVC	261.8	57	67	--	90
351	MW-9A	976502.9	124485.8	267.76	TPVC	266.1	30.7	40.7	--	--
352	MW-9B	976503.6	124479.1	267.87	TPVC	266.1	58.2	68.2	--	--
217	MW-9C	976503.3	124473.6	268.09	TPVC	266.3	79	90	--	94
482	N01	979147.8	126556.0	--	--	--	--	--	--	--
483	N02	979767.2	126623.0	--	--	--	--	--	--	--
375	nearFH19	978900.7	126413.0	--	--	--	--	--	--	--
484	P01	981838.2	124649.8	--	--	--	--	--	--	--
485	P02	981887.1	125105.9	--	--	--	--	--	--	--
65	P-03	976979.6	124880.4	263.27	TSC	261.3	--	--	--	--
335	P-1	974088.3	124847.5	279.26	Shelter	276.6	13.9	14.9	--	--
276	P-10	979466.8	125859.0	252.70	--	250.4	7.5	8.5	--	--
277	P-11	979689.2	126100.9	254.54	--	252.5	7.5	8.5	--	--
361	P-12	980380.2	125709.4	252.03	--	252.0	9	10	--	--
295	P-13	981806.6	126346.1	250.84	--	248.3	7.5	8.5	--	--
338	P-14	981843.1	124952.7	248.69	--	246.7	7	8	--	--
271	P-15	978953.7	126170.9	252.08	TPVC	251.4	7	8	--	--
280	P-16	979986.6	126500.0	260.43	TPVC	258.3	12	13	--	--
282	P-17A	980125.1	126109.1	252.54	--	250.6	8	9	--	--
283	P-17B	980124.1	126110.1	253.66	--	252.6	12	13	--	--
383	P1-SG1	974066.3	124879.1	268.91	BOLT HEAD	--	--	--	--	--
384	P1-SG2	974066.9	124878.4	271.89	BOLT HEAD	--	--	--	--	--
336	P-2	975100.9	125281.9	271.79	Shelter	268.6	17	18	--	--
385	P2-SG1	975037.3	125304.6	262.62	BOLT HEAD	--	--	--	--	--
386	P2-SG2	975040.9	125298.9	260.11	SG2	--	--	--	--	--
387	P2-SG3	975043.9	125294.6	260.11	SG3	--	--	--	--	--
388	P2-SG4	975045.6	125284.0	260.11	SG4	--	--	--	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
269	P-9A	978624.2	126009.9	254.73	--	253.1	7	8	--	--
270	P-9B	978624.0	126015.8	255.01	--	252.6	9.2	10.2	--	--
18	PA-1	980332.1	123667.2	--	--	255.1	--	8.7	--	--
19	PA-2	980334.7	123737.3	--	--	254.9	--	8.7	--	--
20	PA-3	980388.4	123703.1	--	--	255.3	--	7.8	--	--
354	PFHprodWell	981195.6	126601.6	251.68	--	249.2	30	40	--	--
552	PW-10D	975149.6	125118.0	276.53	TPVC	273.8	94.71	104.71	--	--
551	PW-10M	975142.3	125124.8	276.47	TPVC	274.0	50.15	60.15	--	--
554	PW-11D	975172.4	125172.1	272.62	TOC	269.7	93.11	103.11	--	101
553	PW-11M	975180.9	125167.0	272.45	TOC	269.9	46.4	56.4	--	--
557	PW-12D	975427.9	125266.2	267.68	TOC	265.7	87	97	--	--
556	PW-12M	975437.2	125255.7	268.06	TOC	265.8	57.8	68	--	--
558	PW-12R	975437.6	125267.4	267.78	TOC	265.7	113.9	134	--	100
555	PW-12S	975427.3	125256.4	267.75	TOC	265.7	18.1	28.1	--	--
561	PW-13D	975691.7	125297.7	269.58	TOC	267.6	94.3	104.35	--	103
560	PW-13M	975699.9	125292.8	269.95	TOC	267.9	59.8	70	--	--
559	PW-13S	975692.0	125287.5	269.75	TOC	267.7	20.3	30.3	--	--
564	PW-14D	975764.9	125098.0	268.94	TOC	266.8	102.71	112.71	--	111.5
563	PW-14M	975757.3	125104.2	268.89	TOC	266.8	60	70	--	--
562	PW-14S	975756.4	125094.6	268.77	TOC	266.8	20.03	30.03	--	--
531	PW-1D	975507.1	125011.0	266.76	TOC	266.9	84.48	94.48	--	94
530	PW-1S	975498.5	125008.0	266.91	TOC	267.0	26.02	36.02	--	--
534	PW-2D	975255.1	124963.5	273.34	TPVC	269.7	96.17	106.17	--	102
533	PW-2M	975264.5	124972.7	270.54	TPVC	268.4	49.83	59.83	--	--
535	PW-2R	975254.7	124973.6	273.27	TPVC	268.9	113.93	133.93	--	102
532	PW-2S	975264.3	124962.1	271.04	TPVC	268.5	19.62	29.62	--	--
537	PW-3D	975056.3	125240.1	272.38	TPVC	269.8	84.85	94.85	--	94.5
536	PW-3S	975065.3	125235.5	272.39	TPVC	269.8	19.76	29.76	--	--
539	PW-4D	974963.8	124756.7	274.49	TOC	272.0	62	72	--	70
538	PW-4M	974974.7	124756.4	273.81	TPVC	271.8	31.87	41.87	--	--
541	PW-5D	975206.8	124969.2	275.13	TPVC	272.5	97.83	107.83	--	106.5
540	PW-5M	975198.9	124963.3	275.88	TPVC	273.0	52.4	62.4	--	--
542	PW-5R	975206.9	124959.1	275.31	TPVC	272.5	122.76	132.76	--	106
545	PW-6D	975014.3	124943.8	279.01	TOC	277.0	87.6	97.6	--	94
544	PW-6M	975005.4	124932.2	279.10	TPVC	276.4	40.39	50.39	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
546	PW-6R	975015.9	124934.2	278.58	TOC	276.3	101.04	111.04	--	95
543	PW-6S	975004.8	124942.1	279.12	TOC	276.7	23.63	33.63	--	--
548	PW-7M	974748.6	124890.1	275.84	TPVC	273.6	53.29	63.29	--	--
547	PW-7S	974747.6	124900.1	275.84	TPVC	273.2	32.72	42.72	--	--
549	PW-8M	974856.2	125140.4	276.05	TPVC	273.3	31.37	41.37	--	--
550	PW-9M	974857.5	125165.4	275.56	TPVC	272.5	31.88	41.88	--	--
14	RFW-1	980111.6	123484.1	--	--	255.7	8	28	28	--
15	RFW-2	980419.4	123831.6	253.87	--	253.8	10	35	35	--
16	RFW-3	980457.3	124035.2	253.51	--	253.5	13	43	43	--
17	RFW-4	980142.7	124069.5	252.15	--	251.6	6	16	16	--
247	RW1	975397.4	127471.0	--	--	-2.0	59	340	--	--
569	RW-1	974751.8	125000.5	267.19	TSC	273.7	31.65	41.65	--	--
248	RW2	975425.1	127514.8	--	--	--	--	--	--	--
570	RW-2	974799.4	124838.7	267.15	TSC	273.4	22.04	32.04	--	--
245	RW3	974864.4	126779.8	--	--	-2.0	111	420	--	--
571	RW-3	975168.5	124805.8	268.79	TSC	270.0	18.45	28.45	--	--
284	RW4	980479.8	126905.0	280.08	--	278.3	--	23	--	--
244	RW6	974672.7	126362.0	--	--	--	--	--	--	--
287	RW9	981114.8	127599.2	271.45	--	270.4	--	22	--	--
128	SavageWell	978473.2	124848.0	--	--	261.0	35	45	--	--
588	SB-01	976165.9	125868.3	--	--	263.4	--	--	94.5	--
589	SB-02	976069.8	125390.7	--	--	266.0	--	--	104.	--
590	SB-03	976500.1	124641.6	--	--	262.5	--	--	90.5	--
591	SB-04	976509.5	125564.3	--	--	262.6	--	--	63.	--
592	SB-05(MW-102)	976774.8	125063.3	--	--	259.7	--	--	73.	--
593	SB-06	976863.6	124649.0	--	--	262.1	--	--	83.	--
594	SB-07(MW-103)	977151.7	125420.8	--	--	259.3	--	--	65.	--
595	SB-08	977779.6	124359.9	--	--	260.9	--	--	40.	--
596	SB-09(MW-104)	977680.2	125910.9	--	--	256.6	--	--	35.	--
597	SB-10(MW-105)	977857.0	125286.7	--	--	257.7	--	--	63.	--
598	SB-11(MW-106)	977167.8	124510.3	--	--	259.2	--	--	60.	--
390	SG(outcrop)	981834.5	126399.5	239.39	SG	--	--	--	--	--
519	SMA	974862.6	124913.3	--	--	--	--	--	--	--
520	SMB	974819.0	124876.1	--	--	--	--	--	--	--
521	SMC	974860.0	124883.3	--	--	--	--	--	--	--

Appendix 1. Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

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Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
522	SMD	974860.0	124898.9	--	--	--	--	--	--	--
523	SME	974860.0	124868.5	--	--	--	--	--	--	--
524	SMF	974794.1	124896.8	--	--	--	--	--	--	--
525	SMG	974859.6	124928.1	--	--	--	--	--	--	--
526	SMH	974860.0	124852.9	--	--	--	--	--	--	--
527	SMI	974860.0	124891.3	--	--	--	--	--	--	--
528	SMJ	974860.0	124838.5	--	--	--	--	--	--	--
529	SMK	974860.0	124824.5	--	--	--	--	--	--	--
572	SP-1	974885.1	124935.8	266.58	TSC	274.5	60.66	65.66	--	66.8
340	SP-10	975407.8	126569.5	263.92	--	262.4	1	6	--	--
291	SP-11	981256.9	126375.4	249.67	--	247.7	8.5	9.5	--	--
290	SP-18	981032.5	126481.6	250.17	--	248.2	4.5	7.5	--	--
573	SP-2	974910.9	125063.9	266.57	TSC	275.3	59.71	64.71	--	--
279	SP-2	979817.2	126368.5	251.94	TPVC	249.9	1	6	--	--
268	SP-3	978256.8	126568.9	256.30	--	255.3	4.5	9.5	--	--
267	SP-4	977995.7	127200.0	258.63	--	257.1	2.5	7.5	--	--
304	SP-5	977271.9	126837.8	257.07	--	255.3	2.5	7.5	--	--
252	SP-6	976792.4	126621.2	261.05	TPVC	260.0	3	8	--	--
251	SP-7	977551.4	127255.9	258.66	TPVC	258.2	4.5	9.5	--	--
339	SP-9	976276.6	126593.0	261.16	--	259.4	1.5	6.5	--	--
250	SPZ-1	976415.4	128176.9	259.17	TPVC	257.4	2	7	--	--
285	SPZ-2	980666.6	126449.9	252.23	TPVC	250.2	3.5	8.5	--	--
574	SVE-1	974927.1	124888.1	--	--	275.0	8.37	23.36	--	--
575	SVE-2	974946.5	124988.0	--	--	276.3	9.41	24.41	--	--
576	SVE-3	974966.9	125106.6	--	--	273.4	12.34	27.34	--	--
577	SVE-4	974828.7	124901.9	--	--	274.0	12.66	27.66	--	--
578	SVE-5	974846.8	125001.1	--	--	274.8	7.87	23.87	--	--
579	SVE-6	974870.3	125128.9	--	--	273.7	12.39	27.39	--	--
362	USGS-DISK	978965.1	126138.8	250.02	--	--	--	--	--	--
486	VP1001	974973.9	124781.0	--	--	--	--	--	--	--
487	VP1002	974871.8	124748.3	--	--	--	--	--	--	--
488	VP1003	974764.9	124838.3	--	--	--	--	--	--	--
489	VP1004	974688.3	124902.7	--	--	--	--	--	--	--
490	VP1005	974782.9	125005.6	--	--	--	--	--	--	--
491	VP1006	974922.8	124990.3	--	--	--	--	--	--	--

Appendix 1.   Information on wells and vertical profile points, Savage Municipal Well Superfund site, Milford, N.H.—Continued

[All units in feet; Horizontal datum based on 2,000-foot grid New Hampshire State Planar coordinate system North American Datum 1983; vertical datum based on feet above National Geodetic Vertical Datum 1929; depth in feet below land surface; well name descriptions on page ix in this report; location of some wells are on figure 2; some wells not shown on figure 2; --, no data; wells are sorted alphabetically. Description of measurement point: TSC, top of steel casing; TPVC, top of polyvinyl chloride pipe; shelter, top of shelter floor; SG, staff gage; SG2, second staff gage; SG3, third staff gage; SG4, fourth staff gage; TCONC, top of concrete; RIM, rim of manhole cover; BOLT HEAD, top of bolt; WELLCVR, well cover; TINRSC, top of inner steel casing; AHPUMP, air line reading at pump; top rebar, top of rebar pipe; USGS disc, top of U.S. Geological Survey disc; VENT, vent hole at pump; TOC, top of casing; PWMC, production well metal casing]

Well number	Well name	Easting	Northing	Altitude of measure-ment point	Description of measurement point	Altitude of land surface	Top of opening below land surface	Bottom of opening below land surface	Depth to refusal below land surface	Depth to bedrock below land surface
492	VP1007	974916.6	125089.2	--	--	--	--	--	--	--
493	VP1008	974843.1	124868.1	--	--	--	--	--	--	--
494	VP1010	974662.1	125064.6	--	--	--	--	--	--	--
495	VP1011	974753.9	125052.5	--	--	--	--	--	--	--
496	VP1012	974838.8	125051.6	--	--	--	--	--	--	--
497	VP1013	974958.5	125128.4	--	--	--	--	--	--	--
498	VP1014	974834.1	125154.4	--	--	--	--	--	--	--
499	VP1015	974917.1	125191.6	--	--	--	--	--	--	--
500	VP1016	974686.8	124998.9	--	--	--	--	--	--	--
501	VP2001	975032.6	125199.6	--	--	--	--	--	--	--
502	VP2002	975054.8	125116.5	--	--	--	--	--	--	--
503	VP2003	975053.1	125046.1	--	--	--	--	--	--	--
504	VP2004	975053.1	124962.3	--	--	--	--	--	--	--
505	VP2005	975088.4	124827.3	--	--	--	--	--	--	--
506	VP2006	975054.5	125003.6	--	--	--	--	--	--	--
507	VP2007	975060.1	124892.2	--	--	--	--	--	--	--
508	VP2008	975143.9	124858.0	--	--	--	--	--	--	--
509	VP3002	975183.2	125171.2	--	--	--	--	--	--	--
510	VP3003	975217.8	125071.9	--	--	--	--	--	--	--
511	VP3004	975233.4	124979.3	--	--	--	--	--	--	--
512	VP3005	975197.6	124894.6	--	--	--	--	--	--	--
513	VP3006	975313.6	124781.6	--	--	--	--	--	--	--
514	VP4001	975384.6	125246.0	--	--	--	--	--	--	--
515	VP4002	975598.9	125229.8	--	--	--	--	--	--	--
516	VP4003	975631.1	125083.4	--	--	--	--	--	--	--
517	VP4004	975598.7	124960.9	--	--	--	--	--	--	--
518	VP4006	975711.6	124809.1	--	--	--	--	--	--	--
391	WLR-1	973834.4	124843.1	282.80	Shelter	--	--	--	--	--
586	WLR-1 staff	973834.4	124843.1	269.21	SG	--	--	--	--	--
337	WLR4	978297.6	125583.7	257.38	Shelter	251.3	4	5	--	--
393	WLR-5	980644.9	126283.6	254.27	Shelter	--	--	--	--	--
585	WLR-5 rebar	980644.9	126283.6	245.24	Top rebar	--	--	--	--	--
122	WW-125	975152.7	129134.8	--	--	269.0	--	--	--	--

Appendix 2.   Tetrachloroethylene concentrations for data points used in figure 14, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[Location of wells shown on figure 2. PCE, tetracholoroethylene; Depth code: shallow is 0–40 feet below land surface, medium is 40.1–70 feet, deep is 70.1 feet to bedrock; VP, vertical profile; wells have only one sample collected per depth code, whereas VP points have a minimum of three samples collected per depth code; site type names explained in abbreviation section of report; Source of data: Camp, Dresser, and McKee, Inc. (2001)]

Well number	Name	Depth code	Maximum PCE concentration, in micrograms per liter	Median PCE concentration, in micrograms per liter
630	VP5001	Shallow	840.0	219.0
631	VP5002	Shallow	670.0	140.0
632	VP5003	Shallow	481.0	69.5
633	VP5004	Shallow	603.0	76.0
634	VP5005	Shallow	1,595.0	743.0
635	VP5006	Shallow	321.0	50.0
636	VP5007	Shallow	589.0	124.5
637	VP5008	Shallow	556.0	286.5
638	VP5009	Shallow	1,543.0	130.0
233	MW-16A	Shallow	7.8	7.8
235	MW-27	Shallow	2.0	2.0
404	B95-9	Shallow	190.0	190.0
530	PW-1S	Shallow	370.0	370.0
532	PW-2S	Shallow	19.0	19.0
536	PW-3S	Shallow	2.0	2.0
538	PW-4M	Shallow	2.0	2.0
543	PW-6S	Shallow	6,200.0	6,200.0
547	PW-7S	Shallow	2.0	2.0
549	PW-8M	Shallow	88.0	88.0
550	PW-9M	Shallow	2.0	2.0
555	PW-12S	Shallow	13.0	13.0
559	PW-13S	Shallow	180.0	180.0
562	PW-14S	Shallow	220.0	220.0
1	NWP	Shallow	532.0	480.0
2	SWP	Shallow	178.0	125.0
3	CI	Shallow	109.0	97.5
4	NEP	Shallow	7,170.0	6,940.0
5	SEP	Shallow	1.4	1.0
630	vp5001	Medium	1,203.0	152.00
631	VP5002	Medium	154.0	57.00
632	VP5003	Medium	444.0	130.50
633	VP5004	Medium	886.0	291.50
634	VP5005	Medium	302.0	119.00
635	VP5006	Medium	579.0	352.00
636	VP5007	Medium	16.0	4.50

Appendix 2. Tetrachloroethylene concentrations for data points used in figure 14, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.—Continued

[Location of wells shown on figure 2. PCE, tetracholoroethylene; Depth code: shallow is 0–40 feet below land surface, medium is 40.1–70 feet, deep is 70.1 feet to bedrock; VP, vertical profile; wells have only one sample collected per depth code, whereas VP points have a minimum of three samples collected per depth code; site type names explained in abbreviation section of report; Source of data: Camp, Dresser, and McKee, Inc. (2001)]

Well number	Name	Depth code	Maximum PCE concentration, in micrograms per liter	Median PCE concentration, in micrograms per liter
637	VP5008	Medium	145.0	1.85
638	VP5009	Medium	510.0	2.68
46	MI-32	Medium	150.0	150.00
321	MW-16B	Medium	4.3	4.30
398	B95-3	Medium	2.0	2.00
400	B95-5	Medium	2.0	2.00
401	B95-6	Medium	2.0	2.00
407	B95-12	Medium	2.0	2.00
408	B95-13	Medium	200.0	200.00
533	PW-2M	Medium	260.0	260.00
539	PW-4D	Medium	2.0	2.00
540	PW-5M	Medium	140.0	140.00
544	PW-6M	Medium	5,900.0	5,900.00
548	PW-7M	Medium	2.5	2.50
551	PW-10M	Medium	210.0	210.00
553	PW-11M	Medium	4.7	4.70
556	PW-12M	Medium	70.0	70.00
560	PW-13M	Medium	120.0	120.00
563	PW-14M	Medium	600.0	600.00
1	NWP	Medium	573.0	558.00
2	SWP	Medium	226.0	204.00
3	CI	Medium	29,500.0	529.00
4	NEP	Medium	20,200.0	8,875.00
5	SEP	Medium	8.7	1.10
630	VP5001	Deep	750.0	422.00
631	VP5002	Deep	656.0	353.00
633	VP5004	Deep	526.0	240.50
634	VP5005	Deep	194.0	174.00
635	VP5006	Deep	1,033.0	933.50
636	VP5007	Deep	9.1	4.95
637	VP5008	Deep	0.8	0.75
638	VP5009	Deep	662.0	639.50
344	MW-16C	Deep	170.0	170.00
403	B95-8	Deep	4.7	4.70
409	B95-15	Deep	43.0	43.00

Appendix 2. Tetrachloroethylene concentrations for data points used in figure 14, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.—Continued

[Location of wells shown on figure 2. PCE, tetracholoroethylene; Depth code: shallow is 0–40 feet below land surface, medium is 40.1–70 feet, deep is 70.1 feet to bedrock; VP, vertical profile; wells have only one sample collected per depth code, whereas VP points have a minimum of three samples collected per depth code; site type names explained in abbreviation section of report; Source of data: Camp, Dresser, and McKee, Inc. (2001)]

Well number	Name	Depth code	Maximum PCE concentration, in micrograms per liter	Median PCE concentration, in micrograms per liter
531	PW-1D	Deep	370.0	370.00
534	PW-2D	Deep	320.0	320.00
537	PW-3D	Deep	2.0	2.00
541	PW-5D	Deep	190.0	190.00
545	PW-6D	Deep	16,000.0	16,000.00
552	PW-10D	Deep	660.0	660.00
554	PW-11D	Deep	9.1	9.10
557	PW-12D	Deep	110.0	110.00
561	PW-13D	Deep	790.0	790.00
564	PW-14D	Deep	910.0	910.00

Appendix 3.   Information on barrier-trench depths, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.

[NAD 83, North American Datum 1983; NGVD 29, altitude in feet above National Geodetic Vertical Datum of 1929; --, no data; 13+15, reference line segment 13, station number 15 shown on figure 17; Source of data: Sverdrup Environmental, Inc., written commun., 1999]

Line and station number	Easting, in feet, N.H. State Planar coordinate system NAD 83	Northing, in feet, N.H. State Planar coordinate system NAD 83	Elevation of land surface, in feet above NGVD 29	Elevation of depth of trench, in feet above NGVD 29	Final depth of trench, in feet be-low land surface	Key depth if encountered refusal, in feet below land surface	Key material	Comment
0+90	974759.6250	125079.9922	271	202	69	--	--	
0+80	974753.1875	125072.3672	271	204	67	--	--	
0+70	974747.2500	125064.3359	271	203.5	67.5	--	--	
0+60	974742.6875	125055.4453	271	203	68	--	--	
0+50	974738.5000	125046.3672	271	208	63	--	--	
0+40	974735.3125	125036.8906	271	207.5	63.5	--	--	
0+30	974732.6250	125027.2734	271	209	62	--	--	
0+20	974730.1250	125017.5859	271	209	62	--	--	
0+10	974727.6875	125007.8750	271	207	64	--	--	
0+0	974725.5000	124998.1250	271	207	64	--	--	
14+70	974722.5000	124983.6094	271	209	62	--	--	
14+60	974720.6250	124973.7891	271	208.5	62.5	--	--	
14+50	974718.8125	124963.9531	271	208	63	--	--	
14+40	974717.5625	124954.0391	271	207	64	--	--	
14+30	974717.5625	124944.0547	271	207	64	--	--	
14+20	974718.9375	124934.1563	271	206	65	--	--	
14+10	974720.6875	124924.3047	271	211	60	--	--	
14+0	974722.5000	124914.4766	271	211	60	63	--	
13+90	974724.3125	124906.0469	271	214	57	60	--	
13+80	974726.5000	124896.2891	271	216	55	60	--	
13+70	974728.8750	124886.5781	271	221	50	57	--	
13+60	974731.4375	124876.9063	271	213.5	57.5	55	--	
13+50	974734.1875	124867.2969	271	210	61	50	--	
13+40	974737.4375	124857.8438	271	203	68	66.5	Till	Key depth and material old station 13+15.
13+30	974741.5000	124848.7422	271	207.5	63.5	63.5	Bedrock	Key depth and material old station 13+15.
13+20	974746.6250	124840.1328	271	203	68	76.5	Till	Key depth and material old station 11+80.
13+10	974752.4375	124832.0078	271	203	68	--	--	
13+0	974758.8125	124824.3203	271	203	68	68	Bedrock	
12+90	974770.0000	124813.5938	271	202	69	--	--	
12+80	974777.6250	124807.1719	271	202	69	69	Bedrock	

Appendix 3. Information on barrier-trench depths, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H. —Continued

[NAD 83, North American Datum 1983; NGVD 29, altitude in feet above National Geodetic Vertical Datum of 1929; --, no data; 13+15, reference line segment 13, station number 15 shown on figure 17; Source of data: Sverdrup Environmental, Inc., written commun., 1999]

Line and station number	Easting, in feet, N.H. State Planar coordinate system NAD 83	Northing, in feet, N.H. State Planar coordinate system NAD 83	Elevation of land surface, in feet above NGVD 29	Elevation of depth of trench, in feet above NGVD 29	Final depth of trench, in feet below land surface	Key depth if encountered refusal, in feet below land surface	Key material	Comment
12+70	974785.9375	124801.6641	271	202	69	--	--	
12+60	974794.8750	124797.2031	271	202	69	69	Bedrock	
12+50	974804.0000	124793.0469	271	197	74	--	--	
12+40	974813.3750	124789.5547	271	197.5	73.5	--	--	
12+30	974822.9375	124786.6563	271	199	72	--	--	
12+20	974832.6250	124784.1563	271	194	77	--	--	
12+10	974842.4375	124782.5156	271	200.5	70.5	--	--	
12+0	974852.3750	124781.2500	271	201	70	72	Till	
11+90	974863.0625	124780.6797	271	202	69	--	--	
11+80	974873.0625	124780.4141	271	212	59	--	--	
11+70	974883.0625	124780.2344	271	212	59	68	Bedrock	
11+60	974893.0625	124780.1641	271	206	65	65	Bedrock	
11+50	974903.0625	124780.4219	271	204	67	67	Bedrock	
11+40	974913.0625	124780.9063	271	203.5	67.5	--	--	
11+30	974923.0625	124781.4141	271	203.5	67.5	--	--	
11+20	974933.0000	124781.9219	271	205.5	65.5	--	--	
11+10	974943.0000	124782.4453	271	207.5	63.5	--	--	
11+0	974953.0000	124783.0234	271	210.5	60.5	--	--	
10+90	974963.2500	124783.7031	271	208.5	62.5	--	--	
10+80	974973.1875	124784.3906	271	206	65	63	Bedrock	
10+70	974983.1875	124785.0781	271	204.5	66.5	67.5	Bedrock	
10+60	974993.1875	124785.7656	271	198.5	72.5	69	Bedrock	
10+50	975003.1250	124786.5156	271	196.5	74.5	75	Bedrock	
10+40	975013.0625	124787.5156	271	197	74	75.5	Bedrock	
10+30	975023.0000	124788.5938	271	195	76	75.5	Bedrock	
10+20	975032.9375	124789.8516	271	195	76	75	Bedrock	
10+10	975042.6875	124791.9766	271	193.5	77.5	76.5	Bedrock	
10+0	975052.4375	124794.3125	271	192.5	78.5	76.5	Bedrock	
9+90	975060.3125	124796.3594	271	190	81	--	--	
9+80	975069.9375	124799.0781	271	187.5	83.5	83.5	Bedrock	

Appendix 3.   Information on barrier-trench depths, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H.
—Continued

[NAD 83, North American Datum 1983; NGVD 29, altitude in feet above National Geodetic Vertical Datum of 1929; --, no data; 13+15, reference line segment 13, station number 15 shown on figure 17; Source of data: Sverdrup Environmental, Inc., written commun., 1999]

Line and station number	Easting, in feet, N.H. State Planar coordinate system NAD 83	Northing, in feet, N.H. State Planar coordinate system NAD 83	Elevation of land surface, in feet above NGVD 29	Elevation of depth of trench, in feet above NGVD 29	Final depth of trench, in feet be- low land surface	Key depth if encountered refusal, in feet below land surface	Key material	Comment
9+70	975079.4375	124802.2344	271	183	88	88	Bedrock	
9+60	975088.7500	124805.8750	271	181	90	90	Bedrock	
9+50	975097.8750	124809.8672	271	181.5	89.5	--	--	
9+40	975107.0625	124813.9141	271	180	91	91	Bedrock	
9+30	975116.1875	124817.9609	271	179	92	92	Till	
9+20	975125.3125	124822.0000	271	175	96	96	Till	
9+10	975134.2500	124826.5078	271	182	89	--	--	
9+0	975142.8125	124831.6875	271	182	89	--	--	
8+90	975150.1875	124836.9609	271	180	91	--	--	
8+80	975158.2500	124842.8672	271	179.5	91.5	91.5	Bedrock/ Boulders in Till	
8+70	975166.2500	124848.8906	271	171.5	99.5	99.5	Till	
8+60	975174.1875	124855.0234	271	173.5	97.5	--	--	
8+50	975181.8125	124861.4453	271	174	97	--	--	
8+40	975189.1250	124868.2656	271	177	94	--	--	
8+30	975196.0625	124875.4609	271	179	92	92	Bedrock	
8+20	975202.2500	124883.3125	271	173	98	98.5	Till	
8+10	975208.1250	124891.4063	271	180.5	90.5	--	--	
8+0	975213.7500	124899.6484	271	180	91	--	--	
7+90	975218.0625	124908.8047	271	178	93	93	Bedrock/Till	
7+80	975221.1250	124918.3047	271	172	99	99	Till	
7+70	975223.3750	124928.0391	271	173.5	97.5	--	--	
7+60	975224.1250	124938.0078	271	173.5	97.5	--	--	
7+50	975224.8125	124947.9844	271	166	105	105	Till	
7+40	975225.5625	124957.9531	271	172.5	98.5	--	--	
7+30	975226.2500	124967.9297	271	172	99	--	--	
7+20	975226.7500	124977.9063	271	169	102	--	--	
7+10	975226.4375	124987.9063	271	161.5	109.5	109.5	Bedrock	
7+0	975225.9375	124997.8906	271	163.5	107.5	88.5	Bedrock	
6+90	975225.0625	125008.4844	271	164.5	106.5	--	--	
6+80	975224.0000	125018.4297	271	164	107	--	--	

Appendix 3. Information on barrier-trench depths, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H. —Continued

[NAD 83, North American Datum 1983; NGVD 29, altitude in feet above National Geodetic Vertical Datum of 1929; --, no data; 13+15, reference line segment 13, station number 15 shown on figure 17; Source of data: Sverdrup Environmental, Inc., written commun., 1999]
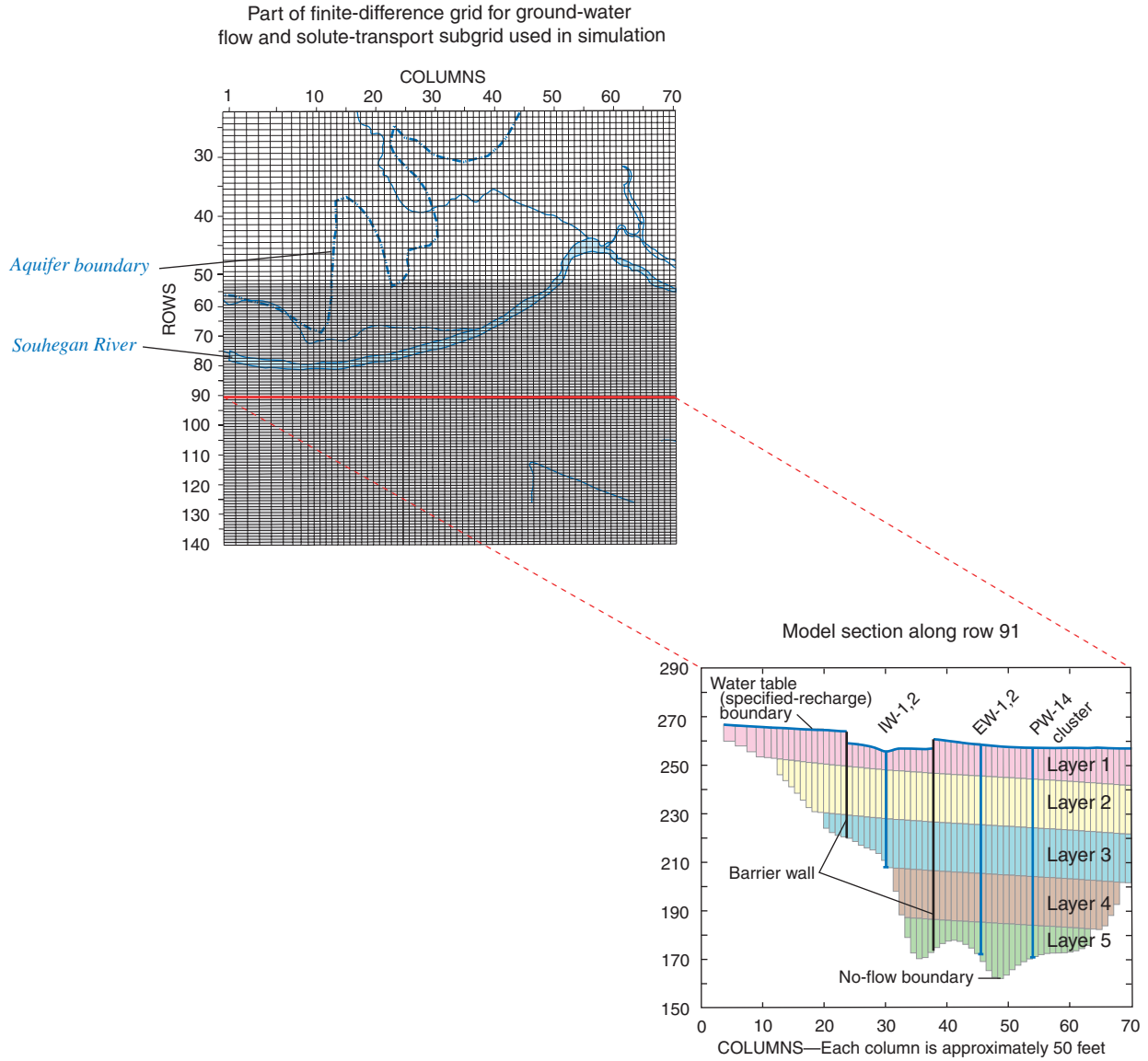
Line and station number	Easting, in feet, N.H. State Planar coordinate system NAD 83	Northing, in feet, N.H. State Planar coordinate system NAD 83	Elevation of land surface, in feet above NGVD 29	Elevation of depth of trench, in feet above NGVD 29	Final depth of trench, in feet below land surface	Key depth if encountered refusal, in feet below land surface	Key material	Comment
6+70	975222.1875	125028.2500	271	164	107	--	--	
6+60	975220.0625	125038.0313	271	171.5	99.5	99.5	Bedrock	
6+50	975217.9375	125047.7813	271	161	110	110	Bedrock	
6+40	975214.7500	125057.2656	271	161	110	109	Till	
6+30	975211.0625	125066.5781	271	164	107	--	--	
6+20	975207.0625	125075.7344	271	165	106	--	--	
6+10	975202.3125	125084.5156	271	165	106	106	Bedrock	
6+0	975197.1250	125093.0625	271	166.5	104.5	104.5	Bedrock	
5+90	975192.7500	125100.2578	271	167	104	104	Bedrock	
5+80	975187.0625	125108.4688	271	167.5	103.5	--	--	
5+70	975180.8125	125116.2969	271	168	103	--	--	
5+60	975174.3125	125123.8750	271	168	103	103	Bedrock	
5+50	975167.5000	125131.2344	271	169	102	102	Bedrock	
5+40	975160.4375	125138.2969	271	168.5	102.5	--	--	
5+30	975153.0625	125145.0547	271	167.5	103.5	--	--	
5+20	975145.4375	125151.5000	271	167	104	--	--	
5+10	975137.6250	125157.7188	271	163	108	108	Bedrock	
5+0	975129.5625	125163.6641	271	162	109	109	Bedrock	
4+90	975121.2500	125169.2578	271	164.5	106.5	106.5	Bedrock	
4+80	975112.5000	125174.0469	271	161.5	109.5	--	--	
4+70	975103.3750	125178.1875	271	163	108	--	--	
4+60	975094.0625	125181.8750	271	166	105	--	--	
4+50	975084.6250	125185.1328	271	169	102	102	Bedrock	
4+40	975075.0625	125188.0625	271	175	96	96	Bedrock	
4+30	975065.4375	125190.6406	271	182	89	89	Bedrock	
4+20	975055.6875	125192.9063	271	182	89	--	--	
4+10	975045.8750	125194.9766	271	186	85	--	--	
4+0	975036.0625	125196.8359	271	187	84	84	Bedrock	
3+90	975025.9375	125198.3828	271	188	83	--	--	
3+80	975016.0000	125199.4609	271	187.5	83.5	--	--	

Appendix 3.   Information on barrier-trench depths, Operable Unit 1 (OU1), Savage Municipal Well Superfund site, Milford, N.H. —Continued

[NAD 83, North American Datum 1983; NGVD 29, altitude in feet above National Geodetic Vertical Datum of 1929; --, no data; 13+15, reference line segment 13, station number 15 shown on figure 17; Source of data: Sverdrup Environmental, Inc., written commun., 1999]

Line and station number	Easting, in feet, N.H. State Planar coordinate system NAD 83	Northing, in feet, N.H. State Planar coordinate system NAD 83	Elevation of land surface, in feet above NGVD 29	Elevation of depth of trench, in feet above NGVD 29	Final depth of trench, in feet below land surface	Key depth if encountered refusal, in feet below land surface	Key material	Comment
3+70	975006.0000	125200.0625	271	188	83	83	Bedrock	
3+60	974996.0000	125200.1250	271	188.5	82.5	--	--	
3+50	974986.0625	125199.5313	271	189	82	--	--	
3+40	974976.1250	125198.3281	271	188.5	82.5	83	Bedrock	
3+30	974966.2500	125196.6250	271	194.5	76.5	--	--	
3+20	974956.5000	125194.4844	271	194	77	--	--	
3+10	974946.8125	125192.0313	271	194	77	77	Bedrock	
3+0	974937.1875	125189.3047	271	195	76	76	Bedrock	
2+90	974928.0625	125186.4609	271	196.5	74.5	77	Bedrock	
2+80	974918.5625	125183.3828	271	201	70	77	Bedrock	
2+70	974909.0625	125180.1875	271	202	69	69	Bedrock	
2+60	974899.6875	125176.6875	271	201	70	--	--	
2+50	974890.5000	125172.8594	271	200	71	--	--	
2+40	974881.3750	125168.7188	271	201.5	69.5	69.5	Bedrock	
2+30	974872.4375	125164.2578	271	202	69	69	Bedrock	
2+20	974863.6875	125159.4375	271	202.5	68.5	--	--	
2+10	974855.1250	125154.2422	271	203	68	--	--	
2+0	974846.8125	125148.6797	271	207	64	64	Bedrock	
1+90	974839.5000	125143.5703	271	203	68	61.5	Bedrock	
1+80	974831.3125	125137.8281	271	203	68	61.5	Bedrock	
1+70	974823.1875	125131.9922	271	202.5	68.5	--	--	
1+60	974815.1250	125126.1172	271	200.5	70.5	--	--	
1+50	974807.0625	125120.2422	271	200	71	--	--	
1+40	974799.0625	125114.2031	271	204.5	66.5	--	--	
1+30	974791.1875	125108.0703	271	206	65	--	--	
1+20	974783.3750	125101.8203	271	206	65	--	--	
1+10	974775.6875	125095.4219	271	202	69	--	--	
1+0	974768.1250	125088.8672	271	202	69	--	--	

Part of finite-difference grid for ground-water
flow and solute-transport subgrid used in simulation

Model section along row 91

COLUMNS—Each column is approximately 50 feet

Appendix 4.   Vertical discretization for model row 91 of the finite-difference grid, Savage Municipal Supply Well Superfund site, Milford, N.H. Well locations shown on figure 2.