HYDROLOGY OF, AND WATER QUALITY IN, THE OPEN BURNING AREA AND VICINITY, PICATINNY ARSENAL, NEW JERSEY, 1989-90

By Donald A. Storck

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per day (ft/d)	0.3048	meter per day
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius

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

Abbreviations used in report:

µg/g	microgram per gram	ng/g	nanogram per gram
µg/kg	microgram per kilogram	PCB's	polychlorinated biphenyls
µg/L	microgram per liter	TCE	trichloroethylene
mg/L	milligram per liter	VOC's	volatile organic compounds

USAEHA	U.S. Army Environmental Hygiene Agency
USARDEC	U.S. Army Armaments Research Development and Engineering Center
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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ABSTRACT

This report presents the results of a study to determine whether the shallow ground-water system at Picatinny Arsenal, Morris County, New Jersey, has been contaminated as a consequence of operations at the open burning area. This area has been used since World War II for the burning of waste explosives and materials contaminated with explosives. Results of previous investigations at the site indicate that the soil in this area is contaminated with metals, base/neutral- and acid-extractable compounds, explosive compounds, and propellants.

Twenty-seven wells were installed and sampled in 1989 and 1990 for analysis of ground water for inorganic constituents, trace elements, nutrients, and explosive compounds. Six of these wells also were sampled for analysis for base/neutral- and acid-extractable compounds, and organochlorine and organophosphorus pesticides; and water samples from eight wells were analyzed for volatile organic compounds. In addition, two wells in the open burning area were sampled for analysis for dioxin and furan compounds. Surface-water and streambed-material samples were collected at three sites in Green Pond Brook to determine whether contaminants have migrated to the brook.

Contour maps constructed from water levels measured during four periods in 1989 and 1990 show that ground-water flow generally is nearly horizontal and toward Green Pond Brook. On the basis of hydraulic-head measurements and estimates of horizontal hydraulic conductivities and porosity, the average velocity of the ground water is estimated to be 0.03 to 1.8 feet per day.

Concentrations of iron and manganese in ground-water samples from the unconfined aquifer were consistently greater than U.S. Environmental Protection Agency secondary drinking-water regulations. Because similarly high concentrations of these constituents have been found in ground-water samples at the arsenal, they are not considered to be a result of activities at the open burning area. No inorganic or organic constituents were detected in ground-water samples in concentrations greater than the U.S. Environmental Protection Agency primary drinking-water regulations.

Results of analyses indicate that contaminants from the open burning area probably are contributing to elevated concentrations of lead, zinc, and explosive compounds found in the streambed material. Other trace elements and polynuclear aromatic hydrocarbons probably are derived from both the open burning area and upstream sources. Volatile organic compounds were detected in surface-water samples at low concentrations, although most were found upstream from the open burning area. No organic or inorganic constituents were detected in surface-water samples in concentrations that exceeded U.S. Environmental Protection Agency drinking-water regulations.

INTRODUCTION

Picatinny Arsenal is located just north of the Wisconsinan terminal moraine in north-central New Jersey (fig. 1). About 5,500 people are employed in research and development of munitions and weapons at the installation. The installation previously was known as the U.S. Army Armament Research and Development Command (1978-83) and the U.S. Army Armament Research and Development Center (1983-86). Since 1986, it has been known officially as the U.S. Army Armament Research Development and Engineering Center (USARDEC). The arsenal encompasses more than 1,500 buildings on 6,491 acres (Sargent and others, 1986).

The site of the arsenal has a long industrial history. Middle Forge, one of the first forges in New Jersey, was established there in 1749. The forge later became part of Mount Hope Iron Works, which provided cannon shot and other iron implements for the Revolutionary War. In 1880, the U.S. War Department established the Picatinny Powder Works at the site, and, since 1907, as a result of expanding activities, the facility has been known as Picatinny Arsenal. During World War I, the arsenal produced many types of ammunition; during World War II, production was expanded to include bombs, high explosives, pyrotechnics, and other ordnance items. In recent years, the arsenal's mission has changed to research and development of large-caliber munitions (Sargent and others, 1990).

A 7-acre area near the arsenal's southern boundary (termed the "open burning area") has been used since World War II for the burning of waste explosives and materials contaminated with explosives. Prior to 1985, waste was burned directly on the land surface. Currently, wastes are placed in pans and ignited.

Results of previous investigations at the open burning area by the U.S. Army and its contractors indicate that the soil in this area is contaminated with metals, base/neutral- and acid-extractable compounds, explosive compounds, and propellants. The potential exists for these contaminants to migrate from the soil to the ground-water and surface-water systems. A U.S. Army contractor installed and sampled water from five wells, and the results of water-quality analyses indicated the presence of several organic compounds in the ground water; however, because the wells were installed with a backhoe, the water samples may have been contaminated with organic compounds that were present in the soil. To address the problem, the U.S. Geological Survey (USGS), in cooperation with the USARDEC, conducted an investigation during 1989-90 to determine the hydrogeologic conditions at the open burning area site. The investigation was designed to define the ground-water flow system, to determine the nature of ground-water/surface-water interactions, and to determine whether the shallow ground-water system has been contaminated as a result of operations at the open burning area. Contamination of surface water, streambed material, and soils also was investigated.

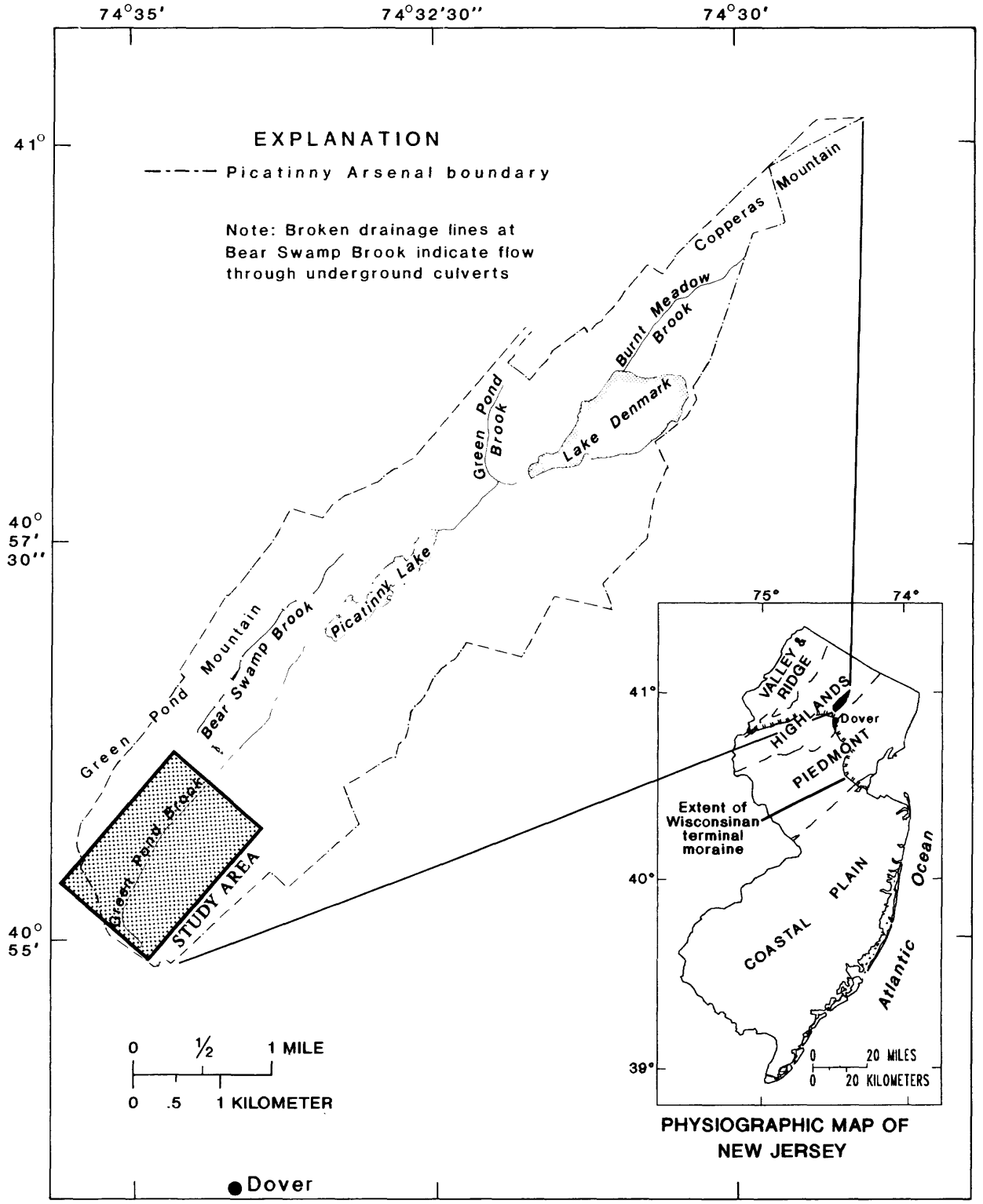


Figure 1.--Location of Picatinny Arsenal, New Jersey.
(Modified from Sargent and others, 1986)

Purpose and Scope

This report describes the results of a study conducted during 1989-90 to determine hydrogeologic conditions and the extent of contamination of shallow ground water and surface water at the open burning area at Picatinny Arsenal. The report includes results of test drilling at 20 sites, and results of chemical analyses of 27 ground-water samples from 27 wells and 18 surface-water samples from 3 sites. Also included in the report are results of chemical analyses of 18 streambed-material samples from 3 sites in Green Pond Brook and 10 soil samples from the open burning area.

Stream discharge and head differences between surface water and shallow ground water were measured at six and five sites, respectively. Results of these measurements, made to determine the direction of flow between ground water and surface water, are presented. In addition, ground-water levels measured in a maximum of 61 monitoring wells 4 times during 1989 and 1990 are included.

Previous Investigations

The USGS first began studying the ground water at Picatinny Arsenal in 1958. Results of previously completed field investigations and published reports provided background information for the current study. Gill and Vecchioli (1965) presented hydrologic data on the availability of ground water in Morris County. Lacombe and others (1986) used surface-geophysical techniques to investigate ground-water contamination and define the hydrogeologic framework at the arsenal. Methods included electromagnetic-conductivity surveys to delineate areas of high apparent conductivity, which may indicate ground-water contamination, and seismic-refraction and electric-resistivity surveys to delineate subsurface units.

Sargent and others (1986) compiled ground-water-quality data for 56 wells at the arsenal collected from 1958 through 1985. An investigation by Harte and others (1986) included test drilling and installation of 21 monitoring wells during 1982-84. Imbrigiotta and others (1988) evaluated sampling devices used to collect well-water samples for analysis for purgeable organic compounds. Sargent and others (1990) defined the extent of ground-water contamination and rate of contaminant movement in the building 24 area, and identified contamination in the unsaturated zone and surface water. The report includes the results of test drilling and installation of 33 monitoring wells in 1987 and the results of chemical analyses of ground-water and surface-water samples.

In addition to work done by the USGS, several other studies have been conducted to determine the geologic framework and hydrology of, and to identify ground-water and surface-water contamination at, Picatinny Arsenal. The U.S. Army Environmental Hygiene Agency (USAEHA) conducted a study of hydrogeology and ground-water contamination from 1979 through 1984. J.W. Bauer (U.S. Army Environmental Hygiene Agency, written commun., 1979) investigated the hydrogeology and the potential effect of wastewater-disposal practices on ground-water quality. D.C. Bayha (U.S. Army Environmental Hygiene Agency, written commun., 1984) presented an assessment of ground-water quality at the arsenal. Results of his investigation at the

open burning area in 1983-84 indicated that soils were contaminated with explosives residues, lead, and cadmium.

Frew and others (1989) identified sources of contamination, defined site hydrology, and compiled results of extensive chemical analyses of groundwater, surface-water, streambed-material, and soil samples from 33 sites at Picatinny Arsenal. Results of test drilling and installation of 29 monitoring wells from December 1987 through February 1989 were reported and the potential for contaminant migration was assessed. Benioff and others (1991) presented site-specific information on known and (or) potential sources of contamination that included site histories, a description of site geology and hydrology, a description of existing contamination, and proposed remedial investigation plans.

Acknowledgments

The author thanks Theodore Gabel and other personnel of the Environmental Affairs Office of the U.S. Army Armament Research Development and Engineering Center for assistance in the planning and implementation of this investigation. Thanks also are extended to Ira May and Roxanne Moran of the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) for invaluable help in, and support of, this investigation, and to Carey Carpenter Compton of the U.S. Environmental Protection Agency (USEPA) for assistance in the collection of field data.

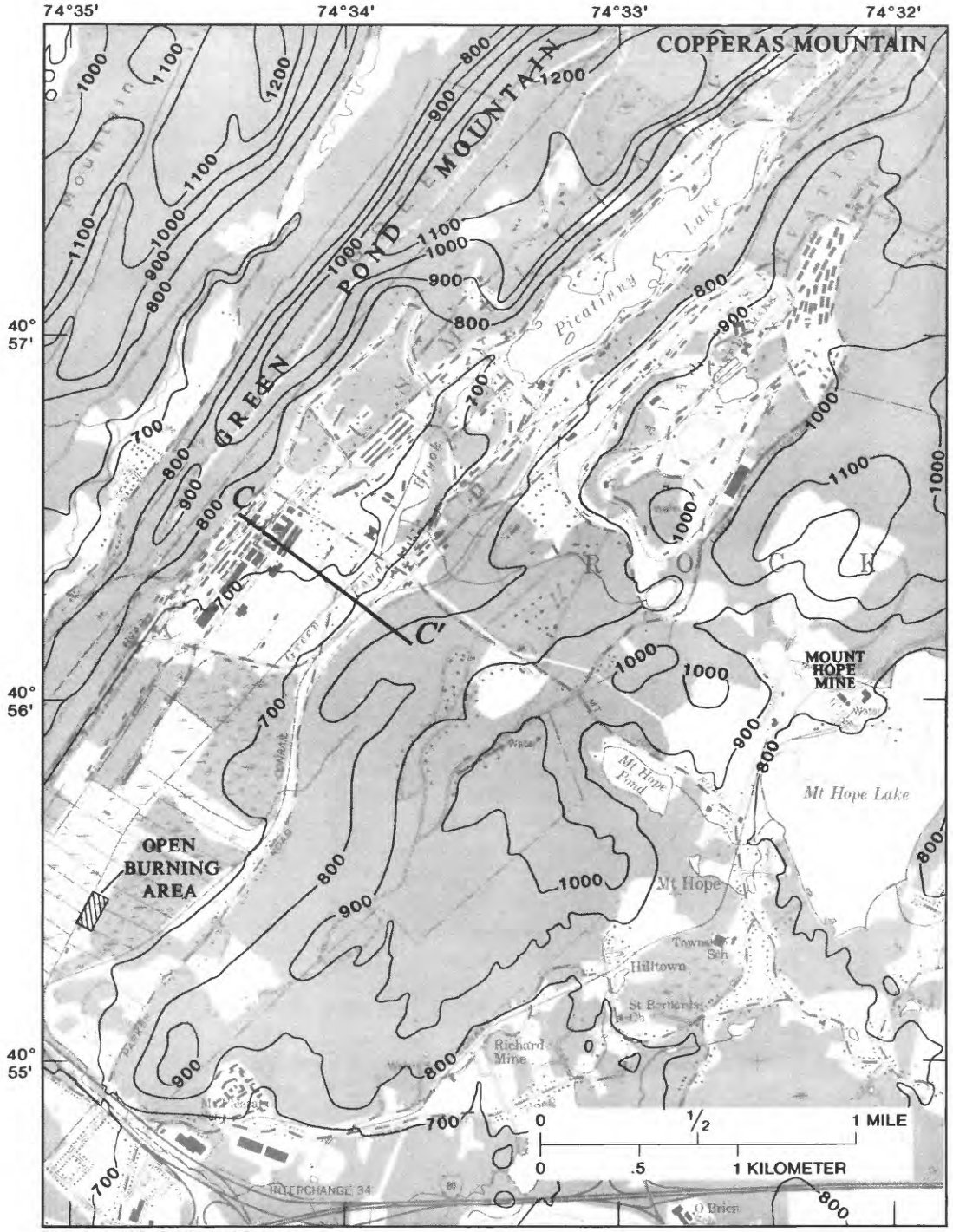
DESCRIPTION OF STUDY AREA

Picatinny Arsenal is located within the Green Pond Syncline, a structural region of the New Jersey Highlands Physiographic Province (fig. 1). The New Jersey Highlands comprises a northeast-southwest-trending system of folded and faulted Proterozoic to Devonian rocks that form a sequence of valleys and ridges. The ridges typically are broad, rounded, or flat-topped; the valleys typically are deep and narrow. Generally, a 400- to 600-ft difference in elevation separates ridge crest from valley floor (Wolf, 1977, p. 226).

Location and Physiography

The arsenal lies within an elongated valley that is bounded by Green Pond Mountain on the west, Copperas Mountain on the northeast, and an unnamed mountain on the east and southwest (fig. 2). Green Pond and Copperas Mountains are rugged with steep, rocky slopes and elevations that exceed 1,200 ft. The slopes on the eastern boundary are less rugged and less steep, with maximum elevations of about 1,100 ft.

The open burning area consists of approximately 7 acres adjacent to Green Pond Brook near the southern boundary of the arsenal. The site is bounded to the north and east by inactive landfills and to the south and east by swamplands.



Base from U.S. Geological Survey, 1:24,000, quadrangle, Dover, 1954

EXPLANATION

800 — TOPOGRAPHIC CONTOUR--Interval 100 feet. Datum is sea level

C — C' LINE OF SECTION--Shown in figure 7

PICATINNY ARSENAL BOUNDARY

Figure 2.--Physical features in the vicinity of Picatinny Arsenal. (Modified from Sargent and others, 1990)

Geologic Setting

The Green Pond Syncline is a narrow, northeast-trending, faulted syncline containing narrow outliers of Paleozoic rocks. The Paleozoic rocks typically lie unconformably on the Proterozoic rocks, which are exposed on the eastern side of the syncline. Thrust faults and folds in the Paleozoic rocks have obscured the original contact between the basement and cover rocks (Lyttle and Epstein, 1987).

Bedrock

The oldest bedrock unit, a pinkish buff to greenish buff, hornblende granite and associated alaskite of Middle Proterozoic age, is exposed at the southeastern entrance to the arsenal (Puffer, 1980, p. 50). The granite is mapped as an alaskite in which mafic minerals comprise less than 5 percent of the rock by volume. The alaskite facies is closely associated with magnetite-ore deposits that were mined west of the arsenal (table 1).

The Hardyston Quartzite is a Lower Cambrian, fine- to medium-grained, white to dark-gray, thin- to medium-bedded, feldspathic quartzite interbedded with arkose, quartz-pebble conglomerate, and silty shale or phyllite. The contact with the underlying Proterozoic granite is unconformable and abrupt. The unit is 0 to 100 ft thick in New Jersey (Lyttle and Epstein, 1987).

The Leithsville Formation is a Lower and Middle Cambrian, interbedded, light- to medium-gray, coarse-grained dolomite and calcitic dolomite containing thin layers of quartz and dolomitic sandstone (Wolf, 1977, p. 46). The Leithsville Formation is approximately 800 ft thick. The lower contact typically is gradational with the underlying Hardyston Formation.

The Green Pond Conglomerate is a Lower and Middle Silurian, gray to reddish-gray sandstone and conglomerate with predominantly white quartz and minor gray, green, red, and yellow chert, red shale, and red sandstone cobbles (Lyttle and Epstein, 1987). The lower contact is separated from the Leithsville Formation by the Green Pond Fault. Thickness ranges from 984 to 1,394 ft (Lyttle and Epstein, 1987).

Glacial Deposits

Continental ice sheets advanced across the study area at least twice during the Quaternary Period (Stanford, 1989). As a result, the bedrock surface is covered by a mantle of unconsolidated glacial deposits. These deposits are predominantly till in the upland areas and stratified drift in the valleys. In the study area, the distribution and characteristics of the stratified drift reflect the manner in which the area was deglaciated. Deglaciation began approximately 18,000 years ago and progressed in stages. The southernmost extent of glaciation is delineated by a terminal moraine at the southwestern boundary of the arsenal. The initial melting of ice north of the terminal moraine caused the formation of a temporary proglacial lake, Lake Picatinny, in the Green Pond Brook valley. Glacial Lake Picatinny was dammed across the southern end by the moraine, and the glacier blocked northward drainage. The glacier receded to the south end of the present-day Picatinny Lake where a ridge of till was deposited. The lake drained to the

Table 1.--Stratigraphic and hydrogeologic characteristics of geologic units at Picatinny Arsenal

[Modified from Drake, 1969, table 20; Sims, 1958, pl. 1; Gill and Vecchioli, 1965, table 3]

Time-stratigraphic unit			Geologic unit	Maximum thickness (in feet)	Lithology	Hydrogeologic characteristics
Erathem	System	Series	Formation or lithologic unit			
Cenozoic	Quaternary	Holocene	Alluvium	10	Ranges from a sandy loam in the valley to a stony gravel on hillsides	Too thin to be tapped
			Swamp deposits (muck)	30	Black, brown, and gray organic material	High permeability along organic layers
		Pleistocene	Stratified drift	200+	Present in the form of glaciofluvial and glaciolacustrine deposits, mostly sand- to clay-size sediments; exhibits stratification and in some cases rhythmic laminations (varves)	Yield depends on degree of sorting and grain size; the well-sorted and coarse-grained deposits are good aquifers with yields up to 2,200 gallons per minute; clay and silt deposits generally are unsuitable as aquifers
			Unstratified drift	100+	Present in the form of ground, terminal, and recessional moraine. Deposits generally are tightly packed and poorly sorted; grain sizes range from boulders to clay	Yield depends on degree of sorting and packing; generally low yields
					Unconformity	
Paleozoic	Silurian	Middle and Lower	Green Pond Conglomerate	1500+	Coarse quartz conglomerate interbedded with and grading upward into quartzite and sandstone, generally massive and red but may contain white and green beds	Generally yields small amount of water from fractures and joints
					Unconformity	
	Cambrian	Middle and Lower	Leithsville Formation	1000+	Predominantly a light- to medium-gray, microcrystalline, locally stylolitic rock to a fissile, siliceous to dolomitic micrite texture rock; commonly highly weathered to a medium-yellow, silty clay	Contains water-bearing fractures and solution cavities that generally have moderate yields of up to 380 gallons per minute
					Gradational	
		Lower	Hardyston Quartzite	200	Orthoquartzite to conglomeratic; generally well indurated	Generally few fractures; yields small amounts of water
					Unconformity	
Proterozoic			Alaskite		Medium- to coarse-grained, predominantly granitoid gneiss composed principally of microperthite, quartz, and oligoclase; includes local bodies of microantiperthite granite and granite pegmatite; amphibolite inclusions are common	All three lithologic units have similar hydrologic characteristics; ground water occurs in fractures and joints; yields generally are low, and range from 26 to 75 gallons per minute
			Hornblende granite		Medium- to coarse-grained, predominantly granitoid gneiss composed principally of microperthite, quartz oligoclase, and hornblende; includes local bodies of biotite granite, horneblende granite gneiss, granodiroite, and granite pegmatite; amphibolite inclusions are common	
			Biotite-quartz-feldspar gneiss		Medium-to coarse-grained gneiss of widely varying composition; the predominant facies consists of biotite, quartz, and oligoclase; minor facies are characterized by abundant garnet and microperthite, and locally by sillimanite and graphite	

southeast through a gap in a bedrock ridge at an elevation of about 700 ft and was filled with a sequence of sediments; sublacustrine sand and gravel was overlain by lake-bottom and deltaic fine-grained sand and silt, and capped by deltaic sands and gravels. Following deglaciation, deposits of silt and clay and, finally, peat formed in floodplains and large ice-blocked depressions along Green Pond Brook.

Three distinct sedimentary facies have been distinguished from sediment samples and borehole geophysical data collected between Picatinny Lake and the terminal moraine (Sargent and others, 1990). In order of increasing depth, they are (1) deltaic sands and gravels (20 to 62 ft thick) found to the north of the study area; (2) lake-bottom and deltaic fine-grained sand and silt (55 to 93 ft thick); and (3) sublacustrine sand and gravel (20 to 90 ft thick), both found at the open burning area. The percentage of a sediment sample with particle sizes less than 0.25-, 0.125-, and 0.062-millimeter sieve mesh size in relation to depth below land surface is shown in figure 3. This plot shows variations in particle size in the lake-bottom and deltaic deposits. The area between each line represents the percentage of the sediment fraction present in the sample.

The distribution of particle sizes in the aquifers and confining units reflects the variability in the energy of deposition of meltwater during deglaciation. After formation of Glacial Lake Picatinny, meltwater streams carried sediments into the lake where they were deposited. Where the stream entered the lake, alluvial fans and deltas formed. In the main body of the lake, seasonal changes caused deposition of thin layers of alternating fine- and coarse-grained material. Particle size generally ranges from coarse to fine both downvalley and vertically downward from the land surface toward the confining unit (Stanford, 1989).

Surficial Deposits

The surficial deposits in the study area are typically gray silt, sand, and clay overlain by brown peat. In the swamp and marsh areas to the south and east of the open burning area, these deposits are overlain by dark brown to black muck and organic silts that are generally less than 10 ft thick. Inside the open burning area and at adjacent landfills, the area is topped with artificial fill composed of excavated till, sand, gravel, rock, and construction debris that is generally less than 5 ft thick (Stanford, 1989).

Lithologic sections were constructed from natural-gamma-ray and lithologic logs of wells in or near the open burning area (fig. 4). These sections show alternating layers of silt, sand, and clay underlying the study area (fig. 5). Section A-A′, which is parallel to Green Pond Brook, indicates the presence of discontinuous deposits of silt and clay. The logs of well 1179A-1 show silt and clay deposits from 5 to 20 ft below land surface. The log of well 1179-1, however, shows only 7 ft of silt and clay from 8 to 15 ft below land surface, and fine- to coarse-grained sand from 0 to 8 ft and 15 to 70 ft below land surface. Section B-B′, which is perpendicular to Green Pond Brook, shows silt and clay deposits greater than 50 ft thick in some areas.

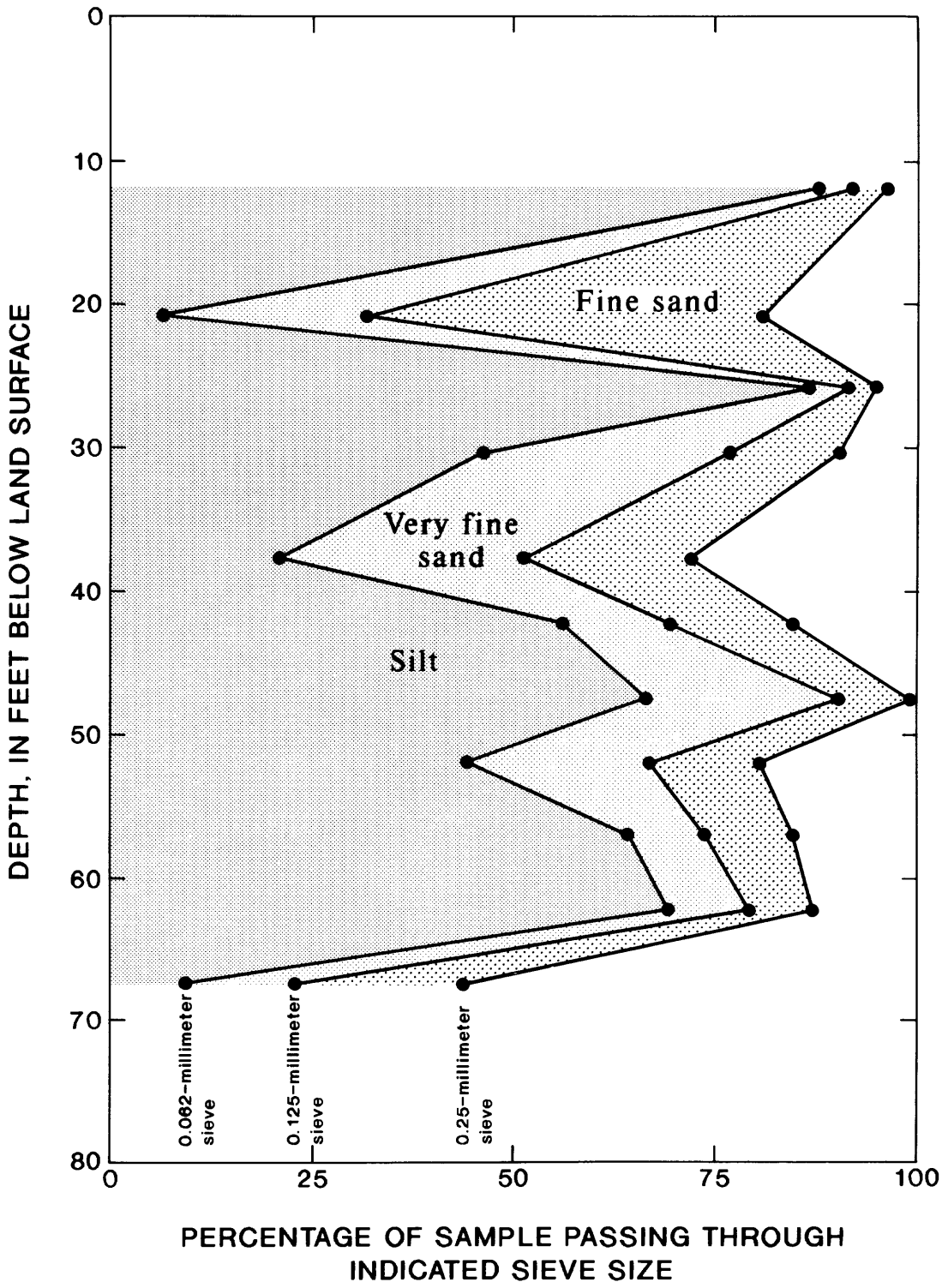


Figure 3.--Percentage of sediment sample less than 0.25-, 0.125-, and 0.062-millimeter sieve mesh size in relation to depth below land surface, well 1179-4A. (Well location shown in figure 6)

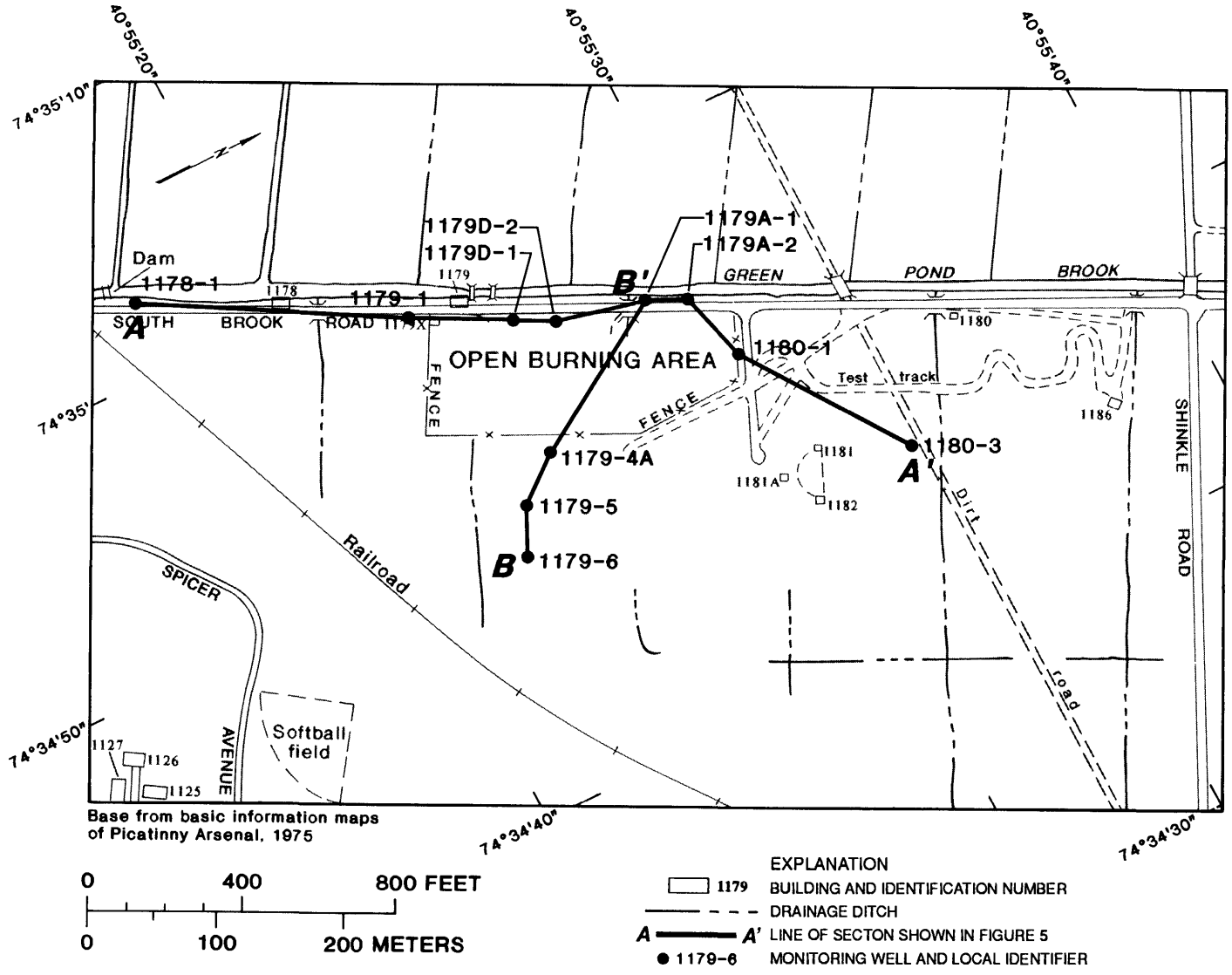


Figure 4.--Locations of lithologic sections in the study area.

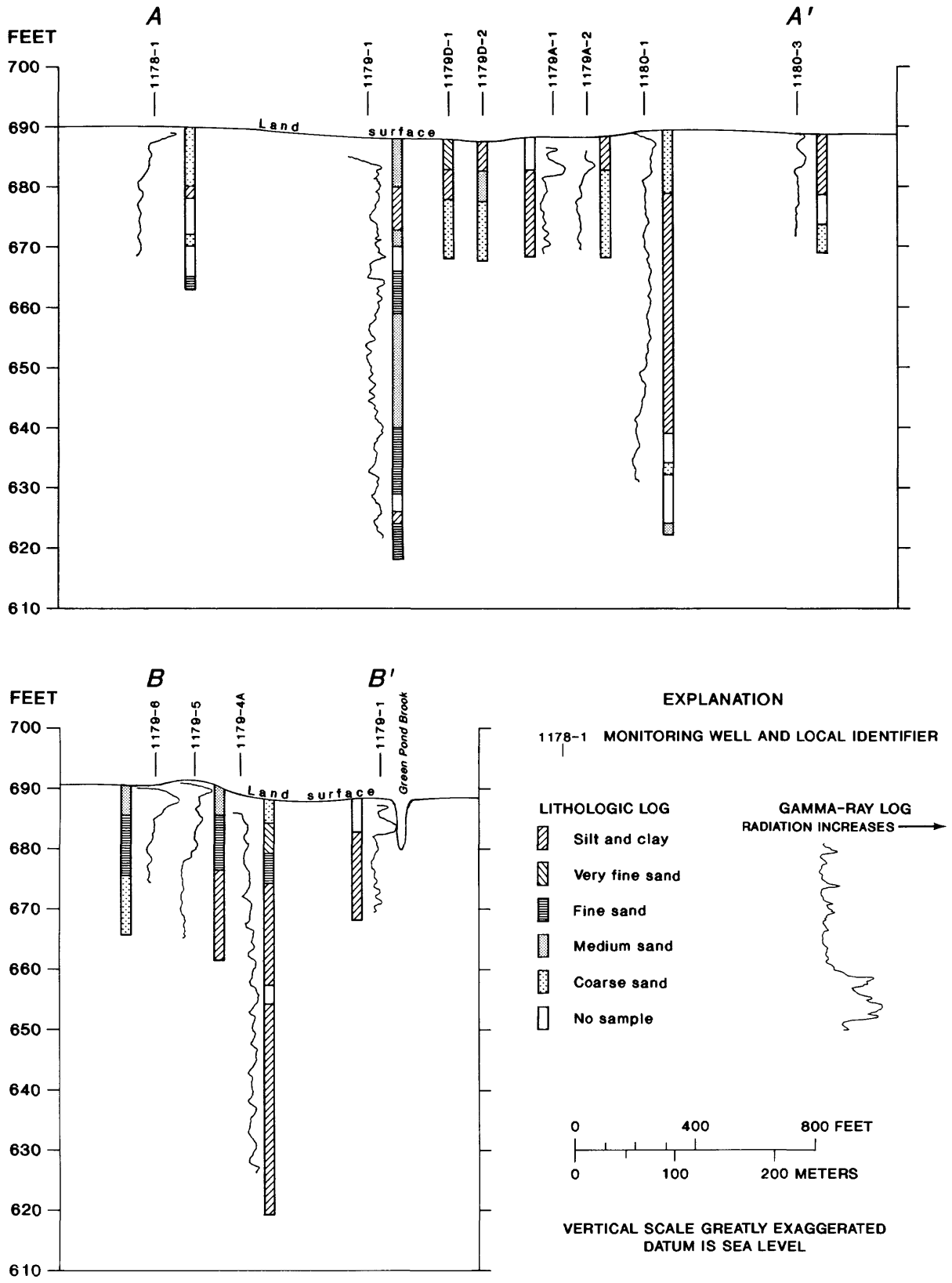


Figure 5.--Lithologic sections showing natural-gamma-ray and lithologic logs for wells in or near the open burning area. (Lines of sections shown in figure 4)

DATA COLLECTION AND ANALYTICAL METHODS

Data collection for this investigation began in 1989 and included the installation and sampling of 27 monitoring wells in and around the open burning area. In addition, water levels were measured in all available wells during spring and fall in 1989 and 1990. Hydraulic-head differences between ground water and surface water were measured through the streambed of Green Pond Brook at five sites on April 25, 1990. Stream discharge in Green Pond Brook was measured at six sites on April 4, 1989. Stream-discharge and water-level data from automatic water-level recorders installed as part of other ongoing USGS investigations at the arsenal were compiled and used to prepare streamflow and water-level hydrographs.

Additional information presented in this report was collected and (or) analyzed by USARDEC and USATHAMA personnel or their contractors. This information includes chemical quality of soil samples from the open burning area and streambed-material samples from Green Pond Brook.

Well Drilling and Measurement of Ground-Water Levels

In order to refine the description of the geology and ground-water-flow system and to characterize the quality of ground water in the study area, twenty-three 2-in.-I.D. (nominal inside diameter) monitoring wells were installed in the unconfined aquifer (described on p. 18) in and around the open burning area. The sites were selected on the basis of the results of preliminary investigations conducted by the U.S. Army and its contractors (D.C. Bayha, U.S. Army Environmental Hygiene Agency, written commun., 1984; Frew and others, 1989). The wells range in depth from 13.6 to 61.3 ft below land surface; their locations are shown in figure 6. The wells were installed by using a hollow-stem auger and were constructed of polyvinyl chloride (PVC) casing and screens. All of the wells were installed with 10-ft-long screens because of the presence of fine-grained sediments in the aquifer and to maximize the volume of water available for sampling. Wells were distributed throughout accessible parts of the study area. In order to expand the existing monitoring-well network in the confined aquifers (described on p. 18), four 2-in.-I.D. wells were installed at three sites; well depths range from 22 to 151 ft below land surface. The wells were installed by using the mud-rotary method and were constructed of PVC casing with 10-ft PVC screens. In addition, four well clusters were installed to determine vertical water-level gradients and vertical stratification of chemical constituents. Results of borehole geophysical logging and collection of split-spoon core samples aided in the selection of screened intervals. Screens were placed in the coarsest material encountered during drilling based on lithologic and geophysical data. Well-construction information and specific-capacity data for wells installed in 1989 and previously installed wells are shown in table 2.

In order to reduce the possibility of cross-contamination of wells during installation, all drilling equipment, well casings, and screens were steam-cleaned prior to installation in the borehole. Hollow-stem auger wells were completed by inserting the well screen and casing into the auger flight. A sand pack was placed from the bottom of the borehole to a minimum of 5 ft above the top of the screen. The auger flights then were removed,

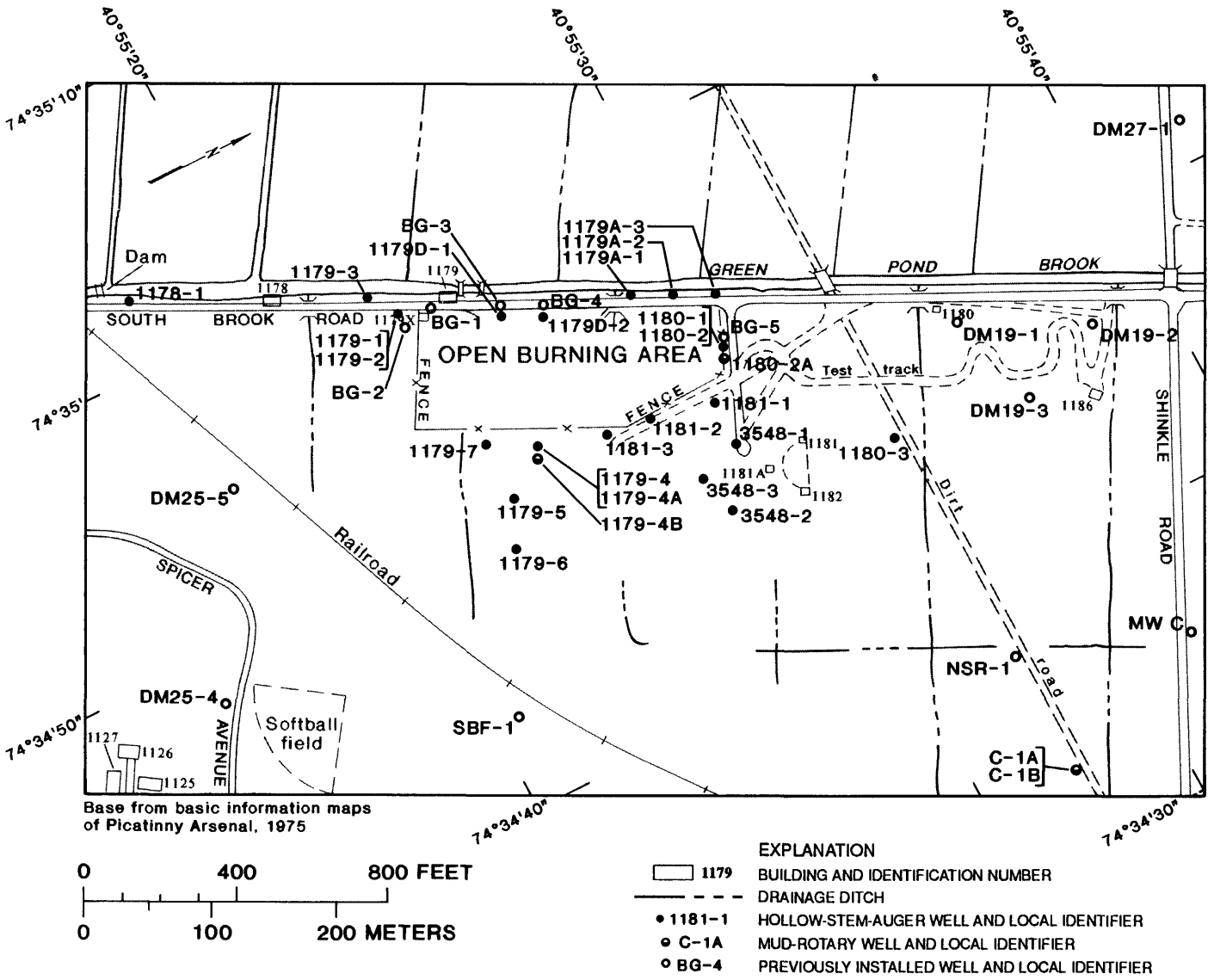


Figure 6.--Locations of wells installed in or near the open burning area April 19 through September 29, 1989, and previously installed wells.

Table 2.--Well-construction and specific-capacity data for selected wells in the study area

[ft, feet; LSD, land-surface datum; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot; all wells are screened in stratified drift (geologic unit code 112SFDF); --, not measured; 00, indicates exact date of construction is unknown]

Well number	Local well identifier	Date completed	Altitude of land surface (ft above sea level)	Depth of screened interval (ft below LSD)	Screen diameter (inches)	Static water level (ft below LSD)	Date water level measured	Pumping water level (ft below LSD)	Pumping period (hours)	Yield (gal/min)	Specific capacity ((gal/min)/ft)
271243	1178-1	04-20-89	690.2	11.9- 21.9	2	5.45	06-15-89	10.83	1.0	16.0	2.97
271248	1179-1	04-26-89	688.0	40.2- 50.2	2	1.87	06-15-89	2.44	2	7	12.28
271249	1179-2	04-19-89	688.1	20.7- 30.7	2	.96	06-15-89	3.74	.5	5	1.78
271244	1179-3	04-19-89	687.8	10.2- 20.2	2	2.06	06-15-89	7.48	1	25	4.61
271250	1179-4	04-27-89	689.2	12.2- 22.2	2	2.64	06-20-89	12.95	1	.25	.02
271251	1179-4A	05-02-89	689.1	49.4- 59.4	2	2.32	06-23-89	28.6	2.2	.75	.03
271252	1179-4B	09-18-89	689.2	141.2-151.2	2	10.2	09-11-90	--	--	--	--
271246	1179-5	04-27-89	691.5	17.3- 27.3	2	3.62	06-19-89	20.68	1.6	1.5	.09
271245	1179-6	04-27-89	690.6	9.8- 19.8	2	2.68	06-20-89	12.2	2	2.5	.26
271247	1179-7	04-28-89	689.8	8.0- 18.0	2	3.06	06-23-89	10.05	2	4.0	.57
271259	1179A-1	04-25-89	688.1	12.4- 22.4	2	3.36	06-28-89	12.82	1	6.0	.63
271262	1179A-2	04-25-89	688.1	9.5- 19.5	2	3.24	06-28-89	9.72	1	5	.77
271266	1179A-3	04-25-89	688.4	12.5- 22.5	2	3.59	09-26-89	--	--	--	--
271253	1179D-1	08-09-89	688.0	10.4- 20.4	2	3.18	09-27-89	--	.3	10	--
271255	1179D-2	08-09-89	687.8	10.6- 20.6	2	3.34	09-27-89	--	.5	7	--
271263	1180-1	04-21-89	689.1	51.3- 61.3	2	.36	06-15-89	2.95	1	20	7.72
271264	1180-2	04-24-89	689.7	10.5- 20.5	2	4.18	06-15-89	12.42	1	8.5	1.03
271265	1180-2A	09-22-89	689.2	124.1-134.1	2	7.97	09-11-90	--	--	--	--
271267	1180-3	08-10-89	688.8	7.6- 17.6	2	2.09	09-21-89	--	.7	6	--
271261	1181-1	04-26-89	688.5	12.0- 22.0	2	2.34	06-14-89	10	2	6	.78
271257	1181-2	04-26-89	688.2	12.9- 22.9	2	1.97	06-14-89	22	4.0	2.6	.13
271254	1181-3	04-27-89	688.5	12.5- 22.5	2	1.75	06-19-89	19.4	2	5	.28
271260	3548-1	04-26-89	689.4	10.2- 20.2	2	2.42	06-16-89	19.1	2.7	8	.48
271258	3548-2	05-25-89	690.9	3.6- 13.6	2	2.76	06-14-89	13.6	6	1	.09
271256	3548-3	08-10-89	690.1	12.2- 22.2	2	2.27	09-20-89	19.1	--	.9	.05
271717	BG-1	06-23-84	687.3	1.3- 7.3	4	2.37	04-03-89	--	--	--	--
271718	BG-2	06-23-84	688.3	3.1- 9.1	4	1.79	04-03-89	--	--	--	--
271719	BG-3	06-23-84	688.1	3.4- 9.4	4	2.35	04-03-89	--	--	--	--
271720	BG-4	06-23-84	687.8	2.8- 8.8	4	3.08	04-03-89	--	--	--	--
271721	BG-5	06-23-84	690.2	4.7- 10.7	4	2.47	04-03-89	--	--	--	--
271268	C-1A	09-27-89	691.7	77.2- 87.2	2	1.11	10-27-89	--	--	--	--
271269	C-1B	09-29-89	691.4	12.3- 22.3	2	1.67	10-27-89	22	1.5	1.3	.06
271332	DM19-1	12-30-87	690.1	9.5- 19.5	4	4.94	02-17-88	--	1.0	3.	--
271333	DM19-2	01-04-88	690.9	9.5- 19.5	4	5.61	03-07-88	--	--	--	--
271334	DM19-3	01-05-88	690.9	10.0- 20.0	4	4.69	03-07-88	--	--	--	--
271345	DM25-4	12-29-87	695.4	9.5- 19.5	4	3.56	02-16-88	--	1.0	3.	--
271346	DM25-5	01-07-88	691.9	9.5- 19.5	4	4.26	03-07-88	--	--	--	--
271347	DM27-1	01-06-88	687.6	10.0- 20.0	4	0.41	03-07-88	--	--	--	--
270251	LF 2 OBS	12-07-82	693.3	60.0- 65.0	4	18.8	01-04-83	56.5	.1	8.	.21
270233	MW C	12-24-81	690.7	10.0- 30.0	4	3.50	12-24-81	10.5	3.0	10.	1.43
271716	NSR-1	00-00-86	689.1	[1]12.	2	.74	04-03-89	--	--	--	--
271715	SBF-1	00-00-86	694.8	[1]16.	2	4.20	04-03-89	--	--	--	--
271129	SB1-3 OBS	07-28-88	690.2	24. - 34.	4	3.0	07-26-88	--	--	--	--
271131	SB2-2 OBS	08-04-88	688.4	25. - 35.	4	8.0	08-03-88	--	--	--	--

[1] The exact depth of screened interval is unknown; number shown is the depth of well.

and the remainder of the borehole was filled with a 100-percent bentonite grout. All of the wells were completed near land surface in flush-mounted locking roadway boxes or above-ground locking protective casings, which were cemented at the top of the borehole to protect the well.

After completion of the well, the altitude of land surface and top of casing at each new well were surveyed to the nearest one-hundredth of a foot. In order to remove particles from the screen and sand pack, the wells were developed by pumping until relatively clear water was produced. If drawdown in the well was great, the well was developed by a combination of air lifting, pumping, and surging to remove particles. At selected wells, natural-gamma-ray logs were run to determine the lithologic characteristics of the surrounding area. Selected lithologic logs for wells in the study area are presented in the appendix.

Ground-water levels were measured four times during 1989 and 1990 to develop water-level-contour maps for the unconfined glacial aquifer. On April 3 and April 4, 1989, prior to the installation of wells at the open burning area, water levels in 34 previously installed wells in the southern part of the arsenal were measured. During September 25 through 27, 1989, and April 24 and 25, 1990, water levels in 27 new monitoring wells also were measured. On September 11, 1990, water levels in 47 wells near the open burning area were measured. The locations of wells within the study area in which water levels were measured and used to prepare water-level-contour maps are shown in figure 6; well-construction information is listed in table 2.

Installation of Mini-Piezometers and Measurement of Surface-Water Stage and Discharge

Mini-piezometers were installed at five sites through the streambed of Green Pond Brook on April 25, 1990, to determine the direction of flow between ground water and surface water. By measuring hydraulic head below the streambed relative to the surface-water elevation, the direction of flow to or from the brook can be determined.

The mini-piezometer is a temporary, hand-driven well consisting of a 5-ft-long, 3/8-in.-I.D. pipe that contains a 1/4-in.-O.D. (nominal outside diameter) steel tubing and a 3-in.-long slotted screen. A 3-ft-long drive sleeve screws onto the top of the pipe. The unit is driven through the streambed by using a pipe that slides over the drive sleeve and strikes a coupling on the drive sleeve. Depths of the screens ranged from 4 to 6 ft below the stream surface.

Surface-water elevations were determined from six staff gages installed along the reach of the channel of Green Pond Brook. The altitude of each staff gage was surveyed to the nearest one-hundredth of a foot. Stream discharges were measured at these sites on April 4, 1989, and September 24 through 26, 1989, according to methods described by Rantz (1982).

Collection of Ground-Water, Surface-Water, and Streambed-Material Samples, and Laboratory Methods

Ground-water samples for analysis for cations, anions, nutrients, trace elements, and organic compounds were collected from 27 wells from August 1, 1989, through August 28, 1990. Samples were collected, filtered, and preserved in accordance with accepted USGS field techniques (Brown and others, 1970; Wood, 1976). Field measurements included specific conductance, pH, temperature, dissolved oxygen, and alkalinity. The wells were purged by using a small-diameter, stainless-steel and Teflon[1] submersible pump. Samples for analysis for inorganic constituents and nutrients were collected with the same pump. Samples for analysis for organic constituents were collected by using a Teflon point-source bailer with Teflon-coated support wire. One well (1179-4B) was purged by using an air jet because of the large drawdown and low specific capacity. All samples from this well were collected by using a bailer.

Wells that were expected to contain the lowest contaminant concentrations were sampled first and those that were expected to contain the highest contaminant concentrations were sampled last. In order to reduce the potential for cross-contamination between wells, sampling equipment was washed with soap and water, rinsed with methanol and deionized water, and then rinsed with deionized water. Prior to sample collection, equipment was flushed several times with well water. Samples were collected after removal of at least three casing volumes of water and after measurements of specific conductance, pH, and temperature had stabilized (no observable change in measurement in several minutes). Immediately following collection, samples were preserved and prepared for shipment to the laboratory.

Surface-water and streambed-material samples were collected monthly at three sites on Green Pond Brook from January 1990 through June 1990 by the USGS and were analyzed for trace elements, explosive compounds, base/neutral- and acid-extractable compounds, pesticides, and volatile organic compounds (VOC's) by a USATHAMA contract laboratory. Samples were collected and preserved in accordance with accepted USGS field techniques (Guy and Norman, 1970; Brown and others, 1970).

Concentrations of inorganic constituents and nutrients in ground-water samples were determined by using the methods of Fishman and Friedman (1989) at the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado. Concentrations of organic constituents, including base/neutral- and acid-extractable compounds, VOC's, organochlorine and organophosphorus pesticides, and polychlorinated biphenyls (PCB's), were determined by using the methods described in Wershaw and others (1987) at the NWQL. The methods used for determination of organic compounds are equivalent to USEPA Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater 608, 624, and 625 (Longbottom and Lichtenberg, 1982). Quality-assurance checks were conducted on the basis of the methods of Friedman and Erdmann (1982).

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[1] The use of brand or trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Analyses of ground-water samples for 31 VOC's (listed in table 5, p. 38) were performed at the USGS New Jersey District laboratory in Trenton, New Jersey. The method used was a modification of USEPA methods 601 and 602 (Longbottom and Lichtenberg, 1982). Modifications included the use of a wide-bore capillary chromatograph column; two selective detectors, a Hall electrolytic conductivity detector and a photoionization detector connected in series; and subambient cooling.

The USATHAMA contract laboratory used several protocols for analyzing surface-water and streambed-material samples. All trace elements, except mercury, were determined by means of inductively coupled argon plasma method and graphite furnace atomic adsorption. Mercury was analyzed by means of covapor atomic adsorption. Base/neutral-, acid-extractable, and other semivolatile organic compounds were analyzed by means of gas chromatography/ mass spectrometry (GC/MS) according to USEPA method 625 protocols for those analyses that are not described under the USEPA contract-laboratory protocol. For compounds described by the contract-laboratory protocol, the reporting limit specified for that protocol was used. VOC's were determined by GC/MS by using USEPA method 624 (U.S. Environmental Protection Agency, 1979). Sample analyses for pesticides followed USEPA method 608 (Longbottom and Lichtenberg, 1982).

HYDROLOGY

Water enters the study area as precipitation, flows overland or through various combinations of bedrock, till, and stratified drift, and then discharges into streams and ponds. Three aquifers have been defined in Green Pond Valley--an unconfined glacial aquifer, a confined glacial aquifer, and a confined bedrock aquifer (Sargent and others, 1990). The unconfined glacial aquifer consists of deltaic sands and gravels to the north of the study area and lake-bottom and deltaic fine-grained sand and silt to a depth of approximately 50 to 70 ft below land surface within the study area (fig. 7).

Ground Water

In order to determine the direction of ground-water flow and, potentially, the direction of contaminant movement, four maps were constructed showing the altitude and configuration of the water table in April and September 1989 and 1990 (figs. 8 through 11). Ground water flows in the direction of decreasing hydraulic gradient, perpendicular to the direction of the potentiometric contours. Patterns of ground-water flow typically are different in spring than in fall. In spring, water levels are commonly higher than they are in fall because of changes in storage resulting from seasonal variations in precipitation and evapotranspiration. This seasonal fluctuation in water levels is commonly observed in shallow, unconfined aquifers composed of fine- to coarse-grained materials (Sargent and others, 1990).

Water Levels and Direction of Flow

Figures 12 and 13 show water-level fluctuations at monitoring well LF 2 OBS for 1985-90 and at monitoring wells SB1-3 OBS and SB2-2 OBS for 1989-90, respectively.

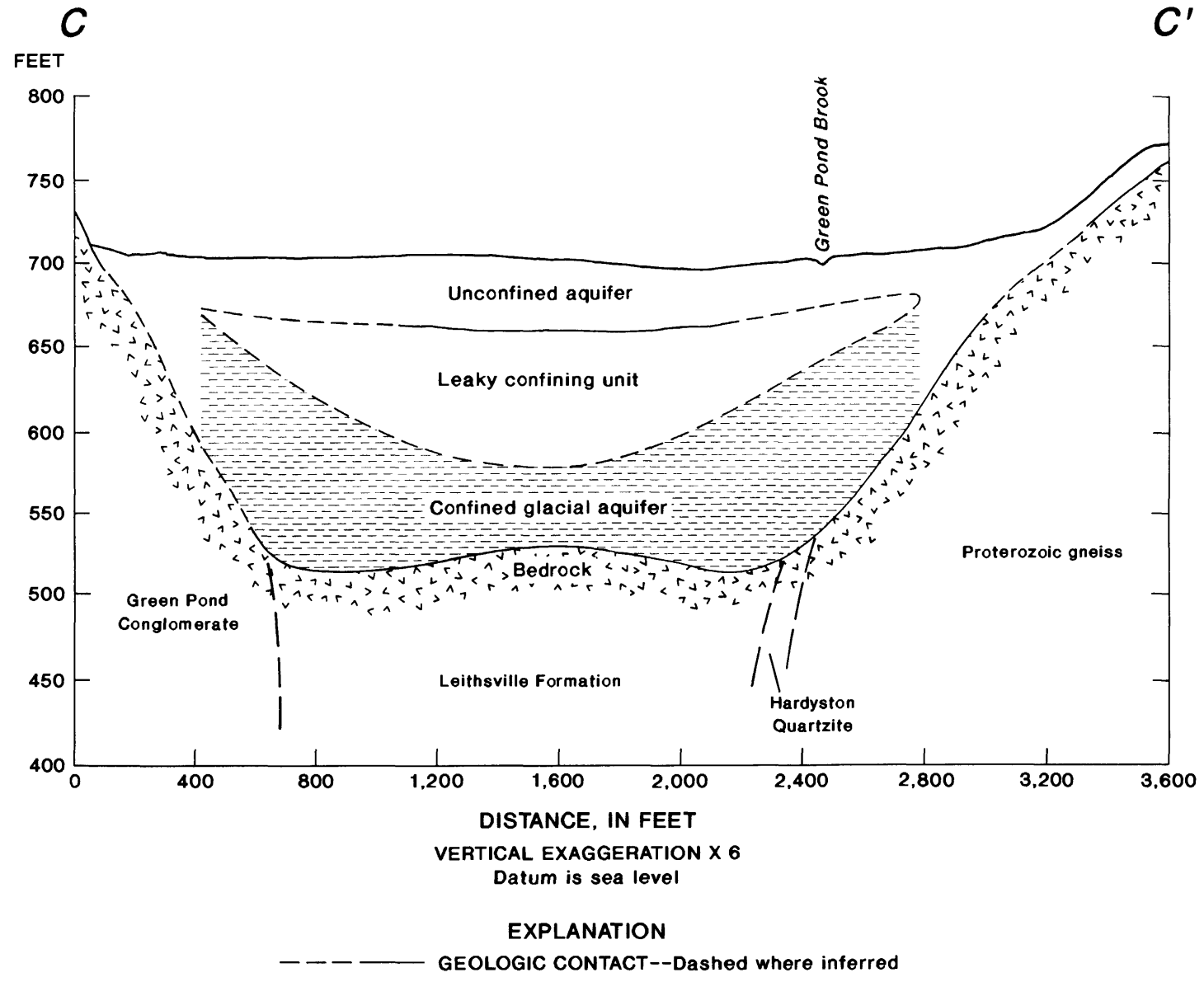

Figure 7.--Generalized hydrogeologic section showing bedrock and aquifer units at Picatinny Arsenal. (Line of section shown in figure 2. Modified from Sargent and others, 1990)

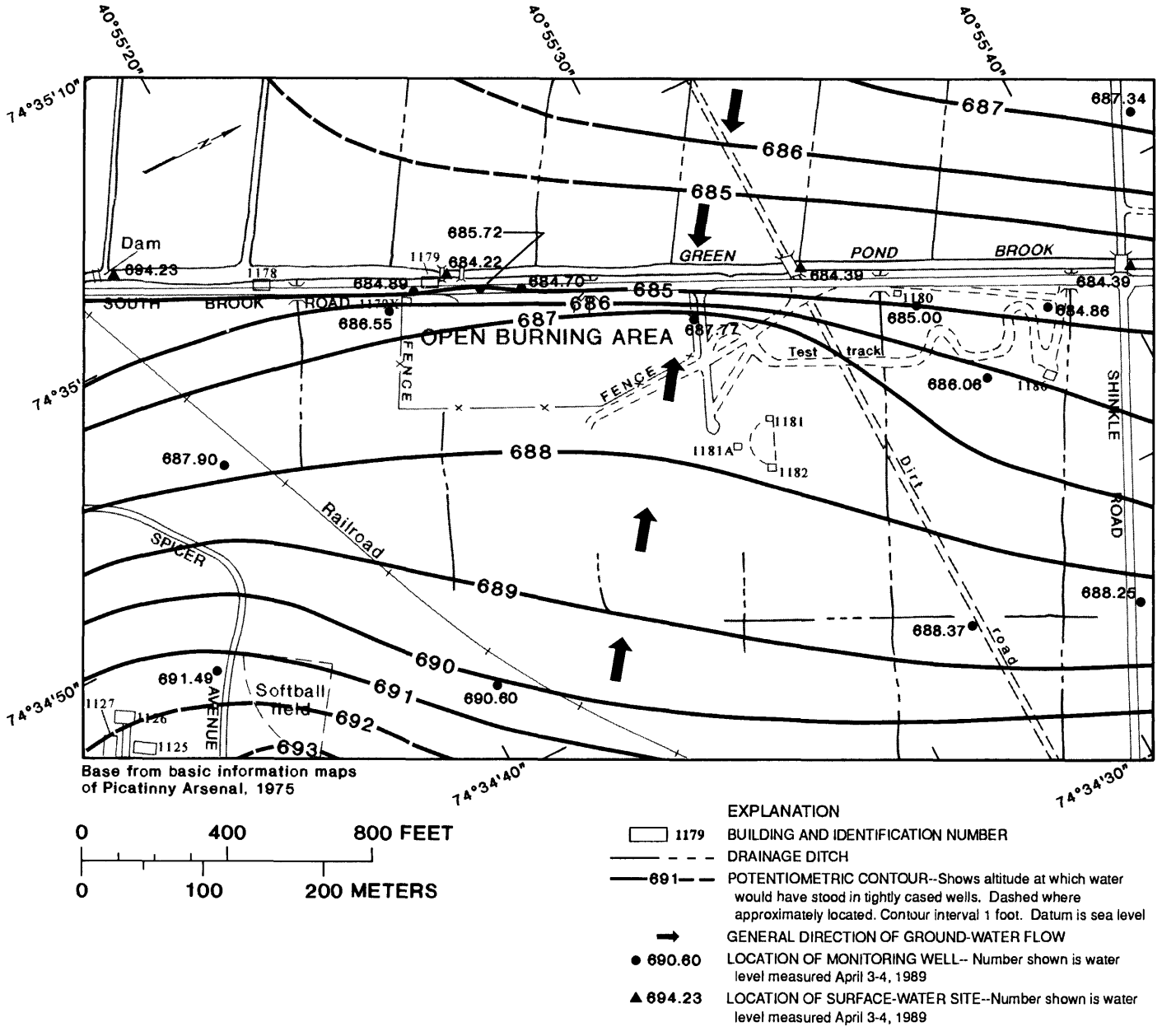

Figure 8.--Altitude of the water table in the study area, April 3-4, 1989.

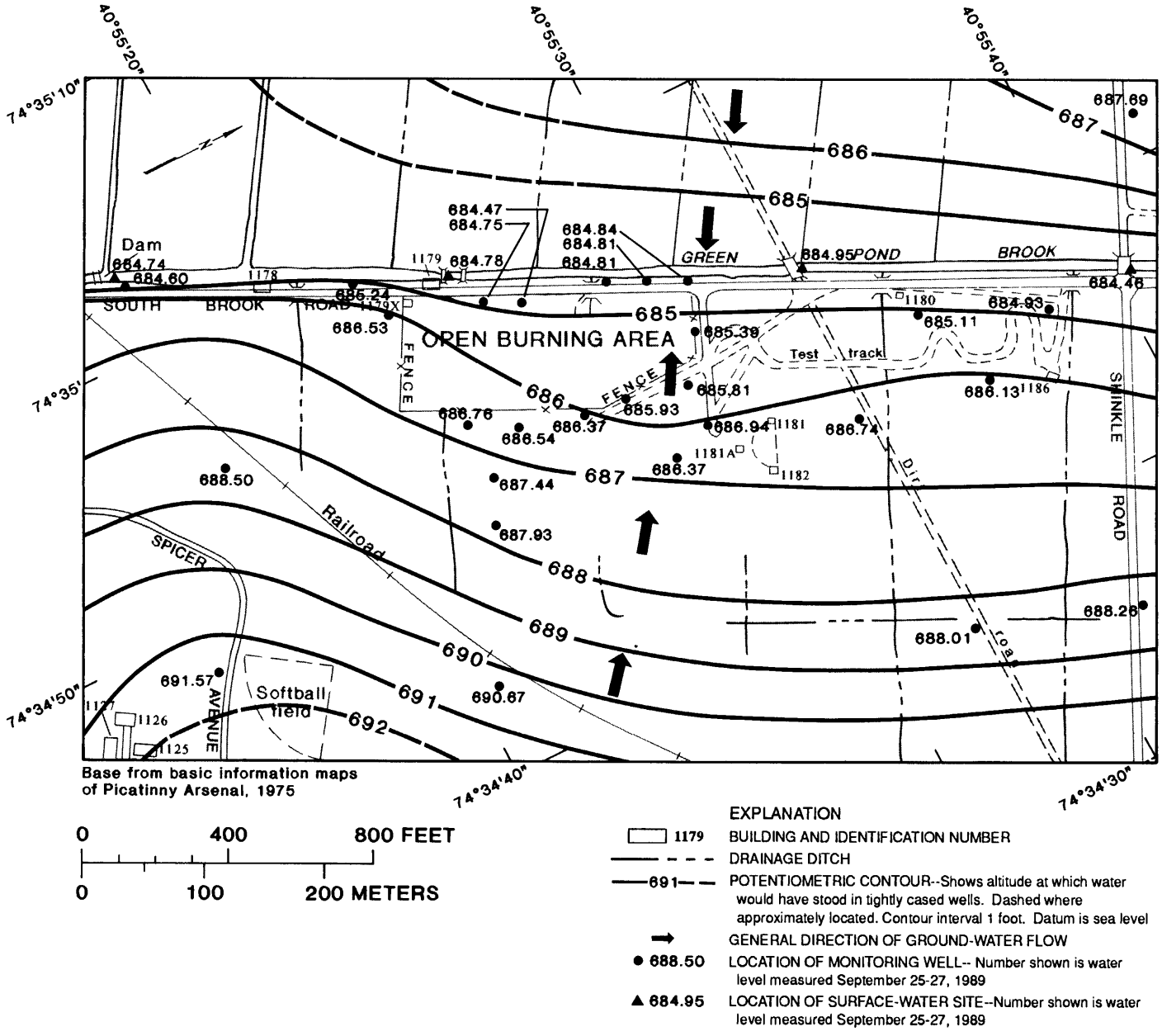

Figure 9.--Altitude of the water table in the study area, September 25-27, 1989.

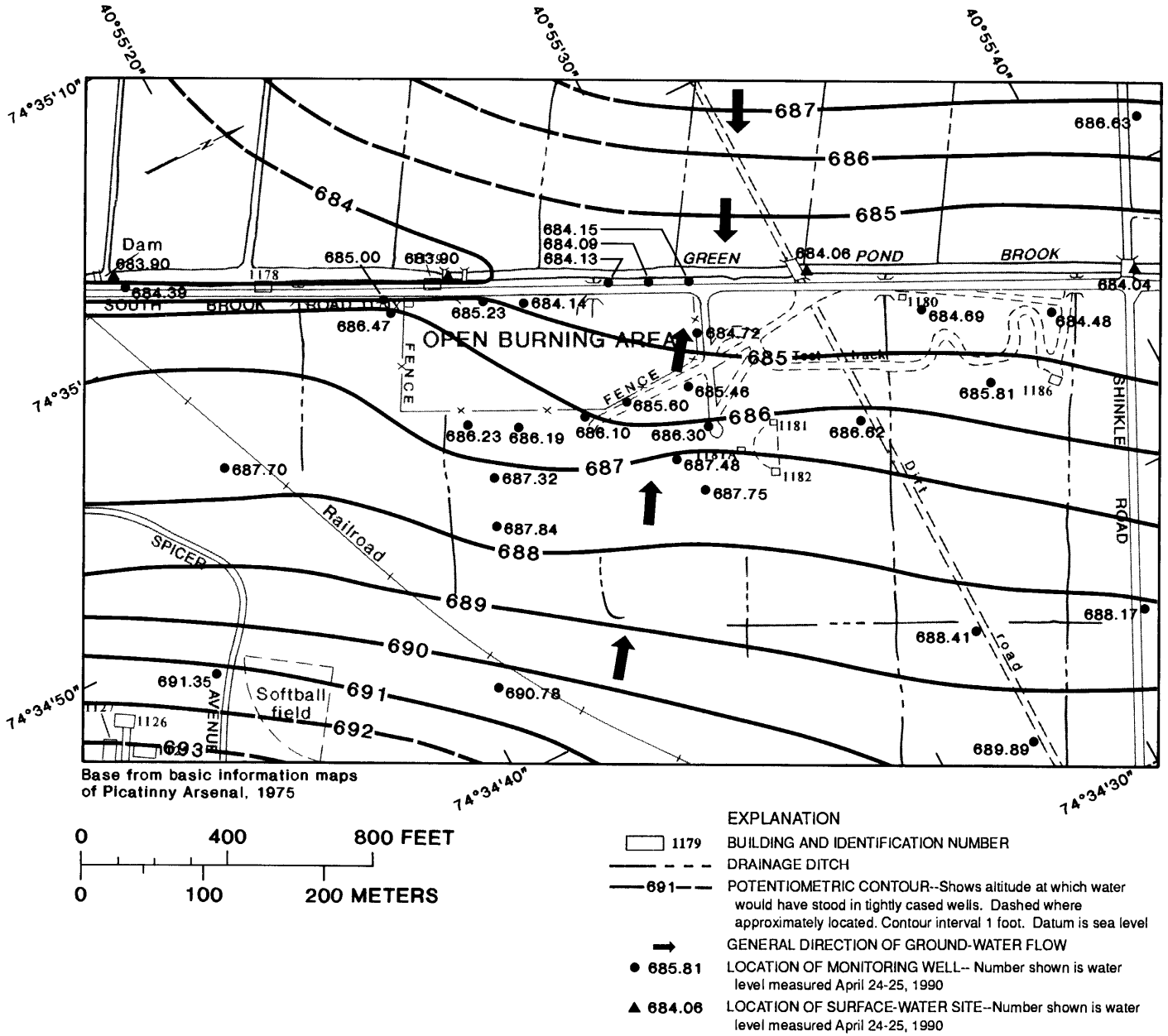

Figure 10.--Altitude of the water table in the study area, April 24-25, 1990.

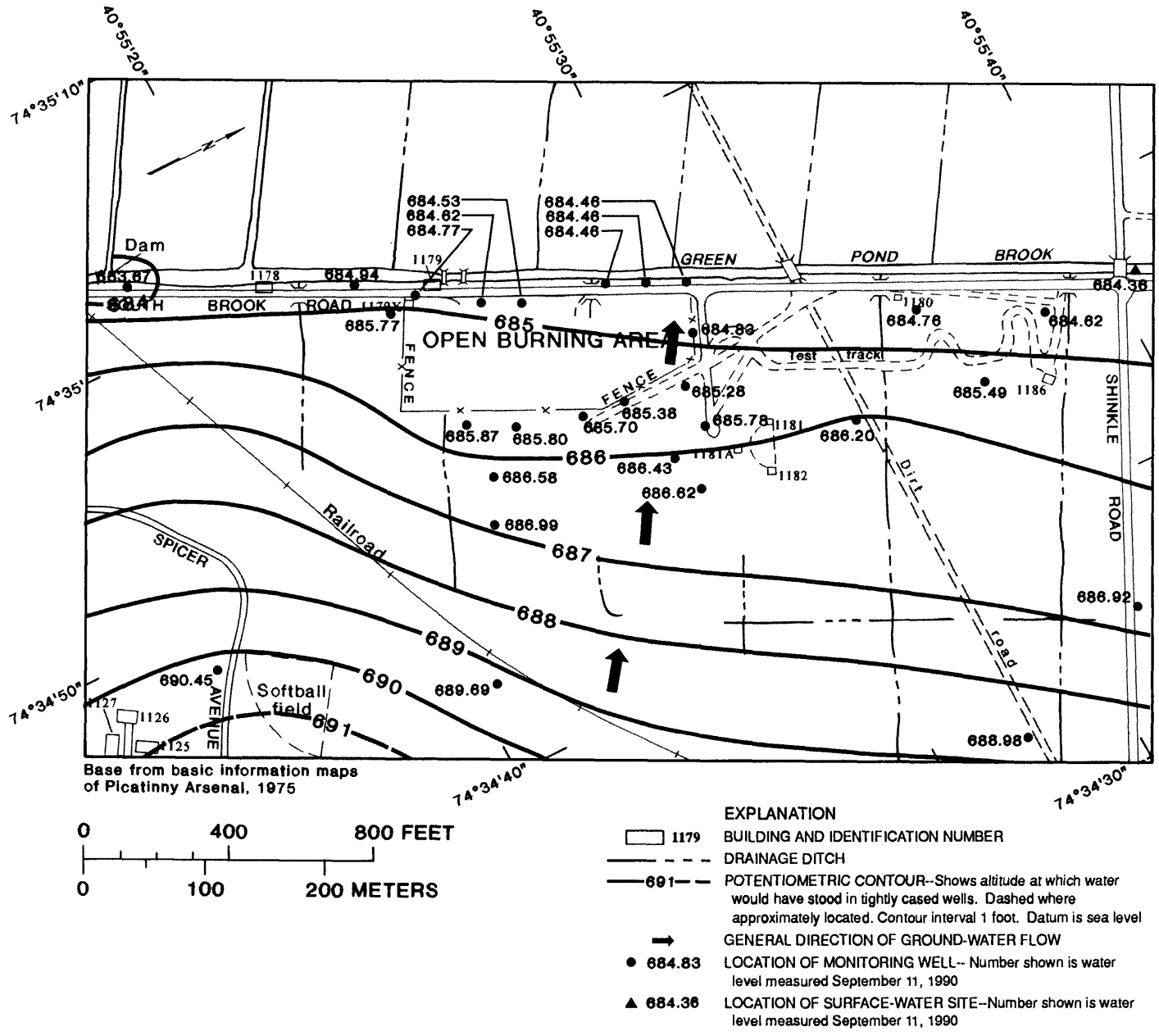

Figure 11.--Altitude of the water table in the study area, September 11, 1990.

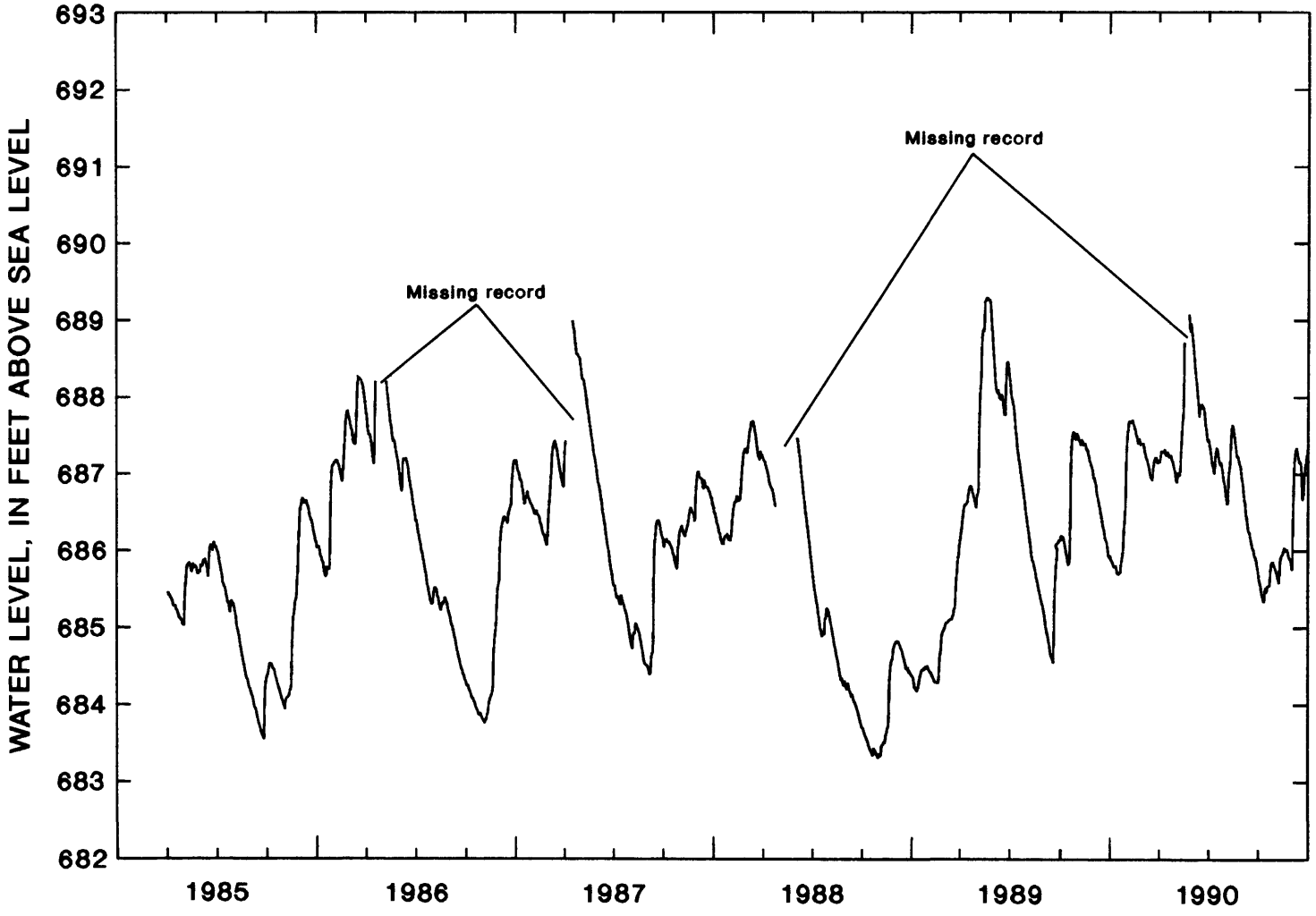

Figure 12.--Water level in well LF 2 OBS, April 1985-December 1990.
(Well location shown in figure 16)

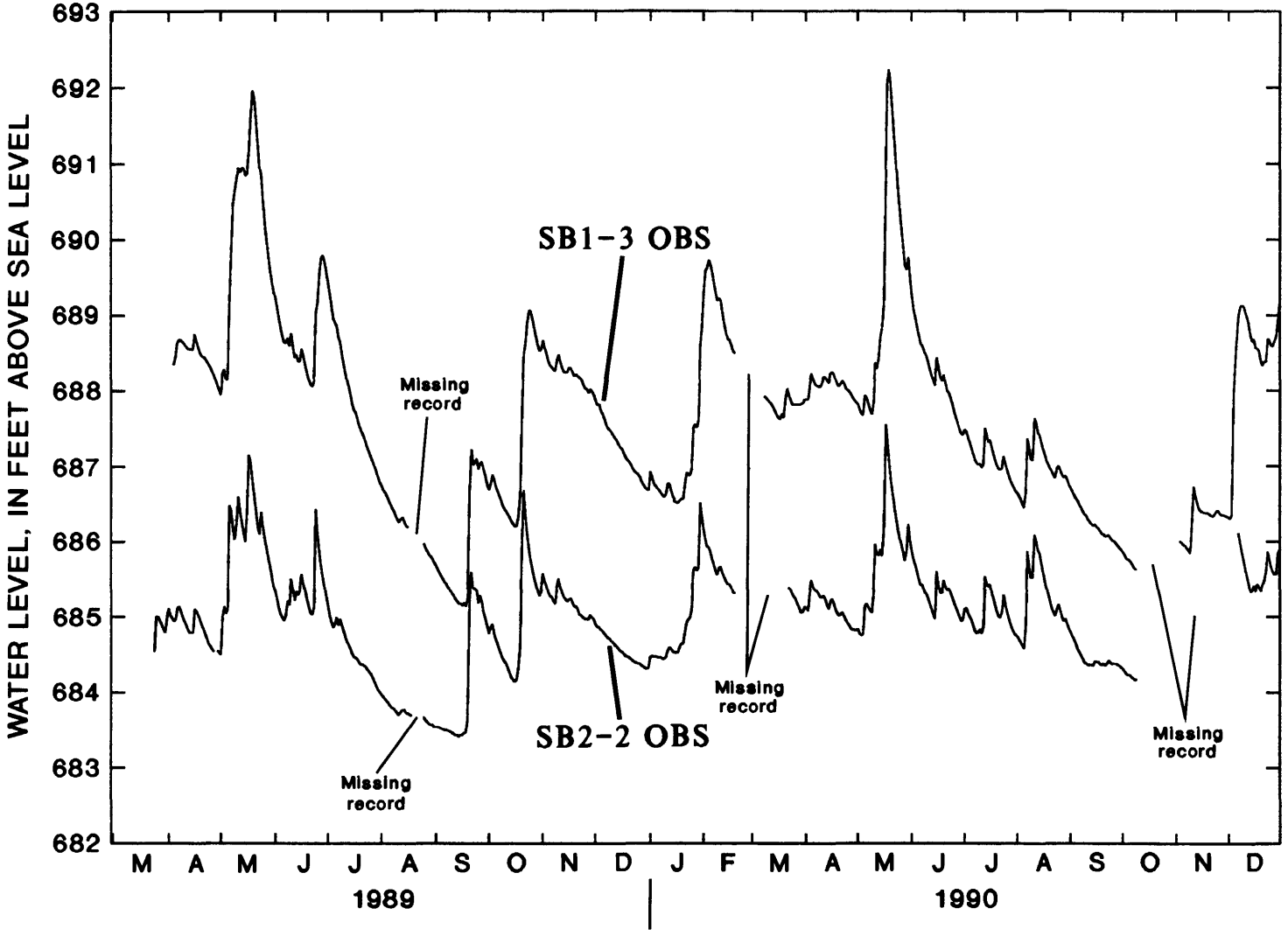

Figure 13.--Water level in wells SB1-3 OBS and SB2-2 OBS, March 1989-December 1990. (Well location shown in figure 16)

Ground-water flow in the unconfined aquifer near the open burning area in April 1989 and April 1990 (figs. 8 and 10, respectively) generally was nearly horizontal and toward Green Pond Brook. Water levels in September 1989 and September 1990 (figs. 9 and 11, respectively) were similar to those in April 1989 and April 1990 as a result of unusually wet conditions in those years. Water moved predominantly toward the stream in response to a cross-valley gradient with a smaller downvalley component of flow. Near the southern boundary of the arsenal, Green Pond Brook changes direction from southwest to southeast (fig. 1). In this area, flow was downvalley, but still perpendicular to Green Pond Brook. Both the downvalley and cross-valley gradients are controlled primarily by the streambed gradient and local variations in recharge, saturated thickness, and aquifer hydraulic conductivity.

Variations in head across the study area were greater in spring than in fall. The difference in head between wells SBF-1 and 1179A-1 was 6.5 ft in April 1990 (fig. 10) and 5 ft in September 1990 (fig. 11). The cross-valley gradient is the result of ground-water recharge at the base of the valley walls and at the water table, and ground-water discharge into Green Pond Brook.

The streamflow and stage of Green Pond Brook are controlled by a weir near the southern boundary of the arsenal and a dam located about 800 ft south of the open burning area. The presence of these controls can modify the seasonal changes in ground-water levels near the open burning area. Swamplands and drainage ditches in the southern half of the arsenal can store water that backs up from Green Pond Brook.

Information on the confined glacial aquifers in the study area is limited. Water-level data from wells at the southern boundary of the arsenal and from the three deep wells installed as part of this study indicate that the downvalley component of flow is greater in the confined glacial aquifer than in the unconfined aquifer at the open burning area. In April 1990, heads were measured in wells 1180-2, 1180-1, and 1180-2A; screened intervals in these wells are 10 to 20 ft, 51 to 61 ft, and 124 to 134 ft below land surface, respectively. The difference between the heads in wells 1180-2 and 1180-1 was 3.2 ft, and flow was upward. The difference between the heads in wells 1180-1 and 1180-2A was 7.1 ft, and flow was downward.

Rate of Flow

The rate of flow in an unconfined aquifer can be determined according to Darcy's Law if certain hydraulic properties of the aquifer are known. By assuming that the aquifer is homogeneous and isotropic, the velocity of ground water (V) can be estimated with the equation

$$V = KI/n,$$

where K is the hydraulic conductivity,
I is the head gradient, and
n is the effective porosity.

Horizontal hydraulic conductivities and effective porosity were determined from lithologic logs and grain-size analyses of sediments from selected wells. A horizontal hydraulic conductivity was assigned to each unit of known thickness on the basis of lithologic characteristics. Values for each of the units were then added, and the result divided by the total aquifer thickness for that well, yielding an average horizontal hydraulic conductivity for the total thickness of the strata. The average horizontal hydraulic conductivity of the unconfined aquifer, consisting of medium-grained sand to silt sediments, ranges from 5 to 20 ft/d (Lohman, 1972, p. 53). The average hydraulic conductivity of sediments in the unconfined aquifer in the study area is estimated to be as high as 100 ft/d (L.M. Voronin, U.S. Geological Survey, written commun., 1990).

The effective porosity for sediments consisting of medium-grained sands to silt was estimated from a table (Freeze and Cherry, 1979, p. 37) to range from 0.25 to 0.50. Average head gradients, calculated from differences in water levels in wells across the study area, ranged from 0.0032 ft/ft in fall 1990 to 0.0046 ft/ft in spring 1990. By using the minimum and maximum values for all the variables in the above equation, the average velocity of ground water is estimated to range from 0.03 to 1.8 ft/d.

Surface Water

Green Pond Brook, the major stream in the study area, flows southwest through Picatinny Arsenal. The brook is a tributary to the Rockaway River, which flows into Boonton Reservoir, a water-supply reservoir for Jersey City, New Jersey. Green Pond Brook drains the long, narrow valley between Green Pond Mountain and Copperas Mountain to the west and north, and an unnamed mountain to the east. Streamflow and stage of Green Pond Brook can be regulated at two points within the southern part of the arsenal--by a dam at the outflow of Picatinny Lake and a small flood-control dam about 800 ft downstream from the open burning area. The open burning area and its immediate vicinity are relatively flat with poorly drained soils, except near the valley walls (Eby, 1976). Several intermittent streams discharge into Green Pond Brook just north of the open burning area. The area also is drained by a series of ditches cut perpendicular to Green Pond Brook.

The USGS maintains three streamflow-gaging stations on Green Pond Brook within the boundary of the arsenal. The southernmost station, Green Pond Brook at Wharton, New Jersey, is about 100 ft upstream from the point at which Green Pond Brook flows off the arsenal property and about 2,300 ft downstream from the open burning area. The station has a drainage area of 12.6 mi^2 and has been active since October 1982.

The streamflow hydrograph for Green Pond Brook at Wharton for January 1, 1988, through September 30, 1990, is shown in figure 14. The streamflow hydrograph shows that Green Pond Brook exhibits a large, sharp response to rainfall because of rapid runoff from the steep slopes of the valley walls. The recession of the streamflow hydrograph tends to be prolonged as a result of storage in the lakes and swamplands of the basin, bank storage, and an increase in ground-water discharge. Daily mean discharge for Green Pond Brook at Wharton during the 1989 water year was 24.7 ft^3/s. A peak instantaneous discharge of 229 ft^3/s was recorded on May 17, 1989. The instantaneous low-flow discharge for the 1989 water year was 2.8 ft^3/s on

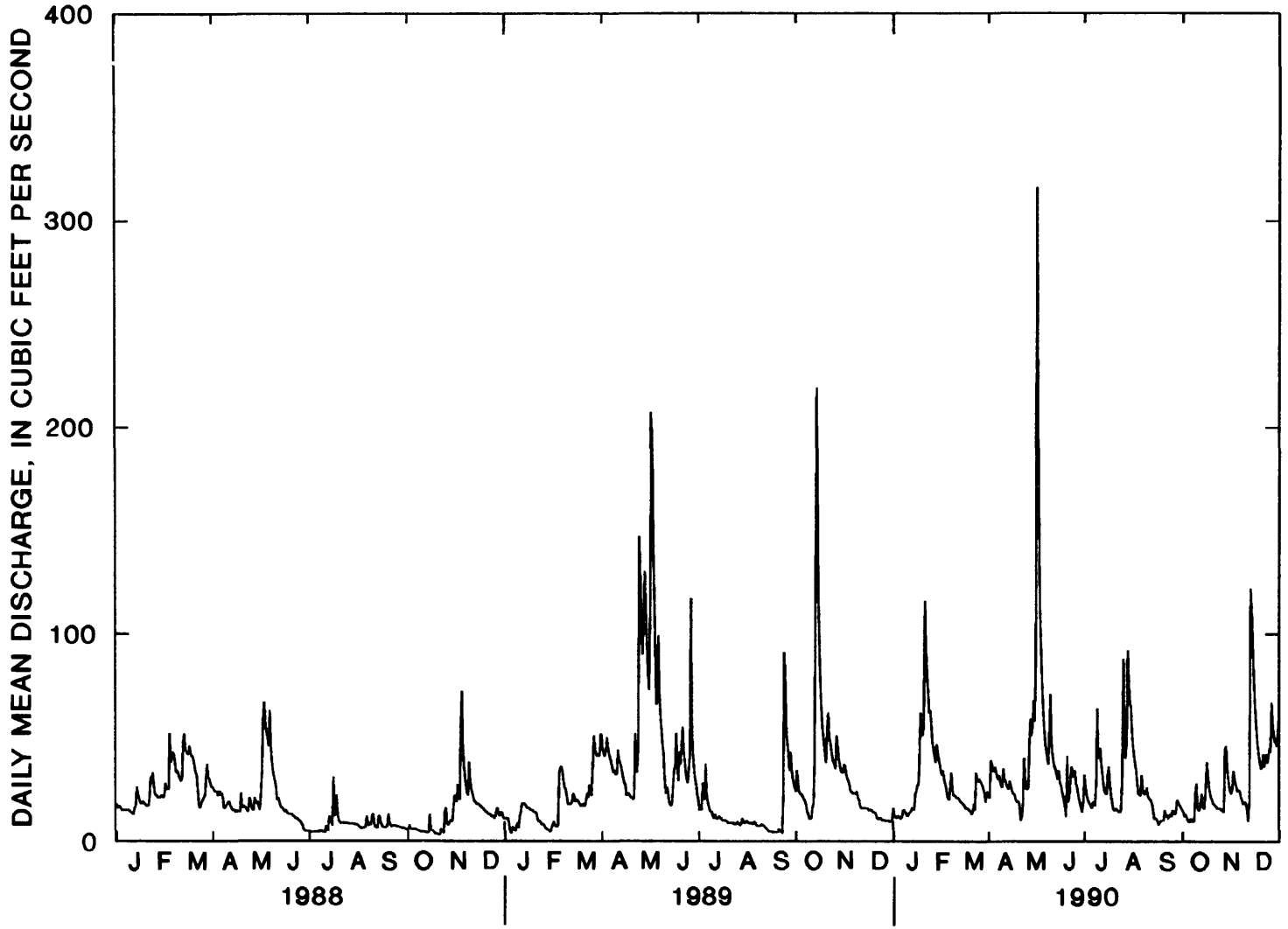

Figure 14.--Discharge of Green Pond Brook at Wharton, New Jersey, 1988-90.
(Location of streamflow-gaging station shown in figure 16)

October 30, 1988. The average discharge for the period of record is 14.4 ft^3/s. The peak discharge for the period of record is 572 ft^3/s on April 5, 1984.

Ground-Water/Surface-Water Interactions

Three methods were used to determine the direction of flow of water between Green Pond Brook and the unconfined aquifer. The first method, the use of water-level-contour maps to show ground-water flow direction, indicates that the brook is the discharge area for the unconfined aquifer (figs. 8 through 11).

To confirm the direction of flow, mini-piezometers were installed at five sites in Green Pond Brook near the open burning area to compare the hydraulic head of the ground water in the unconfined aquifer just below the streambed to the elevation of the surface water. Differences in head between the ground water and the stream on April 25, 1990, indicate that ground water was discharging into the stream at all five sites. Head differences ranged from 0.82 ft at site MP-3 to 0.03 ft at site MP-2. The locations of mini-piezometer sites and calculated head differences are shown in figure 15.

The third method used to determine the direction of flow between ground water and surface water was the measurement of stream discharge. A series of stream discharge measurements was made along the stream reach on April 4, 1989--a period of stable, low flow--to determine whether stream discharge increased downstream along the reach (indicating a gaining stream) or decreased downstream along the reach (indicating a losing stream). Results of the measurements and locations of surface-water sites along Green Pond Brook are shown in figure 16.

Flow in Green Pond Brook generally increased in the downstream direction, indicating surface-water and (or) ground-water inflow to the stream. Discharge increased from 32.4 ft^3/s at site SG#6 to 41.0 ft^3/s at the Green Pond Brook at Wharton site. Flow increased from 37.4 ft^3/s at site SG#5 to 51.3 ft^3/s at site SG#4, but then decreased to 34.8 ft^3/s at site SG#3. Although part of the increase in flow at site SG#4 resulted from inflow from an intermittent stream entering Green Pond Brook about 500 ft north of the open burning area, the discharge measurement at site SG#4 is considered to be inaccurate because of poor measuring conditions at the site. The streambed at the cross-section where discharge was measured consists of soft, fine-grained sand, silt, and mud, making accurate measurements of depth difficult. The results of the stream-discharge measurements are considered inconclusive because they vary irregularly along the reach of the channel.

WATER QUALITY

Ground-water, surface-water, and soil contamination within the arsenal are well documented on the basis of studies conducted by the U.S. Army and its contractors. In March 1986, the U.S. Army requested that the USGS assess ground-water quality at Picatinny Arsenal as required under the Resource Conservation and Recovery Act. In March 1990, Picatinny Arsenal was placed on the National Priority List as a Superfund site.

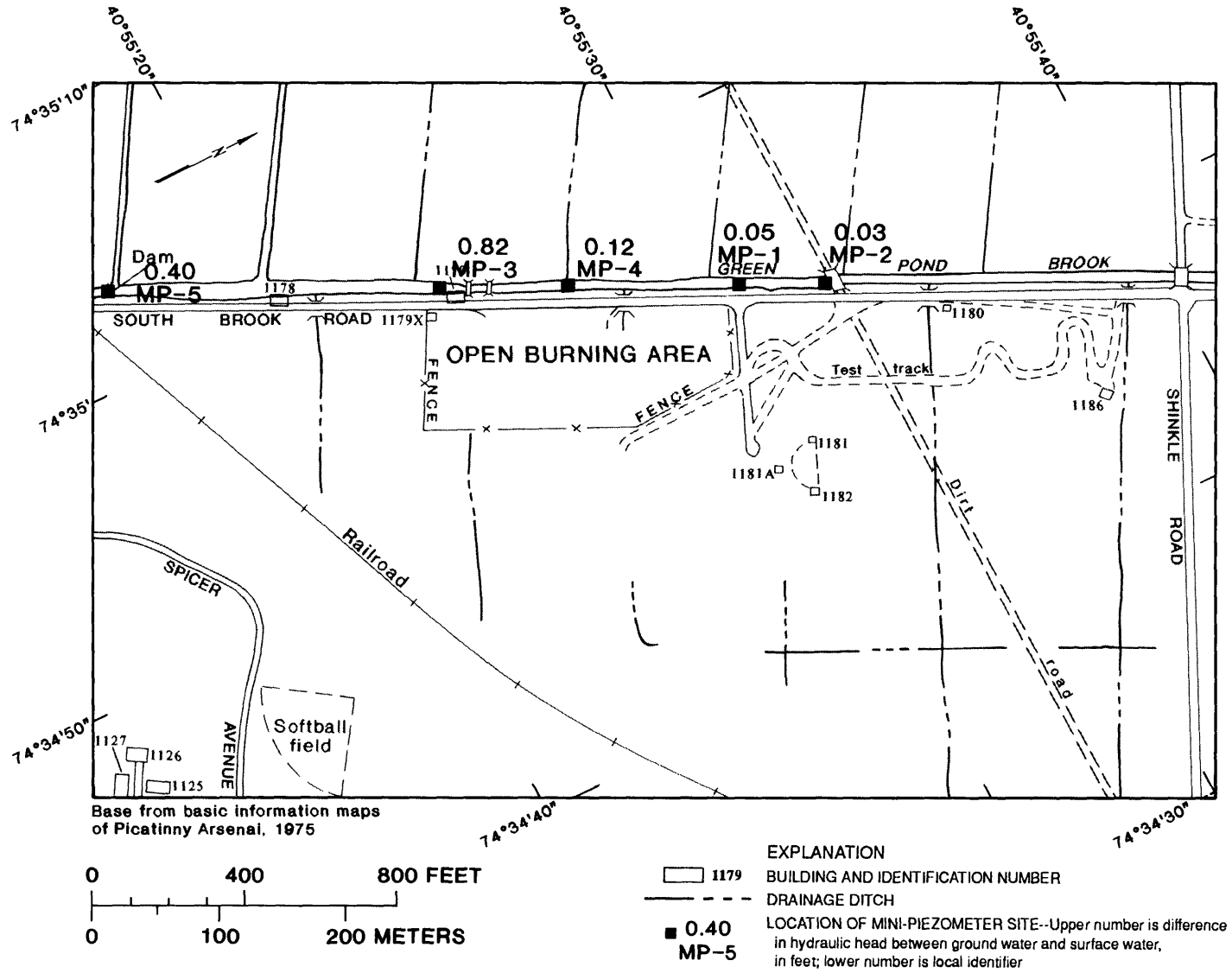

Figure 15.--Locations of mini-piezometer sites near the open burning area and differences in hydraulic head between ground water and surface water, April 25, 1990.

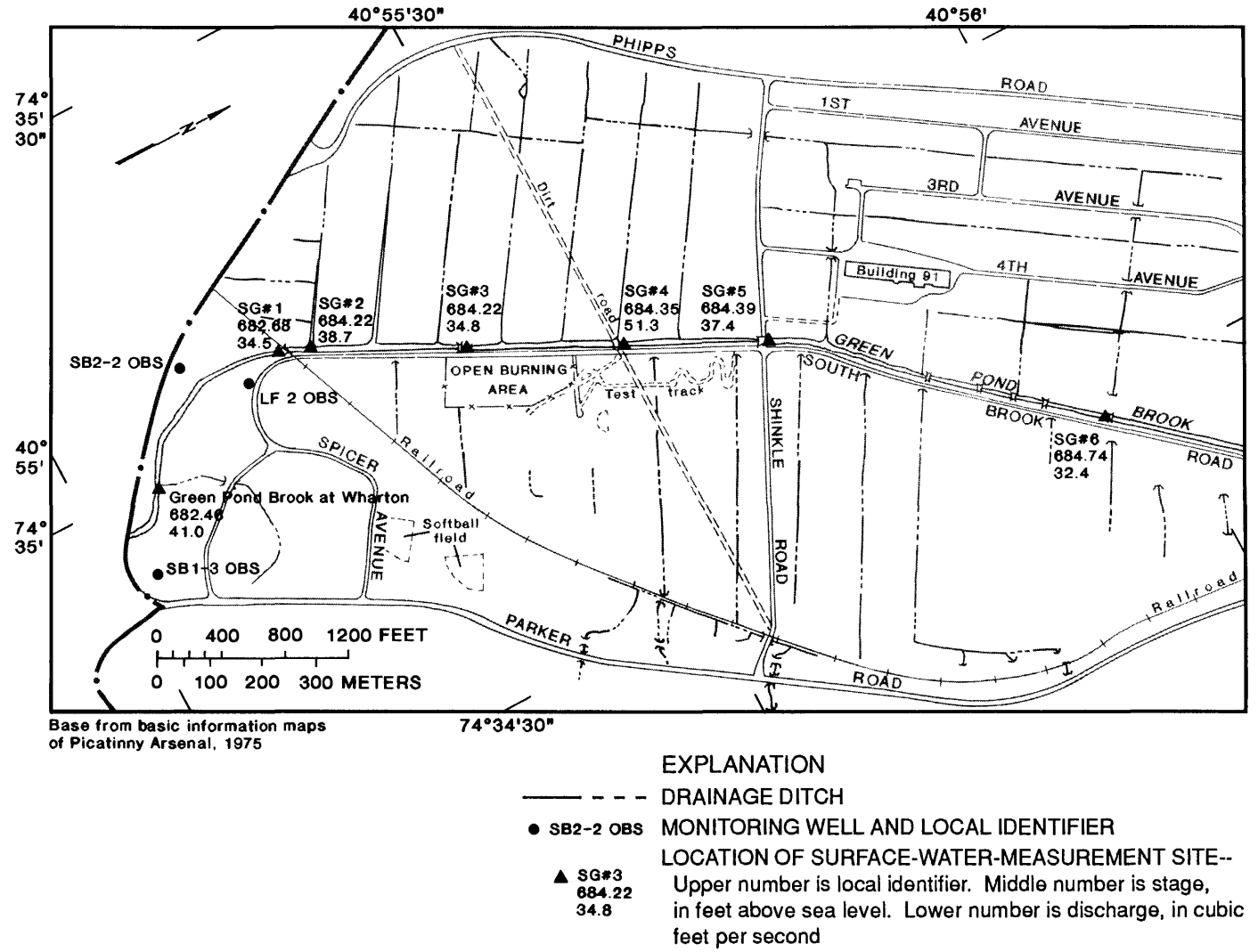

Figure 16.--Locations of surface-water sites and discharge of Green Pond Brook, April 4, 1989.

Ground Water

Ground-water samples were collected over a 1-year period from August 1, 1989, through August 28, 1990, from 24 wells screened in the unconfined glacial aquifer and 3 wells screened in the confined glacial aquifer--1179-4B, 1180-2A, and C-1A--that range in depth from 87 to 151 ft below land surface. These samples were analyzed for inorganic constituents, trace elements, nutrients, and explosive compounds. Six water samples also were analyzed for base/neutral- and acid-extractable compounds, organochlorine and organophosphorus pesticides, and PCB's. Water samples from eight wells were analyzed for VOC's, and samples from two wells inside the open burning area were analyzed for dioxin and furan compounds.

Inorganic Constituents and Trace Elements

Ground-water samples from 27 wells were analyzed for physical properties and selected chemical constituents at the NWQL. The results of these analyses are presented in table 3. Results of the analysis of a duplicate sample collected from well 1179A-2, also presented in table 3, compare very well with the results of the original analyses.

In water samples from wells in the open burning area and vicinity, concentrations of only two inorganic constituents, iron and manganese, and one chemical property, pH, exceeded the USEPA secondary maximum contaminant levels[2] (SMCL's) of 0.3 mg/L, 0.05 mg/L, and 6.5 to 8.5, respectively (U.S. Environmental Protection Agency, 1988c). No inorganic constituents or trace elements were detected at concentrations greater than USEPA maximum contaminant levels[3] (MCL's) (U.S. Environmental Protection Agency, 1988a; U.S. Environmental Protection Agency, 1988c). Concentrations of iron and manganese were high throughout the study area, although concentrations in water samples from the deep wells were much lower than those in water samples from the shallow wells. Concentrations of iron in samples from wells screened in the unconfined aquifer ranged from 11 to 24,000 μg/L, whereas concentrations of iron in samples from wells screened in the confined glacial aquifer ranged from 4 to 19 μg/L. Values of pH in water samples from wells in the study area ranged from 6.5 to 9.3, although values for the deep wells (8.5-9.3) were greater than those for the shallow wells

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[2] Secondary Maximum Contaminant Level: Contaminants that affect the aesthetic quality of drinking water. At high concentrations or values, health implications as well as aesthetic degradation may also exist. Secondary Maximum Contaminant Levels are not Federally enforceable but are intended as guidelines for the States. (U.S. Environmental Protection Agency, 1988c)

[3] Maximum Contaminant Level: Enforceable, health-based regulation that is to be set as close to the Maximum Contaminant Level Goal as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of USEPA finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration). (U.S. Environmental Protection Agency, 1988a)

Table 3.--Results of analyses of ground-water samples from wells in or near the open burning area for selected physical and chemical characteristics, nutrients, common constituents, and trace elements

[Constituents are dissolved except as noted; concentrations in milligrams per liter, except as noted; <, less than; --, constituent or characteristic not determined; °C, degrees Celsius; DUP, duplicate sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; number in parentheses is constituent-analysis code used by the U.S. Geological Survey National Water-Quality Laboratory, Denver, Colorado]

Local well identifier	Date	Water temperature (°C) (00010)	Field pH (units) (00400)	Field specific conductance (µS/cm) (90095)	Dissolved oxygen (00300)	Laboratory alkalinity (as $CaCO_3$) (90410)	Field alkalinity (as $CaCO_3$) (00410)	Dissolved solids (70300)	Ammonia (as N) (00608)
1178-1	08-03-89	12.0	6.6	171	0.2	39	54	109	0.18
1179-1	08-03-89	12.0	8.1	185	.2	87	92	118	.19
1179-2	08-03-89	15.5	7.8	164	.2	90	91	103	.39
1179-3	08-03-89	12.0	7.3	228	.2	86	84	134	.19
1179-4	08-02-89	12.0	6.8	497	.2	187	202	293	.42
1179-4A	08-02-89	11.5	8.7	202	.2	100	110	127	.13
1179-4B	08-28-90	--	8.7	226	--	74	--	142	.04
1179-5	08-02-89	12.0	7.6	400	.2	118	110	230	.03
1179-6	08-04-89	12.5	6.5	441	1.3	81	86	194	.10
1179-7	09-05-89	13.0	6.6	397	.7	114	142	206	.96
1179A-1	08-04-89	13.5	6.6	360	.1	135	158	234	1.0
1179A-2	08-04-89	15.0	6.7	330	.1	131	167	287	.97
1179A-2 DUP	08-04-89	15.0	6.7	330	.1	131	167	241	.98
1179A-3	08-04-89	14.0	6.7	389	.1	179	228	249	1.0
1179D-1	07-10-90	11.5	6.7	313	.3	120	--	198	.36
1179D-2	07-10-90	12.5	6.6	396	.3	118	--	208	.29
1180-1	08-02-89	12.0	8.3	214	.2	88	96	141	.04
1180-2	08-01-89	14.5	6.7	463	.2	172	194	267	1.5
1180-2A	05-31-90	11.5	8.5	205	.3	91	82	116	.08
1180-3	03-22-90	8.5	6.8	312	.1	84	112	204	.29
1181-1	08-02-89	11.5	6.8	356	.2	138	160	261	.52
1181-2	08-02-89	14.0	6.7	268	.1	107	137	177	1.1
1181-3	08-02-89	14.5	6.6	358	.1	137	159	245	1.0
3548-1	08-01-89	13.0	6.6	362	.1	132	154	260	.65
3548-2	08-01-89	13.5	6.9	340	.2	94	108	229	.21
3548-3	05-31-90	11.0	6.9	366	1.2	118	120	194	.39
C-1A	08-07-90	12.0	9.9	279	.7	109	--	168	.03
C-1B	03-22-90	10.0	7.6	--	.8	119	112	188	.05

Local well identifier	Ammonia + organic N (as N) (00623)	Nitrite (as N) (00613)	Nitrite + nitrate (as N) (00631)	Phosphorus (00666)	Ortho-phosphate (00671)	Calcium (00915)	Magnesium (00925)	Sodium (00930)	Potassium (00935)
1178-1	<0.20	<0.01	<0.10	0.12	0.12	15	5.4	6.3	0.60
1179-1	.30	<.01	<.10	.15	.15	23	6.9	6.5	.70
1179-2	.40	<.01	<.10	.08	.06	25	6.5	5.8	.30
1179-3	.80	<.01	<.10	<.01	<.01	25	11	4.6	.70
1179-4	.70	<.01	<.10	<.01	<.01	50	17	25	1.6
1179-4A	.50	<.01	<.10	.07	.06	25	1.9	19	.30
1179-4B	<.20	<.01	.20	1.40	1.10	13	3.6	31	.70
1179-5	<.20	.06	.87	<.01	<.01	38	14	24	1.2
1179-6	.40	.01	.76	<.01	<.01	25	9.3	19	1.4
1179-7	1.0	<.01	<.10	<.01	<.01	35	13	17	1.2
1179A-1	1.9	<.01	<.10	.20	.20	39	11	6.6	1.8
1179A-2	1.8	<.01	<.10	.18	.18	42	13	6.8	2.5
1179A-2 DUP	1.8	<.01	<.10	.18	.18	42	13	6.7	2.1
1179A-3	1.2	<.01	<.10	<.01	.19	52	15	12	1.8
1179D-1	.90	<.01	<.10	.07	.06	33	11	12	1.1
1179D-2	<.20	<.01	.10	.03	.01	33	13	25	.70
1180-1	<.20	<.01	<.10	.11	.10	29	8.1	6.2	.60
1180-2	1.4	<.01	<.10	.03	.03	53	16	12	3.3
1180-2A	.20	<.01	<.10	.80	.78	18	4.2	19	.60
1180-3	.60	.02	<.10	.12	.15	30	9.2	16	.40
1181-1	.60	<.01	<.10	.17	.18	46	16	14	2.2
1181-2	1.9	<.01	<.10	.07	.08	34	11	6.7	1.5
1181-3	1.4	<.01	<.10	<.01	<.01	44	11	11	2.2
3548-1	.70	<.01	<.10	.03	.02	47	15	9.8	1.9
3548-2	.60	<.01	<.10	.08	.08	40	10	11	1.3
3548-3	.50	<.01	<.10	.02	<.01	39	9.5	15	1.2
C-1A	.50	<.01	<.10	4.40	1.20	12	4.4	46	1.1
C-1B	1.5	.01	<.10	.04	.05	38	7.9	20	1.0

Table 3.--Results of analyses of ground-water samples from wells in or near the open burning area for selected physical and chemical characteristics, nutrients, common constituents, and trace elements--Continued

Local well identifier	Chloride (00940)	Sulfate (00945)	Silica (as SiO_2) (00955)	Arsenic (µg/L) (01000)	Barium (µg/L) (01005)	Beryllium (µg/L) (01010)	Cadmium (µg/L) (01025)	Chromium (µg/L) (01030)	Cobalt (µg/L) (01035)	Copper (µg/L) (01040)
1178-1	8.4	20	17	1	13	<0.5	<1	<5	13	<10
1179-1	1.8	9.0	15	6	21	<.5	<1	<5	<3	<10
1179-2	1.9	7.0	18	17	31	<.5	<1	<5	3	<10
1179-3	8.3	18	15	<1	17	<.5	<1	<5	3	<10
1179-4	27	23	15	4	80	<.5	1	<5	13	<10
1179-4A	1.2	7.0	9.1	11	8	<.5	<1	<5	<3	<10
1179-4B	10	22	10	5	12	<.5	<1	<5	<3	<10
1179-5	35	27	10	1	29	<.5	<1	<5	<3	<10
1179-6	19	28	13	1	37	<.5	<1	<5	43	<10
1179-7	27	21	16	<1	56	<.5	1	<5	<3	<10
1179A-1	11	11	19	3	140	<.5	2	<5	24	<10
1179A-2	14	20	21	2	150	<.5	2	<5	29	<10
1179A-2 DUP	14	19	21	2	160	<.5	2	<5	27	<10
1179A-3	18	14	23	2	150	<.5	1	<5	20	<10
1179D-1	23	7.3	13	7	80	<.5	2	<5	<3	<10
1179D-2	52	9.1	13	3	45	<.5	3	<5	<3	<10
1180-1	10	12	14	3	15	<.5	<1	<5	<3	<10
1180-2	20	20	25	10	110	<.5	<1	<5	13	<10
1180-2A	3.1	11	9.7	3	6	<.5	<1	<5	<3	<10
1180-3	28	14	18	2	27	<.5	<1	<5	20	<10
1181-1	28	25	18	2	130	<.5	<1	<5	12	<10
1181-2	10	20	17	1	95	<.5	1	<5	15	<10
1181-3	16	19	17	2	120	<.5	2	<5	24	<10
3548-1	18	34	20	2	87	<.5	1	<5	16	<10
3548-2	22	35	19	3	48	<.5	2	<5	9	<10
3548-3	19	18	16	16	73	<.5	<1	<5	<3	<10
C-1A	8.2	22	13	10	7	<.5	<1	<5	<3	<10
C-1B	25	11	9.3	1	13	<.5	<1	<5	<3	<10

Local well Identifier	Iron (µg/L) (01046)	Lead (µg/L) (01049)	Manganese (µg/L) (01056)	Molybdenum (µg/L) (01060)	Nickel (µg/L) (01065)	Silver (µg/L) (01075)	Strontium (µg/L) (01080)	Vanadium (µg/L) (01085)	Zinc (µg/L) (01090)	Lithium (µg/L) (01130)
1178-1	8,600	20	640	<10	<10	<1.0	28	<6	<3	<4
1179-1	320	<10	120	<10	<10	<1.0	65	<6	8	<4
1179-2	2,100	<10	160	<10	<10	<1.0	59	<6	11	<4
1179-3	3,200	<10	500	<10	<10	<1.0	37	<6	32	<4
1179-4	10,000	<10	1,000	<10	<10	<1.0	130	<6	7	6
1179-4A	20	10	51	20	<10	<1.0	140	<6	6	<4
1179-4B	8	<10	13	<10	<10	<1.0	120	<6	3	<4
1179-5	110	<10	350	<10	<10	1.0	72	<6	5	<4
1179-6	6,500	<10	1,300	<10	40	<1.0	58	<6	52	6
1179-7	12,000	<10	700	<10	<10	<1.0	68	<6	19	5
1179A-1	21,000	<10	2,100	<10	<10	<1.0	96	17	7	8
1179A-2	24,000	<10	2,100	<10	<10	<1.0	110	13	7	8
1179A-2 DUP	24,000	<10	2,100	<10	10	<1.0	120	13	<3	8
1179A-3	22,000	10	1,500	<10	<10	<1.0	210	<6	<3	13
1179D-1	1,000	<10	560	<10	<10	<1.0	84	<6	43	5
1179D-2	5,500	<10	590	<10	<10	<1.0	53	<6	<3	4
1180-1	28	<10	270	<10	<10	<1.0	74	<6	32	<4
1180-2	15,000	20	1,400	<10	<10	<1.0	320	<6	<3	30
1180-2A	4	<10	47	<10	<10	<1.0	120	<6	<3	<4
1180-3	6,500	<10	1,600	<10	<10	<1.0	77	7	4	6
1181-1	12,000	20	990	<10	<10	<1.0	120	<6	16	7
1181-2	15,000	<10	1,000	<10	<10	<1.0	90	15	<3	6
1181-3	23,000	<10	1,300	<10	<10	<1.0	180	9	8	5
3548-1	20,000	20	1,600	<10	10	<1.0	220	6	11	16
3548-2	8,700	10	1,200	<10	<10	<1.0	130	<6	<3	7
3548-3	360	<10	750	<10	10	<1.0	170	<6	<3	5
C-1A	19	<10	4	<10	<10	<1.0	85	6	3	<4
C-1B	11	<10	17	<10	<10	<1.0	120	<6	<3	<4

(6.5-8.7). These values are typical for this area, and similar pH values and concentrations of iron and manganese can be found throughout the arsenal (Sargent and others, 1986). Aquifer sediment, which may be coated with hydrous oxides of iron and manganese, can contribute these constituents to the ground water under the reducing conditions and neutral pH (Hem, 1985) that exist in the swampy areas surrounding the open burning area. Aquifer sediment in the confined glacial aquifer typically contains more dolomitic material and exists under less reduced conditions compared to the sediment in the unconfined aquifer; therefore, concentrations of iron and manganese in the water samples decrease with increasing pH.

Several trace elements were found at concentrations greater than the reporting limits but less than USEPA MCL's. Arsenic, zinc, and lead were detected in water samples at concentrations greater than 10 µg/L. Arsenic was detected in 25 of 27 water samples, with a maximum concentration of 17 µg/L in well 1179-2. Zinc was detected in 17 samples, with a maximum of 52 µg/L at well 1179-6. Lead was detected in seven samples, with a maximum concentration of 20 µg/L at wells 1178-1, 1180-2, 1181-1 and 3548-1.

The geographic distribution of the wells in the study area that contained the highest concentrations of these and other trace elements did not exhibit any discernible pattern. Water from wells immediately downgradient from the open burning area did not contain higher concentrations of trace elements than wells upgradient from the site. The slightly elevated concentrations of trace elements found in the ground-water samples may be, in part, the result of activities at the former landfill sites north and east of the open burning area.

Other trace elements whose concentrations were found to exceed the reporting limits, their maximum concentrations, and the number of wells in which they were detected are as follows: cadmium, 3 µg/L, 12 wells; silver, 1 µg/L, 1 well; nickel, 40 µg/L, 4 wells; and barium, 160 µg/L, 27 wells. Concentrations of chromium, copper, and beryllium in all ground-water samples analyzed for these constituents were less than the method reporting limit.

Concentrations of all common constituents and nutrients determined in the ground-water samples were low compared to USEPA drinking-water regulations. Maximum concentrations of chloride and sulfate were 35 mg/L, well below the USEPA SMCL's of 250 mg/L. Maximum concentrations of nitrite (as nitrogen) and nitrate plus nitrite (as nitrogen) detected in the water samples were 0.06 and 0.87 mg/L, respectively, both at well 1179-5. These concentrations are well below USEPA MCL's of 1 and 10 mg/L, respectively, for these constituents.

Organic Compounds

Ground-water samples from 25 wells were analyzed for explosive compounds, and samples from two wells were analyzed for dioxin and furan compounds, at a USATHAMA contract laboratory. Samples from six wells were analyzed at the NWQL for the following constituents: base/neutral- and acid-extractable compounds, organochlorine and organophosphorus pesticides, and PCB's. The local well identifiers of the wells from which samples were analyzed for each type of organic compound are listed below. Water from all

wells installed during this study, except wells 1180-3 and C-1B, was analyzed for explosive compounds. Duplicate samples were collected at three wells and analyzed for explosive compounds (wells 1179A-1 and 1179-7) and for dioxin and furan compounds (well 1179D-2). The results of the analyses of the original and duplicate samples were identical; none of these compounds were present at a concentration greater than the respective reporting limit.

Base/neutral- and acid-extractable compounds	Organochlorine and organophosphorus pesticides and polychlorinated biphenyls	Dioxins/ furans
1178-1	1178-1	1179D-1
1179-7	1179-7	1179D-2
1179A-1	1179A-1	
1179D-1	1179D-1	
1179D-2	1179D-2	
1181-1	1181-1	

The compounds determined in ground-water samples and their corresponding reporting limits are listed in table 4. Other than VOC's, only two organic compounds were detected in ground-water samples. Bis (2-ethylhexyl) phthalate, a plasticizer, was detected in the water sample from well 1178-1 at a concentration of 9.0 μg/L. This compound is common in the environment. Its presence at such a low concentration probably is an artifact of field or laboratory procedures rather than an indicator of ground-water contamination. Mirex was detected in the water sample from well 1179D-2 at a concentration of 0.02 μg/L. Although Mirex has never been used at the arsenal, it has been detected in many streambed-material samples at concentrations exceeding 5,000 μg/kg. The source of the Mirex is unknown.

Ground-water samples from eight wells were analyzed for VOC's, one at the NWQL and seven at the New Jersey District laboratory. The results of these analyses are presented in table 5. Duplicate samples were collected from two wells, 1179-7 and 1179A-1. The results of these analyses compare well with the results of the original analyses.

Four VOC's were detected in ground-water samples, although all were present at concentrations near the reporting limit. Two of the compounds are most likely field or laboratory artifacts. Methylene chloride, found at a maximum concentration of 0.4 μg/L, is a common laboratory contaminant and has been found previously in blank samples analyzed at the New Jersey District laboratory. Chloroform, detected at a concentration of 0.3 μg/L, is commonly found in chlorinated water and probably is a residual from procedures used in cleaning sample equipment.

Trichloroethylene was detected in water samples from three wells at a maximum concentration of 3.4 μg/L. A possible source of this contaminant in water from well 1178-1 is an inactive landfill east of the well. The other

Table 4.--Reporting limits of selected organic compounds determined in samples from six wells in the study area

Compound	Reporting limit (micrograms per liter)	Compound	Reporting limit (micrograms per liter)
Base/neutral-extractable organic compounds			
Benzo (g,h,i) perylene	10	Hexachloroethane	5
1,2-Dichlorobenzene	5	Indeno (1,2,3-c,d) pyrene	10
1,3-Dichlorobenzene	5	bis (2-Chloroethyl) ether	5
1,4-Dichlorobenzene	5	bis (2-Ethylhexyl) phthalate	5
Naphthalene	5	bis (2-Chloroethoxy) methane	5
Nitrobenzene	5	bis (2-Chloroisopropyl) ether	5
2,4-Dinitrotoluene	5	Isophorone	5
2,6-Dinitrotoluene	5	N-Nitrosodi-n-propylamine	5
4-Bromophenyl phenyl ether	5	N-Nitrosodiphenylamine	5
4-Chlorophenyl phenyl ether	5	1,2,4-Trichlorobenzene	5
Phenanthrene	5	Di-n-octyl-phthalate	10
Pyrene	5	Di-n-butyl phthalate	5
Anthracene	5	Hexachlorobutadiene	5
Benzo (a) anthracene	5	Benzo-k-fluoranthene	10
Benzo (b) fluoranthene	10	Benzo-a-pyrene	10
Acenphthylene	5	N-Butylbenzyl phthalate	5
Acenaphthene	5	Chrysene	10
Dimethyl phthalate	5	Diethyl phthalate	5
Fluoranthene	5	N-Nitrosodimethylamine	5
Fluorene	5	Dibenzo (a,h) anthracene	10
Hexachlorocyclopentadiene	5	2-Chloronaphthalene	5
Acid-extractable organic compounds			
Phenol	5	2,4-Dichlorophenol	5
2-Nitrophenol	5	2,4,6-Trichlorophenol	20
4-Nitrophenol	30	3-Methyl-4-chlorophenol	30
2,4-Dinitrophenol	20	2-Methyl-4,6 dinitrophenol	30
Pentachlorophenol	30	2,4-Dimethylphenol	5
2-Chlorophenol	5		
Organochlorine/organophosphorus pesticides and polychlorinated biphenyls			
Aldrin	.01	Heptachlor epoxide	.01
Chlordane	.1	Hexachlorobenzene	5
DEF	.01	Lindane	.01
Diazinon	.01	Malathion	.01
Dieldrin	.01	Methoxychlor	.01
Disulfoton	.01	Methyl parathion	.01
2,2-bis (Para-chlorophenyl)-1,1-dichloroethane (DDD)	.01	Methyl trithion	.01
2,2-bis (Para-chlorophenyl)-1,1-dichloroethene (DDE)	.01	Mirex	.01
2,2-bis (Para-chlorophenyl)-1,1,1-trichloroethane (DDT)	.01	Parathion	.01
Endosulfan	.01	Perthane	.1
Endrin	.01	Phorate	.01
Ethion	.01	Polychlorinated biphenyls (PCB's)	.1
Heptachlor	.01	Polychlorinated naphthalenes (PCN's)	.1
		Toxaphene	1
		Trithion	.01
Explosive compounds			
2,4-Dinitrotoluene	2	Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	2
2,6-Dinitrotoluene	2	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	2
1,3-Dinitrobenzene	2	N-methyl-N,2,4,6-tetranitroaniline (Tetryl)	2
Nitrobenzene	2		
sym-Trinitrobenzene	2		
Trinitrotoluene (TNT)	2		
Dioxin and furan compounds			
2,3,7,8-Tetrachlorodibenzo-para-dioxin	.064	Tetrachlorodibenzo-furans	.049
Tetrachlorodibenzo-para-dioxin	.064	Pentachlorodibenzo-furans	.26
Pentachlorodibenzo-para-dioxin	1.2	Hexachlorodibenzo-furans	4.6
Hexachlorodibenzo-para-dioxin	4.3		

Table 5.--Results of analyses of ground-water samples from wells in or near the open burning area for selected volatile organic compounds

[All constituents are total; concentrations in micrograms per liter; DUP, duplicate sample; <, less than; --, constituent not determined; number in parentheses is constituent-analysis code used by the U.S. Geological Survey National Water-Quality Laboratory, Denver, Colorado]

Local well identifier	Vinyl chloride (39175)	Chloro-ethane (34311)	Bromo-methane (30202)	Tri-chloro-fluoro-methane (34488)	1,1-Dichloro-ethylene (34501)	Methylene chloride (34423)	Trans 1,2-dichloro ethylene (34546)	1,1-Dichloro-ethane (34496)	Cis-1,2-dichloro-ethylene (77093)	Chloro-form (32106)
1178-1	<0.2	<0.2	<0.2	<0.2	<0.2	0.4	<0.2	<0.2	<0.2	.3
[1]1179-7	<.2	<.2	<.2	<.2	<.2	<.2	[2]<.2	<.2	--	<.2
1179-7 DUP	<.2	<.2	<.2	<.2	<.2	.3	<.2	<.2	<.2	<.2
1179A-1	<.2	<.2	<.2	<.2	<.2	.4	<.2	<.2	<.2	<.2
1179A-1 DUP	<.2	<.2	<.2	<.2	<.2	.3	<.2	<.2	<.2	<.2
1179D-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179D-2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1180-3	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	.6	<.2
1181-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
C-1B	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Local well identifier	1,1,1-Tri-chloro ethane (34506)	Carbon tetra-chlor-ide (32102)	1,2-Di-chloro-ethane (32103)	Benzene (34030)	Tri-chloro-ethylene (39180)	1,2-Di-chloro-propane (34541)	Di-chloro-bromo-methane (32101)	2-Chloro-ethyl vinyl ether (34576)	Trans-1,3-dichloro-propene (34699)	Toluene (34010)
1178-1	<0.2	<0.2	<0.2	<0.2	0.6	<0.2	<0.2	<0.2	<0.2	<0.2
1179-7	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179-7 DUP	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179A-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179A-1 DUP	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179D-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179D-2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1180-3	<.2	<.2	<.2	<.2	3.4	<.2	<.2	<.2	<.2	<.2
1181-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
C-1B	<.2	<.2	<.2	<.2	.3	<.2	<.2	<.2	<.2	<.2

Local well identifier	Cis-1,3-dichloro propene (34704)	1,1,2-Tri-chloro-ethane (34511)	Tetra-chloro-ethylene (34475)	Di-bromo-chloro-methane (32105)	Chloro-benzene (34301)	Ethyl-benzene (34371)	Bromo-form (32104)	1,1,2,2-Tetra-chloro-ethane (34516)	1,2-Dichloro-benzene (34536)	1,3-Dichloro-benzene (34566)	1,4-Dichloro-benzene (34571)
1178-1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1179-7	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179-7 DUP	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179A-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179A-1 DUP	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179D-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1179D-2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1180-3	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1181-1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
C-1B	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

[1] The sample from this well was analyzed at National Water-Quality Laboratory, in Denver, Colorado. Samples from all other wells listed in this table were analyzed at the New Jersey District laboratory in Trenton, N.J.

[2] The U.S. Geological Survey National Water-Quality Laboratory in Denver, Colorado, reports the sum of the concentrations of trans- and cis-1,2-dichloroethylene as trans-1,2-dichloroethylene

wells that contained water in which trichloroethylene was detected (wells 1180-3 and C-1B) are upgradient (east) of the open burning area. The source of the contamination is unknown. No VOC's were detected in concentrations above the USEPA MCL's.

Surface Water and Soils

Results of an investigation conducted by a USARDEC contractor indicated that soils within the open burning area are heavily contaminated with metals and base/neutral- and acid-extractable compounds (Frew and others, 1989). Soil samples were collected from 10 sites--8 near the burning pans adjacent to Green Pond Brook and 2 about 100 ft east of the burning pans. Soil samples were analyzed for explosive compounds, metals, VOC's, and base/neutral- and acid-extractable compounds. Results indicated that lead, mercury, zinc, cadmium, and chromium were present in nearly all samples at concentrations greater than those typically found in soil samples at Picatinny Arsenal. Explosive compounds, including RDX, HMX, TNT, nitroglycerine, trinitrobenzene compounds, and dinitrotoluene compounds, were detected in many samples, most commonly near the burning pans. More than 20 base/neutral- and acid-extractable compounds were identified and many other compounds were tentatively identified.

In order to more completely define the extent of contamination within the open burning area, 10 additional soil samples were collected and analyzed for dioxin and furan compounds. Composite samples, each consisting of four subsamples taken from locations near each burning pan, were collected at eight sites. Soil samples were collected from two sites near scrap metal piles east of the burning pans. The locations of dioxin and furan compounds soil-sampling sites are shown in figure 17.

Tetrachlorodibenzo-para-dioxin was detected in soil samples 9 and 10, with a maximum concentration of 0.91 ng/g. Octachlorodibenzo-para-dioxin was detected in all 10 samples, with a maximum concentration of 744 ng/g. Octachlorodibenzofuran was detected in 5 of 10 samples, with a maximum concentration of 1.87 ng/g. Results of analyses for dioxin and furan compounds are shown in table 6.

In order to determine whether contaminants from soil within the open burning area have migrated to Green Pond Brook, streambed-material and surface-water samples were collected by the USGS at three sites. Six samples were collected at each site from January 9, 1990, through June 6, 1990. Samples were analyzed at a USATHAMA contract laboratory for trace elements, explosive compounds, base/neutral- and acid-extractable compounds, pesticides, and VOC's. The locations of the streambed-material and surface-water sampling sites are shown in figure 18. Site GPB #1 is located about 30 ft upstream from the open burning area; surface-water and streambed-material quality there were considered to be representative of background conditions. Site GPB #2 is adjacent to the open burning area and site GPB #3 is approximately 300 ft upstream from the point at which Green Pond Brook flows off the arsenal property.

The lithology of the streambed affects the presence and distribution of contaminants. Fine-grained sediments that contain a high concentration of naturally occurring organic material and are found in reaches of the channel

Table 6.--Results of analyses of soil samples from the open burning area for selected dioxin and furan compounds

[Constituents are total; concentrations in nanograms per gram; --, constituent not detected; all samples listed in this table were analyzed at a U.S. Army Armaments Research Development and Engineering Center contract laboratory]

Site number	Tetra-chloro-dibenzo-para-dioxin	Penta-chloro-dibenzo-para-dioxin	Hexa-chloro-dibenzo-para-dioxin	Hepta-chloro-dibenzo-para-dioxin	Octa-chloro-dibenzo-para-dioxin
1	--	0.92	--	2.13	11.4
2	--	.46	7.64	152	744
3	--	--	--	1.99	12.0
4	--	--	1.27	.59	3.56
5	--	--	--	--	1.00
6	--	--	--	1.61	5.71
7	--	--	--	1.34	3.92
8	--	--	--	.99	5.18
9	.91	--	.42	3.18	18.0
10	.61	--	--	7.49	33.9

Site number	Tetra-chloro-dibenzo-furan	Penta-chloro-dibenzo-furan	Hexa-chloro-dibenzo-furan	Hepta-chloro-dibenzo-furan	Octa-chloro-dibenzo-furan
1	--	--	--	--	--
2	--	--	--	.50	1.87
3	--	--	--	--	--
4	--	--	--	--	--
5	--	--	--	--	--
6	--	--	--	--	.47
7	--	--	--	--	--
8	--	--	--	--	.73
9	--	--	--	.37	.84
10	--	--	--	.29	1.07

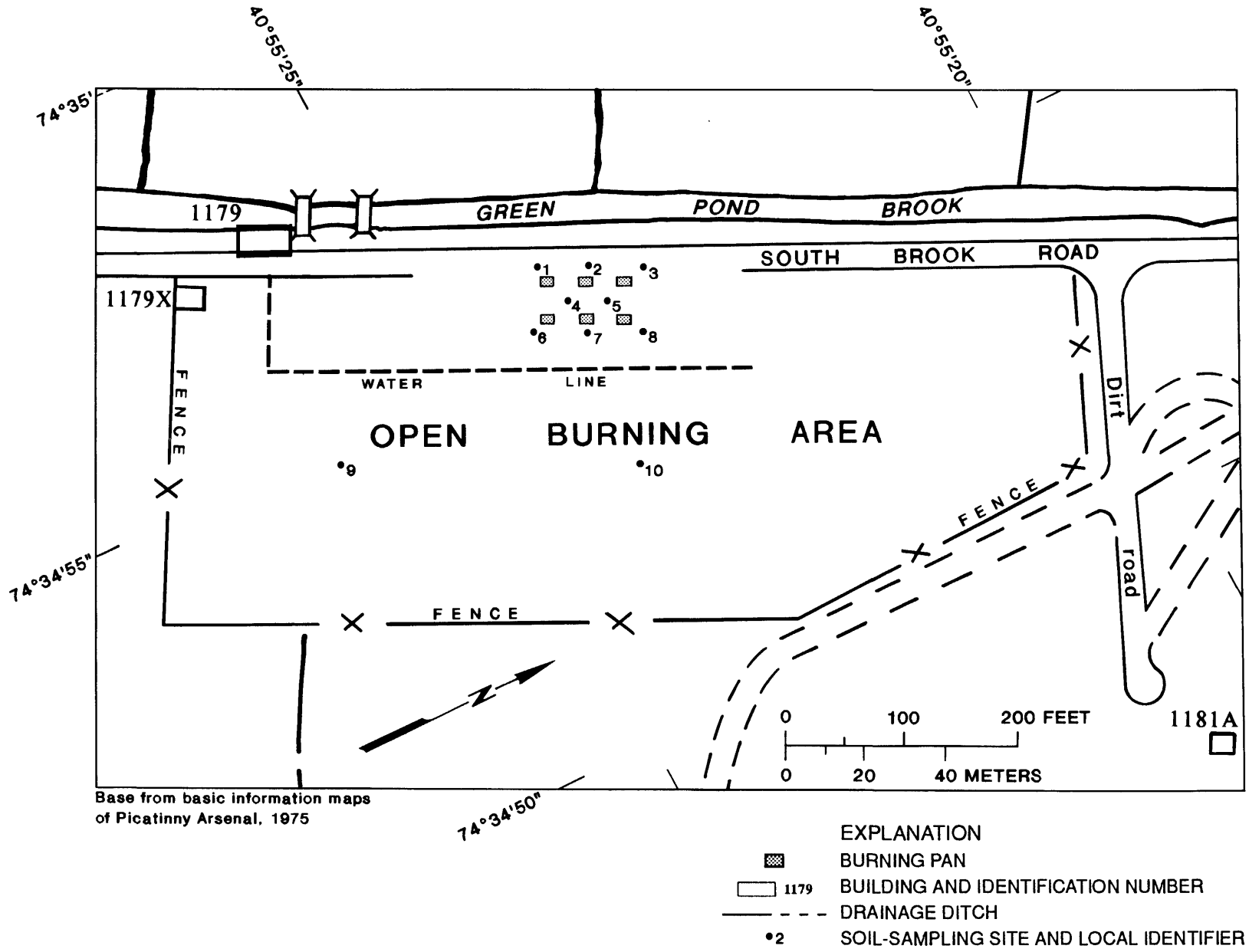

Figure 17.--Locations of soil-sampling sites in the open burning area.

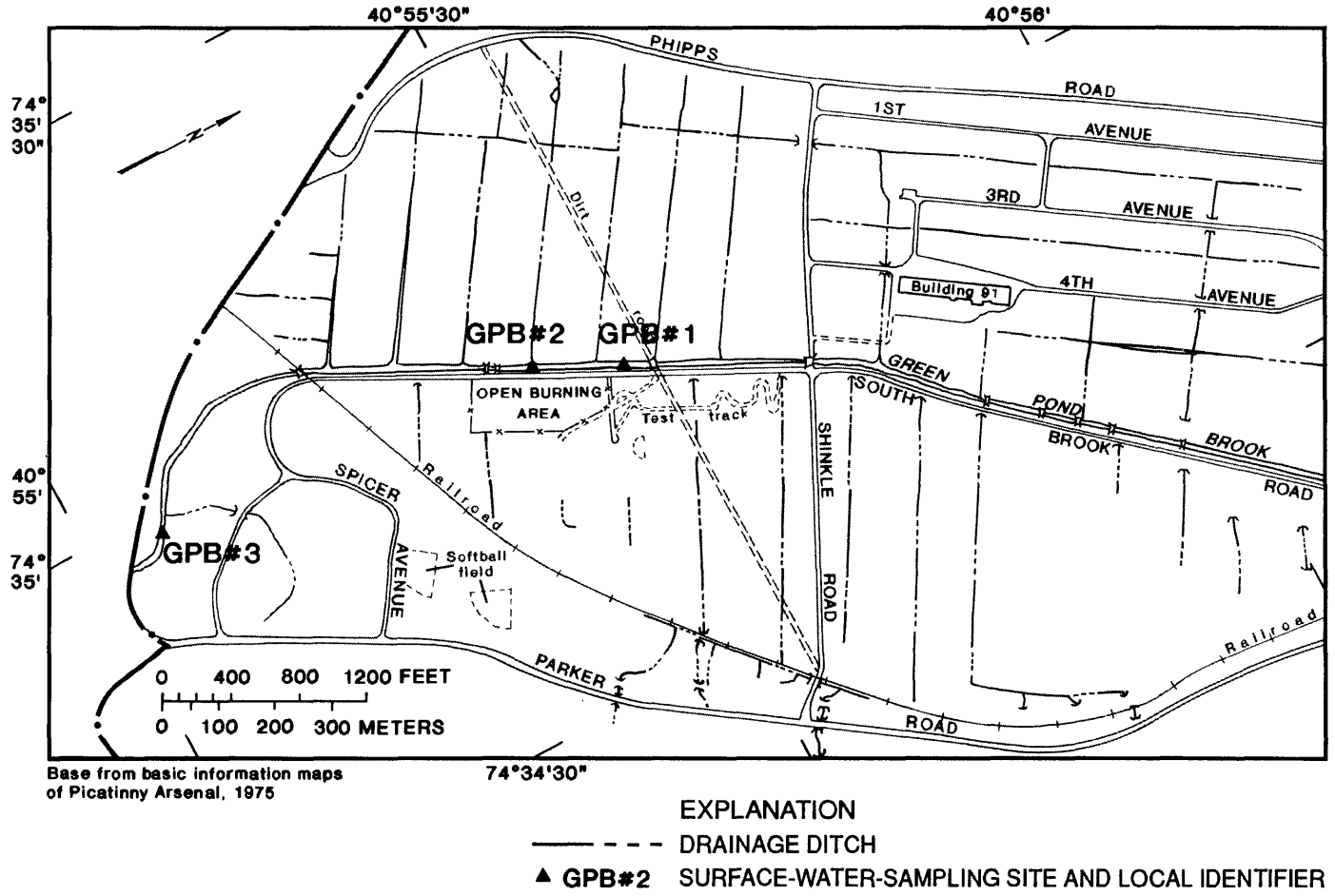

Figure 18.--Locations of streambed-material and surface-water sampling sites on Green Pond Brook.

where streamflow velocities are slow have a high capacity to store contaminants. The streambed material at sites GPB #1 and GPB #2 consists of laminated fine-grained sand, silt, and clay, whereas the streambed material at site GPB #3 is composed of boulders and cobbles of the terminal moraine, and, therefore, would be expected to contain lower concentrations of chemicals produced by human activities than streambed material at sites GPB #1 and GPB #2.

Results of analyses of streambed-material samples are shown in table 7. The table includes all constituents whose concentrations were found to be greater than the reporting limit in one or more samples.

Concentrations of trace elements determined in streambed-material samples from sites GPB #1 and GPB #2 were greater than those typically found at the arsenal. In general, trace elements were detected more frequently and at higher concentrations at site GPB #2 than at site GPB #1. Arsenic, lead, and zinc were detected in all samples, including those from site GPB #3. The maximum concentrations of lead and zinc (1,520 μg/g and 10,300 μg/g, respectively) were found in samples from site GPB #2. The maximum concentration of arsenic was 8.14 μg/g, in a sample from site GPB #1. In addition, barium and copper were detected in all samples from site GPB #2, but the maximum concentrations (3,860 μg/g and 21,200 μg/L, respectively) were found at site GPB #1. Maximum concentrations of chromium, nickel, and silver were 229 μg/g, 61.7 μg/g, and 8.25 μg/g, respectively, at site GPB #1.

These data indicate that contaminants from the open burning area are contributing to the elevated concentrations of lead and zinc found in the streambed material; however, arsenic, barium, nickel, and chromium are probably derived from both the open burning area and upstream sources.

Explosive compounds, like trace elements, were detected more frequently and at higher concentrations at site GPB #2 than at site GPB #1. None of the seven explosive compounds found in streambed-material samples were detected at site GPB #3. The maximum concentrations of six of these compounds were found at site GPB #2. Trinitrotoluene was detected in four samples from site GPB #2 at a maximum concentration of 3.52 μg/g. Nitrocellulose was detected in two samples from site GPB #2 at a maximum concentration of 153 μg/g. Nitrobenzene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, and nitroglycerine were detected only in samples from site GPB #2, indicating that the open burning area probably is a source of these constituents. The maximum concentrations of these compounds were 0.353 μg/g, 25.2 μg/g, 1.43 μg/g, and 5.33 μg/g, respectively. RDX was detected in one sample from site GPB #1 at a concentration of 3.46 μg/g, indicating that the source of this contaminant is upstream from the open burning area.

Nine base/neutral- and acid-extractable compounds were detected in streambed-material samples. Most of the compounds detected were polynuclear aromatic hydrocarbons and phthalate compounds. In general, constituents

Table 7.--Results of analyses of streambed-material samples from Green Pond Brook for selected trace elements, explosive compounds, base/neutral- and acid-extractable compounds, and other compounds

[Concentrations in micrograms per gram; RDX, Hexahydro-1,3,5-trinitro-1,3,5-triazine; <, less than; >, greater than; --, constituent not determined; all samples listed in this table were analyzed at a U.S. Army Toxic and Hazardous Materials Agency contract laboratory]

Site number	Date	Sulfate	Barium	Cadmium	Copper	Nickel	Zinc	Silver	Chromium	Lead	Arsenic
GPB #1	01-09-90	<90.4	3,860	<3.05	21,200	61.7	9,320	4.44	104	1,140	8.14
	02-12-90	<90.4	139	<3.05	223	<12.6	296	8.25	113	48.6	4.80
	03-06-90	<90.4	<29.6	<3.05	<58.6	<12.6	258	<2.50	149	94.7	4.13
	04-10-90	<90.4	<29.6	10.9	<58.6	<12.6	154	<2.50	129	53.0	3.70
	05-08-90	<90.4	80.0	12.0	<58.6	<12.6	161	5.63	229	41.7	2.83
	06-12-90	<90.4	126	<3.05	<58.6	<12.6	258	8.56	92.8	139	4.38
GPB #2	01-09-90	<90.4	791	<3.05	10,500	<12.6	4,200	<2.50	49.5	1,520	3.28
	02-12-90	<90.4	668	<3.05	4,520	45.2	1,450	<2.50	39.5	1,080	2.14
	03-06-90	270	>200	<3.05	2,540	47.2	2,120	<2.50	52.6	332	5.12
	04-10-90	<90.4	524	<3.05	4,370	<12.6	1,890	<2.50	34.1	926	3.21
	05-08-90	<90.4	843	<3.05	18,300	<12.6	10,300	<2.50	47.3	229	2.27
	06-12-90	<90.4	1,030	<3.05	6,460	29.0	2,180	<2.50	57.1	172	1.94
GPB #3	01-09-90	<90.4	<29.6	<3.05	<58.6	<12.6	65.8	<2.50	<12.7	9.93	1.43
	02-12-90	--	--	--	--	--	--	--	--	--	--
	03-06-90	<90.4	<29.6	<3.05	<58.6	<12.6	86.6	<2.50	<12.7	10.5	2.67
	04-10-90	<90.4	<29.6	<3.05	<58.6	<12.6	88.8	<2.50	<12.7	22.9	4.15
	05-08-90	<90.4	<29.6	<3.05	258	<12.6	189	<2.50	<12.7	6.90	1.45
	06-12-90	<90.4	<29.6	<3.05	108	<12.6	86.0	<2.50	<12.7	7.61	2.08

Site number	Date	Nitro-glycer-ine	RDX	2,4,6-Trinitro-toluene	Nitro-cellu-lose	2,4-Dinitro-toluene	2,6-Dinitro-toluene	Nitro-benzene
GPB #1	01-09-90	<4.00	3.46	1.84	58.2	<0.700	<0.425	<0.225
	02-12-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	03-06-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	04-10-90	<4.00	<.587	<.456	54.9	<.140	<.085	<.045
	05-08-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	06-12-90	<4.00	<.587	<.456	--	<.140	<.085	<.045
GPB #2	01-09-90	<4.00	<.587	.826	30.5	<.140	<.085	<.045
	02-12-90	<4.00	<.587	1.07	153	.304	<.085	.353
	03-06-90	5.33	<.587	3.52	<10.4	25.2	1.43	<.045
	04-10-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	05-08-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	06-12-90	<4.00	<.587	.509	--	<.140	<.085	<.045
GPB #3	01-09-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	02-12-90	--	--	--	--	--	--	--
	03-06-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	04-10-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	05-08-90	<4.00	<.587	<.456	<10.4	<.140	<.085	<.045
	06-12-90	<4.00	<.587	<.456	--	<.140	<.085	<.045

Table 7.--Results of analyses of streambed-material samples from Green Pond Brook for selected trace elements, explosive compounds, base/neutral- and acid-extractable compounds, and other compounds--Continued

Site number	Date	Anthracene	Benzo-[K]fluor-anthene	Bis-(2-ethyl-hexyl) phthalate	Chrysene	Di-N-butyl phthalate	Fluor-anthene	N-Nitroso-diphenyl-amine	Phenan-threne
GPB #1	01-09-90	<0.165	<0.330	<3.10	<0.600	1.53	<0.340	<0.950	0.737
	02-12-90	.117	.317	<.620	.499	<.061	.442	<.190	.263
	03-06-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	04-10-90	<.033	<.066	<.620	<.120	<.061	.301	<.190	.122
	05-08-90	<.033	<.066	<.620	<.120	<.061	.173	<.190	.085
	06-12-90	<.033	<.066	<.620	<.120	<.061	.359	<.190	.147
GPB #2	01-09-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	02-12-90	<.033	<.066	<.620	<.120	1.28	<.068	<.190	.051
	03-06-90	<.033	<.066	<.620	<.120	25.2	<.068	3.52	<.033
	04-10-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	05-08-90	<.033	<.066	<.620	<.120	1.17	<.068	<.190	<.033
	06-12-90	<.033	<.066	1.45	<.120	.680	<.068	<.190	<.033
GPB #3	01-09-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	02-12-90	--	--	--	--	--	--	--	--
	03-06-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	04-10-90	<.033	<.066	27.2	<.120	<.061	<.068	<.190	<.033
	05-08-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033
	06-12-90	<.033	<.066	<.620	<.120	<.061	<.068	<.190	<.033

Site number	Date	Pyrene	Trichloro-naphthalenes	Tetrachloro-naphthalenes	Acetone	Toluene	Xylenes
GPB #1	01-09-90	<0.165	5.71	1.43	<0.017	<0.001	<0.002
	02-12-90	.512	--	--	.16	<.001	.763
	03-06-90	<.033	--	--	<.017	<.001	<.002
	04-10-90	.363	--	--	<.017	.212	<.002
	05-08-90	.216	--	--	<.017	<.001	<.002
	06-12-90	.423	--	--	<.017	<.001	1.67
GPB #2	01-09-90	<.033	--	--	<.017	<.001	<.002
	02-12-90	<.033	--	--	<.017	<.001	<.002
	03-06-90	<.033	--	--	<.017	<.001	<.002
	04-10-90	<.033	--	--	<.017	<.001	<.002
	05-08-90	<.033	--	--	<.017	<.001	<.002
	06-12-90	<.033	--	--	<.017	<.001	<.002
GPB #3	01-09-90	<.033	--	--	<.017	<.001	<.002
	02-12-90	--	--	--	--	--	--
	03-06-90	<.033	--	--	<.017	<.001	<.002
	04-10-90	<.033	--	--	<.017	<.001	<.002
	05-08-90	<.033	--	--	<.017	<.001	<.002
	06-12-90	<.033	--	--	<.017	<.001	<.002

were detected most frequently in samples from site GPB #1, indicating a source of contamination upstream from the open burning area. Anthracene, benzo (k) fluoranthene, chrysene, fluoranthrene, and pyrene were detected only in samples from site GPB #1; however, di-n-butylphthalate and n-nitrosodiphenylamine were detected at site GPB #2 at maximum concentrations of 25.2 μg/g and 3.52 μg/g, respectively, indicating that these compounds probably are derived from the open burning area.

Results of analyses of surface-water samples (table 8) indicate that no inorganic or organic constituent concentrations exceeded USEPA drinking-water regulations; however, trace elements, explosive compounds, and VOC's were detected at concentrations near the method reporting limits. (Table 8 also includes only those constituents whose concentrations were found to be greater than the reporting limit in one or more samples.)

Barium was the only trace element determined that was detected in all surface-water samples. Its maximum concentration was 31.3 μg/L at site GPB #1. Copper, lead, and zinc were detected in samples from all sites. Maximum concentrations of copper and zinc were 18.3 μg/L and 61.7 μg/L, respectively, also at site GPB #1. Cadmium and chromium were detected only in samples from site GPB #1. Arsenic was detected in one sample from site GPB #2, at a concentration of 2.7 μg/L.

Two explosive compounds, HMX and nitrocellulose, were detected in surface-water samples. HMX was detected in one sample from site GPB #1, at a concentration of 1.9 μg/L. Nitrocellulose was found in nine samples, most frequently at site GPB #1, although the maximum concentration (2,400 μg/L) was measured in a sample from site GPB #3.

Fourteen VOC's were detected in surface-water samples at concentrations near the method reporting limit. Of these 14 constituents, 11 were detected only in samples from site GPB #1, and 10 of these were found only in 1 sample. Trichloroethylene and 1,2-dichloroethylene were found at all three sites; trichloroethylene was found in all samples. Maximum concentrations of trichloroethylene and 1,2-dichloroethylene were 1.71 μg/L and 3.01 μg/L, respectively, both in samples from site GPB #2.

These data indicate that the open burning area has little effect on the quality of surface water in Green Pond Brook and that the trace elements, explosive compounds, and organic compounds detected in these samples probably originate from sources upstream from site GPB #1.

SUMMARY AND CONCLUSIONS

This study was designed to determine whether the shallow ground water and surface water at Picatinny Arsenal, New Jersey, have been contaminated as a result of operations at the open burning area. Results of preliminary analyses of soil and ground-water samples collected by the U.S. Army and its contractors show the presence of significant contamination at the site. Therefore, 27 wells were installed in and around the open burning area to facilitate collection of additional samples. Water samples collected from these wells were analyzed for inorganic constituents, trace elements, nutrients, and explosive compounds. Samples from six wells were analyzed for base/neutral- and acid-extractable compounds, organochlorine and

organophosphorus pesticides, and polychlorinated biphenyls. In addition, samples from two wells were analyzed for dioxin and furan compounds, and samples from eight wells were analyzed for volatile organic compounds. Surface-water and streambed-material samples were collected from Green Pond Brook at sites upstream from, adjacent to, and downstream from, the open burning area to determine whether contaminants have migrated to the brook.

On the basis of hydraulic heads measured in spring and fall 1990, and estimates of hydraulic conductivities and porosity, the average velocity of ground water near the open burning area was estimated to be from 0.03 to 1.8 feet per day.

Water-level-contour maps showing the altitude and configuration of the water table in spring and fall 1989 and 1990 indicate that the direction of shallow ground-water flow was toward Green Pond Brook during these periods. Head differences measured on April 25, 1990, by use of mini-piezometers also indicate that shallow ground water in the open burning area discharges to Green Pond Brook. The results of stream-discharge measurements at seven sites in Green Pond Brook were inconclusive.

Concentrations of iron and manganese in ground water were found to be consistently greater than U.S. Environmental Protection Agency secondary maximum contaminant levels. Samples collected in 1989 and 1990 contained iron and manganese at maximum concentrations of 24,000 and 2,100 micrograms per liter, respectively. Concentrations of these constituents in water samples from wells screened in the confined glacial aquifer were much lower. Iron concentrations ranged from 4 to 19 micrograms per liter, and manganese concentrations ranged from 4 to 47 micrograms per liter.

Several organic compounds, including trichloroethylene, mirex, and bis (2-ethylhexyl) phthalate, were detected in ground-water samples at low concentrations. These contaminants do not appear to be the result of operations at the open burning area but could be related to the presence of inactive landfills in the vicinity or with other sites north of the open burning area.

Results of an investigation conducted by a U.S. Army Armaments Research Development and Engineering Center contractor indicated that soils within the open burning area are contaminated with trace elements, explosive compounds, base/neutral- and acid-extractable compounds, and dioxin and furan compounds. Results of analyses of samples collected by the U.S. Geological Survey indicate that contaminants from the open burning area probably are contributing the elevated concentrations of lead, zinc, nitrobenzene, 2,4- and 2,6-dinitrotoluene, and nitroglycerine found in the streambed material. Arsenic, barium, copper, chromium, and polynuclear aromatic hydrocarbons probably are derived from both the open burning area and upstream sources.

Fourteen volatile organic compounds were detected in surface-water samples at concentrations near the method detection limit, although most were detected in samples collected upstream from the open burning area. Results of analyses indicate that no organic or inorganic constituent concentrations exceeded U.S. Environmental Protection Agency drinking-water regulations.

Table 8.--Results of analyses of surface-water samples from Green Pond Brook for selected trace elements, explosive compounds, volatile organic compounds, and other compounds

[Concentrations in micrograms per liter; <, less than; --, constituent not determined; HMX, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine; all samples listed in this table were analyzed at a U.S. Army Toxic and Hazardous Materials Agency contract laboratory]

Site number	Date	Arsenic	Barium	Cadmium	Chromium	Copper	Lead	Zinc
GPB #1	01-09-90	<2.54	31.3	4.80	6.56	18.3	<1.26	61.7
	02-12-90	<2.54	17.0	<4.01	<6.02	<8.09	<1.26	<21.1
	03-06-90	<2.54	18.7	<6.02	<42.7	<375	1.84	<2.62
	04-10-90	<2.54	19.5	<4.01	<6.02	<8.09	2.82	<21.1
	05-08-90	<2.54	19.5	<4.01	<6.02	<8.09	2.82	<21.1
	06-12-90	<2.54	22.0	<4.01	<6.02	9.90	5.10	<21.1
GPB #2	01-09-90	2.77	26.2	<4.01	<6.02	10.3	2.17	35.1
	02-12-90	<2.54	17.5	<4.01	<6.02	<8.09	<1.26	<21.1
	03-06-90	<2.54	16.2	<6.02	<42.7	<375	<1.26	<2.62
	04-10-90	<2.54	21.1	<4.01	<6.02	<8.09	<2.50	<21.1
	05-08-90	<2.54	19.4	<4.01	<6.02	<8.09	<1.26	<21.1
	06-12-90	<2.54	29.0	<4.01	<6.02	<8.09	3.58	<21.1
GPB #3	01-09-90	<2.54	29.3	<4.01	<6.02	12.3	<1.26	45.3
	02-12-90	<2.54	18.8	<4.01	<6.02	<8.09	1.63	<21.1
	03-06-90	<2.54	18.1	<6.02	<42.7	<375	<1.26	<2.62
	04-10-90	<2.54	21.4	<4.01	<6.02	<8.09	1.41	<21.1
	05-08-90	<2.54	18.7	<4.01	<6.02	<8.09	<1.26	<21.1
	06-12-90	<2.54	27.2	<4.01	<6.02	<8.09	10.5	<21.1

Site number	Date	Sulfate	Nitrate + nitrite	HMX	Nitro-cellulose	Bis (2-ethylhexyl) phthalate	Carbon disulfide	1,1,2-Trichloro-1,2,2-trifluoroethene
GPB #1	01-09-90	16,000	178	1.90	691	<4.80	<0.50	--
	02-12-90	12,100	184	<1.65	717	<4.80	<.50	--
	03-06-90	14,800	183	<1.65	921	<4.80	<.50	--
	04-10-90	13,400	181	<1.65	1,230	<4.80	<.50	--
	05-08-90	12,900	245	<1.65	1,260	<4.80	1.36	--
	06-12-90	10,000	405	<1.65	<553	<4.80	<.50	--
GPB #2	01-09-90	16,200	200	<1.65	941	<4.80	<.50	--
	02-12-90	12,300	197	<1.65	1,420	<4.80	<.50	--
	03-06-90	13,800	188	<1.65	<553	14.5	<.50	--
	04-10-90	13,800	220	<1.65	<553	<4.8	<.50	--
	05-08-90	12,500	265	<1.65	<553	<4.8	<.50	--
	06-12-90	11,500	455	<1.65	<553	<4.8	<.50	--
GPB #3	01-09-90	17,300	186	<1.65	<553	<4.8	<.50	20.0
	02-12-90	12,400	200	<1.65	<553	<4.8	<.50	--
	03-06-90	15,100	175	<1.65	1,560	<4.8	<.50	--
	04-10-90	13,900	220	<1.65	<553	<4.8	<.50	--
	05-08-90	12,800	295	<1.65	2,400	<4.8	<.50	--
	06-12-90	12,500	450	<1.65	<553	<4.8	<.50	--

Table 8.--Results of analyses of surface-water samples from Green Pond Brook for selected trace elements, explosive compounds, volatile organic compounds, and other compounds--Continued

Site number	Date	1,1,1-Trichloroethene	1,1-Dichloroethylene	1,1-Dichloroethane	1,2-Dichloroethylene[1]	Benzene	Trichlorofluoromethane	Carbon tetrachloride
GPB #1	01-09-90	<0.50	<0.50	<0.68	2.04	<0.50	<1.40	<0.58
	02-12-90	<.50	<.50	<.68	.71	<.50	<1.40	<.58
	03-06-90	<.50	<.50	<.68	1.26	<.50	<1.40	<.58
	04-10-90	<.50	<.50	<.68	.93	<.50	<1.40	<.58
	05-08-90	1.58	1.51	.78	1.65	.85	4.51	2.10
	06-12-90	<.50	<.50	<.68	<.50	<.50	<1.40	<.58
GPB #2	01-09-90	<.50	<.50	<.68	3.01	<.50	<1.40	<.58
	02-12-90	<.50	<.50	<.68	.86	<.50	<1.40	<.58
	03-06-90	<.50	<.50	<.68	1.26	<.50	<1.40	<.58
	04-10-90	<.50	<.50	<.68	1.26	<.50	<1.40	<.58
	05-08-90	<.50	<.50	<.68	.97	<.50	<1.40	<.58
	06-12-90	<.50	<.50	<.68	<.50	<.50	<1.40	<.58
GPB #3	01-09-90	<.50	<.50	<.68	1.16	<.50	<1.40	<.58
	02-12-90	<.50	<.50	<.68	.72	<.50	<1.40	<.58
	03-06-90	<.50	<.50	<.68	1.07	<.50	<1.40	<.58
	04-10-90	<.50	<.50	<.68	.55	<.50	<1.40	<.58
	05-08-90	<.50	<.50	<.68	.76	<.50	<1.40	<.58
	06-12-90	<.50	<.50	<.68	<.50	<.50	<1.40	<.58

Site number	Date	Chloroform	Chlorobenzene	Ethylbenzene	Toluene	1,1,2,2-Tetrachloroethane	Trichloroethylene	Xylene
GPB #1	01-09-90	<0.50	<0.50	2.95	<0.50	<0.51	0.86	28.3
	02-12-90	<.50	<.50	<.50	<.50	<.51	1.05	<.84
	03-06-90	<.50	<.50	<.50	<.50	<.51	1.62	<.84
	04-10-90	<.50	<.50	<.50	<.50	<.51	1.14	<.84
	05-08-90	.96	.80	.84	.97	.56	1.62	<.84
	06-12-90	<.50	<.50	<.50	<.50	<.51	1.43	<.84
GPB #2	01-09-90	<.50	<.50	<.50	.61	<.51	1.71	<.84
	02-12-90	<.50	<.50	<.50	<.50	<.51	1.05	<.84
	03-06-90	<.50	<.50	<.50	<.50	<.51	1.62	<.84
	04-10-90	<.50	<.50	<.50	<.50	<.51	1.52	<.84
	05-08-90	<.50	<.50	<.50	<.50	<.51	.49	<.84
	06-12-90	<.50	<.50	<.50	<.50	<.51	1.71	<.84
GPB #3	01-09-90	<.50	<.50	<.50	<.50	<.51	1.33	<.84
	02-12-90	<.50	<.50	<.50	<.50	<.51	1.14	<.84
	03-06-90	<.50	<.50	<.50	<.50	<.51	1.43	<.84
	04-10-90	<.50	<.50	<.50	<.50	<.51	1.24	<.84
	05-08-90	<.50	<.50	<.50	<.50	<.51	.54	<.84
	06-12-90	<.50	<.50	<.50	<.50	<.51	1.33	<.84

[1] Includes both cis- and trans-1,2-dichloroethylene.

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APPENDIX--Lithologic logs for selected wells installed in 1989

[Altitude in feet above sea level; cm, centimeter; mm, millimeter; >, greater than]

WELL NUMBER: 271243 (1178-1)
Altitude of land surface: 690.2 feet
Samples from hollow-stem-auger cuttings unless otherwise noted

Lithology	Depth interval (feet below land surface)	
Sand, coarse- to medium-grained with small amount of very coarse-grained sand, pebbles (1 cm) and organic material, brownish gray (5YR4/1); sand and pebbles are subangular to subrounded, subelongated to subspherical; poorly sorted, predominantly quartz.	0.0	5.0
Sand, medium- to coarse-grained and organic material, cobbles (6 cm) and pebbles (1 cm), brownish gray (5YR4/1); medium- to coarse-grained sand is subangular to subrounded, subspherical; cobbles and pebbles are subrounded to rounded, subspherical to spherical; very poorly sorted, predominantly quartz.	5.0	10.0
Silt and clay matrix with some coarse-grained sand, brownish gray (5YR4/1); sand is subrounded to subspherical; moderately to well sorted, primarily silt.	10.0	12.0
No sample.	12.0	18.0
Sand, very coarse-grained to pebbles, granitic quartz grains (1 cm), some ferrous minerals, with some coarse- to medium-grained sand, no homogeneous color, color is roughly dark yellowish brown (10YR4/2); subangular, subelongated; poorly sorted, predominantly quartz. Note: Sample from split-spoon core.	18.0	20.0
No sample.	20.0	25.0
Sand, fine-grained matrix with coarse- to very coarse-grained sand and crystalline pebbles (1 cm), moderate yellowish brown (10YR5/4); fine-grained material is subrounded to rounded and spherical, larger grained material is subangular, subelongated; poorly sorted predominantly quartz. Note: Sample from split-spoon core.	25.0	27.0

WELL NUMBER: 271248 (1179-1)
Altitude of land surface: 688.0 feet
Samples from split-spoon cores
unless otherwise noted.

Lithology	Depth interval (feet below land surface)	
Sand, medium- to coarse-grained with some very coarse-grained sand, small amount of silt to clay and organic material, moderate brown (5YR3/4); subangular to subrounded; very poorly sorted. Note: Sample from hollow-stem-auger core.	0.0	1.5
Organic material with silt and occasional coarse- to very coarse-grained sand, dusky brown (5YR2/2) to grayish brown (5YR3/2); sand is subrounded to rounded; poorly sorted. Note: Sample from hollow-stem-auger core.	1.5	7.0
Sand, medium- to coarse-grained with some very coarse-grained sand, brownish gray (5YR4/1); subangular to subrounded, subspherical; poorly sorted, predominantly quartz. Note: Sample from hollow-stem-auger core.	7.0	8.0
Clay and silt, with some coarse- to very-coarse (>20 mm) shale fragments, shale fragments are subangular and elongated; well sorted, clay porphyry. Note: Sample from hollow-stem-auger core.	8.0	10.0
Silt and clay matrix with some coarse- and very coarse-grained sand, dark yellowish brown (10YR4/2); sand grains are subrounded and sub-spherical; well sorted. Note: Sample from Waterloo core.	10.0	15.0
Sand, medium-grained with small amount coarse-grained sand, dark yellowish brown (10YR4/2); subangular to subrounded, subelongated to subspherical; well sorted, predominantly quartz.	15.0	18.0
No sample.	18.0	22.0
Sand, very fine-grained to silt, dark yellowish brown (10YR4/2); rounded, spherical grains; well sorted, predominantly quartz.	22.0	24.0
No sample.	24.0	27.0

WELL NUMBER: 271248 (1179-1)--Continued Lithology	Depth interval (feet below land surface)	
Sand, fine- to medium-grained, dark yellowish brown (10YR4/2); subangular to subrounded, subspherical; well sorted, predominantly quartz with mica and magnetite grains dispersed throughout.	27.0	29.0
Sand, medium-grained, moderate yellowish brown (10YR5/4); subrounded, subspherical; well sorted, predominantly quartz.	28.0	30.0
No sample.	30.0	32.0
Sand, medium-to fine-grained, dark yellowish brown (10YR4/2); subrounded to rounded, subspherical grains; well sorted, predominantly quartz with mangetite and biotite flakes.	32.0	34.0
Sand, coarse-grained, dark yellowish brown (10YR4/2); subangular to subrounded, subspherical; moderately sorted, predominantly quartz.	34.0	39.0
No sample.	39.0	42.0
Sand, medium- to coarse-grained, dark yellowish brown (10YR4/2); some large crystalline cobbles (1 cm), subrounded to rounded, subspherical to spherical; moderately sorted, predominantly quartz.	42.0	44.0
No sample.	44.0	47.0
Sand, fine-grained, dark yellowish brown (10YR4/2); rounded to subrounded, spherical to subspherical; well sorted, predominantly quartz.	47.0	49.0
No sample.	49.0	52.0
Sand, very fine- to fine-grained with medium-grained sand, quartz and granitic pebbles (5 mm) present, dark yellowish brown (10YR4/2); very fine grains are rounded, medium-sized grains and pebbles are subangular to subrounded and subspherical; moderately sorted, predominantly quartz.	52.0	54.0

WELL NUMBER: 271248 (1179-1)--Continued Lithology	Depth interval (feet below land surface)	
Sand, fine- to medium-grained with very coarse pebbles, dark yellowish brown (10YR4/2); smaller grains are subangular to subrounded and subspherical, larger grains are subangular and subelongated; poorly sorted, predominantly quartz.	54.0	56.0
No sample.	56.0	57.0
Sand, medium- to fine-grained, and coarse- to very coarse-grained sand, pebbles, and granitic cobble, fractured, round, porphyritic (4 cm), some ferrous minerals, dark yellowish brown (10YR5/4); smaller grains are subrounded, larger grains are subangular and subspherical to subelongated; poorly sorted, predominantly quartz.	57.0	59.0
No sample.	59.0	62.0
Sand, very fine-grained to silt, dark yellowish brown (10YR5/4); very well sorted.	62.0	64.0
Sand, fine- to medium-grained, dark yellowish brown (10YR5/4); subangular to subrounded, subspherical; well sorted, predominantly quartz.	64.0	66.0
No sample.	66.0	68.0
Sand, very fine- to fine-grained, with some medium-grained sand, dark yellowish brown (10YR5/4); fine-grained sand is rounded and spherical, less prominant larger grains are subangular and subelongated; moderately sorted, predominantly quartz.	68.0	70.0

WELL NUMBER: 271249 (1179-2) Altitude of land surface: 688.1 feet Lithology	Depth interval (feet below land surface)	
No sample.	0	18.0

WELL NUMBER: 271249 (1179-2)--Continued

Lithology	Depth interval (feet below land surface)	
Silt and clay matrix with some coarse- to very coarse-grained sand dispersed throughout, dark yellowish brown (10YR4/2); sand grains are subrounded and subspherical; well sorted. Note: Sample from hollow-stem auger cuttings.	18.0	20.0
Sand, very fine-grained to silt with coarse to very coarse grains of loosely consolidated sand, dark yellowish brown (10YR4/2); subrounded to rounded, spherical; very well sorted. Note: Sample from split-spoon core.	18.0	20.0

WELL NUMBER: 271244 (1179-3)
Altitude of land surface: 687.8 feet

Lithology	Depth interval (feet below land surface)	
No sample.	0	17.0
Sand, medium- to fine-grained, dark yellowish brown (10YR4/2); subangular to subrounded, spherical; moderately sorted, predominantly quartz. Note: Sample from split-spoon core.	17.0	19.0

WELL NUMBER: 271250 (1179-4)
Altitude of land surface: 689.2 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Sand, medium- to fine-grained, silt and organic material, grayish brown (5YR3/2); subrounded, subspherical; moderately sorted.	0.0	5.0
Clay and silt, olive gray (5Y4/1); very well sorted.	5.0	10.0
Sand, coarse- to medium-grained, and clay; sand is olive black (5Y2/1); grains are subangular to subrounded, subspherical; moderately to poorly sorted, predominantly quartz.	10.0	15.0

WELL NUMBER: 271250 (1179-4)--Continued Lithology	Depth interval (feet below land surface)	
Sand, medium- to fine-grained, dusky yellowish brown (10YR2/2); subrounded and subspherical; moderately sorted, predominantly quartz.	15.0	20.0
Sand, fine- to medium-grained, olive gray (5Y4/1); subrounded to rounded, spherical grains; well sorted, predominantly quartz.	20.0	25.0

WELL NUMBER: 271251 (1179-4A) Altitude of land surface: 689.1 feet Samples from Waterloo cores unless otherwise noted. Lithology	Depth interval (feet below land surface)	
Top soil, silty organic material with very coarse-grained sand and pebbles (4-5 mm), ferric (red) staining near surface, grayish brown (5YR3/2); sand is subrounded and subelongated; moderately to poorly sorted. Note: Sample from hollow-stem-auger cuttings.	0.0	5.0
Silt, sand, very fine- to fine-grained, and organic material, olive black (5Y2/1); subrounded, subspherical sand grains; moderately sorted. Note: Sample from hollow-stem-auger cuttings.	5.0	10.0
Sand, fine- to medium-grained, medium dark gray (N-4); subangular to subrounded, subspherical; well sorted predominantly quartz.	10.0	15.0
Silt, with medium-grained sand and pebbles (1 cm), olive gray (5Y4/1); sand is subangular, subspherical; poorly to moderately sorted.	15.0	20.0
Silt, dark yellowish brown (10YR4/2); very well sorted Note: Sample from split-spoon core.	20.0	32.0
No sample.	32.0	35.0

WELL NUMBER: 271251 (1179-4A)--Continued Lithology	Depth interval (feet below land surface)	
Clay and silt, dark yellowish brown (10YR4/2); very well sorted.	35.0	50.0
Clay and silt, olive gray (5YR4/1); very well sorted.	50.0	65.0
Clay, olive gray (5YR4/1); very well sorted.	65.0	70.0

WELL NUMBER: 271246 (1179-5) Altitude of land surface: 691.5 feet Samples from hollow-stem-auger cuttings. Lithology	Depth interval (feet below land surface)	
Sand, medium- to fine-grained, brownish gray (5YR4/1); subrounded, subspherical to spherical; moderately sorted, predominantly quartz.	0.0	5.0
Sand, fine- to medium-grained, dark yellowish brown (10YR4/2); subrounded to rounded, subspherical to spherical; well sorted, predominantly quartz.	5.0	10.0
Sand, fine-grained, olive gray (5Y4/1); rounded, spherical grains; well sorted, predominantly quartz.	10.0	15.0
Sand, coarse- to very-coarse grained, with medium-grained sand, olive gray (5Y4/1); larger grains are subangular and subelongated to subspherical, medium grains are subrounded and subspherical; poorly sorted, predominantly quartz.	15.0	20.0
Silt and very fine-grained sand with small amount of coarse- to medium-grained sand, dark yellowish brown (10YR4/2); coarse grains are subangular to subrounded, subspherical; moderately sorted, primarily silt.	20.0	30.0

WELL NUMBER: 271245 (1179-6)
Altitude of land surface: 690.6 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Sand, medium- to coarse-grained, dark yellowish brown (10YR4/2); subrounded to rounded grains, spherical; moderately sorted, predominantly quartz.	0.0	5.0
Sand, medium- to fine-grained, olive gray (5Y4/1); subrounded to rounded, spherical; well sorted, predominantly quartz.	5.0	15.0
Sand, coarse- to very coarse-grained, pebbles (3-4 mm), olive gray (5Y4/1); subrounded, subspherical grains; poorly sorted, predominantly quartz.	15.0	25.0

WELL NUMBER: 271247 (1179-7)
Altitude of land surface: 689.8 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Silt, organic material and small amount of coarse- to very coarse-grained sand, grayish brown (5YR3/2); subrounded, subspherical sand grains; primarily silt.	0.0	5.0
Silt, with very-fine to fine-grained sand, dusky yellowish brown (10YR2/2); rounded, spherical grains; well sorted.	5.0	10.0
Silt, with coarse- to medium-grained sand, olive gray (5Y4/1); subrounded, subspherical grains; moderately sorted.	10.0	15.0
Sand, coarse- to very coarse-grained with some silt and clay, olive gray (5Y4/1); subangular, subspherical; poorly sorted, predominantly quartz.	15.0	20.0

WELL NUMBER: 271259 (1179A-1)
Altitude of land surface: 688.1 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
No sample.	0	5.0
Clay and silt, with small amount of medium-grained sand, olive gray (5Y4/1); very well sorted.	5.0	10.0
Clay and silt, olive gray (5Y4/1); very well sorted.	10.0	15.0
Silt and medium-grained sand, olive gray (5Y4/1); well sorted.	15.0	20.0

WELL NUMBER: 271262 (1179A-2)
Altitude of land surface: 688.1 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Organic material, silt, top soil, with some coarse- to very coarse-grained sand, dusky brown (5YR2/2); sand is subrounded to rounded and elongated, moderately sorted.	0.0	5.0
Sand, coarse- to very coarse-grained with silt, brownish gray (5YR4/1); subrounded, subelongated to subspherical; moderately to poorly sorted, predominantly quartz.	5.0	10.0
Sand, very coarse-grained and pebbles (>1 cm), with some silt and clay, olive gray (5Y4/1); subrounded, subspherical; poorly sorted, predominantly quartz.	10.0	15.0
Sand, coarse- to medium-grained, dark yellowish brown (10YR4/2); subrounded to rounded, spherical grains; moderately sorted, predominantly quartz.	15.0	20.0

WELL NUMBER: 271259 (1179A-3)
Altitude of land surface: 688.4 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Topsoil with medium- to coarse-grained sand, dusky brown (5YR2/2); sand is subangular and subspherical; moderately sorted.	0.0	5.0
Silt, with some very coarse-grained sand and quartz pebbles (1 cm), brownish gray (5YR4/1); sand is angular to subangular, subspherical; moderately to poorly sorted.	5.0	10.0
Sand, medium- to coarse-grained with silt and pebbles (3-4 mm), dark yellowish brown (10YR4/2); subrounded, spherical; moderately sorted, predominantly quartz.	10.0	15.0
Sand, coarse-grained with a small amount of silt, olive gray (5Y4/1); subrounded, subelongated to subspherical; poorly to moderately sorted, predominantly quartz.	15.0	20.0

WELL NUMBER: 271253 (1179D-1)
Altitude of land surface: 688.0
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Top soil, very fine-grained sand and silt with a small amount of medium-grained sand, grayish brown (5YR3/2); well sorted.	0.0	5.0
Clay and silt, olive gray (5Y4/1); very well sorted.	5.0	10.0
Sand, coarse- to very coarse-grained, olive gray (5Y4/1); subangular to subrounded, subelongated to subspherical; poorly sorted, predominantly quartz.	10.0	20.0

WELL NUMBER: 271255 (1179D-2)
Altitude of land surface: 687.8 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Top soil, very fine-grained sand to silt with a small amount of medium-grained sand, grayish brown (5YR3/2); well sorted.	0.0	5.0
Sand, medium- to coarse-grained, olive gray (5Y4/1); subangular, subspherical grains; moderately sorted.	5.0	10.0
Sand, coarse- to very coarse-grained, olive gray (5Y4/1); subangular to subrounded, subelongated to subspherical; poorly sorted, predominantly quartz.	10.0	20.0

WELL NUMBER: 271263 (1180-1)
Altitude of land surface: 689.1 feet
Samples from hollow-stem-auger cuttings unless otherwise noted.

Lithology	Depth interval (feet below land surface)	
Sand, coarse- to very coarse-grained, with pebbles (1 cm), dark yellowish brown (10YR4/2); subrounded to rounded, spherical; poorly sorted, predominantly quartz.	0.0	5.0
Sand, coarse- to very coarse-grained with pebbles and cobbles (3 cm), silt and clay, dark yellowish brown (10YR4/2); sand is subrounded to rounded and spherical; very poorly sorted, 75 percent sand, 25 percent clay.	5.0	10.0
Silt, with very coarse-grained sand and pebbles (1 cm), small amount of clay, dark yellowish brown (10YR4/2); sand is subangular to subrounded; 70 percent silt, 30 percent pebbles.	10.0	15.0
No sample.	15.0	25.0
Clay, olive gray (5Y4/1); well sorted. Note: Sample from Waterloo core.	25.0	30.0
Silt and clay, brownish gray (5YR4/1); very well sorted. Note: Sample from Waterloo core.	30.0	35.0

WELL NUMBER: 271263 (1180-1)--Continued

Lithology	Depth interval (feet below land surface)	
Clay and silt, dark yellowish brown (10YR4/2); very well sorted, also contains concretions (4 cm). Note: Sample from Waterloo core.	35.0	40.0
Sand, very fine-grained to silt, dark yellowish brown (10YR4/2); some elongated shale fragments (2-3 mm); very well sorted. Note: Sample from Waterloo core.	40.0	45.0
Silt and clay with some intermixed pebbles and cobbles (1.5-3 cm), dark yellowish brown (10YR4/2); well sorted, clay porphyry. Note: Sample from Waterloo core.	45.0	50.0
No sample	50.0	55.0
Sand, very coarse-grained, with medium-, fine-, and very fine-grained sand, pebbles (5-8 mm) and cobbles (1-5 cm), dark yellowish brown (10YR4/2); graphite and magnetite present; sand is subrounded to rounded, and subspherical, coarse-grained sand and larger material is subangular to angular and subelongated; very poorly sorted, predominantly quartz. Note: Sample from split-spoon core.	55.0	57.0
No sample	57.0	65.0
Sand, medium- to coarse-grained with some fine sand, dark yellowish brown (10YR4/2); graphite, magnetite and epidote present, fine sand is subrounded to rounded and subspherical to spherical, coarser sand is subangular and subelongated; poorly sorted, predominantly quartz. Note: Sample from split-spoon core.	65.0	67.0

WELL NUMBER: 271264 (1180-2)
Altitude of land surface: 689.7 feet

Lithology	Depth interval (feet below land surface)	
No sample.	0	15.0
Sand, coarse- to very coarse-grained, with pebbles (8 mm), dark yellowish brown (10YR4/2); subrounded to rounded, spherical; poorly sorted, predominantly quartz. Note: Sample from hollow-stem-auger cuttings.	15.0	20.0

WELL NUMBER: 271267 (1180-3)
Altitude of land surface: 688.8 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Top soil, silt, organic material with very coarse-grained sand and pebbles (4-6 mm); grayish brown (5YR3/2); sand is subrounded, subspherical; moderately well sorted.	0.0	5.0
Clay and silt with pebbles (1 cm), cobbles (2-3 cm) and small amount of coarse-grained sand, olive gray (5Y4/1); pebbles and cobbles are subrounded and subelongated, poorly sorted.	5.0	10.0
No sample.	10.0	15.0
Sand, coarse- to very coarse-grained with small amount of silt, dark yellowish brown (10YR4/2); sand is subangular to subrounded and subspherical; moderately to poorly sorted.	15.0	20.0

WELL NUMBER: 271261 (1181-1)
Altitude of land surface: 688.5 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Sand, fine- to very fine-grained with some organic material, grayish black (N-2); rounded, spherical; very well sorted, predominantly quartz.	0.0	5.0

WELL NUMBER: 271261 (1181-1)--Continued Lithology	Depth interval (feet below land surface)	
Clay and silt, with medium- to coarse-grained sand, olive gray (5Y4/1); sand is subangular and subelongated; moderately to well sorted.	5.0	10.0
Clay and sand, fine- to medium-grained, sand is dark gray (N-3), clay is olive gray (5Y4/1); sand grains are subangular to subrounded and subspherical; sand is moderately to well sorted and predominantly quartz, clay is very well sorted.	10.0	15.0
Sand, coarse- to very coarse-grained with silt, olive gray (5Y4/1); sand is subangular to subrounded, subspherical; poorly to moderately sorted.	15.0	25.0

WELL NUMBER: 271257 (1181-2) Altitude of land surface: 688.2 feet Samples from hollow-stem-auger cuttings. Lithology	Depth interval (feet below land surface)	
Organic material and silt with pebbles, (0.5-1 cm) with small amount of coarse- to very coarse-grained sand, dusky yellowish brown (10YR2/2); pebbles and sand are subangular, subspherical; poorly sorted.	0.0	5.0
Silt and very coarse-grained sand to pebbles, olive gray (5Y4/1), sand and pebbles are subangular to subrounded, subelongated to elongated; moderately to poorly sorted.	5.0	15.0
Sand, coarse- to very coarse-grained with silt, olive gray (5Y4/1); subrounded, subspherical grains; moderately sorted, predominantly quartz.	15.0	25.0

WELL NUMBER: 271254 (1181-3)
Altitude of land surface: 688.5 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Organic material, silt with pebbles (0.5-1 cm) and coarse- to very coarse-grained sand, dusky yellowish brown (10YR2/2); pebbles and sand are subangular, subspherical; poorly sorted.	0.0	5.0
Silt with very coarse-grained sand to pebbles, dusky yellowish brown (10YR2/2); sand and pebbles are subangular to subrounded, subelongated, moderately to poorly sorted.	5.0	10.0
Sand, coarse- to very coarse-grained with silt, olive gray (5Y4/1); subangular to subrounded, subspherical grains; moderately sorted, predominantly quartz.	10.0	20.0
Silt with coarse- to very coarse-grained sand and pebbles olive gray (5Y4/1); sand and pebbles are subrounded, subspherical; poorly sorted.	20.0	25.0

WELL NUMBER: 271260 (3548-1)
Altitude of land surface: 689.4 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Sand, medium- to coarse-grained with some very coarse-grained sand, grayish black (N-2); subrounded, subspherical grains; moderately sorted, predominantly quartz.	0.0	5.0
Silt and clay, with coarse-grained sand, olive gray (5Y4/1); sand grains are subrounded and subelongated, well to moderately sorted, predominantly clay and silt.	5.0	10.0
Sand, medium- to coarse-grained with pebbles (4 mm) and silt, olive black (5Y2/1); pebbles are rounded and subspherical, medium- to coarse-grained material is subangular to subrounded and subspherical; moderately sorted, predominantly quartz.	10.0	15.0

WELL NUMBER: 271260 (3548-1)--Continued

Lithology	Depth interval (feet below land surface)	
Sand, coarse- to very coarse-grained, olive gray (5Y4/1), subangular, subelongated to subspherical; poorly sorted, predominantly quartz.	15.0	20.0
Sand, coarse- to very coarse-grained, dark yellowish brown (10YR4/2); subrounded, subelongated to elongated; poorly sorted, predominantly quartz.	20.0	25.0

WELL NUMBER: 271258 (3548-2)
Altitude of land surface: 690.9 feet
Samples from split-spoon core unless otherwise noted.

Lithology	Depth interval (feet below land surface)	
Sand, coarse- to very coarse-grained with silt, olive gray (5Y4/1); subangular to angular, subelongated to subspherical; moderately sorted, predominantly quartz. Note: Sample from hollow-stem-auger cuttings.	0.0	5.0
No sample.	5.0	8.0
Sand, coarse- to very coarse-grained, with shale fragments (0.5-1 cm), dark yellowish brown (10YR4/2); sand is subangular to subrounded and subelongated, shale pebbles are elongated and subrounded to rounded, shales show ferric staining, graphite also present; very poorly sorted, predominantly quartz.	8.0	10.0
Sand, fine- to coarse-grained, with some very coarse-grained sand, dark yellowish brown (10YR4/2); medium- to fine-grained sand is subrounded and subspherical, large grains are subrounded, and subelongated, moderately sorted, predominantly quartz. Note: Sample from Waterloo core.	10.0	15.0
Silt and clay, dark yellowish brown (10YR4/2); very well sorted.	15.0	18.0
Sand, very fine-grains to silt, dark yellowish brown (10YR4/2); very well sorted. Note: Sample from Waterloo core.	18.0	30.0

WELL NUMBER: 271258 (3548-2)--Continued

Lithology	Depth interval (feet below land surface)	
Silt, dark yellowish brown (10YR4/2); some thin clay laminations (1-2 mm); well sorted.	30.0	32.0
No sample.	32.0	35.0
Silt, dark yellowish brown (10YR4/2); very well sorted.	35.0	58.0
No sample.	58.0	60.0
Sand, fine- to medium-grained, dark yellowish brown (10YR4/2); magnetite and epidote present, subangular to subrounded, subspherical, moderately to well sorted, predominantly quartz.	60.0	63.0
No sample.	63.0	65.0
Sand, medium- to coarse-grained, with some very coarse-grained sand and crystalline pebbles (1 cm), dark yellowish brown (10YR4/2); magnetite, graphite, and epidote also present, smaller grains are subangular to subrounded and subspherical, larger grains and pebbles are subangular to angular, and subelongated; poorly sorted, predominantly quartz.	65.0	68.0

WELL NUMBER: 271256 (3548-3)
Altitude of land surface: 690.1 feet
Samples from hollow-stem-auger cuttings.

Lithology	Depth interval (feet below land surface)	
Sand, medium- to fine-grained, olive gray (5Y4/1); rounded, spherical grains; well sorted, predominantly quartz.	0.0	5.0
Sand, medium- and coarse-grained, olive gray (5Y4/1); subangular to subspherical; moderately sorted, predominantly quartz.	5.0	10.0
Sand, very coarse- to coarse-grained, olive gray (5Y4/1); subangular to subspherical; moderately to poorly sorted, predominantly quartz.	10.0	15.0
Sand, fine-grained with very coarse-grained sand and pebbles (1 cm), olive gray (5Y4/1); very coarse sand is subangular, subspherical, pebbles are rounded and elongated, moderately to poorly sorted, predominantly quartz.	15.0	20.0