Results Of The Basewide Monitoring Program At Wright-Patterson Air Force Base, Ohio, 1993-1994

By Charles W. Schalk, William L. Cunningham, and others

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
inch (in.)	25,400	micron
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	square hectometer
	Mass	
ounce	28.5	gram
	Volume	
gallon (gal)	3.785	liter
gallon (gal)	3,785	milliliter
gallon (gal)	3,785,000	microliter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	3.785	liter per minute
million gallons per day (Mgal/d)	0.04381	cubic meter per second
cubic foot per second per mile ($ft^3/s/mi$)		liter per second per meter
	Rate of accumulation	
inch per year (in/yr)	25.4	millimeter per year

Temperature, in degrees Celsius (°C), can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$F = 1.8(°C) + 32$$

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

Abbreviated water-quality units used in this report: Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). These units express the concentration of chemical constituents in solution as weight (milligrams or micrograms) of solute per unit volume (liter) of solvent (water). Volumes of water-quality samples are given in liters (L) or milliliters (mL). Pore sizes of membrane filters are given in micrometers (µm). Activities of gross alpha and gross beta are presented in picocuries per liter (pCi/L). Turbidity is presented in nephelometric turbidity units (NTU).

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Results of the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio, 1993-94

By Charles W. Schalk, William L. Cunningham, and others

ABSTRACT

Geologic and hydrologic data were collected at Wright-Patterson Air Force Base (WPAFB), Ohio, as part of a Basewide Monitoring Program (BMP) that began in 1992. The BMP was designed as a long-term project to characterize ground-water and surface-water quality (including streambed sediments), describe water-quality changes as water enters, flows across, and exits the Base, and investigate the effects of activities at WPAFB on regional water quality.

Ground water, surface water, and streambed sediment were sampled in four rounds between August 1993 and September 1994 to provide the analytical data needed to address the objectives of the BMP. Surface-water-sampling rounds were designed to include most of the seasonal hydrologic conditions encountered in southwestern Ohio, including baseflow conditions and spring runoff. Ground-water-sampling rounds were scheduled for times of recession and recharge.

Ground-water data were used to construct water-table, potentiometric, and vertical gradient maps of the WPAFB area. Water levels have not changed significantly since 1987, but the effects of pumping on and near the Base can have a marked effect on water levels in localized areas. Ground-water gradients generally were downward throughout Area B (the southwestern third of the Base) and in the eastern third of Areas A and C (the northeastern two-thirds of the Base), and were upward in the vicinity of Mad River. Stream-discharge measurements verified these gradients.

Many of the U.S. Environmental Protection Agency maximum contaminant level (MCL) exceedances of inorganic constituents in ground water were associated with water from the bedrock. Exceedances of concentrations of chromium and nickel were found consistently in five wells completed in the glacial aquifer beneath the Base. Five organic compounds [trichloroethylene (TCE), tetrachloroethylene (PCE), vinyl chloride, benzene, and bis(2-ethylhexyl)phthalate] were detected at concentrations that exceeded MCLs; all of the TCE, PCE, and vinyl chloride exceedances were in water from the glacial aquifer, whereas the benzene exceedance and most of the bis(2-ethylhexyl)phthalate exceedances were in water from the bedrock. TCE (16 exceedances) and PCE (11 exceedances) most frequently exceeded the MCLs and were detected in the most samples.

A decrease in concentrations of inorganic and organic compounds with depth suggest that many constituents detected in ground-water samples are associated partly with human activities, in addition to their natural occurrence. Included in the list of these constituents are nickel, chromium, copper, lead, vanadium, zinc, bromide, and nitrate. Many constituents are not found at depths greater than 60 to 80 feet, possibly indicating that human effects on ground-water quality are limited to shallow flow systems. Organic compounds detected in shallow or intermediate-depth wells were aligned mostly with flowpaths that pass through or near identified hazardous-waste sites.

Few organic contaminants were detected in surface water. The only organic compound to exceed MCLs for drinking water was

bis(2-ethylhexyl) phthalate, but it was detected at concentrations just above the MCL. Inorganic constituents detected at concentrations exceeding MCLs include beryllium (twice), lead (once), thallium (once), and gross alpha radiation (once). No polycyclic aromatic (PAHs) were detected in surface-water samples. The highest concentrations of contaminants detected during a storm event were in samples from upgradient locations, indicating that off-Base sources may contribute to surface-water contamination.

Inorganic and organic contaminants were found in streambed sediments at WPAFB, primarily in Areas A and C. Trace metals such as lead, mercury, arsenic, and cadmium were detected at 16 locations at concentrations considered "elevated" according to a ranking scheme for sediments. PAHs were the organic compounds detected most frequently and in highest concentration; organochlorine pesticides and petroleum hydrocarbons also were found. Highest concentrations of organic and inorganic constituents in streambed sediment were detected at interior or downgradient locations, indicating that some of these contaminants may have been derived from Base activities.

INTRODUCTION

Wright-Patterson Air Force Base (WPAFB) is an active U.S. Air Force base encompassing about 8,500 acres in southwestern Ohio, northeast of the city of Dayton in Clark, Montgomery, and Greene Counties (fig. 1). WPAFB is currently maintained and supported by the 88th Air Base Wing and hosts the Air Force Materiel Command Headquarters, the Air Force Museum, and many administrative, research, and development groups.

In 1980, under the mandate of the Comprehensive Environmental Response, Compensation, and Liability Act, the Air Force initiated the Installation Restoration Program (IRP) to assess and control the migration of environmental contamination that might have resulted from past operations and waste-disposal practices at Air Force facilities. The long-range objectives of the IRP at WPAFB are to assess the extent and nature of contamination at past hazardous-waste-disposal sites and to develop remedies for those sites that pose a hazard to the environment and to human health.

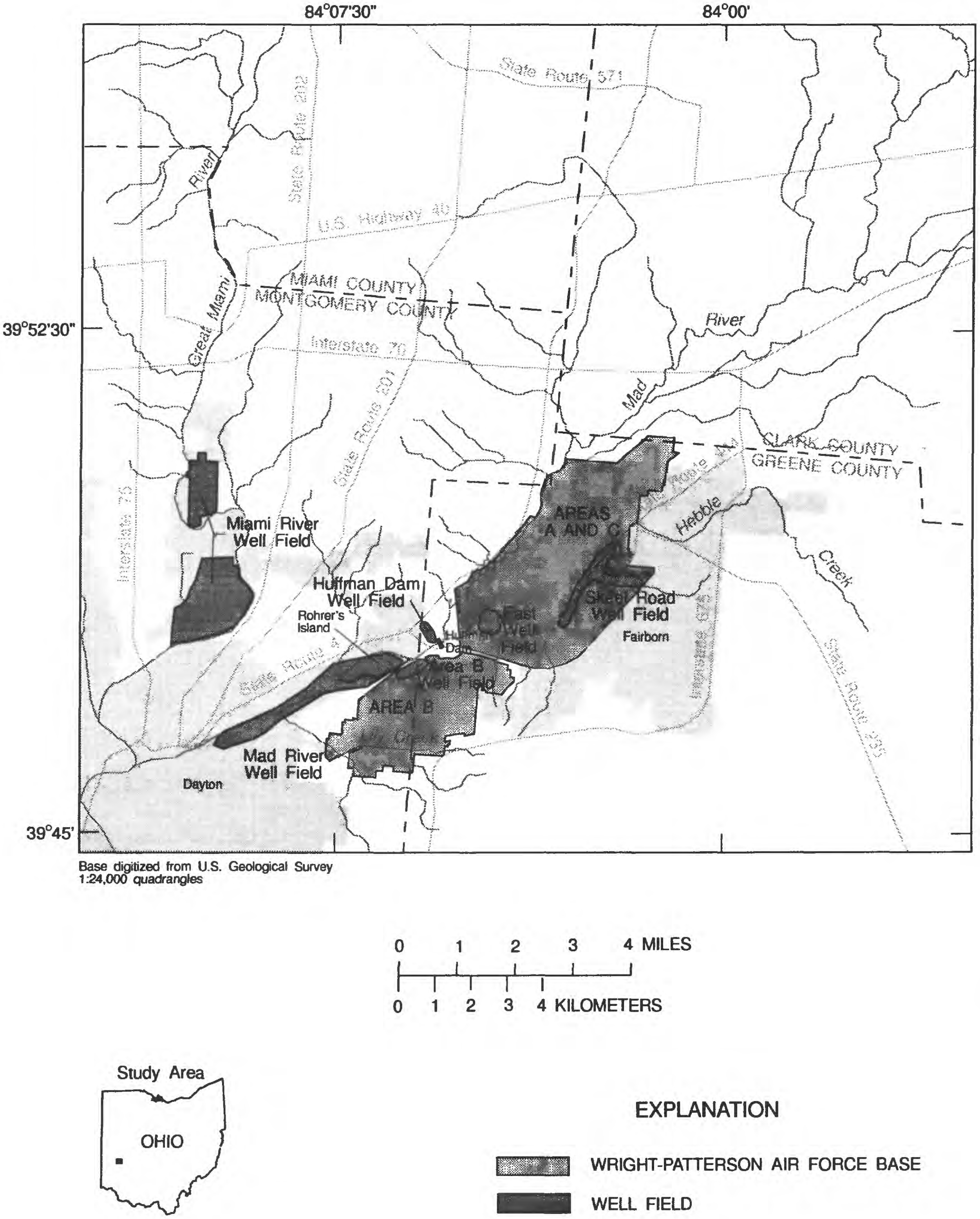
Many environmental studies and investigations of varying scopes have been done at WPAFB. A Phase I Record Search was done from September 1981 through February 1982 (Engineering-Science, 1982). A Phase II, Stage 1 study was done at 20 sites from November 1983 through September 1985 (Weston, 1985). Site investigations at three landfills were done from April 1986 through September 1986 (Dames and Moore, 1986a, 1986b). A Phase II, Stage 2 study was done on 27 sites from October 1986 through July 1989 (Weston, 1989). Eight earthfill-disposal zones (Engineering-Science, 1992) and 16 other sites (SAIC, 1993) were investigated. Numerous geophysical surveys were completed as part of the investigations. Engineering-Science (1992) completed the Site Inspection Report in August 1992.

Following these investigations, remedial efforts at WPAFB concentrated on sites that were grouped into operable units (OUs), which are geographical areas within the Base that encompass identified hazardous-waste sites. Approximate boundaries of the 11 OUs on WPAFB are delineated in figure 2.

In 1990, site assessment and field investigation reports were completed by Battelle/IT Corporation (IT Corporation, 1990). The reports generally addressed ground-water quality near OU5 and OU8 and regional ground-water-quality issues. An evaluation of previously collected data showed that detectable concentrations of organic solvents had been found in 94 of 265 monitoring and production wells. The reports noted that water from various WPAFB and Mad River Well Field production wells contained PCE, TCE, or their degradation products. This study concluded that although many of the production wells were contaminated by PCE and (or) TCE, plumes could not be delineated because of the distribution of detections.

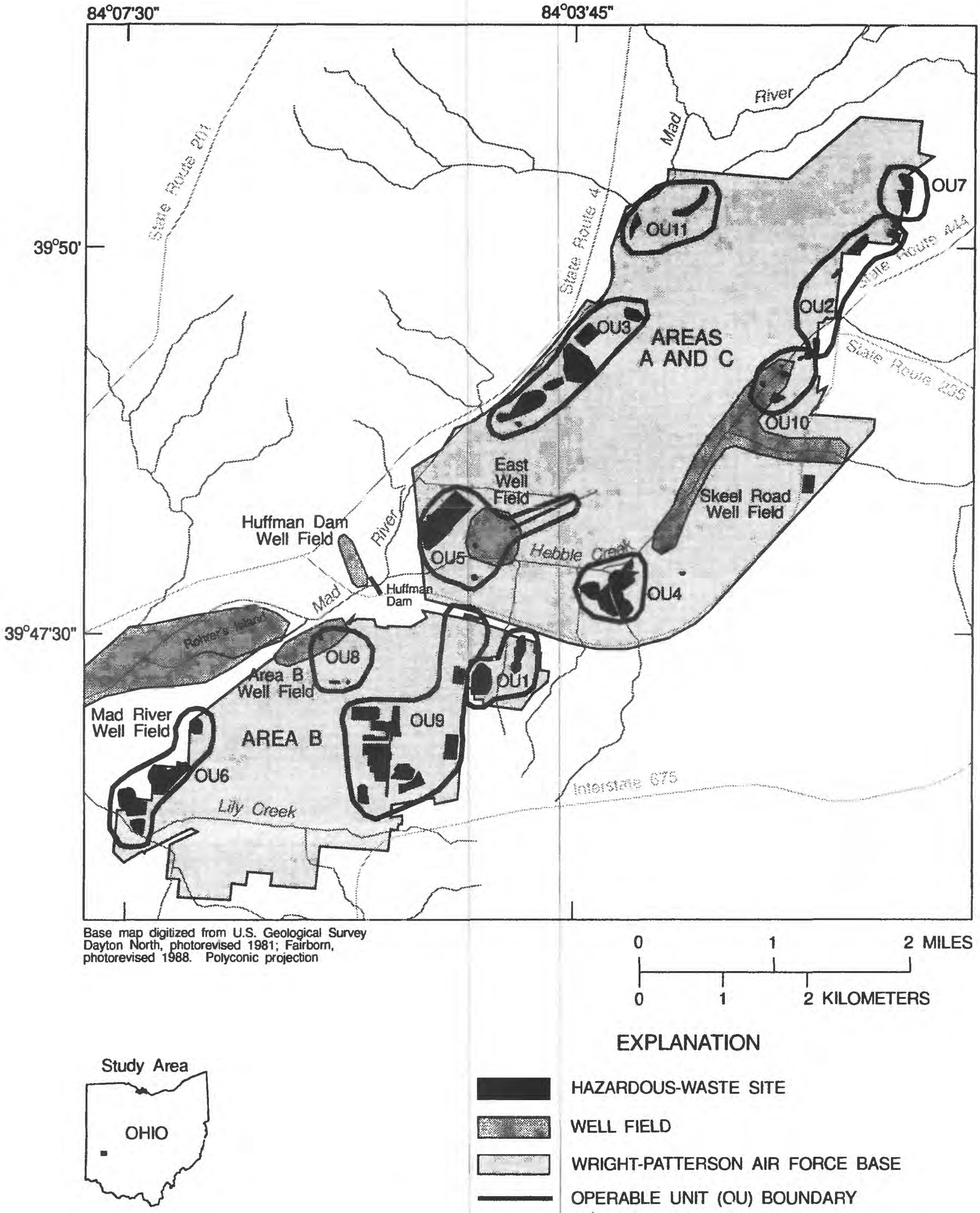
Description of the Basewide Monitoring Program

In 1987, the U.S. Geological Survey (USGS) and the Environmental Management (EM) branch of WPAFB began a cooperative hydrogeologic study in support of the Base IRP. Subsequent to the hydrogeologic study and in support of the IRP program, the 88th Air Base Wing Air Force Materiel Command, Office of Environmental Management, cooperated



Base digitized from U.S. Geological Survey 1:24,000 quadrangles

Figure 1. Location of Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 2. Locations of operable units and hazardous-waste sites on Wright-Patterson Air Force Base, Ohio.

with the USGS in a Basewide Monitoring Plan (BMP) designed to characterize ground-water and surface-water quality in and near the Base.

The BMP was designed as a multiyear program to identify trends in regional water quality by monitoring water quality at the Base perimeter. The objectives of the BMP are to (1) characterize current ground-water and surface-water quality, (2) describe water-quality changes as water enters, flows across, and exits the Base, and (3) investigate the effects of activities at WPAFB on regional water quality.

Purpose and Scope

This report presents the results and implications of activities during the first year (1993-94) of the BMP. Included are a summary of the drilling and sampling phases of the project; interpretations of the geology of the area; and information regarding the quantity and quality of the surface water and ground water at WPAFB. The effects of Air Force activities at WPAFB on the regional flow systems are addressed, where applicable. Geologic and hydrogeologic mapping, particle-tracking applications of simulated ground-water flow, and various statistical methods, including kriging and the use of basic statistics, were used to meet these reporting goals. This report will be used by WPAFB and its governing regulatory agencies to evaluate the progress of the BMP, assist in continuing remediation studies on WPAFB, and develop the scope of future remediation projects on WPAFB.

Description of the study area

Although the activities of the BMP were limited to the area inside Base boundaries, a description of the area centered on WPAFB is warranted. WPAFB lies between the cities of Fairborn and Dayton in southwestern Ohio (fig. 1). It is divided into three administrative areas (A, B, and C). Land surface in the area is flat to gently rolling, and land-surface altitudes range from about 780 to 1,000 ft above sea level. Much of WPAFB is on the flood plain of Mad River, which flows northeast-southwest through the study area and along the western boundary of WPAFB. Huffman Dam, a flood-control structure on Mad River that does not restrict normal flow, is just downstream of Areas A and C and about 1 mi northeast of Dayton's Mad River Well Field. Tributaries to Mad River in the WPAFB area include Mud Run and Hebble, Trout, and Lily Creeks.

The climate of the WPAFB area is characterized by warm summers and moderately cold winters (Walton and Scudder, 1960). Mean annual air temperature is 52.8°F, with temperatures in July averaging 75.3°F and temperatures in January averaging 30.1°F. Mean annual precipitation is 36.81 in. Prevailing winds are from the west and southwest.

The geologic setting near WPAFB consists of Ordovician and Silurian-age bedrock overlain by unconsolidated Pleistocene-age glacial deposits. Most of WPAFB is underlain by the Upper Ordovician-age Richmond group, which consists of calcareous shale with fossiliferous limestone interbeds. The shale layers are soft and fissile, and may be as thick as 20 ft. The limestone is hard and dense, occurs in beds ranging in thickness from a few inches to 2 ft, and composes about 25 to 50 percent of the sequence (Walton and Scudder, 1960; Dumouchelle and de Roche, 1991). Exposures of the Richmond Group are found in Montgomery County (Norris and others, 1948) and within Mad River Valley in southwestern Clark County (Norris and others, 1952). In the vicinity of WPAFB, the upper part of the Richmond Group is exposed at a railroad cut at the southern end of Huffman Dam.

In upland areas near Dayton, the Richmond Group is overlain by the Lower Brassfield Limestone of Silurian age. The Brassfield Limestone is thick, massive, and evenly bedded near its base, but thin and irregularly bedded near the top (Walton and Scudder, 1960). At some locations, the base consists of a granular limestone. The Brassfield Limestone is a light-gray to brown, relatively pure limestone as much as 30 ft thick (Norris and Spieker, 1966). Outcrops of the Brassfield Limestone have been noted along Mud Run and in southern Clark County (Norris and others, 1952), in scattered locations in northwestern Montgomery County (Norris and others, 1948) and in Greene County (Norris and others, 1950). The limestone has been quarried near Fairborn (Norris and others, 1950).

Most of the bedrock near WPAFB is covered by Wisconsin-age glacial deposits. Illinoian and pre-Illinoian glacial deposits can underlie the Wisconsinan deposits in the deepest parts of the buried valleys. Generally, the glacial deposits consist of till and outwash. The till, a heterogenous clay-rich mixture of clay to boulder-sized sediments deposited directly by the ice, generally covers the upland areas. The till ranges from less than 1 ft to more than 80 ft thick, and can contain lenses of sand and gravel. Bedrock valleys typically are filled with sand and gravel outwash deposited by the glacial meltwaters as valley-train deposits. The valley-train deposits can be almost 300 ft thick. Till lenses are present in parts of the outwash (Walton and Scudder, 1960). Downstream from Huffman Dam near WPAFB, buried till sheets may extend completely across the bedrock valley, and may separate the valley-train deposits into two distinct aquifers. In other areas, the till layers consist of irregular lenses and may be absent locally (Norris and Spieker, 1966). Generally well-sorted coarse sand and gravel kames were deposited by glacial meltwaters along some of the valley walls. Modern stream valleys contain thin deposits of alluvium consisting of both sorted and unsorted accumulations of sand, silt, gravel, and clay (Walton and Scudder, 1960).

Ground water from the valley-train deposits is the primary source of drinking water in the WPAFB area. Wells in the aquifer commonly yield more than 1,000 gal/min. All Montgomery County's public-water supply, including that for the city of Dayton, is from ground water, and the county withdraws more ground water than any other county in Ohio (Veley, 1993). Dayton's primary well field is along Mad River, centered on Rohrer's Island; about 50 Mgal/day are pumped from this well field. A line of wells just downstream from Huffman Dam produces another 2 Mgal/day. The buried valley aquifer system in the Dayton area was designated as a sole-source aquifer in 1988 (U.S. Environmental Protection Agency, 1993).

Fairborn and WPAFB also rely solely on ground water for municipal supply. Fairborn produces about 0.5 Mgal/day from a well field within 1 mi of the northern boundary of WPAFB; a second well field adjacent to WPAFB's east boundary is used during emergencies and periods of high demand. WPAFB operates two well fields (fig. 2). Skeel Road well field produces about 1.9 Mgal/day, and Area B well field produces about 1.7 Mgal/day. A third well field on WPAFB, East well field, has not been used extensively since 1987.

METHODS OF STUDY

By Kathleen M. Sarver

The BMP Work Plan (Cunningham and others, 1993) provides an overall technical and management strategy for the BMP. It provides the mechanism for planning site activities and rationale for all fieldwork and interpretation of results. The BMP Work Plan refers extensively to the existing Base Project Work Plan, The Final Work Plan for the Remedial Investigation and Feasibility Study for Wright-Patterson Air Force Base, Ohio, for 39 IRP Sites, as amended (Engineering-Science, 1990) for methods and procedures used in the investigation.

Sampling-Network Establishment

The investigative approach of the BMP was designed to assess the effects of past practices at WPAFB on regional ground-water and surface-water quality. Sampling locations were established around the borders of and within WPAFB so that water-quality data could be used to make general statements concerning the quality of water entering and exiting the Base. Locations established where water enters WPAFB were designated as "upgradient"; where water exits the Base, as "downgradient"; and well within Base boundaries, as "interior". The rationale for these designations was based on water levels and simulated particle tracking, which are described later in the report.

The ground-water-monitoring network was designed to provide adequate vertical and areal coverage of the glacial deposits in and around the Base. The ground-water-monitoring network consisted of 113 wells at 46 (of the 49) well clusters (fig. 3). Wells included in the network were completed at the water table, intermediate depths within the glacial deposits, the glacial/bedrock interface, or in bedrock (these characteristics are listed for each well in table 12). The network encompassed Areas A, B, and C and included wells within the boundaries of many operable units on Base. The hydraulic position (upgradient, downgradient, or interior) of each well cluster relative to the Base is summarized in table 1.

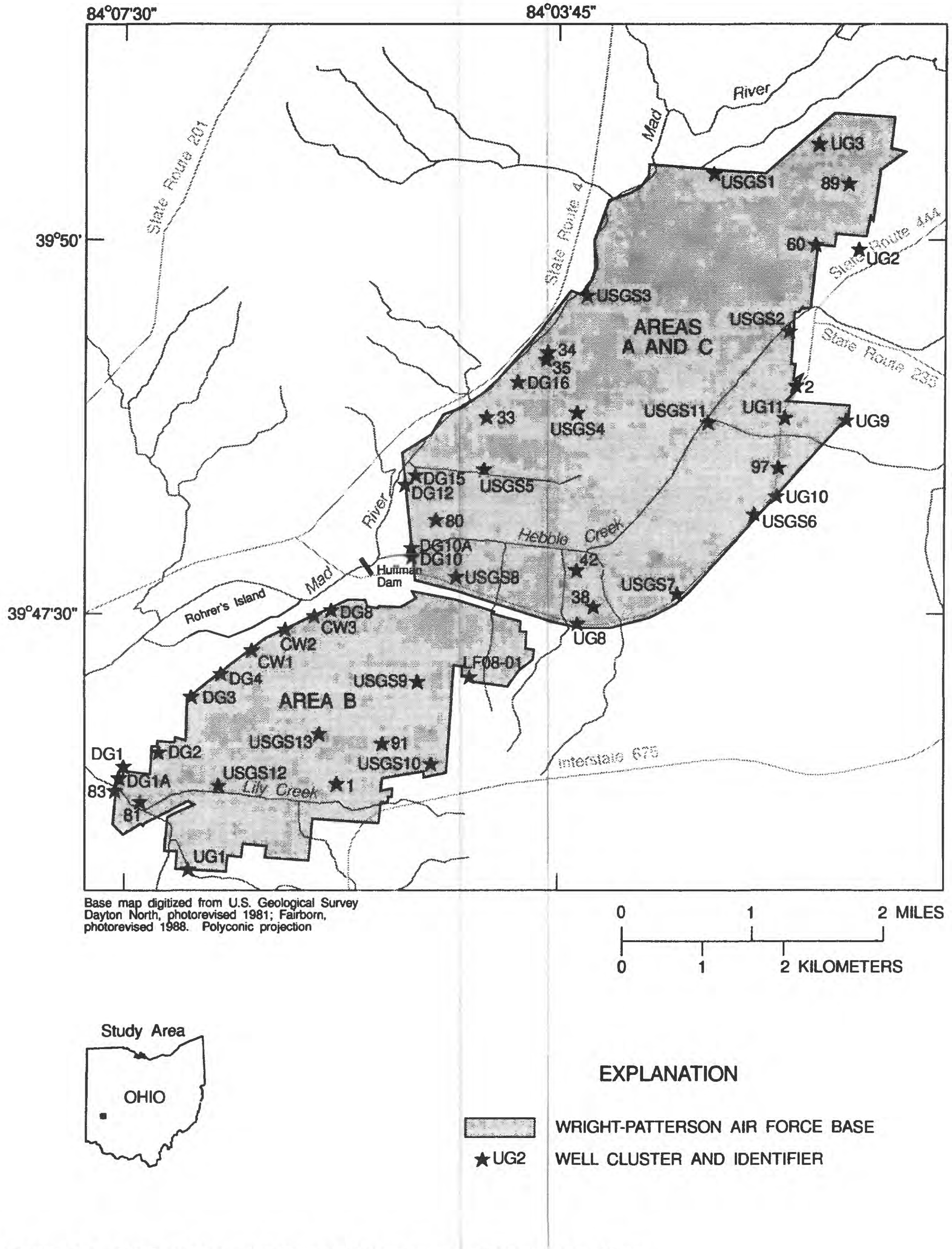
Surface-water and streambed-sediment sampling locations were chosen to monitor selected flows entering, flowing across, and exiting the Base property. The surface-water and streambed-sediment sampling network consists of 28 sampling locations (fig. 4) that include National Pollutant Discharge Elimination System (NPDES) outfalls, small intermittent streams, perennial streams such as Hebble Creek, and large streams such as Mad River. Six interior sampling stations were established by the USGS to

Table 1. Cluster locations by administrative area and position along regional hydraulic gradient, Wright-Patterson Air Force Base (locations of clusters are shown in figure 3)

Upgradient cluster locations	Interior cluster locations	Downgradient cluster locations
	Areas A and C	
2	38	33
UG3	42	34
UG8	60	35
UG9	80	DG10
UG10	89	DG10A
USGS1	97	DG12
USGS6	UG2	DG15
USGS7	UG11	DG16
	USGS2	USGS3
	USGS4	
	USGS5	
	USGS8	
	USGS11	
	Area B	
LF08-01	1	83
UG1	81	CW1
USGS10	91	CW2
	USGS9	CW3
	USGS12	DG1
	USGS13	DG1A
		DG2
		DG3
		DG4
		DG8

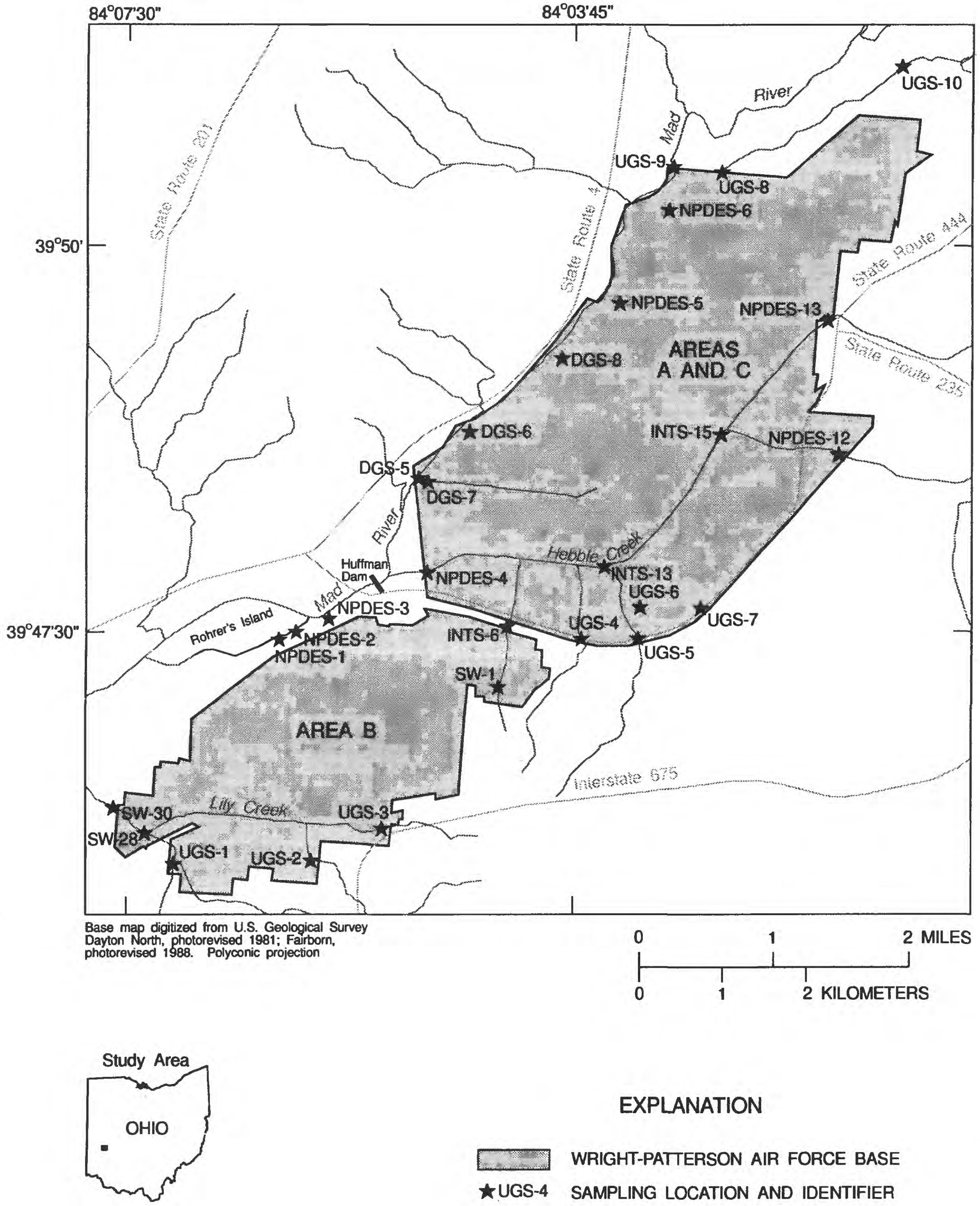
determine the chemical quality of discharges into Mad River (NPDES-5 and NPDES-6), Hebble Creek (INTS-13 and INTS-15), Lily Creek (SW-28), and an unnamed stream draining the northeastern section of area B (INTS-6). These sampling stations were established to determine the effects of runway activity, golf course chemical applications, road runoff, and coal storage area runoff, respectively (Cunningham and others, 1993). The position (hydraulically upgradient, downgradient, or interior) of each surface-water and streambed-sediment station relative to the Base is summarized in table 2.

The field program of the BMP consisted of establishing the ground-water, surface-water, and streambed-sediment sampling networks (January 1993– August 1993) and subsequent sampling periods (August 1993–September 1994). Field tasks that established the ground-water-sampling network were inspecting existing monitoring wells, drilling, and installing and developing monitoring wells. Field tasks that established the surface-water and streambed-sediment sampling networks were inspecting locations for accessibility and safety conditions, marking reference points for measuring stream stage, determining reaches on the streams for discharge measurements and sample collections, and photographing each location. The BMP field tasks through September 1994 are summarized in table 3.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 3. Well clusters on Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 4. Streambed-sediment and surface-water sampling locations on Wright-Patterson Air Force Base, Ohio.

Table 2. Streambed-sediment and surface-water-monitoring locations by administrative area and position along regional hydraulic gradient, Wright-Patterson Air Force Base (locations shown on figure 4)

Upgradient location	Interior location	Downgradient location
	Areas A and C	
NPDES-12	INTS-13	DGS-5
NPDES-13	INTS-15	DGS-6
UGS-4	NPDES-5	DGS-7
UGS-5	NPDES-6	DGS-8
UGS-6		NPDES-4
UGS-7		
UGS-8		
UGS-9		
UGS-10		
	Area B	
SW-1	INTS-6	NPDES-1
UGS-1	SW-28	NPDES-2
UGS-2		NPDES-3
UGS-3		SW-30

Inspection and Maintenance of Existing Monitoring Wells

Seventy-seven wells completed prior to initiation of the BMP were included as part of the BMP ground-water-monitoring network. Before a well was included in the BMP, it had to meet criteria relating to its location, construction material, external condition, and structural integrity. The internal casings of 20 4-in. monitoring wells were videotaped in January 1993 to verify the depth of the screened interval and the structural integrity of the well casing. Downhole images of the wells were recorded with a videocamera attached to a wire cable that was lowered slowly through the well casing. Items noted during videotaping included screened interval, total depth, location of casing joints, water level, and water clarity. Many of the wells had not been used for some time prior to the BMP, and encrustation was seen on many of the well screens. Accordingly, all existing monitoring wells were redeveloped prior to sampling.

Existing monitoring wells were redeveloped from January through July 1993. Redevelopment consisted of bailing several gallons of water from the bottom of the well to remove loose sediment, then alternately pumping and surging with a 2-in. diameter submersible pump. Development was considered complete when three consecutive measurements of pH, specific conductance, and temperature were stable, and turbidity stabilized at less than 25 nephelometric turbidity units (NTU). Miscellaneous other maintenance (labeling, concrete pad repair, and others) also was performed on existing wells, as necessary.

Drilling

To supplement the existing monitoring wells and complete the ground-water-monitoring network, USGS initiated a drilling program in March 1993. Results of the drilling program are summarized in the section entitled “Geologic findings.”

Most of the boreholes were drilled using the rotasonic drilling technique. The rotasonic method was chosen because of its rapid drilling rate, continuous and relatively undisturbed lithologic samples, relatively small volume of drill cuttings, and clean operating conditions (Wright and Cunningham, 1994). The rotasonic drill rig has a sonic vibratory head, which combines rotation and high-frequency vibration to advance a dual line of drill pipe. A 4-in. diameter core barrel with a carbide button bit was attached to the inner string of drill pipe. During drilling, the core barrel was advanced ahead of the drive casing in 10- to 20-ft increments to collect a continuous geologic

Table 3. Summary of field tasks for the Basewide Monitoring Program, Wright-Patterson Air Force Base, January 1993–September 1994

[EPA, Environmental Protection Agency]

Task	Dates	Comments
Inspection of existing wells	January - March 1993	Determined usability
Redevelopment of existing wells	January - July 1993	Many wells not sampled in 5+ years
Drilling program/well installation	March - July 1993	Rotasonic & hollow stem auger
Well development	April - August 1993	
Dedicated pump installation	April - August 1993	Grundfos[1] Redi-Flo II with Teflon tubing
Surface-water and streambed-sediment network establishment	June 1992	
Measurement of water levels	July 1992 - March 1995	Monthly
Surveying	August - October 1993; December 1993 - February 1994	Established measuring point altitudes and locations
Ground-water sampling	August - September 1993	103 wells[2], Ohio EPA oversight
	October 1993 - January 1994	93 wells
	April 1994	73 wells
	August - September 1994	42 wells
Surface-water sampling	August 1993	21 locations, Ohio EPA oversight
	November 1993	22 locations
	August 1994	24 locations, storm event
	September 1994	18 locations
Streambed-sediment sampling	August 1993	25 locations
	November 1993	22 locations, Ohio EPA oversight
	April 1994	25 locations
	September 1994	25 locations

1 - Use of trade names is for identification purposes only, and does not constituted endorsement by the U.S. Geological Survey.
2 - The number of wells and locations sampled by the U. S. Geological Survey, not including those sampled by other organizations.

sample. No drilling fluid was used in the coring process. Following coring, 6-in. diameter drill casing was advanced outside the drill pipe and core barrel to serve as an outer casing. Typically, between 10 and 100 gal of drilling fluid (water) were added to advance each interval of outer drill casing. The core barrel was then withdrawn from the borehole and the sample extruded into a plastic sleeve. The plastic sleeve containing the geologic sample was transferred to a sample stand for examination. Small holes were slit in the plastic every few feet and the core was screened for organic vapors with hand-held organic vapor analyzers (OVA), one having a photoionization detector (PID) and the other a flame ionization detector (FID). Soil samples that were to be screened for the presence of volatile organic compounds (VOCs) (see next paragraph) were collected through additional slits. The plastic sleeve of the core then was opened completely, and the lithology examined and described in a log book. A composite sample of the drill cuttings was collected at 5-ft intervals from land surface to the total depth of each borehole for lithologic archiving and grain-size analysis.

All field observations were recorded in log books specially designed for the project.

The first borehole at each cluster was drilled to bedrock. In each bedrock borehole, soil samples were collected to screen for selected VOCs using a portable gas chromatograph (GC). These samples were collected at 5-ft intervals starting at land surface, at major lithologic breaks, and at depths thought to contain organic compounds based on the PID and FID readings. The field screening was used to determine vertical and lateral extent of contamination and to aid in placement of well screens for best interception of possible contaminants. Following the PID and FID scan of each plastic-encased core, another small hole was cut into the sample sleeve and a stainless-steel scoop used to remove 5 - 10 g of soil from the center of the core. This sample was placed in a labeled, 40-mL glass vial, sealed with a Teflon lid, chilled, and transported to the USGS field laboratory. At the field laboratory, the sample vial was placed in a 50 °C water bath and allowed to equilibrate for at least 3 minutes. The sample was then agitated for 1 minute and 250 μL of air was withdrawn from the headspace for analysis. The headspace air was analyzed using a Photovac 10S Plus portable GC, which was capable of detecting a variety of VOCs. The following VOCs were targeted during field screening: carbon tetrachloride; chloroform; 1,1,1-trichloroethane; trichloroethylene; tetrachloroethylene; benzene; toluene; ethylbenzene; and meta-, para-, and ortho-xylenes (reported as total xylenes). The method for field screening was based on U.S. Environmental Protection Agency (USEPA) method 3810 (U.S. Environmental Protection Agency, 1986).

During drilling at three clusters (DG1, DG1A, and DG3), ground-water samples were collected and screened for VOCs using a portable GC, in support of the OU6 investigation being conducted by EM contractors. To collect the samples, the drill crew replaced the core barrel with a stainless-steel well point and lowered the well point through the outer casing to the bottom of the hole. The outer casing was then raised a few feet to expose the screen to the target zone. A 2-in. submersible pump was lowered through the drill stem into the water, and three casing volumes plus the volume of drilling water added while advancing the last string of casing was purged from the well point. The pump then was removed and a ground-water sample collected with a Teflon bailer. The water sample was poured into a labeled 40-mL glass vial, sealed with a Teflon lid, stored on ice, and transported to the USGS field laboratory. At the field laboratory, about 15 mL of water was removed from the vial; the remainder was allowed to equilibrate in a 50 °C water bath for at least 3 minutes. The sample was removed from the water bath and shaken for 1 minute; 250 μL of air were withdrawn from the headspace for analysis. The VOCs analyzed were the same as those for the soil headspace analyses.

After reaching total depth, each borehole was logged to bedrock with a natural-gamma probe. The geophysical log was displayed on a screen and was recorded on paper for later examination. The natural-gamma log was used to supplement the lithologic log and to estimate relative clay content of the geologic units.

After completion of the bedrock borehole at each cluster, the lithologic log, gamma log, and field-screening analytical results were used to determine screen-placement intervals and the number of wells to be installed at that cluster. Once the screened intervals were selected, grain-size analyses were done on the lithologic samples from each screened interval. The analyses were done by placing a sediment sample of known weight on a series of sieves having decreasing mesh sizes from top to bottom. As the sieves were shaken, the sample separated according to mesh sizes. The weight of the sample remaining on each sieve was converted to a percentage of the total sample weight, and the data graphed as percentage finer by weight and grain size. The grain-size distributions from the sieve results were used to select the appropriate slot size for each well screen.

Three of the shallow boreholes (MT-234, MT-235, and MT-238; see table 4 at back of report) were drilled with a 3.75-in. inner diameter hollow-stem auger driven by a Mobile Drill B40 drilling rig. Formation samples were collected with a 2-ft long, 2-in. diameter split-spoon drive sampler. Soil samples were obtained at 5-ft intervals by driving the split-spoon sampler ahead of the lead auger into the undisturbed stratum.

Monitoring Well Installation and Development

Thirty-six of the 42 boreholes drilled during the BMP were converted to monitoring wells at 15 well clusters; all of these wells were completed in the glacial aquifer. Each cluster consisted of a well screened at the water table and one or more intermediate wells screened in the glacial deposits. Boreholes not converted to wells were filled from total depth to land surface with bentonite pellets or with cement grout containing 5 percent bentonite powder. These abandoned boreholes were filled with grout using a tremie pipe while the outer casing was incrementally removed. Monitoring wells were constructed with 2-in. diameter, flush joint, schedule 5, type 304 stainless-steel well casing, with a section of flush joint wire-wrapped well screen coupled to the bottom. Wells open to the water table were constructed using 15-ft screens that straddled the water table; all other wells were constructed with 10-ft screens. Slot sizes were 0.010 or 0.015 in., and were chosen to retain 99 percent of the filter pack, based on grain-size analyses. Construction details of the monitoring wells (including those drilled prior to the BMP) are included in table 4.

The monitoring wells were installed through the inside of the outer drill casing to the desired depth. Boreholes that were drilled deeper in consolidated sediments than the desired depth of the well were backfilled with bentonite pellets and at least 2 ft of sand to fill the hole to the desired depth. In noncohesive sediments, the outer drill casing was pulled to the desired depth and formation material allowed to collapse. After the well was set, filter pack was placed around the well screen to about 3 ft above the top of the screen while the outer casing was slowly removed. A bentonite pellet seal at least 3 ft thick was installed above the filter pack. The remaining annular space was filled with 1:20 bentonite slurry using the tremie method, while the outer drill casing was removed incrementally. A 5-ft protective steel casing with a hinged lockable lid and a weep hole was placed over each well. A sloping concrete pad was constructed around each well to prevent surface-water intrusion. A brass survey pin was established in each concrete pad for identification and survey purposes. Three or more steel guard posts were installed around each well. Specific construction details for each well were recorded in well-construction log books. Borehole logs, well-construction logs, and soil and water GC logs were compiled in a standard format for new and existing wells and were provided to WPAFB (Sarver, 1993).

The newly drilled wells were developed in the manner described previously. Development was considered complete when three consecutive measurements of pH, specific conductance, and temperature were stable, and turbidity stabilized at less than 25 NTU.

All water produced during well development, and later during decontamination activities and the first two ground-water-sampling periods, was contained at the field site and transferred to large holding tanks at a Base storage location. When the tanks were filled, the waste water was sampled and analyzed. Waste-water results were relayed to city of Dayton personnel; following their approval, all waste water was discharged to a sanitary sewer. During subsequent ground-water-sampling periods, purge water from selected wells was discharged to the ground based on previous analytical results.

Surface-Water and Streambed-Sediment Networks

Surface-water and streambed-sediment-sampling locations were established in June 1992. Photographs of each location were taken and maintained on file. Each location was inspected for accessibility; detailed directions were written for locations that were difficult to find. Safety precautions concerning traffic conditions, bank steepness, or other hazards were compiled for each location. Specific reaches that were optimal for discharge measurements and (or) sample collections were noted and marked for each location.

Reference marks for stream-stage measurements and sample-collection points were established for locations at bridges or near other permanent structures. These reference marks were not surveyed.

Data Collection

Hydrologic and water-quality data were collected during the BMP to support project goals pertaining to the effects of WPAFB on regional flow systems. This section addresses the methods used to measure water levels in wells and to collect environmental samples of ground water, surface water, and streambed sediment.

Water-Level Monitoring

Water levels were measured monthly in 109 wells in the ground-water network unless weather conditions prevented access to the wells. The water levels were measured by use of electric tapes, which were marked in 0.01-ft increments. Following each measurement, the electric tape was cleaned with methanol and rinsed with deionized water to prevent cross-contamination. The water-level port of the well cap was used as the measuring point for most wells. A measuring point on each well (top of stainless-steel well casing or water-level port) was established. The location and altitude of the measuring point and brass survey pin in the concrete pad of each well were surveyed. Water levels (depth below measuring point) were converted to altitudes (above sea level) by subtracting the measured depth to water from the altitudes of the measuring points. The water-level network includes six wells equipped with automatic water-level recorders (fig. 5). Two of the recorders (on GR-208 and GR-210, established in August 1989) are within 900 ft of Mad River and provide a means of examining interaction between ground water and Mad River. Recorder well GR-248, established in June 1989, is located in OU-2. Two of the wells (GR-330 and GR-332, established in April 1991) are located in cluster USGS6. Recorder well GR-329 was established in December 1992 and is the only recorder well located in Area B (at cluster USGS13). All these wells are equipped with data recorders to monitor hourly water levels and water temperatures. Three of the wells (GR-329, GR-330, and GR-332) also are equipped with sensors that measure specific conductance hourly. All water-level data are published in the yearly Water Resources Data for Ohio reports (Shindel and others, 1989-1994).

Ground-Water Sampling

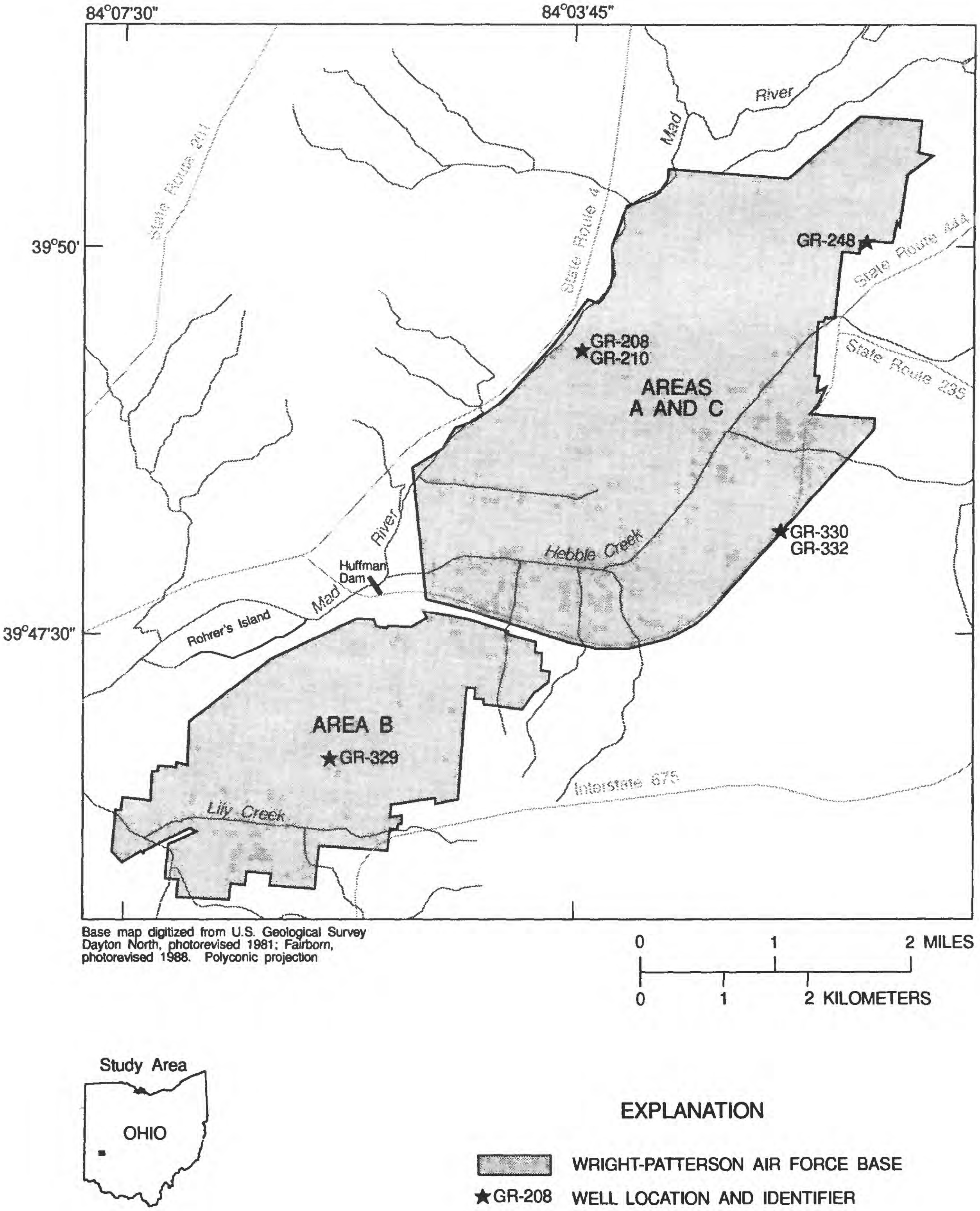
Ground water was sampled during periods in the first year of the BMP (table 3). Successively fewer wells were sampled during each sampling period on the basis of previous analytical results and consultation with an EM representative. The analyte list also varied slightly for each period. To avoid duplication of effort, the USGS and EM contractors coordinated ground-water sampling at locations common to the BMP and OU investigations. After sampling and analysis, the appropriate data were provided to the USGS for inclusion in the BMP.

After well development was completed, most monitoring wells were equipped with dedicated 2-in. diameter, variable flow rate Grundfos Redi-Flo II submersible pumps. Each dedicated pump installation consisted of the pump (constructed of type 316 stainless-steel and Teflon components), Teflon riser tubing, Teflon-coated power cord, and Teflon-coated stainless-steel safety wire attached to a well-cap assembly. Prior to pump installation, depth to water and total depth of the well were measured. The pumps generally were installed at the top or just above the screened interval; in low-yielding wells, the pump was placed near the bottom of the screened interval. Wells in some OU's were not equipped with dedicated submersible pumps because of program requirements for the OU studies.

Prior to purging and sampling, depth to water was measured to the nearest 0.01 ft. The volume of standing water in a well and the filter pack below the well seal were calculated as one purge volume. At least three purge volumes were removed from each well to replace stagnant water in the well with fresh water from the water-bearing formation. Specific conductance, pH, temperature, and concentration of dissolved oxygen were monitored in a flow-through cell with a multiprobe meter during purging. Turbidity of the purge water was measured with a turbidimeter. Prior to sample collection, the flow rate was decreased to about 0.7 L/min and the flow-through cell disconnected. The water sample then was collected by filling the pre-preserved sample containers directly from the dedicated discharge tubing, in accordance with standard operating procedures outlined in the BMP Work Plan (Cunningham and others, 1993). Samples for filtered metals and gross alpha/gross beta analyses were filtered directly into pre-preserved sample containers through disposable in-line filters (2.5 micron and 0.45 micron, respectively) attached to the end of the discharge tubing. After collection, the samples were chilled and shipped by overnight courier to the contract laboratory (Quanterra Environmental Services, West Sacramento, California) for analysis. Compounds for which ground-water samples were analyzed are listed in table 5; various subsets of these compounds were analyzed for each sampling period. Analytical procedures followed by the laboratory for sample analysis were in accordance with the standard operating procedures outlined in the BMP Work Plan (Cunningham and others, 1993). Analytical data packages met contract laboratory program (CLP) reporting requirements, where applicable.

Surface-Water and Streambed-Sediment Sampling

Surface-water and streambed-sediment samples were collected four times from August 1993 to September 1994 (table 3). Three of the locations (NPDES-1, NPDES-2, and NPDES-3) (fig. 4) were not sampled for streambed sediment because these locations are culverts that trap no sediments. Several surface-water locations were dry during sampling periods, and were not sampled. One sampling round was made at high flow during a storm that produced



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 5. Locations of wells equipped with hourly recorders, Wright-Patterson Air Force Base, Ohio.

Table 5. Methods of ground-water and surface-water-quality analysis

[PCBs, polychlorinated biphenyls; CLP, contract laboratory program; ICP, inductively coupled plasma; --, not applicable]

Type of analysis	Method	Comments
Volatile organic compounds	C8240 (CLP)	34 compounds
Semivolatile organic compounds	C8270 (CLP)	64 compounds
Organochlorine pesticides and PCBs	C608 (CLP)	28 compounds
Chlorinated herbicides	SW8150	10 compounds
Gross alpha and gross beta	SW9310	- -
Total petroleum hydrocarbons	E418.1	- -
Inorganic anions	E300	5 compounds
ICP metals	C200.7 (CLP)	18 metals
Arsenic	C206.2 (CLP)	graphite furnace
Lead	C239.2 (CLP)	graphite furnace
Mercury	C245.1 (CLP)	cold vapor extraction
Selenium	C270.2 (CLP)	graphite furnace
Thallium	C279.2 (CLP)	graphite furnace
Total Cyanide	C335.2 (CLP)	- -

extensive runoff. Contractors working in OU6 sampled UGS-1, SW-28, and SW-30 during round 2 for surface-water and streambed-sediment quality, and provided the analytical results to the USGS.

Streambed-sediment samples were collected at each sampling station from one or more points of deposition across a stream transect. Streambed-sediment samples were collected using a stainless-steel scoop, transferred to a stainless-steel bowl, and composited using the scoop. Sample jars were filled with composited material from the bowl. Samples for VOC analysis were not composited, but were grabbed directly from one of the sediment traps.

Surface-water samples were collected on the basis of methods that depended on the surface-water body, width, depth, and rate of discharge. When conditions warranted, surface-water quality and suspended-sediment samples were collected on the basis of the equal-width-increment method (Edwards and Glysson, 1988; Ward and Harr, 1990). A depth-integrated sampler consisting of a Teflon bottle and nozzle was lowered to the bottom of the stream and raised back to the surface at an equal transit rate at about 20 verticals equally spaced across the stream. The volume of sample collected at each vertical was therefore proportional to the flow at that section, resulting in a discharge-weighted sample (Edwards and Glysson, 1988). The number of vertical samples collected across the stream transect depended on stream width. In many cases, however, streams were too shallow or velocities too low to collect depth-integrated, discharge-weighted samples, and the sample was collected by filling the Teflon bottle (without a nozzle) several times at one location on the stream transect. Samples for VOC analysis were collected as a grab sample. All normal environmental samples except those for VOC analysis were composited in a Teflon-coated stainless-steel churn splitter; samples paired with quality-assurance/quality-control samples (such as replicates or spikes) were composited using a cone splitter because of the high volume (greater than 5 gal) of water needed. Suspended-sediment bottles and sample bottles for water quality were filled from the splitter after compositing. Samples for filtered metals and gross alpha/gross beta analyses were filtered from the churn with a peristaltic pump, silicone tubing, and a disposable in-line 0.45 micron filter. Field measurements for specific conductance, pH, temperature, and dissolved oxygen were taken directly from the surface-water body during sampling with a multiprobe meter.

After collection, the surface-water quality and streambed-sediment samples were chilled and shipped by overnight courier to a contract laboratory for analysis. Master lists of compounds for which surface-water and streambed-sediment quality samples were analyzed are provided in tables 5 and 6, respectively. Subsets of these compounds were analyzed during each sampling period. Data were reported according to USEPA's Contract Laboratory Program (CLP) when applicable. Suspended-sediment samples were shipped to another contract laboratory for analysis.

Quality-Assurance and Quality-Control Measures

Many measures were implemented by the USGS during data collection to ensure that appropriate levels of quality assurance (QA) and quality control (QC) were achieved. These QA/QC measures served to ensure the quality, precision, accuracy, completeness, and representativeness of data generated during the BMP. This section addresses QA/QC measures followed during the field program and a summary of the data-validation process.

Field Program

All water used during the field program was obtained from an on-Base hydrant (Base drinking water that had been filtered through a cascade system of carbon-bed treatment cylinders). Water from this source was analyzed for the complete suite of chemical constituents prior to initiation of, and periodically during, the field program. Deionized water used for decontamination was obtained from the USGS - Ohio District office; this water also was sampled and analyzed periodically.

After videotaping of the boreholes, the videocamera and cable were placed on plastic sheeting and rinsed with laboratory-grade detergent solution and deionized water.

All drilling equipment (such as drilling rig, tools, and casing) was steam cleaned at the beginning of the drilling program in a designated decontamination area designed to contain decontamination wastes and waste waters. Between boreholes at each cluster, the back of the rig, core barrel, and drill casing were steam cleaned at the drill site. Between clusters, the rig was taken to the decontamination area, where the entire rig, tools and casing were thoroughly steam cleaned. Petroleum-free Teflon was the only lubricant used during drilling, and only sparingly. Soil cuttings and drilling water generated during drilling were contained in drums or waste-water-storage tanks and transported to a central location, where they were stored pending EM approval for proper disposal. QA/QC measures for collection of water samples during drilling consisted of steam cleaning the stainless-steel well point between each use, cleaning the submersible pump and tubing by washing with laboratory-grade detergent solution followed by deionized water rinse, and using disposable Teflon bailers for sample collection. The well casings and screens were steam cleaned prior to installation to remove potential contaminants. Addition of water to the borehole during well installation was minimized to reduce the potential for introducing contaminants to the aquifer. During well development, the outside of the submersible pump and tubing was washed with a laboratory-grade detergent solution and rinsed with copious amounts of deionized water. The inside of the pump and tubing was decontaminated by circulating detergent solution followed by deionized water.

Field personnel wore surgical gloves during collection of soil samples for field screening with the portable GC. The stainless-steel scoops used to collect the soil samples were decontaminated with a laboratory-grade detergent wash, rinsed with deionized water, rinsed with methanol, rinsed several times with deionized water, allowed to air dry, and wrapped in aluminum foil until used again. Field instruments were calibrated daily, and calibration notes recorded. QA/QC samples were included in the soil and ground-water-sampling protocol for field screening with the portable GC. Fifteen percent of all samples were replicates; 5 percent were matrix spike/matrix spike duplicates.

Guidelines for decontamination of equipment used to sample surface water and streambed sediment were established and strictly followed. The stainless-steel bowls and spoons for streambed-sediment collection were decontaminated by the following procedure at the USGS office prior to each sampling period: detergent solution wash, deionized water rinse, 10 percent nitric acid rinse, deionized water rinse, methanol rinse, hexane rinse, and several deionized water rinses. Sufficient bowls and spoons were available so that no decontamination was necessary in the field. During

Table 6. Methods of streambed-sediment-quality analysis

[PCBs, polychlorinated biphenyls; CLP, contract laboratory program; ICP, inductively coupled plasma; --, not applicable]

Type of analysis	Method	Comments
Volatile organic compounds	C8240 (CLP)	34 compounds
Semivolatile organic compounds	C8270 (CLP)	64 compounds
Organochlorine pesticides and PCBs	C8080 (CLP)	28 compounds
Chlorinated herbicides	SW8150	10 compounds
Total petroleum hydrocarbons	E418.1	--
ICP metals	C200.7 (CLP)	18 metals
Arsenic	C206.2 (CLP)	graphite furnace
Lead	C239. 2 (CLP)	graphite furnace
Mercury	C245.1 (CLP)	cold vapor extraction
Selenium	C270.2 (CLP)	graphite furnace
Thallium	C279.2 (CLP)	graphite furnace
Total cyanide	C335.2 (CLP)	--

surface-water sampling, the Teflon churns and peristaltic pump tubing for filtering were decontaminated using the steps outlined above for streambed-sediment equipment.

Several steps were taken to minimize contamination and degradation of ground-water samples collected for chemical analysis. The potential for cross-contamination during ground-water sampling was eliminated by the installation of dedicated pumps. Surgical gloves were worn by field personnel during sampling and were changed frequently. Ground-water samples were collected into laboratory-prepared, pre-preserved containers and were immediately chilled to minimize the potential for sample degradation.

The sample numbers assigned to environmental samples collected by USGS were designed to be unique, to provide information about the type of sample collected, and to facilitate database query. Each USGS sample number consisted of AAAAABBCCD-DDDDD, as defined below.

AAAAA-	Sample id (GR###, MT### = well number; UGS##, DGS##, INT##, SW0##, NPD## = surface water site; TB100 = trip blank; EB### = equipment blank; AB### = ambient blank; MB### = method blank)
BB-	Type of sample (01 = ground water, 02 = surface water, 03= streambed sediment, 04 = blank water)
CC-	QA information (01 = regular, 02 = field duplicate, 03 = equipment-rinsate blank, 04 = ambient blank, 05 = trip blank, 06 = matrix spike, 07 = matrix-spike duplicate, and 08 = resampled)
DDDDDD	year, month, day

For example, GR4340102931108 was a ground-water field-duplicate sample collected on November 8, 1993, from well GR-434. Sample UGS060307940912 was a streambed-sediment matrix-spike duplicate collected from site UGS-6 on September 12, 1994. Sample labeling, packaging, handling and chain of custody

Table 7. Sampling schedule for quality-assurance and quality-control samples

Matrix	Trip blanks	Field duplicates or replicates	Equipment-rinsate blanks	Matrix spike/ matrix-spike duplicates	Ambient blanks	Method blanks
Ground water	1 per day	1 per 10 samples	One[1]	1 per 20 samples	1 per period	3 total
Surface water	1 per day	1 per 10 samples	1 per 10 samples	1 per 20 samples	1 per period	0
Streambed sediment	0	1 per 10 samples	1 per 10 samples	1 per 20 samples	1 per period	0

1 - An equipment-rinsate blank was performed on a pump prior to installation; the pumps were certified clean by the manufacturer prior to shipment.

procedures outlined in the BMP Work Plan (Cunningham and others, 1993) were strictly followed.

As a quality-control check on field activities (including sample collection, containment, shipping and handling) and laboratory precision and bias, several types of field QC samples accompanied the environmental samples to the laboratory during each sampling period. These samples included trip blanks, ambient blanks, equipment-rinsate blanks, matrix spike/matrix-spike duplicates, field duplicates and replicates, and method blanks. The number of field QC samples associated with each medium is summarized in table 7. Field QC samples were analyzed for all target parameters of the specific sampling period, except trip blanks and method blanks which were analyzed only for VOCs.

Ohio EPA provided on-site oversight periodically during the USGS field program. Personnel from Ohio EPA visited several times during the drilling program to observe the drilling procedure and obtain progress reports. Concurrently with USGS sampling at a given location, Ohio EPA personnel collected samples to be sent to a separate laboratory at least once during sampling of each medium.

All field work and procedures performed during data collection were thoroughly documented in project log books and (or) on the appropriate log forms. Field documentation was reviewed periodically for completeness and accuracy. This documentation is maintained on file at the USGS - Ohio District office.

Data Validation

For all sampling periods during the BMP, 100 percent of the analytical data generated by the analytical laboratory were validated to determine completeness of data-package deliverables and achievement of project-specific data-quality objectives. An independent environmental firm was contracted by the USGS to perform most of the data-validation services for the BMP. The data were validated at Hazardous Waste Remedial Actions Program (HAZWRAP) Level C, at a minimum, as defined in the Quality Assurance Project Plan (QAPjP) included in the 39 Sites RI/FS Work Plan (Engineering-Science, 1990). The standard operating procedures for data validation detailed in the QAPjP are based on USEPA and HAZWRAP guidelines. Quality-control criteria evaluated during data validation included items such as holding times, sample-quantitation limits, instrument tuning and calibration, field quality-control samples, and laboratory-analysis procedures. The results of data validation were used to determine the need for re-sampling and analysis and to determine data usability (unusable, qualitative, or quantitative).

All of the samples collected by USGS at WPAFB were processed and analyzed in sample delivery groups (SDGs) consisting of 20 or fewer samples collected from one or more sampling locations, generally on a given day or within several days. Numerous laboratory quality-control samples were analyzed with each SDG. During data validation, each SDG was evaluated independently, and separate data-validation reports prepared for each SDG. Each data-validation report included detailed results of the data validation, review comments, and the analytical results with laboratory flags and data-validation qualifiers listed. Data-validation results for each sampling period were summarized for WPAFB by the USGS for that period. Complete analytical data packages and individual data-validation reports for each SDG are on file at the Ohio District office of the USGS.

After the laboratory analytical results were validated, data-qualifier codes were applied to the data to qualify specific analyte results if sample analysis did not meet acceptance criteria specified in the project

QAPjP. Applicable data-qualifier definitions applied during data validation were as follows:

R - The sample results were rejected due to serious deficiencies in the ability to analyze the sample and meet quality-control criteria. The presence or absence of the analyte cannot be verified.

J - The analyte was positively identified; however, quality-control results indicated that the reported concentration may not be accurate. The associated concentration of the analyte was approximate.

U - The analyte was analyzed for, but was not detected above the reported sample-quantitation limit.

UJ - The analyte was not detected above the reported quantitation limit. However, the reported quantitation limit was approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

N - The analysis indicated the presence of an analyte where presumptive evidence is present to make a "tentative identification."

NJ - The analysis indicated the presence of an analyte that had been "tentatively identified" and the associated concentration was approximate.

These data qualifiers were applied and reported with the validated data, as applicable.

Several quality-control deviations were more common than others during data validation. Most deviations concerned exceedances of limits on percent recoveries and other controls of laboratory QA/QC samples: furnace post-digestion spike recoveries; matrix-spike percent recoveries; continuing calibration percent recoveries; dilution percent recoveries; and analytical spike percent recoveries. The data affected by these deviations were qualified as estimated detects (J) or estimated nondetects (UJ). Poor recoveries of surrogate compounds and internal standards caused results of some analyses of organic compounds to be flagged as estimated (J).

A second type of QA/QC deviation that resulted in the qualification of data was the presence of compounds in laboratory and (or) field blanks. When compounds were detected in blanks at concentrations similar to those in the samples, the data were flagged as undetected (U) with the detection limit raised to the level of contamination in each sample. This type of deviation occurred throughout all four rounds and all three matrices; commonly detected compounds in blanks included:

- the VOCs methylene chloride, acetone, 2-butanone, and 2-methyl-2-pentanone;
- phenol in streambed-sediment samples from round 2;
- some semivolatile organic compounds (SVOCs) in streambed-sediment samples from round 4;
- zinc in water samples from rounds 1, 2, 3, and 4;
- manganese in water samples from rounds 2, 3, and 4;
- copper in water samples from rounds 3 and 4;
- aluminum, antimony, and potassium in water samples from round 4;
- and a few other isolated compounds.

The third type of QA/QC deviation was the exceedance of holding times for some samples. In many cases, holding times were exceeded for a sample that was reanalyzed for reasons pertaining to other QA/QC problems, such as exceedance of percent-recovery limits. In cases such as these, the laboratory reported to the USGS only the results in which they had more confidence; all of the results, however, were subject to validation by the contracted firm. Gross exceedances of holding times caused data to be rejected (R); minor exceedances caused data to be considered estimated (J). Pesticides in water from NPDES-4, round 1, were not analyzed due to a scheduling error. Results that were qualified due to holding-time exceedances (not including data from reanalyzed samples) include:

- pesticides from one SDG, streambed sediment, round 1 (6-8 days over, estimated (J));
- five herbicides, surface water, NPDES-12, round 1 (11 days over, estimated (J));
- five rerun herbicides, surface water, 12 locations, round 1 (1-6 days over, estimated (J));
- total petroleum hydrocarbons, streambed sediment, DGS-7, round 2 (minor, estimated (J));
- all pesticides, streambed sediment, round 3 (minor, estimated (J));

- cyanide, streambed sediment, NPDES-12, round 3 (minor, estimated (UJ));
- nitrates and nitrites, surface water, nine locations, round 3 (minor, estimated (J));
- SVOCs, surface water, NPDES-13, round 4 (minor, estimated (J));
- SVOCs, ground water, GR-216, round 4 (severe; all non-detects rejected (R), all detects estimated (J))

The distribution of samples collected, analyses performed, and compounds analyzed among ground-water, surface-water, streambed-sediment, and QA/QC matrices is shown in figure 6. Forty-four percent of the analyses were performed on ground-water samples; about 15 percent of analyses were performed on surface-water and streambed-sediment samples, respectively. Thirty percent of all samples (including blanks and spikes) were associated with QA/QC.

Also displayed in figure 6 is a chart showing completeness of data obtained during the BMP. The "rejected" category in figure 6d includes those data rejected during validation and the analytes affected by missed or broken samples. "Unqualified" data are those that required no qualifiers after data validation, whereas "qualified" data were subjected to qualification during validation. The BMP Work Plan (Cunningham and others, 1993) recommends at least 95 percent completeness of data; data collected during the BMP were 99.4 percent complete.

Data Management and Storage

The U.S. Air Force requires that all data associated with environmental management at its facilities be submitted to the Installation Restoration Program Information Management System (IRPIMS) for storage. IRPIMS is maintained at Brooks Air Force Base, Texas, by the Air Force Center for Environmental Excellence (AFCEE) and its contractors. Because WPAFB is an Air Force facility currently in IRP status, data collected at WPAFB as part of the BMP are subject to this submission requirement.

All data collected as part of the BMP were stored in a database designed by the USGS at its National Water Quality Laboratory (NWQL) in Arvada, Colorado. The design of the database addressed several aspects of this and other Air Force environmental programs to (1) meet on-site data-storage and retrieval needs; (2) relate all reference and locational data to the collection and analysis of a sample using relational database technology; and (3) download data into files that meet the submission requirements of IRPIMS. The database consists of three groups of tables: well and site information, analytical data, and QA/QC reference data. Tables comprising the well and site portion of the database pertain to well construction, lithology, sampling locations, and hazardous-waste sites. The analytical data, including sample identifiers, analytical methods, and results of normal and QA/QC samples, are stored in the chemical-data tables. Project-specific reference data, such as reporting limits, holding times, and regulatory standards for each constituent, are housed in the QA/QC part of the database.

Well and site information was stored in the database to enable analytical data to be related to the sampling locations and their characteristics, such as well depth or discharge rate. Data regarding locations and sites established on WPAFB before the BMP, but used for the BMP, were obtained from AFCEE. Other available data were converted into suitable formats, then loaded to the database. Water-level records were entered directly into the database through a data-entry screen.

Chemical reference data for the BMP were obtained from the NWQL after program requirements were determined by WPAFB, its regulatory agencies, and the laboratory. The data were loaded into the database and updated periodically to reflect changes in regulatory standards or project detection limits.

Analytical data were received from the laboratory on magnetic tape. Samples were reported in groups of no more than 20, distinguished as one "project" by the laboratory. After the data were downloaded, subsequent processing was needed to link the analytical data to the appropriate QA/QC reference and sample-collection data.

GEOLOGIC FINDINGS OF DRILLING PROGRAM

By Kathleen M. Sarver

A brief summary of the geologic setting around WPAFB is provided in the introduction to this report. In this section, a summary of the findings from the drilling program at WPAFB and new bedrock-surface-altitude data at WPAFB from the BMP and other recent studies are presented. The reader is referred to the following publications for more detailed information on the geologic setting near Dayton, Ohio: Norris and others (1948, 1950, and 1952); Walton and Scudder (1960); Norris and Spieker (1966); Dumouchelle (1992), and Dumouchelle and others (1993).

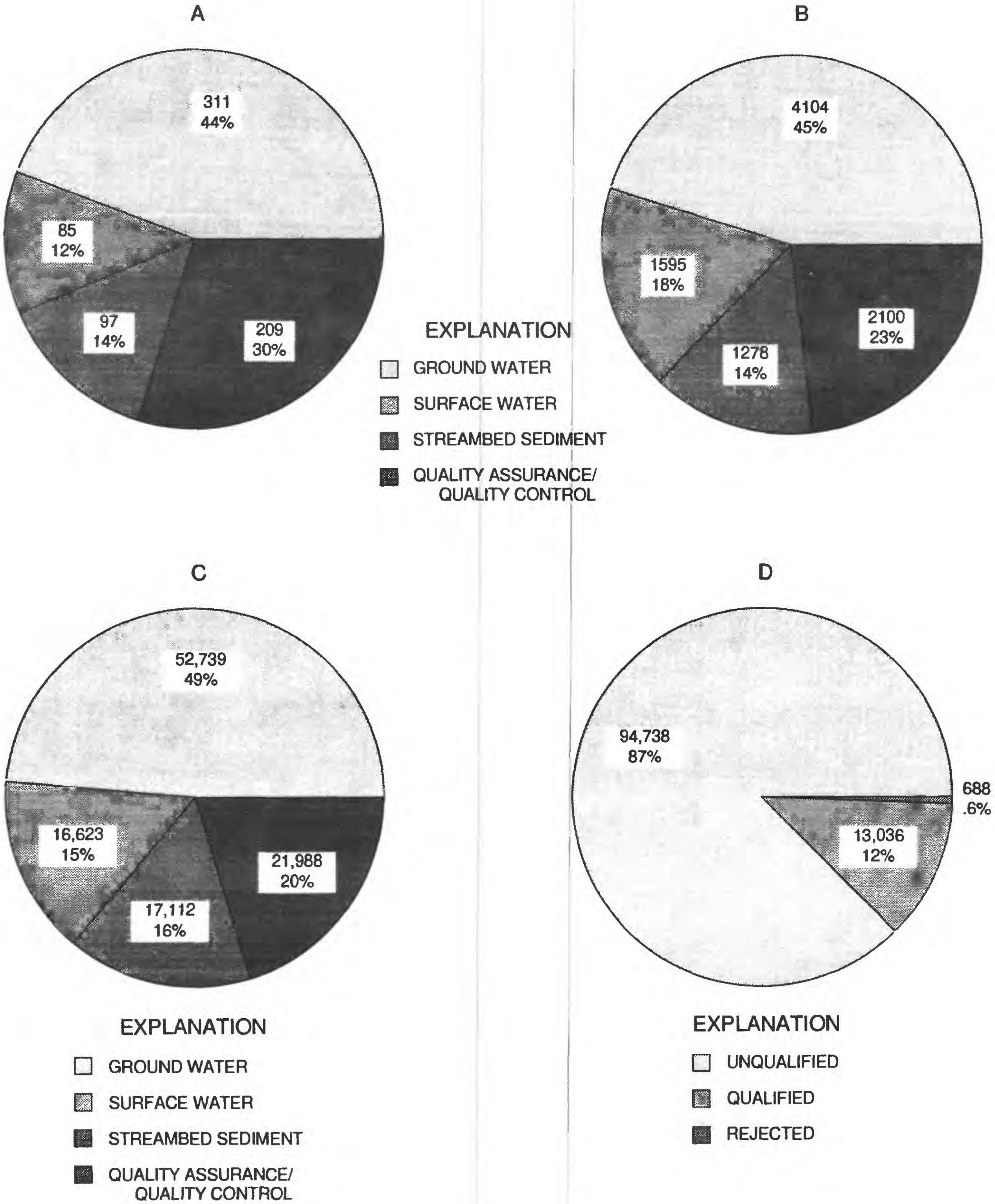


Figure 6. Data collected during the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio: (A) distribution of samples collected among matrices, (B) distribution of analytical methods among matrices, (C) distribution of analytes among matrices, and (D) completeness of data collected.

Table 8. Drilling summary for the Basewide Monitoring Program, Wright-Patterson Air Force Base

Administrative area	Number of boreholes	Number of boreholes to bedrock	Drilled depth (feet)	Drilled depth in unconsolidated sediment (feet)	Drilled depth in bedrock (feet)
Basewide	42	18	4,231	4,150.5	80.5
A and C	23	11	1,998	1,946.0	52.0
B	19	7	2,233	2,204.5	28.5

During the BMP, 42 boreholes were drilled at 18 cluster locations. The drilling program is summarized in table 8. The unconsolidated deposits encountered during the BMP consisted mainly of outwash deposits ranging from fine-grained sands to gravels. Lenses of predominately fine-grained clay or silt were sometimes present within the outwash deposits. Bedrock consisted of weathered shale or weathered shale with limestone interbeds, and ranged in color from whitish gray to dark greenish gray. Complete lithologic descriptions and other field observations are presented in Sarver (1993), and are not repeated here. The borehole depths and well-construction data at each cluster are provided in table 4.

Dumouchelle (1992) examined more than 1,000 well logs and soil borings to determine the altitude of top of bedrock in a 13-mi by 14-mi area near Dayton. Bedrock-surface altitudes were plotted on a base map and contoured at 50-ft intervals (fig. 7). Several deep buried valleys in the bedrock surface are shown on the map. The major buried valley trends generally north-south, but trends northeast-southwest beneath WPAFB. Several tributaries to the main bedrock valley also are delineated.

Since the completion of Dumouchelle's (1992) map, the BMP and other Base programs have obtained additional altitude data of the bedrock surface. Contours on the bedrock surface were drawn for areas where the understanding of the bedrock-surface configuration had altered significantly since 1992, due to geologic exploration done as part of the BMP and the other studies (fig. 7). Bedrock-altitude data were obtained from various sources.

During the BMP, 18 of the 42 boreholes drilled at WPAFB reached bedrock. Data from the 18 boreholes were used to update the bedrock-surface map of Dumouchelle (1992). The new bedrock-surface-data points used to update the bedrock-surface map are listed in table 9.

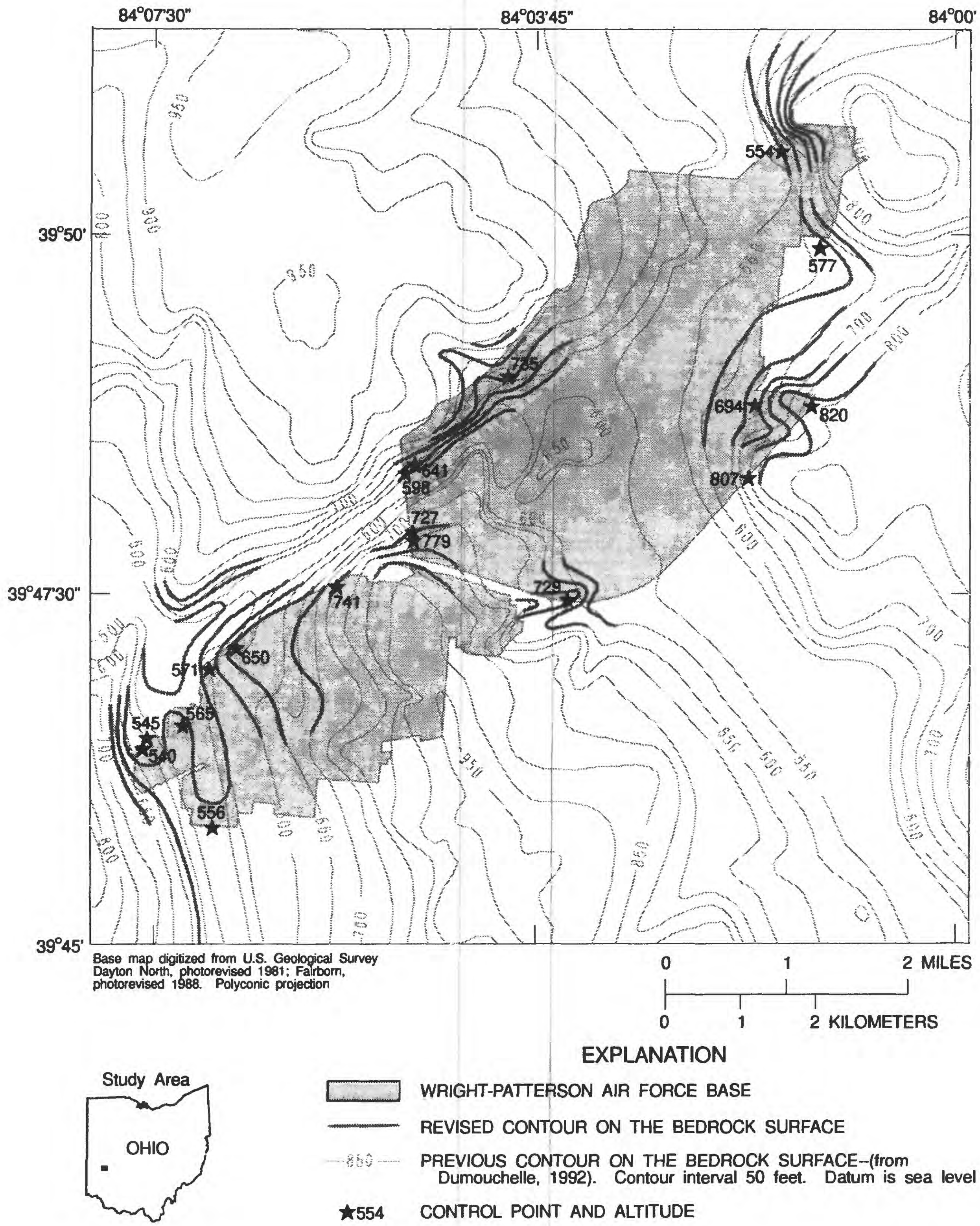
The most significant modification to the bedrock contours as a result of the additional data points is evident in the southwest part of Area B. Depth to bedrock ranges from 135 ft to 221 ft at clusters DG2, DG3, and DG4. To the southwest and southeast of Area B, bedrock was encountered at altitudes no lower than 540 ft above sea level. On the basis of seven additional bedrock data points, the location and delineation of a north-south trending bedrock valley in the southwest corner of Area B has been modified; these data points indicate that the altitude of bedrock is higher than 500 ft above sea level throughout most of that buried valley.

In the western part of Areas A and C, bedrock was encountered at 63 to 192 ft below land surface at 3 locations (clusters DG12, DG15, and DG16). As a result, minor revisions were made to the orientation of several contours, further delineating a small northwest-southeast trending bedrock valley tributary to the main bedrock valley.

In the eastern part of Areas A and C, depth to bedrock is less than 35 ft at UG9 and UG10, and was 137 ft at UG11. These points emphasize the presence of, and further define, a bedrock high east of the Base. Northeast of Areas A and C, the configuration of several contours was altered slightly based on the bedrock altitude at UG3. The bedrock altitude at UG2 was used to further define a northeast-southwest trending tributary valley. Other local changes were made to the bedrock contours in the southern portion of Areas A and C based on the bedrock altitudes at UG8, DG10, and DG10A.

HYDROLOGIC DATA

Ground-water, surface-water, and streambed-sediment data were collected at WPAFB to facilitate completion of the BMP objectives. In addition to the matrix-quality data that were collected as the core of the program, data pertaining to ground-water resources and streamflow are given below. Hydrologic



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

EXPLANATION

▨ WRIGHT-PATTERSON AIR FORCE BASE

REVISED CONTOUR ON THE BEDROCK SURFACE

850 PREVIOUS CONTOUR ON THE BEDROCK SURFACE--(from Dumouchelle, 1992). Contour interval 50 feet. Datum is sea level

★554 CONTROL POINT AND ALTITUDE

Figure 7. Previous and revised bedrock topography at Wright-Patterson Air Force Base, Ohio.

Table 9. Data points used to revise the bedrock-topography map, Wright-Patterson Air Force Base, Ohio

Cluster	Borehole	Administrative area	Depth to bedrock (feet below land surface)	Bedrock altitude (feet above sea level)
DG1	MT-239	B	240	545
DG1A	MT-236	B	242	540
DG2	MT-247	B	221	565
DG3	MT-245	B	211	571
DG4	MT-242	B	135	650
DG8	MT-248	B	52	741
UG1	MT-249	B	245	556
DG10	GR-418	A/C	12	779
DG10A	GR-428	A/C	64	727
UG8	GR-412	A/C	102	729
UG9	GR-427	A/C	17	820
UG10	GR-423	A/C	33	807
UG11	GR-430	A/C	137	694
UG2	GR-433	A/C	249	577
UG3	GR-424	A/C	272	554
DG12	GR-414	A/C	192	598
DG15	GR-419	A/C	147	641
DG16	GR-440	A/C	63	735

data used in this report were provided to WPAFB[1] and are available upon request.

Ground Water

Because ground water is important to the economy and welfare of the Dayton area, USEPA designated the Mad River buried valley aquifer system a sole-source aquifer in 1988 (U.S Environmental Protection Agency, 1993). Although much of the attention given to ground water commonly addresses concerns of quality, understanding the ground-water-flow system must be the foundation for any interpretations of water-quality data.

Some ground-water data collected during the BMP help to assess the aquifer as a resource. Characteristics such as water temperature, water levels, and flow gradients provide the data whereby recharge and discharge areas, directions of flow, and hydrologic conditions in and around hazardous-waste sites can be evaluated and addressed. Further, these characteristics can be used to prepare and calibrate a ground-water-flow model.

Temperature

Temperature and water-level traces for GR-208, GR-210, and GR-248 are shown on figure 8 (locations shown on fig. 5). The temperature traces indicate seasonal variations; generally, ground-water temperatures are coldest in May and warmest in November, lagging about 4 months behind seasonal extremes at the land surface (which are described in the introduction to this

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[1] Cunningham, W.L., 1994a, Round 1 technical memorandum, Basewide Monitoring Program, Wright-Patterson Air Force Base, 130 p. with appendices.

---- 1994b, Round 2 technical memorandum, Basewide Monitoring Program, Wright-Patterson Air Force Base, 121 p. with appendices.

---- 1994c, Round 3 technical memorandum, Basewide Monitoring Program, Wright-Patterson Air Force Base, 120 p. with appendices.

Schalk, C.W., 1995, Round 4 technical memorandum, Basewide Monitoring Program, Wright-Patterson Air Force Base, 123 p. with appendices.

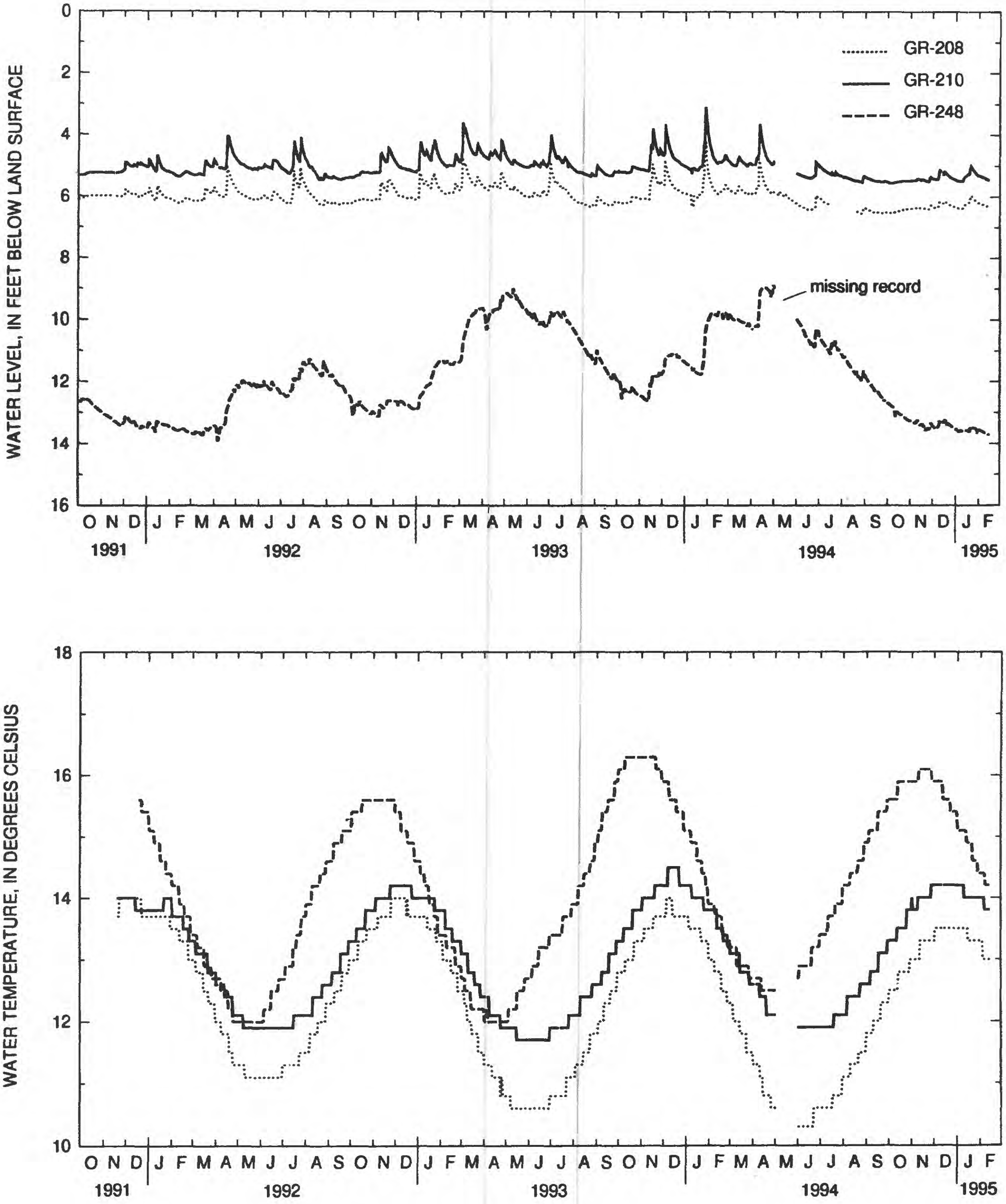


Figure 8. Graphs showing water levels and temperatures in wells GR-208, GR-210, and GR-248 at Wright-Patterson Air Force Base, Ohio.

report). Temperatures recorded at GR-248 have much higher peaks, shorter lag time, and wider range than do those at GR-208 and GR-210. These responses are because of direct solar radiation, which affects GR-248 because that well is shallow and is in an open area. GR-208 also is shallow, but it and GR-210 are in a heavily forested area, shielded from direct sunlight.

The temperature traces for GR-208 and GR-210 mimic one another, but temperatures in GR-208 (the shallower of the two wells) generally are cooler than those in GR-210. The water-temperature range in GR-208 is greater than that in GR-210 because GR-208, being shallower, is more likely to be affected by surface temperatures. Because GR-208 is shallower, temperatures in GR-208 do not lag as far behind surface temperatures as do those in GR-210.

Water Levels

By Robin M. Timmons

Water levels in GR-208 and GR-210 are affected by precipitation and by river stage (see Ground-Water and Surface-Water Relations). Ground-water levels near Mad River generally are stable; highs and lows are dampened because the stage in Mad River moderates the fluctuations of water levels in areas near the river. Because of the influence of the river, the water levels recorded at GR-208 and GR-210 cannot be used to calculate ground-water recharge accurately. Water levels in GR-248, however, can be used to estimate recharge rates because GR-248 is located away from the river and its effects. Dumouchelle and others (1993) used ground-water-recession data from GR-248 to estimate ground-water recharge from precipitation at 12.4 to 15.8 in/yr in the glacial deposits.

As described in the introduction to this report, till lenses and (or) layers in the glacial outwash were used to distinguish between shallow, intermediate, and deep parts of the glacial aquifer on WPAFB. Potentiometric maps were prepared using water levels measured in shallow and intermediate-depth wells during December 1993, May 1994, and October 1994 (figs. 9-14 at back of report). Additional water levels for the specified months from OUs 4, 6, and 10 (OUs are shown in fig. 2) were provided by the Base. Only wells screened in glacial sediments on WPAFB and in immediately adjacent areas were used.

Water levels in many parts of WPAFB were lowest (of the three reporting periods) in October 1994, and highest in May 1994. This results as precipitation during spring months generally provides greatest amounts of recharge to ground water, causing water levels to rise; and the autumn of 1994 was fairly dry and warm, providing little recharge to ground water. These water-level trends were more noticeable at intermediate depths, perhaps because of the additional effects of pumping at intermediate depths.

The area in which water levels fluctuated the greatest was in northwestern Area B. As noted above, water levels were highest in May 1994 at shallow and intermediate depths, and lowest in October 1994 at both depths. In December 1993, May 1994, and October 1994, water levels at intermediate depths were as much as 2.5 ft, 1.6 ft, and 6 ft lower, respectively, than water levels at shallow depths in northwestern Area B. Water levels in shallow wells in October 1994 were 6 to 8 ft lower than water levels in shallow wells in May 1994, and October intermediate-depth water levels were almost 11 ft lower than those in May 1994. Because of these fluctuations in water levels, the configuration of contour lines in that area are more variable than in any other area on WPAFB. Low water levels in December 1993 and May 1994 in northwestern Area B could be the result of pumping at the Mad River Well Field superimposed over natural hydrologic conditions. Pumping at Rohrer's Island affects the water levels in intermediate wells more than those in shallow wells because many of the Rohrer's Island wells are completed below the clay layer which separates shallow from deeper aquifers.

In other parts of WPAFB, relatively few differences between water levels at intermediate and shallow depths during each time period were observed. In OU5, water levels in most shallow wells were less than 1 ft different than those in intermediate-depth wells; in northeastern Areas A and C, water-level differences between shallow and intermediate-depth wells were about 1 ft in all 3 months.

Water levels measured in 1993 and 1994 were compared with those measured in 1987 (Schalk, 1992, not shown). For the most part, water levels have not changed appreciably during that 7-year span in the WPAFB area. The only significant differences between the map presented by Schalk and those prepared for the BMP are in the southwestern part of Area B. Water levels at 780 ft during the BMP were at about 760 ft during Schalk's study; however, more data were available for the BMP in OUs 4, 6, and 10 than had been available for the 1987 study. Therefore, the maps presenting 1993 and 1994 data are more detailed in those areas. Changes in pumping rates in wells at Rohrer's Island can affect water levels in wells closest to the center of pumping. Schalk used glacial and bedrock wells in the 1992 study to map water levels in a region much larger than WPAFB, whereas the scope of this study was limited to the Base.

Schalk (1992) concluded that the regional ground-water system is at steady state (that is, the volume of ground water in storage is constant), and the data presented here support that conclusion. Intermittent pumping and local recharge have minor effect on ground-water storage at a regional scale.

Flow Paths

Although the BMP did not include any ground-water-flow model development, a model developed previously (Dumouchelle and others, 1993) was used to help interpret water-quality data. A particle-tracking code was used to obtain information concerning the directions of flow from model output. A review of the model, its input-data sets, its assumptions, and its applications is warranted here. The model used in this study has been documented fully in Dumouchelle and others (1993) and Sheets (1994).

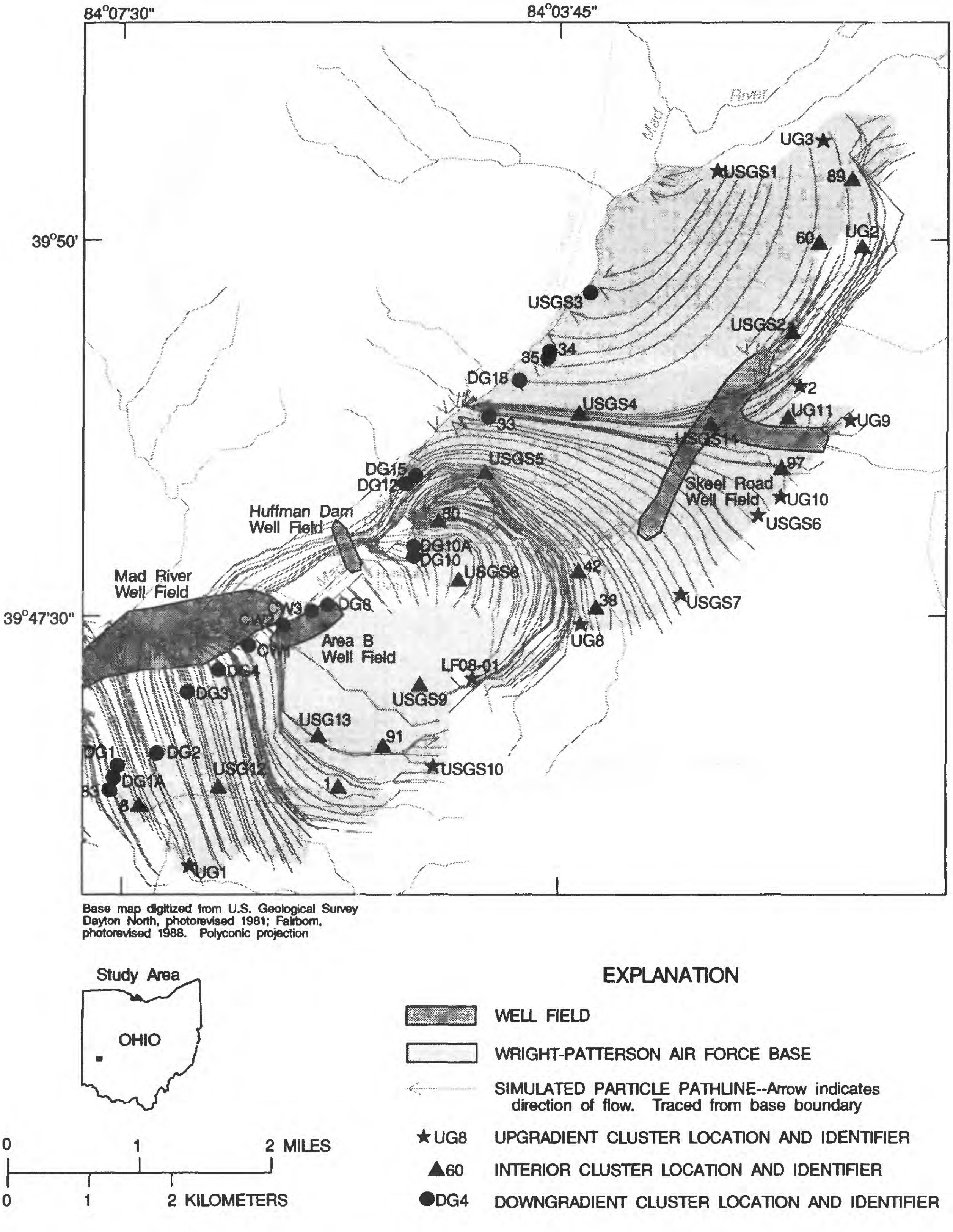
Cunningham and others (1994) summarize the model and particle-tracking program as follows:

> A three-dimensional ground-water-flow model calibrated to steady-state ground-water-flow conditions of October-December 1987 was developed by Dumouchelle and others (1993) for an area including the Base. The USGS computer code MODFLOW (McDonald and Harbaugh, 1988) was used for the simulation. The purpose of the model was, in part, to determine and evaluate sources and sinks of regional ground-water flow. These sources and sinks included the Mad River and its tributaries.
>
> The model consists of three layers that simulate ground-water flow in the buried-valley aquifer as well as in the upland bedrock. Layer 1 simulates the unconfined nature of flow in the uppermost part of the buried-valley aquifer and the entire permeable thickness of the upland bedrock aquifer. Layer 2 of the model simulates the central part of the buried-valley aquifer, in which most of the water-supply wells are completed. Layer 3 of the model simulates the part of buried-valley aquifer that is bounded by the bottom of layer 2 and by the impermeable bedrock underlying the valley. Layers 2 and 3 were modeled as confined aquifers. The presence of discontinuous deposits of poorly permeable clays and silts defines the boundaries between layers 1 and 2 and between layers 2 and 3. Lateral boundaries to ground-water flow were based on the locations of ground-water divides and surface-water bodies, and on calculated flux through valley cross-sections. The model was calibrated to water levels measured in 1987, results of a gain-loss study on the major rivers and tributaries, and vertical-gradient data collected at nested wells.

Pumping rates for the period of model calibration were obtained for all pumping centers producing more than approximately 10 gal/min. These centers are primarily in industrial areas, in municipalities, and on the Base. The city of Dayton's Mad River Well Field [fig. 2] was the largest pumping center included in the model; withdrawals were approximately 50 Mgal/d. For the steady-state calibration of the model, the Skeel Road and East Well Fields at WPAFB were pumped at 1.9 and 1.1 Mgal/d, respectively. Area B wells at WPAFB were not active for the time period used for the calibration.

Since model calibration (1988), wells designed to produce about 20 Mgal/d have been constructed on the downstream side of Huffman Dam, and a well producing approximately 0.9 Mgal/d has been completed about 1 mi northeast of Huffman Dam [fig. 1]. Currently (1994), the Huffman Dam Well Field is pumping a combined total of approximately 2 Mgal/d. In a predictive simulation, these pumping centers and the current (1994) rates of pumping were added to the model that was produced by Dumouchelle and others (1993). Particle pathlines are based on this predictive simulation. Area B wells were not active for the time period used for the calibration; the East Well Field has not been active since 1988, so it was not simulated here.

Particle pathlines were computed on the basis of flow in each cell of the regional model by use of the USGS particle-tracking code MODPATH (Pollock, 1989). MODPATH is a three-dimensional post-processing program for particle tracking designed for use with output from simulations obtained with the computer code MODFLOW. The particle pathlines are based on advective particle movement and traveltimes—no diffusion, dispersion, or chemical or microbiological retardation is incorporated into the movement of particles that trace the particle pathlines.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 15. Simulated paths of ground-water flow on Wright-Patterson Air Force Base, Ohio, 1994.

Horizontal flow paths simulated by the model described above are shown in figure 15. Cunningham and others (1994) originally presented the results illustrated in figure 15; their results are reproduced here because of their importance to understanding the distributions of various constituents from anthropogenic sources in ground water (discussed later). Many of the ground-water-flow paths originating near Base boundaries pass through operable units containing landfills and other hazardous-waste sites, and these landfills potentially can affect regional ground-water quality.

The effect of pumping on ground-water flow is shown on figure 15. Ground water originating at the water table near the northern end of the Base can be captured in the Skeel Road well field or can discharge to Mad River. Water from OUs 1 and 4 migrates toward OU5 and Huffman Dam. Nearly all the ground water originating in Area B moves toward the Rohrer's Island well field. Further discussion involving simulated ground-water-flow paths is presented in the Ground-Water Quality section.

Water Quality

By Gary L. Rowe

The following sections on ground-water quality describe inorganic constituents and organic compounds detected in samples collected during the first four rounds of sampling (table 3) of the BMP at WPAFB. Locations of well clusters sampled during the first year of BMP are shown in figure 16. Most observations regarding the types and distributions of inorganic constituents and organic compounds found in ground water at WPAFB are based on examination of the data collected during the first and second sampling rounds as these sampling rounds had the largest number of samples and include concentrations of dissolved metals.

For ease of discussion, inorganic constituents are divided into four groups: (1) field measurements of properties such as temperature, specific conductance, pH, turbidity and dissolved oxygen; (2) major constituents including common cations and anions present at concentrations greater than 2 mg/L (Na, K, Ca, Mg, Cl, and SO_4); (3) minor constituents, usually present at concentrations less than 2 mg/L, including trace metals, nutrients, and cyanide; and (4) radiochemical data, including gross alpha and gross beta activities. Organic compounds are subdivided according to the following categories: (1) VOCs; (2) SVOCs; (3) organochlorine pesticides and polychlorinated biphenyls (PCBs); (4) chlorinated herbicides; and (5) petroleum hydrocarbons.

At the start of each section, quality-control data and procedures used to validate project analytical data are reviewed. Then data regarding exceedances of USEPA maximum contaminant levels (MCLs) for samples collected during the first year (four rounds) of the BMP are presented. Spatial and temporal trends in the concentrations of selected constituents or water-quality measurements are evaluated. Potential sources of constituents (both anthropogenic and natural) as well as geochemical and hydrogeologic processes that affect the fate and transport of inorganic and organic contaminants in ground water are discussed.

The number of wells sampled and the types of analyses performed during the four sampling rounds decreased from a high of 113 during round 1 to 42 for round 4. The types of analyses performed on ground-water samples also varied; a summary of the types of analyses done each sampling round is given in table 10. Ground-water sampling sites by sampling round are summarized in table 11.

For purposes of examining general trends in ground-water quality, wells were classified according to the following categories: (1) aquifer in which they are screened (bedrock or glacial), (2) relative depth (water table, intermediate, or deep [near the glacial-bedrock interface]); and (3) position along the regional ground-water gradient (upgradient, interior, downgradient). The first two categories were considered because previous work by Dumouchelle and others (1993) has shown that marked compositional differences exist between waters of the bedrock and glacial aquifers, and that certain inorganic constituents (particularly those derived from anthropogenic activities) show vertical compositional trends in the glacial aquifer. The third category is used to examine changes in ground-water quality as water enters, flows across, and exits WPAFB along regional flow paths. Properties of wells sampled during the four rounds of the BMP are given in table 12 at back of report.

Water quality as a function of aquifer type, relative depth of completion in the glacial aquifer, and position along the regional ground-water gradient are discussed, primarily by use of summary statistics. Wells sampled during the BMP are completed in three hydrogeologic units: (1) Pleistocene sands and gravels of glacial origin, (2) Ordovician shales and limestones of the Richmond Group, and (3) the Silurian Brassfield limestone. One well (GR-309) was completed in the Brassfield limestone. This well yields

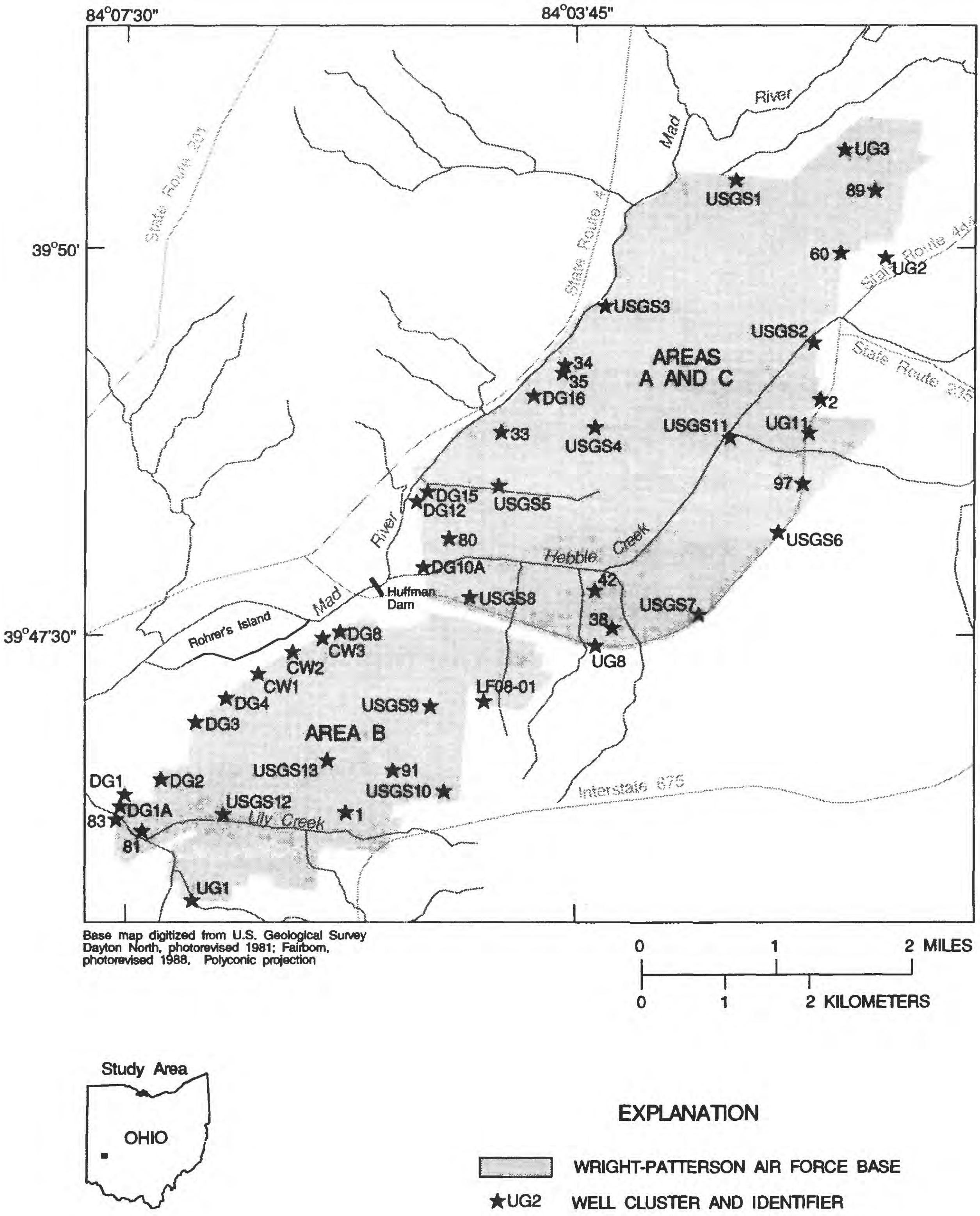


Figure 16. Location of well clusters sampled during the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio.

Table 10. Number of analyses performed on ground-water samples during the first year (1993-94) of the Basewide Monitoring Program, Wright-Patterson Air Force Base

Analysis	Round 1	Round 2	Round 3	Round 4
pH (field)	113	91	72	42
Turbidity (field)	90	74	71	40
Specific conductance (field)	113	91	72	42
Water temperature (field)	113	91	72	42
Dissolved Oxygen (field)	94	64	54	42
Total metals	124[a]	106	86	41
Dissolved metals	103	20	1	0
Anions	101	107	81	41
Gross alpha and gross beta activity	106	106	0	0
Volatile organic compounds	114[b]	106	86	41
Semi-volatile organic compounds	114[b]	107	81	41
Organochlorine pesticides and polychlorinated biphenyls (PCBs)	111	105	0	0
Chlorinated herbicides	111	68	0	0
Petroleum hydrocarbons	113	107	0	0

a - includes analyses duplicated on 11 wells by other contractors.
b - includes analyses duplicated on 1 well by other contractors.

Table 11. Wells sampled in the first year (1993-94) of the Basewide Monitoring Program at Wright-Patterson Air Force Base

[QA/QC, quality assurance and quality control; FD, field duplicate; MS, matrix spike and matrix-spike duplicate]

Well ID	Cluster ID	Round sampled	QA/QC samples	Well ID	Cluster ID	Round sampled	QA/QC samples
GR-283	1	1, 2, 3	none	GR-287	DG8	1, 2, 3, 4	FD, 3; MS, 4
GR-288	2	1, 2, 3, 4	FD, 3	MT-248	DG8	1, 2, 3, 4	none
GR-289	2	1, 2, 3, 4	none	GR-401	LF08-01	1, 2, 3	FD, 1; MS, 2
GR-435	2	1, 2, 3, 4	FD, 1, 4	GR-402	LF08-01	1, 2, 3	none
GR-214	33	1, 2, 3, 4	FD, 2	MT-249	UG1	1, 2	FD, 1; MS, 2
GR-215	33	1, 2, 3, 4	none	MT-250	UG1	1, 2	none
GR-216	33	1, 2, 3, 4	none	MT-251	UG1	1, 2, 3, 4	none
GR-280	34	1, 2, 3	FD, 2[a]	MT-252	UG1	1, 2, 3, 4	FD, 4
GR-278	35	1, 2, 3	MS, 2[a]	GR-430	UG11	1, 2, 3	none
GR-234	38	1, 2, 3	none	GR-431	UG11	1, 2, 3, 4	FD, 1, 4
GR-242	38	1, 2, 3	MS, 2[b]	GR-433	UG2	1, 2, 3, 4	FD, 4
GR-236	42	1, 2, 3	FD, 3	GR-437	UG2	1, 2, 3, 4	FD, 1; MS, 4
GR-244	42	1, 2, 3	none	GR-438	UG2	1, 2, 3, 4	FD, 3; MS, 2
GR-256	60	1, 2, 3	none	GR-439	UG2	1, 2, 3	none
GR-257	60	1, 2, 3	FD, 1	GR-425	UG3	1, 2, 3, 4	FD, 2; MS, 4
GR-264	80	1, 2, 3, 4	none	GR-426	UG3	1, 2, 3, 4	none
MT-125	81	1, 2, 3	FD, 3	GR-412	UG8	1, 2, 3	none
MT-129	81	1, 2, 3	none	GR-413	UG8	1, 2, 3, 4	none
MT-126	83	1, 2, 3	MS, 1	GR-315	USGS1	1	none
GR-275	89	1, 2, 3	none	GR-316	USGS1	1, 2, 3, 4	none

Table 11. Wells sampled in the first year (1993-94) of the Basewide Monitoring Program at Wright-Patterson Air Force Base—Continued

Well ID	Cluster ID	Round sampled	QA/QC samples	Well ID	Cluster ID	Round sampled	QA/QC samples
GR-299	89	1, 2, 3	none	GR-317	USGS1	1, 2	none
GR-286	91	1, 2, 3	FD, 1, 2; MS, 2, 3	GR-310	USGS10	1	none
GR-298	97	1, 2, 3, 4	FD, 2, 3	GR-311	USGS11	1	none
MT-222	CW1	1, 2, 3	none	GR-333	USGS11	1, 2, 3, 4	none
MT-223	CW1	1, 2, 3, 4	MS, 4	GR-334	USGS11	1, 2, 3, 4	none
MT-224	CW1	1, 2, 3, 4	none	GR-335	USGS11	1, 2	MS, 1
MT-225	CW2	1, 2, 3, 4	FD, 4	GR-436	USGS11	1, 2, 3, 4	none
MT-226	CW2	1, 2, 3, 4	FD, 2; MS, 3	MT-133	USGS12	1	none
MT-227	CW2	1, 2, 3, 4	FD, 1	MT-152	USGS12	1, 2, 3	none
MT-228	CW3	1, 2, 3, 4	none	MT-153	USGS12	1, 2, 3	MS, 1
MT-229	CW3	1, 2, 3, 4	MS, 2	GR-313	USGS13	1, 2	none
MT-230	CW3	1, 2, 3, 4	FD, 3	GR-329	USGS13	1, 2, 3, 4	none
MT-234	DG1	1, 2, 3	none	GR-314	USGS2	1, 2	none
MT-239	DG1	1, 2, 3	FD, 2	GR-318	USGS2	1, 2, 3, 4	none
MT-240	DG1	1, 2, 3	none	GR-319	USGS2	1, 2	none
MT-241	DG1	1, 2, 3	none	GR-303	USGS3	1, 2	MS, 2[c]
GR-428	DG10A	1, 2, 3	FD, 2; MS, 1	GR-320	USGS3	1, 2, 3, 4	MS, 1, 3
GR-429	DG10A	1, 2, 3	none	GR-304	USGS4	1, 2	none
GR-414	DG12	1, 2	none	GR-321	USGS4	1, 2, 3, 4	FD, 1, 3
GR-415	DG12	1, 2	FD, 2	GR-322	USGS4	1, 2	MS, 2
GR-416	DG12	1, 2, 3	MS, 3	GR-305	USGS5	1, 2	none
GR-417	DG12	1, 2, 3	none	GR-323	USGS5	1, 2, 3, 4	none
GR-419	DG15	1, 2	none	GR-324	USGS5	1, 2, 3, 4	none
GR-420	DG15	1, 2, 3, 4	FD, 3	GR-306	USGS6	1	none
GR-421	DG15	1, 2, 3, 4	FD, 2; MS, 1	GR-330	USGS6	1, 2, 3, 4	FD, 2; MS, 3
GR-434	DG15	1, 2, 3, 4	FD, 1	GR-331	USGS6	1, 2	none
GR-440	DG16	1, 2, 3	none	GR-332	USGS6	1, 2	none
MT-235	DG1A	1, 2, 3	none	GR-432	USGS6	1, 2, 3	FD, 1
MT-237	DG1A	1, 2, 3	FD, 3	GR-307	USGS7	1	none
MT-231	DG2	1, 2, 3	none	GR-326	USGS7	1, 2, 3	none
MT-232	DG2	1, 2, 3	MS, 2	GR-327	USGS7	1, 2	none
MT-247	DG2	1, 2	none	GR-328	USGS7	1, 2	none
MT-238	DG3	1, 2, 3	FD, 1	GR-308	USGS8	1, 2	none
MT-244	DG3	1, 2, 3	none	GR-309	USGS9	1, 2, 3	none
MT-245	DG3	1, 2, 3	none	GR-312	USGS9	1	none
MT-246	DG3	1, 2, 3	none				
MT-242	DG4	1, 2, 3	none				
MT-243	DG4	1, 2, 3	none				

[a] - Pesticides/PCBs, anions, and gross alpha and beta only.

[b] - Semivolatiles, pesticides/PCBs (polychlorinated biphenyls), petroleum hydrocarbons, anions, cyanide, and gross alpha and beta only.

[c] - Herbicides only.

dilute calcium-magnesium-bicarbonate water that is compositionally different from the brackish sodium-chloride water yielded by wells completed in the Ordovician shale (Dumouchelle and others, 1993). Because water from GR-309 did not contain any constituents at concentrations exceeding MCLs and did not contain any organic compounds of anthropogenic origin, samples from GR-309 were not included in the summary-statistics tables given in subsequent sections.

The depth designations assigned to wells completed in the glacial aquifer are relative; shallowest wells are those whose screened intervals intercept the water table, intermediate wells are those screened below the water table but above the glacial-bedrock contact, and deep wells are those whose screened intervals are near (20 ft or less) the glacial-bedrock interface. Because the depths to the water table and bedrock vary greatly throughout the study area, differences in depths of shallow, intermediate, and deep wells in a cluster can range from 10 to more than 100 ft. Wells classified as intermediate or deep at one cluster can have depths that are less than those of similarly classified wells at another cluster. For the regional ground-water gradient subgroup, a set of summary statistics was calculated for all wells in Areas A and C, and Area B, respectively, to determine whether significant differences in water quality existed between these administrative areas of the Base.

Data sets from rounds 1 and 2 were combined to calculate summary statistics because these rounds contained the largest numbers of wells sampled. The summary statistics were calculated from the qualified and unqualified detections only and do not include "non-detects" (censored data). Non-parametric statistical techniques are available for evaluating censored data sets (Helsel and Gilliom, 1986); however, because the main purpose of this report is to describe the effects of WPAFB on the detection and distribution of constituents in ground water at the Base, non-detects were not included in the statistical analysis. The summary statistics are used to describe the concentrations of inorganics according to the categories mentioned above. The median concentration is emphasized in the discussions because the median is affected only minimally by outlier concentrations (high or low) and therefore is better than the mean concentration to provide an estimate of the central tendency of the data set. The median is considered to be an appropriate summary statistic because most water-quality data sets are not symmetric around the mean, or skewed (Helsel and Hirsch, 1992).

Inorganic Constituents and Physical Properties

In this section, measurements of physical properties and concentrations of metals, anions, nutrients, and radiochemicals in ground water are discussed. A variety of natural processes are present that can affect the concentrations of inorganic constituents, including reactions between ground water and dissolved gases, reactions with organic matter, and reactions with aquifer rock or sediments. Human and biological activities also can affect the concentrations of some inorganic constituents, although the effects of these processes usually can be inferred only. In each of the subsections, hydrogeologic, geochemical, or anthropogenic processes that can affect observed trends are discussed.

Quality Control and Data Validation

Quality assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the inorganic data collected in each of the four sampling rounds generally were met. General summaries of data-validation results assessing the overall quality of the inorganic data for each of the four sampling rounds are available upon request (unpublished data, U.S. Geological Survey, Columbus, Ohio).

Frequency of Detection of Inorganic Constituents

The number of detections (qualified and unqualified) of inorganic constituents in rounds 1 and 2 of the BMP are shown in figure 17 and listed in table 13. Data in table 13 indicate that the most frequently detected metals in unfiltered ground-water samples were barium, calcium, magnesium, sodium, iron, manganese, and potassium, which were found in more than 75 percent of the samples (fig. 17). Among the less commonly detected metals, the relative frequency of detections in unfiltered samples was (from most to least) arsenic, aluminum, chromium, zinc, nickel, lead, copper, vanadium, cobalt, selenium, thallium, and silver. Beryllium, cadmium, and mercury were not detected in any unfiltered samples but were detected in one well each in filtered samples collected during rounds 1 and 2. Although concentrations of antimony are shown in table 13 and figure 17, its relatively high detection frequency probably was because of

Table 13. Detections of inorganic constituents in ground-water samples, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[dissolved, sample was filtered through a 2.5 micron filter; total, sample was not filtered]

Constituent	Number of samples analyzed	Number of detections	Number of maximum contaminant level exceedances	Percent detections	Percent maximum contaminant level exceedances
Metals					
Aluminum, dissolved	120	16	0	13.0	0.0
Aluminum, total	230	71	0	30.9	0.0
Antimony, dissolved	123	2	0	1.6	0.0
Antimony, total	230	12	12	5.3	5.3
Arsenic, dissolved	123	41	0	33.3	0.0
Arsenic, total	230	75	0	32.6	0.0
Barium, dissolved	123	122	1	99.2	0.8
Barium, total	230	229	2	99.6	0.9
Beryllium, dissolved	123	0	0	0.8	0.0
Beryllium, total	230	0	0	0.0	0.0
Cadmium, dissolved	120	2	0	1.6	0.0
Cadmium, total	230	0	0	0.0	0.0
Calcium, dissolved	123	122	0	99.6	0.0
Calcium, total	230	229	0	99.6	0.0
Chromium, dissolved	123	12	1	9.8	0.8
Chromium, total	230	50	6	21.7	2.6
Cobalt, dissolved	123	3	0	2.4	0.0
Cobalt, total	230	11	0	4.8	0.0
Copper, dissolved	123	8	0	6.5	0.0
Copper, total	230	23	0	10.0	0.0
Iron, dissolved	123	99	0	80.5	0.0
Iron, total	230	207	0	90.0	0.0
Lead, dissolved	123	4	0	3.3	0.0
Lead, total	230	31	1	13.5	0.4
Magnesium, dissolved	123	122	0	99.2	0.0
Magnesium, total	230	229	0	99.7	0.0
Manganese, dissolved	123	92	0	74.8	0.0
Manganese, total	230	206	0	89.6	0.0
Mercury, dissolved	123	1	0	0.8	0.0
Mercury, total	230	0	0	0.0	0.0
Nickel, dissolved	123	10	2	8.1	1.6
Nickel, total	230	228	4	14.8	1.7
Potassium, dissolved	123	100	0	81.3	0.0
Potassium, total	230	173	0	75.2	0.0
Selenium, dissolved	123	7	0	5.7	0.0
Selenium, total	230	8	0	3.5	0.0

Table 13. Detections of inorganic constituents in ground-water samples, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base—Continued

Constituent	Number of samples analyzed	Number of detections	Number of maximum contaminant level exceedances	Percent detections	Percent maximum contaminant level exceedances
Metals--continued					
Silver, dissolved	123	0	0	0.0	0.0
Silver, total	230	4	0	1.7	0.0
Sodium, dissolved	123	120	0	97.6	0.0
Sodium, total	230	228	0	99.1	0.0
Thallium, dissolved	123	2	2	1.6	1.6
Thallium, total	230	8	2	3.5	0.9
Vanadium, dissolved	123	0	0	0.0	0.0
Vanadium, total	230	15	0	6.5	0.0
Zinc, dissolved	123	9	0	7.3	0.0
Zinc, total	230	37	0	16.1	0.0
Other inorganics					
Bromide	208	38	0	18.3	0.0
Chloride	208	208	0	100.0	0.0
Nitrite	196	0	0	0.0	0.0
Nitrate	196	62	0	31.6	0.0
Sulfate	208	201	0	96.6	0.0
Cyanide	227	5	1	2.2	0.4
Gross alpha	212	197	7	92.9	3.3
Gross beta	212	195	9	92.0	4.3

analytical interferences (see next section). With respect to anions, the relative frequency of detections was (from most to least) chloride, sulfate, nitrate, and bromide. Nitrite was not detected in any samples. Gross alpha and gross beta activities were detected in more than 90 percent of the samples.

Frequency of Detection of Inorganic Constituents in Unfiltered and Filtered Ground-Water Samples

Several trace metals - notably aluminum, chromium, copper, lead, nickel, and zinc - were detected in filtered samples less frequently than in unfiltered samples (table 13, fig. 17), indicating that significant fractions of these metals were associated with particulate matter that could not pass through a 2.5 μm filter. In contrast, arsenic, iron, manganese, selenium, and all major cations (Na, K, Ca, Mg) were detected in filtered samples at about the same frequency as in unfiltered samples, indicating that these metals either were dissolved or were associated with colloidal materials that had effective diameters less than 2.5 μm. The filtration process decreased aluminum, chromium, cobalt, copper, lead, nickel, silver, thallium, and vanadium concentrations below detection levels in most ground-water samples (table 14). This supports the hypothesis that these metals were associated mostly with particulate matter in ground water.

Exceedances of Drinking-Water Standards

Concentrations of nine inorganic constituents exceeded or equaled (which hereafter will be discussed as exceedances) current or proposed USEPA MCLs in ground-water samples. Metals detected at concentrations exceeding MCLs include barium, chromium, lead, nickel, antimony, and thallium (table 15). Cyanide concentrations (table 15) and gross alpha and beta activities (table 16) also exceeded MCLs. Locations of wells from which samples containing MCL exceedances were collected during the first year

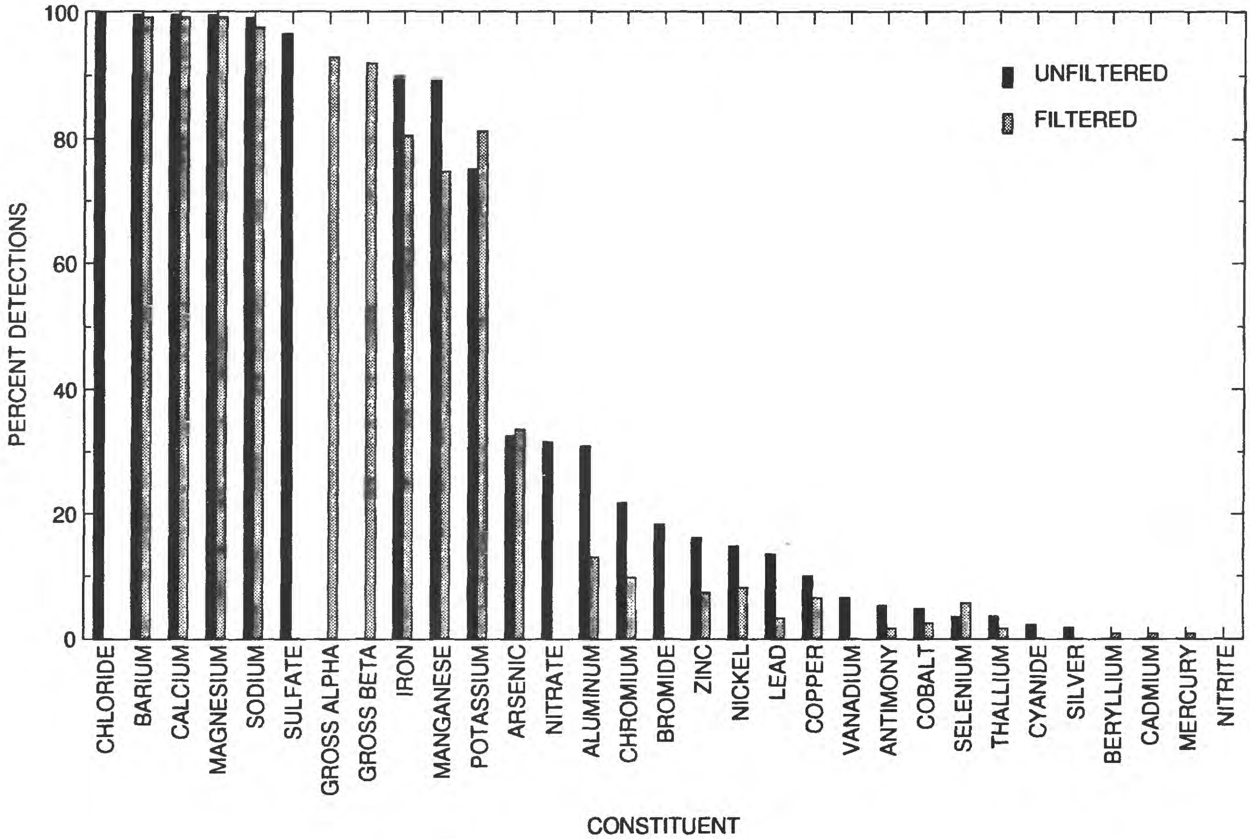


Figure 17. Percentage of detections of inorganic constituents in ground water, rounds 1 and 2, August 1993–January 1994, at Wright-Patterson Air Force Base, Ohio.

of the BMP are shown in figures 18-21 at back of report.

Antimony was detected in 16 ground-water samples at concentrations exceeding its MCL (6.0 µg/L). To determine whether the initial antimony detections were due to an interference in the multi-element inductively-coupled plasma (ICP) emission spectroscopic technique, the USGS asked the laboratory to reanalyze the affected samples by graphite-furnace atomic-absorption spectrometry. Many of the samples had been destroyed before the request for reanalysis; however, four ground-water samples and four surface-water samples were reanalyzed. Ground-water samples with antimony concentrations greater than 30 µg/L by ICP did not contain detectable antimony concentrations at the reporting limit of 1.5 µg/L by graphite furnace. Ground-water samples in which antimony was detected were from wells with depths ranging from 16 to 215 ft below land surface and were located in upgradient, interior, and downgradient clusters in both administrative areas. In addition, antimony was not detected at levels exceeding the MCL more than once in samples from any well (table 15). Therefore, it appears highly unlikely that antimony is present in ground water at WPAFB at concentrations exceeding the reporting limits (20-34 µg/L) obtained with the ICP technique.

Eight exceedances of MCLs of inorganic constituents were associated exclusively with water sampled from wells completed in the bedrock. These include the exceedances for barium, cyanide, and lead, and almost half the reported exceedances for thallium. Ground water from bedrock wells also had the majority of MCL exceedances reported for gross alpha and gross beta radioactivity in round 1 (table 16). Ground water from bedrock well GR-311 sampled in round 1 had MCL exceedances for barium, chromium, lead, cyanide, gross alpha, and gross beta (tables 15, 16). Results of data analysis presented in later sections indicate that some of the constituents with MCL exceedances in ground water from bedrock wells are of natural origin.

Thallium exceeded the MCL in samples from four wells completed in the glacial aquifer (GR-316,

Table 14. Metal detections in unfiltered and filtered ground-water samples, round 1, August–September 1993, Wright-Patterson Air Force Base

[--, not applicable]

Metal	Number detections (out of 99 samples)	Number of detections in unfiltered (total) samples	Number of detections in filtered samples where metal also was detected in unfiltered sample	Number of detections in filtered samples where metal was not detected in unfiltered sample	Percentage of samples where filtration lowered concentration of metal below detection level
Aluminum	38	37	13	1	65
Antimony	12	12	0	0	100
Arsenic	41	33	29	8	12
Barium	99	99	99	0	0
Beryllium	0	0	0	0	--
Cadmium	2	0	2	2	--
Calcium	99	99	99	0	0
Chromium	27	21	4	6	81
Cobalt	7	5	1	2	80
Copper	20	14	2	6	86
Iron	93	92	83	1	10
Lead	17	14	1	3	93
Magnesium	99	99	99	0	0
Manganese	90	90	73	0	19
Mercury	0	0	0	0	--
Nickel	9	8	3	1	63
Potassium	84	79	74	5	6
Selenium	6	2	0	4	100
Silver	3	3	0	0	100
Sodium	99	99	97	0	2
Thallium	8	6	0	2	100
Vanadium	6	6	0	0	100
Zinc	3	0	0	3	--

GR-317, GR-323, GR-332). All of the MCL exceedances were at or slightly above the MCL (2.0 µg/L, equal to the reporting limit); subsequent samples collected from those wells during later rounds did not contain detectable concentrations of thallium.

MCL exceedances for chromium and nickel were reported for eight wells completed in the glacial aquifer. For nickel, these included GR-298, GR-333, MT-238, and MT-252; for chromium, GR-329, GR-331, GR-333, MT-234, MT-238, and MT-243. Except for well GR-331, all the wells were of shallow or intermediate depth of less than 55 feet. Exceedances of MCLs for chromium and nickel were in samples from interior or downgradient wells in Area B, but from interior or upgradient wells in Areas A and C. The consistency of chromium concentrations in MT-234, MT-238, and MT-243 was poor over sampling rounds 1, 2, and 3. For these wells, chromium concentrations exceeded the MCL only in round 2 samples, but were far below the MCL in samples from rounds 1 and 3. Chromium and nickel concentrations were above the MCL in samples from GR-333 only in round 2. Chromium concentrations in samples from GR-333 for rounds 1, 3, and 4 collected by USGS personnel did not exceed 26 µg/L (turbidity did not exceed 9 NTU), whereas the chromium concentration reported for the sample collected by private contractors in round 2 exceeded 1300 µg/L (turbidity was 31 NTU). Similar patterns were observed in the nickel concentrations reported for samples from GR-333 and for chromium and nickel concentrations reported for samples from GR-331. These data indicate possible

Table 15. Exceedances of maximum contaminant levels in ground-water samples, metals and cyanide, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[REG, regular sample; DUP, field-duplicate sample; MCL, maximum contaminant level in drinking water; Q, validation qualifier; J, estimated concentration; --, not applicable. All concentrations are micrograms per liter]

Well	Cluster	Sample type	Analysis	Constituent	Concentration	MCL	Q
ROUND 1							
GR-303	USGS3	REG	Unfiltered	Thallium	2.29	2.0	J
GR-308	USGS8	REG	Unfiltered	Thallium	2.79	2.0	J
GR-310	USGS10	REG	Unfiltered	Thallium	2.0	2.0	--
GR-311	USGS11	REG	Unfiltered	Barium	2050	2000.0	--
GR-311	USGS11	REG	Filtered	Barium	2090	2000.0	--
GR-311	USGS11	REG	Filtered	Chromium	188	100.0	--
GR-311	USGS11	REG	Unfiltered	Lead	184	15.0	--
GR-311	USGS11	REG	--	Cyanide	278	200.0	--
GR-315	USGS1	REG	Unfiltered	Barium	2380	2000.0	--
GR-316	USGS1	REG	Filtered	Thallium	2.6	2.0	--
GR-317	USGS1	REG	Filtered	Thallium	2.2	2.0	--
GR-323	USGS5	REG	Unfiltered	Thallium	2.12	2.0	J
GR-331	USGS6	REG	Unfiltered	Chromium	162	100.0	--
GR-332	USGS6	REG	Unfiltered	Thallium	2.5	2.0	--
GR-401	LF08-01	REG	Unfiltered	Antimony	38.9	6.0	--
GR-413	UG8	REG	Unfiltered	Antimony	32.2	6.0	--
GR-417	DG12	REG	Unfiltered	Antimony	29.3	6.0	--
GR-428	DG10A	REG	Unfiltered	Antimony	36.9	6.0	--
MT-129	81	REG	Unfiltered	Antimony	35.9	6.0	--
MT-133	USGS12	REG	Unfiltered	Antimony	34.5	6.0	--
MT-229	CW3	REG	Unfiltered	Antimony	33.8	6.0	--
MT-235	DG1A	REG	Unfiltered	Antimony	47.9	6.0	--
MT-237	DG1A	REG	Unfiltered	Antimony	34.4	6.0	--
MT-238	DG3	REG	Filtered	Nickel	121	100.0	--
MT-238	DG3	REG	Unfiltered	Nickel	135	100.0	--
MT-238	DG3	DUP	Unfiltered	Nickel	106	100.0	--
MT-238	DG3	DUP	Filtered	Nickel	125	100.0	--
MT-239	DG1	REG	Unfiltered	Antimony	36.7	6.0	--
MT-242	DG4	REG	Unfiltered	Antimony	38.9	6.0	--
MT-247	DG2	REG	Unfiltered	Antimony	40.4	6.0	--
ROUND 2							
GR-298	97	REG	Unfiltered	Nickel	102	100.0	--
GR-329	USGS13	REG	Unfiltered	Chromium	126	100.0	--
GR-333	USGS11	REG	Unfiltered	Chromium	1310	100.0	--
GR-333	USGS11	REG	Filtered	Nickel	119	100.0	--
GR-333	USGS11	REG	Unfiltered	Nickel	239	100.0	--
MT-229	CW3	REG	Unfiltered	Thallium	3.2	2.0	J
MT-243	DG4	REG	Unfiltered	Chromium	128	100.0	--
MT-238	DG3	REG	Unfiltered	Chromium	323	100.0	--
MT-238	DG3	REG	Unfiltered	Nickel	127	100.0	--
MT-234	DG1	REG	Unfiltered	Chromium	171	100.0	--

Table 15. Exceedances of maximum contaminant levels in ground-water samples, metals and cyanide, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base—Continued

Well	Cluster	Sample type	Analysis	Constituent	Concentration	MCL	Q
ROUND 3							
GR-215	33	REG	Unfiltered	Antimony	20.2	6.0	--
GR-216	33	REG	Unfiltered	Antimony	20.7	6.0	--
GR-275	89	REG	Unfiltered	Antimony	22.8	6.0	--
GR-286	91	REG	Unfiltered	Antimony	20.6	6.0	--
GR-329	USGS13	REG	Unfiltered	Chromium	102	100.0	--
MT-238	DG3	REG	Filtered	Nickel	132	100.0	--
MT-238	DG3	REG	Unfiltered	Nickel	135	100.0	--
ROUND 4							
GR-329	USGS13	REG	Unfiltered	Chromium	622	100.0	--
MT-252	UG1	REG	Unfiltered	Nickel	139	100.0	--
MT-252	UG1	DUP	Unfiltered	Nickel	123	100.0	--

Table 16. Exceedances of maximum contaminant levels in ground-water samples, gross alpha and beta, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[REG, regular sample; MCL, maximum contaminant level in drinking water; Q, validation qualifier; J, estimated concentration; --, not applicable. All concentrations are picocuries per liter]

Well	Cluster	Sample type	Analysis	Constituent	Concentration	MCL	Q
ROUND 1							
GR-214	33	REG	SW9310	Gross alpha	19	15.0	J
GR-311	USGS11	REG	SW9310	Gross alpha	44	15.0	--
GR-313	USGS13	REG	SW9310	Gross alpha	25	15.0	--
GR-332	USGS6	REG	SW9310	Gross alpha	59.6	15.0	--
GR-419	DG15	REG	SW9310	Gross alpha	53.9	15.0	--
MT-133	USGS12	REG	SW9310	Gross alpha	15.7	15.0	--
MT-241	DG1	REG	SW9310	Gross alpha	18.3	15.0	--
ROUND 2							
GR-313	USGS13	REG	SW9310	Gross alpha	18	15.0	--
ROUND 1							
GR-304	USGS4	REG	SW9310	Gross beta	39	30.0	--
GR-311	USGS11	REG	SW9310	Gross beta	77	30.0	--
GR-312	USGS9	REG	SW9310	Gross beta	37	30.0	--
GR-313	USGS13	REG	SW9310	Gross beta	57	30.0	--
GR-315	USGS1	REG	SW9310	Gross beta	44	30.0	--
GR-332	USGS6	REG	SW9310	Gross beta	58.0	30.0	--
GR-419	DG15	REG	SW9310	Gross beta	62.1	30.0	--
MT-133	USGS12	REG	SW9310	Gross beta	65	30.0	--
ROUND 2							
GR-313	USGS13	REG	SW9310	Gross beta	44.6	30.0	--

contamination of the round 2 samples; further sampling will be required to provide clear evidence of contamination. In contrast, nickel concentrations increase each sampling round in water from MT-252 and exceed the MCL each sampling round in water from MT-234. The consistency of these data indicate that ground water at MT-252 and MT-234 contains nickel at concentrations that approach or exceed drinking-water standards. However, the degree of chromium contamination in ground water from wells MT-234, MT-238, MT-243, GR-331, and GR-333 is poorly defined due to the wide variations in chromium concentrations found between sampling rounds and because differences in the sampling procedures used by USGS and privately contracted personnel may have affected the quality of the data.

Gross alpha was detected during round 1 in exceedance of the MCL in samples from glacial wells GR-214, GR-332, GR-419, and MT-241 (table 16). Samples from GR-332 and GR-419 also had gross beta concentrations in excess of the MCL for round 1. The only well which had repeat exceedances for both gross alpha and gross beta in round 2 was GR-313, a bedrock well completed in the interior part of Area B.

Field-Measured Properties of Ground Water

In this section, spatial and statistical descriptions of water-quality properties measured in the field during the first year of the BMP are presented. Chemical and physical properties measured in the field include pH, specific conductance, temperature, turbidity, and dissolved oxygen concentrations.

Bedrock-aquifer and glacial-aquifer wells

Summary statistics for field-measured properties of water from bedrock and glacial wells sampled in rounds 1 and 2 are shown in table 17. These data indicate that ground water from the bedrock aquifer had markedly higher specific conductance and turbidity than water from the glacial aquifer. Elevated turbidity in the bedrock waters probably was related to the use of bailers to obtain samples. Turbidity was higher than the standard (25 NTU) at the time of sampling in 26 of 305 samples for which turbidity data were available. Five of the 26 elevated turbidity measurements were of water from the bedrock, and 14 others were reported by private contractors during their sampling periods. Elevated specific conductance in the bedrock water was related to high sodium and chloride concentrations, which will be discussed later. Ground water from bedrock also had a lower median dissolved oxygen concentration and a slightly higher median pH than water from the glacial aquifer. Ground-water temperatures are not markedly different between the two aquifers.

Glacial aquifer—variation with depth

Summary statistics for field-measured properties of all glacial wells sampled in rounds 1 and 2 with depth in the aquifer are shown in table 18. To illustrate trends with depth, the median concentrations reported in table 18 have been normalized to the median concentration for the shallow well group for each constituent shown (fig. 22). This normalization results in a value of 1.0 for the shallow subgroup median, with increases or decreases relative to shallow median indicated by values greater than or less than 1.0, respectively. Water temperature, concentration of dissolved oxygen, and specific conductance decrease with depth. The trend in water temperature with depth may reflect seasonal variations in air temperature that are more likely to affect shallow wells than intermediate or deep wells. Dissolved-oxygen concentrations, which generally are high in the precipitation that recharges the aquifer, are steadily depleted by reactions with organic matter and reduced sulfur and iron minerals in aquifer sediment (Dumouchelle and others, 1993). A plot of round 1 and 2 dissolved-oxygen concentrations with depth indicates (except for a few outliers from deep wells that probably are related to calibration errors) that concentrations of dissolved oxygen greater than 1 or 2 mg/L are uncommon in the glacial aquifer at depths greater than 100 ft (fig. 23).

The decrease in specific conductance with depth may be related to two factors: (1) chemical reactions (such as precipitation of calcite) that reduce solute concentrations in deep ground water; or (2) the effects of anthropogenic activities on shallow ground-water quality. Such activities include the application of soluble inorganic compounds such as road salt or fertilizers, and will serve to increase the specific conductance of recharging ground water. Such increases will be most evident in shallow recharge areas of the glacial aquifer.

No trends are apparent with respect to pH or turbidity. The lack of trend with respect to pH is expected as the pH of ground water in the glacial aquifer is buffered within relatively narrow limits by carbonate minerals (Dumouchelle and others, 1993). Turbidity of the sample is affected by a number of factors, including

Table 17. Field-measured properties by aquifer, rounds 1 and 2, August 1993–January 1994, all wells, Wright-Patterson Air Force Base

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius, mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Parameter	Units	Bedrock aquifer					Glacial aquifer				
		Minimum	Maximum	Number of measurements	Mean	Median	Minimum	Maximum	Number of measurements	Mean	Median
Specific conductance	µS/cm	1,770	16,640	18	4,170	3,260	420	1,990	190	817	788
pH	units	6.9	8.7	20	7.5	7.3	6.6	7.9	190	7.1	7.1
Water temperature	deg C	13.3	19.6	20	15.0	14.7	11.0	20.9	190	14.4	14.2
Dissolved oxygen	mg/L	0.0	7.2	19	1.2	0.3	0.0	18.6	145	2.5	1.0
Turbidity	NTU	4.0	106	22	26.9	16.6	0.1	400	150	18.9	1.3

Table 18. Field-measured properties by depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius, mg/L, milligrams per liter; NTU, nephelometric turbidity units; DP, deep; IN, intermediate; WT, water table]

Parameters	Units	Screen depth	Minimum	Maximum	Number of measurements	Mean	Median
Specific conductance	µS/cm	DP	582	920	19	710	710
		IN	573	1,990	104	801	782
		WT	420	1,750	67	871	867
pH	units	DP	6.7	7.5	19	7.1	7.1
		IN	6.7	7.5	104	7.1	7.1
		WT	6.6	7.9	67	7.1	7.0
Water temperature	deg C	DP	11.0	18.2	19	13.7	13.4
		IN	11.5	18.3	104	14.0	13.9
		WT	11.8	20.9	67	15.0	14.7
Dissolved oxygen	mg/L	DP	0	7.3	17	1.3	0.3
		IN	0	18.6	75	2.4	0.9
		WT	0	9.8	53	3.0	2.2
Turbidity	NTU	DP	0.2	48.7	16	5.6	1.3
		IN	0.1	338	82	24.5	1.3
		WT	0.1	400	52	14.1	1.4

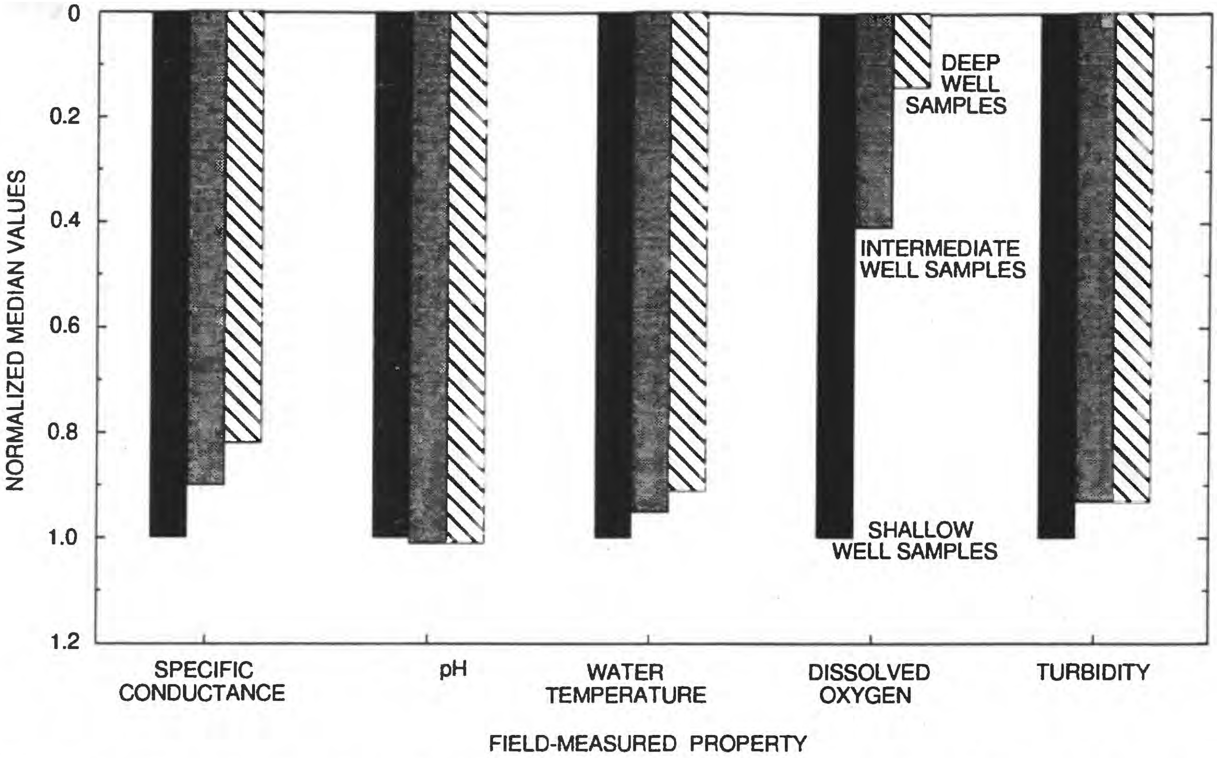


Figure 22. Normalized medians of field-measured properties with depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base, Ohio. (Median values for each property were normalized to the median of the shallow subgroup. Therefore, all shallow values are equal to 1.0.)

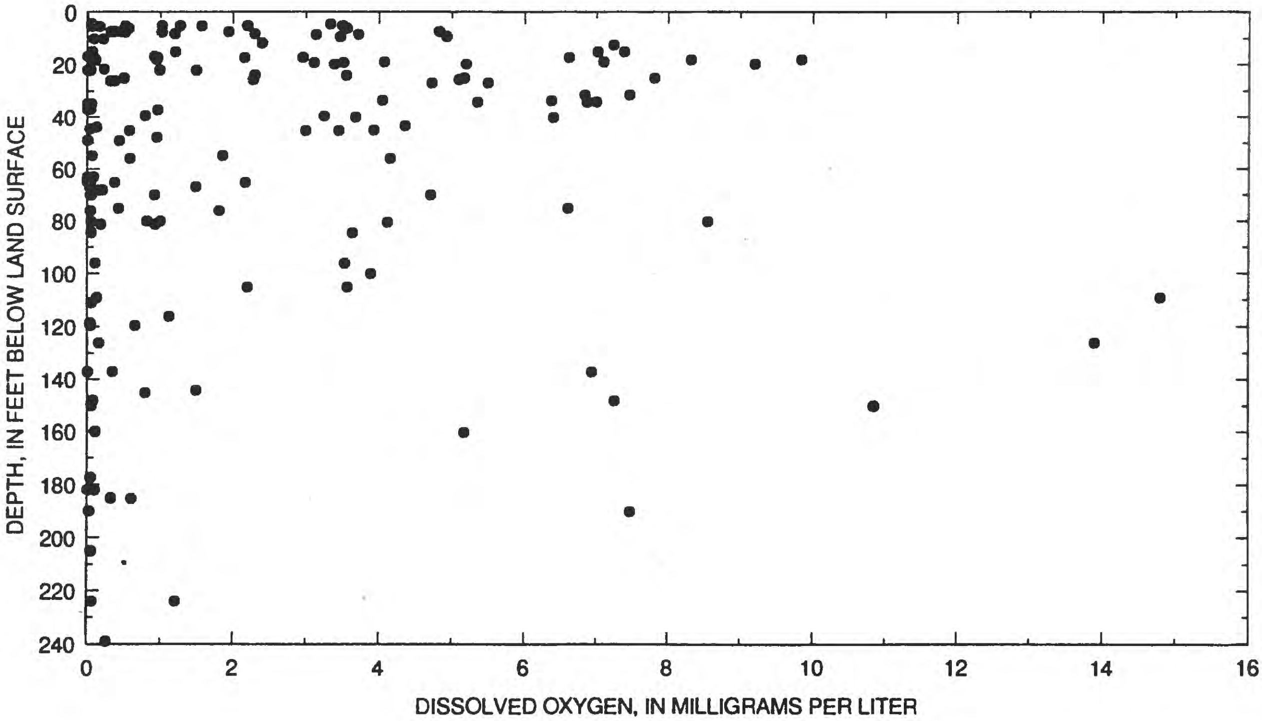


Figure 23. Concentration of dissolved oxygen with depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base, Ohio.

aquifer-sediment type, drilling and development methods, screen size, purge rate, and well yield. These properties are likely to vary randomly in the glacial aquifer so that a discernible trend with depth is unlikely.

Glacial aquifer—variation along the regional ground-water gradient

Summary statistics for field-measured properties of all glacial wells sampled in rounds 1 and 2 with position along the regional ground-water gradient in the glacial aquifer are shown in table 19. Separate sets of summary statistics are presented for glacial wells in Area B and Areas A and C so that trends by administrative area can be identified if present. Specific conductance increased in ground water along the regional ground-water gradient in Areas A and C, whereas it increased from upgradient to interior wells but decreased slightly from interior to downgradient wells in Area B (table 19, fig. 24). Dissolved-oxygen concentrations generally decreased along the regional ground-water gradient in both administrative areas of the Base. No trends in water temperature, pH, or turbidity along the regional ground-water gradient are apparent.

Major Inorganic Constituents

In this section, spatial and summary statistic descriptions (detections only) of major constituents in ground water at the Base are presented. Major constituents are defined as those whose concentrations regularly exceed 2 mg/L. In ground water at WPAFB, these are sodium, potassium, calcium, magnesium, chloride, sulfate. Bicarbonate, which was not included as an analyte for this program, also has been shown to be a major anion (Dumouchelle and others, 1993).

Bedrock-aquifer and glacial-aquifer wells

Summary statistics for major constituents for all bedrock and glacial wells sampled in rounds 1 and 2 are shown on table 20. The data show that sodium and chloride are the dominant cations in water from the Ordovician bedrock, whereas calcium, magnesium, and occasionally sodium are the dominant cations in water from the glacial aquifer. These data are consistent with the findings of Dumouchelle and others (1993) who showed that ground water at WPAFB can be subdivided into two compositional groups: (1) sodium chloride (Na-Cl) waters collected from wells completed in the Ordovician bedrock; and (2) calcium-magnesium-bicarbonate ($Ca\text{-}Mg\text{-}HCO_3$) waters collected from wells completed in the glacial aquifer.

The mean and median concentrations of major cations and anions in the glacial aquifer are similar, indicating near-normal distributions. In contrast, the mean concentration of each major constituent in the bedrock aquifer exceeds the corresponding median concentration, indicating positive skewness in the data. The range of concentrations of each constituent except sulfate was larger in water from the bedrock aquifer than in water from the glacial aquifer. These data indicate that the major-ion chemistry of the bedrock aquifer is more variable than that of the glacial aquifer.

Median sodium and chloride concentrations in bedrock water are almost 20 times greater than those observed in the glacial aquifer. However, the molar sodium/chloride (Na/Cl) ratios calculated for the two water types based on the concentrations in table 20 are similar: 0.77 and 0.71 for the glacial and bedrock aquifers, respectively (molar ratios are calculated by dividing the concentration of each element in mg/L by its molecular weight). These ratios infer similar sources of sodium and chloride for both aquifers. However, molar Na/Cl ratios of water in the glacial aquifer vary significantly with depth, indicating that the similarity of Na/Cl ratios of the two aquifers probably is fortuitous. Mass-balance calculations from the median sodium and chloride concentrations given in table 20 suggest that the amount of leakage from Ordovician bedrock to the glacial aquifer cannot be more than 10 percent, consistent with calculations of Dumouchelle and others (1993).

Glacial aquifer—variation with depth

Summary statistics for major constituents in glacial-aquifer water sampled in rounds 1 and 2 (detects only) with depth in the aquifer are shown in table 21 and figure 25. Median concentrations of calcium, sodium, and chloride are observed to decrease with depth, whereas median concentrations of magnesium, potassium and sulfate show no consistent trends with depth.

As noted by Dumouchelle and others (1993), high concentrations of sodium and chloride in the upper parts of the glacial aquifer are related to the application of salt (halite), to roads on and adjacent to the Base during winter months. Molar Na/Cl ratios for the shallow, intermediate, and deep subgroups

Table 19. Field-measured properties by area and position along the regional ground-water gradient, rounds 1 and 2, August 1993–January 1994, glacial wells, Wright-Patterson Air Force Base

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; D, downgradient; I, interior; U, upgradient]

			Areas A and C					**Area B**				
Parameter	**Units**	**Position Code**	**Minimum**	**Maximum**	**Number of measurements**	**Mean**	**Median**	**Minimum**	**Maximum**	**Number of measurements**	**Mean**	Median
Specific conductance	µS/cm	D	573	1,028	31	791	846	676	1,200	40	817	786
		I	420	1,990	63	859	822	666	936	10	833	886
		U	580	1,196	36	782	770	601	991	10	738	671
pH	units	D	6.8	7.9	31	7.2	7.2	6.7	7.4	40	7.0	6.9
		I	6.7	7.6	63	7.1	7.1	6.8	7.2	10	7.0	6.9
		U	6.8	7.6	36	7.2	7.2	6.6	7.4	10	7.0	7.0
Water temperature	deg C	D	12.0	20.9	31	13.9	13.2	11.0	18.2	40	14.3	14.2
		I	12.0	19.6	63	14.5	14.4	14.3	18.8	10	15.2	14.8
		U	12.8	18.3	36	14.3	13.7	13.2	17.7	10	14.3	13.8
Dissolved oxygen	mg/L	D	0.0	7.3	30	2.0	1.2	0.0	9.8	39	2.4	0.5
		I	0.0	10.9	32	2.4	1.0	0.1	8.6	9	1.9	0.5
		U	0.0	18.6	25	3.3	1.8	0.0	14.8	10	3.5	2.7
Turbidity	NTU	D	0.1	48.7	28	4.8	1.4	0.2	21.4	34	4.1	1.3
		I	0.1	400	41	43.5	1.9	0.3	10.1	9	2.2	0.7
		U	0.2	186	30	24.1	1.2	0.7	21.2	8	4.6	1.5

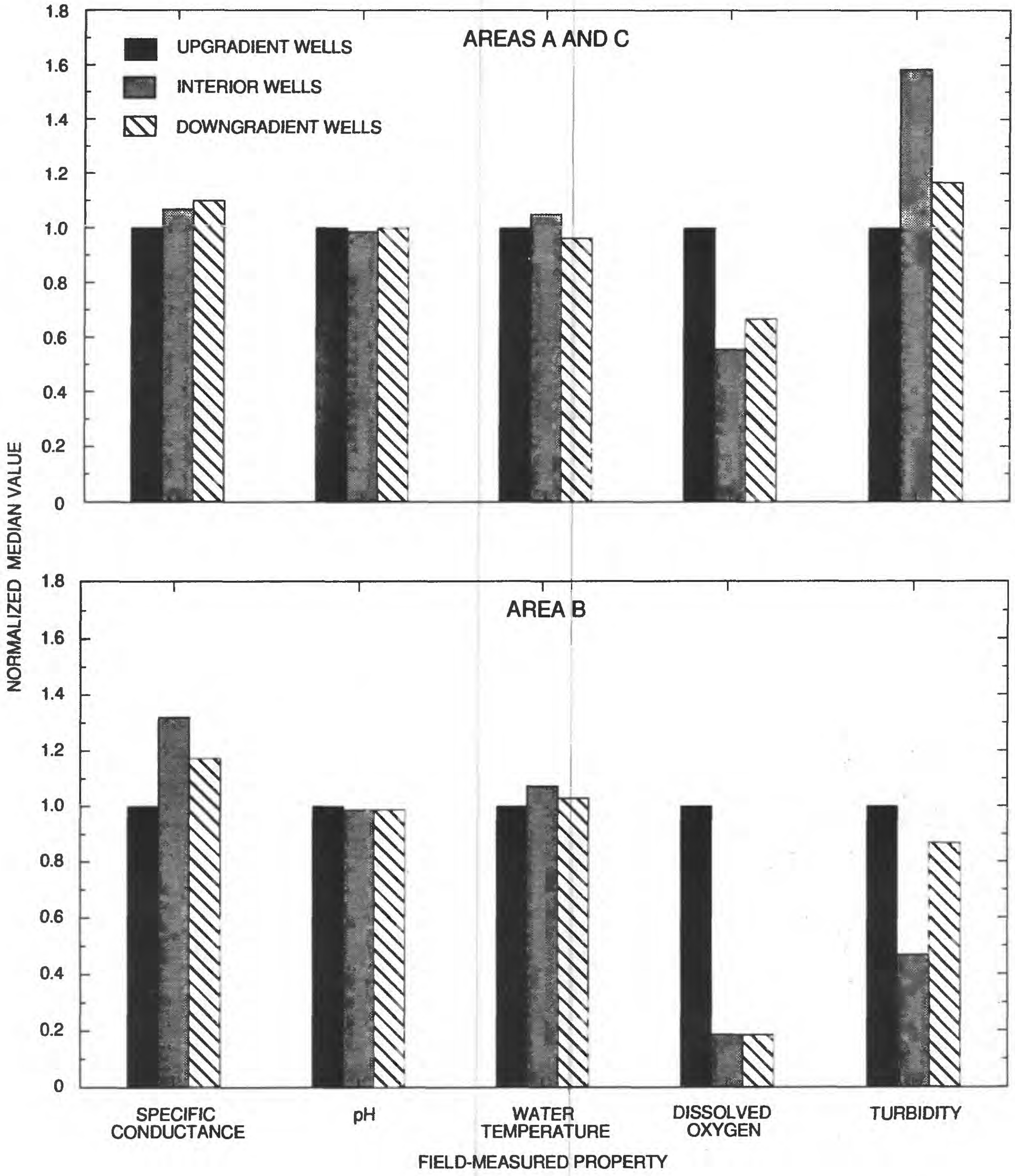


Figure 24. Normalized medians of field-measured properties with position along the regional ground-water gradient, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base, Ohio. (Median values for each property were normalized to the median of the upgradient subgroup. Therefore, all upgradient values are equal to 1.0.)

calculated from the median concentrations given in table 21 are 0.95, 0.66, and 2.38, respectively. Of these values, only the ratio for the shallow subgroup is similar to the Na/Cl molar ratio calculated for water affected by the dissolution of halite (1.0). This observation strongly supports the hypothesis that elevated sodium and chloride concentrations in shallow parts of the glacial aquifer beneath WPAFB are due to human activities on and adjacent to the Base.

A plot of the log of the sum of sodium and chloride concentrations with depth indicates that deicing activities affect ground water to a depth approaching 70 ft (fig. 26). This depth is statistically significant, as results of a rank-sum test (Helsel and Hirsch, 1992) indicate that the median sodium plus chloride concentration (69 mg/L) of wells with depths less than 70 ft is different from the median sodium plus chloride concentration (18 mg/L) of wells deeper than 70 ft at a probability exceeding 99.99 percent. These data imply that other contaminants introduced into the aquifer by human activities, such as VOCs and metals, likely would be concentrated in the upper 70 ft of the glacial aquifer.

Glacial aquifer— variation along the regional ground-water gradient

Summary statistics for major constituents with position along the regional ground-water gradient in the glacial aquifer are given in table 22. Median concentrations in table 22 were normalized to the median concentration of the upgradient well group for Areas A and C and Area B, respectively (fig. 27). The only major constituents with varying median concentrations along the regional ground-water gradient were sodium, chloride, and to a lesser extent, sulfate. In both administrative areas, median sodium and chloride concentrations increased sharply from upgradient to interior positions, but decreased somewhat from interior to downgradient positions. Because most of the interior well clusters on the Base are adjacent to or downgradient of major roads and highways, this pattern is expected. Also, flow paths from upgradient to interior wells have a greater downward component than do flow paths from interior to downgradient wells, favoring direct recharge of salt-laden runoff. The flatter gradients from interior to downgradient wells will result in dilution of salt concentrations as younger recharge waters mix with older ground water. Median sodium and chloride concentrations at the downgradient positions were higher than those at the upgradient positions (table 22, fig. 27), indicating that ground-water quality in many of the downgradient wells was affected by human activities at or adjacent to the Base.

Minor Inorganic Constituents

In this section, spatial and statistical descriptions of minor constituents in ground water at the Base from 1993-94 are presented. Minor constituents are defined as those whose concentrations were typically less than 2 mg/L. On the basis of this definition, the following were classified as minor constituents: aluminum, antimony, arsenic, barium, beryllium, bromide, cadmium, cobalt, copper, cyanide, iron, lead, manganese, mercury, nickel, nitrite, nitrate, selenium, silver, thallium, vanadium, and zinc. Of these, beryllium, cadmium, cobalt, cyanide, mercury, selenium, and silver were detected so rarely that statistically significant descriptions of the distribution and detection of these constituents in ground water at the Base are not possible. Because MCLs are defined for total concentrations, spatial and statistical descriptions in the following sections on minor inorganic constituents were based on analytical results obtained for unfiltered samples.

Bedrock-aquifer and glacial-aquifer wells

Summary statistics for minor constituents for all bedrock and glacial wells sampled in rounds 1 and 2 are shown in table 23. The data indicate that median concentrations of aluminum, barium, bromide, cobalt, copper, iron, lead, and manganese in water from the Ordovician bedrock were higher than the median concentrations of these constituents in water from the glacial aquifer. The statistical significance of this was not quantified due to the limited number of detections for most constituents in either the bedrock or glacial subgroup (table 23). As noted previously, MCL exceedances for barium, cyanide, and lead were associated with water sampled from one bedrock well (GR-311) whereas MCL exceedances for nickel and chromium were associated solely with water from the glacial aquifer.

Glacial aquifer—variation with depth

Summary statistics for minor constituents of glacial wells sampled in rounds 1 and 2 as a function of relative depth in the glacial aquifer are shown in table 24. Median concentrations of aluminum, arsenic,

Table 20. Major constituents (unfiltered) by aquifer, rounds 1 and 2, August 1993–January 1994, all wells, Wright-Patterson Air Force Base

[All concentrations in milligrams per liter]

Constituent	Bedrock aquifer					Glacial aquifer				
	Minimum	Maximum	Number of detections	Mean	Median	Minimum	Maximum	Number of detections	Mean	Median
Calcium	20.2	489	19	155	133	40.9	190	208	104	104
Magnesium	3.0	233	19	73.5	58.9	10.5	78.4	208	37.4	36.6
Sodium	13.2	1,940	19	550	410	3.6	186	207	27.5	20.8
Potassium	2.6	6.3	19	2.9	2.7	0.7	1.1	153	2.8	2.3
Chloride	51.4	5,140	19	1,230	887	2.5	477	187	51.5	41.6
Sulfate	1.4	188	12	54.1	38.0	9.5	219	187	62.5	61.3

Table 21. Major constituents (unfiltered) by depth in the glacial aquifer, rounds 1 and 2, August 1993 - January 1994, Wright-Patterson Air Force Base

[All concentrations in milligrams per liter; DP, deep, IN, intermediate; WT, water table]

Constituent	Screen depth	Minimum	Maximum	Number of detections	Mean	Median
Calcium	DP	77.4	110	22	92	91.3
	IN	64.4	190	109	104	104
	WT	40.9	171	77	108	109
Magnesium	DP	30.0	47.6	22	36.9	36.1
	IN	27.4	78.4	109	38.5	37.8
	WT	10.5	59.7	77	36	35.8
Sodium	DP	5.5	48.6	21	18.8	17.9
	IN	3.6	117	109	21.0	17.3
	WT	5.4	186	77	39.1	31.4
Potassium	DP	1.2	3.5	14	2.4	2.4
	IN	0.7	10.5	73	2.7	2.1
	WT	1.1	10.4	66	3.1	2.5
Chloride	DP	2.6	70.5	22	23.3	11.6
	IN	2.5	477	95	48.8	40.6
	WT	4.2	234	70	64.1	50.9
Sulfate	DP	9.5	98.2	22	43.2	48.8
	IN	12.6	127	95	64.3	64.2
	WT	21	219	70	66.1	60.2

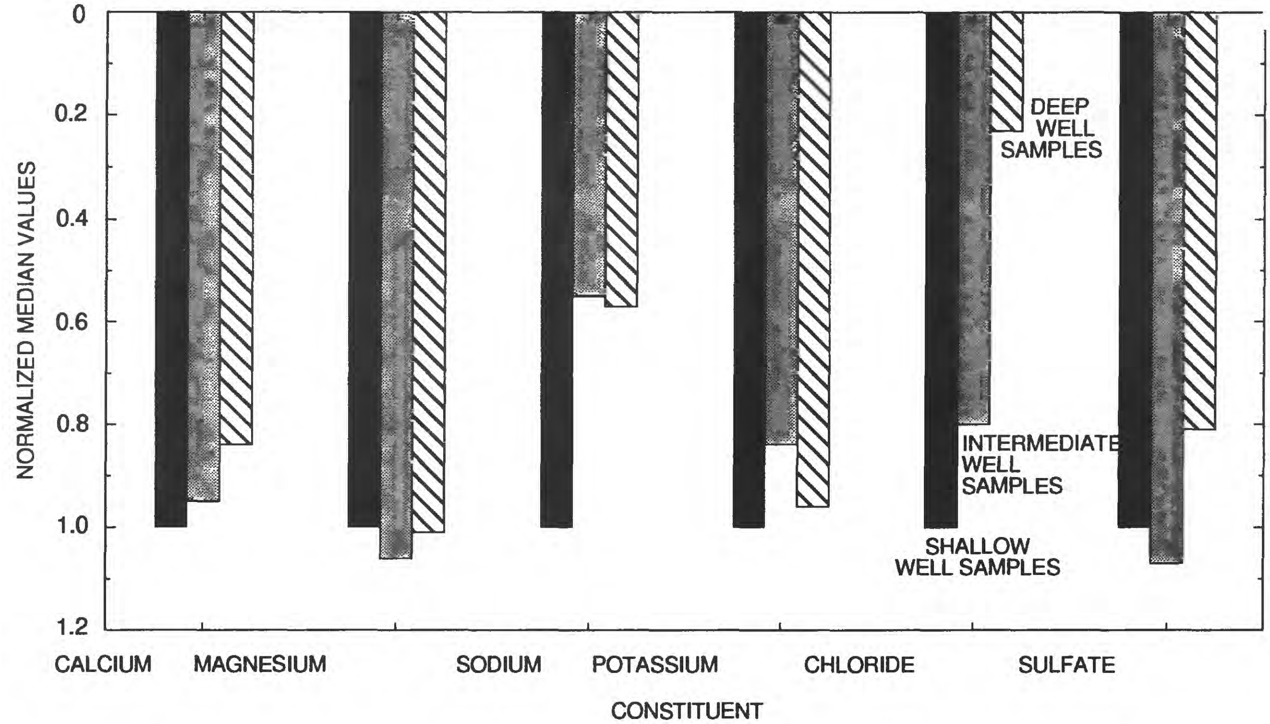


Figure 25. Normalized median concentrations of major constituents with depth in the glacial aquifer, round 1 and 2, August 1993–January 1994, at Wright-Patterson Air Force Base, Ohio. (Median values for each constituent were normalized to median of the shallow subgroup. Therefore, all shallow values are equal to 1.0.)

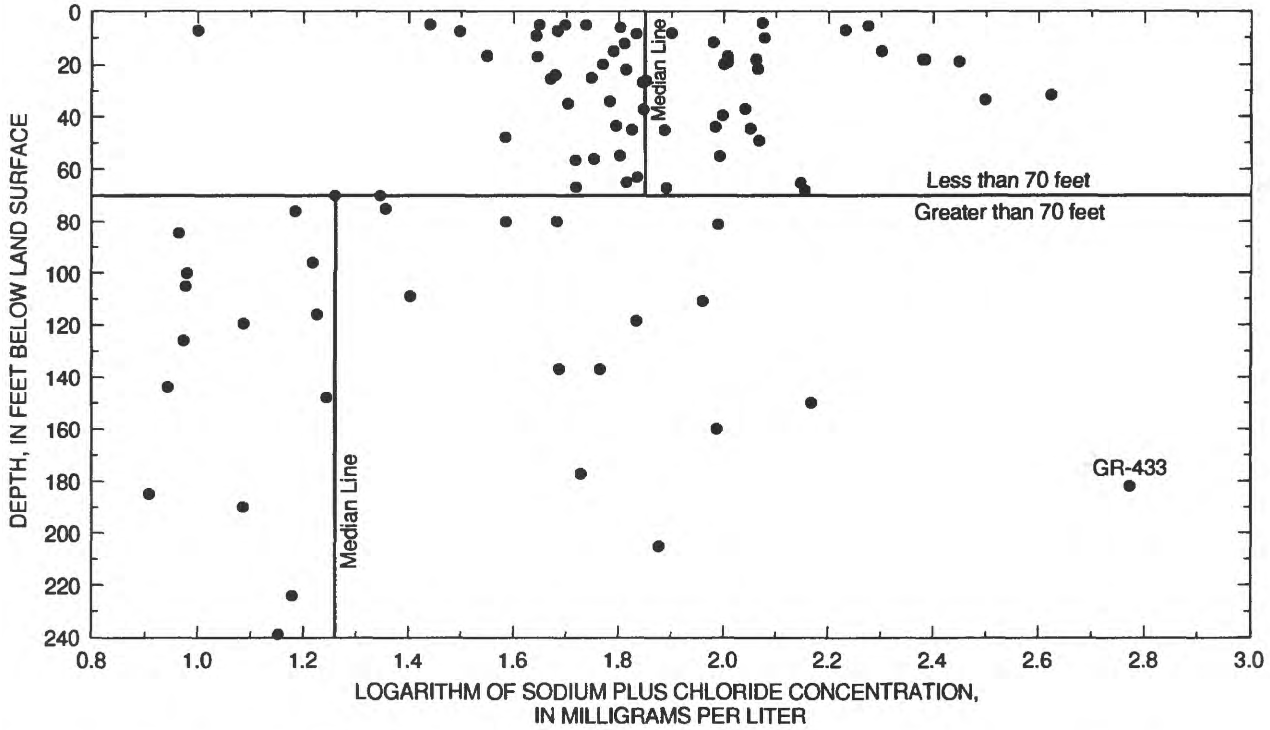


Figure 26. Sum of sodium and chloride concentrations with depth in the glacial aquifer, round 1, August–September 1993, at Wright-Patterson Air Force Base, Ohio. (Vertical lines indicate calculated medians for glacial wells with depth less than or greater than 70 feet.)

barium, iron, lead, manganese, and vanadium increased with depth, whereas median concentrations of chromium, copper, nickel, and zinc decreased with depth, at least partially (fig. 28). Maximum concentrations in table 24 indicate that MCL exceedances for chromium and nickel were in wells in the shallow and intermediate subgroups. Most detections of these constituents and bromide, copper, lead, nitrate, and zinc were in samples from primarily shallow and intermediate depths.

Because the median concentrations with depth (fig. 28) were, for several constituents, based on few detections, it is worth examining the specific concentrations with depth in the glacial aquifer. Round 1 concentrations of aluminum, arsenic, barium, chromium, copper, lead, iron, manganese, nitrate, nickel, vanadium, and zinc with well depth are shown in figures 29-32 at back of report. Several patterns are seen in these figures. First, concentrations were relatively evenly distributed with depth; this pattern applied to aluminum, arsenic, lead, and manganese. Second, concentrations were relatively evenly distributed with depth but lower concentrations generally were found at shallow depths; this pattern applied to iron and barium. Third, most detections, regardless of concentration, were found at shallow depths; this pattern applied to chromium, copper, nickel, nitrate, vanadium, and zinc.

The best example of the first pattern is arsenic, where concentrations well below the MCL were found to depths greater than 180 ft (fig. 29). This pattern of relatively even distribution with depth suggests that arsenic occurs naturally in the aquifer and that the small concentration range observed is representative of ambient arsenic concentrations in the aquifer. Aluminum-concentration distributions were similar to those of arsenic, but five outliers obscure the pattern somewhat. Total aluminum concentrations probably were related to the amount of clay particles in the unfiltered samples; therefore, outliers probably represent highly turbid samples rich in clay particles derived from the glacial sediments around the well screen.

The second pattern of concentration with depth is seen for iron and barium. Iron and barium concentrations formed two distinct clusters when plotted with depth; shallow samples generally had lower concentrations than deeper samples (figs. 29, 30). Both constituents probably are derived from natural sources in aquifer sediments; therefore, their concentration profiles are controlled mostly by natural geochemical processes. Controls on iron concentrations in the glacial aquifer were discussed in Dumouchelle and others (1993) and are related to oxidation-reduction reactions and the solubility of ferric hydroxide. The main control on iron solubility in the glacial aquifer is the presence of dissolved oxygen. Under oxygenated conditions, ferrous iron is oxidized to ferric iron, which is highly insoluble at near-neutral pH. As dissolved oxygen is depleted in recharging ground water, reduction and dissolution of iron-bearing phases occur, producing elevated concentrations of ferrous iron in ground water. Marked increases in the concentration of iron occurred 60-70 ft below land surface (fig. 30), which also is where dissolved-oxygen concentrations decreased (fig. 23).

Concentrations of barium in the glacial aquifer probably are controlled by solubility constraints imposed by the precipitation of the barium-sulfate mineral barite (Hem, 1992). Theoretically, if barite solubility is controlling barium concentrations, then barium concentrations should decrease as sulfate concentrations increase. In fact, the data collected during the BMP indicate that barium concentrations decreased as sulfate concentrations increased. Saturation-index calculations from the aqueous speciation code WATEQ4F (Ball and Nordstrom, 1991) indicate that water in the glacial aquifer is saturated to slightly supersaturated with respect to barite. These facts indicate that barium concentrations in the glacial aquifer are controlled by the solubility of barite.

The third pattern, in which detections were primarily in samples from shallow depths (50-60 ft) in the glacial aquifer, is best exemplified by chromium, copper, and nickel. Redox chemistry plays an important role in the depth to which chromium is transported in the aquifer. Chromium is transported readily under aerobic conditions as hexavalent chromium, which is highly soluble. However, under anaerobic conditions, hexavalent chromium is reduced to trivalent chromium, which is much less soluble and more prone to sorption (Hem, 1992; Kent and others, 1994). The scarcity of detections of chromium below depths of 50 to 60 ft can reflect the transition from aerobic to anaerobic conditions in the glacial aquifer (fig. 23).

For lead, vanadium, and zinc, the presence of multiple detections at depths greater than 60 ft could indicate natural sources of these elements in the aquifer, low-level contamination introduced during sampling or analysis, or both. In fact, a combination of natural and anthropogenic sources is likely to explain

Table 22. Major constituents (unfiltered) by area and position along the regional ground-water gradient, rounds 1 and 2, August 1993–January 1994, glacial wells, Wright-Patterson Air Force Base

[All concentrations in milligrams per liter; D, downgradient; I, interior; U, upgradient]

		Areas A and C					Area B				
Constituent	Position Code	Minimum	Maximum	Number of detections	Mean	Median	Minimum	Maximum	Number of detections	Mean	Median
Calcium	D	71.7	161	34	111	111	82.3	146	38	107	107
	I	49.9	190	60	107	106	87.9	125	8	114	118
	U	40.9	132	35	96.2	98.5	78.9	93.6	6	86.4	86.4
Magnesium	D	28.5	40.0	34	35.1	35.6	3.5	49.1	38	37.4	38.8
	I	14.2	78.4	60	40.1	40.3	39.9	45.4	8	41.9	41.5
	U	10.5	47.2	35	35.2	35.6	33.6	42.1	6	36.2	35.1
Sodium	D	4.3	48.6	34	19.0	17.4	12.7	114	38	29.1	24.2
	I	4.0	186	60	34.3	25.4	39.9	45.4	8	41.9	41.5
	U	3.6	131	35	28.3	14.0	5.3	43.9	12	19.1	11.3
Potassium	D	1.1	7.6	17	2.7	2.1	0.9	3.9	38	2.2	2.1
	I	0.8	8.4	41	2.6	2.4	1.0	2.3	7	1.8	1.7
	U	1.1	10.5	23	5.3	4.7	0.9	3.0	7	2.0	2.5
Chloride	D	4.6	73.3	32	33.0	36.5	24.7	160	54	49.5	45.5
	I	9.1	477	46	83.3	53.7	11.9	151	14	59.0	54.2
	U	2.6	184	29	36.3	23	2.5	65.9	12	16.3	8.4
Sulfate	D	21.2	107	32	62.2	63.0	32.8	121	54	68.6	64.3
	I	21.0	219	46	74.6	63.4	34.6	106	14	62.0	62.4
	U	9.5	127	29	46.4	43.6	12.6	60	12	28.5	24.0

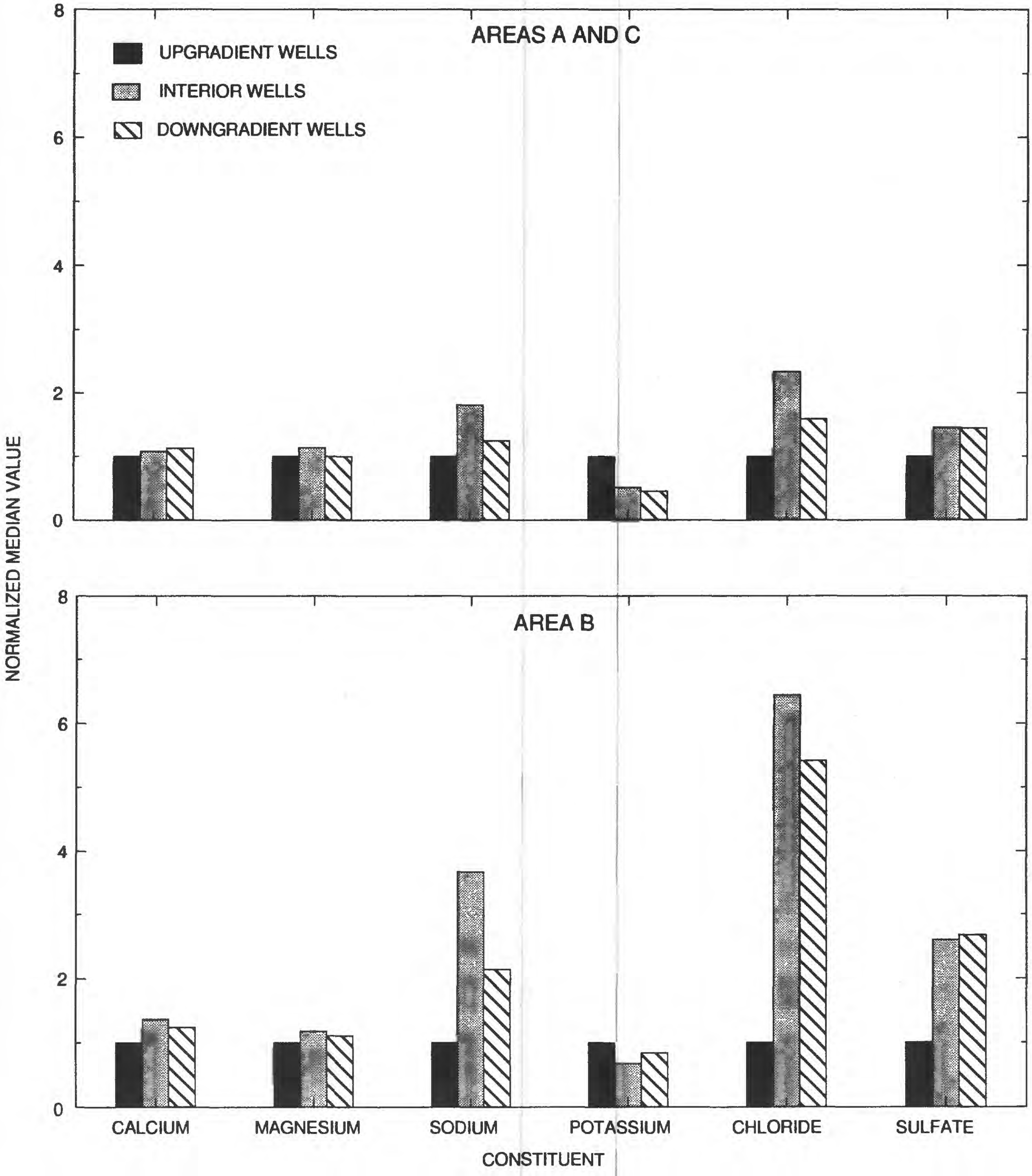


Figure 27. Normalized median concentrations of major constituents with position along the regional ground-water gradient, rounds 1 and 2, August 1993–January 1994, at Wright-Patterson Air Force Base, Ohio. (Median values for each constituent were normalized to the median of the upgradient subgroup. Therefore, all upgradient values are equal to 1.0.)

Table 23. Minor constituents (unfiltered) by aquifer, rounds 1 and 2, August 1993–January 1994, all wells, Wright-Patterson Air Force Base

[All concentrations in micrograms per liter; --, no detections]

Constituent	Bedrock Aquifer					Glacial Aquifer				
	Minimum	Maximum	Number of detections	Mean	Median	Minimum	Maximum	Number of detections	Mean	Median
Aluminum	61.4	3,660	14	435	165	15.6	5,750	57	306	78
Antimony	34.5	34.5	1	--	--	29.3	47.9	11	36.8	36.7
Arsenic	1.6	1.6	1	--	--	0.5	20.4	72	6.8	6.4
Barium	31.8	2,380	19	622	254	35.2	913	208	195	155
Beryllium	--	--	--	--	--	--	--	--	--	--
Bromide	1,100	38,500	18	10,000	7,800	42	29,200	20	1,680	290
Cadmium	--	--	--	--	--	--	--	--	--	--
Chromium	3.9	17.2	7	10	8.7	3.6	1,310	43	65.8	11.8
Cobalt	9.1	13.5	2	11.3	11.3	7.6	34.2	9	13.4	8.6
Copper	4.1	38.9	5	18.3	14.1	2.7	28.7	18	9.08	6.3
Cyanide	278	278	1	--	--	10	57	4	23.3	13
Iron	369	121,000	19	13,600	3,300	6.8	10,900	186	1,530	860
Lead	1.1	184	3	65.6	11.8	0.8	13.2	28	2.4	1.8
Manganese	28.2	4,490	19	464	134	11.8	239	33	54.6	40.1
Mercury	--	--	--	--	--	--	--	--	--	--
Nickel	34.1	34.1	1	--	--	11.8	239	33	54.6	40.1
Nitrate	1,700	1,700	1	--	--	50 0	5,600	61	2,040	1,800
Selenium	--	--	--	--	--	2.3	15	8	5.55	3.6
Silver	8.1	8.1	1	--	--	1.8	19.4	3	7.8	2.2
Thallium	2.0	2.8	3	2.4	2.3	1.1	3.2	5	2.1	2.1
Vanadium	6.6	6.6	1	--	--	0.66	5.6	14	2.78	2.5
Zinc	2.5	2.7	2	2.6	2.6	1.8	57.3	35	10.5	7.2

Table 24. Minor constituents (unfiltered) by depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[DP, deep, IN, intermediate; WT, water table; --, no detections. All concentrations are micrograms per liter..

Constituents	Aquifer -depth code	Minimum	Maximum	Number of detections	Mean	Median
Aluminum	DP	16.4	1,580	9	335	74.6
	IN	16	5,750	31	364	86.6
	WT	1.9	15.2	13	5.3	3.4
Antimony	DP	36.7	36.9	2	36.8	36.8
	IN	33.8	40.4	5	36.7	35.9
	WT	29.3	47.9	4	37.1	35.6
Arsenic	DP	3.7	18.3	12	8.6	7.9
	IN	0.5	20.4	47	6.80	6.6
	WT	1.9	15.2	13	5.33	3.4
Barium	DP	70.3	402	22	240	256
	IN	55.0	913	109	222	161
	WT	35.2	687	77	144	124
Beryllium	DP	--	--	--	--	--
	IN	--	--	--	--	--
	WT	--	--	--	--	--
Bromide	DP	200	200	1	--	--
	IN	42	360	11	225	290
	WT	100	29,200	8	3,870	295
Cadmium	DP	--	--	--	--	--
	IN	--	--	--	--	--
	WT	--	--	--	--	--
Chromium	DP	6.1	25.9	3	17.3	19.9
	IN	3.6	162	13	33.0	7.7
	WT	4	1,310	27	87.0	11.8
Cobalt	DP	--	--	--	--	--
	IN	7.6	8.2	3	7.93	8
	WT	7.7	34.2	6	16.1	10.2
Copper	DP	10.2	28.7	2	19.5	19.5
	IN	2.7	13	8	5.7	4.8
	WT	4.1	21.4	8	9.9	8.8
Cyanide	DP	13	13	1	--	--
	IN	10	57	3	26.7	13
	WT	--	--	--	--	--
Iron	DP	25	4,840	21	2,065	1,940
	IN	11	4,350	98	1,760	1,575
	WT	7	10,900	67	1,030	194
Lead	DP	1.7	3.6	4	2.6	2.5
	IN	1.1	13.2	14	2.7	1.8
	WT	0.8	6.5	10	2.0	1.3
Manganese	DP	43.7	530	20	172	78.8
	IN	1.6	1,390	100	122	74.7
	WT	1.6	1,160	65	150	42.7

Table 24. Minor constituents (unfiltered) by depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base—*Continued*

Constituent	Aquifer -depth code	Minimum	Maximum	Number of detections	Mean	Median
Mercury	DP	--	--	--	--	--
	IN	--	--	--	--	--
	WT	--	--	--	--	--
Nickel	DP	33.5	33.5	1	--	--
	IN	11.8	85.4	7	42.7	33.6
	WT	15.4	239	25	58.7	41.4
Nitrate	DP	290	2,500	3	1,700	2,200
	IN	240	3,500	19	1,700	1,600
	WT	50	5,600	39	2,200	1,800
Selenium	DP	--	--	--	--	--
	IN	3.1	3.1	1	--	--
	WT	2.3	15	7	5.9	4
Silver	DP	--	--	--	--	--
	IN	2.2	19.4	2	10.8	10.8
	WT	1.8	1.8	1	--	--
Thallium	DP	2.5	2.5	1	--	--
	IN	1.4	3.2	3	2.2	2.1
	WT	1.1	1.1	1	--	--
Vanadium	DP	1.5	4.8	2	3.2	3.2
	IN	1.3	3.5	5	2.5	2.6
	WT	0.7	5.6	7	2.9	2.4
Zinc	DP	1.8	20.3	4	7.1	3.2
	IN	2.3	57.3	16	13.3	9.2
	WT	2.5	19.4	15	8.5	6.9

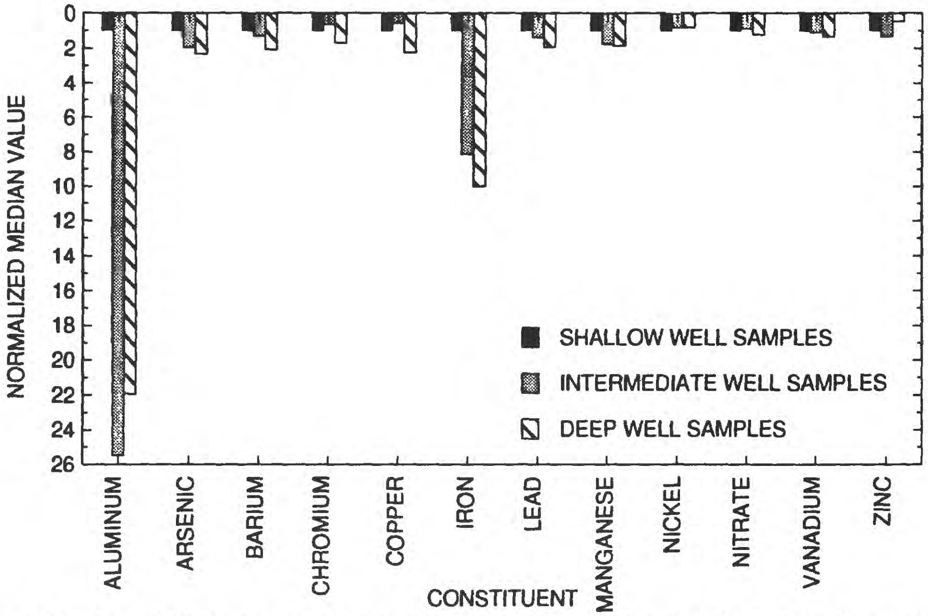


Figure 28. Normalized median concentrations of minor constituents with depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, at Wright-Patterson Air Force Base, Ohio. (Median values for each constituent were normalized to the median of the shallow subgroup. Therefore, all shallow values are equal to 1.0.)

the detection of these elements in samples from depths greater than 60 feet. However, because most detections were from samples from shallow wells indicates that most lead, zinc, and vanadium in ground water were derived from human activities on or adjacent to the Base.

Distributions of nitrate concentrations in the glacial aquifer reflect source and geochemical effects. Nitrate in ground water at concentrations exceeding 1 mg/L is almost always of anthropogenic origin, derived from manufactured fertilizers, feedlots, or sewage effluent. As an anion, nitrate is readily transported in surface and vadose-zone water recharging the aquifer. It is the stable form of nitrogen under aerobic conditions but degrades microbially under anaerobic conditions. This process of denitrification has been shown to occur in many aquifers affected by agrochemicals or sewage or septic-tank effluent (Korom, 1992). Nitrate rarely was detected below depths of 50-60 ft, which is evidence that denitrification of dissolved nitrate occurred in the glacial aquifer (fig. 31). Further evidence of denitrification is that the depth interval at which nitrate effectively disappears from ground water corresponds with the depth interval marking the transition from aerobic to anaerobic conditions (fig. 23). Given the lack of MCL exceedances for nitrate, it appears that current land-use practices at the Base, in combination with natural denitrification, preclude development of deleterious concentrations of nitrate in the glacial aquifer.

Glacial aquifer - variation along the regional ground-water gradient

Summary statistics for concentrations of minor constituents with position along the regional ground-water gradient in the glacial aquifer in Areas A and C and Area B are given in table 25 at back of report. For many minor constituents, grouping the wells by administrative area and position along the regional ground-water gradient reduced the number of detections to levels below statistical importance. However, sufficient data exist to make general statements regarding the distributions of aluminum, arsenic, barium, chromium, iron, lead, manganese, nickel, and nitrate with position along the ground-water gradient in each administrative area.

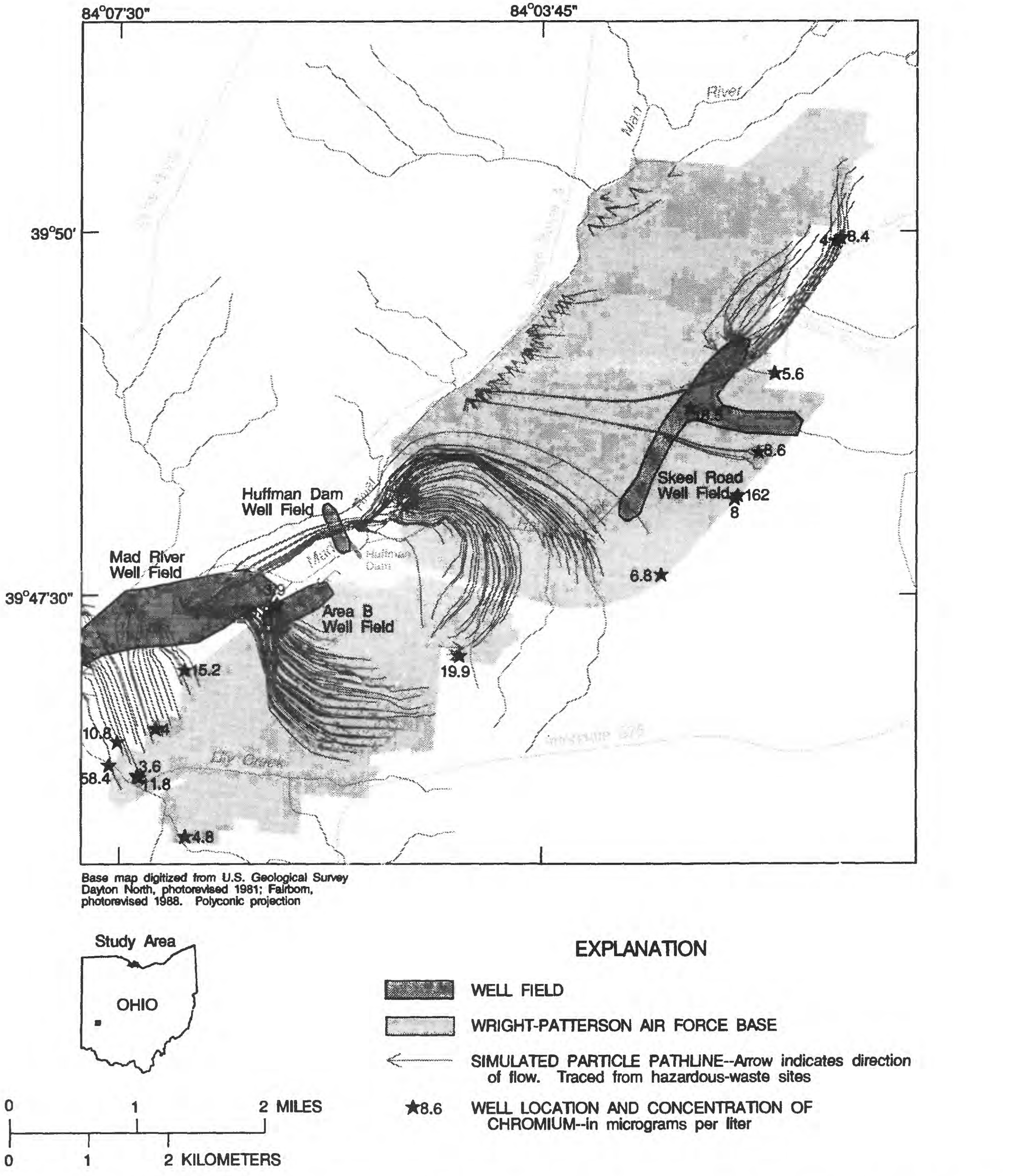
Arsenic concentrations increased along the ground-water gradient in Areas A and C wells, but decreased along the ground-water gradient in Area B wells table 25. Barium concentrations were relatively constant in Areas A and C, but decreased along the flow path in Area B wells (which was consistent with the inverse increase of sulfate concentrations along this flow path). Manganese concentrations increased along the regional gradient in both administrative areas. Chromium and nickel concentrations increased along flow paths in both administrative areas (table 25 and figs. 33 and 34; however, the sharpest increases in both elements occurred between the upgradient and interior subgroups in Areas A and C wells but between the interior and downgradient subgroups for Area B wells. Iron concentrations followed a similar pattern in Areas A and C wells. These trends probably were related to the proximity of each flow-path subgroup to IRP sites in each administrative area. In Areas A and C, upgradient and interior glacial wells are closest to IRP sites, whereas in Area B, interior and downgradient wells are closest to IRP sites. For iron, the trends can be related to anthropogenic effects or to natural processes in the glacial aquifer. No consistent trends were observed for lead or aluminum in either administrative area.

Gross Alpha and Gross Beta

Ground-water samples were analyzed for gross alpha and gross beta analyses during rounds 1 and 2. Alpha- and beta-emitting substances can be derived from natural or anthropogenic sources. In natural waters, alpha-emitters are derived primarily from isotopes of radium and radon, which are daughter products of the uranium and thorium series. Beta-emitters also are derived from some members of those series and from potassium-40 and rubidium-87 (Hem, 1989). Gross alpha and gross beta activities cannot be used to establish the concentration of specific radionuclides in a sample.

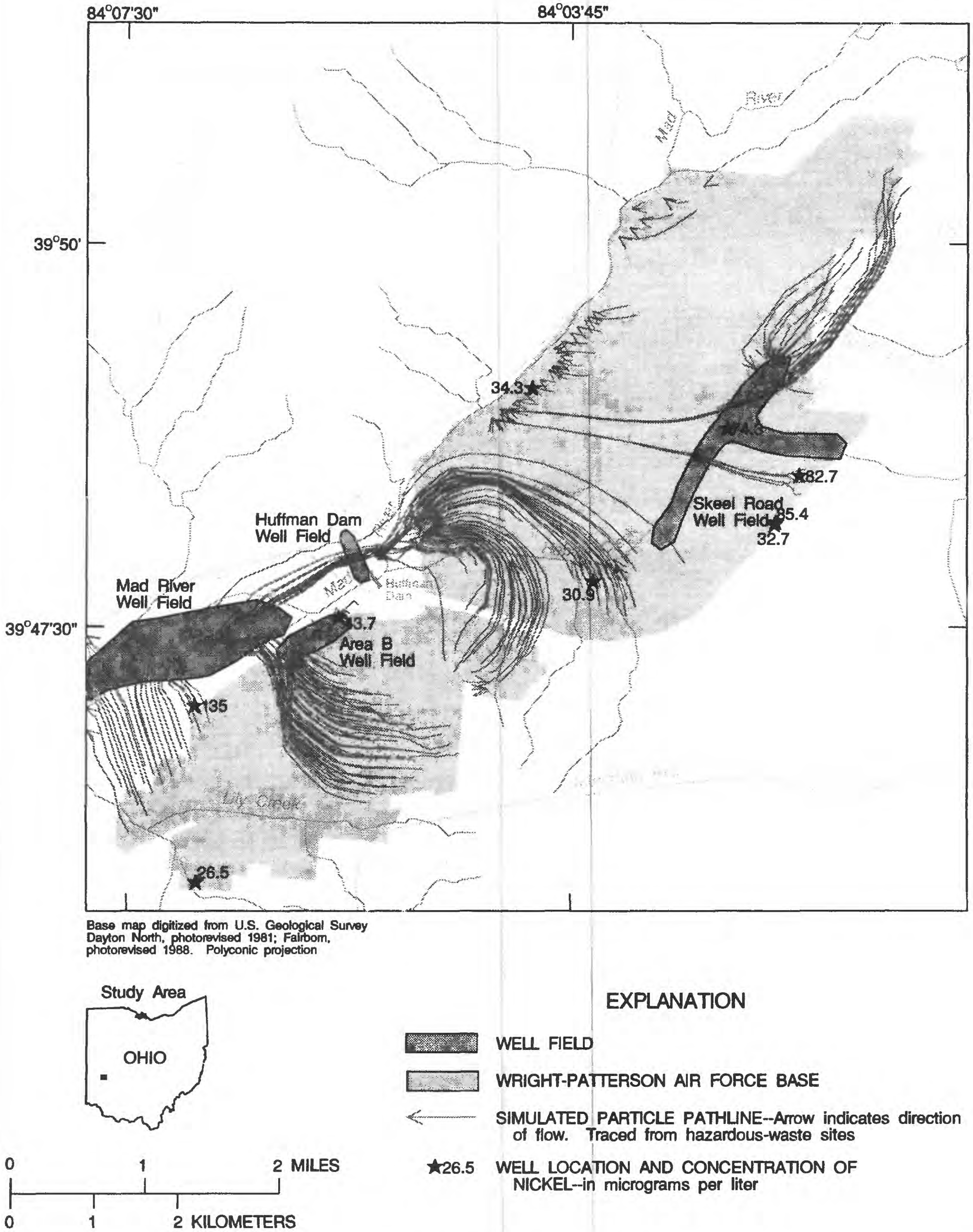
Bedrock-aquifer and glacial-aquifer wells

Summary statistics of gross alpha and gross beta concentrations in bedrock and glacial wells sampled in rounds 1 and 2 are shown in table 26. Elevated gross alpha and gross beta concentrations were found in samples from the Ordovician bedrock. Exceedances of gross alpha and gross beta MCLs for rounds 1 and 2 were primarily in water from bedrock wells, by a margin greater than two to one over the number of exceedances in water from glacial wells (table 16). Almost 80 percent of the gross beta exceedances were associated with samples from bedrock wells; this may indicate elevated concentrations of potassium in



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 33. Distribution of chromium concentrations in the glacial aquifer, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 34. Distribution of nickel concentrations in the glacial aquifer, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.

particulates derived from shale-rich units of the Ordovician bedrock.

Glacial aquifer–variation with depth

Summary statistics for gross alpha and gross beta activities in wells sampled in rounds 1 and 2 with depth in the glacial aquifer are shown in table 27. No trend in gross alpha or gross beta concentrations with depth is indicated in the data. A plot of gross alpha and gross beta activities with well depth for round 1 (fig. 35) shows that low-level concentrations of both radionuclides were found at all depths. Of 212 samples in rounds 1 and 2, concentrations exceeding 15 pCi/L were found in 3 samples. No clustering of elevated concentrations at shallow depths was found; therefore, it is likely that elevated gross alpha and gross beta concentrations reflect natural variability in the glacial aquifer.

Glacial aquifer–variation along the regional ground-water gradient

Summary statistics of gross alpha and gross beta activities in water from glacial wells sampled in rounds 1 and 2 of the BMP as a function of position along the regional ground-water gradient in Areas A and C and Area B are given in table 28. No statistically significant differences in gross alpha or gross beta concentrations as a function of position along the regional ground-water gradient were found for either Areas A and C or Area B.

Organic Compounds

In this section, the detection and distribution of the following classes of organic compounds in ground water are discussed: (1) VOCs; (2) SVOCs; (3) organochlorine pesticides and polychlorinated biphenyls (PCBs); (4) chlorinated herbicides; and (5) petroleum hydrocarbons (TPH). Except for some organic compounds that may be analyzed as part of the petroleum hydrocarbon method, almost all of the organic compounds found in ground water at the Base are of anthropogenic origin. The distribution of organic compounds in ground water at the Base reflects the combined effects of source, local hydrogeology, and geochemical properties of specific compounds.

Because the number of detections for almost all organic compounds was very low (or absent entirely), summary statistic tables were not generated. Instead, frequency of detection, MCL exceedances, and depth

Table 26. Radionuclides by aquifer, all wells, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base
[units are picocuries per liter]

Constituent	Aquifer	Minimum	Maximum	Number of detections	Mean	Median
Gross Alpha	Bedrock	-5.0	44.0	21	8.1	4.7
Gross Alpha	Glacial	-0.2	59.6	176	3.3	1.8
Gross Beta	Bedrock	1.8	77.0	21	28.3	26.9
Gross Beta	Glacial	-0.1	62.1	174	4.7	3.1

Table 27. Radionuclides by depth in the glacial aquifer, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base
[units are picocuries per liter; DP, deep; IN, intermediate; WT, water table]

Constituent	Depth	Minimum	Maximum	Number of detections	Mean	Median
Gross Alpha	DP	0.1	59.6	20	8.7	2.6
Gross Alpha	IN	-0.2	18.3	92	2.6	1.6
Gross Alpha	WT	-0.2	19.0	64	2.7	2.0
Gross Beta	DP	1.7	62.1	20	10.1	3.6
Gross Beta	IN	-0.1	26.7	89	3.5	2.7
Gross Beta	WT	0.0	24.0	65	4.6	3.4

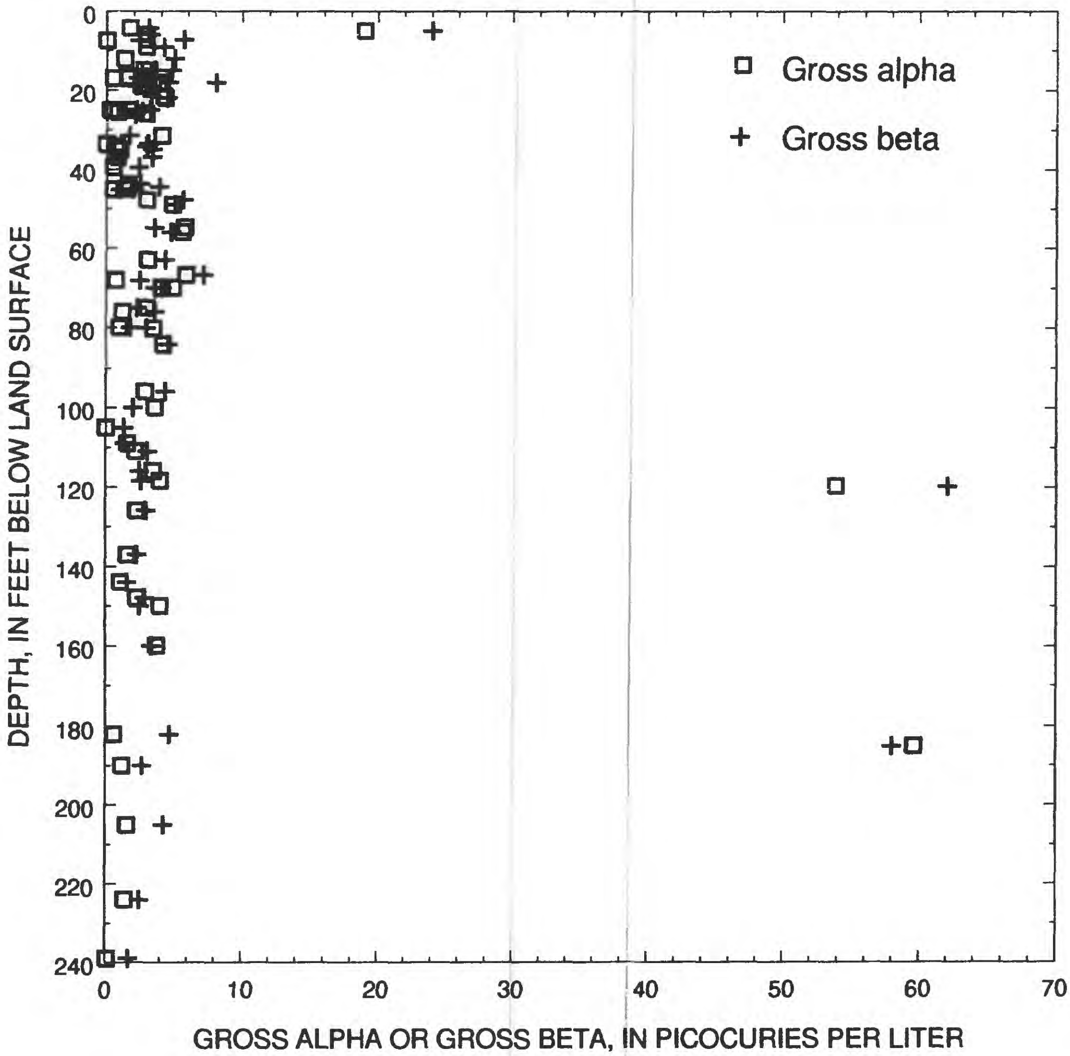


Figure 35. Gross alpha and gross beta concentrations with depth in the glacial aquifer, round 1, August–September 1993, Wright-Patterson Air Force Base.

and areal distributions of organic compounds are discussed.

Quality Control and Data Validation

Quality-assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the organic data collected in each of the four sampling rounds generally were met. More detailed descriptions of the quality-control deficiencies associated with each group of analytes, including data-validation summaries, are available in the technical memoranda provided to the Base.

Frequency of Detection of Organic Compounds

Unqualified detections of organic compounds and petroleum hydrocarbons were reported in samples from 34 of the 111 wells (approximately 31 percent) sampled in the first year of the BMP. Samples from an additional 23 wells had qualified detections of organic compounds. Percent detections and MCL exceedances of all organic compounds (based on all four sampling rounds) are given in table 29. The most frequently-detected VOCs were trichloroethylene (TCE) (12.5 percent) and tetrachloroethylene (PCE) (5.8 percent). Other VOCs detected more than once were 1,1,1-trichloroethane (1.7 percent), chloromethane (2.3 percent), 1,2-dichloroethene-total (1.2 percent),

Table 28. Radionuclides by administrative area and position along the regional ground-water gradient, rounds 1 and 2, August 1993–January 1994, glacial wells, Wright-Patterson Air Force Base

[all concentrations in picocuries per liter; D, downgradient; I, interior; U, upgradient]

		Areas A and C					Area B				
Constituent	Position code	Minimum	Maximum	Number of detections	Mean	Median	Minimum	Maximum	Num-ber of detections	Mean	Median
Gross alpha	D	1.0	53.9	28	5.3	2.9	-0.2	18.3	51	3.3	1.9
	I	-0.1	12.0	45	1.9	1.4	0.3	8.8	14	2.5	1.6
	U	-0.2	59.6	29	4.1	1.9	1.1	8.2	9	2.9	1.8
Gross beta	D	0.3	62.1	30	6.0	3.2	1.2	26.7	51	4.8	3.3
	I	-0.1	8.4	47	3.0	2.6	0.0	17.8	13	4.3	2.5
	U	1.3	58.0	23	7.4	4.2	1.3	3.9	10	2.3	2.3

vinyl-chloride (0.9 percent), methylene chloride (0.9 percent), chloroform (0.6 percent), and toluene (0.6 percent). Almost all of the detections of chloromethane were qualified. VOCs detected only once on an unqualified basis include benzene, chloroethane, chloromethane, carbon tetrachloride, and 2-hexanone. VOCs that were detected only on a qualified basis included acetone, carbon disulfide, 2-butanone (MEK), and 4-methyl-2-pentanone (MIBK).

TCE, detected in samples from 14 different wells, was the most widespread VOC. The rest of the VOCs, in order of number of wells found, were PCE (eight wells), methylene chloride (five wells), 1,1,1-trichloroethane (four wells), 1,2-dichloroethene-total (two wells), and chloroform (two wells). All other VOCs listed in table 29 were detected in samples collected from single wells.

The most frequently detected SVOC was the plasticizer bis(2-ethylhexyl)phthalate (6.5 percent of all samples). Other SVOCs detected were total phenol (2.3 percent) and di-n-butyl-phthalate (2.1 percent) (table 30). Diethyl phthalate was detected twice, and di-n-octyl phthalate and 4-methylphenol were detected once. More than 75 percent of all detections of SVOCs were qualified. Most SVOCs were detected in no more than one well; only bis(2-ethylhexyl)phthalate was detected in a specific well (GR-433) in more than one sampling round. Only 7 of the 30 (23 percent) ground-water samples containing SVOCs had more than one SVOC in the same sample.

No unqualified detections of pesticides, PCBs, or herbicides were reported for any of the ground-water samples collected in the first year of the BMP (table 29). Qualified concentrations of the pesticides aldrin, beta-BHC, and 4,4'-DDT, and the herbicide 2,4'-D (dichlorophenoxyacetic acid) were reported, however. No PCBs were detected in any ground-water samples. Ground water was not sampled for pesticides, PCBs, or herbicides during rounds 3 and 4 of the BMP.

Petroleum hydrocarbons (TPH) were found in less than 4 percent of the ground-water samples collected during the first year of the BMP (table 29). TPH were not detected in any well more than once. Ground water was not sampled for TPH during rounds 3 and 4 of the BMP.

Exceedances of Drinking-Water Standards

Exceedances of USEPA MCLs for organic compounds are summarized in table 30. Concentrations of four VOCs exceeded the MCL: TCE (MCL of 5 µg/L) in wells GR-286, GR-298, GR-321, GR-333, GR-334, and MT-230; PCE (MCL of 5 µg/L) in wells GR-286, GR-318, and GR-330; vinyl chloride (MCL of 2 µg/L) in well MT-286; and benzene (MCL of 5 µg/L) in well GR-312. Well GR-312 was completed in Ordovician bedrock and was sampled only during round 1. Most TCE exceedances, with the exception of those in samples from GR-298, were only slightly above the MCL. Water from GR-298 had the highest TCE

Table 29. Detections of organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base
[MCL, maximum contaminant level]

Compound	Number of analyses	Number of detections	Percent detections	Number of qualified detections	Percent qualified detections	Number of MCL exceedances	Percent MCL exceedances
Volatile organic compounds							
Acetone	343	3	0.9	3	100	0	0.0
Benzene	343	1	0.3	0	0	1	0.3
2-Butanone	343	1	0.3	1	100	0	0.0
Chloroethane	343	1	0.3	0	0	0	0.0
Chloroform	343	2	0.6	0	0	0	0.0
Chloromethane	343	8	2.3	7	88	0	0.0
Carbon tetrachloride	343	1	0.3	0	0	0	0.0
1,2-Dichloroethene (total)	343	4	1.2	0	0	0	0.0
2-Hexanone	343	1	0.3	0	0	0	0.0
Methylene chloride	343	3	0.9	0	0	0	0.0
4-Methyl-2-pentanone	343	1	0.3	1	100	0	0.0
Tetrachloroethene	343	20	5.8	0	0	11	3.2
1,1,1-Trichloroethane	343	8	2.3	2	25	0	0.0
Trichloroethene	343	43	12.5	0	0	16	4.7
Toluene	343	2	0.6	1	50	0	0.0
Vinyl chloride	343	3	0.9	0	0	3	0.9
Semivolatile organic compounds							
Bis(2-ethylhexyl)phthalate	338	22	6.5	19	86	4	1.2
Di-n-butyl phthalate	338	7	2.1	6	86	0	0.0
Diethyl phthalate	338	2	0.6	2	100	0	0.0
Di-n-octyl phthalate	338	1	0.3	1	100	0	0.0
4-Methylphenol (p-cresol)	338	1	0.3	1	100	0	0.0
Phenol	338	8	2.3	6	75	0	0.0
Organochlorine pesticides and polychlorinated biphenyls							
Aldrin	218	1	0.5	1	100	0	0.0
Beta-BHC	218	1	0.5	1	100	0	0.0
4,4'-DDT	218	3	1.4	3	100	0	0.0
Chlorinated herbicides							
2,4'-D (Dichlorophenoxyacetic acid)	213	1	0.5	1	100	0	0.0
Petroleum hydrocarbons							
Petroleum hydrocarbons	189	7	3.7	0	0	0	0.0

concentrations reported in all four sampling rounds (28-52 µg/L). Exceedances of the MCL for TCE were observed in samples from GR-286, GR-298, GR-321, and GR-333 in all sampling rounds, but from GR-334 only in round 4 and from MT-230 in rounds 2, 3, and 4. TCE concentrations were below detection limits in samples from GR-334 for rounds 1, 2, and 3, and were near the reporting limit (1.0 µg/L) in samples from MT-230 for rounds 1 and 3. Samples from GR-330 had the highest PCE concentrations (13-37 µg/L), especially in rounds 3 and 4. Concentrations of PCE in samples from GR-318 were three times higher than the MCL in all four rounds. Concentrations of PCE in samples from GR-286 were at or only slightly above

Table 30. Exceedances of maximum contaminant levels for organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[REG, regular; DUP, duplicate; VOC, volatile organic compound; SVOC, semivolatile organic compound; MCL, maximum contaminant level; Q, qualifier; J, estimated concentration; --, not applicable. All concentrations are micrograms per liter]

Well	Cluster	Sample type	Analysis	Compound	Concentration	MCL	Q
				ROUND 1			
GR-286	91	REG	VOC	Tetrachloroethylene	6.0	5.0	--
GR-286	91	REG	VOC	Trichloroethylene	7.0	5.0	--
GR-286	91	REG	VOC	Vinyl chloride	12	2.0	--
GR-286	91	DUP	VOC	Tetrachloroethylene	6.0	5.0	--
GR-286	91	DUP	VOC	Trichloroethylene	6.0	5.0	--
GR-286	91	DUP	VOC	Vinyl chloride	12	2.0	--
GR-298	97	REG	VOC	Trichloroethylene	32	5.0	--
GR-311	USGS11	REG	SVOC	Bis(2-ethylhexyl)phthalate	12	6.0	--
GR-312	USGS9	REG	VOC	Benzene	5.0	5.0	--
GR-315	USGS1	REG	SVOC	Bis(2-ethylhexyl)phthalate	7.0	6.0	J
GR-318	USGS2	REG	VOC	Tetrachloroethylene	15	5.0	--
GR-318	USGS2	REG	VOC	Tetrachloroethylene	13	5.0	--
GR-321	USGS4	REG	VOC	Trichloroethylene	5.0	5.0	--
GR-321	USGS4	DUP	VOC	Trichloroethylene	5.0	5.0	--
GR-330	USGS6	REG	VOC	Tetrachloroethylene	20	5.0	--
GR-333	USGS11	REG	VOC	Trichloroethylene	6	5.0	--
GR-433	UG2	REG	SVOC	Bis(2-ethylhexyl)phthalate	16	6.0	--
GR-288	2	REG	SVOC	Bis(2-ethylhexyl)phthalate	12	6.0	J
				ROUND 2			
GR-286	91	REG	VOC	Tetrachloroethylene	6.0	5.0	--
GR-286	91	REG	VOC	Trichloroethylene	6.0	5.0	--
GR-286	91	REG	VOC	Vinyl chloride	2.0	2.0	--
GR-286	91	DUP	VOC	Tetrachloroethylene	5.0	5.0	--
GR-286	91	DUP	VOC	Trichloroethylene	5.0	5.0	--
GR-286	91	DUP	VOC	Vinyl chloride	2.0	2.0	--
GR-298	97	REG	VOC	Trichloroethylene	51	5.0	--
GR-298	97	DUP	VOC	Trichloroethylene	52	5.0	--
GR-318	USGS2	REG	VOC	Tetrachloroethylene	12	5.0	--
GR-330	USGS6	REG	VOC	Tetrachloroethylene	13	5.0	--
GR-330	USGS6	DUP	VOC	Tetrachloroethylene	12	5.0	--
GR-333	USGS11	REG	VOC	Trichloroethylene	6	5.0	--
MT-230	CW3	REG	VOC	Trichloroethylene	8.0	5.0	--
				ROUND 3			
GR-286	91	REG	VOC	Trichloroethylene	5.0	5.0	--
GR-286	91	REG	VOC	Vinyl chloride	20	2.0	--
GR-298	97	REG	VOC	Trichloroethylene	28	5.0	--
GR-298	97	DUP	VOC	Trichloroethylene	28	5.0	--
GR-318	USGS2	REG	VOC	Tetrachloroethylene	12	5.0	--
GR-321	USGS4	REG	VOC	Trichloroethylene	5.0	5.0	--
GR-321	USGS4	DUP	VOC	Trichloroethylene	5.0	5.0	--
GR-330	USGS6	REG	VOC	Tetrachloroethylene	22	5.0	--
GR-333	USGS11	REG	VOC	Trichloroethylene	6.0	5.0	--
GR-433	UG2	REG	SVOC	Bis(2-ethylhexyl)phthalate	31	6.0	J
MT-230	CW3	DUP	VOC	Trichloroethylene	9.0	5.0	--
MT-252	UG1	REG	SVOC	Bis(2-ethylhexyl)phthalate	17	6.0	--
				ROUND 4			
GR-298	97	REG	VOC	Trichloroethylene	43	5.0	--
GR-318	USGS2	REG	VOC	Tetrachloroethylene	13	5.0	--
GR-321	USGS4	REG	VOC	Trichloroethylene	7.0	5.0	--
GR-330	USGS6	REG	VOC	Tetrachloroethylene	37	5.0	--
GR-334	USGS11	REG	VOC	Trichloroethylene	7.0	5.0	--
MT-230	CW3	REG	VOC	Trichloroethylene	7.4	5.0	--

the MCL in the three rounds that well was sampled. Vinyl chloride concentrations in water from well GR-286 ranged from 2.0 to 20 µg/L.

Wells contaminated with excessive concentrations of organics are generally near the east-central parts of the Base (figs. 36-39 at back of report); all are classified as upgradient or interior wells except for MT-230 at cluster CW3. All wells contaminated with excessive organics were completed in the glacial aquifer except MT-312, which was completed 136 ft below land surface in bedrock. The wells in the glacial aquifer were completed at depths of less than 50 ft except for MT-230 (76.4 ft) and GR-334 (155 ft).

The only MCL exceedances recorded for SVOCs were for bis(2-ethylhexyl)phthalate. These were detected in samples from GR-288, GR-311, GR-315, GR-433, and MT-252. Of these wells, GR-311 and GR-315 are completed in the Ordovician bedrock with screened intervals at depths greater than 250 feet below land surface, whereas GR-433 is completed at a depth of 192 feet in the glacial aquifer. Because bis(2-ethylhexyl)phthalate rarely is found in water from bedrock or deep glacial wells, further sampling will be required to verify the presence of this compound in ground water.

Volatile Organic Compounds

A summary of all detections of VOCs in ground water during the first year of the BMP is given in table 31. Most detections of VOCs were in samples from wells completed in the glacial aquifer. As noted previously, GR-312 was the only bedrock well that contained any detectable VOCs. The sample collected from this well contained benzene at a concentration equivalent to the MCL (5 µg/L) and detectable concentrations of toluene, 2-butanone, and three SVOCs. This well is beside a parking lot at the top of a hill in Area B and produces little water. Water in GR-312 may have been contaminated during or after drilling.

The data in table 31 indicate that most VOCs in the glacial aquifer were found at shallow and intermediate depths. A plot of total VOC concentrations (sum of all detected VOC concentrations) with depth for data collected during the first year of the BMP indicates that total VOC concentrations exceeding 10 µg/L rarely were found at depths greater than 50 ft below land surface (fig. 40). Most of the concentrations reported for wells completed at depths greater than 100 ft were qualified. The pattern in figure 40 is similar to that of several minor inorganic constituents

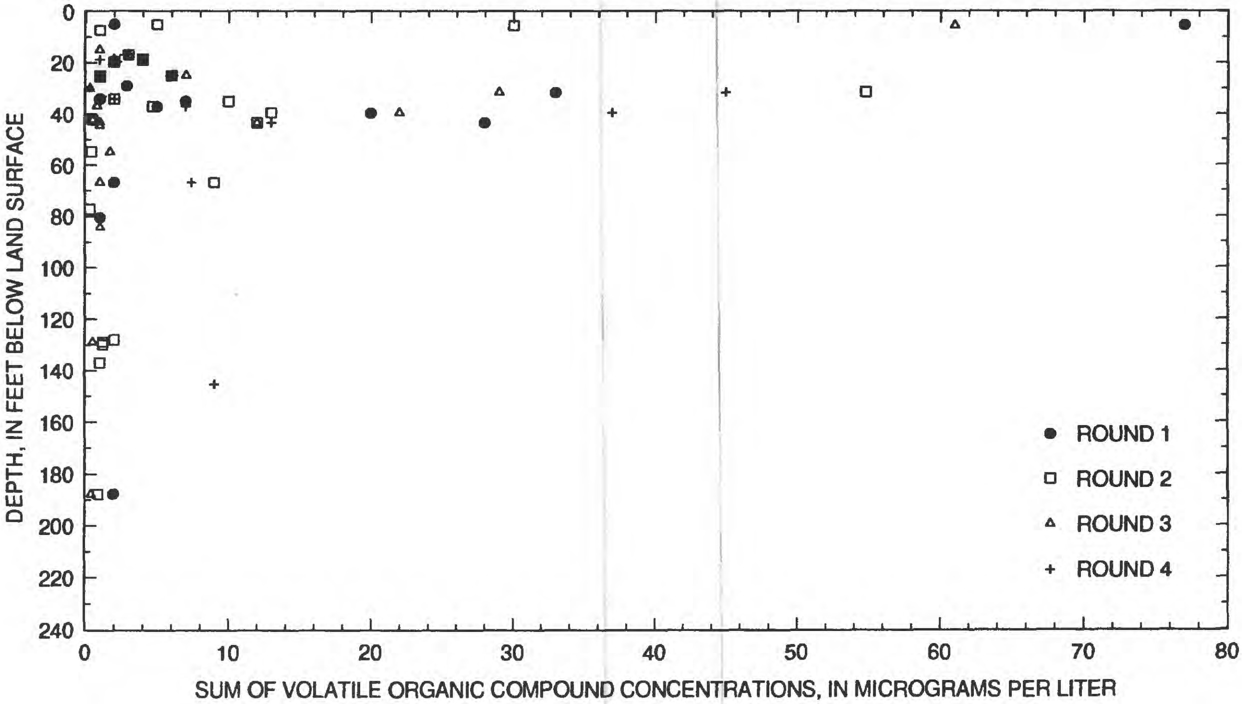


Figure 40. Sum of volatile organic compound concentrations with depth in the glacial aquifer, all rounds, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.

Table 31. Volatile organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[WT, water table; IN, intermediate; DP, deep; bed, bedrock; U, upgradient; I, interior; D, downgradient; Q, qualifier; J, estimated concentration; --, not applicable. All concentrations are micrograms per liter.]

Well	Cluster	Aquifer-depth code	Area	Position code	Compound	Sample round	Concentration	Q
GR-288	2	WT	A/C	U	Chloroform	4	1.0	--
GR-288	2	WT	A/C	U	Tetrachloroethene	2	2	--
GR-288	2	WT	A/C	U	Tetrachloroethene	3	2.0	--
GR-288	2	WT	A/C	U	Tetrachloroethene	4	1.7	--
GR-289	2	IN	A/C	U	Tetrachloroethene	1	1	--
GR-435	2	IN	A/C	U	Methylene chloride	3	1.0	--
GR-214	33	WT	A/C	D	Carbon tetrachloride	2	2	--
GR-214	33	WT	A/C	D	Trichloroethylene	1	2	--
GR-214	33	WT	A/C	D	Trichloroethene	2	2	--
GR-214	33	WT	A/C	D	Trichloroethene	3	2.0	--
GR-214	33	WT	A/C	D	Trichloroethene	4	2.0	--
GR-215	33	IN	A/C	D	Trichloroethene	1	2	--
GR-215	33	IN	A/C	D	Trichloroethene	2	2	--
GR-215	33	IN	A/C	D	Trichloroethene	3	2.0	--
GR-215	33	IN	A/C	D	Trichloroethene	4	2.2	--
GR-298	97	WT	A/C	I	1,1,1-Trichloroethane	2	1.3	--
GR-298	97	WT	A/C	I	Tetrachloroethene	1	1.0	--
GR-298	97	WT	A/C	I	Tetrachloroethene	2	2.5	--
GR-298	97	WT	A/C	I	Tetrachloroethene	3	1.0	--
GR-298	97	WT	A/C	I	Tetrachloroethene	4	2.0	--
GR-298	97	WT	A/C	I	Trichloroethene	1	32	--
GR-298	97	WT	A/C	I	Trichloroethene	2	51	--
GR-298	97	WT	A/C	I	Trichloroethene	3	28	--
GR-298	97	WT	A/C	I	Trichloroethene	4	43	--
GR-419	DG15	DP	A/C	D	Acetone	2	1.2	J
GR-420	DG15	IN	A/C	D	Methylene chloride	3	1.0	--
GR-434	DG15	WT	A/C	D	Methylene chloride	3	1.0	--
GR-440	DG16	WT	A/C	D	Chloroethane	2	1	--
GR-437	UG2	IN	A/C	I	Carbon disulfide	1	0.9	J
GR-437	UG2	IN	A/C	I	Chloromethane	1	2	J
GR-333	USGS11	WT	A/C	I	1,1,1-Trichloroethane	1	1	J
GR-333	USGS11	WT	A/C	I	1,1,1-Trichloroethane	2	1	J
GR-333	USGS11	WT	A/C	I	1,1,1-Trichloroethane	3	1.0	--
GR-333	USGS11	WT	A/C	I	Acetone	2	3	J
GR-333	USGS11	WT	A/C	I	Trichloroethene	1	6	--
GR-333	USGS11	WT	A/C	I	Trichloroethene	2	6	--
GR-333	USGS11	WT	A/C	I	Trichloroethene	3	6.0	--
GR-334	USGS11	IN	A/C	I	1,1,1-Trichloroethane	4	1.0	--
GR-334	USGS11	IN	A/C	I	Chloroform	4	1.0	--
GR-334	USGS11	IN	A/C	I	Trichloroethene	4	7.0	--
GR-318	USGS2	IN	A/C	I	Tetrachloroethene	1	13	--
GR-318	USGS2	IN	A/C	I	Tetrachloroethene	1	15	--
GR-318	USGS2	IN	A/C	I	Tetrachloroethene	2	12	--

Table 31. Volatile organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base—*Continued*

Well	Cluster	Aquifer-depth code	Area	Position code	Compound	Sample round	Concen-tration	Q
GR-318	USGS2	IN	A/C	I	Tetrachloroethene	3	12	--
GR-318	USGS2	IN	A/C	I	Tetrachloroethene	4	13	--
GR-321	USGS4	IN	A/C	I	Trichloroethene	1	5.0	--
GR-321	USGS4	IN	A/C	I	Trichloroethene	2	4.7	--
GR-321	USGS4	IN	A/C	I	Trichloroethene	3	5.0	--
GR-321	USGS4	IN	A/C	I	Trichloroethene	4	7.0	--
GR-324	USGS5	IN	A/C	I	Acetone	2	2.0	J
GR-330	USGS6	WT	A/C	U	Tetrachloroethene	1	20	--
GR-330	USGS6	WT	A/C	U	Tetrachloroethene	2	13	--
GR-330	USGS6	WT	A/C	U	Tetrachloroethene	3	22	--
GR-330	USGS6	WT	A/C	U	Tetrachloroethene	4	37	--
MT-126	83	WT	B	D	Carbon disulfide	3	0.3	J
GR-286	91	WT	B	I	1,2-Dichloroethene	1	52	--
GR-286	91	WT	B	I	1,2-Dichloroethene	2	16	--
GR-286	91	WT	B	I	1,2-Dichloroethene	3	33	--
GR-286	91	WT	B	I	Tetrachloroethene	1	6.0	--
GR-286	91	WT	B	I	Tetrachloroethene	2	6.0	--
GR-286	91	WT	B	I	Tetrachloroethene	3	3.0	--
GR-286	91	WT	B	I	Trichloroethene	1	7.0	--
GR-286	91	WT	B	I	Trichloroethene	2	6.0	--
GR-286	91	WT	B	I	Trichloroethene	3	5.0	--
GR-286	91	WT	B	I	Vinyl chloride	1	12	--
GR-286	91	WT	B	I	Vinyl chloride	2	2.0	--
GR-286	91	WT	B	I	Vinyl chloride	3	20	--
MT-222	CW1	WT	B	D	Trichloroethene	2	1.0	--
MT-222	CW1	WT	B	D	Trichloroethene	3	1.0	--
MT-223	CW1	IN	B	D	Trichloroethene	1	1.0	--
MT-223	CW1	IN	B	D	Trichloroethene	2	1.0	--
MT-225	CW2	WT	B	D	Trichloroethene	2	1.0	--
MT-225	CW2	WT	B	D	Trichloroethene	4	1.0	--
MT-226	CW2	IN	B	D	Trichloroethene	1	1.0	--
MT-226	CW2	IN	B	D	Trichloroethene	2	2.0	--
MT-226	CW2	IN	B	D	Trichloroethene	3	1.0	--
MT-226	CW2	IN	B	D	Trichloroethene	4	2.0	--
MT-228	CW3	WT	B	D	Trichloroethene	2	1.0	--
MT-229	CW3	IN	B	D	Trichloroethene	1	1.0	--
MT-230	CW3	DP	B	D	1,2-Dichloroethene	2	1.0	--
MT-230	CW3	DP	B	D	Trichloroethene	1	2.0	--
MT-230	CW3	DP	B	D	Trichloroethene	2	8.0	--
MT-230	CW3	DP	B	D	Trichloroethene	3	1.0	--
MT-230	CW3	DP	B	D	Trichloroethene	4	7.4	--
MT-234	DG1	WT	B	D	Chloromethane	3	0.8	J
MT-240	DG1	IN	B	D	Carbon disulfide	3	0.5	J
MT-240	DG1	IN	B	D	Chloromethane	2	0.5	J
MT-241	DG1	IN	B	D	Carbon disulfide	2	0.3	J

Table 31. Volatile organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base—*Continued*

Well	Cluster	Aquifer-depth code	Area	Position code	Compound	Sample round	Concentration	Q
MT-241	DG1	IN	B	D	Carbon disulfide	3	0.5	J
MT-241	DG1	IN	B	D	Chloromethane	2	0.6	J
MT-241	DG1	IN	B	D	Toluene	2	0.3	J
MT-237	DG1A	IN	B	D	2-Hexanone	3	1	--
MT-237	DG1A	IN	B	D	Carbon disulfide	2	0.4	J
MT-237	DG1A	IN	B	D	Chloromethane	3	0.7	J
MT-238	DG3	WT	B	D	Chloromethane	2	0.9	J
MT-244	DG3	IN	B	D	Carbon disulfide	2	0.3	J
MT-245	DG3	DP	B	D	4-Methyl-2-pentanone	1	2.0	J
MT-245	DG3	DP	B	D	Carbon disulfide	3	0.4	J
MT-245	DG3	DP	B	D	Chloromethane	2	0.9	J
MT-246	DG3	IN	B	D	Chloromethane	2	1	--
GR-287	DG8	WT	B	D	1,1,1-Trichloroethane	1	2.0	--
GR-287	DG8	WT	B	D	1,1,1-Trichloroethane	2	2.0	--
GR-287	DG8	WT	B	D	1,1,1-Trichloroethane	3	1.0	--
GR-287	DG8	WT	B	D	Trichloroethene	1	2.0	--
GR-287	DG8	WT	B	D	Trichloroethene	2	2.0	--
GR-287	DG8	WT	B	D	Trichloroethene	3	1.0	--
GR-287	DG8	WT	B	D	Trichloroethene	4	1.0	--
GR-312	USGS9	bed	B	I	2-Butanone	1	7.0	J
GR-312	USGS9	bed	B	I	Benzene	1	5.0	--
GR-312	USGS9	bed	B	I	Toluene	1	2.0	--

such as chromium and nickel. This indicates that most anthropogenic contamination of the glacial aquifer was confined to depths less than 50-60 feet.

The spatial distributions of VOC detections in each of the depth subgroups are illustrated in figures 41-43 at back of report. Three observations are noteworthy: (1) the pattern of VOC detections is nearly identical for the shallow and intermediate subgroups; (2) ground water along the eastern boundary of Areas A and C can be receiving VOCs from outside the Base; and (3) wells in which VOCs have been detected at shallow or intermediate depths in the glacial aquifer are aligned along simulated regional flow paths. The best example of item 3 is the line of contaminated shallow and intermediate-depth wells that follow a southwesterly flow path across the central part of Areas A and C (figs. 41-42, respectively). In Area B, the wells contaminated with VOCs, chromium, and nickel are downgradient of the numerous IRP sites that line the western boundary of Area B.

Semivolatile Organic Compounds

A summary of SVOCs detected in ground-water samples during the first year of the BMP is given in table 32. Almost all (85 percent) of the concentrations were estimated. Although detection of more than one SVOC in a single sample was common, detections of the same SVOCs in subsequent samples at a specific well were rare; only samples from GR-433 had successive detections of an SVOC (bis(2-ethylhexyl) phthalate). One of those detections was estimated. SVOCs, particularly bis(2-ethhexyl)phthalate and phenol, were detected in several wells completed in the Ordovician bedrock, usually at concentrations near the detection limit. However, samples from two wells (GR-311 and GR-315) had MCL exceedances for bis(2-ethylhexyl)phthalate. Many of the bedrock wells are screened at depths exceeding 200 ft and are far removed from any known sources of SVOCs (figs. 44, 45). Therefore, these detections were because of natural occurrences of these compounds in the bedrock or low-level contamination. Because several SVOC

Table 32. Semivolatile organic compounds in ground-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[WT, water table; IN, intermediate; DP, deep; bed, bedrock; U, upgradient; I, interior; D, downgradient; Q, qualifier; J, estimated concentration; --, not applicable. All concentrations are micrograms per liter]

Well	Cluster	Aquifer-depth code	Area	Position code	Compound	Sample round	Concentration	Q
GR-288	2	WT	A/C	U	Bis(2-ethylhexyl) phthalate	1	12	J
GR-289	2	IN	A/C	U	Bis(2-ethylhexyl) phthalate	1	4	J
GR-435	2	IN	A/C	U	Bis(2-ethylhexyl) phthalate	1	4	J
GR-215	33	IN	A/C	D	Di-n-butyl phthalate	1	6	--
GR-216	33	IN	A/C	D	Di-n-butyl phthalate	1	2	J
GR-264	80	WT	A/C	I	Bis(2-ethylhexyl) phthalate	3	1.0	J
GR-264	80	WT	A/C	I	Di-n-butyl phthalate	3	1.0	J
GR-440	DG16	WT	A/C	D	Di-n-butyl phthalate	1	2	J
GR-431	UG11	WT	A/C	I	Bis(2-ethylhexyl) phthalate	4	1.0	J
GR-433	UG2	IN	A/C	I	Bis(2-ethylhexyl) phthalate	1	16	--
GR-433	UG2	IN	A/C	I	Bis(2-ethylhexyl) phthalate	3	31	J
GR-433	UG2	IN	A/C	I	Phenol	1	1.0	J
GR-425	UG3	IN	A/C	U	Bis(2-ethylhexyl) phthalate	3	1.0	J
GR-426	UG3	WT	A/C	U	Bis(2-ethylhexyl) phthalate	3	1.1	J
GR-315	USGS1	bed	A/C	U	Bis(2-ethylhexyl) phthalate	1	7.0	J
GR-315	USGS1	bed	A/C	U	Phenol	1	7.0	J
GR-316	USGS1	IN	A/C	U	Bis(2-ethylhexyl) phthalate	3	1.1	J
GR-317	USGS1	IN	A/C	U	Bis(2-ethylhexyl) phthalate	1	1.0	J
GR-311	USGS11	bed	A/C	I	Bis(2-ethylhexyl) phthalate	1	12	--
GR-311	USGS11	bed	A/C	I	Di-n-octyl phthalate	1	2.0	J
GR-311	USGS11	bed	A/C	I	Phenol	1	9.0	J
GR-334	USGS11	IN	A/C	I	Bis(2-ethylhexyl) phthalate	2	1.1	J
GR-436	USGS11	IN	A/C	I	Bis(2-ethylhexyl) phthalate	3	1.0	J
GR-436	USGS11	IN	A/C	I	Phenol	3	68	--
GR-314	USGS2	bed	A/C	I	Bis(2-ethylhexyl) phthalate	2	4.0	J
GR-320	USGS3	WT	A/C	D	Bis(2-ethylhexyl) phthalate	3	2.0	J
GR-320	USGS3	WT	A/C	D	Di-n-butyl phthalate	3	1.0	J
GR-304	USGS4	bed	A/C	I	Phenol	1	1.0	J
GR-306	USGS6	bed	A/C	U	Phenol	1	1.0	J
GR-307	USGS7	bed	A/C	U	Bis(2-ethylhexyl) phthalate	1	1.0	J
GR-307	USGS7	bed	A/C	U	Phenol	1	1.0	J
MT-126	83	WT	B	D	Di-n-butyl phthalate	2	1	J
MT-241	DG1	IN	B	D	Bis(2-ethylhexyl) phthalate	1	2.0	J
MT-235	DG1A	WT	B	D	Di-n-butyl phthalate	2	0.9	J
MT-238	DG3	WT	B	D	Diethyl phthalate	2	3	J
MT-246	DG3	IN	B	D	Diethyl phthalate	2	4	J
MT-252	UG1	WT	B	U	Bis(2-ethylhexyl) phthalate	3	17	--
GR-310	USGS10	bed	B	U	Bis(2-ethylhexyl) phthalate	1	1.0	J
GR-312	USGS9	bed	B	I	4-Methylphenol	1	1.0	J
GR-312	USGS9	bed	B	I	Bis(2-ethylhexyl) phthalate	1	1.0	J
GR-312	USGS9	bed	B	I	Phenol	1	19	--

compounds (particularly the two most common, phenol and bis(2-ethylhexyl)phthalate) were found in method and equipment blanks, and other rounds of sampling generally failed to confirm the presence of these compounds, the reported SVOC detections should be considered with caution.

Although few detections were observed, some evidence supports the limited presence of SVOC compounds in ground water at the Base. In particular, a plot of SVOC detections with depth (fig. 45) indicates that most SVOC detections were in samples from shallow (less than 60 ft) glacial wells, similar to the distributions observed for several VOCs and minor constituents. In addition, detections of SVOC compounds were, in many cases, related spatially to IRP sites that could be sources of SVOCs (fig. 45).

Organochlorine Pesticides and Polychlorinated Biphenyls

All pesticide and PCB detections reported for ground-water samples collected during the first year of the BMP are listed in table 33. All pesticide concentrations were estimated and low. The pesticides detected were aldrin, beta BHC, and 4,4'-DDT. All detections were in samples from shallow or intermediate-depth wells and all were in samples from wells at downgradient locations (fig. 46). The data indicate that ground-water contamination by organochlorine pesticides and PCBs is minimal at BMP locations.

Chlorinated Herbicides

A single qualified detection of 2,4-D was reported from GR-438 in cluster UG2, a shallow well near the eastern boundary of Areas A and C adjacent to a park in Fairborn (see fig. 16). This detection may represent application of 2,4-D at the park or along the Base boundary. Only a single detection indicates that herbicide contamination of ground water is minimal at the Base.

Petroleum Hydrocarbons

A summary of petroleum hydrocarbon detections in ground-water samples collected during the first year of the BMP is given in table 34. Distribution with depth in the glacial aquifer or position along the regional gradient is not apparent in the data. Some correlation with IRP sites is indicated in Area B (fig. 47). However, the detections in Area B generally were in samples from wells completed at depths greater than 120 ft, making it unlikely that petroleum hydrocarbons are being derived directly from the shallow IRP sites. Neither of the two Areas A and C detections are associated with known IRP sites. Both wells are located on the eastern boundary of Areas A and C and could be affected by sources adjacent to WPAFB. Alternatively, these and the Area B detections could represent low-level contamination.

Surface Water

WPAFB lies within the Mad River drainage basin, and contributes flow to Mad River through a network of drainage tiles and ditches, unnamed perennial and intermittent streams, and storm sewers. Mad River flows from northeast to southwest along the western border of WPAFB. Tributaries to Mad River include Hebble, Trout, and Lily Creeks, Mud Run, and small unnamed perennial and intermittent streams (fig. 4).

Discharge

By Peter R. Wright

The quantity of flow in a stream directly affect the quality of the water in the stream. In order to interpret accurately the quality of surface-water at WPAFB and understand the relation between ground-water and surface-water systems, discharge at each location was measured in conjunction with the collection of a water-quality sample at that location.

Flow conditions during the study were characterized using stream-discharge data, measured during each sampling round. Flow conditions on Mad River additionally were characterized from continuous-stage record data collected at USGS gaging station "Mad River near Dayton", station number 03270000, located just downstream of Huffman Dam. Discharge data collected during each round at 03270000 were evaluated using a streamflow and base-flow duration curve (fig. 48) prepared from the daily mean streamflows recorded for the entire period of record. The percentage of time a given discharge was equaled or exceeded was estimated from the flow duration curve (Koltun, 1995). Baseflow comprises an increasingly greater percentage of the total flow as percent duration increases. Baseflow is the ground-water discharge component of streamflow (Todd, 1980).

Discharge in Mad River during rounds 1 and 3 was measured as 355 and 360 ft^3/sec, respectively, at the USGS gage, about 80 percent of which was

Table 33. Organochlorine pesticides and polychlorinated biphenyls in ground-water samples, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[WT, water table, IN, intermediate; D, downgradient; Q, qualifier; J, estimated concentration. All concentrations are micrograms per liter]

Well	Cluster	Aquifer-depth code	Area	Position code	Compound	Sample round	Concentration	Q
GR-216	33	IN	A/C	D	beta BHC	1	0.007	J
GR-440	DG16	WT	A/C	D	4,4'-DDT	2	0.04	J
GR-440	DG16	WT	A/C	D	Aldrin	1	0.003	J
MT-240	DG1	IN	B	D	4,4'-DDT	2	0.02	J
MT-246	DG3	IN	B	D	4,4'-DDT	2	0.03	J

Table 34. Petroleum hydrocarbons in ground-water samples, rounds 1 and 2, August 1993–January 1994, Wright-Patterson Air Force Base

[IN, intermediate; DP, deep; WT, water table; U, upgradient; I, interior; D, downgradient; TPH, petroleum hydrocarbons. All concentrations are milligrams per liter and are unqualified]

Well	Cluster	Aquifer-depth code	Area	Position code	Analysis	Sample round	Concentration
GR-435	2	IN	A/C	U	TPH	1	1.10
GR-328	USGS7	DP	A/C	U	TPH	2	1.00
MT-125	81	WT	B	I	TPH	1	7.40
MT-240	DG1	IN	B	D	TPH	2	0.10
MT-241	DG1	IN	B	D	TPH	2	0.20
MT-245	DG3	DP	B	D	TPH	2	0.09
MT-246	DG3	IN	B	D	TPH	2	0.10

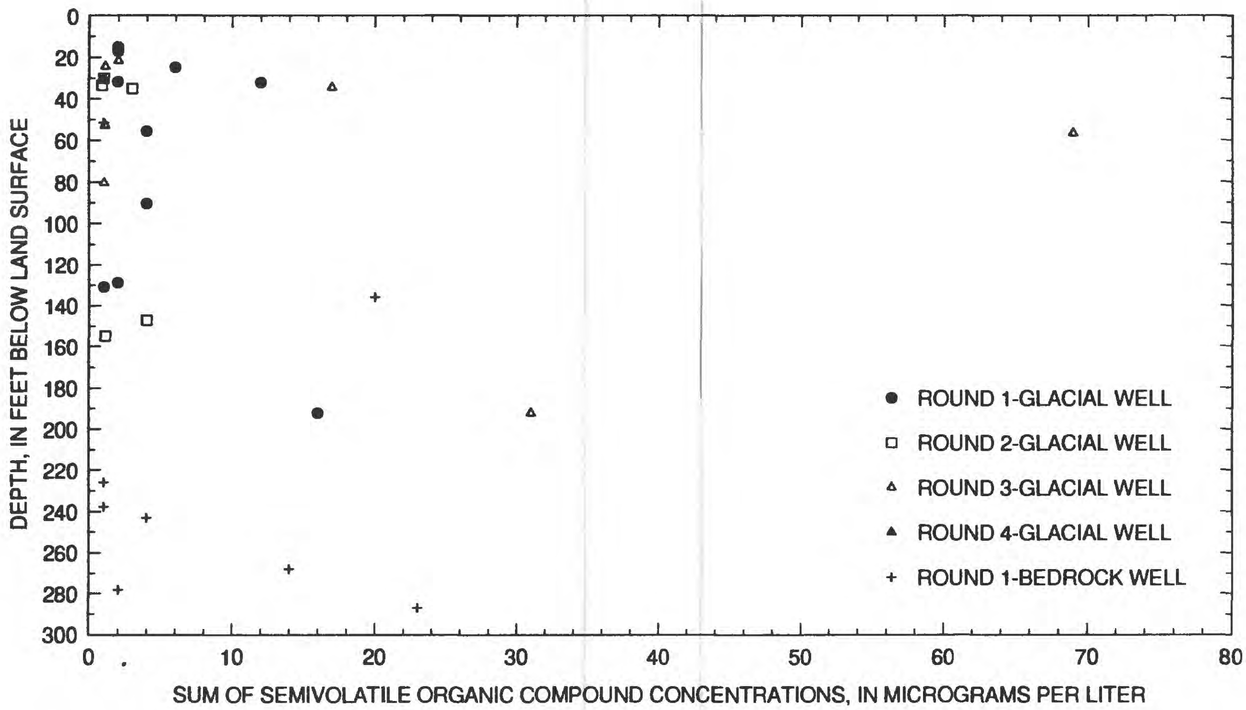
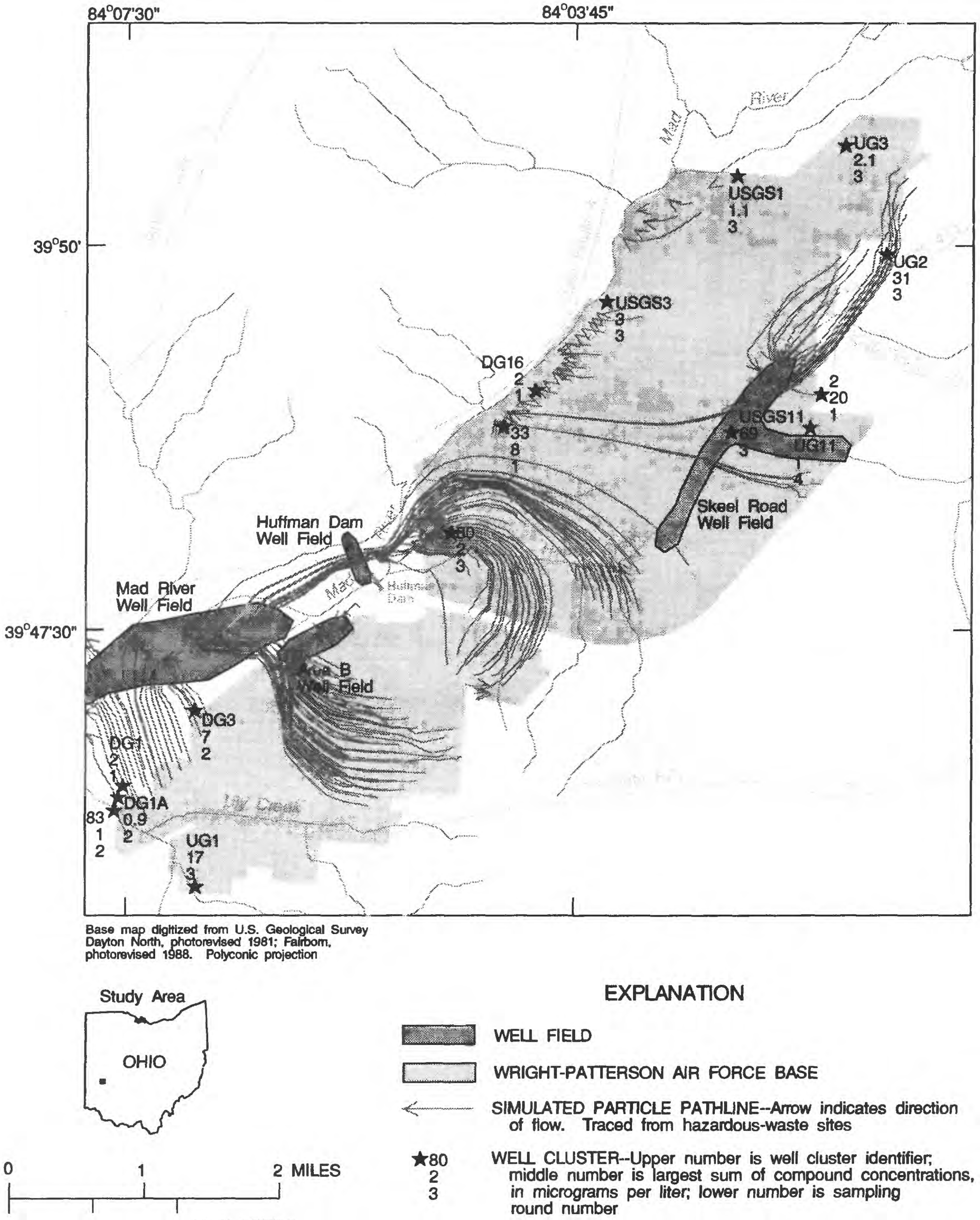
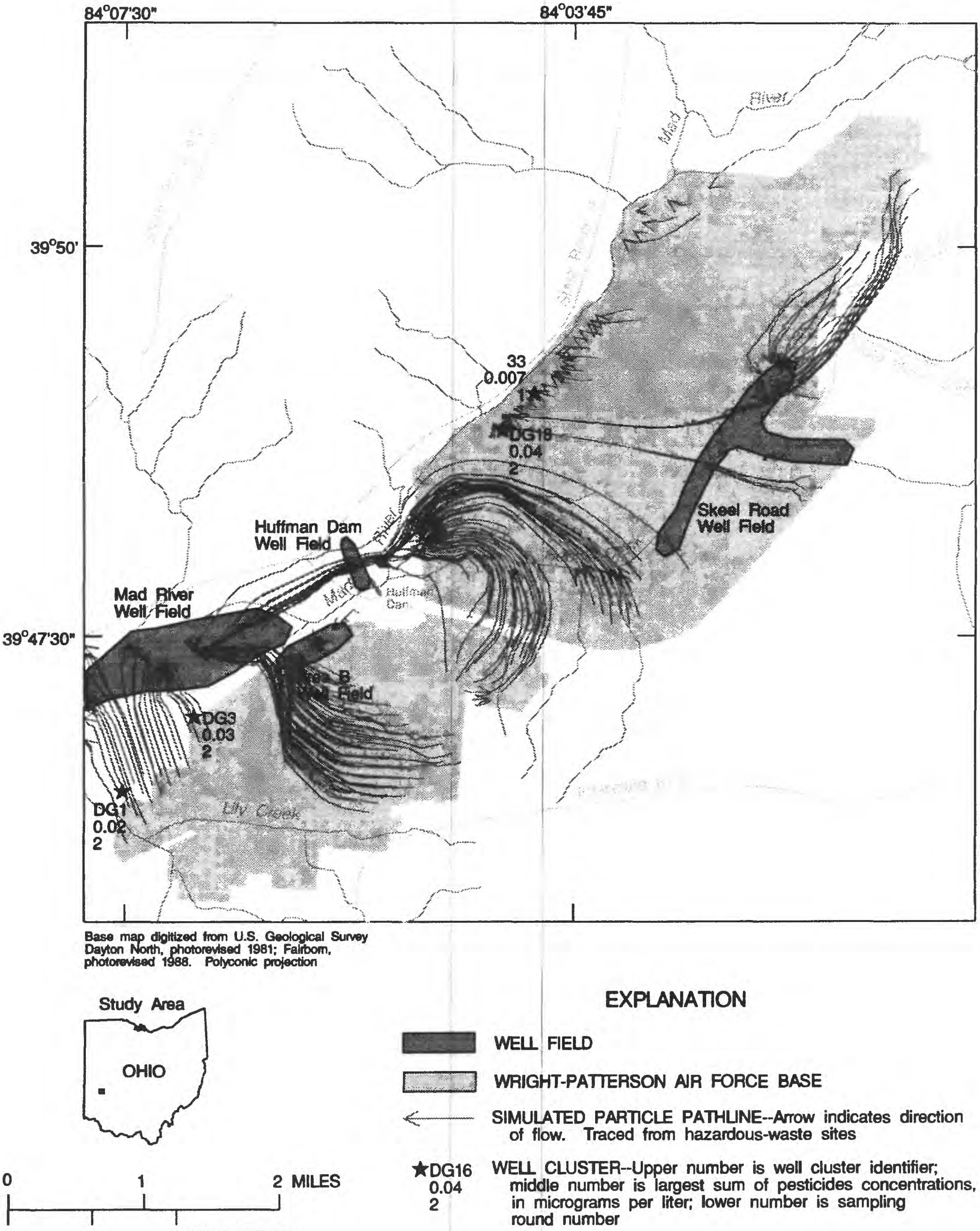


Figure 44. Sum of semivolatile organic compound concentrations with depth in the glacial aquifer, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base, Ohio.



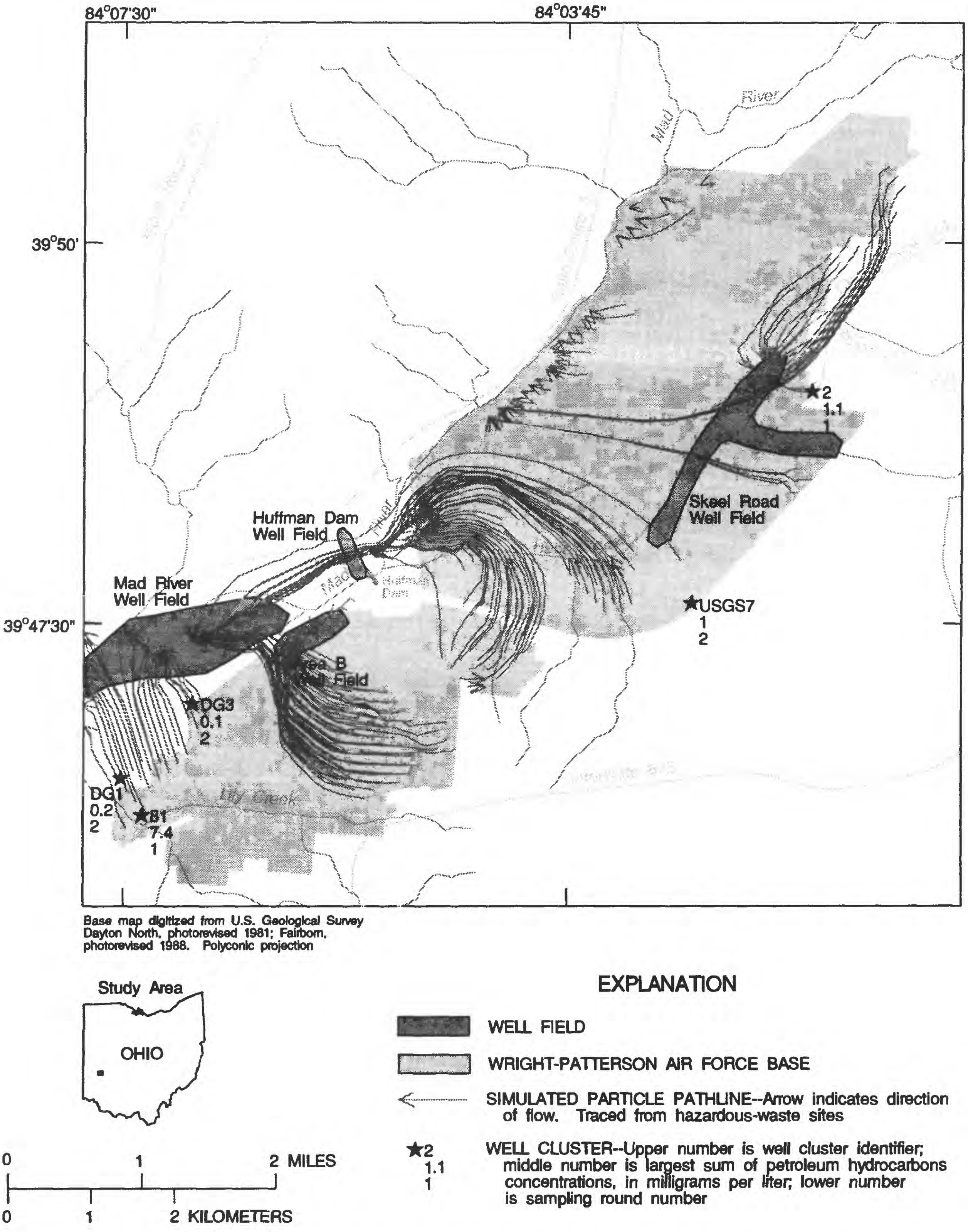
Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 45. Concentrations of semivolatile organic compounds in glacial wells, all rounds, August 1993-September 1994 at Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 46. Concentrations of pesticides in glacial wells, rounds 1 and 2, August 1993-January 1994 at Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 47. Concentrations of petroleum hydrocarbons in glacial wells, rounds 1 and 2, August 1993-January 1994 at Wright-Patterson Air Force Base, Ohio.

baseflow (fig. 48). These streamflows would be equalled or exceeded about 62 percent of the time. During round 2, discharge in Mad River was 733 ft^3/sec (of which about 75 percent was baseflow), a flow equalled or exceeded 20 percent of the time. The percentage of baseflow contribution was smallest during round 2 and highest during round 4, when discharge was 259 ft^3/sec. This streamflow would be equalled or exceeded 78 percent of the time.

Surface-Water and Ground-Water Relations

By Peter R. Wright

Generally, discharge was measured each time a surface-water-quality sample was collected. These discharge measurements were used along with ground-water levels (Shindel and others, 1991, 1992, and 1993) and ground-water gradients (table 35) to estimate ground-water and surface-water relations at WPAFB. Only the baseflow-discharge data (rounds 1, 2, and 4) were included in the analysis of ground-water and surface-water relations.

One factor affecting the gain or loss of water in a stream is the relation between the altitude of water in the stream and the altitude of the water table, assuming the two are connected hydraulically. When the water-table altitude is higher than the stream-water altitude, the stream gains water from the water table. When the stream-water altitude is higher than the water-table altitude, the stream loses water to the water table. Thus, as the position of the water table changes, a stream can gain or lose water alternately. The discharge measurements taken during the BMP were rated for accuracy by field personnel. The ratings varied from "good" to "poor." Each measurement rating indicates a percentage of error related to the conditions under which the measurement was taken. Conditions affecting the quality of measurements include the magnitude and direction of flow and cross-section geometry (Rantz and others, 1911). A "good" measurement is considered to have 5 percent error, a "fair" measurement, 8 percent error, and a "poor" measurement, greater than 8 percent error.

Discharge-measurement error was considered in the determination of ground- and surface-water

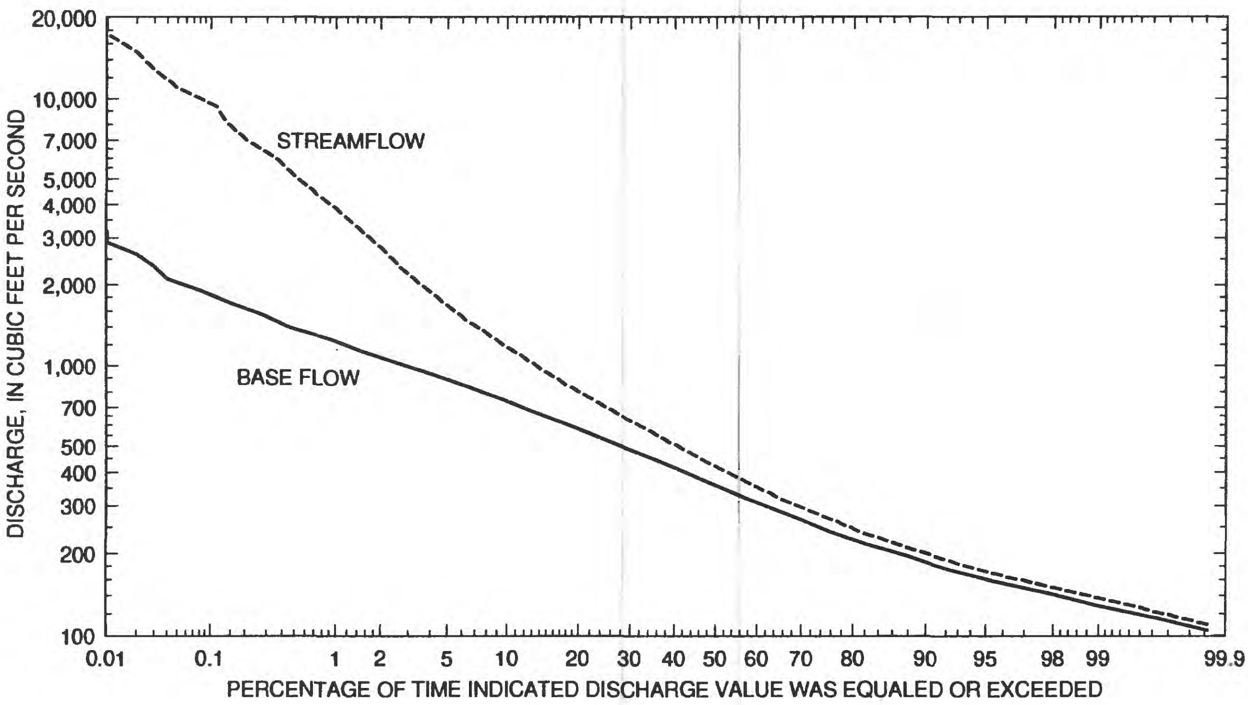


Figure 48. Streamflow and base-flow duration curves for Mad River near Dayton, Ohio. (From Koltun, 1995).

Table 35. Vertical hydraulic gradients at well clusters, December, 1993 and May and October, 1994, Wright-Patterson Air Force Base

[Negative sign denotes downward flow (recharge); --, no data]

Well cluster	Hydraulic gradient, intermediate to shallow, December 1993	Hydraulic gradient, deep to intermediate, December 1993	Hydraulic gradient, intermediate to shallow, May 1994	Hydraulic gradient, deep to intermediate, May 1994	Hydraulic gradient, intermediate to shallow, October 1994	Hydraulic gradient, deep to intermediate, October 1994
2	0.002	-0.051	0.012	-0.056	0.001	-0.051
33	0.011	0.008	0.021	0.008	-0.011	0.056
34	0.055	--	0.099	--	--	--
38	--	--	-0.001	--	--	--
42	--	--	-0.005	--	--	--
60	-0.078	--	-0.097	--	-0.076	--
1	-0.014	--	-0.015	--	-0.051	--
89	0.001	--	0.004	--	0.001	--
CW1	-0.107	-0.164	0.249	-0.149	-0.093	-0.178
CW2	-0.004	-0.241	-0.086	-0.191	-0.007	-0.290
CW3	0.011	-0.004	0.017	-0.006	0.008	-0.002
DG1	0.007	-0.008	0.010	-0.003	0.010	-0.006
DG10A	-0.001	--	0.004	--	-0.003	--
DG12	0.003	-0.005	-0.009	-0.015	0.005	-0.006
DG15	-0.005	0.034	-0.011	0.031	-0.006	0.041
DG1A	-0.011	--	-0.003	--	-0.003	--
DG2	-0.006	-0.087	-0.020	-0.067	-0.006	-0.076
DG3	-0.044	-0.135	-0.029	-0.097	-0.080	-0.079
DG4	-0.093	--	-0.072	--	-0.128	--
DG8	-0.017	--	--	--	-0.004	--
LF08-01	0.083	--	0.128	--	0.117	--
UG1	0.011	0	0.013	-0.028	0.013	0.001
UG11	-0.003	--	0.005	--	-0.001	--
UG2	0.008	-0.007	-0.001	-0.018	0.069	-0.009
UG3	0	--	-0.002	--	0.001	--
UG8	-0.151	--	-0.165	--	-0.146	--
USGS1	0.030	--	0.034	--	0.030	--
USGS11	0.001	-0.001	0.002	0.001	0.004	-0.001
USGS12	-0.001	-0.035	-0.001	-0.038	-0.002	-0.022
USGS13	-0.099	--	-0.023	--	-0.105	--
USGS2	-0.026	-0.006	-0.032	-0.005	-0.026	0.009
USGS3	0.022	--	0.020	--	0.012	--
USGS4	0.009	0.004	0.009	0.007	0.010	0.013
USGS5	0.010	0.042	0.010	0.038	0.008	0.033
USGS6	0.010	-0.007	0.004	-0.002	-0.068	-0.002
USGS7	0.002	-0.036	0.003	-0.043	0.004	-0.039

relations. However, when stream-discharge data were unavailable or inconclusive, some generalizations were made based on ground-water levels and data from previous investigations (Koltun, 1995; Dumouchelle and others, 1993). A discussion of ground-water and surface-water relations for Mad River, Mud Run, and Hebble Creek follows. Insufficient data were available to make conclusions regarding ground and surface-water interactions along sections of Trout Creek, Lily Creek, or any of the unnamed tributaries included in the BMP.

Two water-quality locations were along Mad River. The upstream location was UGS-9; the downstream location was DGS-5, located 50 ft downstream of the confluence of Mad River and Trout Creek (fig. 4). Discharges at UGS-9 were measured upstream of the bridge during low-flow periods and from the bridge during high flow. High-flow measurements of discharge were not obtained at DGS-5, but were approximated by subtracting the discharge at NPDES-4 (near the mouth of Hebble Creek) from the discharge estimated at the gage downstream.

Discharge measurements of Mad River were rated as "poor" to "good." Discharges on Mad River, associated measurement error, and distance along Mad River for rounds 1 and 2 are shown in figure 49. The data indicate that, for the reach of Mad River between UGS-9 and the gage, the change in discharge was less than the measurement error. However, water-level data and results from previous investigations (Dumouchelle and others, 1993) indicate that Mad River was gaining along the same reach.

Discharge data from round 2 indicate that Mad River lost flow to the underlying aquifer between UGS-9 and DGS-5. Two factors indicate the discharge data are misleading. First, water levels measured during November 1993 indicate that ground-water gradients were upward near Mad River (table 35), thus discharging to the river. Second, as observed by Dumouchelle and others (1993), ground-water levels and stage data for Mad River indicated that the aquifer and Mad River were connected hydraulically. Water levels in GR-208, stage in Mad River, and daily precipitation for the months of November and December, 1993, are shown in figure 50. All three traces correlate closely; however, peaks in water levels probably resulted from peaks in stage rather than from precipitation because of the near proximity of GR-208 to Mad River. If the ground-water-level fluctuations were due primarily to changes in river stage, then the loss of streamflow along the reach between UGS-9 and the gage would be accounted for as bank storage. Bank storage is water stored in stream banks during stream-stage fluctuations (Singh, 1968).

Discharge data were collected at four locations along Hebble Creek: NPDES-13, INTS-15, INTS-13, and NPDES-4 (fig. 4). Discharges from sewer outflows and tributaries to Hebble Creek were not measured at their confluences with Hebble Creek. The reach of Hebble Creek between NPDES-13 and INTS-15 is lined with concrete, and any gains or losses within this reach are not due to natural hydrologic processes. According to discharges measured during rounds 1, 2, and 4, Hebble Creek probably lost water between INTS-15 and INTS-13 and gained water between INTS-13 and NPDES-4. Data collected in 1990 (Dumouchelle and others, 1993) indicate that Hebble Creek lost water between INTS-15 and NPDES-4. The contrast between the 1990 and 1993-94 measurements could have been caused by fluctuations of the water table from natural (recharge from precipitation) or anthropogenic (pumping at wells) effects. Well fields that could influence water levels along Hebble Creek include the East well field (which was operated regularly until 1988), Skeel Road well field, and the pump-and-treat system in OU5 (fig. 15).

Discharge data collected during rounds 1 and 4 at UGS-10 and UGS-8 indicate that Mud Run lost 0.44 and 0.33 $ft^3/s/mi$, respectively. Losses to the aquifer could have resulted from differences in the stream altitudes between Mud Run and Mad River, pumping at sand-and-gravel mining operations nearby, or evaporation.

WATER QUALITY

By James M. Parnell

Surface-water samples were collected during four rounds from August 1993 to September 1994. Whether a surface-water sample was collected at a given location depended on the quantity of water flowing at that location during the sampling round. Several locations were alternately flowing and dry during the four rounds; consequently, the locations sampled and the number of samples differed from round to round. Locations sampled and the types of samples collectedruffed during the four rounds are presented in table 36. Of the 28 surface-water sampling locations included in the BMP, NPDES-1 and NPDES-2 were not sampled. Both are inaccessible at high flow and are affected by backwater from Mad River.

Base-flow conditions prevailed during rounds 1, 2, and 4. Round 3 sampling on August 4, 1994, was in response to rainfall. Data from the three baseflow rounds were compiled for statistical analysis, whereas data from round 3 were analyzed separately.

Samples were collected for chlorinated herbicides and petroleum hydrocarbons in rounds 1 and 2, but were omitted from rounds 3 and 4 because no additional useful information was expected from those

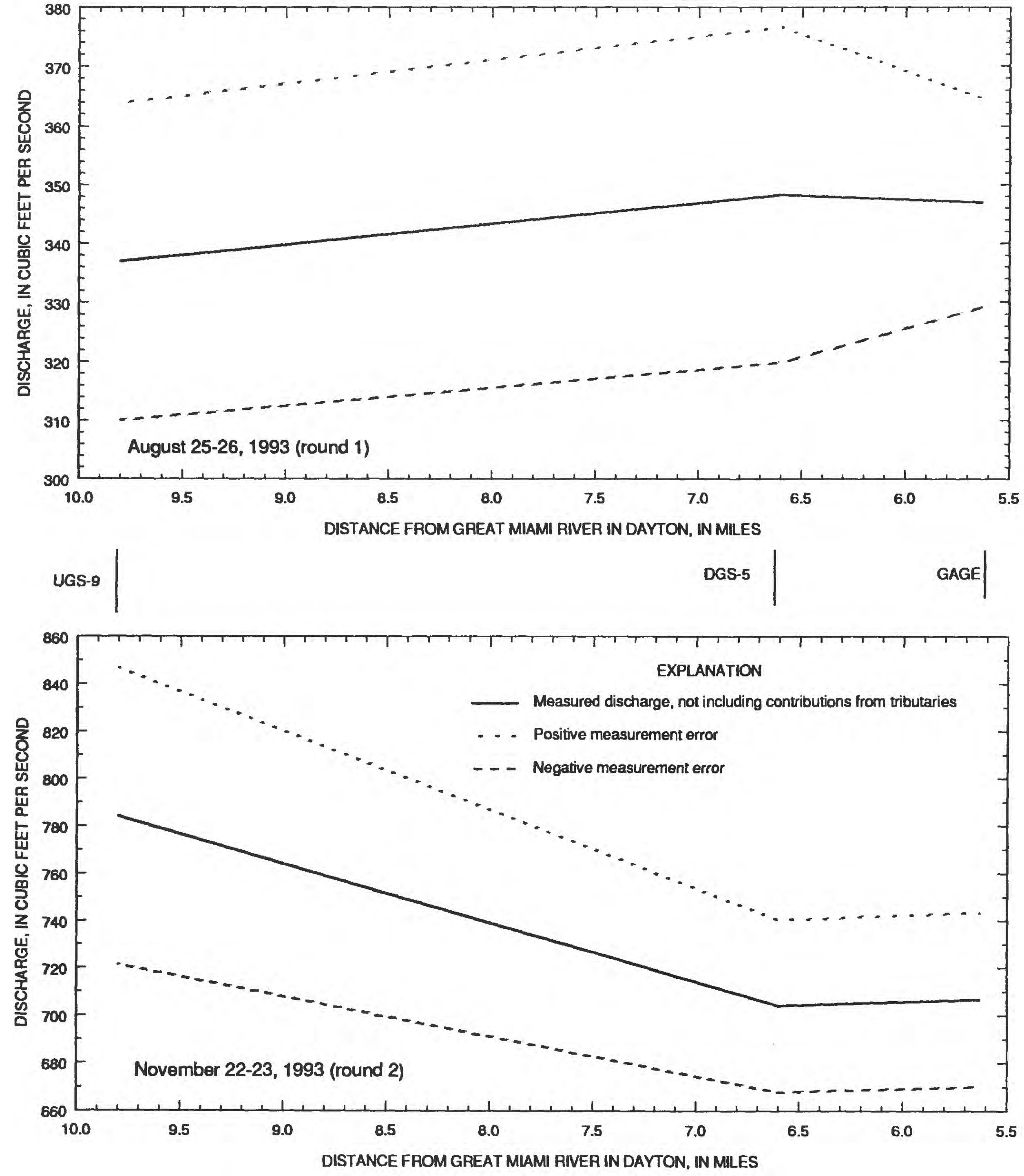


Figure 49. Discharges at locations on Mad River near Dayton, Ohio, rounds 1 and 2, August—November 1993.

analyses. Samples for VOCs, SVOCs, pesticides/PCBs, gross alpha and beta activities, cyanide, and unfiltered and filtered metals were obtained and analyzed in every round (table 37).

Ohio EPA provides guidance concerning surface-water quality on the basis of several criteria, including water use, biological habitat, and human health (Ohio Environmental Protection Agency, 1993).

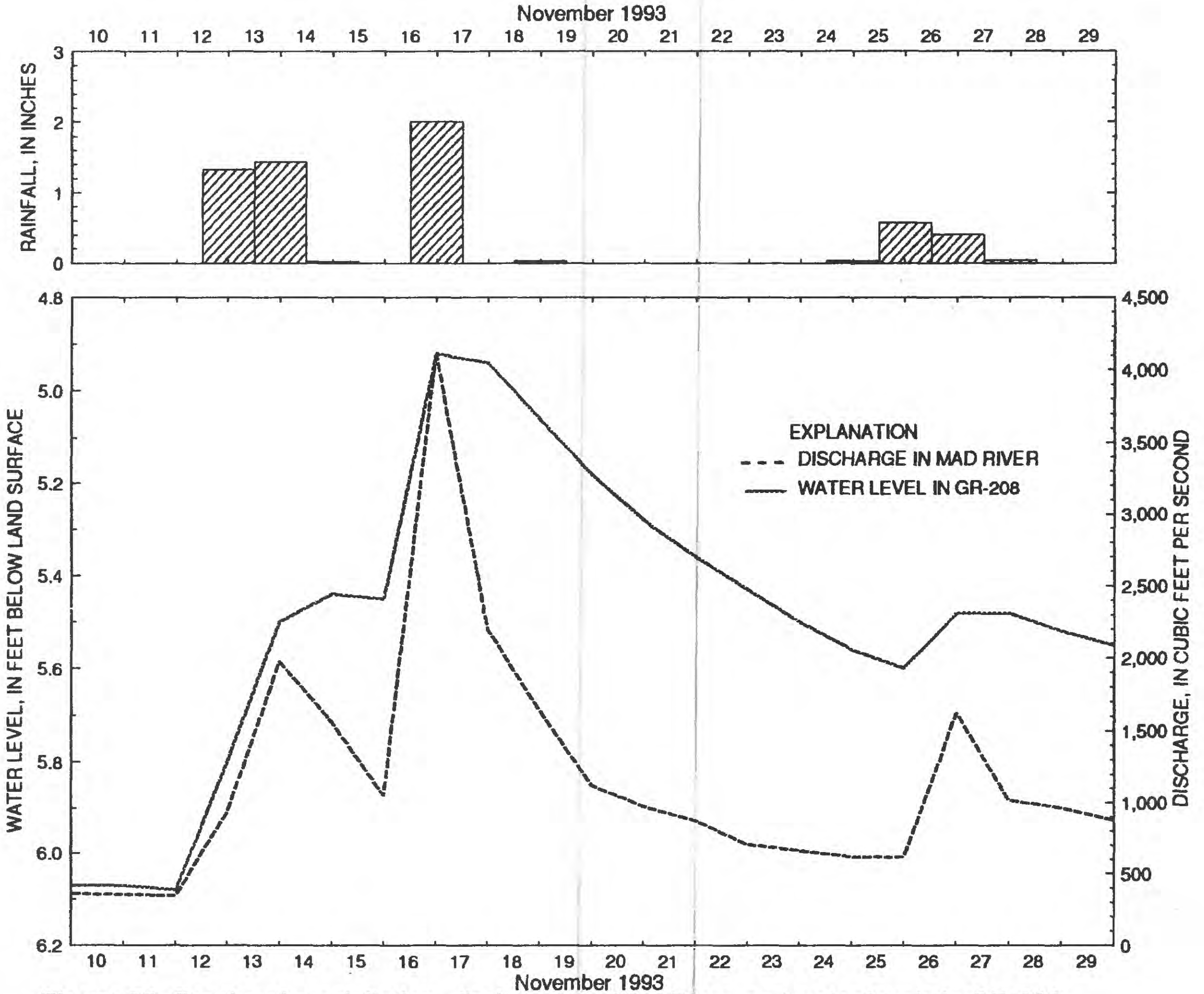


Figure 50. Graphs of precipitation, discharges in Mad River, and water levels in GR-208, November 10–29, 1993.

Because of abundance of ground water in highly productive aquifers in the Great Miami River basin, surface water is not used for drinking in the Dayton area. However, surface-water-quality data were compared to the same standards (MCLs) as ground-water-quality data throughout the BMP because surface water is used to recharge the glacial aquifer articially at recharge lagoons in the area. Consequently, concentrations of constituents in surface water were compared to MCLs, which were considered the governing standards.

The concentrations of inorganic constituents and organic compounds that were determined quantitatively in surface-water samples during the four sampling rounds were compiled in the technical memoranda for WPAFB and are available upon request. Summary statistics of the chemical concentrations are presented in the form of boxplots and (or) tables throughout this section. Statistics data include detections and non-detections, when applicable; concentrations equal to one-half the actual reporting limit determined by the laboratory were used to represent non-detections.

Surface-water locations were grouped into three subsystems on WPAFB for the analysis of water-quality data (fig. 51). Each subsystem consists of sampling locations on the main branch and tributary branches. Mad River subsystem (three upgradient, two interior, and six downgradient locations) includes locations on Mad River, Mud Run, Trout Creek, Hebble Creek (NPDES-4 only), and other small streams. Hebble Creek susbystem (seven upgradient, three interior, and one downgradient locations) includes locations on several tributaries, including one tributary that flows through Area B. Lily Creek subsystem (three upgradient, one interior, and one downgradient locations) includes locations on streams that flow in the southern part of Area B.

Table 36. Types of surface-water and streambed-sediment samples by sampling round, Wright-Patterson Air Force Base

[FR, field replicate; MS, matrix spike and matrix spike duplicate; QA, quality assurance; --, not applicable]

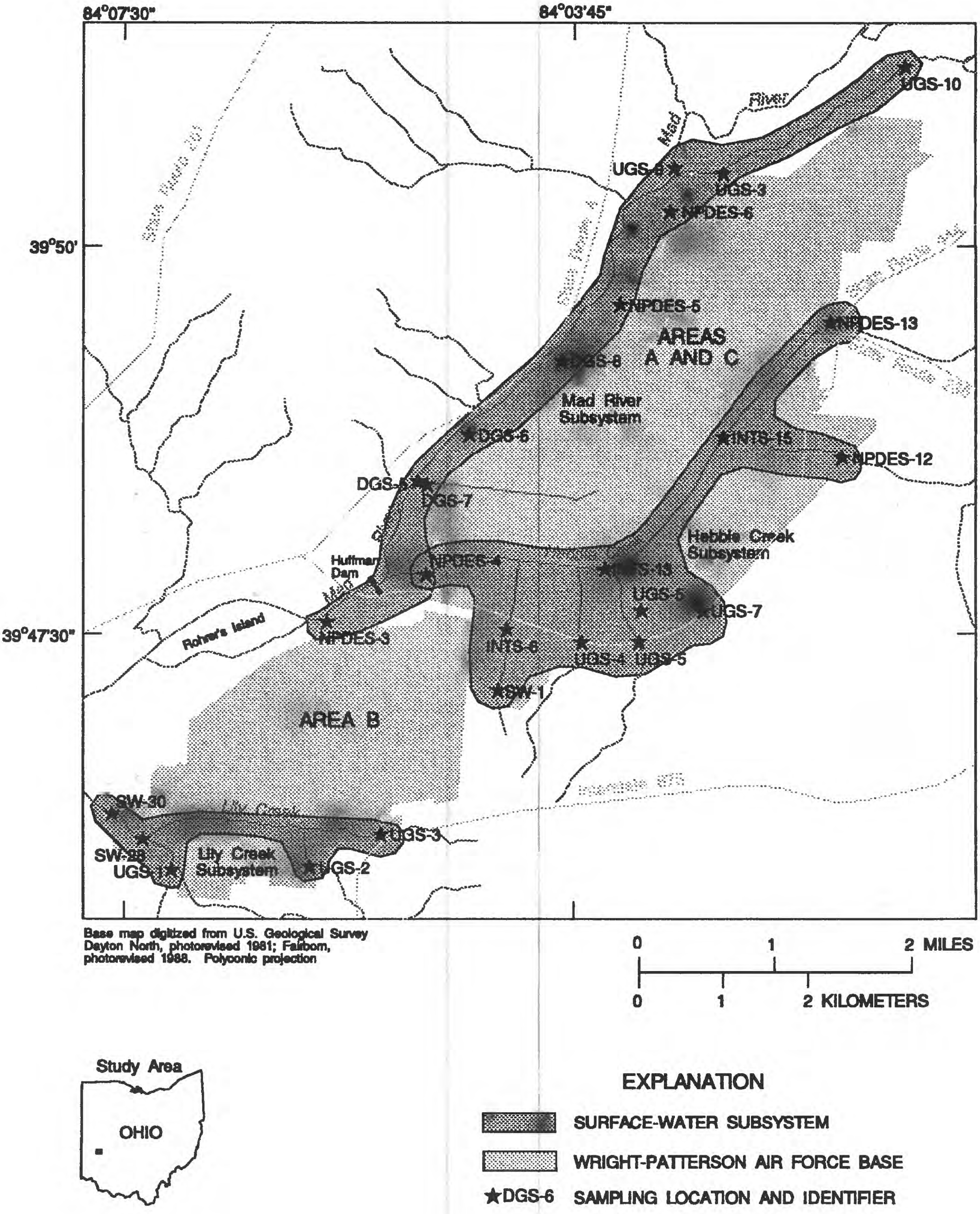
Location	Round surface water sampled[1]	QA sample type and round collected, surface water	Round streambed sediment sampled[2]	QA sample type and round collected, streambed sediment
DGS-5	1, 2, 3, 4	--	1, 2, 3, 4	--
DGS-6	2	--	1, 2, 3, 4	--
DGS-7	1, 2, 3, 4	--	1, 2, 3, 4	FR, 3
DGS-8	1, 2, 3	--	1, 2, 3, 4	--
INTS-13	1, 2, 3, 4	FR, 2, 4	1, 2, 3, 4	FR, 3
INTS-15	1, 2, 3, 4	FR, 3	1, 2, 3, 4	--
INTS-6	1, 2, 3, 4	FR, 1	1, 2, 3, 4	FR, 1; MS, 1, 2
NPDES-13	1, 2, 3, 4	--	1, 2, 3, 4	MS, 4
NPDES-12	2, 3, 4	MS, 4	1, 2, 3, 4	FR, 2, 4; MS, 3
NPDES-3	1, 2, 3, 4	--	none	--
NPDES-4	1, 2, 3, 4	MS, 1	1, 2, 3, 4	FR, 4; MS, 1
NPDES-5	2, 3	--	1, 2, 3, 4	--
NPDES-6	none	--	1, 2, 3, 4	FR, 2
SW-1	2, 3	FR, 2	1, 2, 3, 4	--
SW-28	1, 2, 3	FR, 1; MS, 3	1, 2, 3, 4	--
SW-30	1, 2, 3	--	1, 2, 3, 4	MS, 4
UGS-1	1, 2, 3, 4	--	1, 2, 3, 4	FR, 1
UGS-2	1, 2, 3, 4	FR, 4	1, 2, 3, 4	FR, 1
UGS-3	1, 2, 3, 4	--	1, 2, 3, 4	--
UGS-4	1, 2, 3	--	1, 2, 3, 4	MS, 2, 3
UGS-5	1, 2, 3, 4	FR, 2; MS, 3, 4	1, 2, 3, 4	--
UGS-6	1, 2, 3, 4	FR, 3	1, 2, 3, 4	FR, 4
UGS-7	2, 3, 4	--	1, 2, 3, 4	FR, 2
UGS-8	1, 2, 3, 4	FR, 3	1, 2, 3, 4	FR, 3
UGS-9	1, 2, 3, 4	FR, 4	1, 2, 3, 4	--
UGS-10	1, 2, 3, 4	--	1, 2, 3, 4	--

[1] Sampling dates for surface-water rounds: 1, August 1993; 2, November 1993; 3, August 1994; 4, September 1994.

[2] Sampling dates for streambed-sediment rounds: 1, August 1993; 2, November 1993; 3, April 1994; 4, September 1994.

For ease of discussion, inorganic constituents are divided into several subgroups including: (1) field-measured physical properties determined during sampling such as temperature, specific conductance, pH, suspended sediment, and dissolved oxygen; (2) major cations and anions (except bicarbonate) present at concentrations normally higher than 2 mg/L (sodium, potassium, calcium, magnesium, chloride, nitrate, and sulfate); (3) minor cations and anions, normally present at concentrations less than 2 mg/L; and (4) gross alpha and gross beta activities. Organic constituents are subdivided according to the following categories: (1) VOCs; (2) SVOCs; (3) organochlorine pesticides and polychlorinated biphenyls (PCBs); (4) chlorinated herbicides; and (5) petroleum hydrocarbons.

Quality-control data and procedures used to validate project analytical data are reviewed at the start of



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 51. Surface-water subsystems on Wright-Patterson Air Force Base, Ohio.

Table 37. Analytical methods used for surface-water and streambed-sediment samples, August 1993 - September 1994, Wright-Patterson Air Force Base

[PCBs, polychlorinated biphenyls; CLP, contract laboratory program]

Analytical method	Round analyzed for surface water[1]	Round analyzed for streambed sediment[2]
Volatile organic compounds (C8240) (CLP)	1, 2, 3, 4	1, 2, 3, 4
Semivolatile organic compounds (C8270) (CLP)	1, 2, 3, 4	1, 2, 3, 4
Pesticides and PCBs (C608 water, C8080 soil) (CLP)	1, 2, 3, 4	1, 2, 3, 4
Chlorinated herbicides (SW8150)	1, 2	1, 3
Total petroleum hydrocarbons (E418.1)	1, 2	1, 2
Cyanide (C335.2) (CLP)	1, 2, 3, 4	1, 2, 3, 4
Gross alpha/beta (SW9310)	1, 2, 3, 4	none
Anions (E300)	1, 2, 3, 4	none
Total metals (C200.7, C206.2, C239.2, C245.1, C270.2, C279.2) (CLP)	1, 2, 3, 4	1, 2, 3, 4
Dissolved metals (C200.7, C206.2, C239.2, C245.1, C270.2, C279.2) (CLP)	1, 2, 3, 4	none

[1] Sampling dates for surface-water rounds: 1, August 1993; 2, November 1993; 3, August 1994; 4, September 1994.

[2] Sampling dates for streambed-sediment rounds: 1, August 1993; 2, November 1993; 3, April 1994; 4, September 1994.

each section. The frequency of detection of compounds is then discussed. Data regarding exceedances of USEPA MCLs for samples collected during the first year of the BMP are presented. Spatial trends in the detected amounts of selected constituents are evaluated. Potential sources of constituents (anthropogenic and natural) and geochemical and hydrogeologic processes that affect the fate and transport of inorganic and organic contaminants in surface water are discussed, where applicable.

Inorganic Constituents and Field-Measured Properties

Inorganic constituents included in the BMP sampling program were unfiltered and filtered metals, anions, cyanide, and gross alpha and beta activities. Physical water-quality properties obtained at the time of sampling also are discussed in this section. The metals and anions are divided into major and minor constituents, as defined previously.

Quality Control and Data Validation

Quality assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the inorganic data collected in each of the four sampling rounds generally were met. Most of the sample analyses for metals were acceptable with qualification, and all sample analyses for cyanide were acceptable without qualification in all rounds.

Antimony was detected at concentrations exceeding the MCL (6.0 µg/L) in surface-water samples obtained during round 2. After reanalysis by graphite furnace (see the full explanation in the ground-water-quality section), antimony was found in three of the reanalyzed surface-water samples, but at concentrations much lower than those of the original analyses. Antimony was detected at concentrations exceeding the MCL in subsequent sampling of ground water and surface water; no further reanalysis was done, but probably most antimony detections and all exceedances of the MCL for antimony are because of ICP interference, and not because of high concentrations of antimony in the samples.

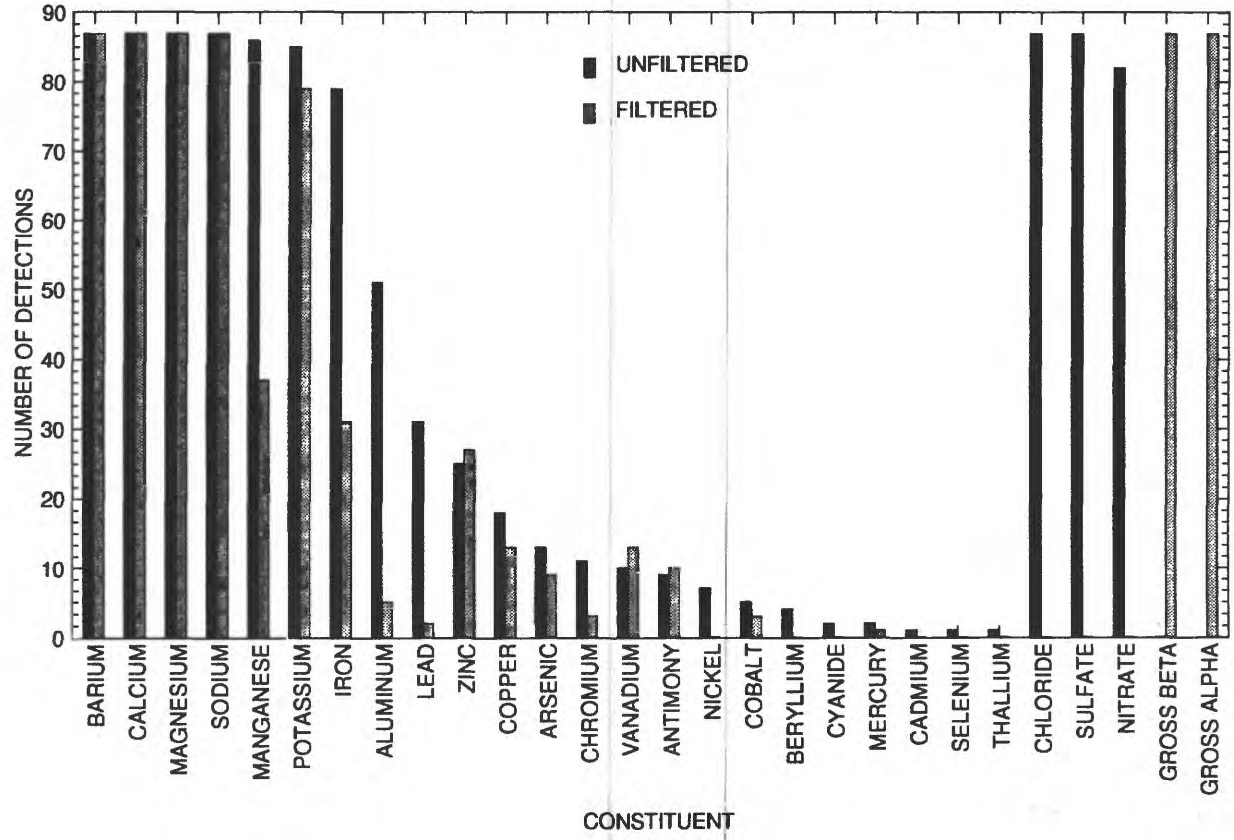


Figure 52. Detections of inorganic constituents in surface-water samples, all rounds, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.

Frequency of Detection of Inorganic Constituents and Field-Measured Properties

Field measurements of pH, specific conductance, dissolved oxygen, water temperature, and suspended sediment were obtained at more than 75 percent of the sampling locations (table 38). In most cases, equipment malfunction resulted in missing data in sampling rounds 1, 2 and 4. Some data are missing from the round 3 sampling because insufficient numbers of instruments were available to supply every sampling team. Specific conductance and pH were measured at 86 of the 87 sampling locations; dissolved oxygen was measured least frequently (at 71 of the 87 locations).

Inorganic constituents that were detected in each of the 87 unfiltered surface-water samples include barium, calcium, magnesium, sodium, chloride, and sulfate, (fig. 52 and table 38). The four cations also were detected in every filtered surface-water sample. Other inorganic constituents detected in more than 75 percent of the unfiltered samples include (from most to least frequent) manganese, potassium, nitrate, and iron. Silver, bromide, and nitrite were not detected in any surface-water sample. Inorganic constituents detected in fewer than 10 percent of the unfiltered samples include cadmium, selenium, thallium, mercury, cyanide, beryllium, cobalt, and nickel. The rest of the inorganic constituents, detected in 10-75 percent of the unfiltered samples, were (from most to least frequently detected) aluminum, lead, zinc, copper, arsenic, chromium, vanadium, and antimony.

Frequency of Detection and Relative Concentrations of Inorganic Constituents in Unfiltered and Filtered Surface-Water Samples

Many of the metals were detected less frequently in filtered samples than in unfiltered samples, and among the most notable in this category were aluminum, chromium, iron, manganese, nickel, and lead (table 38). Detections of each of these were at least 57 percent fewer in filtered samples than in unfiltered samples. These data indicate that significant amounts of these metals were associated with particulate matter that cannot pass through a 0.45 μm filter. In contrast,

Table 38. Frequency of detection of inorganic constituents and field-measured properties in surface-water samples, August 1993–September 1994, Wright-Patterson Air Force Base, Ohio

[R, round; Tot, Total number of detections; MCL, number of exceedances of maximum contaminant levels; --, not applicable]

Property or constituent	Number of Samples	Unfiltered						Filtered					
		R1	R2	R3	R4	Tot	MCL	R1	R2	R3	R4	Tot	MCL
pH	87	20	25	23	18	86	--	--	--	--	--	--	--
Specific conductance	87	20	25	23	18	86	--	--	--	--	--	--	--
Dissolved oxygen	87	20	20	13	18	71	--	--	--	--	--	--	--
Water temperature	87	20	20	21	18	79	--	--	--	--	--	--	--
Suspended sediment	87	18	22	24	17	81	--	--	--	--	--	--	--
Aluminum	87	13	6	24	8	51	0	0	3	2	0	5	0
Antimony	87	3	3	3	0	9	6	2	0	8	0	10	10
Arsenic	87	3	0	7	3	13	0	5	0	4	0	9	0
Barium	87	20	25	24	18	87	0	20	25	24	18	87	0
Beryllium	87	1	1	2	0	4	1	0	0	0	0	0	0
Cadmium	87	0	1	0	0	1	0	0	0	0	0	0	0
Calcium	87	20	25	24	18	87	0	20	25	24	18	87	0
Chromium	87	0	1	10	0	11	0	1	0	2	0	3	0
Cobalt	87	0	4	1	0	5	0	2	0	0	1	4	0
Copper	87	12	3	1	2	18	0	4	2	0	7	13	0
Iron	87	16	21	24	18	79	0	12	4	15	0	31	0
Lead	87	14	1	14	2	31	1	1	1	0	0	2	0
Magnesium	87	20	25	24	18	87	0	20	25	24	18	87	0
Manganese	87	20	25	24	17	86	0	19	12	2	4	37	0
Mercury	87	0	0	1	1	2	0	0	0	0	1	1	0
Nickel	87	0	6	1	0	7	0	0	0	0	0	0	0
Potassium	87	20	23	24	18	85	0	20	25	24	10	79	0
Selenium	87	1	0	0	0	1	0	0	0	0	0	0	0
Silver	87	0	0	0	0	0	0	0	0	0	0	0	0
Sodium	87	20	25	24	18	87	0	20	25	24	18	87	0
Thallium	87	0	0	1	0	1	1	0	0	0	0	0	0
Vanadium	87	0	0	9	1	10	0	1	0	7	5	13	0
Zinc	87	2	5	6	12	25	0	11	4	3	9	27	0
Bromide	87	0	0	0	0	0	0	--	--	--	--	--	--
Chloride	87	20	25	24	18	87	0	--	--	--	--	--	--
Nitrate	87	20	24	23	15	82	0	--	--	--	--	--	--
Nitrite	87	0	0	0	0	0	0	--	--	--	--	--	--
Sulfate	87	20	25	24	18	87	0	--	--	--	--	--	--
Cyanide	87	0	1	1	0	2	0	--	--	--	--	--	--
Gross alpha	87	--	--	--	--	--	--	20	25	24	18	87	1
Gross beta	87	--	--	--	--	--	--	20	25	24	18	87	0

trace metals such as arsenic, cobalt, copper, vanadium, and zinc, and all major metals, were detected about as frequently in filtered samples as in unfiltered samples, indicating that these metals were dissolved or were associated with very fine particulate matter. Metals that were not detected in filtered samples were silver, beryllium, cadmium, nickel, selenium, and thallium. Mercury was detected once and lead twice in filtered samples.

Concentrations of metals in unfiltered samples were compared with those in the corresponding filtered samples, and the percent differences in concentration were recorded. These percent differences for each metal were compiled and subjected to statistical analysis, and the results are displayed in figure 53. Negative percent differences indicate that for the unfiltered/filtered sample pair, the concentration of a metal in the filtered sample was greater than the concentration of that metal in the corresponding unfiltered sample. Only data that included at least one detection in the unfiltered/filtered sample pair were used; that is, if a metal was not detected in either the unfiltered or the filtered sample, those data were not included in the statistical analysis. To complete each pair when a metal was detected in only one of the two samples, a concentration equal to one-half the actual reporting limit was used to estimate the missing concentration.

Concentrations of several metals were notably less in filtered samples than in unfiltered samples; among these were aluminum, cobalt, chromium, iron, manganese, nickel, and lead. Metals such as barium, calcium, potassium, magnesium, and sodium were detected in filtered samples at concentrations similar to those in unfiltered samples. Concentrations of a few metals, including arsenic, cobalt, copper, antimony, vanadium, and zinc, ranged widely in unfiltered and filtered samples, though these data were affected by non-detections in one-half of the sample pair.

Exceedance of Drinking-Water Standards

All exceedances of MCLs for inorganic constituents in surface-water samples are listed in table 39. Three constituents (antimony, beryllium, and gross alpha) were detected at concentrations exceeding the MCLs during baseflow rounds; four constituents (antimony, beryllium, lead, and thallium) were detected at concentrations exceeding the MCLs during the storm round. All exceedances of antimony probably were because of interferences in the ICP method, as explained previously. During round 2, dissolved antimony originally was detected at 33.8 µg/L in a sample from INTS-15; this sample was reanalyzed by graphite furnace, and the resulting concentration was 7.7 µg/L. Beryllium, with an MCL of 1.0 µg/L, was detected at 1.9 µg/L at NPDES-12 during round 3, and at 1.2 µg/L in a duplicate sample obtained at UGS-9 during round 4. Thallium, detected at 3.0 µg/L at UGS-1, exceeded the MCL (2.0 µg/L) during round 3. The concentration of lead (150 µg/L) detected at NPDES-12 during round 3 was 10 times greater than its MCL. Distributions of MCL exceedances in surface water for inorganic compounds other than antimony are shown on figure 54.

Field-Measured Properties of Surface-Water

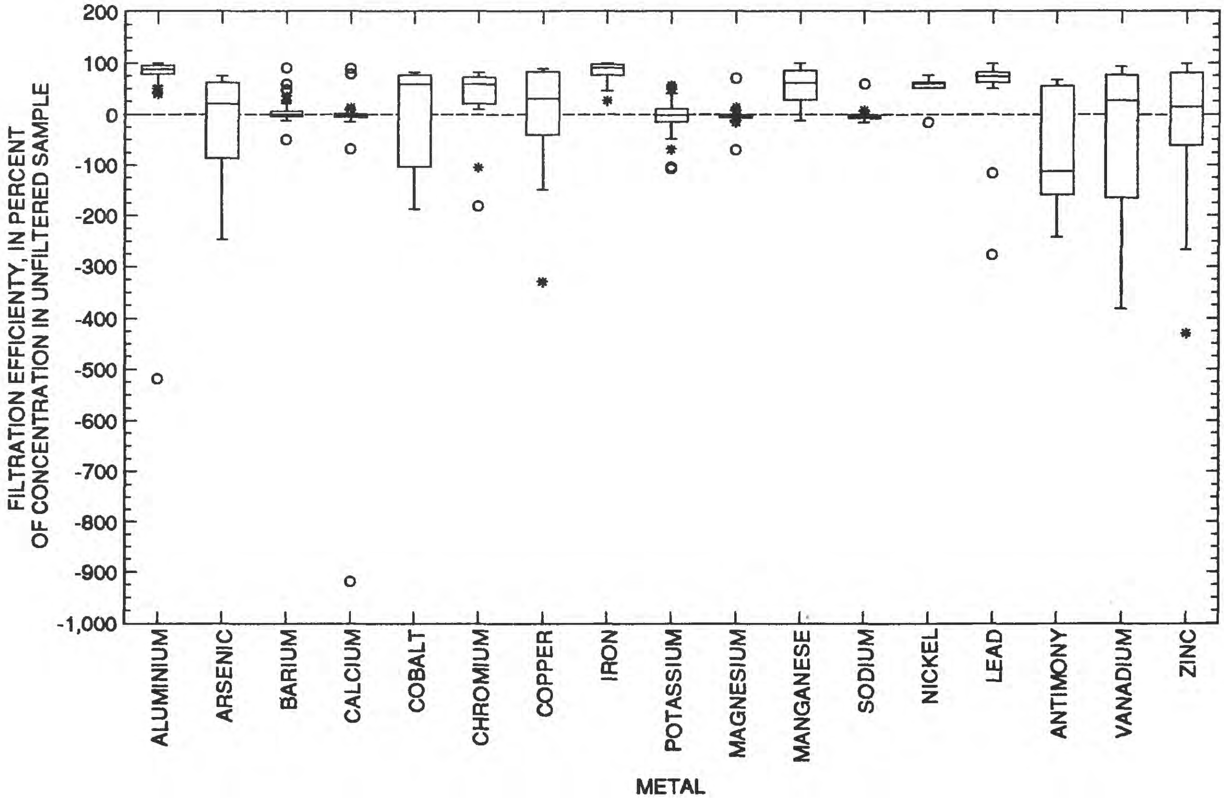
Specific conductance, pH, water temperature, and dissolved oxygen (DO) were measured during all sampling rounds. Concentrations of suspended sediment were determined at a contract laboratory. All data are available upon request and are summarized in table 40 and figure 55.

Extreme values during baseflow rounds

Values of pH ranged from 6.7 at DGS-8 to 8.7 at UGS-5 during baseflow rounds. Nine locations (of which 3 were sampled only once) had median pH values between 7.0 and 8.0, whereas 16 locations had median pH values between 8.0 and 8.4.

Three of the four highest specific-conductance values were recorded at UGS-7 (2,210 µS/cm), UGS-6 (1,510 µS/cm), and UGS-5 (1,200 mS/cm) during round 4, when discharges were lowest. All three locations are on the same stream, and may have been receiving highly conductive water from the same source. The highest median specific conductance at a location for the three baseflow rounds, 1,200 µS/cm, was at UGS-5. Lowest median specific conductances for the three baseflow rounds were at UGS-8, UGS-9, and UGS-10.

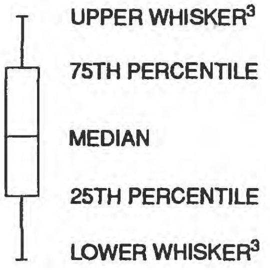
The 19 highest concentrations of DO during baseflow rounds were measured during rounds 2 and 4. Concentrations of DO exceeded 12.0 mg/L at UGS-5, UGS-3, SW-28, SW-30, and INTS-6. The highest median concentration of DO was 11.2 mg/L at INTS-6. Median concentrations of DO were greater than 10.0 mg/L at six other locations. Concentrations of DO were less than 6.0 mg/L at NPDES-4 and DGS-8 during round 2. The lowest median concentration of DO was 4.93 mg/L at DGS-8, which was



EXPLANATION

○ DETACHED VALUE[1]

* OUTSIDE VALUE[2]



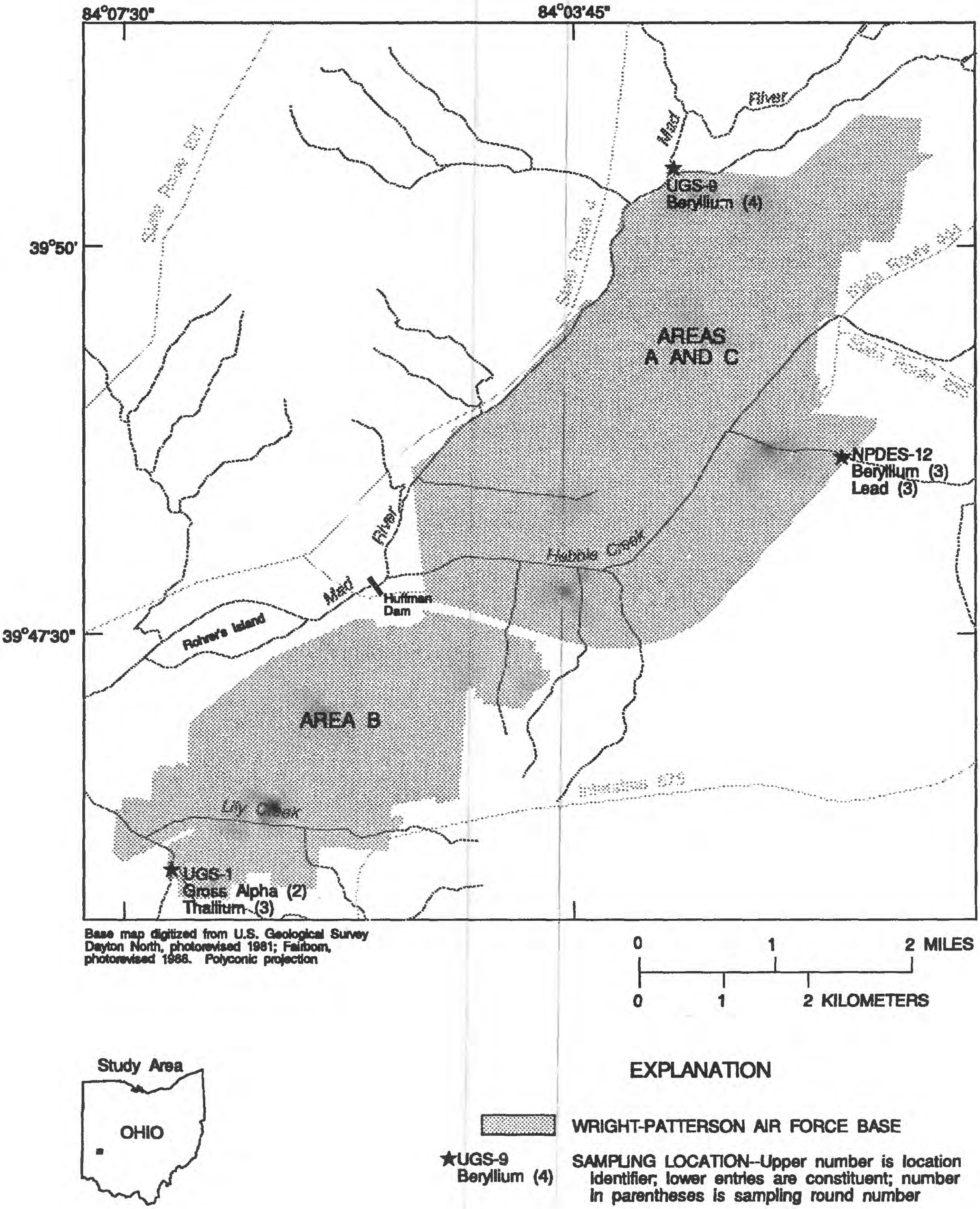
[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as >1.5 and ≤ 3 interquartile ranges from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

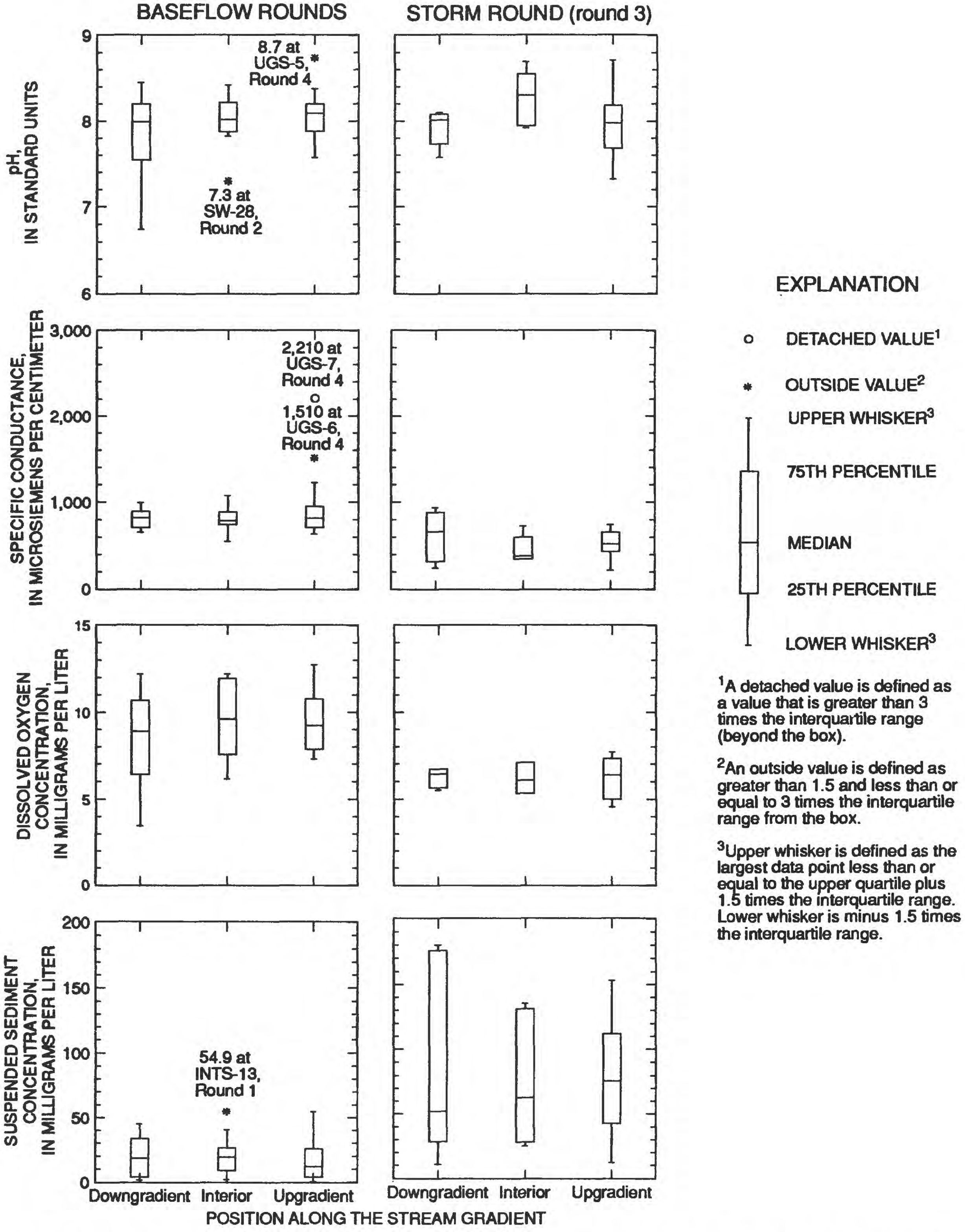
Negative percentages indicate that for the unfiltered/filtered sample pair, the concentration of a metal in the filtered sample was greater than the concentration of that metal in the corresponding unfiltered sample

Figure 53. Effects of filtration on concentrations of metals in surface-water samples, all rounds, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 54. Exceedances of maximum contaminant levels for inorganic constituents in surface-water samples, August 1993-September 1994 at Wright-Patterson Air Force Base, Ohio.



[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 55. Field-measured properties of surface water by position along the stream gradient, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.

Table 39. Exceedances of maximum contaminant levels for inorganic compounds in surface-water samples, August 1993–September 1994, Wright-Patterson Air Force Base

[MCL - maximum contaminant level; mg/L, micrograms per liter; pCi/L, picocuries per liter; J, estimated concentration; --, not applicable]

Location	Round	Sample	Constituent	Concentration	MCL	Units	Qualifier
DGS-7	1	Filtered	Antimony	40.2	6.0	µg/L	--
NPDES-13	1	Filtered	Antimony	35.6	6.0	µg/L	--
UGS-2	1	Unfiltered	Antimony	39.5	6.0	µg/L	--
UGS-3	1	Unfiltered	Antimony	37.1	6.0	µg/L	--
UGS-5	1	Unfiltered	Antimony	34.5	6.0	µg/L	--
INTS-15	2	Filtered	Antimony	7.7	6.0	µg/L	--
UGS-1	2	Filtered	Alpha, gross	19.7	15.0	pCi/L	--
DGS-5	3	Filtered	Antimony	23.6	6.0	µg/L	J
INTS-13	3	Filtered	Antimony	27.1	6.0	µg/L	J
INTS-6	3	Filtered	Antimony	21.2	6.0	µg/L	J
NPDES-12	3	Filtered	Antimony	28.3	6.0	µg/L	J
NPDES-13	3	Filtered	Antimony	34.2	6.0	µg/L	J
NPDES-5	3	Filtered	Antimony	20.0	6.0	µg/L	--
UGS-10	3	Filtered	Antimony	22.5	6.0	µg/L	J
UGS-3	3	Filtered	Antimony	27.2	6.0	µg/L	J
NPDES-12	3	Unfiltered	Antimony	20.2	6.0	µg/L	J
NPDES-12	3	Unfiltered	Beryllium	1.9	1.0	µg/L	--
UGS-2	3	Unfiltered	Antimony	28.8	6.0	µg/L	--
UGS-7	3	Unfiltered	Antimony	19.9	6.0	µg/L	--
NPDES-12	3	Unfiltered	Lead	150	15.0	µg/L	--
UGS-1	3	Unfiltered	Thallium	3.0	2.0	µg/L	--
UGS-9	4	Unfiltered	Beryllium	1.2	1.0	µg/L	--

sampled twice; three other locations had median concentrations of DO less than 8.0 mg/L.

Water temperatures fluctuate seasonally and diurnally. Highest water temperatures were recorded during round 1 (August 1993), and lowest temperatures were recorded during round 2 (November 1993). Diurnal temperature cycles were not indicated in the data analysis.

Fifteen of the highest 20 suspended-sediment concentrations during baseflow rounds were measured during round 2. As was mentioned earlier, sampling round 2 was conducted when baseflow was fairly high; water flowing with high energy can entrain more suspended sediment than water flowing with low energy. Most of the lowest concentrations of suspended sediment were measured during round 4, when flows were lowest. The highest median concentrations of suspended sediment were at INTS-13 and UGS-5; lowest median concentrations were at UGS-6 and NPDES-3 (which is at a culvert).

Trends along the gradient during baseflow rounds

No trends in water temperature, dissolved oxygen, or pH data during baseflow rounds along the stream gradient are evident. Median specific conductance was lowest at interior locations during the baseflow rounds, however it was only 32 µS/cm less than the highest median value, which was at downgradient locations. The median suspended-sediment concentration was about 35 percent greater at downgradient locations than at upgradient locations, indicating that some sediment was being entrained, or sediment-laden water was being added at some unmonitored location, as water flowed across WPAFB.

Extreme values during the storm round

The highest pH recorded during round 3 was 8.7 at NPDES-12, INTS-13, and UGS-5. Lowest values were 7.3 at UGS-7 and 7.5 at UGS-6. This range of pH differs little from that seen during baseflow rounds. In contrast, the extreme values of specific conductance

Table 40. Surface-water field-measured properties by position along the stream gradient, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[mS/cm, microsiemens per centimeter; mg/L, milligrams per liter; deg C, degrees Celsius; D, downgradient; I, interior; U, upgradient]

			Baseflow rounds (August 1993, November 1993, September 1994)					Storm round (August 1994)				
Property	Units	Position code	Minimum	Maximum	Number	Mean	Median	Minimum	Maximum	Number	Mean	Median
pH	Units	D	6.7	8.5	16	7.9	8.0	7.6	8.1	5	7.9	8.0
		I	7.3	8.4	12	8.0	8.0	7.9	8.7	5	8.3	8.3
		U	7.6	8.7	35	8.0	8.1	7.3	8.7	13	8.0	8.0
Specific conductance	µS/cm	D	658	992	16	805	822	245	940	5	615	664
		I	550	1,080	12	809	790	347	725	5	455	382
		U	635	2,210	35	888	816	217	743	13	521	519
Dissolved oxygen	mg/L	D	3.46	12.2	15	8.60	8.9	5.50	6.73	4	6.27	6.43
		I	6.15	12.2	11	9.50	9.6	5.35	7.10	3	6.18	6.08
		U	7.29	12.7	32	9.38	9.2	4.53	7.70	6	6.23	6.39
Water temperature	deg C	D	4.0	27.4	15	14.8	15.2	17.5	23.7	5	22.0	23.0
		I	4.0	26.5	11	16.1	16.0	22.3	24.5	5	23.0	22.7
		U	5.8	24.8	32	15.1	15.9	21.6	24.5	11	23.1	23.0
Suspended sediment	mg/L	D	1.7	44.9	14	19.6	18.3	10.8	180	6	83.9	51.9
		I	2.1	54.9	11	20.3	19.2	25.0	135	5	76.4	62.7
		U	0.5	54.7	32	16.4	11.9	12.1	2,330	13	246	75.6

measured during round 3 were much lower than those during the baseflow rounds, ranging from 217 µS/cm at UGS-7 to 940 µS/cm at NPDES-3. The two locations at which highest specific conductances were measured during the baseflow rounds, UGS-7 and UGS-6, had two of the three lowest specific conductances during round 3. Median specific conductance ranged from 790 to 822 µS/cm during baseflow rounds, whereas median values ranged from 382 to 664 µS/cm during round 3. This is expected, as specific conductance is proportional to the concentrations of ions in the water (Hem, 1992). As concentrations of ionic constituents decreased during round 3, specific conductance also decreased.

Dissolved-oxygen concentration was measured at 13 of the 24 locations sampled during round 3. Maximum concentrations of DO were measured at UGS-8 (7.7 mg/L) and UGS-3 (7.2 mg/L). The lowest concentration of DO was measured at UGS-7 (4.5 mg/L). Dissolved-oxygen concentrations were lower throughout the study area during round 3 than during the baseflow rounds, possibly because of the presence of oxygen-depleting compounds and sediment in the runoff water. Dissolved-oxygen concentrations follow daily cycles and are affected by temperature and biological processes in the stream, such as photosynthesis and respiration (Hem, 1992, p. 155). Respiration rates of biota in surface water are affected by the availability of sunlight. Much of the sampling for the storm round occurred after 8 p.m.; darkness also probably contributed to this decrease in dissolved oxygen.

Median suspended-sediment concentrations were about three to six times greater at each position along the stream gradient during the storm round than during the other rounds. The highest concentration of suspended sediment, measured at NPDES-12, was more than 10 times greater than any other recorded. This large amount of suspended sediment was not seen at locations downstream from NPDES-12, probably because of differences in sampling times. The sample from INTS-15, which is about 0.8 mi downstream from NPDES-12, contained 0.014 times as much suspended sediment as the sample from NPDES-12, but it was sampled 1.5 hours later. All other locations on Hebble Creek were sampled at least 1.5 hours later than NPDES-12. Lowest suspended-sediment concentrations were in samples from UGS-1 and DGS-8.

Trends along the gradient during round 3

Median specific conductance was markedly higher at downgradient locations during round 3 than at upgradient or interior locations; suspended-sediment concentrations followed the opposite trend, with the median concentration highest at upgradient locations and lowest at downgradient locations. Median concentrations of dissolved oxygen and values of pH showed no trends along the stream gradient.

Major Inorganic Constituents

Major constituents in surface water are those whose concentrations in unfiltered samples normally exceeded 2.0 mg/L : calcium, magnesium, potassium, sodium, chloride, nitrate, and sulfate. Bicarbonate was not included in the analyte list for the BMP; however, the anion has been shown to dominate the water chemistry of the area (Dumouchelle and others, 1993).

Baseflow rounds

Sixty-three surface-water samples were collected during baseflow rounds (1, 2, and 4). All major constituents but nitrate (detected in 58 samples) and potassium (detected in 61 samples) were detected in every unfiltered sample. All major cations but potassium (detected in 55 samples) were detected in every dissolved-metals sample.

Most of the highest concentrations of major inorganic constituents during baseflow rounds occurred in round 4, when discharges were lowest. Highest concentrations of sodium (322 mg/L), chloride (521 mg/L), and nitrate (13.7 mg/L) were detected in a sample from UGS-7 during round 4; high concentrations of sodium were detected in samples from UGS-6 (165 mg/L) and UGS-5 (133 mg/L) also during round 4.

Statistical summaries of concentrations of major inorganic constituents in surface-water samples by sampling round and position along the stream gradient are in table 41 and figures 56 and 57. Concentrations of nitrate and potassium were estimated as one-half the actual reporting limit for samples in which those constituents were not detected; these estimated concentrations were included in the calculation of the statistics. Only concentrations of calcium, nitrate, and sulfate showed any trends along the stream gradient. Median baseflow calcium and sulfate concentrations increased slightly from upgradient to downgradient locations, indicating enrichment of the water as it traversed the glacial outwash deposits. The highest median nitrate concentration was from samples collected at interior locations. Median concentrations of the other major constituents varied little with position along the regional gradient.

Storm round

Twenty-four surface-water samples were collected during the storm round (round 3). All major constituents but nitrate (detected in 23 samples) were detected in every unfiltered sample. All major cations were detected in every sample for dissolved metals.

The highest concentrations of calcium (231 mg/L), potassium (25 mg/L), and sulfate (102 mg/L) were detected in a sample from NPDES-12 during round 3. Other high concentrations were detected at UGS-10 (9.19 mg/L potassium) and UGS-3 (87.5 mg/L sodium). Median concentrations of all major constituents but potassium were less during round 3 than during baseflow rounds. Median calcium and magnesium concentrations during round 3 were about 50 percent less than these during baseflow rounds; median sodium and nitrate concentrations, about 25 percent less; median chloride concentrations, 30 percent less; and median sulfate concentrations, about 40 percent less. Most of these changes are because of dilution of the constituent in the larger flow of water that results from precipitation. Median potassium concentrations during round 3 were slightly higher than or about equal to those in rounds 1, 2, and 4.

Median concentrations of calcium, magnesium, nitrate, and sulfate showed similar patters along the regional gradient during round 3; that is, median concentrations for each constituent were higher at upgradient and downgradient locations than at interior locations. Median chloride and sodium concentrations

Table 41. Major inorganic constituents in surface-water samples by position along the stream gradient, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in milligrams per liter; D, downgradient; I, interior; U, upgradient]

Major constituent	Position code	Baseflow rounds (August 1993, November 1993, September 1994)					Storm round (August 1994)				
		Minimum	Maximum	Number	Mean	Median	Minimum	Maximum	Number	Mean	Median
Calcium	D	66.2	118	17	95.2	98.0	20.3	91.8	6	50.8	46.4
	I	62.1	108	12	83.7	79.4	3.51	49.1	5	28.7	32.0
	U	65.0	120	34	89.1	90.3	24.8	231	13	64.8	54.6
Chloride	D	17.3	113	17	55.5	59.7	7.3	137	6	68.8	49.6
	I	23.5	114	12	65.3	55.2	11	156	5	53.2	37.5
	U	25.8	521	34	88.1	63.5	13.7	76.4	13	37.0	29.2
Potassium	D	0.80	5.04	17	2.58	2.49	1.73	4.36	6	2.91	2.86
	I	2.13	6.53	12	3.73	3.58	2.79	4.50	5	3.57	3.41
	U	1.65	8.11	34	3.72	3.23	2.46	25.0	13	5.95	4.51
Magnesium	D	30.9	37.9	17	34.9	34.9	5.04	33.6	6	19.3	19.3
	I	20.5	39.1	12	33.3	35.4	6.63	15.5	5	10.7	10.8
	U	27.5	41.6	34	35.6	36.1	6.86	36.8	13	21.0	19.6
Sodium	D	11.1	76.5	17	31.1	32.5	4.01	96.8	6	43.8	26.7
	I	14.8	106	12	43.7	31.0	5.79	98.1	5	32.8	19.7
	U	11.3	322	34	50.1	33.4	9.98	87.5	13	25.3	17.0
Nitrate	D	0.55	4.7	17	2.36	2.0	0.58	3.0	6	1.44	0.99
	I	0.33	7.8	12	3.39	3.05	0.52	2.0	5	1.06	0.91
	U	0.125	13.7	34	2.64	2.0	0.13	4.8	13	1.59	1.1
Sulfate	D	46.5	81.8	17	63.6	60.6	14.5	70.7	6	39.6	39.3
	I	45.7	125	12	63.4	56.9	16.6	34.6	5	26.8	27.1
	U	35.9	83.6	34	54.3	54.7	12.8	102	13	38.6	34.7

increased with distance along the regional gradient, whereas median potassium concentrations decreased with distance along the regional gradient.

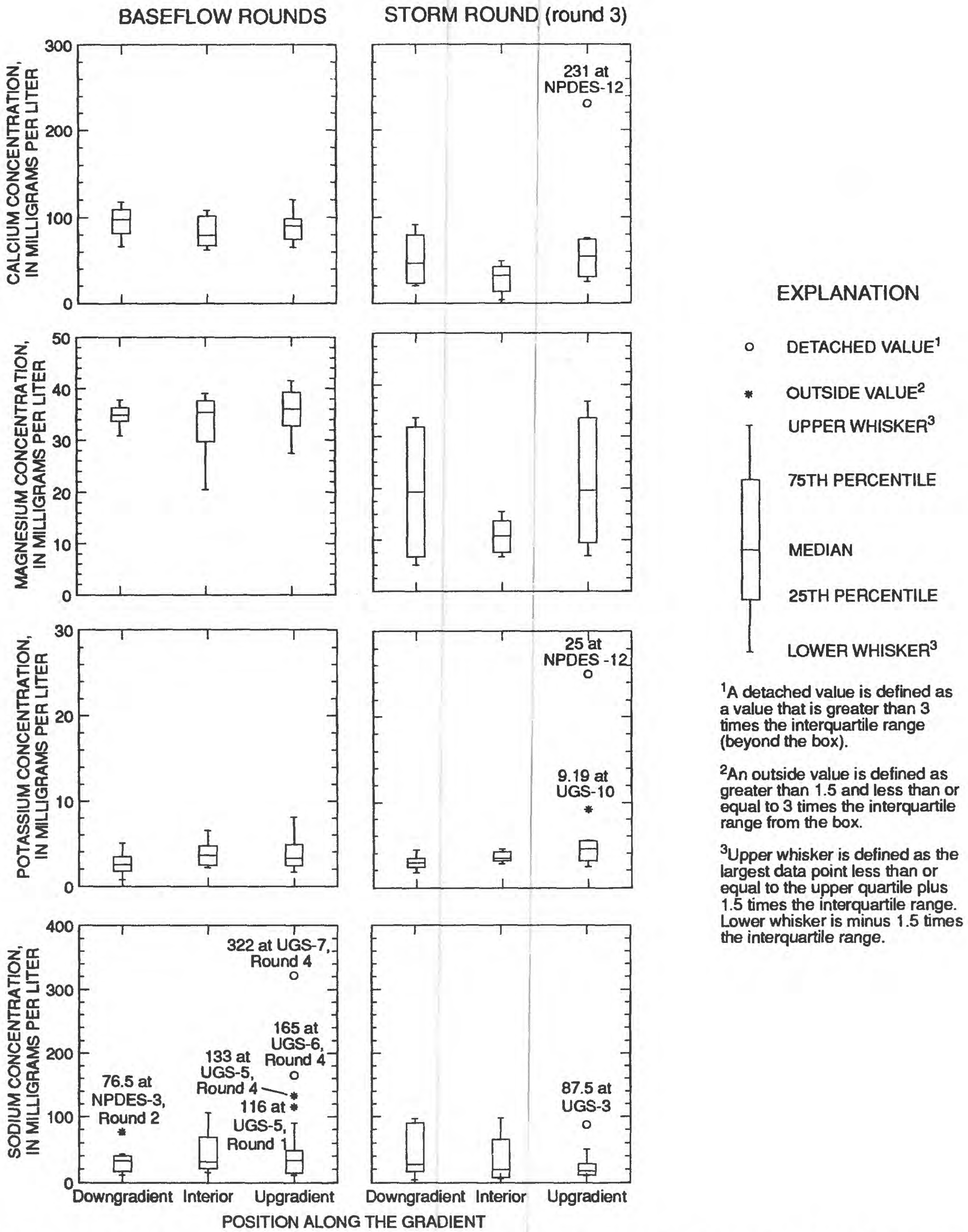
Minor Inorganic Constituents

All minor inorganic constituents detected in surface waters at WPAFB were metals. No bromide or nitrite ions were detected during any sampling round. Silver was not detected in any surface-water sample.

Barium, iron, and manganese

Because barium, iron, and manganese were detected in all or almost all unfiltered surface-water samples, analytical results of those metals were subjected to the same statistical techniques as those for the major inorganic constituents (table 42 and fig. 58). Barium was detected in every unfiltered surface-water sample, iron in 79 samples (92 percent), and manganese in 86 samples (99 percent) (table 38). For nondetections of manganese and iron, concentrations equal to one-half the actual reporting limit were used in the statistical analyses.

The highest concentration of barium during baseflow rounds was measured in a sample from NPDES-5 (178 µg/L, round 2). The next two highest concentrations were in samples from DGS-8 (143 and 141 µg/L), and three of the next highest five concentrations in samples from UGS-3 (133, 126, and 124 µg/L). The two highest concentrations of iron in

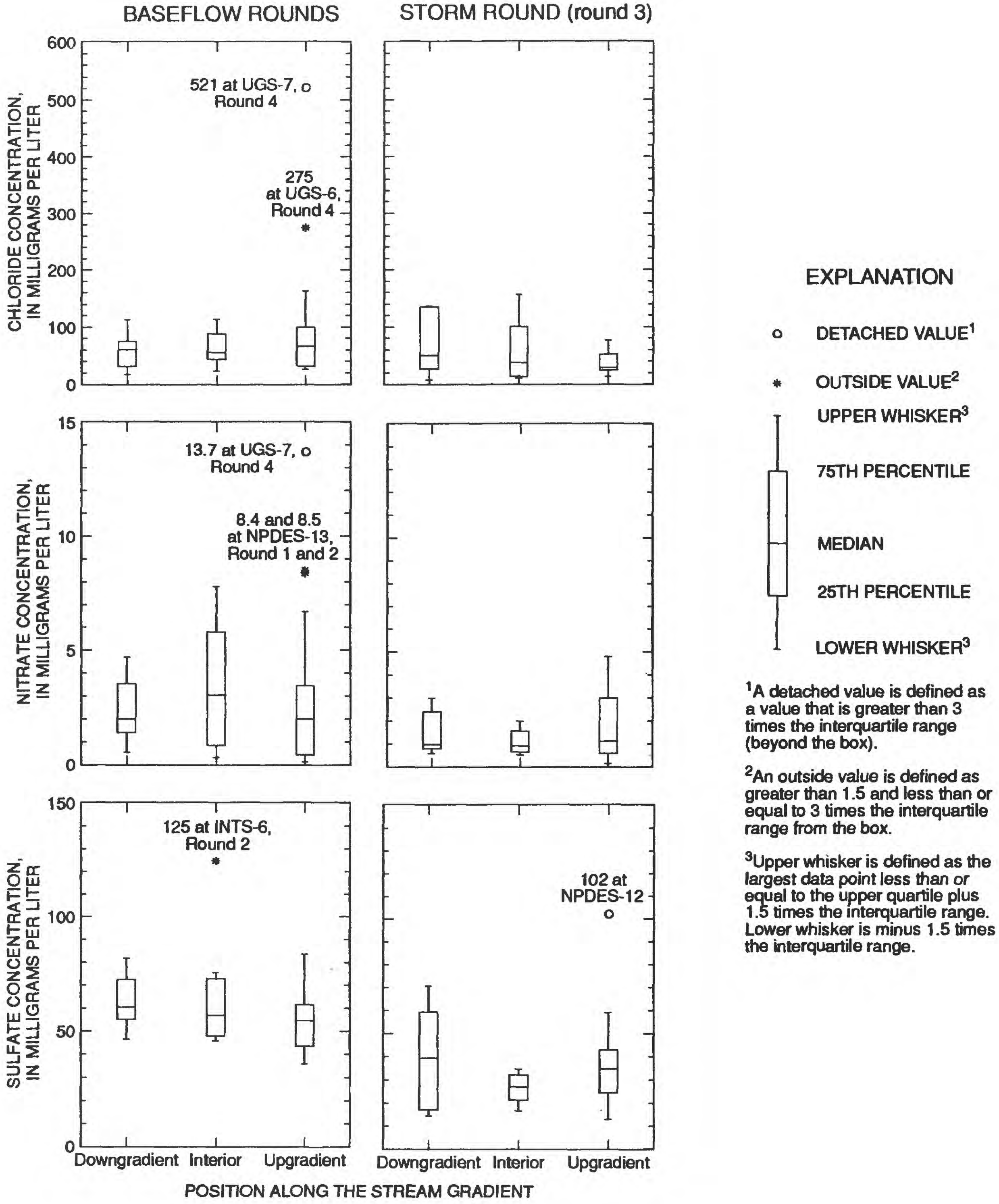


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 56. Concentrations of calcium, magnesium, potassium, and sodium by position along the stream gradient, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.



[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 57. Concentrations of chloride, nitrate, and sulfate by position along the stream gradient, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.

Table 42. Barium, iron, and manganese in surface-water samples by position along the stream gradient, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base
[All units are micrograms per liter; D, downgradient; I, interior; U, upgradient]

Constituent	Position code	Baseflow rounds (August 1993, November 1993, September 1994)					Storm round (August 1994)				
		Minimum	Maximum	Number	Mean	Median	Minimum	Maximum	Number	Mean	Median
Barium	D	65.2	143	17	107	109	36.3	113	6	69.0	59.6
	I	71.6	178	12	111	107	32.0	77.3	5	55.8	59.8
	U	75.1	137	34	108	106	35.6	270	13	90.2	79.3
Iron	D	15.8	360	17	102	75.6	233	1,850	6	912	659
	I	37.7	678	12	212	96.1	460	2,430	5	1,080	821
	U	16.1	323	34	111	105	252	23,700	13	3,840	1,180
Manganese	D	2.3	52.8	17	17.9	8.5	7.5	41.7	6	29.3	31.2
	I	2.3	72.9	12	17.0	9.95	12.4	66.2	5	39.4	38.3
	U	0.45	39.8	34	12.7	9.85	19.0	1,010	13	128	42.4

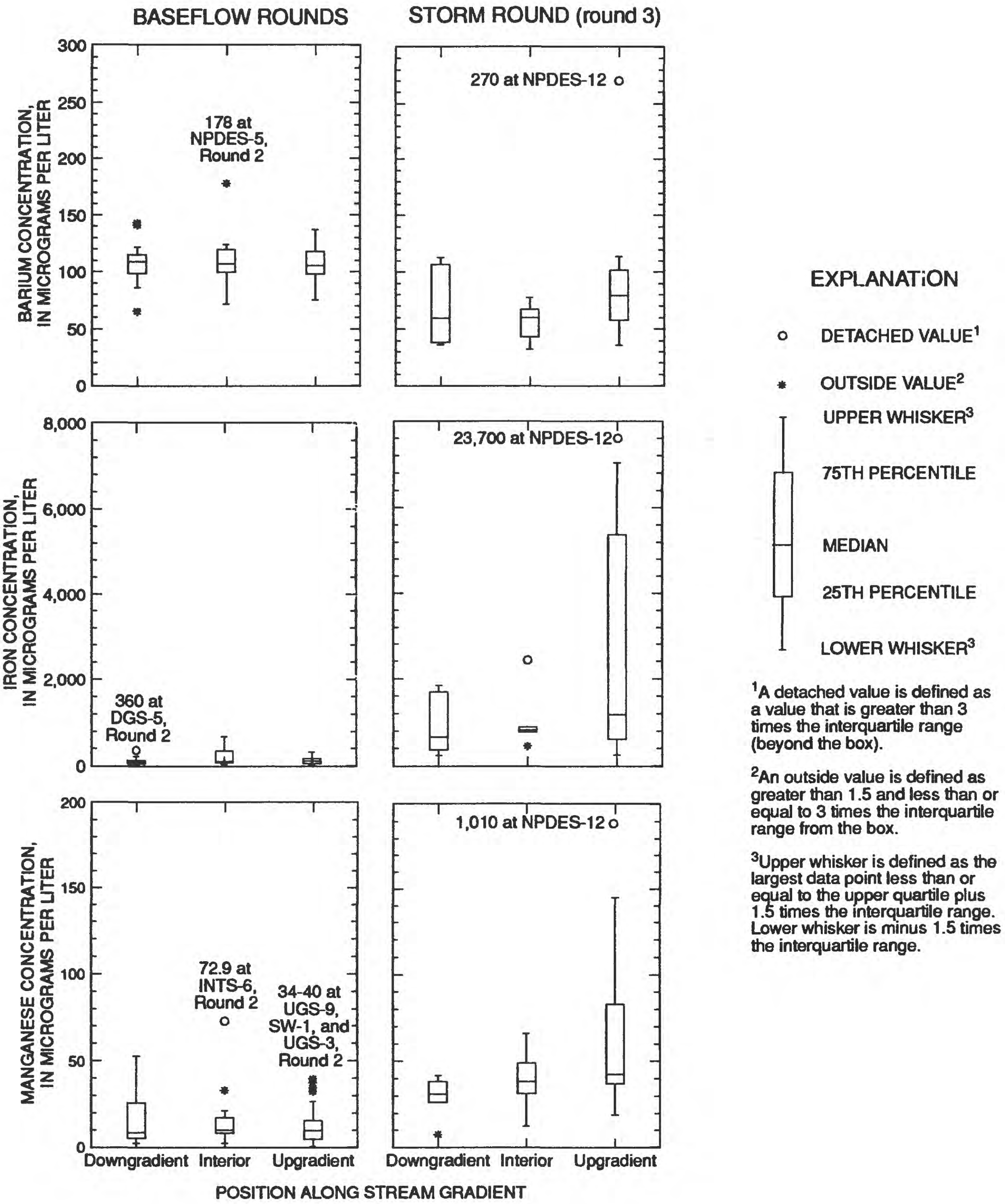
baseflow rounds, 678 and 506 mg/L, were in samples from INTS-13, and concentrations in samples from INTS-6 were third (430 µg/L) and sixth (252 µg/L) highest. Iron concentrations in samples from NPDES-4 were three of the lowest 10 during baseflow rounds. The three highest concentrations of manganese were in samples from INTS-6, DGS-7, and NPDES-4.

Highest concentrations of all three metals in samples during round 3 were in a sample from NPDES-12. The concentration of barium in that sample, 270 µg/L, was more than twice as high as the concentrations of barium in samples from any other location during round 3. In the sample from NPDES-12, iron was detected at a concentration of 23,700 µg/L, more than 3 times higher than any other concentration in surface-water samples during the BMP and almost 35 times higher than any other concentration detected during baseflow rounds. The concentration of manganese in the same sample, 1,010 µg/L, was almost 7 times greater than that in samples from any other location on WPAFB. Locations at which the second, third, and fourth largest concentrations of iron and manganese were detected in samples during round 3 were UGS-4, UGS-7, and UGS-6. Each of these is an upgradient location, as is NPDES-12. These data indicate that stormwater flow entering WPAFB from upgradient sources can contain much higher concentrations of constituents than stormwater flow originating on WPAFB.

Only median iron concentrations showed some trend along the regional gradient during baseflow rounds, decreasing with distance down the stream (fig. 58). Median concentrations of all three metals decreased with distance down the stream during the storm round.

Arsenic, cadmium, mercury, and lead

Concentrations of arsenic, cadmium, mercury, and lead in surface water (and later in streambed sediment) are presented separately to relate the findings of the BMP to those of a study by the Ohio EPA (Counts and Altfater, 1994). The Ohio EPA study was designed in part "to (1) determine background conditions of the Mad River in the vicinity of Wright-Patterson Air Force Base prior to the commencement of treated groundwater discharges, and (2) determine and measure adverse impacts on biological communities and water quality in the study area" (Counts and Altfater, 1994, p. 6). Ohio EPA sampled surface water in October 1992 at 6 locations on Mad River, including locations near NPDES-4, DGS-5, and NPDES-5;



[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 58. Concentrations of barium, iron, and manganese by position along the stream gradient, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio.

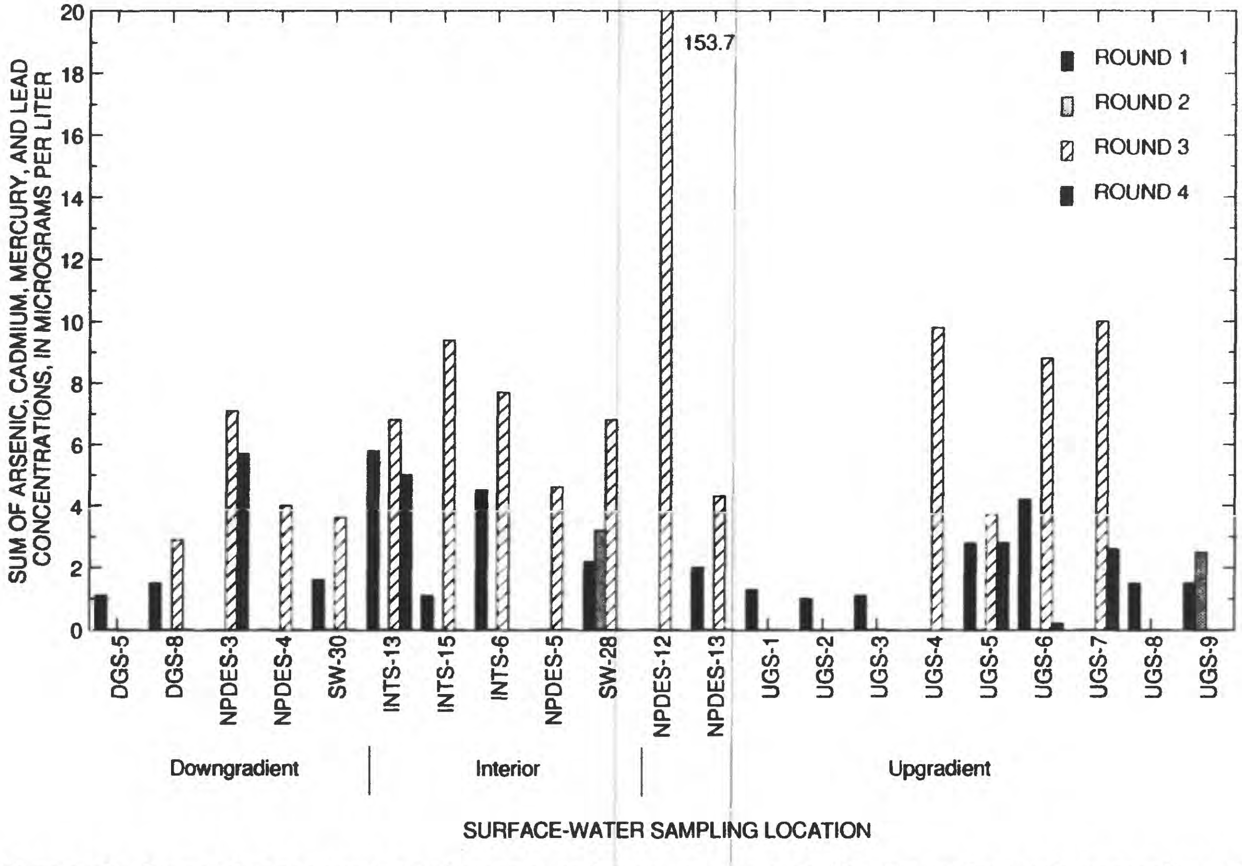


Figure 59. Sums of concentrations of arsenic, cadmium, mercury, and lead in surface-water samples, all rounds, August 1993-September 1994, by location on Wright-Patterson Air Force Base, Ohio.

two locations on Hebble Creek, including NPDES-4 and INTS-13; and at DGS-7 on Trout Creek.

Ohio EPA (Counts and Altfater, 1994) found no arsenic, cadmium, lead, or mercury in samples from any surface-water location sampled in October, 1992. During the BMP, lead was the only one of these constituents detected during baseflow rounds at the five locations included in the Ohio EPA study: twice at INTS-13 (5.8 and 5.0 µg/L) and once at DGS-5 (1.1 µg/L). During round 3, lead was detected in samples from NPDES-4 (4.0 µg/L), INTS-13 (6.8 µg/L), and NPDES-5 (4.6 µg/L). None of these detections exceeded the drinking-water MCL for lead (15 µg/L).

Sums of concentrations of these four metals detected during the BMP at all locations are presented in figure 59. The only concentration that exceeded the MCL was of lead, detected at 150 µg/L in a sample from NPDES-12 during round 3. At no other location did the combined concentrations of these four metals exceed 10 µg/L. Of these metals, most of the detections were of arsenic and lead during rounds 1 and 3. Highest combined concentrations were recorded in round 3 samples from NPDES-12, UGS-7, UGS-4, and INTS-15. No trends of detections or concentrations along the stream gradient are apparent.

Other minor inorganic constituents

Thallium, silver, bromide, and nitrite were not detected in any sample collected during baseflow conditions. Chromium, cyanide, selenium, and vanadium were detected once and beryllium twice during the baseflow rounds.

High concentrations of the remaining trace metals (aluminum, zinc, copper, chromium, vanadium, antimony, nickel, cobalt, beryllium, and selenium) were detected during baseflow rounds:

Aluminum: 568 µg/L, round 4, and 320 µg/L, round 1, at INTS-13.

Antimony: 39.5 µg/L, UGS-2, and 37.1 µg/L, UGS-3, round 1. The concentrations of antimony reported are probably because of interference in the ICP method, and these should not be regarded as definite.

Beryllium: 0.63 µg/L, NPDES-4, round 1.

Chromium: 6.5 µg/L, UGS-1, round 2.

Cobalt: 16.1 µg/L, UGS-9, and 15 µg/L, INTS-6, round 2.

Copper: 43.7 µg/L, round 1, and 39.2 µg/L, round 4, at NPDES-3. Copper was detected 17 times during baseflow rounds, but only in the sample from NPDES-12 (70.1 µg/L) during round 3.

Nickel: 35.8 µg/L, NPDES-12, round 2. All baseflow detections of nickel were during round 2.

Selenium: 3.1 µg/L, DGS-8, round 1 (only detection).

Vanadium: 2.5 µg/L, UGS-2, round 4 (only detection). Vanadium was not detected at the same location twice during the four sampling rounds.

Zinc: 245 µg/L, NPDES-3, round 4; 91.2 µg/L, UGS-6, round 1. All other detected concentrations of zinc during baseflow rounds were less than 40 µg/L.

Of the 10 trace metals detected during round 3, 8 (aluminum, beryllium, cobalt, chromium, copper, nickel, vanadium, and zinc) were detected in highest concentration in the sample from NPDES-12. Concentrations in that sample were three to six times higher than those detected in samples from any other location. Only concentrations of antimony (28.8 µg/L at UGS-2) and thallium (3.0 µg/L at UGS-1, only detection) were highest at locations other than NPDES-12.

Sums of concentrations of minor metals detected during each round of surface-water sampling on WPAFB are presented in figure 60. Locations at which the highest sums of concentrations of minor metals were detected were NPDES-12 (22,253 µg/L), UGS-7 (5,524 µg/L), UGS-4 (4,823 µg/L), and UGS-6 (4,483 µg/L), each during round 3. Each of these is an upgradient location, again indicating that sources adjacent to the Base contribute to high concentrations of metals in stormwater runoff. The high concentrations of metals at NPDES-12, as discussed throughout this section, probably are associated with the high concentrations of suspended sediment at that location (fig. 61) during the storm round.

The number of detections during a given time period can be indicative of chronic contamination potential. The number of detections of minor metals at each location during all four rounds is shown in figure 62. Locations at which these trace metals were detected most frequently include NPDES-12 (82 percent during round 3), UGS-6 (36 percent during round 3), NPDES-3 (36 percent during round 3), and INTS-6 (40 percent during round 3). All of these locations except NPDES-3 are in the Hebble Creek subsystem. Locations at which trace metals were detected least frequently include NPDES-6 and DGS-6 (no detections) and NPDES-5, SW-1, and UGS-3 (2 detections). All of these five locations are in the Mad River and Lily Creek subsystems.

Gross Alpha and Gross Beta

Gross alpha and gross beta activities were detected at low concentrations in surface-water samples. Median concentrations of gross alpha and gross beta did not exceed 1.5 pCi/L and 4 pCi/L, respectively, at any location along the stream gradient (table 43). Gross alpha activity in one sample from UGS-1 (19.7 pCi/L, round 2) was greater than the MCL (15 pCi/L); no other alpha activity exceeded 6 pCi/L. Maximum beta activity recorded was 18.3 pCi/L (at NPDES-12, round 3), well below the MCL (30 pCi/L). Generally, activities of alpha and beta were lower during the storm round than during the three baseflow rounds.

Sources, Transport, and Fate of Inorganic Contaminants

Probable sources for inorganic contaminants in surface water are difficult to identify because of the various pathways by which a contaminant can be transported to the surface water. These transport pathways can include discharge of contaminated ground water, transport of contaminated soil through storm runoff, atmospheric deposition, and discharge of industrial and municipal wastes. High sodium and chloride concentrations can be attributed partially to salting of roads and highways. Light industrial activities (such as those associated with aircraft maintenance) probably contribute metals to the surface-water systems and could account for variations in inorganic constituent concentrations. Most metals in surface water, however, were detected in samples from upgradient locations, indicating that off-Base activities contribute to the inorganic contamination at WPAFB. Metals can accumulate along roads and other public areas during dry weather and be washed into streams during storms.

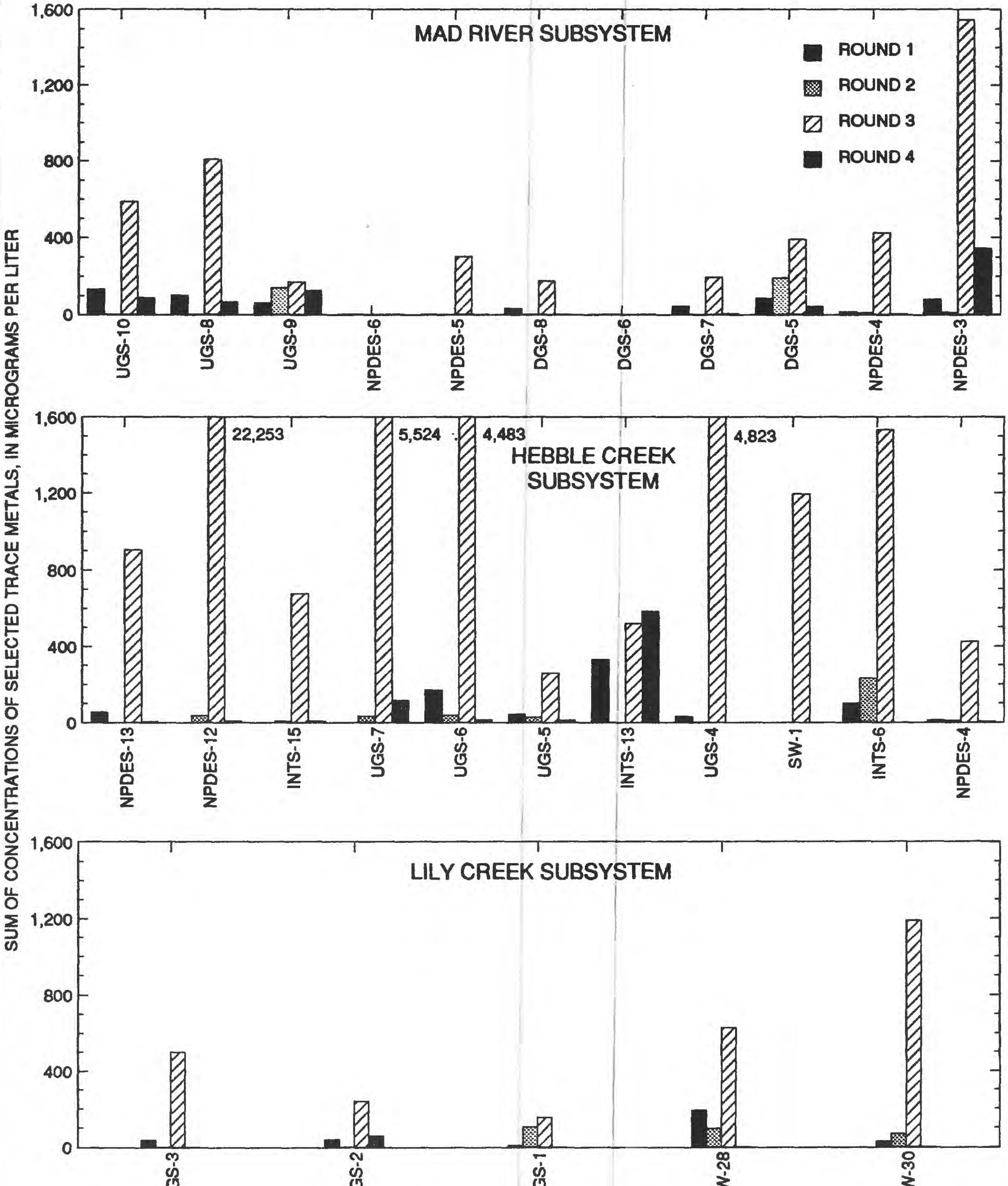


Figure 60. Sums of concentrations of selected trace metals in surface-water samples, all rounds, August 1993-September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio. Constituents are aluminum, zinc, copper, chromium, vanadium, antimony, nickel, cobalt, beryllium, selenium, and thallium.

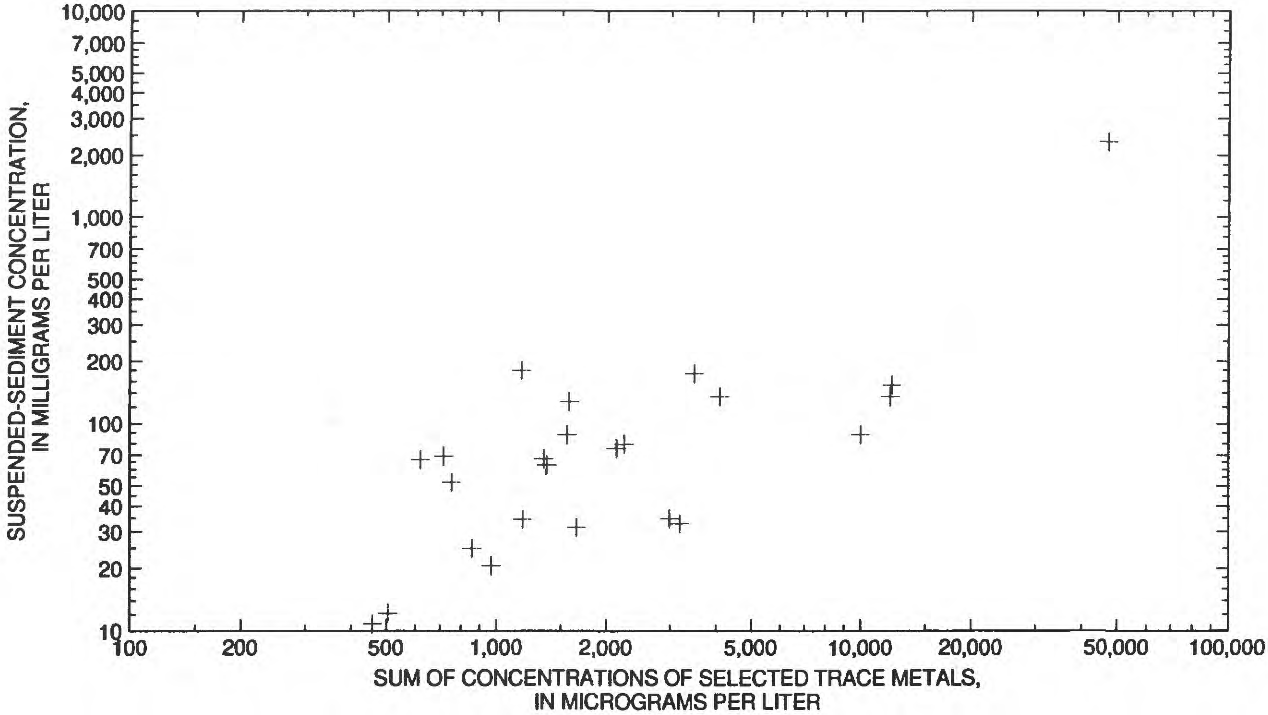


Figure 61. Concentrations of selected trace metals and suspended sediment in surface water, round 3, August 1994, Wright-Patterson Air Force Base, Ohio. Constituents are aluminum, zinc, copper, chromium, vanadium, antimony, nickel, cobalt, beryllium, selenium, and thallium.

Organic Compounds

Organic analyses included in the BMP include volatiles, semivolatiles, organochlorine pesticides and PCBs, chlorinated herbicides, and TPH. All but herbicides (rounds 1 and 2 only) and TPH (rounds 1 and 2 only) were included in the sampling schedule every round.

Quality Control and Data Validation

Quality–assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the inorganic data collected in each of the four sampling rounds generally were met. Low concentrations of methylene chloride and acetone, both common laboratory contaminants, were detected in surface-water-sample method blanks during rounds 2, 3, and 4 and were flagged as undetected (U). Many of the pesticides and PCBs data were flagged as estimated nondetects (UJ) in all four rounds because of machine-calibration problems.

Frequency of Detection of Organic Compounds

Ten VOCs, seven SVOCs, three pesticides, and two herbicides were detected in surface-water samples during the four rounds (fig. 63). All detected concentrations of 2-butanone, 4-methyl-2-pentanone, 4-methylphenol, 4-nitrophenol, phenol, diethyl phthalate, di-n-butyl phthalate, 4,4'-DDE, 4,4'-DDD, and 4,4'-DDT were reported as estimated (J). In all, 62 percent (36 of 58) of all detections of organic compounds were estimated (J). No petroleum hydrocarbons or PCBs were detected in surface-water samples.

The VOC most commonly detected (four times) in surface-water samples was dibromochloromethane. Phthalates were the most commonly detected SVOCs (24 detections), accounting for 89 percent of all SVOC detections. Concentrations of 24 of the 27 SVOC detections (89 percent) were estimated (J). Bis(2-ethylhexyl)phthalate was detected nine times at different locations. Pesticides and chlorinated herbicides were detected four times.

Exceedances of Drinking-Water Standards

Only one organic compound exceeded the MCL during the four rounds of surface-water sampling. Bis(2-ethylhexyl)phthalate (6.0 µg/L MCL) was detected at 16 µg/L in a sample from NPDES-13 during round 2, and at 8.0(J) µg/L in a sample from

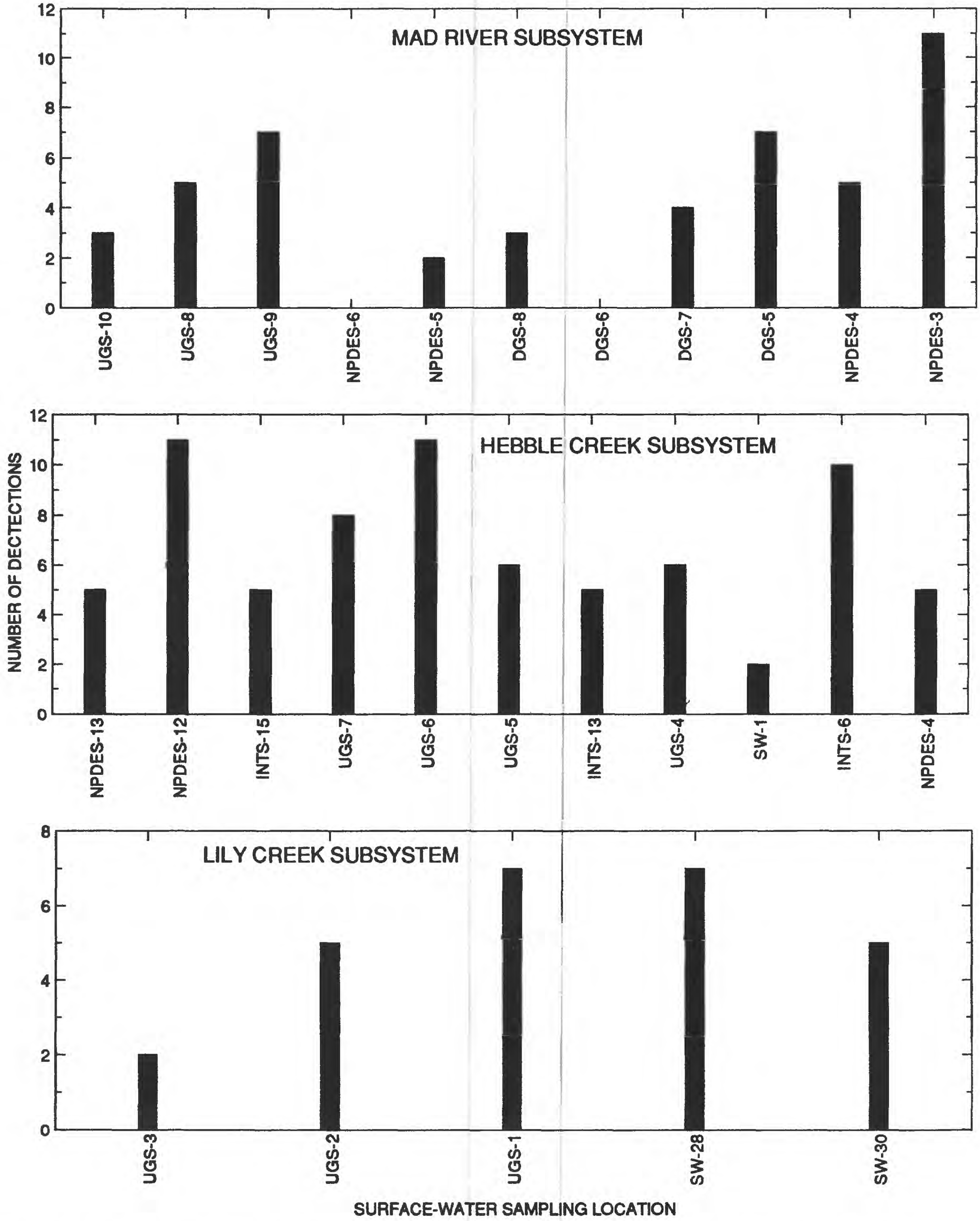


Figure 62. Detections of selected trace metals in surface-water samples, all rounds, August 1993-September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio. Constituents are aluminum, zinc, copper, chromium, vanadium, antimony, nickel, cobalt, beryllium, selenium, and thallium.

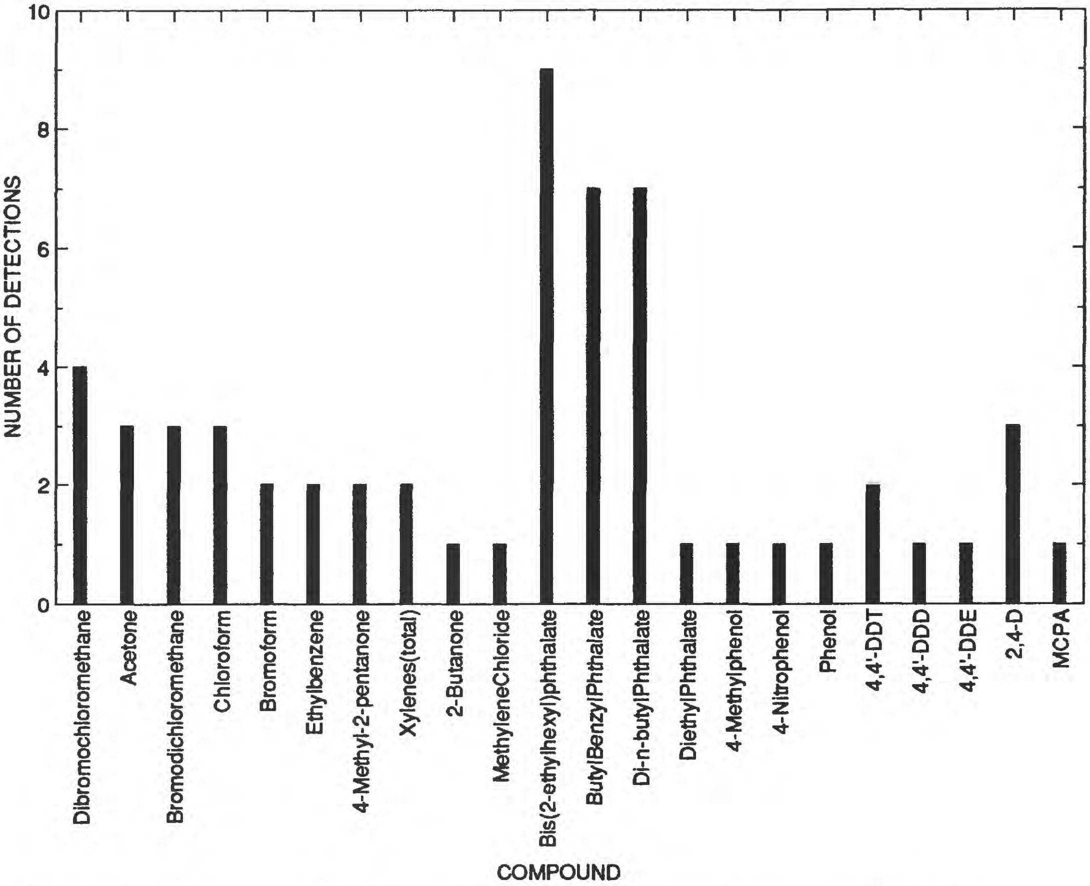


Figure 63. Detections of organic compounds in surface-water samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base, Ohio.

Table 43. Gross alpha and gross beta in surface-water samples by position along the stream gradient, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All units are picocuries per liter; D, downgradient; I, interior; U, upgradient]

		Baseflow rounds (August 1993, November 1993, September 1994)					Storm round (August 1994)				
Constituent	Position code	Minimum	Maximum	Number	Mean	Median	Minimum	Maximum	Number	Mean	Median
Gross alpha activity	D	-0.65	5.1	17	1.79	1.5	-0.34	1.45	6	0.58	0.43
	I	0.06	5.7	12	1.42	1.15	-4.79	0.52	5	-0.64	0.39
	U	-0.16	19.7	34	1.75	0.89	0.03	1.27	13	0.64	0.68
Gross beta activity	D	1.3	12.9	17	3.45	2.92	1.07	3.98	6	3.19	3.45
	I	1.78	11.0	12	4.38	3.93	1.13	4.17	5	2.66	3.25
	U	1.16	15.2	34	4.24	3.75	0.6	18.3	13	4.32	3.19

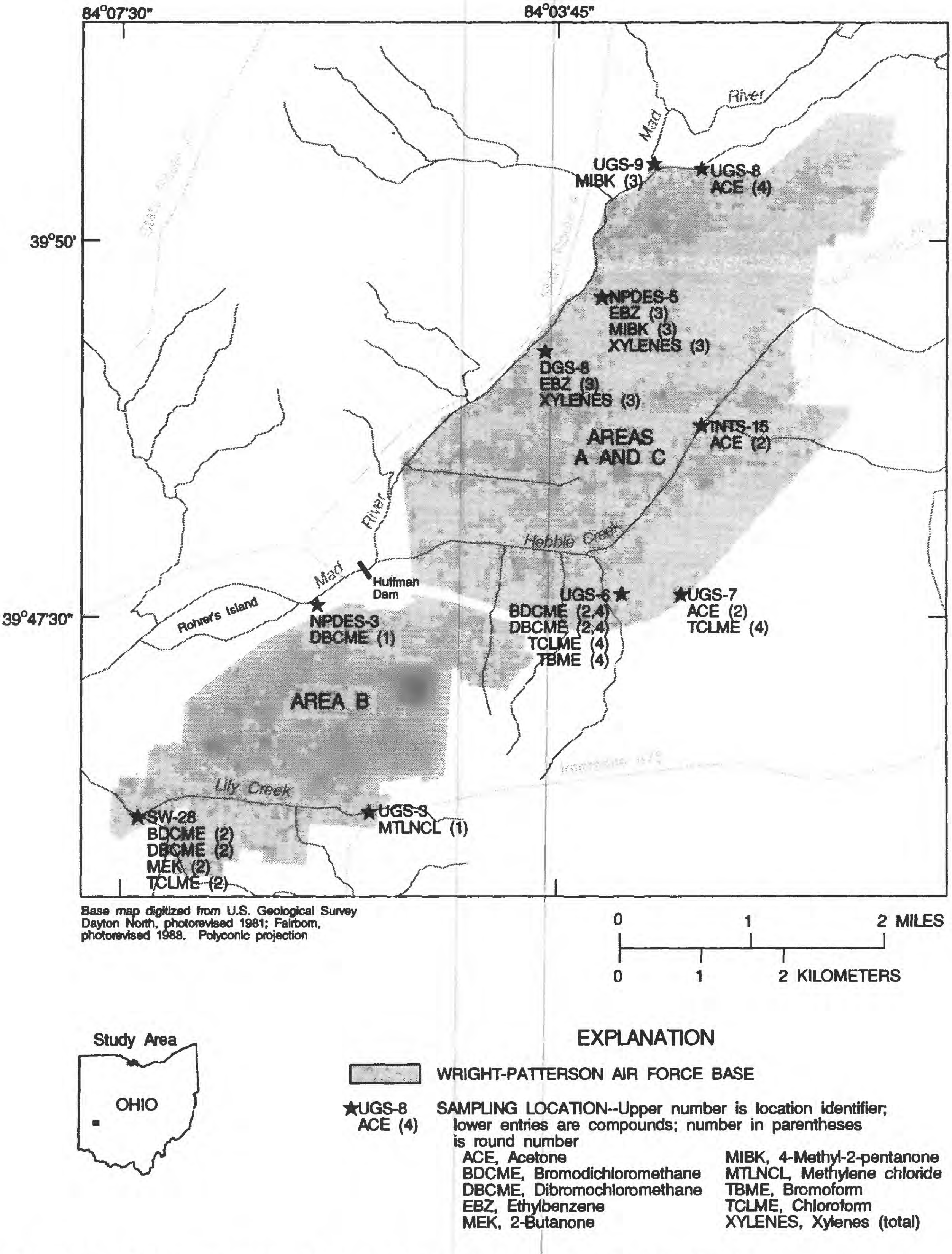


Figure 64. Detections of volatile organic compounds in surface-water samples, all rounds, August 1993-September 1994 at Wright-Patterson Air Force Base, Ohio.

UGS-8 during round 2. During no other round was bis(2-ethylhexyl)phthalate detected at those locations.

Volatile Organic Compounds

VOCs were detected in 14 of 87 surface-water samples; none of the detections exceeded USEPA MCLs for drinking water. Locations at which VOCs were detected are shown in figure 64. The highest concentration of any VOC detected was 80(J) µg/L of 4-methyl-2-pentanone, detected in a sample from UGS-9 during round 3. The highest unqualified concentration of VOCs detected was 15 µg/L of xylenes, detected in samples from DGS-8 and NPDES-5 during round 3. Bromoform, 2-butanone, and 4-methyl-2-pentanone were found at low concentrations in four samples. Chloroform was detected during baseflow rounds in samples from three locations: SW-28 (round 2), UGS-6 (round 4), and UGS-7 (round 4). Dibromochloromethane and bromodichloromethane were detected during rounds 2 and 4 in samples from UGS-6 and during round 2 in a sample from SW-28. Two VOCs, ethylbenzene and total xylenes, each were detected during round 3 in samples from DGS-8 and NPDES-5.

No TCE was detected in surface-water samples during the BMP. From January to June 1992, TCE was found in samples from NPDES-4 several times; median concentration was 4.1 µg/L and maximum concentration was 18.4 µg/L (Counts and Altfater, 1994). TCE may have been absent at NPDES-4 during sampling for the BMP because of the effects of the extraction well in OU-5, which began operation after sampling by OEPA (Counts and Altfater, 1994) but before sampling by the USGS.

VOCs were not widely found in surface-water samples at WPAFB. No conclusions can be made as to their presence and distribution during sampling.

Semivolatile Organic Compounds

Four phthalates (butyl benzyl, bis(2-ethylhexyl), di-n-butyl, and diethyl) and three phenols (4-nitrophenol, phenol, and 4-methylphenol) were found in surface-water samples during the four rounds. All but three of the detections of phthalates were qualified as estimated. The highest concentration of phthalates detected was 20 µg/L (unqualified) of butyl benzyl phthalate at INTS-13 during round 1; the highest concentration of phenols was 5(J) µg/L of diethyl phenol at UGS-1 during round 2. Detections of SVOCs were distributed evenly between both administrative areas. Locations from which samples containing SVOCs were obtained are shown on figure 65. No conclusions can be made as to their presence or distribution during sampling or the relation between their presence and flow rates.

In general, phthalates with low solubilities (di-n-butyl, di-n-octyl, butyl benzyl, and bis(2-ethylhexyl)) (Smith and others, 1988, table 33) were found in surface water. These also were most commonly found in streambed sediment (discussed later). Most phenols are much more soluble than phthalates (Smith and others, 1988, table 21). It is likely that the solubilities of both are low enough that the sediments act as reservoirs but high enough that compounds are released to surface water at slow rates.

Other Organic Compounds

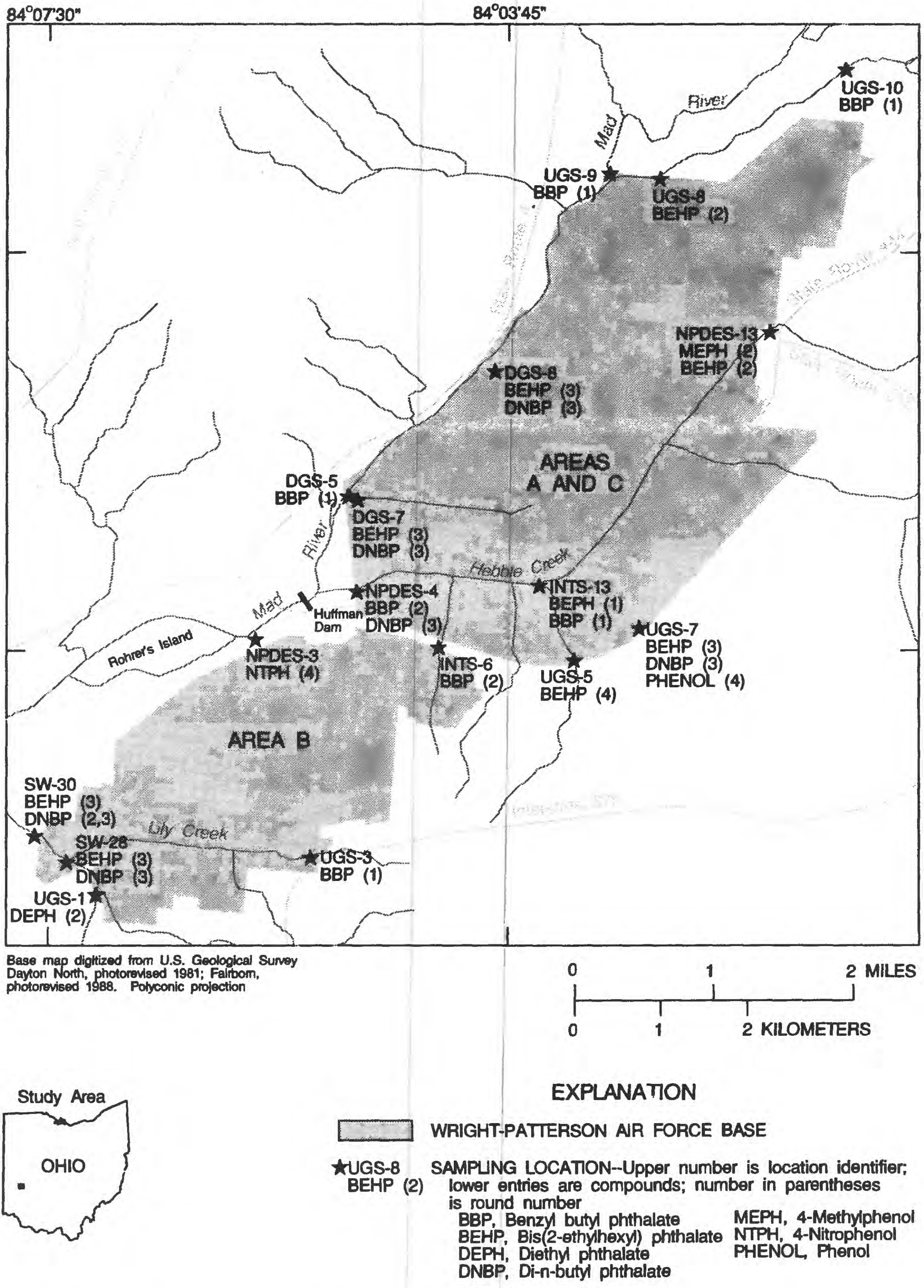
No polychlorinated biphenyls (PCBs) were detected in surface-water samples. The only pesticides detected in surface-water samples were 4,4'-DDT, 4,4'-DDE, and 4,4'-DDD. Each of these was found during round 3 (storm sampling) at UGS-1. These detections probably were result of off-Base activities. 4,4'-DDT also was in a sample from SW-30 during round 2. All detections were at low concentrations and qualified as estimated.

Pesticides and PCBs do not partition readily to surface water from streambed sediments. Most pesticides have solubilities in the same range as those of SVOCs (Smith and others, 1988). Pesticides and PCBs probably are retained for long periods (years) and released in concentrations often too low to detect.

Chlorinated herbicides were included in the analyte list only during rounds 1 and 2. The highest concentration of dichlorophenoxyacetic acid (2,4-D) detected was 10 µg/L at INTS-13; MCPA was detected once at UGS-5 at a concentration of 82 µg/L. Other locations at which herbicides were detected were INTS-6 and INTS-15. No conclusions can be made as to their presence or distribution during sampling or their relation to land use.

Sources, Transport, and Fate of Organic Compounds

Probable sources for organic contaminants in surface water are difficult to identify because of the various compounds that can be transported to the surface water. The distributions and concentrations of organic compounds in surface-water systems are affected by sorption, bioaccumulation, photolysis, hydrolysis, biodegradation, and volatilization



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

EXPLANATION

▨ WRIGHT-PATTERSON AIR FORCE BASE

★UGS-8 BEHP (2) SAMPLING LOCATION--Upper number is location identifier; lower entries are compounds; number in parentheses is round number

BBP, Benzyl butyl phthalate	MEPH, 4-Methylphenol
BEHP, Bis(2-ethylhexyl) phthalate	NTPH, 4-Nitrophenol
DEPH, Diethyl phthalate	PHENOL, Phenol
DNBP, Di-n-butyl phthalate	

Figure 65. Detections of semivolatile organic compounds in surface-water samples, all rounds, August 1993-September 1994 at Wright-Patterson Air Force Base, Ohio.

(Smith and others, 1988). The atmosphere is a major pathway for the transport and deposition of natural and anthropogenic organic chemicals. Vast quantities are released into the atmosphere; field-applied pesticides volatilize into the air or attach to soil matter and are dispersed by the wind; PAH's are emitted by automobile exhaust, fires, or other combustion sources; and PCBs are released from leaking electrical transformers or landfills.

Airborne organic compounds undergo a variety of reactive processes which can alter or destroy them. The reactive processes typically are dominated by either chemical reactions with oxidants, such as ozone, or by photolysis. Physical removal by depositional process can be highly variable depending on atmospheric conditions, and range from hours to weeks or months. Once airborne, stable chemicals such as PCBs can be transported thousands of miles.

Except for VOCs, most trace organics are sorbed to biota or abiotic particles in the water column and then deposited in the stream sediment; without significant biodegradation, these organic compounds can accumulate. If the water is undersaturated with respect to the atmosphere, then there is a net transfer of vapor to the water. The resistance to transfer depends on the phase from which the compound tends to partition; if the compound not in high concentration, diffusion rates are fast. In theory, the equilibrium concentration of a trace organic in air (which in surface-water systems never occurs) and water can be calculated if Henry's Law constant (H) is known. However, organics with low water solubility, such as PCBs,can enter the water column and remain dissolved and unassociated, bind with dissolved or colloidal organics, adsorb onto a particle surface, or be adsorbed into organic matter (Eisenreich and others, 1981). Organic compounds generally were detected more frequently in samples from upgradient locations than from downgradient locations on WPAFB; civilian activities outside Base boundaries probably have greater effect on surface water in the WPAFB area than do activities on the Base.

The environmental fate of organic compounds vary with each compound. VOCs in surface-water systems volatilize and then photodegrade in the atmosphere; SVOCs in surface water biodegrade; pesticides and PCBs are extremely persistent and resist degradation; and herbicides generally have high solubilities and rapidly biodegrade or chemically attenuate by photolytic or hydrolytic reactions.

Streambed-Sediment Quality

Streambed-sediment samples were collected in four rounds from August 1993 to September 1994 at 25 locations on WPAFB (fig. 4; all locations but NPDES-1, -2, and -3). Types of samples collected for each round at each location are listed in table 36. Samples were analyzed for VOCs, SVOCs, pesticides/PCBs, cyanide, and total metals in every round (table 37). Samples were analyzed for chlorinated herbicides in rounds 1 and 3 and petroleum hydrocarbons in rounds 1 and 2. Summary statistics of the chemical concentrations grouped by river subsystem are presented throughout this section. As in the discussions concerning surface-water quality, the summary statistics were calculated from the qualified and unqualified detections primarily. In the few cases where nondetections were analyzed with detections, a concentration equal to one-half the actual reporting limit was used to estimate the concentration at which the constituent was present; this estimated concentration was used in the analysis.

This section is organized to present first the quality of streambed sediments with respect to inorganic constituents, then organic compounds. [In each category, a discussion of the frequency of detections of the constituents is presented, followed by discussions of concentrations at which the constituents were detected.] Findings of the BMP by comparing relative levels of inorganic and organic contaminants at each streambed-sediment location are summarized.

Analysis of streambed-sediment quality was performed on the basis of river subsystems (fig. 52), as was surface-water quality. For surface-water-quality analysis, the Mad River subsystem included 11 locations; for streambed-sediment-quality analysis, the Mad River subsystem included 10 locations, because sediment was not sampled at NPDES-3.

Inorganic Constituents

Inorganic constituents included in streambed-sediment analyses during the BMP were cyanide and metals. Quality-assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the inorganic data collected in each of the four sampling rounds generally were met; most of the data were acceptable with qualification. All results for cyanide analyses of streambed-sediment samples were acceptable without qualification except for one; cyanide in a sample from NPDES-12 during round 3 exceeded the holding time, and the result was qualified as UJ (estimated nondetection).

Frequency of Detection of Inorganic Constituents

All 24 inorganic constituents were detected at least once in streambed-sediment samples (fig. 66). The most frequently detected metals, detected in all 100 samples, were aluminum, arsenic, barium, calcium, chromium, iron, lead, magnesium, manganese, vanadium, and zinc. Other metals detected in more than 70 percent of all samples were copper (99 percent), potassium (95 percent), nickel (86 percent), cobalt (85 percent), sodium (84 percent), and beryllium (73 percent). All but one of the nondetections of potassium and sodium were determined by the laboratory during analysis of samples collected in round 2. Antimony and thallium were detected in one sample each. Of the remaining inorganic constituents (all detected in fewer than 25 percent of the samples), the order of frequency of detection was, from most to least frequently detected, mercury, cadmium, selenium, cyanide, and silver.

Major Inorganic Constituents

Major inorganic constituents— aluminium, calcium, iron, magnesium, manganese, potassium, and sodium—were detected at concentrations routinely exceeding 100 mg/kg. Each of these metals are naturally in the rocks and unconsolidated materials of the study area.

Median concentrations in river subsystems

Median concentrations of major inorganic constituents at locations along river subsystems are displayed in figures 67-72 (at back of report). All boxplots are based on detected concentrations only at each location, except for potassium and sodium, which include some estimated concentrations (see explanation at the beginning of the streambed-sediment-quality section). Two patterns are immediately evident. First, median concentrations of sodium, calcium, and magnesium followed similar trends along each river subsystem; median concentrations of each constituent are higher at UGS-8 and UGS-9 than at UGS-10 on the Mad River subsystem, and so forth for the rest of the locations on each subsystem. This similarity in pattern is especially evident in the median concentrations on the Lily Creek subsystem (figs. 72,73). Second, median concentrations of aluminum, iron, potassium, and possibly manganese along a subsystem indicate a trend opposite that of median concentrations of calcium, magnesium, and

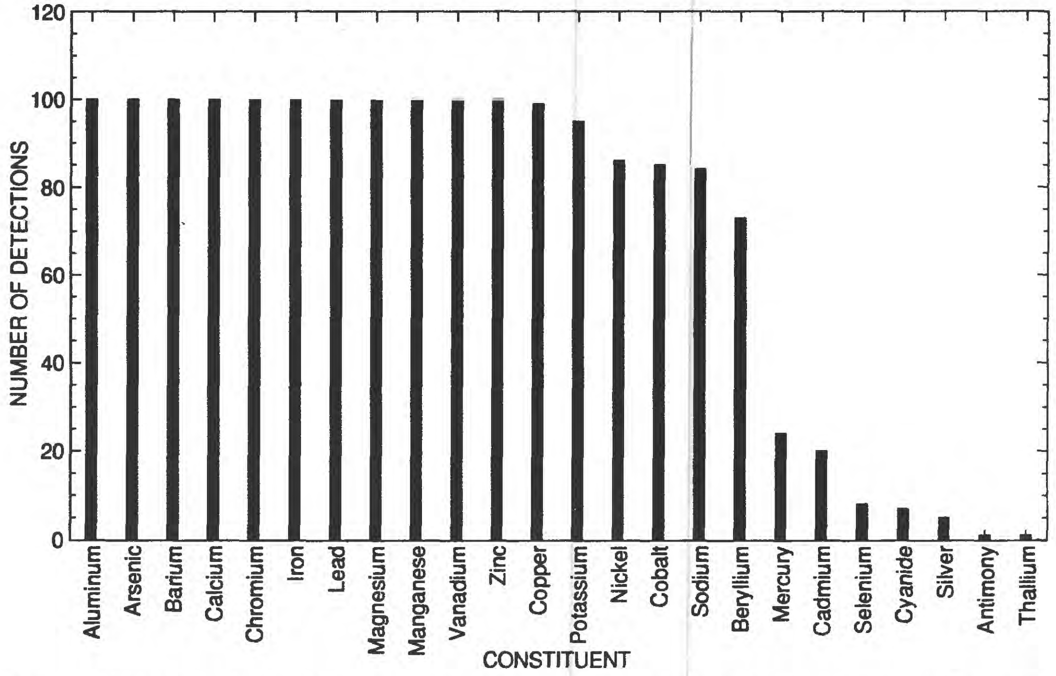


Figure 66. Detections of inorganic constituents in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base, Ohio.

sodium. Whereas concentrations of calcium, magnesium, and sodium were higher at UGS-8 and UGS-9 that at UGS-10, concentrations of aluminum, iron, potassium, and manganese were higher at UGS-10 than at UGS8 or UGS-9. These trends probably give some indication of the mineral composition of naturally-occurring sediments at each location.

On the Mad River subsystem, median concentrations of aluminum, iron, manganese, and potassium were highest at NPDES-6; median concentrations of magnesium and calcium were highest at UGS-9; and median concentration of sodium was highest at DGS-7. On the Hebble Creek subsystem, median concentrations of aluminum, iron, and potassium were highest at UGS-7; median concentration of manganese was highest at SW-1; median concentrations of magnesium and sodium were highest at UGS-5; and median concentration of calcium was highest at NPDES-12. On the Lily Creek subsystem, median concentrations of iron and potassium were highest at SW-30; median concentrations of calcium, magnesium, and sodium were highest at SW-28; median concentration of aluminum was highest at UGS-1; and median concentration of manganese was highest at UGS-2. Few metals were detected at the highest concentrations at the furthest downgradient location in each subsystem, indicating that concentrations at upgradient locations do not affect concentrations at downgradient locations.

The ranges of concentrations of all major inorganic constituents were greatest on the Mad River subsystem and smallest on the Lily Creek subsystem (except the range of manganese concentrations, which was smallest on Hebble Creek). The concentrations of calcium, for example, on the Mad River subsystem (fig. 68) have a wider range than those for Hebble Creek (fig. 70) and Lily Creek (fig. 72).

Two statistical parameters commonly used to indicate the variability of data are standard deviation and range. In an effort to quantify variability in concentrations for all major metals and barium, chromium, nickel, and zinc (discussed in Minor Inorganic Constituents), the range and standard deviation of concentrations for each metal were determined at each location and were divided by the median concentration to obtain a normalized variability factor for that metal at that location. (For example, the range of concentrations of aluminum at UGS-10 was 6,620 mg/kg; the standard deviation was 3,090 mg/kg; and the median was 8,845 mg/kg. Therefore, the normalized range for aluminum at UGS-10 was 6,620 / 8,845 = 0.75, and the normalized standard deviation was 3,090 / 8,845 = 0.35.) An average value of these normalized variability factors for all metals was computed at each location, and the results are presented in figure 73. Locations at which the normalized values were least, such as SW-28 and DGS-6, are those where the concentrations of the 11 metals were least variable. Low variability in the data from each location could result from several factors, including consistent presence of fine-grained material; consistent flow conditions that allow for deposition of fine-grained material; and little seasonal affect on the presence and (or) loading of metals. Variability was highest at UGS-9 and DGS-7. Factors that contribute to high variability include the rockiness of the streambed, where little fine-grained material is present, often due to relatively high flow velocities; streambeds free of obstructions, allowing no preferential deposition of fine-grained materials; and changes in the chemical composition of the streambed sediment from seasonal or other affects.

Extreme concentrations

One method of determining the possibilities of anthropogenic effects on the presence of metals in streambed sediment is to compare the percent distribution of concentrations with the percent distribution of locations. For example, 40 percent (10 of 25) of all locations are in the Mad River subsystem; 44 percent (11 of 25) in the Hebble Creek subsystem; and 20 percent (5 of 25) in the Lily Creek subsystem. (NPDES-4 is counted twice, once each in the Mad River and Hebble Creek subsystems, thereby resulting in the total percentage to exceed 100 percent.) The percent concentration of a metal (the sum of concentrations in a subgroup divided by the sum of concentrations in all groups) can be compared with these "location-distribution percentages" to determine whether concentrations of that metal are higher than expected at some locations. Natural distributions of metals in the sediments are not accounted for in this method, but it can be inferred that elevated concentrations of metals at a location could be from other than natural sources.

High concentrations of metals often were detected in samples from two locations in the Mad River subsystem, NPDES-5 and NPDES-6. Statistics for these two locations were generated separately because the percent concentration at these two locations frequently exceeded 20 percent, although they represent only 8 percent of all locations.

The distributions of major inorganic constituents among the three river subsystems and NPDES-5 and

NPDES-6 are listed in table 44. Aluminum concentrations at NPDES-5 and NPDES-6 contribute to the high percent concentration (61 percent) in the Mad River subsystem. Other metals, such as iron, manganese, and potassium, have percent concentrations slightly elevated in the Mad River subsystem. Calcium and sodium concentrations are distributed fairly evenly among subsystems.

The five highest concentrations of aluminum in streambed-sediment samples ranged from 15,800 to 13,100 mg/kg. Three of the five highest concentrations of aluminum were in samples from NPDES-6; the third and fourth highest concentrations of aluminum were in samples from NPDES-5 and DGS-5. The 17 highest concentrations of aluminum in streambed sediments were in samples obtained at locations in the Mad River subsystem.

The highest concentration of iron in streambed-sediment samples was 36,800 mg/kg at DGS-7; three of the next four highest concentrations

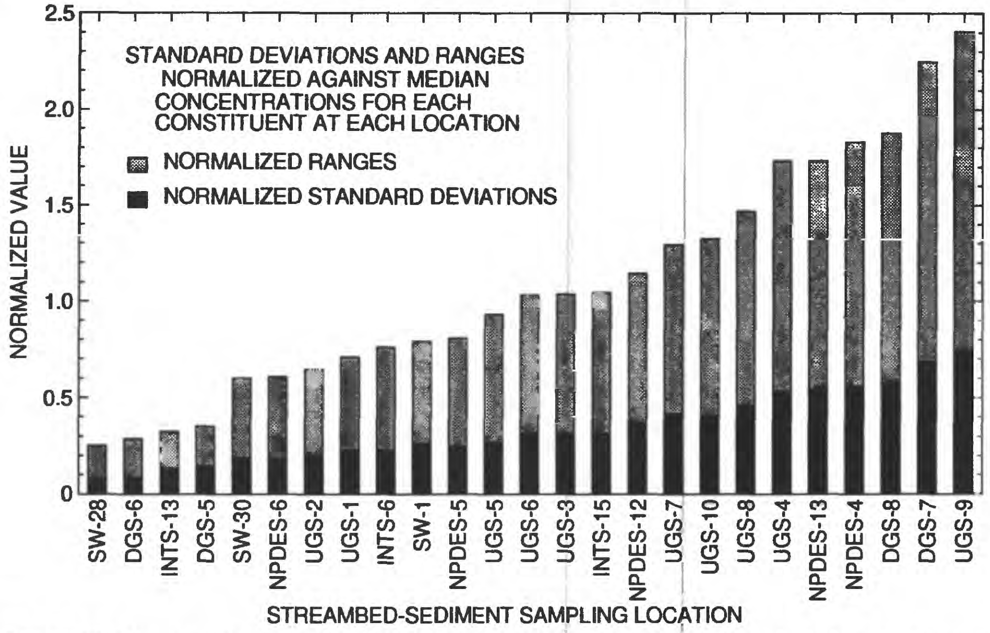


Figure 73. Normalized ranges and standard deviations of concentrations of selected inorganic constituents at streambed-sediment locations, all rounds, August 1993-September 1994, Wright-Patterson Air Force Base, Ohio. Constituents are aluminum, barium, calcium, chromium, iron, magnesium, manganese, nickel, potassium, sodium, and zinc.

Table 44. Distributions of concentrations of major inorganic constituents in streambed-sediment samples from river subsystems on Wright-Patterson Air Force Base, all rounds, August 1993–September 1994

[All concentrations are in milligrams per kilogram]

Metal	Sum of concentrations at NPDES-5 and NPDES-6	Percentage of total at NPDES-5 and NPDES-6	Sum of concentrations at all Mad River locations	Percentage of total at all Mad River locations	Sum of concentrations at Hebble Creek locations	Percentage of total at Hebble Creek locations	Sum of concentrations at Lily Creek locations	Percentage of total at Lily Creek locations
Aluminum	99,800	20	312,000	61	148,000	29	62,130	12
Calcium	691,000	6.3	4,390,000	40	4,710,000	43	2,150,000	20
Iron	172,000	14	596,000	47	508,000	40	204,000	16
Magnesium	159,000	4.4	1,280,000	35	1,700,000	47	775,000	21
Manganese	4,840	11	22,300	50	16,900	38	7,600	17
Potassium	12,400	17	39,100	53	26,700	36	10,200	14
Sodium	886	6.0	5,850	40	6,310	43	3,140	21

(30,700 to 26,000 mg/kg) were in samples from NPDES-6. Twelve of the highest 14 concentrations of iron were in samples obtained at locations in the Mad River subsystem; the other two were in samples from the Hebble Creek subsystem. Four of the eight highest concentrations of magnesium (84,000 to 59,400 mg/kg) were in samples from UGS-8 and UGS-9.

Five of the seven highest concentrations of manganese (2,240 to 997 mg/kg) were in samples from DGS-7 and NPDES-6. Two of the three highest concentrations of sodium (548 to 281 mg/kg) were in samples from UGS-7. Two of the three lowest concentrations of sodium (98 to 69 mg/kg) were in samples from NPDES-6. The three highest concentrations of potassium (2,040 to 1,830 mg/kg) were in samples from NPDES-6. Two of the three lowest concentrations of potassium (262 to 166 mg/kg) were in samples from DGS-8. Three of the eight lowest concentrations of calcium (64,400 to 50,600 mg/kg) were in samples from NPDES-6.

Minor Inorganic Constituents

Concentrations of barium, chromium (total), nickel, and zinc are discussed first in this section because they were discussed separately in the ground-water- and surface-water-quality sections. Concentrations of arsenic, cadmium, mercury, and lead are discussed second because of their relative importance to human health and ecology. The rest of the minor inorganic constituents are discussed last. As in the preceding section, percent distribution of concentrations are used to discuss the possibilities of anthropogenic affects on metals in streambed sediments.

Barium, chromium, nickel, and zinc

Median concentrations of barium, chromium, nickel, and zinc in the streambed sediments of the three river subsystems are shown in figures 74-76. Nickel was the only metal of these four that was not detected in every sample; for nondetections of nickel, estimated concentrations equal to one-half the actual reporting limit were included in the statistics.

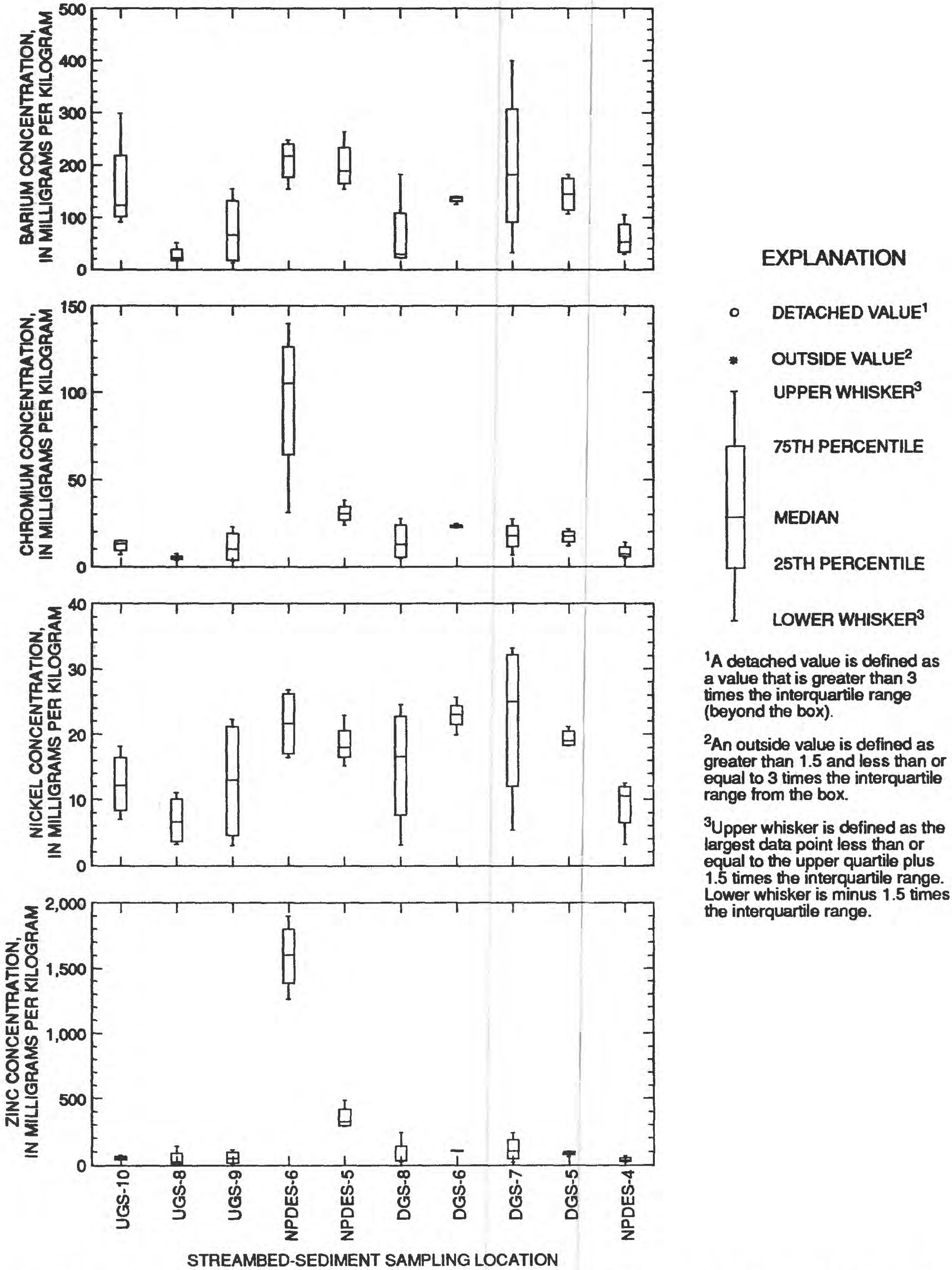
Median concentrations of barium, nickel, and chromium generally follow the same pattern discussed earlier for aluminum, iron, manganese, and potassium; that is, on the Mad River subsystem (fig. 74), median concentrations are higher at UGS-10, NPDES-6, and NPDES-5 than at UGS-8 and UGS-9. The pattern for zinc is similar to that for barium, chromium, and nickel in the Lily Creek subsystem (fig. 76), but is more difficult to see in the Mad River and Hebble Creek subsystems because of high median concentrations at NPDES-6 and UGS-7.

Concentrations of barium, chromium, nickel, and zinc at upgradient locations do not appear to affect concentrations at the most downgradient location. For example, concentrations at DGS-5 are lower than concentrations at most upgradient locations; and concentrations at NPDES-4 and SW-30 are slightly higher than or about the same as those at upgradient locations.

The distributions of barium, chromium, nickel and zinc concentrations are listed in table 45. More than 60 percent of all barium, chromium, and zinc were in samples from locations in the Mad River subsystem, which encompasses 40 percent of all locations. The amount of zinc found in samples from NPDES-5 and NPDES-6 was greater than the amount of zinc found in samples from all other locations combined; some of the zinc at those two locations probably was from anthropogenic sources. About a third of all chromium detected was in samples from NPDES-5 and NPDES-6, again indicating possible anthropogenic effects at those locations.

Twenty-two of the 24 highest concentrations of barium were detected in samples from the Mad River subsystem, including the highest recorded, 400 mg/kg, at DGS-7. The second and third highest concentrations of barium, 399 and 329 mg/kg, respectively, were in samples from INTS-15 in the Hebble Creek subsystem. These two high concentrations at INTS-15 possibly are due to anthropogenic effects; in samples from no other location on Hebble Creek were concentrations of barium greater than 120 mg/kg.
Four of the five highest concentrations of chromium detected (140 to 31.2 mg/kg) were in samples from NPDES-6; four of the 13 highest concentrations of chromium were detected in samples from NPDES-5. Seven of the 10 highest concentrations of nickel (98 to 23 mg/kg) were in samples from DGS-7, DGS-6, and NPDES-6. All but one (32 mg/kg at INTS-15) of the highest 14 concentrations of nickel were in samples from locations in the Mad River subsystem.

All four of the highest concentrations of zinc (1,900 mg/kg to 1,260 mg/kg) were detected in samples from NPDES-6. Four of the next five highest concentrations of zinc (486 to 289 mg/kg) were in samples from NPDES-5. Four of the five lowest concentrations of zinc (10.5 to 17.4 mg/kg) were in samples from UGS-8 and UGS-9.

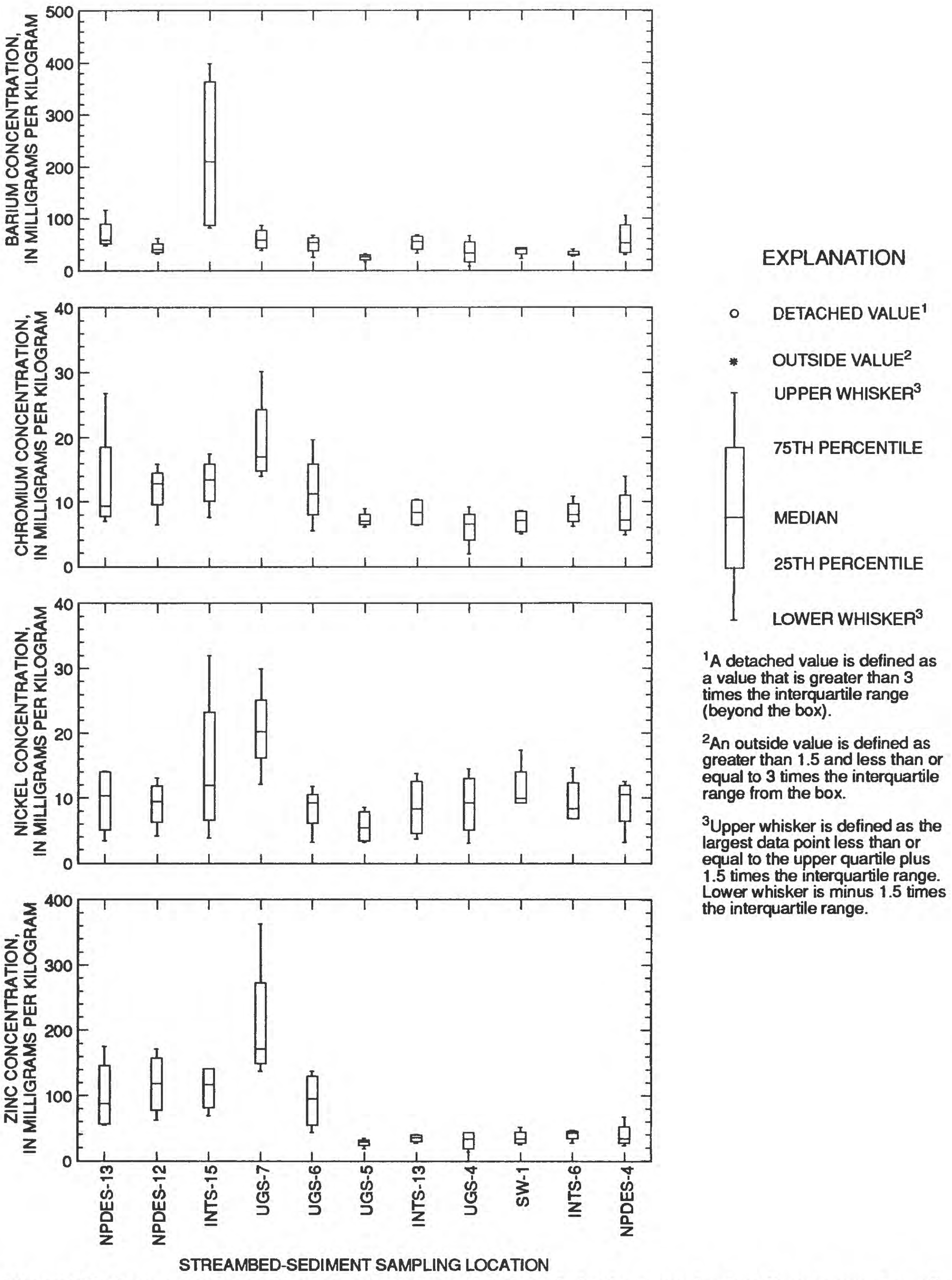


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 74. Concentrations of barium, chromium, nickel, and zinc in streambed-sediment samples, all rounds, August 1993-September 1994, in the Mad River subsystem, Wright-Patterson Air Force Base, Ohio.

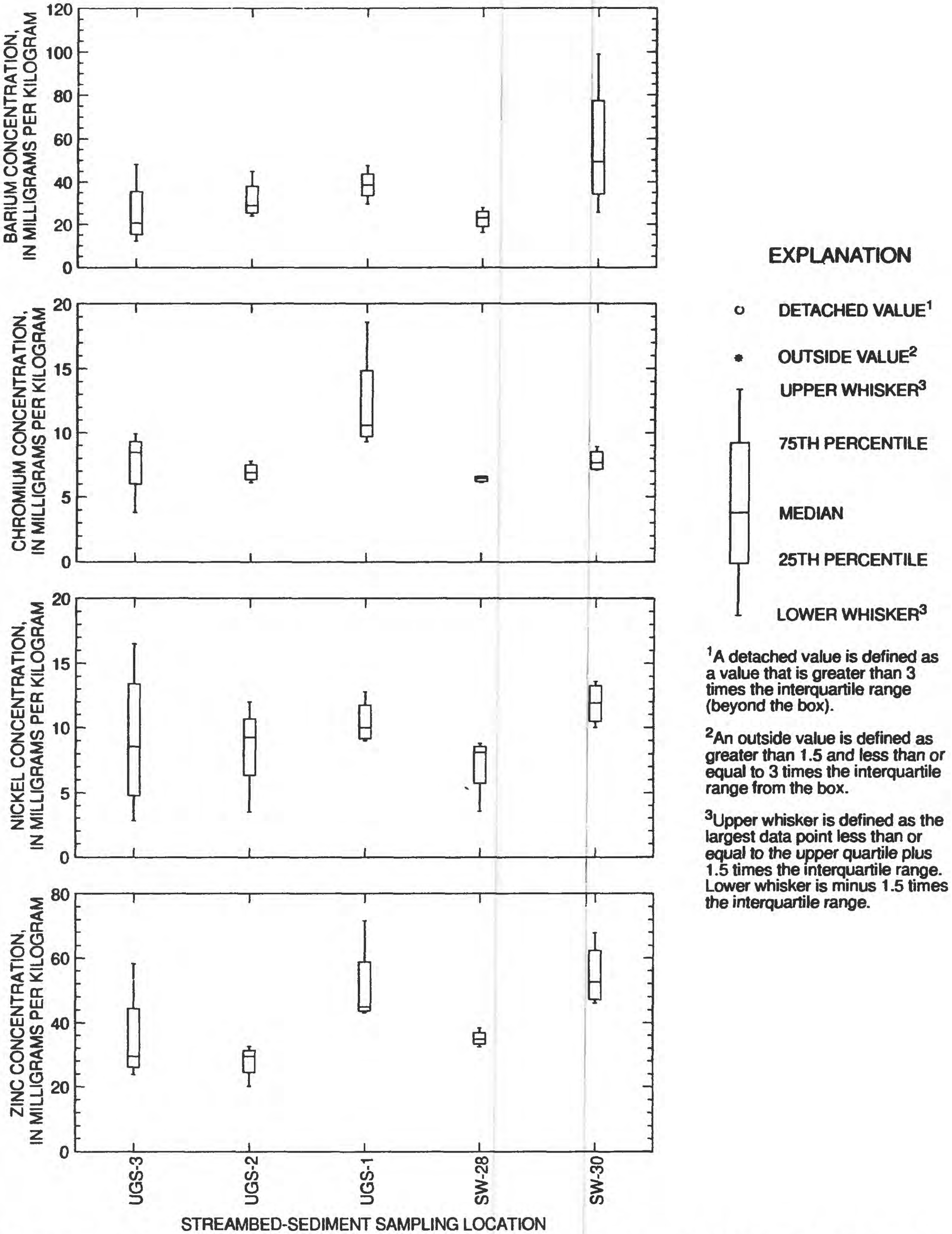


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 75. Concentrations of barium, chromium, nickel, and zinc in streambed-sediment samples, all rounds, August 1993-September 1994, in the Hebble Creek subsystem, Wright-Patterson Air Force Base, Ohio.



[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 76. Concentrations of barium, chromium, nickel, and zinc in streambed-sediment samples, all rounds, August 1993–September 1994, in the Lily Creek subsystem, Wright-Patterson Air Force Base, Ohio.

Arsenic, cadmium, lead, and mercury

In 1992, OEPA sampled 21 locations on Mad River and some of its tributaries, including Hebble and Trout Creeks (Counts and Altfater, 1994) (see discussion in Surface-Water Quality section). Concentrations were assessed qualitatively according to a ranking system devised by Kelly and Hite (1984). According to this ranking system, concentrations of arsenic, cadmium, and mercury were considered "elevated" at 11 mg/kg, 1.0 mg/kg, and 0.1 mg/kg, respectively. Concentrations were considered "highly elevated" at 63 mg/kg for lead and were "extremely elevated" at 0.37 mg/kg for mercury. Two of the locations at which the OEPA detected metals at "elevated" concentrations were INTS-13 and DGS-6; other BMP locations that were sampled by OEPA did not have elevated levels of these metals in the OEPA samples.

During the BMP, arsenic, cadmium, mercury, and lead were detected many times at concentrations approaching or exceeding levels described as "elevated" by OEPA at locations throughout WPAFB (table 46 at back of report). Concentrations of arsenic measured during the BMP exceeded "elevated" levels 6 times; cadmium 17 times; mercury 20 times; and lead 19 times. Most frequent detections of concentrations attaining "elevated" levels were at NPDES-5 and NPDES-6. All four constituents were found at "elevated" levels at DGS-7.

The sums of concentrations of arsenic, cadmium, mercury, and lead in samples from each location during each sampling round are presented in figure 77. Most of the highest concentrations at each location were detected in round 3; high concentrations were detected in samples from SW-30 during round 1. Samples from many of the upgradient locations in rural areas (UGS-10, UGS-9, and UGS-8 on Mad River; SW-1 on Hebble Creek; and UGS-3 and UGS-2 on Lily Creek) contained appreciably lower concentrations of these metals than samples from upgradient locations in urban areas (NPDES-13, NPDES-12, UGS-7, and UGS-6 on Hebble Creek, and UGS-1 on Lily Creek).

Concentrations of arsenic, cadmium, mercury, and lead in samples from downgradient locations on Mad River and Lily Creek were higher than in those from upgradient locations, possibly indicating some contribution of these four metals to the river systems across WPAFB. On Hebble Creek, concentrations of arsenic, cadmium, mercury and lead were lower in samples from downgradient locations than in samples from upgradient locations.

Because of the low concentrations of arsenic, cadmium, mercury, and lead detected at UGS-10, UGS-9, UGS-8, UGS-5, UGS-4, SW-1, UGS-3, and UGS-2, samples from these locations can be used to estimate background concentrations of these metals. Median concentrations at these locations were 5.6 mg/kg for arsenic, 0.24 mg/kg for cadmium, 0.04 mg/kg for mercury, and 6.9 mg/kg for lead.

Other inorganic constituents

Percent distribution of concentrations of selected inorganic constituents are shown in table 48. Nearly all of the antimony, selenium, and thallium was detected in samples from the Mad River subsystem, but because detections were relatively few, the distribution percentages for these three metals probably are misleading. Over one third of all copper was found in

Table 45. Distributions of barium, chromium, nickel, and zinc concentrations in streambed-sediment samples from river subsystems on Wright-Patterson Air Force Base, all rounds, August 1993–September 1994

[All concentrations in milligrams per kilogram]

Metal	Sum of concentrations at NPDES-5 and NPDES-6	Percentage of total at NPDES-5 and NPDES-6	Sum of concentrations at all Mad River locations	Percentage of total at all Mad River locations	Sum of concentrations at Hebble Creek locations	Percentage of total at Hebble Creek locations	Sum of concentrations at Lily Creek locations	Percentage of total at Lily Creek locations
Barium	1,630	20	5,100	61	2,750	33	696	8.4
Chromium	504	33	941	61	460	30	164	11
Nickel	161	13	632	52	438	36	178	15
Zinc	7,790	55	10,100	71	3,370	24	817	5.8

samples from NPDES-5 and NPDES-6, indicating some anthropogenic contribution. Distributions of beryllium, cobalt, and vanadium concentrations are consistent with distributions of locations among the three river subsystems.

Sums of concentrations of these eight metals during the four sampling rounds at each location are shown in figure 78. Samples from most locations on Lily and Hebble Creeks had about the same concentrations during each round, except for UGS-7 and perhaps UGS-6 on Hebble Creek. Samples from these two locations had about 25 percent more of these metals than samples from other locations on Hebble and Lily Creeks. Concentrations in samples from interior and downgradient locations on Mad River, especially NPDES-5 and NPDES-6, are appreciably higher than those in samples from upgradient locations. Median concentrations at the eight "background" locations listed in the section above were: 0.33 mg/kg for silver, 0.22 mg/kg for beryllium, 2.9 mg/kg for cobalt, 7.4 mg/kg for copper, 3.6 mg/kg for antimony, 0.40 mg/kg for selenium, 0.29 mg/kg for thallium, and 11.4 mg/kg for vanadium.

Organic Constituents

Organic compounds included in the analyte list for streambed sediment include VOCs, SVOCs,

Table 47. Distributions of arsenic, cadmium, mercury, and lead concentrations in streambed-sediment samples from river subsystems on Wright-Patterson Air Force Base, all rounds, August 1993–September 1994

[All concentrations in milligrams per kilogram]

Metal	Sum of concentrations at NPDES-5 and NPDES-6	Percentage of total at NPDES-5 and NPDES-6	Sum of concentrations at Mad River locations	Percentage of total at Mad River locations	Sum of concentrations at Hebble Creek locations	Percentage of total at Hebble Creek locations	Sum of concentrations at Lily Creek locations	Percentage of total at Lily Creek locations
Arsenic	55.0	9	251.0	43	253.0	43	104.0	18
Cadmium	66.0	74	79.3	89	10.1	11	0.0	0
Mercury	1.9	43	3.1	71	1.3	29	0.0	0
Lead	2,890.0	49	3,910.0	66	1,640.0	28	377.0	6

Table 48. Distributions of concentrations of selected minor inorganic constituents in streambed-sediment samples from river subsystems on Wright-Patterson Air Force Base, all rounds, August 1993–September 1994

[All concentrations in milligrams per kilogram]

Metal	Sum of concentrations at NPDES-5 and NPDES-6	Percentage of total at NPDES-5 and NPDES-6	Sum of concentrations at Mad River locations	Percentage of total at Mad River locations	Sum of concentrations at Hebble Creek locations	Percentage of total at Hebble Creek locations	Sum of concentrations at Lily Creek locations	Percentage of total at Lily Creek locations
Antimony	0.0	0	4.2	100	0.0	0	0.0	0
Beryllium	4.2	15	14.5	53	9.0	33	4.6	17
Cobalt	59.7	15	179.0	45	161.0	41	72.9	18
Copper	605.0	34	1,110.0	62	548.0	31	162.0	9
Selenium	4.3	22	18.7	97	0.0	0	0.5	3
Silver	1.6	23	4.1	58	4.15	59	0.0	0
Thallium	0.0	0	0.8	100	0.0	0	0.0	0
Vanadium	205.0	14	722.0	49	570.0	39	231.0	16

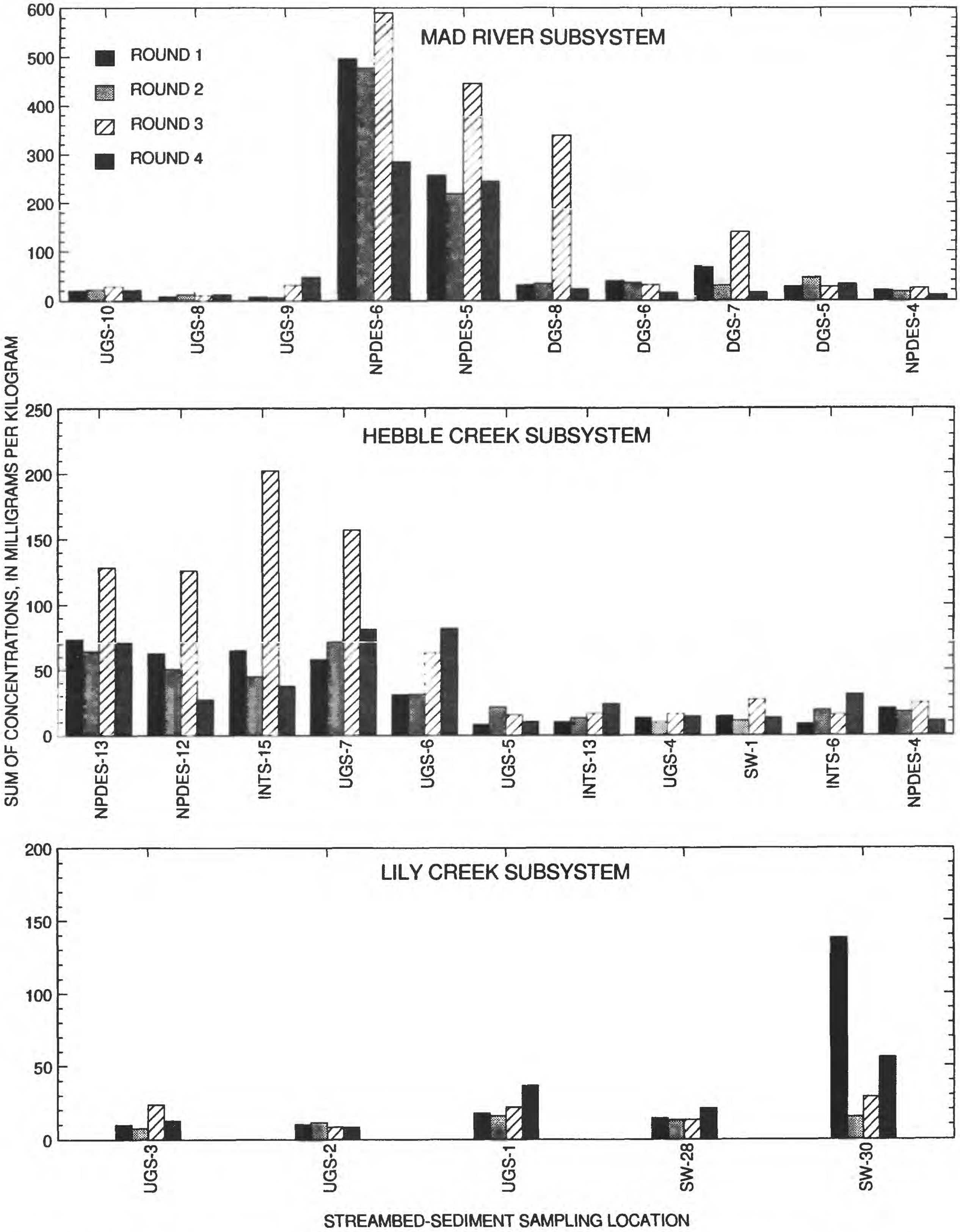


Figure 77. Sums of concentrations of arsenic, cadmium, mercury, and lead in streambed-sediment samples, all rounds, August 1993–September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio.

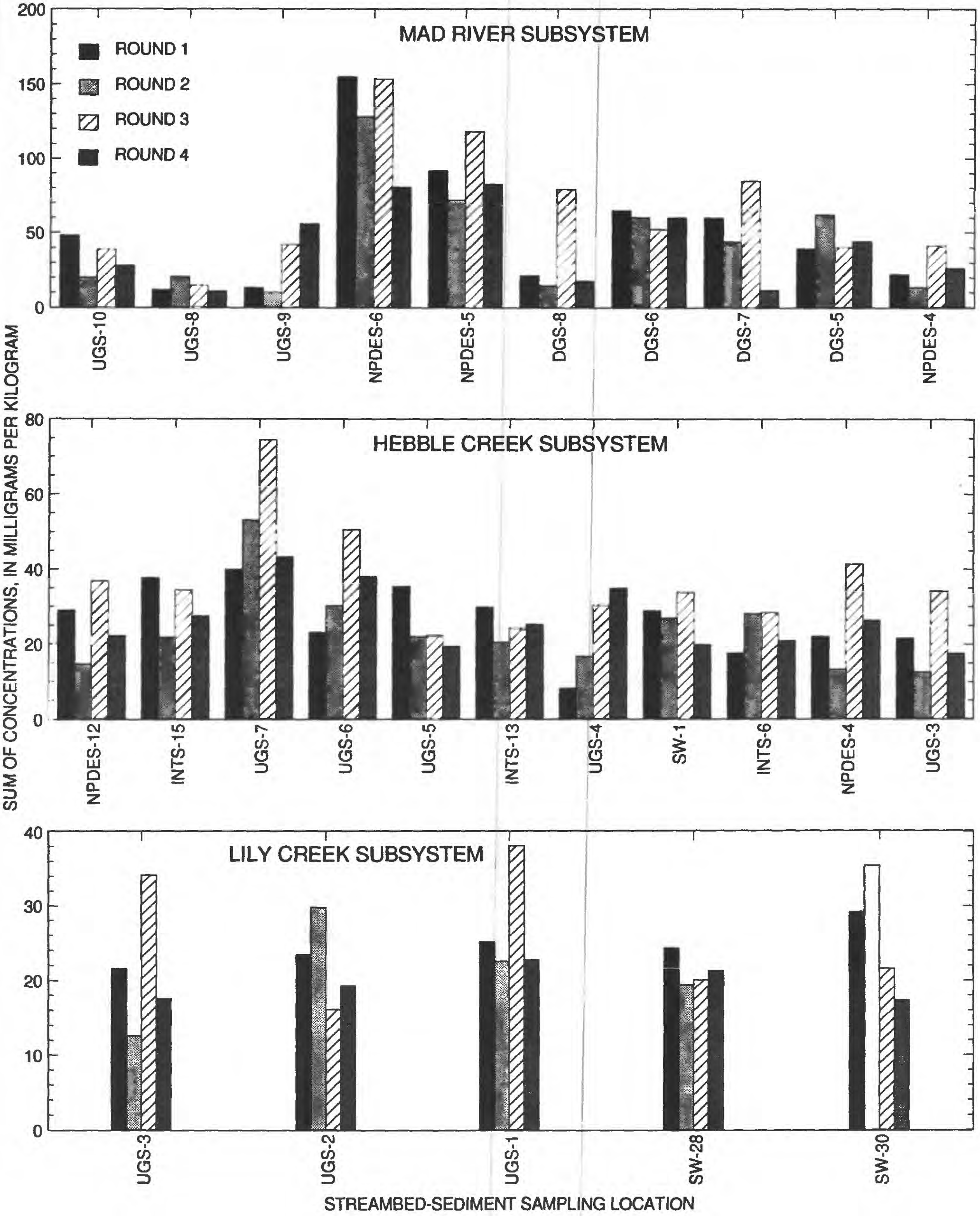


Figure 78. Sums of concentrations of selected minor inorganic constituents in streambed-sediment samples, all rounds, August 1993–September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio. Constituents are antimony, beryllium, cobalt, copper, selenium, vanadium, silver, and thallium.

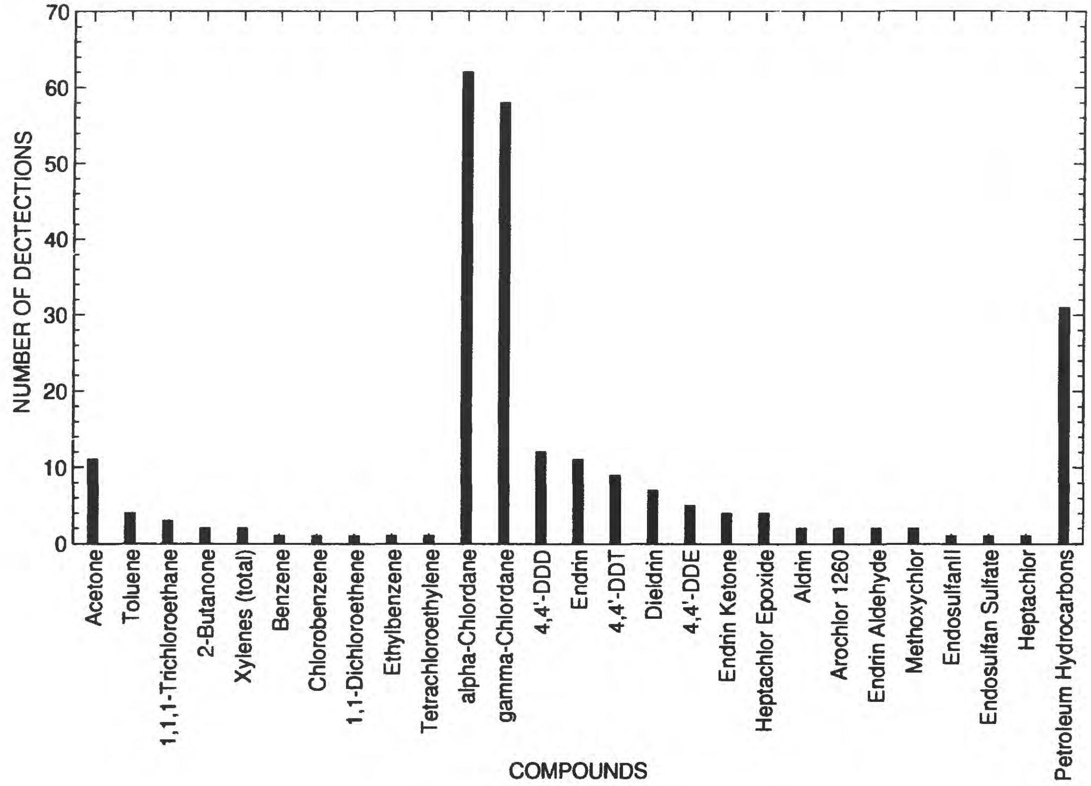


Figure 79. Detections of selected organic compounds in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base,Ohio.

pesticides and PCBs, chlorinated herbicides, and petroleum hydrocarbons (TPH). The analysis for chlorinated herbicides was dropped after round 3, and TPH analysis was discontinued after round 2.

Quality Control and Data Validation

Quality-assurance objectives regarding the accuracy, precision, representativeness, comparability, and completeness of the inorganic data collected in each of the four sampling rounds generally were met. Low concentrations of common laboratory contaminant compounds, such as methylene chloride, acetone, 2-butanone, and 2-methyl-2-pentanone, were detected in streambed-sediment method blanks during all four rounds. Most pesticide concentrations in round 1 and all pesticide concentrations in round 3 were estimated (J) due to minor holding-time exceedances.

Frequency of Detection of Organic Compounds

Histograms of organic-compound detections in streambed-sediment samples are shown in figures 79 and 80. The number of compounds detected in each analyte group, from largest to smallest, were: SVOCs, 28; pesticides, 15; and VOCs, 10. Petroleum hydrocarbons also were detected (31 samples), as was one PCB. No chlorinated herbicides were detected.

VOCs that were detected (not including the laboratory contaminants listed above) were 1,1,1-trichlorethene, total xylenes, benzene, chlorobenzene, 1,1-dichloroethene, tetrachloroethylene (PCE), and toluene. Most of the detections of VOCs in streambed-sediment samples were in round 1, including 1,1,1-trichlorethene at NPDES-5, NPDES-6, and UGS-7; total xylenes at NPDES-6 and UGS-7; 1,1-dichloroethene and PCE at NPDES-6; and toluene at UGS-7 and NPDES-6. Toluene also was detected during round 3 in a sample from DGS-8, and benzene and chlorobenzene were detected during round 4 in a sample from UGS-1.

Eleven of the SVOCs were detected in at least half of the streambed-sediment samples. The most commonly detected SVOCs were polycyclic aromatic hydrocarbons (PAHs), including fluoranthene and pyrene (85 samples), benzo(b) fluoranthene

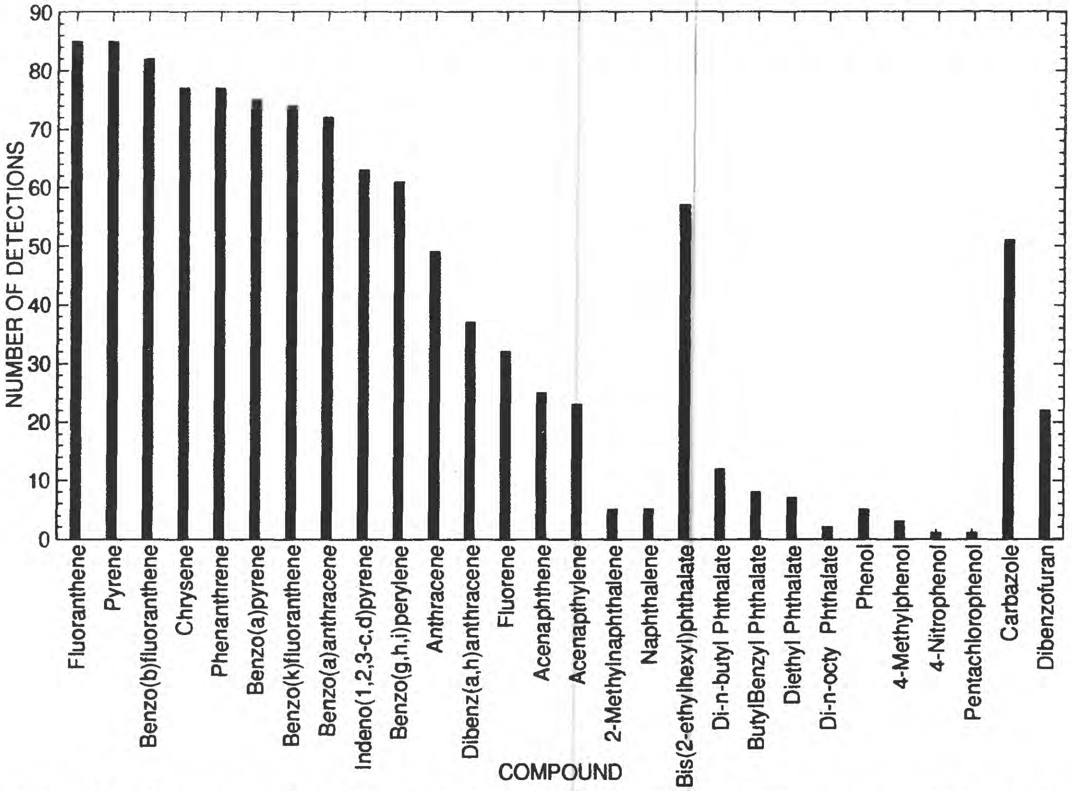


Figure 80. Detections of semivolatile organic compounds in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base, Ohio.

(82 samples), chrysene (77 samples), phenanthrene (77 samples), and benzo(a)pyrene (75 samples).

The only pesticides detected in more than half the samples were alpha-chlordane (62 samples) and gamma-chlordane (58 samples). Others that were detected in more than 5 samples include 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, endrin, and dieldrin.

Volatile Organic Compounds

Excluding the laboratory contaminants mentioned previously, VOCs were detected most frequently in samples from NPDES-6 and UGS-7. The two highest concentrations, 22J and 14 µg/kg, were of 1,1,1-trichloroethane, detected during round 1 in samples from NPDES-6 and UGS-7, respectively. All VOC concentrations detected during the BMP are presented in table 49. Generally, VOCs were neither widespread nor highly concentrated in streambed sediments at WPAFB.

Semivolatile Organic Compounds

Many of the SVOCs were detected in each of the four rounds, although not in every sample. SVOCs were detected at every streambed-sediment location on WPAFB. Most of the SVOCs included in the BMP analyte list are classified as polycyclic aromatic hydrocarbons (PAHs), phthalates, or phenols. Discussion of SVOCs detected in streambed sediments will focus on each SVOC group.

The 26 highest concentrations of PAHs detected, all exceeding 20,000 µg/kg, are listed in table 50. All were detected in samples from seven locations in Areas A and C: DGS-7 (four detections from this list), INTS-15 (five detections), NPDES-12 (one detection), NPDES-13 (four detections), NPDES-5 (six detections), UGS-6 (one detection), and UGS-7 (five detections). Of these, the 20 highest concentrations (57,000 to 22,000 µg/kg) were of fluoranthene, pyrene, benzo(b) fluoranthene, chrysene, and phenanthrene, and 15 were detected during round 3. Another PAH, benzo(a)pyrene, was detected in 75 samples at concentrations ranging from 19,000 (at UGS-7) to 36 (at UGS-4) µg/kg.

Table 49. Detections of volatile organic compounds in streambed-sediment samples at Wright-Patterson Air Force Base, all rounds, August 1993–September 1994

[All concentrations in micrograms per kilogram; J, estimated concentration; --, not applicable]

Location	Sample round	Volatile organic compound	Concentration	Qualifier
DGS-5	4	Acetone	50.0	J
DGS-7	1	Acetone	9.0	J
DGS-7	1	2-Butanone	2.5	J
DGS-7	4	Toluene	2.0	J
DGS-8	4	Acetone	2.0	J
INTS-15	1	Acetone	7.0	J
NPDES-12	2	Acetone	6.0	J
NPDES-13	4	Acetone	3.0	J
NPDES-5	1	1,1,1-Trichloroethane	9.0	J
NPDES-6	1	Toluene	2.0	J
NPDES-6	1	1,1-Dichloroethene	1.0	J
NPDES-6	1	Ethylbenzene	1.0	J
NPDES-6	1	Tetrachloroethylene	1.0	J
NPDES-6	1	1,1,1-Trichloroethane	22.0	J
NPDES-6	1	Xylenes	3.0	J
SW-28	2	Acetone	7.0	J
SW-30	2	Acetone	2.0	J
UGS-1	1	Acetone	190.0	J
UGS-1	2	Acetone	8.0	J
UGS-1	4	Benzene	1.0	J
UGS-1	4	Chlorobenzene	1.0	J
UGS-10	3	2-Butanone	9.2	J
UGS-7	1	Toluene	5.0	J
UGS-7	1	1,1,1-Trichloroethane	14.0	--
UGS-7	1	Xylenes	2.0	J
UGS-8	4	Acetone	3.0	J
UGS-9	3	Toluene	7.0	J

The sums of concentrations of detected PAHs in samples from locations on each river subsystem are shown in figure 81. Highest concentrations during round 1 were found in samples from NPDES-5 and NPDES-13; during round 2 in samples from DGS-7 and UGS-6; and during round 3 in samples from INTS-15, UGS-7, and NPDES-13. Samples from 7 of the 25 locations contained concentrations exceeding 100,000 µg/kg (summed) during at least one sampling round. Most of the locations at which high concentrations of PAHs were detected were upgradient in the Hebble Creek subsystem; downgradient locations, except for SW-30 in the Lily Creek subsystem, mostly were unaffected by PAHs.

Phthalates were detected at every location except UGS-4 and SW-28; the highest 23 concentrations and their associated locations (all in Areas A and C) is presented in table 51. Bis(2-ethylhexyl) was the most commonly detected phthalate (57 samples); the second most frequently detected phthalate was di-n-butyl, detected in 12 samples. Detections of phthalates in streambed-sediment samples was inversely

Table 50. Highest concentrations of polycyclic aromatic hydrocarbons in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in micrograms per kilogram; J, estimated; -- not applicable]

Location	Sample round	Polycyclic aromatic hydrocarbon	Concentration	Qualifier
DGS-7	2	Fluoranthene	57,000	--
DGS-7	2	Phenanthrene	39,000	--
INTS-15	3	Pyrene	35,000	J
INTS-15	3	Fluoranthene	34,000	J
UGS-7	3	Benzo(b)fluoranthene	34,000	--
UGS-7	3	Pyrene	34,000	--
NPDES-5	1	Fluoranthene	32,000	--
INTS-15	3	Benzo(b)fluoranthene	30,000	J
INTS-15	3	Phenanthrene	30,000	J
UGS-7	3	Fluoranthene	30,000	--
DGS-7	2	Pyrene	30,000	--
NPDES-5	1	Pyrene	29,000	J
NPDES-13	3	Fluoranthene	28,000	--
NPDES-13	3	Pyrene	28,000	--
NPDES-5	4	Fluoranthene	27,000	--
NPDES-13	3	Benzo(b)fluoranthene	26,000	--
UGS-7	3	Phenanthrene	25,000	--
NPDES-5	4	Pyrene	25,000	--
NPDES-5	1	Phenanthrene	24,000	--
DGS-7	2	Benzo(b)fluoranthene	23,000	--
INTS-15	3	Benzo(a)anthracene	22,000	--
NPDES-5	1	Benzo(b)fluoranthene	22,000	--
UGS-7	3	Chrysene	21,000	--
UGS-6	2	Fluoranthene	21,000	--
NPDES-12	3	Fluoranthene	21,000	--
NPDES-13	3	Phenanthrene	21,000	--

proportional to their solubilities in water; dimethyl (which was not detected in any sample), diethyl, and di-n-butyl phthalates are most soluble, whereas benzyl butyl and bis(2-ethylhexyl) phthalates are least soluble in water (Smith and others, 1988). Benzyl butyl and di-n-octyl phthalates were detected once and not at all, respectively, in samples from Area B, whereas di-n-octyl and diethyl phthalates were detected twice and not at all, respectively, in samples from Areas A and C.

During round 4 sampling, butyl benzyl phthalate was detected at a concentration of 90,000 µg/kg at NPDES-5. This was the only detection of butyl benzyl phthalate at that location in any of the sampling rounds, and was almost 40 times larger than any other detection of butyl benzyl phthalate. The cause of this high concentration is unknown.

Counts and Altfater (1994) found PAHs at INTS-13 and phthalates at DGS-7. They detected PAHs at INTS-13 at higher concentrations than any found at that location during the BMP. In contrast,

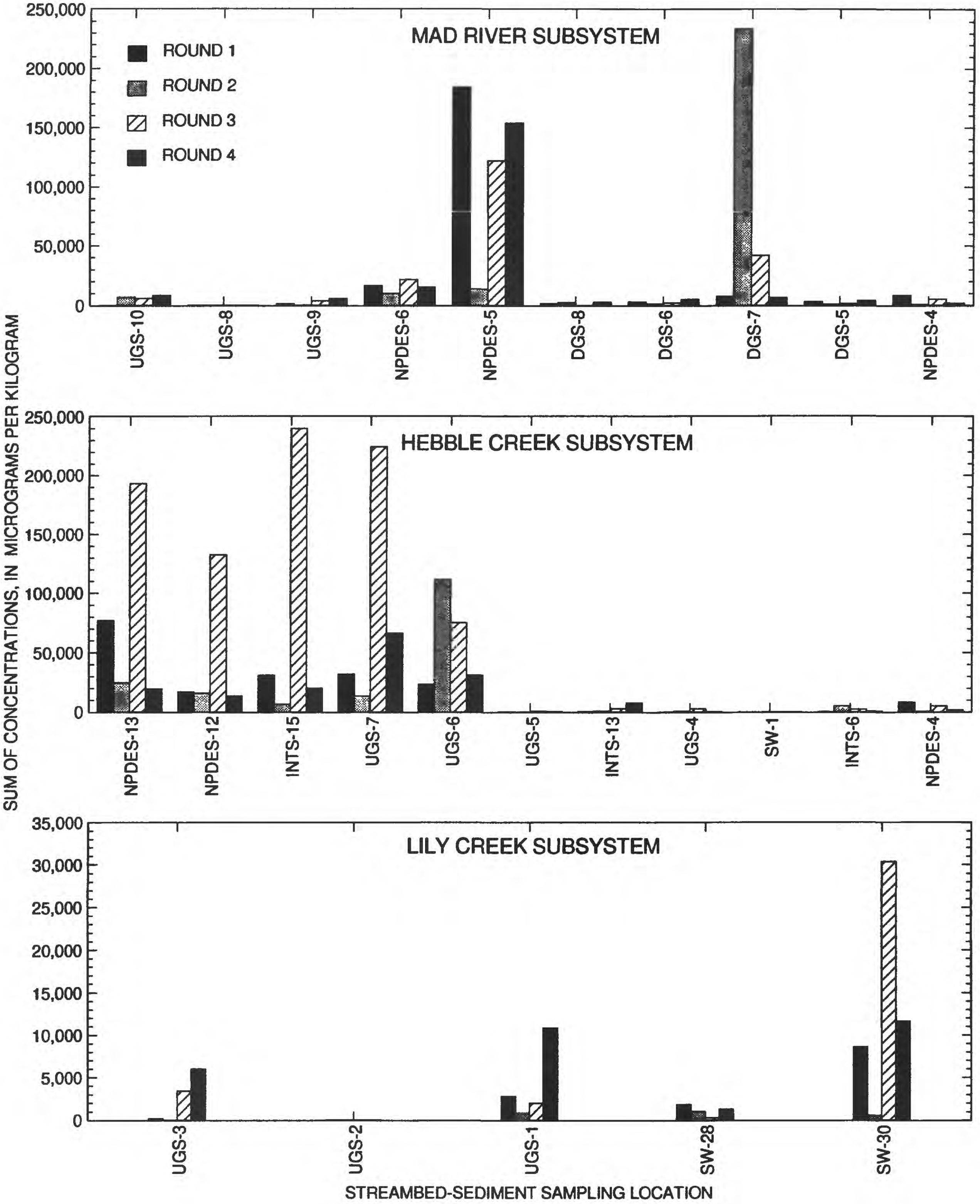


Figure 81. Sums of concentrations of polycyclic aromatic hydrocarbons in streambed-sediment samples, August 1993–September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio.

Table 51. Highest concentrations of phthalate esters in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in micrograms per kilogram; J, estimated, -- not applicable]

Location	Sample round	Semivolatile organic compound	Concentration	Qualifier
NPDES-5	4	Butyl benzyl phthalate	90,000	--
UGS-7	3	Bis(2-ethylhexyl)phthalate	4,900	--
NPDES-13	3	Bis(2-ethylhexyl)phthalate	3,000	J
NPDES-12	3	Di-n-octyl phthalate	2,600	J
NPDES-5	4	Bis(2-ethylhexyl)phthalate	2,600	J
UGS-7	3	Butyl benzyl phthalate	2,300	J
NPDES-5	1	Bis(2-ethylhexyl)phthalate	1,900	J
NPDES-12	3	Bis(2-ethylhexyl)phthalate	1,900	J
NPDES-5	3	Bis(2-ethylhexyl)phthalate	1,800	J
INTS-15	3	Bis(2-ethylhexyl)phthalate	1,500	J
UGS-9	3	Bis(2-ethylhexyl)phthalate	1,300	J
UGS-6	3	Bis(2-ethylhexyl)phthalate	1,200	J
UGS-7	4	Bis(2-ethylhexyl)phthalate	1,200	J
NPDES-6	3	Bis(2-ethylhexyl)phthalate	810	J
NPDES-12	1	Bis(2-ethylhexyl)phthalate	660	J
INTS-15	1	Bis(2-ethylhexyl)phthalate	640	J
UGS-9	4	Bis(2-ethylhexyl)phthalate	620	J
DGS-7	3	Bis(2-ethylhexyl)phthalate	600	J
INTS-6	4	Di-n-butyl phthalate	550	--
NPDES-13	3	Butyl benzyl phthalate	540	J
UGS-6	1	Bis(2-ethylhexyl)phthalate	510	J
NPDES-13	2	Bis(2-ethylhexyl)phthalate	440	J
NPDES-12	3	Butyl benzyl phthalate	400	J

bis(2-ethylhexyl) phthalate was detected twice at INTS-13 during the BMP, but Counts and Altfater did not find any phthalates at that location. They found no PAHs at DGS-7, whereas PAHs were found at DGS-7 during the BMP at concentrations higher than they were at INTS-13. Concentrations of phthalates found at DGS-7 by Counts and Altfater were similar to those found at that location during the BMP. Differences in antecedent conditions, streambed characteristics, or sampling methods possibly can account for these differences.

Summed concentrations of phthalates during each round at locations in each river subsystem are presented in figure 82. The highest concentrations of phthalates were at the same locations as the highest concentrations of PAHs (fig. 81), with minor exceptions. Lily Creek and the downgradient locations on Hebble Creek were mostly unaffected by phthalate contamination, whereas upgradient locations on Hebble Creek and the interior locations on Mad River were affected by phthalate contamination. At most locations, highest concentrations of phthalates were detected during round 3.

Four phenols were detected in samples from streambed sediments (table 52). Concentrations of detected phenols ranged from 2,700 µg/kg at INTS-15 to 59J µg/kg at SW-30. The only phenolic compound detected more than once in samples from one location was 4-methylphenol, detected twice in samples from INTS-15.

Two other SVOCs, carbazole and dibenzofuran, were detected in streambed-sediment samples from WPAFB. The 25 highest concentrations of these compounds are presented in table 53; all were in samples from locations in Areas A and C, and all were estimated (J). Almost half of the highest concentrations were detected during sample round 3.

Organochlorine Pesticides and Polychlorinated Biphenyls

Pesticides were not detected at UGS-2, UGS-3, UGS-5, UGS-8, UGS-10, and SW-1, and were detected only once at DGS-5 and UGS-9. Highest concentrations of the chlordanes, which were the most frequently detected of all pesticides, were at NPDES-5, NPDES-13, and UGS-7 in Areas A and C (table 54). Most pesticides were detected during round 3. Only four detections were at concentrations greater than 50 µg/kg, all at NPDES-5.

Highest concentrations of other detected pesticides are listed in table 55 at back of report. Almost all of the highest concentrations of pesticides were detected in samples during round 3. Highest concentrations of 4,4'-DDT, 4,4'-DDE, and 4,4'-DDD were in samples from NPDES-5. Endrin was detected in samples only from Areas A and C.

Sums of pesticide concentrations detected during each round in samples from locations on river subsystems are presented in figure 83, and areal distributions of sums of pesticide concentrations are shown in figure 84. Nearly all highest concentrations were found during round 3. Only samples from NPDES-5 and NPDES-6 contained summed concentrations exceeding 20 µg/kg in any round other than round 3. Rural upgradient locations (UGS-10, UGS-9, and UGS-8 on Mad River; SW-1 on Hebble Creek; and UGS-3 and UGS-2 on Lily Creek) contained almost no detectable quantities of pesticides during the BMP, whereas urban upgradient locations (NPDES-12, NPDES-13, UGS-7, and UGS-6 on Hebble Creek, and UGS-1 on Lily Creek) contained detectable quantities.

Arochlor 1260, a polychlorinated biphenyl (PCB), was detected twice at NPDES-6, with concentrations of 530J and 190J µg/kg. No other PCBs were detected in streambed sediment.

Chlorinated Herbicides

No herbicides were detected in streambed sediments. Included in the analyte list for herbicides were 2,4,5-T, 2,4-D, 2,4-DB, dalapon, dichloroprop, dicamba, dinoseb, MCPA, MCPP, and 2,4,5-TP (Silvex).

Table 52. Detections of phenolic compounds in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in micrograms per kilogram; J, estimated; -- not applicable]

Location	Sample round	Phenolic compound	Concentration	Qualifier
INTS-15	1	4-Methylphenol	2,700	--
INTS-15	3	Phenol	540	J
INTS-15	3	4-Methylphenol	480	J
UGS-9	3	4-Methylphenol	230	J
DGS-7	1	Phenol	150	J
DGS-7	4	Pentachlorophenol	87	J
DGS-6	3	Phenol	87	J
UGS-10	1	Phenol	84	J
DGS-7	4	4-Nitrophenol	60	J
SW-30	1	Phenol	59	J

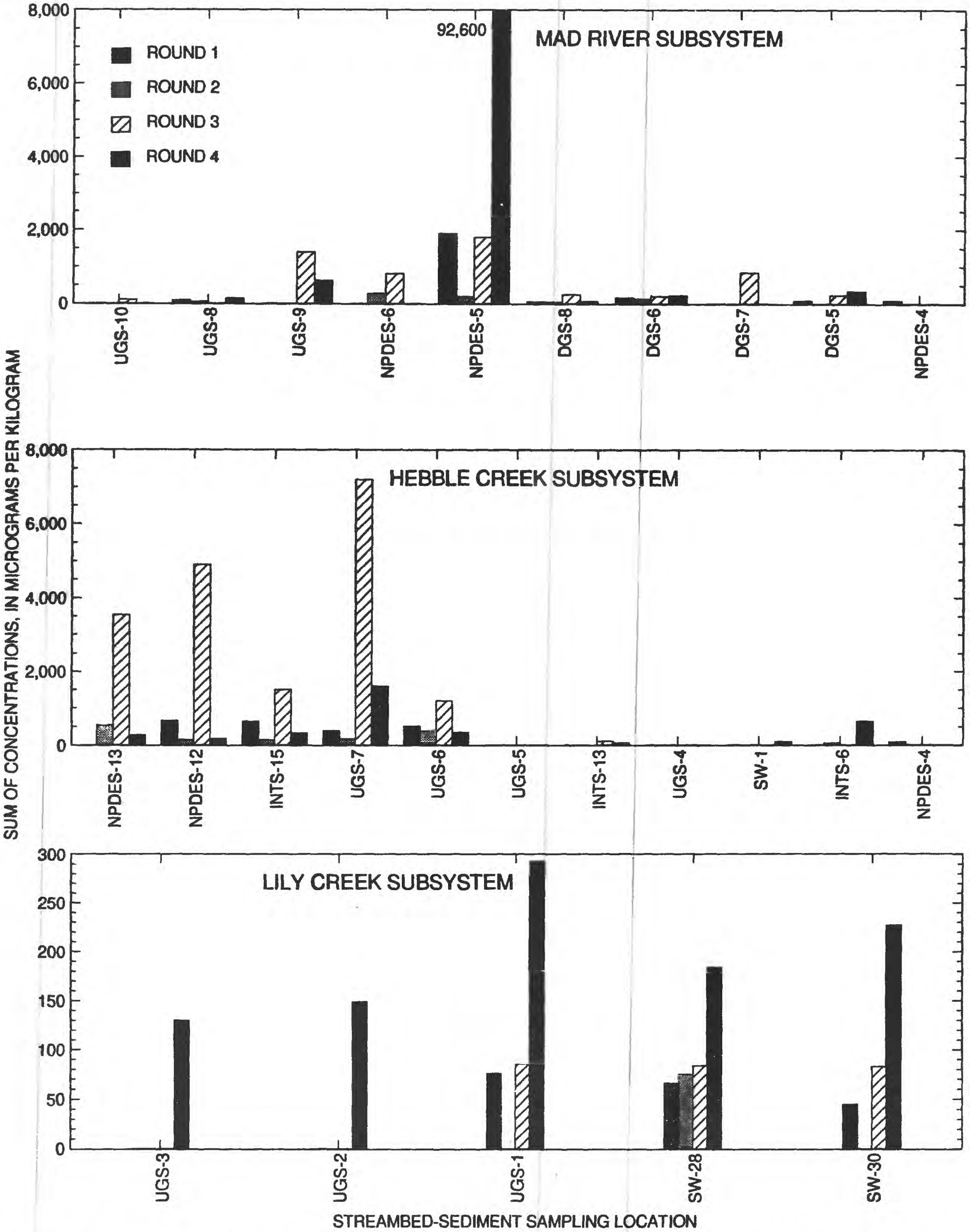


Figure 82. Sums of concentrations of phthalates in streambed-sediment samples, August 1993–September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio.

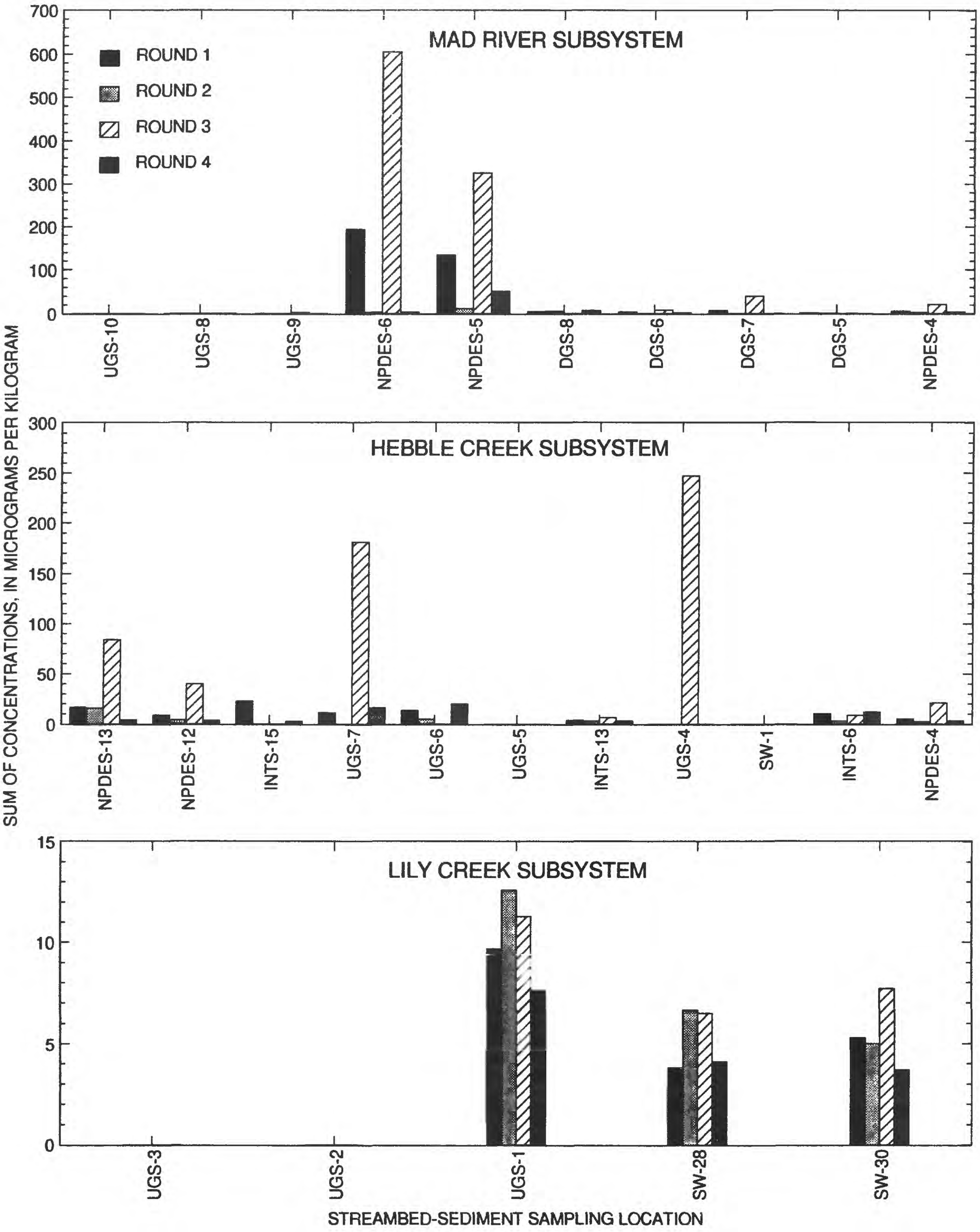


Figure 83. Sums of concentrations of pesticides in streambed-sediment samples, August 1993–September 1994, by river subsystem on Wright-Patterson Air Force Base, Ohio.

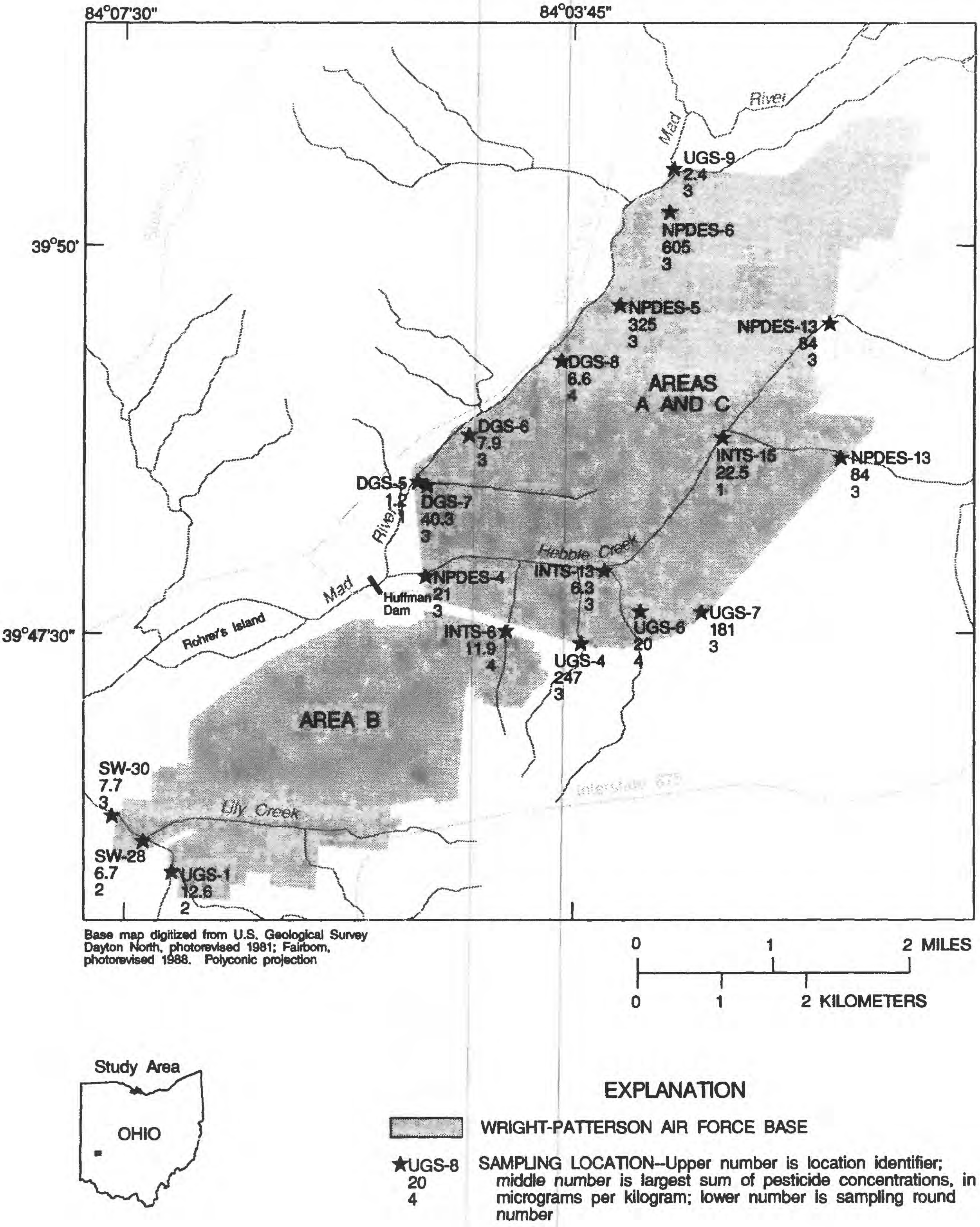


Figure 84. Detections of pesticides in samples from streambed-sediment locations on Wright-Patterson Air Force Base, Ohio, August 1993-September 1994.

Total Petroleum Hydrocarbons

Petroleum hydrocarbons, reported as total petroleum hydrocarbons (TPH), were detected in 31 of 50 (62 percent) streambed-sediment samples during rounds 1 and 2. Locations at which TPH were not detected were DGS-5, DGS-7, UGS-2, UGS-3, UGS-5, and UGS-9.

Concentrations of TPH exceeding 100 mg/kg in streambed sediment are listed in table 56 (at back of report). The two highest concentrations of TPH were detected in samples from NPDES-6; other locations at which TPH concentrations exceeded 300 mg/kg in samples were UGS-6, NPDES-12, UGS-7, UGS-10, NPDES-13, and NPDES-5.

Table 53. Highest concentrations of carbazole and dibenzofuran in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in micrograms per kilogram; J, estimated]

Location	Sample round	Semivolatile organic compound	Concentration	Qualifier
INTS-15	3	Carbazole	18,000	J
UGS-7	3	Carbazole	15,000	J
NPDES-13	3	Carbazole	10,000	J
NPDES-12	3	Carbazole	6,800	J
DGS-7	2	Carbazole	4,500	J
NPDES-5	1	Carbazole	4,400	J
NPDES-5	3	Carbazole	4,100	J
NPDES-5	4	Carbazole	3,500	J
UGS-6	2	Carbazole	2,900	J
INTS-15	3	Dibenzofuran	2,700	J
DGS-7	2	Dibenzofuran	2,500	J
UGS-7	4	Carbazole	2,200	J
NPDES-5	1	Dibenzofuran	1,500	J
UGS-6	2	Dibenzofuran	1,400	J
NPDES-6	3	Carbazole	1,300	J
UGS-6	3	Carbazole	1,200	J
NPDES-12	3	Dibenzofuran	1,200	J
UGS-7	3	Dibenzofuran	1,100	J
NPDES-13	1	Carbazole	1,000	J
NPDES-13	1	Dibenzofuran	910	J
DGS-7	3	Carbazole	890	J
NPDES-13	3	Dibenzofuran	880	J
UGS-6	4	Carbazole	780	J
NPDES-12	4	Carbazole	610	J
NPDES-13	4	Carbazole	570	J

Table 54. Highest concentrations of chlordane pesticides in streambed-sediment samples, all rounds, August 1993 - September 1994, Wright-Patterson Air Force Base
[All concentrations in micrograms per kilogram; J, estimated; -- not applicable]]

Location	Sample round	Pesticide	Concentration	Qualifier
NPDES-5	3	alpha-Chlordane	77.0	J
NPDES-5	3	gamma-Chlordane	72.0	J
NPDES-5	1	alpha-Chlordane	61.0	--
NPDES-5	1	gamma-Chlordane	58.0	--
NPDES-13	3	gamma-Chlordane	43.0	J
NPDES-13	3	alpha-Chlordane	41.0	J
UGS-7	3	gamma-Chlordane	34.0	J
UGS-7	3	alpha-Chlordane	27.0	J
NPDES-5	4	gamma-Chlordane	19.0	J
NPDES-5	4	lpha-Chlordane	18.0	J
NPDES-12	3	alpha-Chlordane	7.70	J
NPDES-12	3	gamma-Chlordane	7.40	J
DGS-7	3	gamma-Chlordane	7.00	J
UGS-6	1	gamma-Chlordane	6.70	J
UGS-1	3	alpha-Chlordane	6.60	--
NPDES-5	2	gamma-Chlordane	6.60	--
DGS-7	3	alpha-Chlordane	6.30	J
NPDES-4	3	alpha-Chlordane	5.70	J
UGS-6	1	alpha-Chlordane	5.40	J
UGS-1	2	gamma-Chlordane	5.20	--
NPDES-4	3	gamma-Chlordane	5.10	--
UGS-1	1	gamma-Chlordane	5.00	J
UGS-1	2	alpha-Chlordane	5.00	--

SUMMARY AND CONCLUSIONS

The Basewide Monitoring Program (BMP) is a multiyear project designed to investigate the quality of ground water, surface water, and streambed sediments at Wright-Patterson Air Force Base (WPAFB), Ohio, from a regional perspective. The objectives are to (1) characterize current ground-water and surface-water quality, (2) describe water-quality changes as water flows across the Base, and (3) investigate the effects of activities at WPAFB on regional water quality. Data obtained during drilling, monitoring, and sampling were used to develop a hydrogeological framework from which the chemical quality of water and sediments could be evaluated.

Most of WPAFB is underlain by the Upper Ordovician-age Richmond group, which consists of calcareous shale with fossiliferous limestone interbeds. The shale layers are soft and fissile, and may be as thick as 20 ft. Glacially-derived valley-train deposits, consisting of till and outwash, fill the bedrock valleys. The valley-train deposits can be almost 300 ft thick. From this aquifer is produced nearly all of the municipal and industrial supply of water.

A bedrock-topography map based on data collected prior to 1993 was updated with data obtained during the drilling phase of the BMP. The most extensive alterations to the map covered the western part of Area B, or the southwestern part of the Base, where wells were drilled in six clusters. Minimum bedrock altitude in that area was about 540 ft above sea level.

Other alterations were drawn in northern Area B, southwestern Areas A and C, east-central areas A and C, and northeastern Areas A and C (which are in the northeastern part of the Base). Most alterations were minimal.

Water levels were measured monthly in more than 100 wells included in the BMP. Water-level data from December 1993 and May and October 1994 were used to map the altitude and configuration of the water table and an intermediate-depth potentiometric surface. Water levels were lowest during October 1994, and were highest during May 1994. Fluctuations on the water-table and potentiometric surface were greatest in northwestern Area B, where pumping at the Mad River well field affected water levels.

The chemical quality of ground and surface waters sampled during the BMP was investigated. The analytical schedules for the BMP originally included volatile organic compunds (VOCs), semivolatile organic compounds (SVOCs), organochlorine pesticides and polychlorinated biphenyls (PCBs), chlorinated herbicides, petroleum hydrocarbons (TPH), gross alpha and beta, cyanide, anions, and filtered and unfiltered metals. Because of the infrequency of detections of herbicides and TPH, these analytes were dropped from all sampling matrices after round 2 except for herbicides in streambed sediment, which were dropped after round 3. Cyanide, gross alpha and beta, and pesticides and PCBs were dropped from the ground-water schedules after round 2 but retained for surface water and streambed sediment. The deletion of these analytical schedules was attributed in part to the lack of these compounds in water and sediment at WPAFB.

Field-measured properties and chemical concentrations obtained during the first four rounds of ground-water sampling indicated that anthropogenic effects on the glacial-drift aquifer underlying WPAFB were limited to about 70 ft below land surface. Most dissolved oxygen was depleted at depths of about 70 ft; concentrations of sodium and chloride, which can be attributed to the salting of roads during winter months, were significantly higher at depths less than 70 ft than at depths greater than 70 ft; and concentrations of VOCs and SVOCs were highest in samples from wells less than 60 ft deep.

Ground water sampled at BMP locations generally was unaffected by traceable contaminant plumes. During the four sampling rounds, TCE, PCE, chromium, and nickel were the primary constituents detected routinely at concentrations exceeding MCLs for drinking water. Well clusters affected by VOCs mostly are in the interior and upgradient parts of Areas A and C. Clusters affected by chromium and nickel were in Area B. Most of these well clusters intercepted or were adjacent to flow paths from hazardous-waste sites. Other organic compounds detected at levels exceeding MCLs were benzene (one sample), vinyl chloride (five samples), and bis(2-ethylhexyl)phthalate (six samples).

Data acquired during the BMP indicate that the surface water on WPAFB generally was not affected by chemical contaminants. Most organic compounds rarely were detected in surface water. A few trace metals were detected infrequently at concentrations exceeding MCLs for drinking water; however, the frequency of detections were insufficient to relate trends in water quality with season, discharge, source location, or land use.

PAHs, phthalates, and some trace metals, most notably mercury, arsenic, lead, and cadmium, were detected consistently in streambed-sediment samples. Locations where concentrations of these compounds were highest were on Hebble Creek other tributaries to Mad River in Areas A and C. Metals, PAHs, and phthalates often are persistent in sediments, and further evaluation in the environmental program at WPAFB is suggested.

One of the objectives of the BMP was to describe the quality of water as it flows across the Base. The BMP provided geologic and water-quality information in areas of the Base not previously investigated. The vertical distribution of contaminants was delineated in the areas investigated. Localized areas of ground-water contamination indicated that some contamination is entering the Base from adjacent areas.

Although the quality of ground and surface water on WPAFB was characterized for the period 1993-94, the effects of WPAFB on the regional flow system cannot be determined completely from data collected during this period. Trend analysis, which is commonly used to describe the stability, improvement, or degradation of water quality with time, generally requires years of data collected on a regular schedule. Regular, long-term monitoring is needed to assess quantitatively and with statistical confidence the effects of WPAFB on regional water quality.

Continued monitoring and a rigorous statistical determination of constituent distribution and changes in concentrations with time, incorporating all past, present, and future data collected on WPAFB, are required for estimating the effects of activities at WPAFB on regional water quality. In conjunction with such work, flow and contaminant-transport modeling can provide additional estimates of regional water-quality effects. Using inputs of contaminant sources and geochemical, biochemical and hydrodynamic processes, a transport model could be used to simulate contaminant concentrations for an assessment of risk at the Base. Caution should be used when applying these models because of the assumptions necessary for their preparation. Data obtained to date (1995) indicate that contamination of surface water is limited, but sufficient data are not available to simulate surface-water flow and contaminant transport.

Future investigations that would enhance the work done to date (1995) on the BMP include the following:

- Selection of a core network of ground-water, surface-water, and streambed-sediment sampling locations for long-term monitoring;
- Long-term sampling of the core network to determine the effects of WPAFB on ground-water quality;
- Identification of adjacent sources of ground-water and surface-water contamination;
- Sampling and collection of hydrologic data to determine ground-water/surface-water relations on contaminant transport; and
- Sampling of streambed sediment (with depth) at Base and adjacent locations to determine the extent of contamination.

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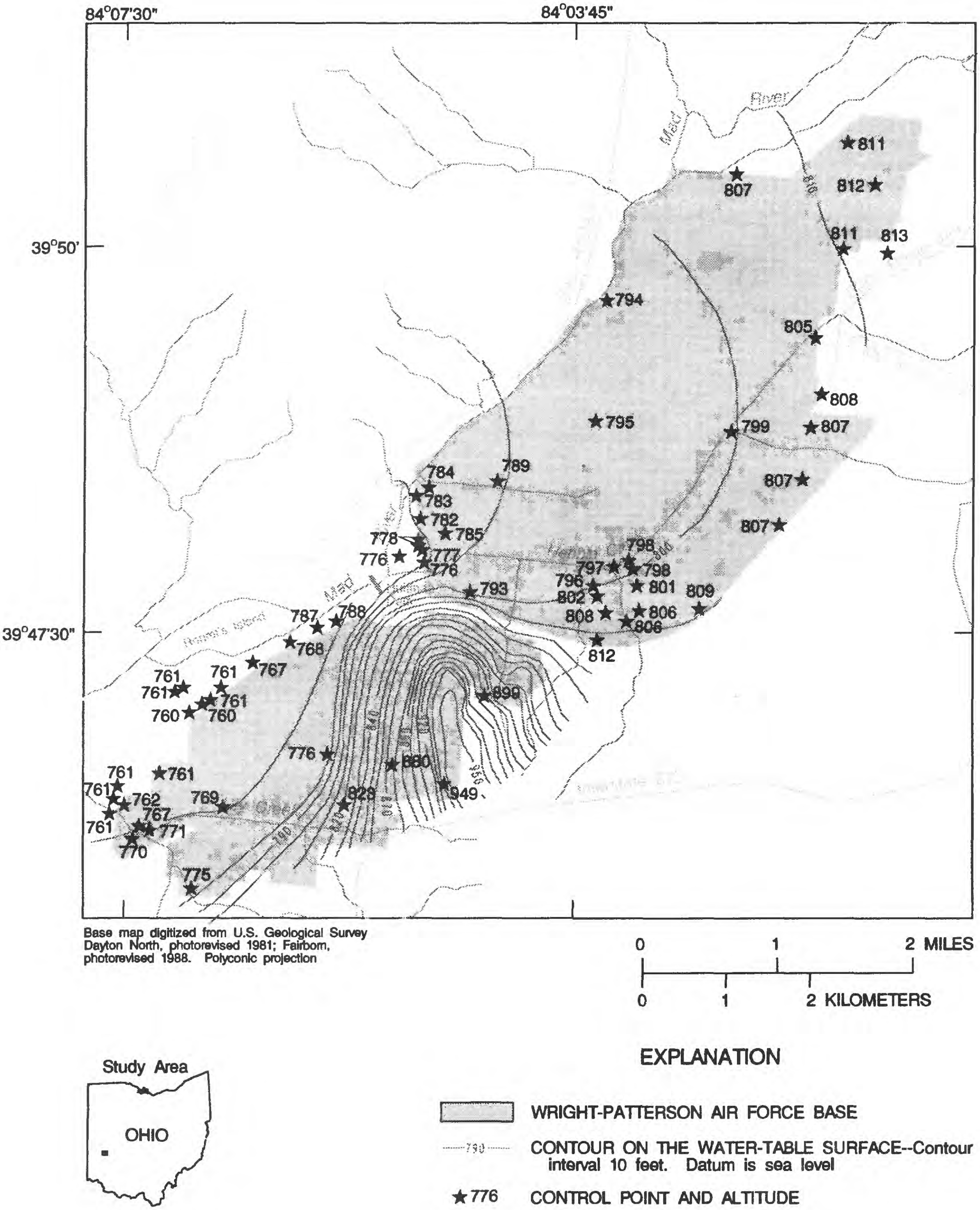
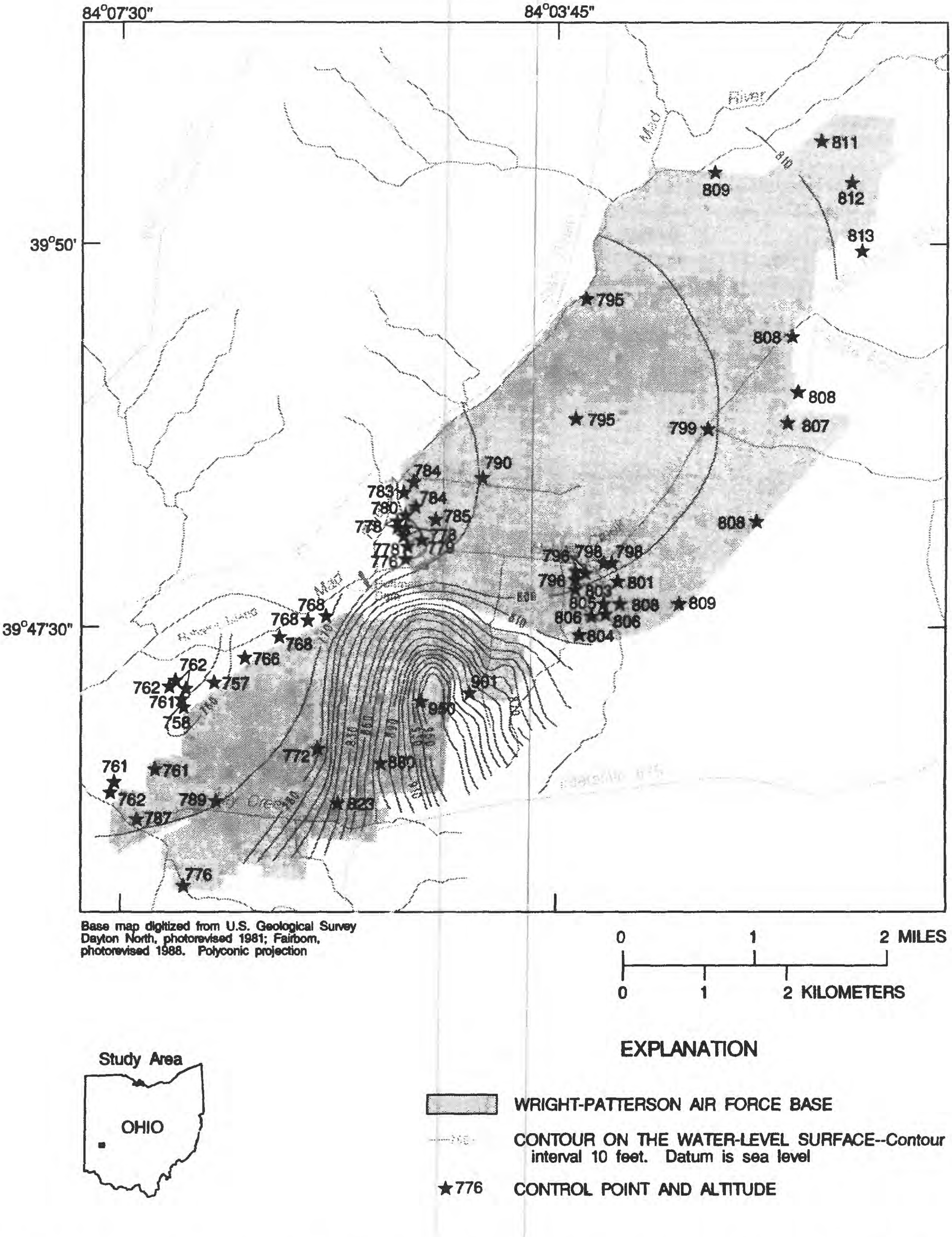


Figure 9. Water-table surface at Wright-Patterson Air Force Base, Ohio, December 1993.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 10. Water levels in intermediate depth wells on Wright-Patterson Air Force Base, Ohio, December 1993.

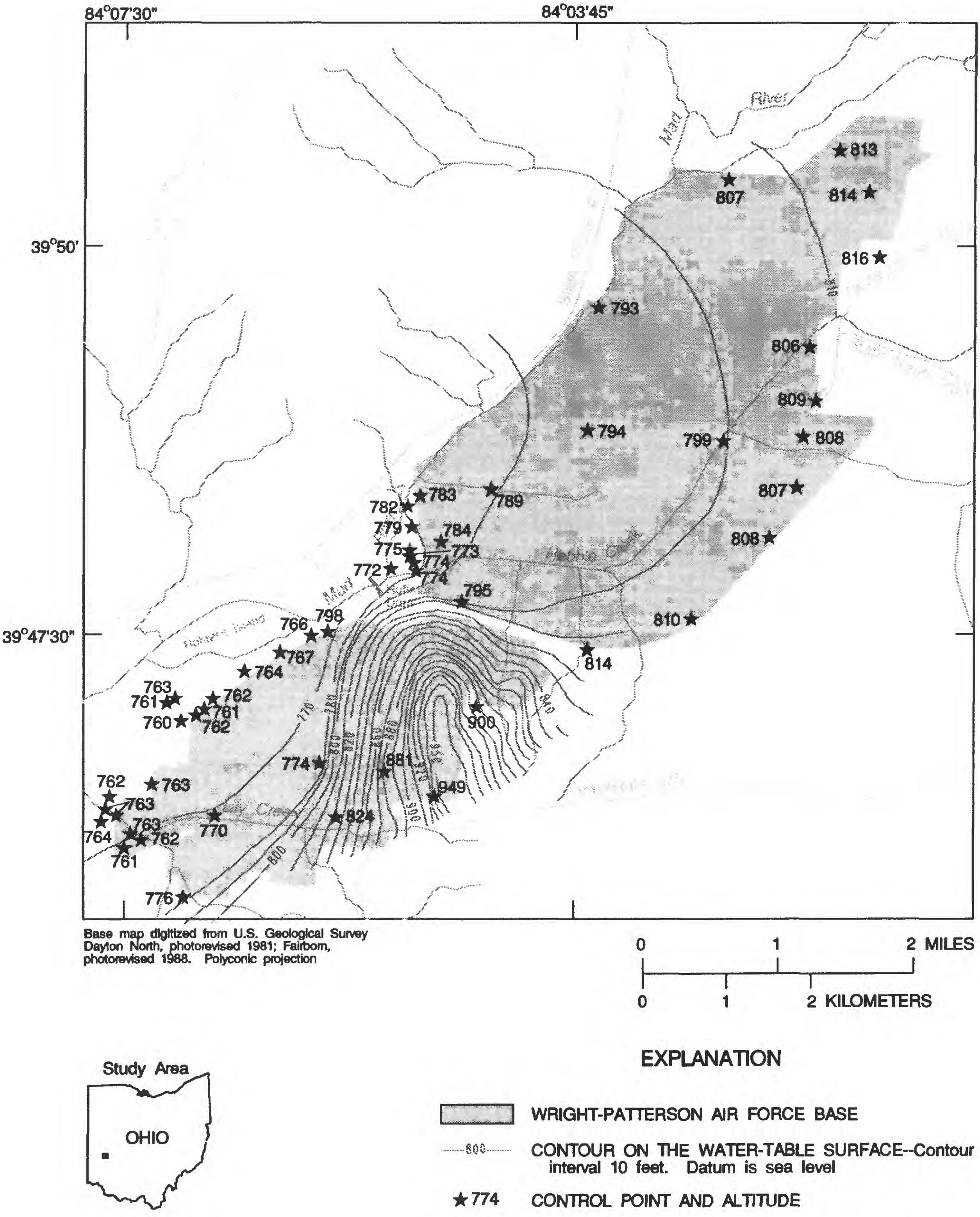


Figure 11. Water-table surface at Wright-Patterson Air Force Base, Ohio, May 1994.

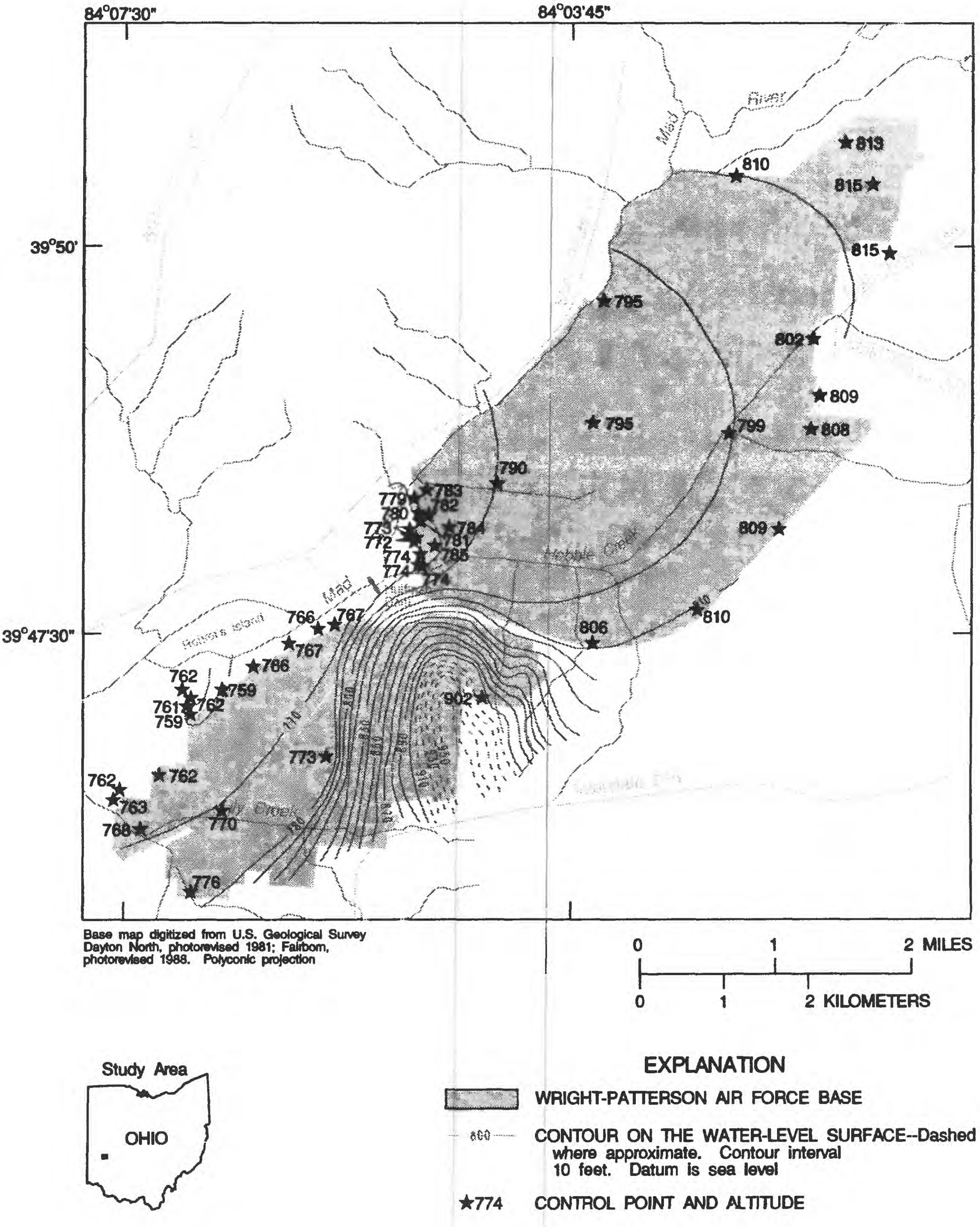


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Figure 12. Water levels in intermediate-depth wells on Wright-Patterson Air Force Base, Ohio, May 1994.

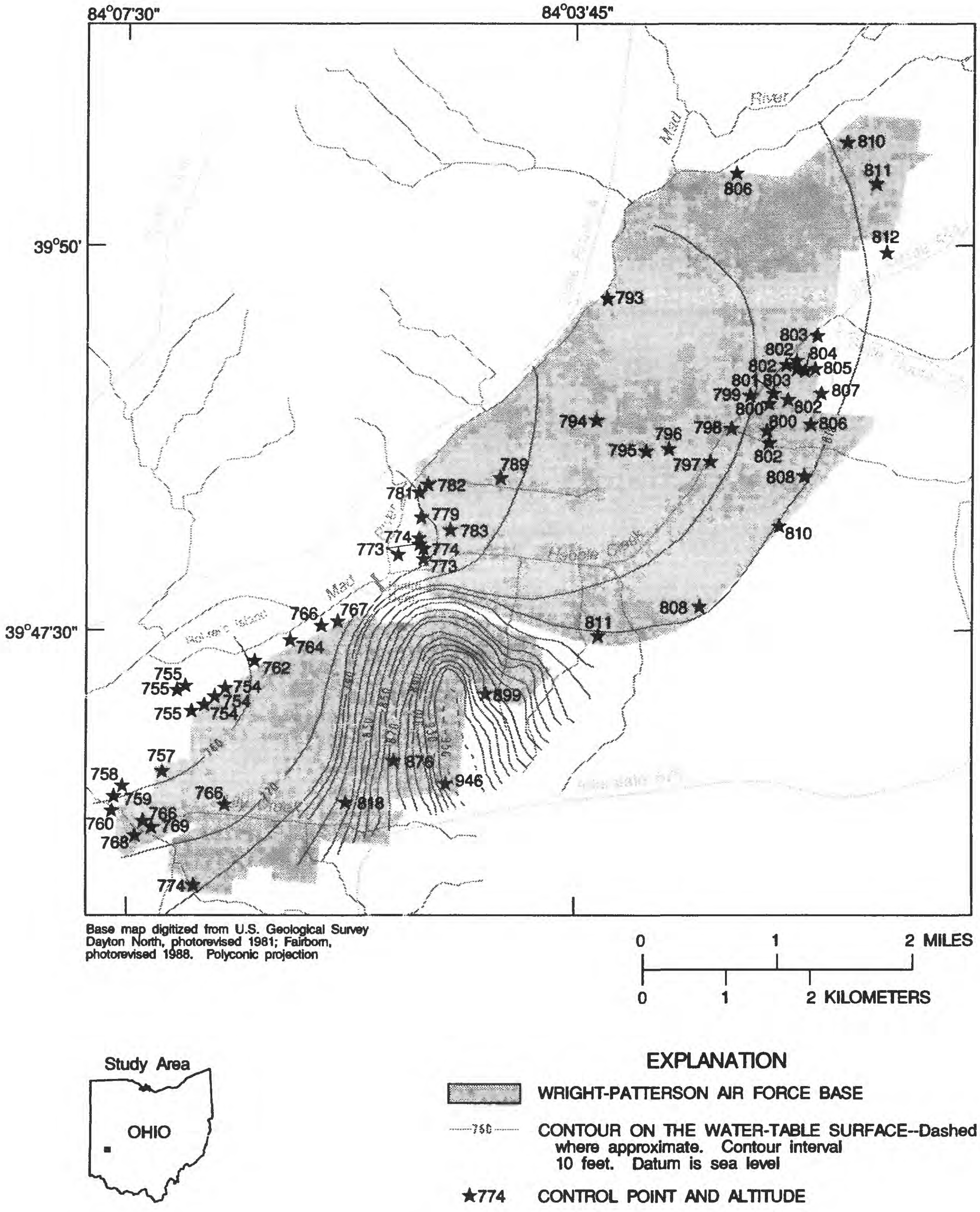

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Figure 13. Water-table surface at Wright-Patterson Air Force Base, Ohio, October 1994.

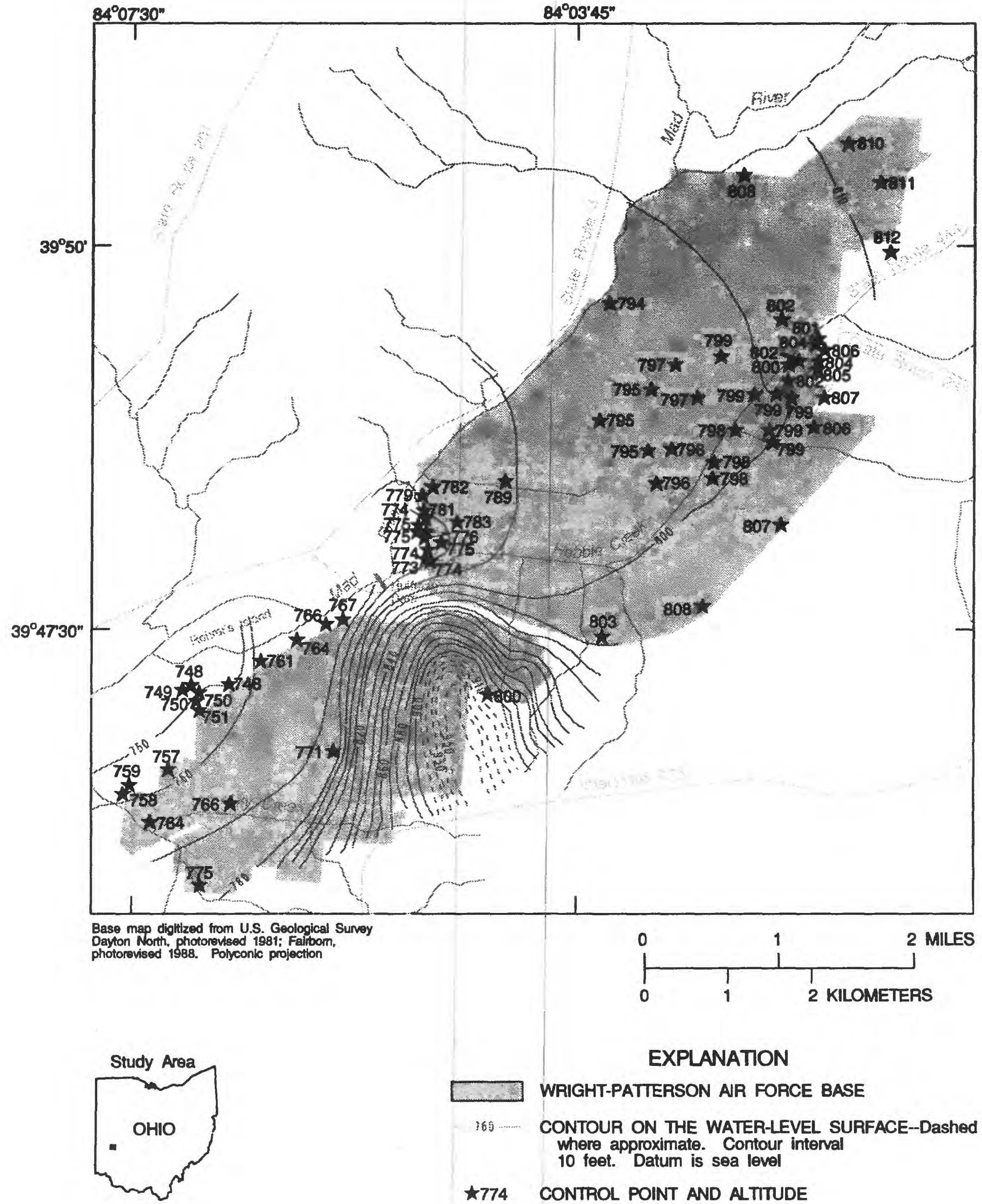

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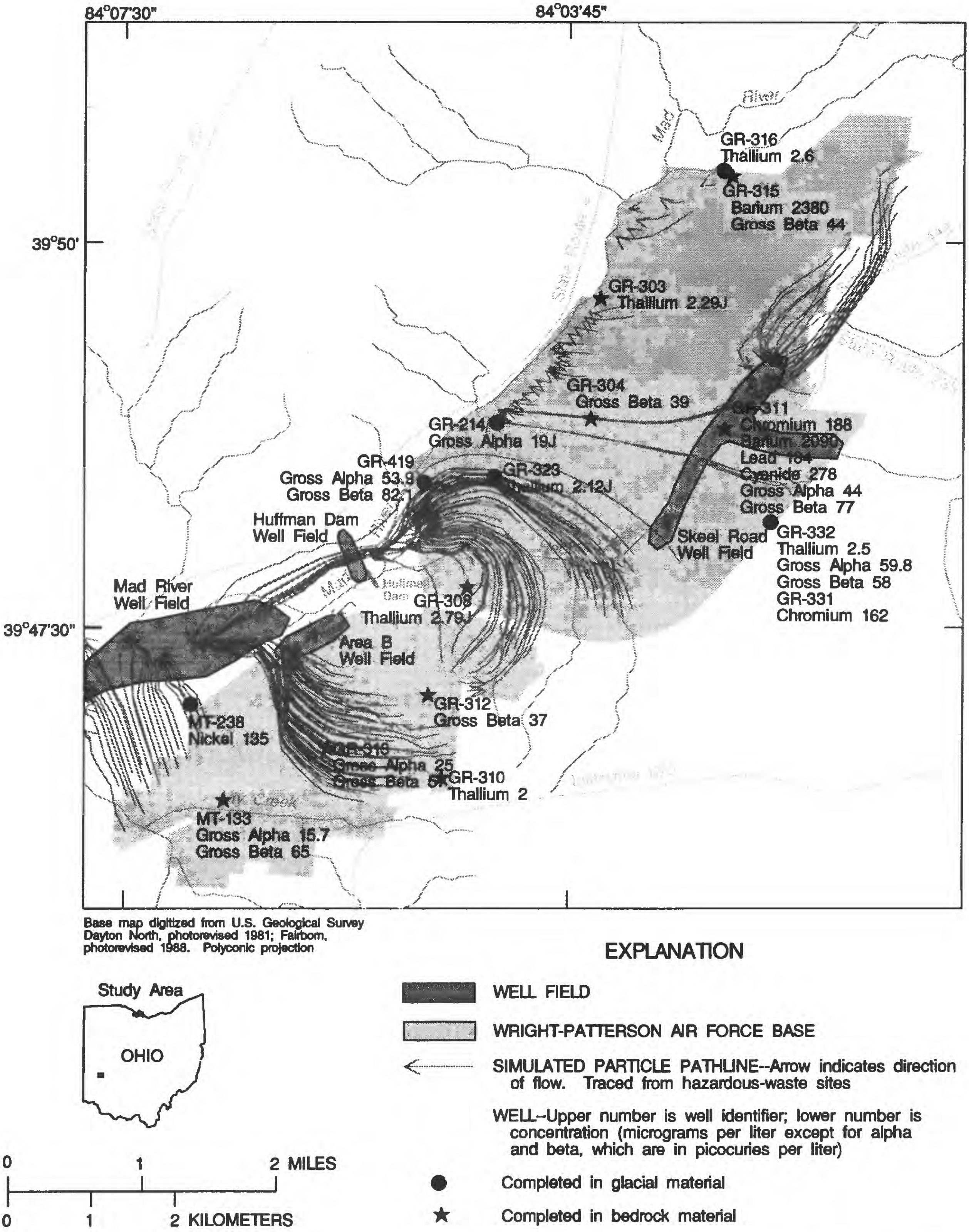
Figure 14. Water levels in intermediate-depth wells on Wright-Patterson Air Force Base, Ohio, October 1994.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

EXPLANATION

▇ WELL FIELD

▒ WRIGHT-PATTERSON AIR FORCE BASE

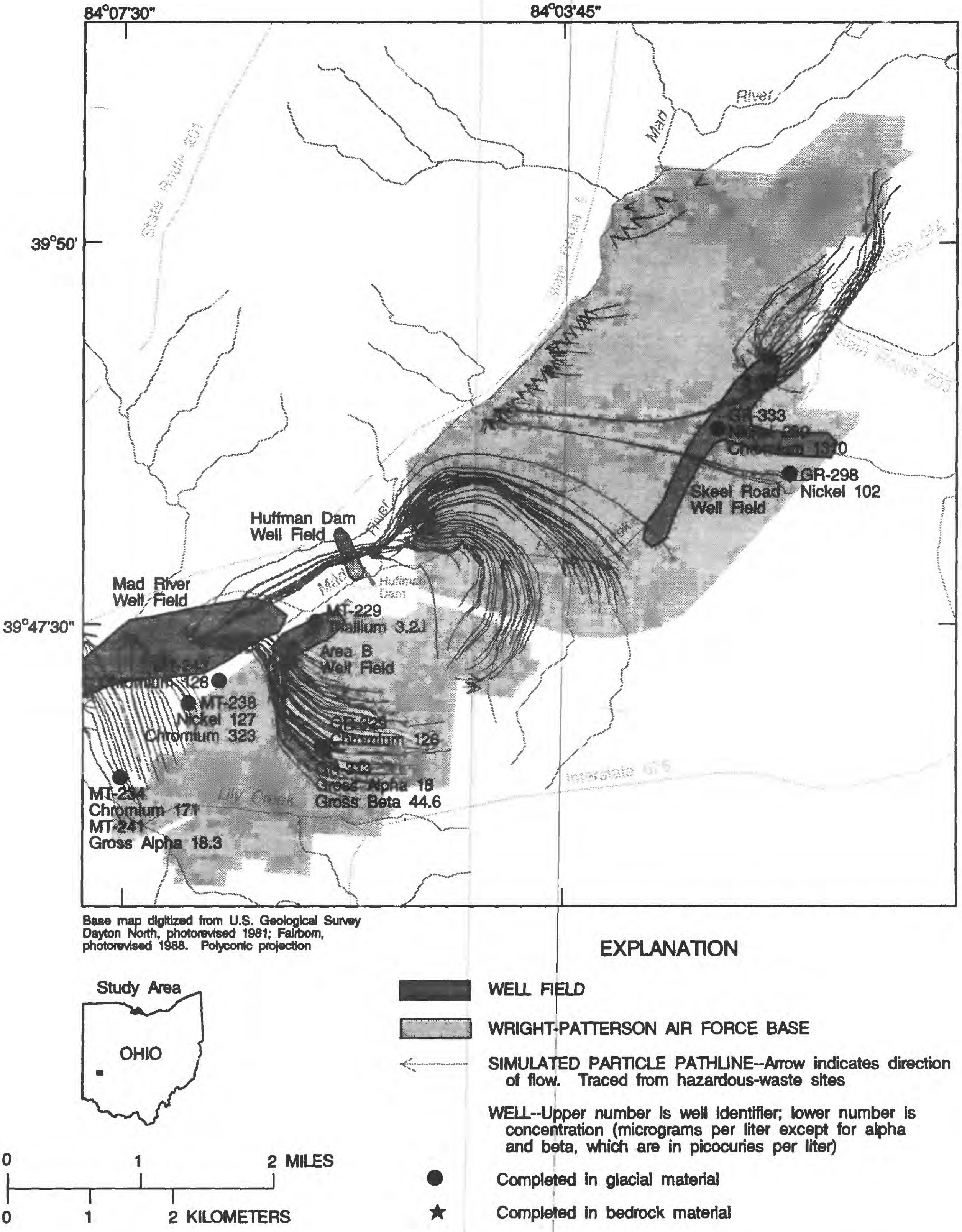
← SIMULATED PARTICLE PATHLINE--Arrow indicates direction of flow. Traced from hazardous-waste sites

WELL--Upper number is well identifier; lower number is concentration (micrograms per liter except for alpha and beta, which are in picocuries per liter)

● Completed in glacial material

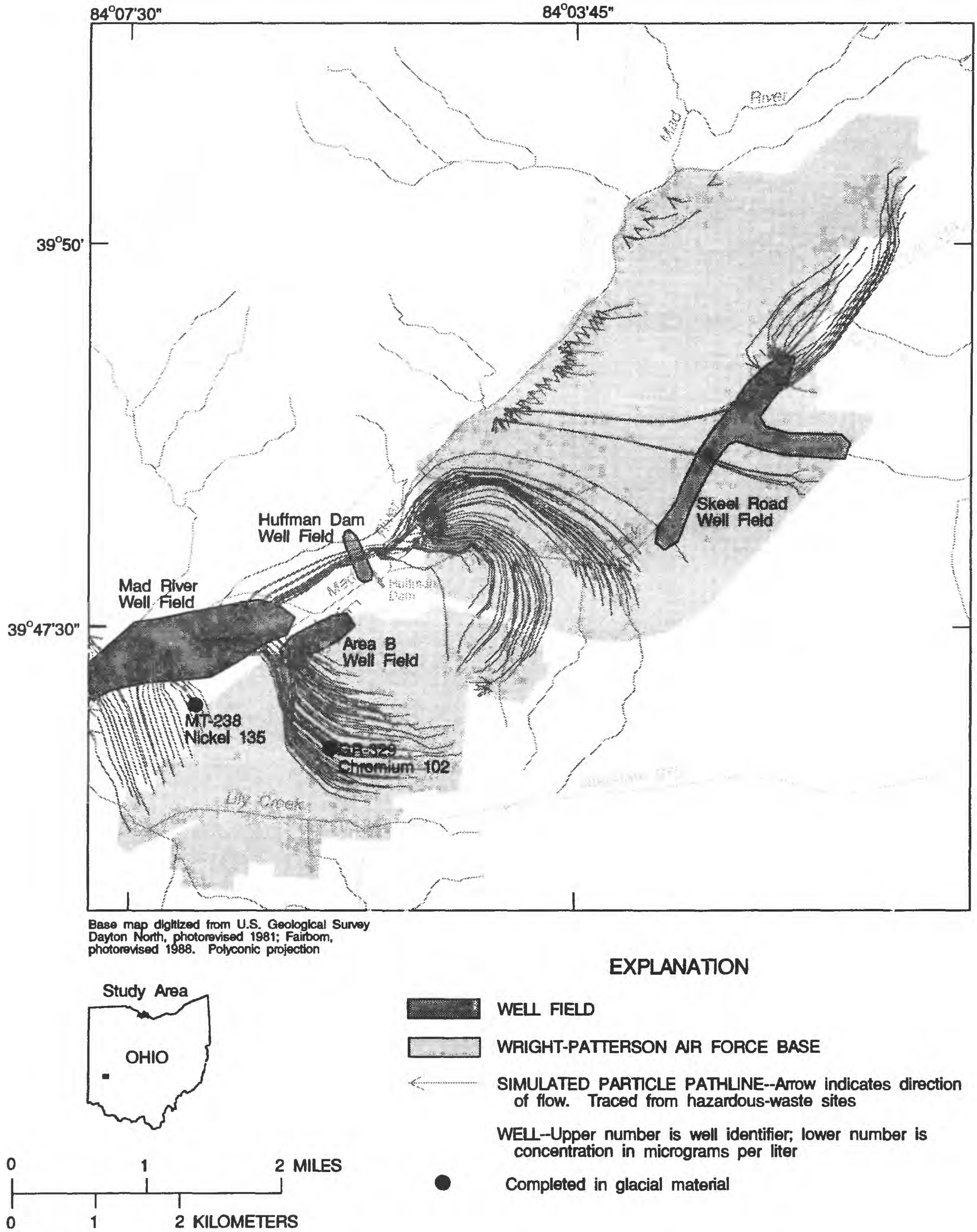
★ Completed in bedrock material

Figure 18. Exceedances of maximum contaminant levels for inorganic constituents in ground water, round 1, August-September 1993 at Wright-Patterson Air Force Base, Ohio.



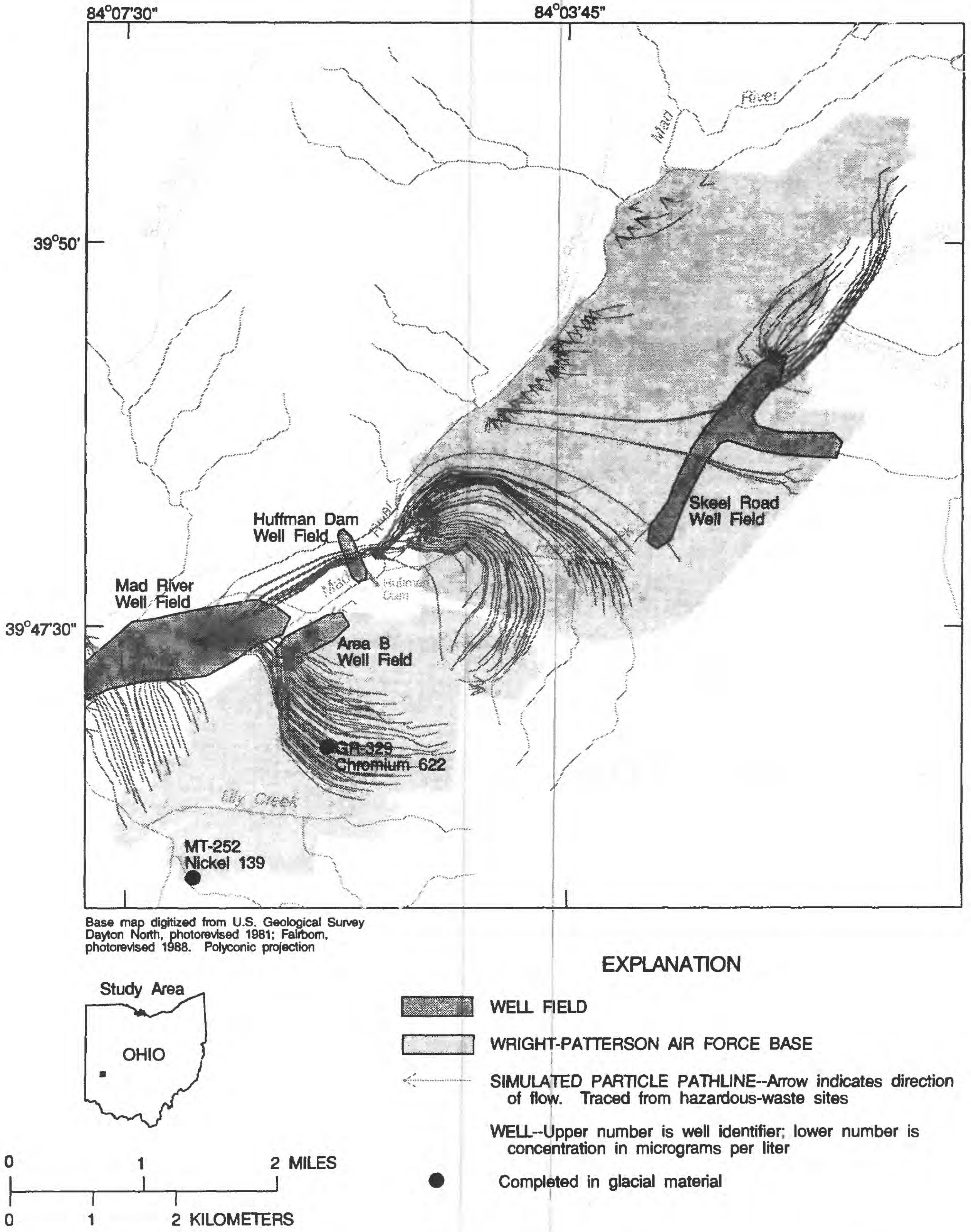
Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 19. Exceedance of maximum contaminant levels for inorganic constituents in ground water, round 2, October 1993-January 1994, Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 20. Exceedance of maximum contaminant levels for inorganic constituents in ground water, round 3, April 1994 Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 21. Exceedance of maximum contaminant levels for inorganic constituents in ground water, round 4, August-September 1994, Wright-Patterson Air Force Base, Ohio.

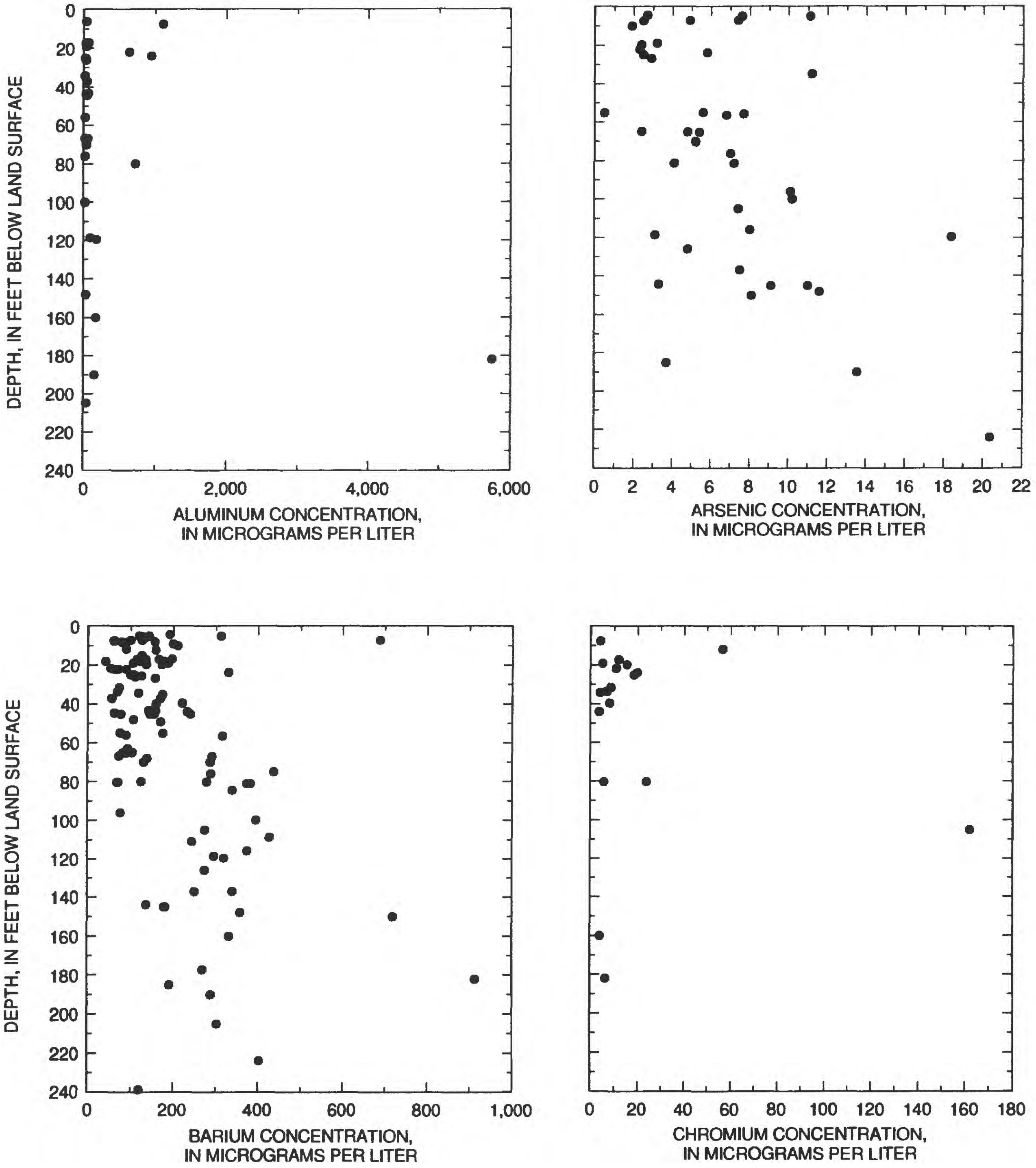


Figure 29. Concentrations of aluminum, arsenic, barium, and chromium with depth in the glacial aquifer, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.

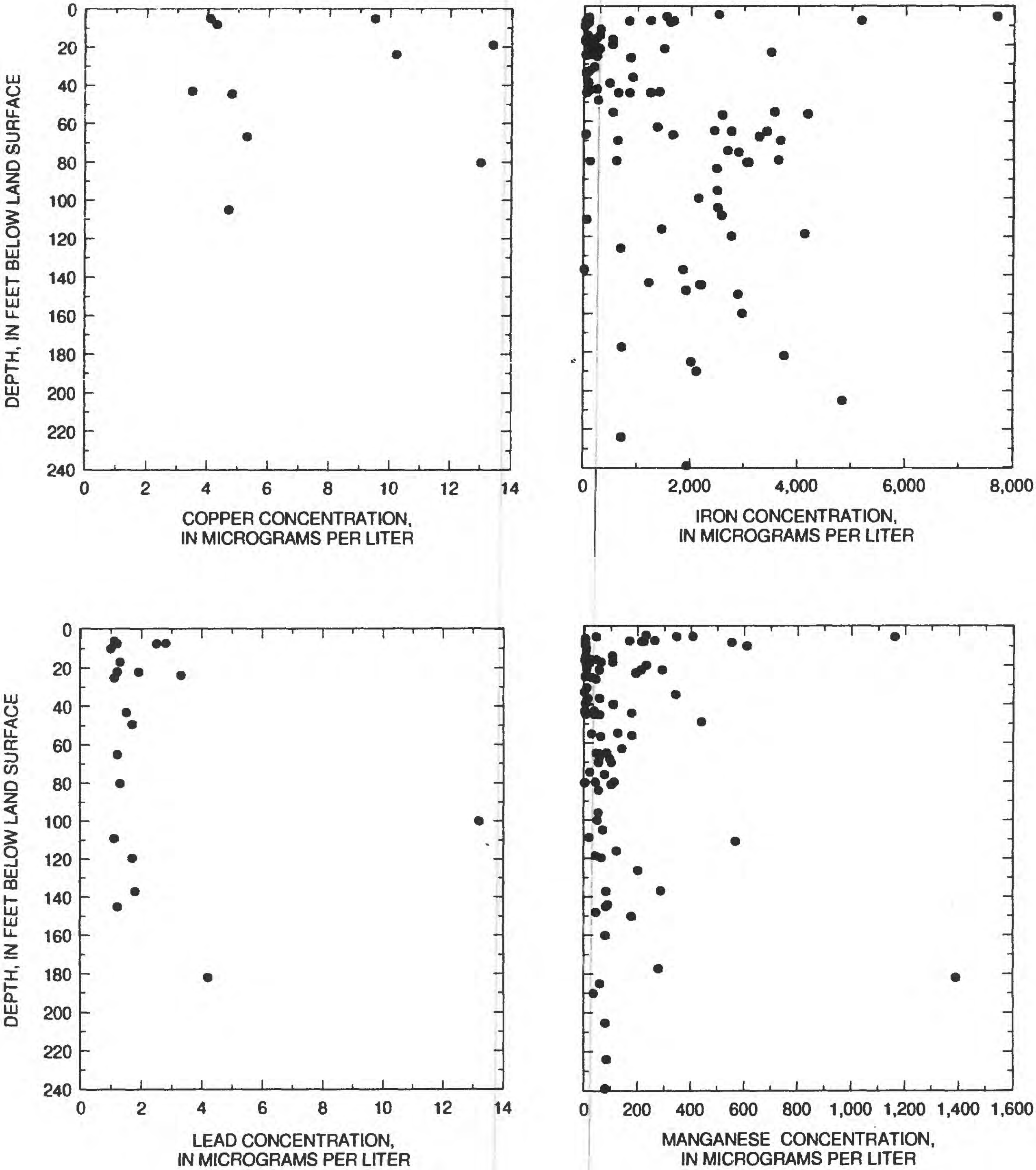


Figure 30. Concentrations of copper, iron, lead, and manganese with depth in the glacial aquifer, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.

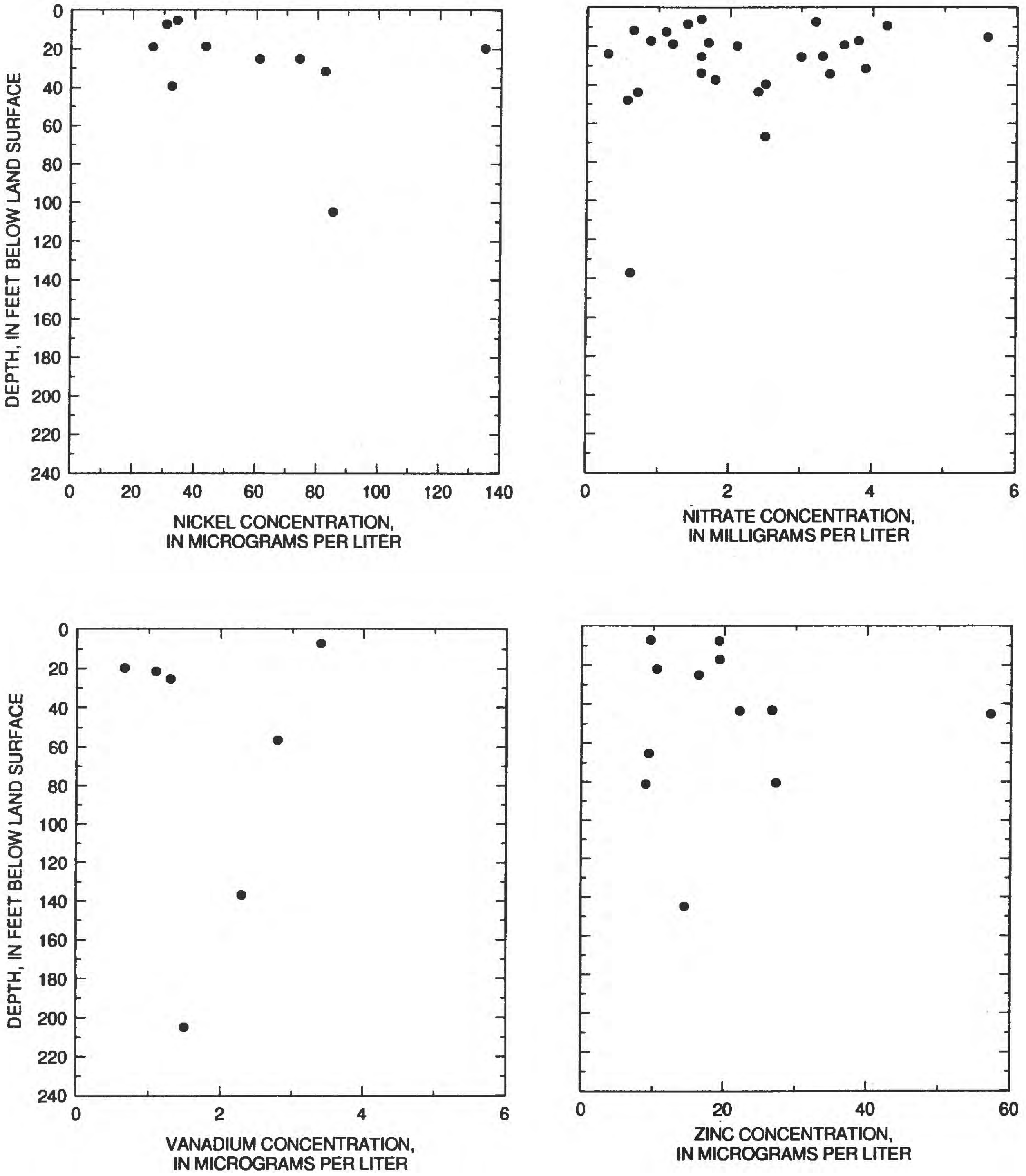


Figure 31. Concentrations of nickel, nitrogen-nitrate, vanadium, and zinc with depth in the glacial aquifer, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.

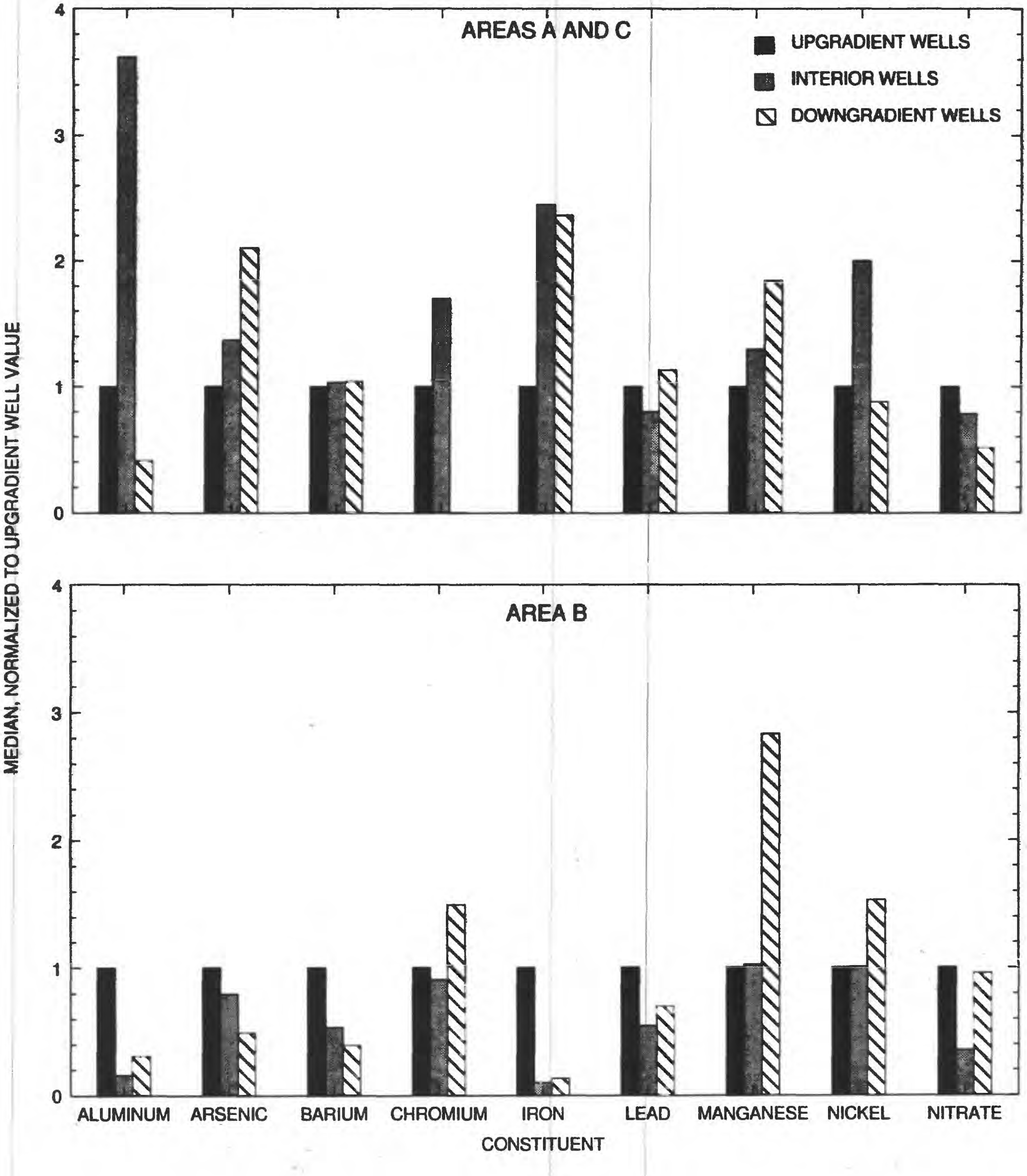
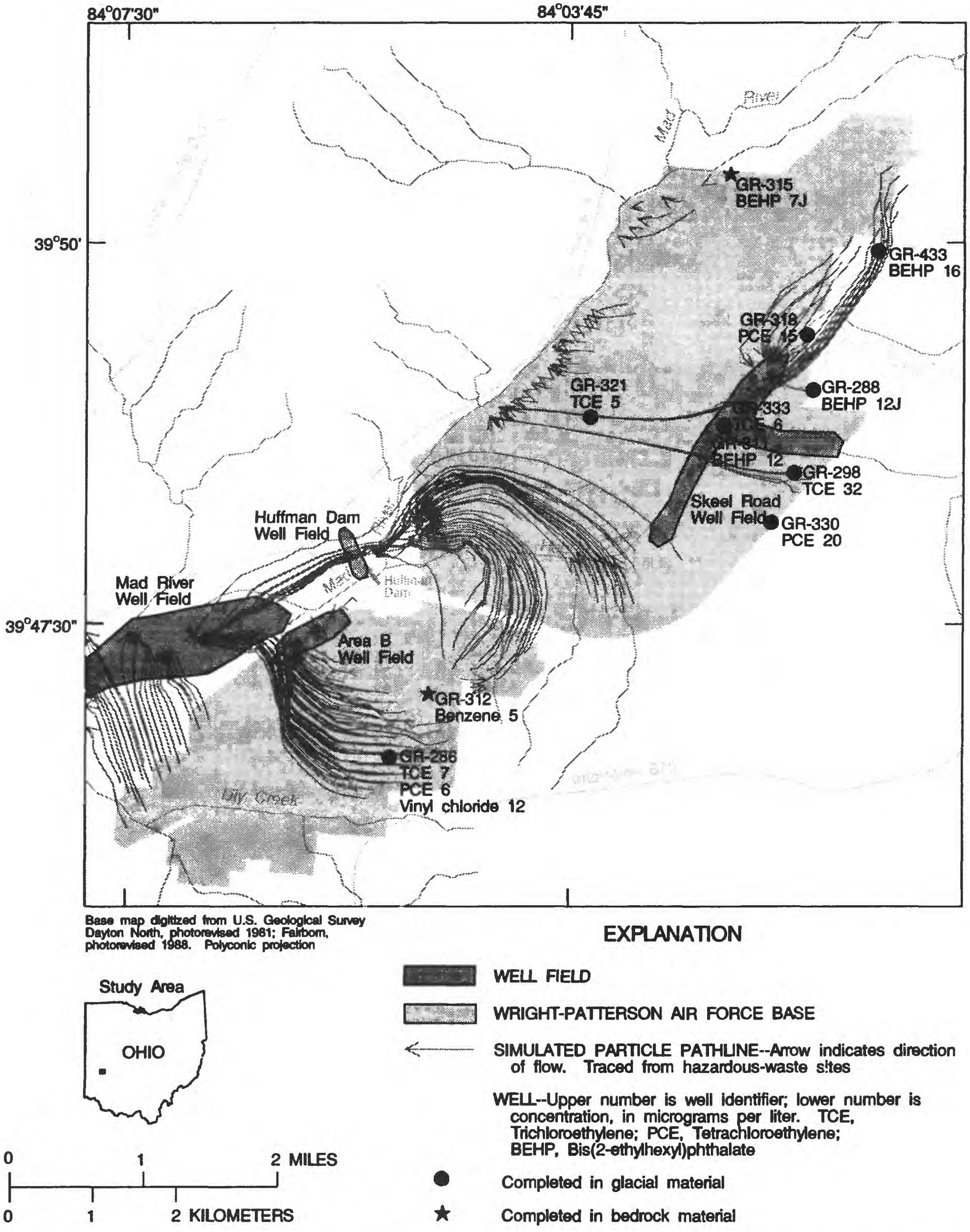


Figure 32. Normalized median concentrations of selected minor constituents with position along the regional ground-water gradient, rounds 1 and 2, August 1993-January 1994, Wright-Patterson Air Force Base, Ohio. (Median values for each constituent were normalized to the median of the upgradient subgroup. Therefore, all upgradient values are equal to 1.0.)



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 36. Exceedances of maximum contaminant levels for organic compounds in ground water, round 1, August-September 1993, Wright-Patterson Air Force Base, Ohio.

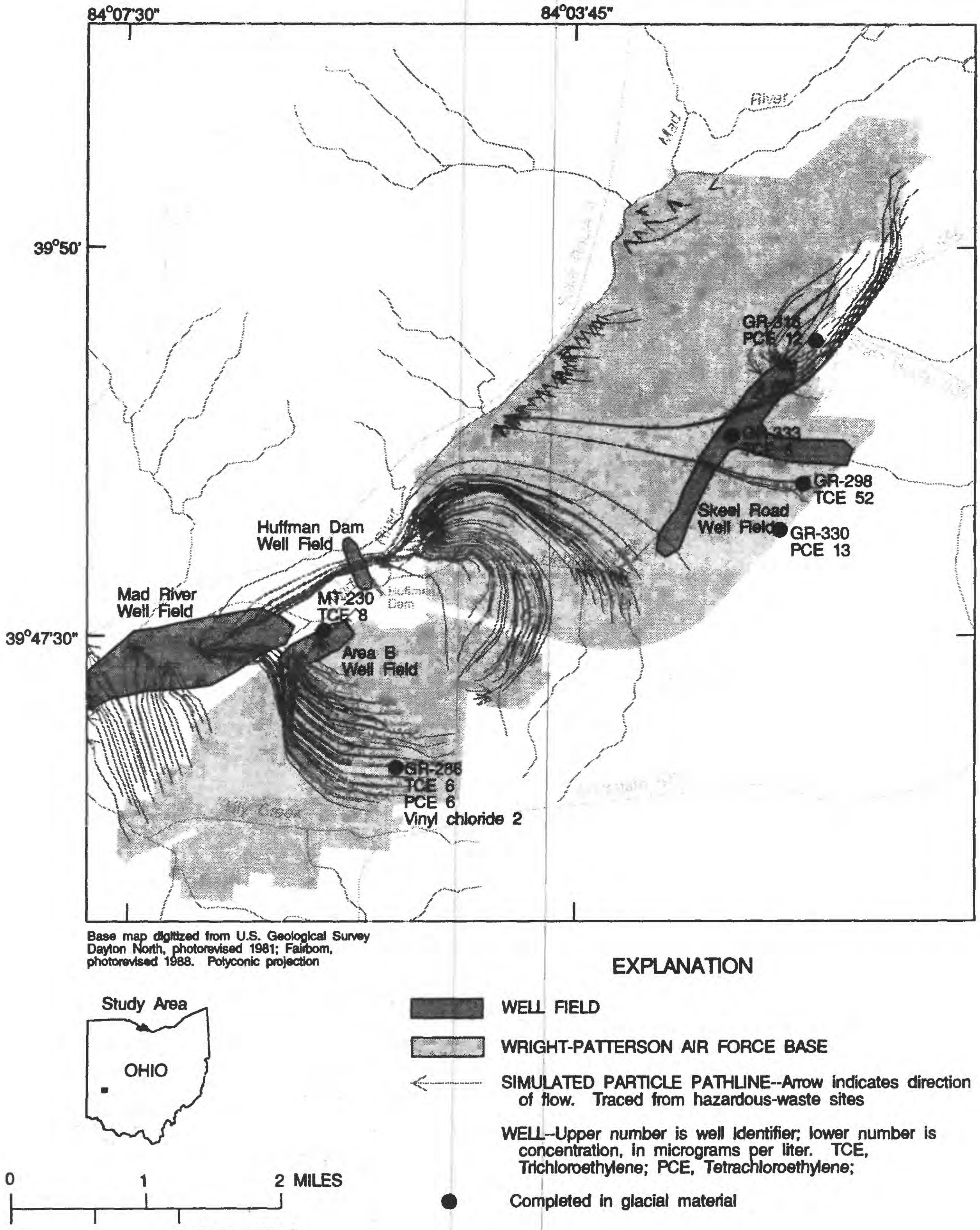


Figure 37. Exceedances of maximum contaminant levels for organic compounds in ground water, round 2, October 1993-January 1994, Wright-Patterson Air Force Base, Ohio.

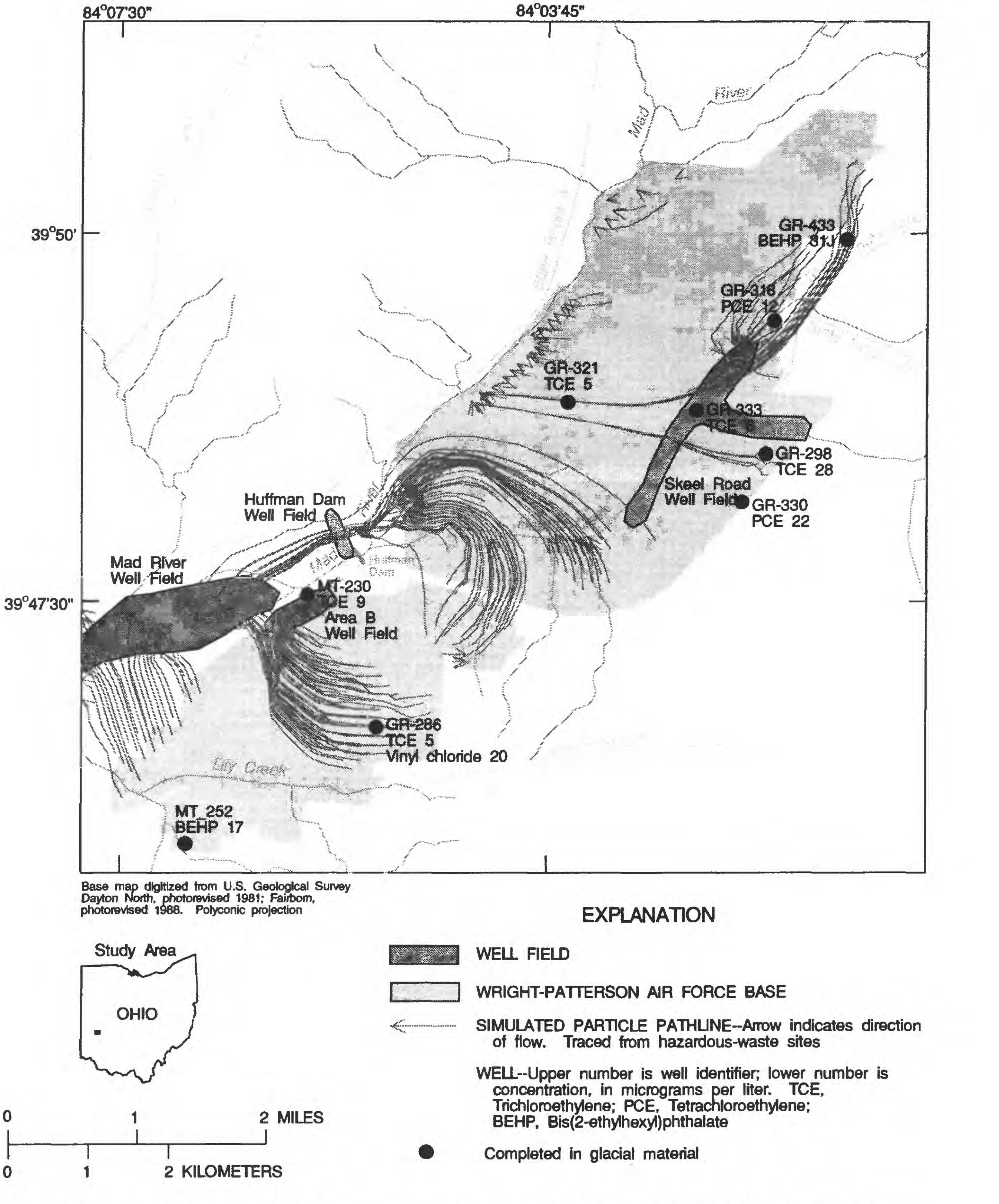


Figure 38. Exceedances of maximum contaminant levels for organic compounds in ground water, round 3, April 1994, Wright-Patterson Air Force Base, Ohio.

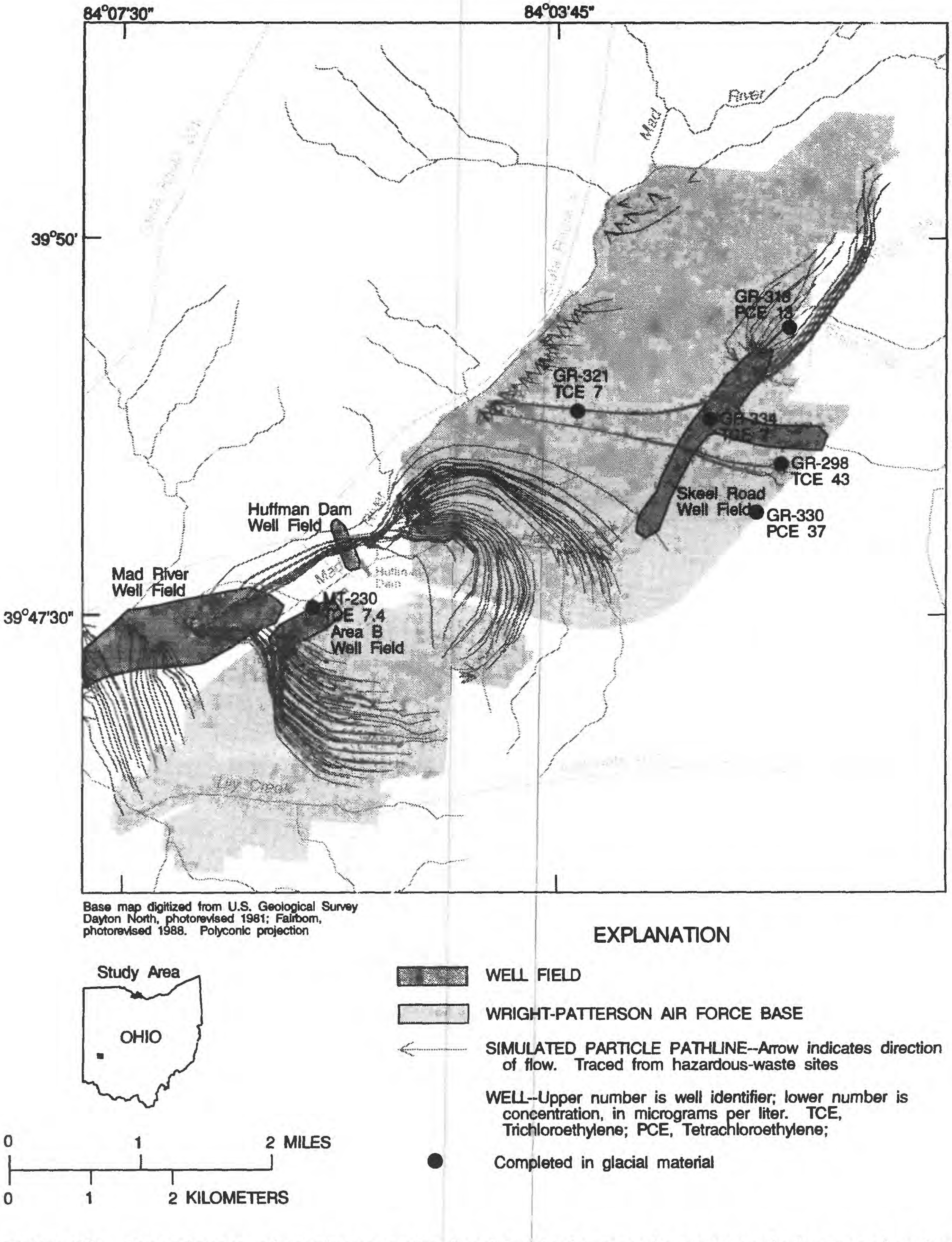
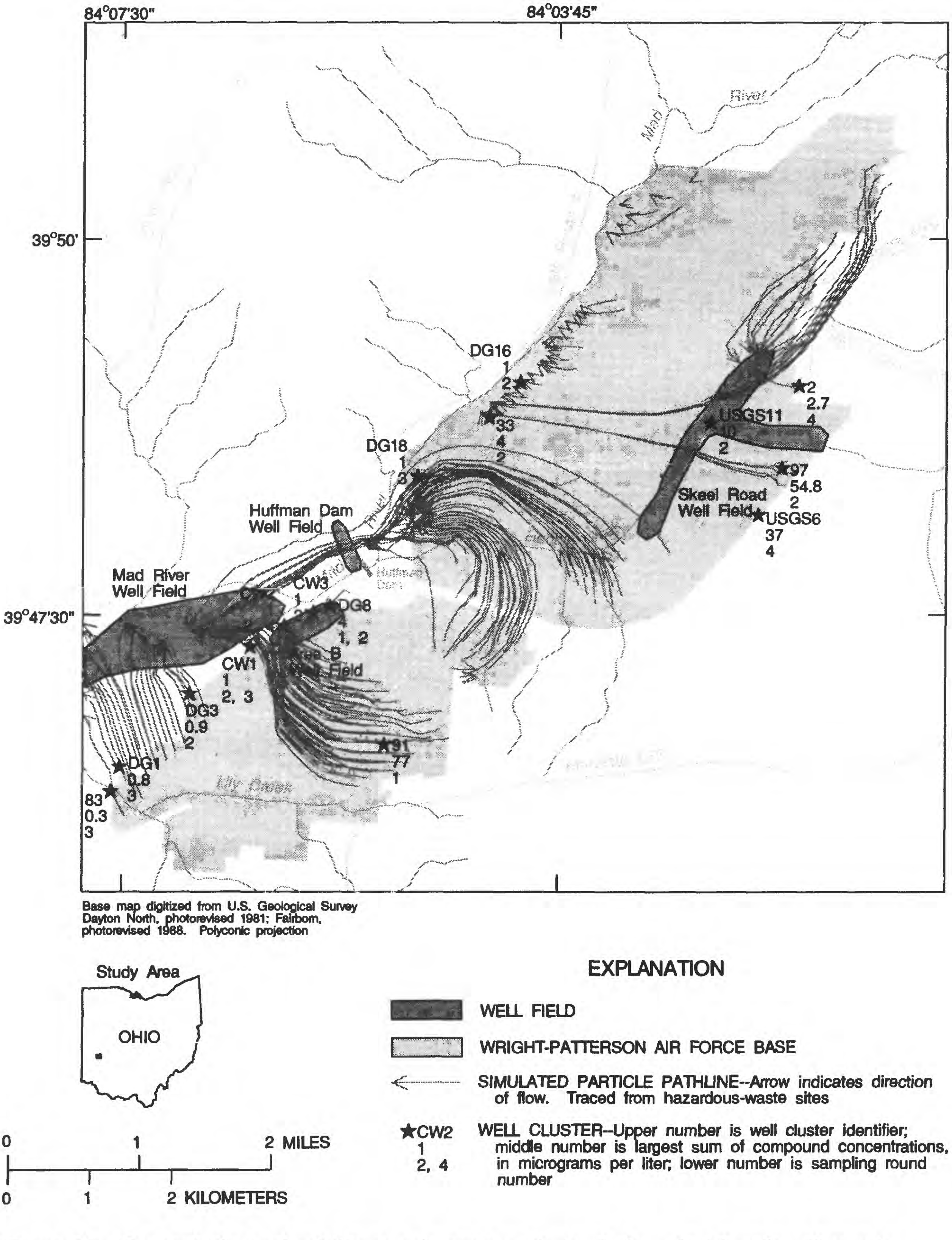
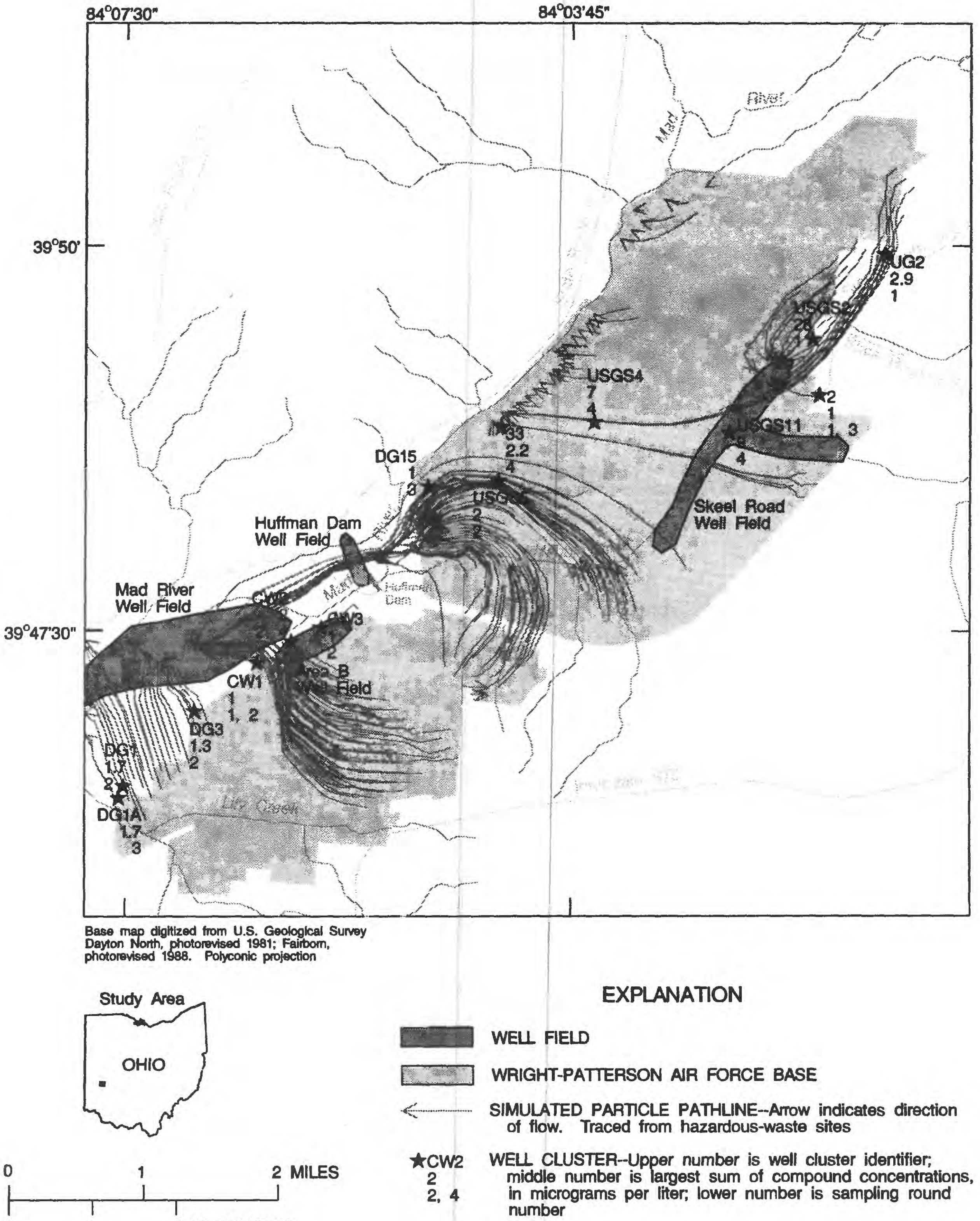


Figure 39. Exceedances of maximum contaminant levels for organic compounds in ground water, round 4, August-September 1994, Wright-Patterson Air Force Base, Ohio.



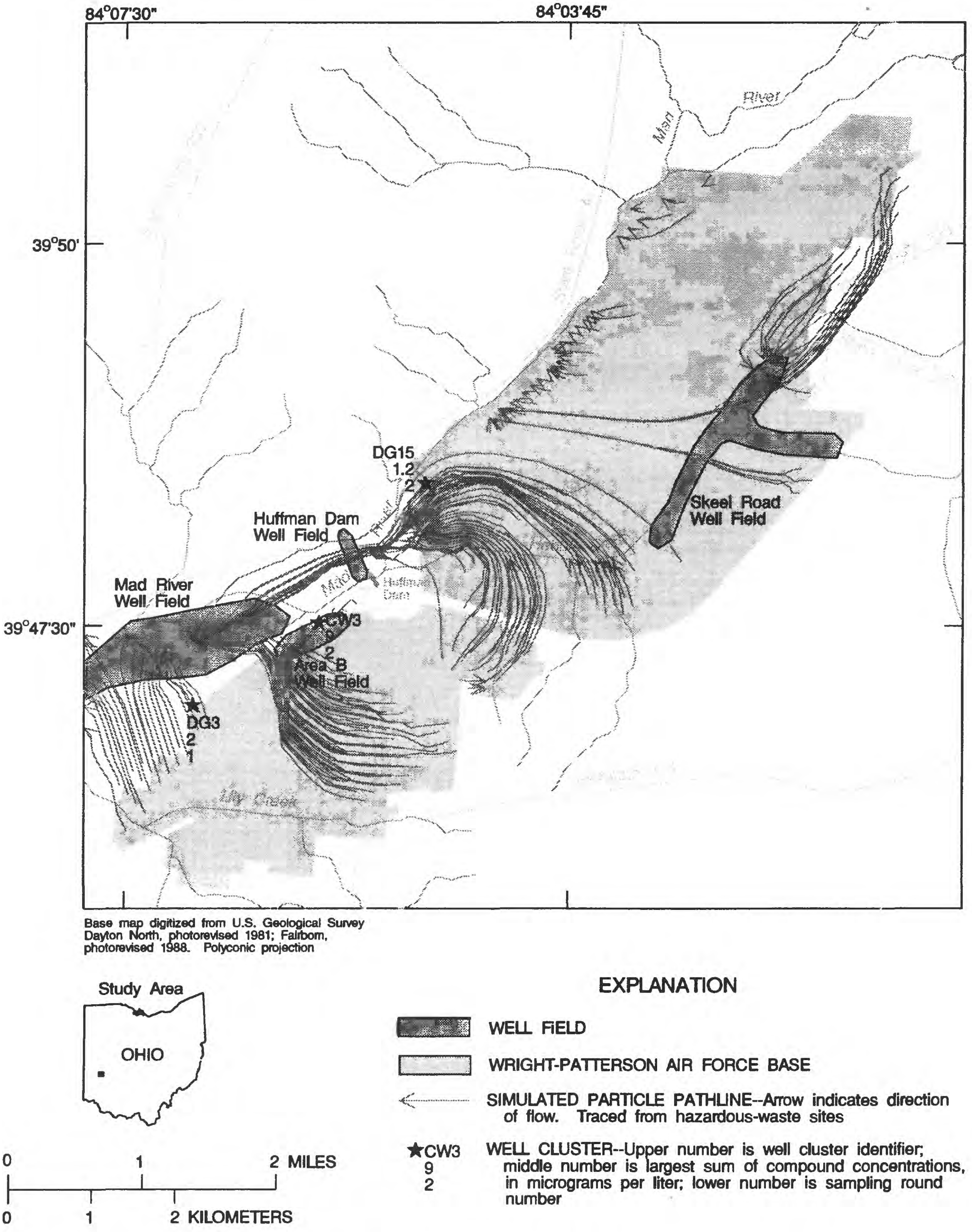
Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 41. Concentrations of volatile organic compounds in shallow glacial wells, all rounds, August 1993-September 1994, at Wright-Patterson Air Force Base, Ohio.



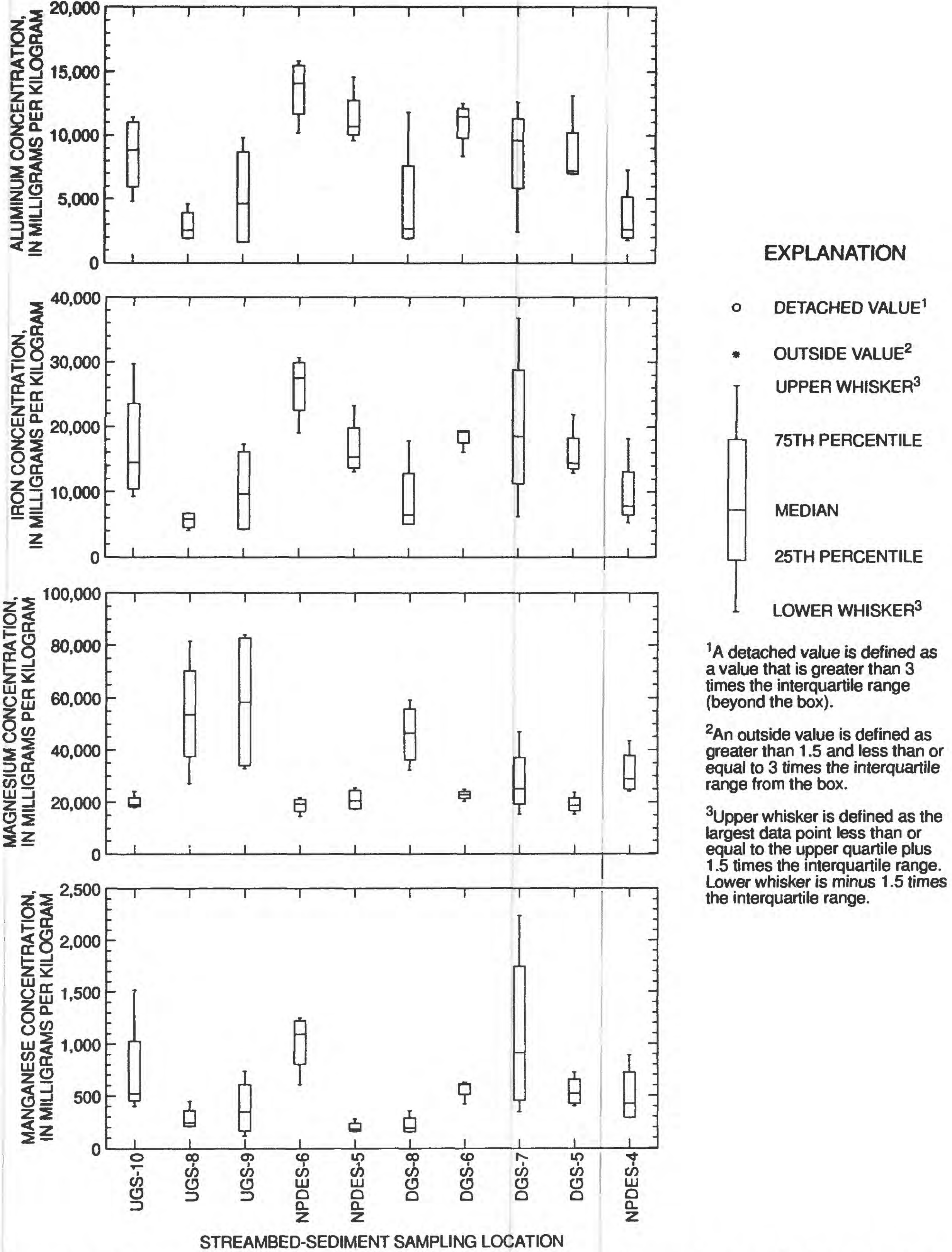
Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 42. Concentrations of volatile organic compounds in intermediate-depth glacial wells, all rounds, August 1993-September 1994, at Wright-Patterson Air Force Base, Ohio.



Base map digitized from U.S. Geological Survey Dayton North, photorevised 1981; Fairborn, photorevised 1988. Polyconic projection

Figure 43. Concentrations of volatile organic compounds in deep glacial wells, all rounds, August 1993-September 1994, at Wright-Patterson Air Force Base, Ohio.

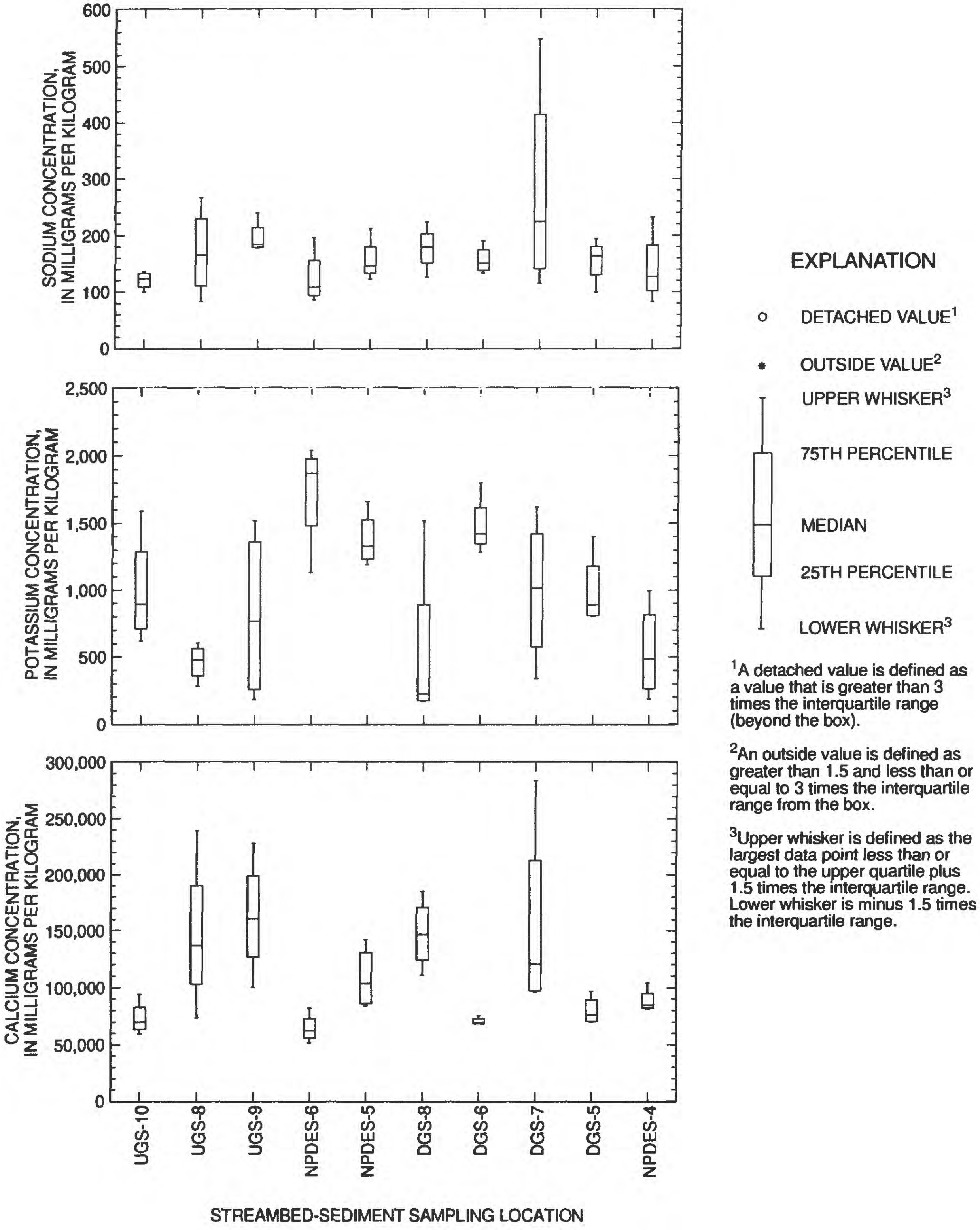


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 67. Concentrations of aluminum, iron, magnesium, and manganese in streambed-sediment samples, all rounds, August 1993-September 1994, in the Mad River subsystem, Wright-Patterson Air Force Base, Ohio.

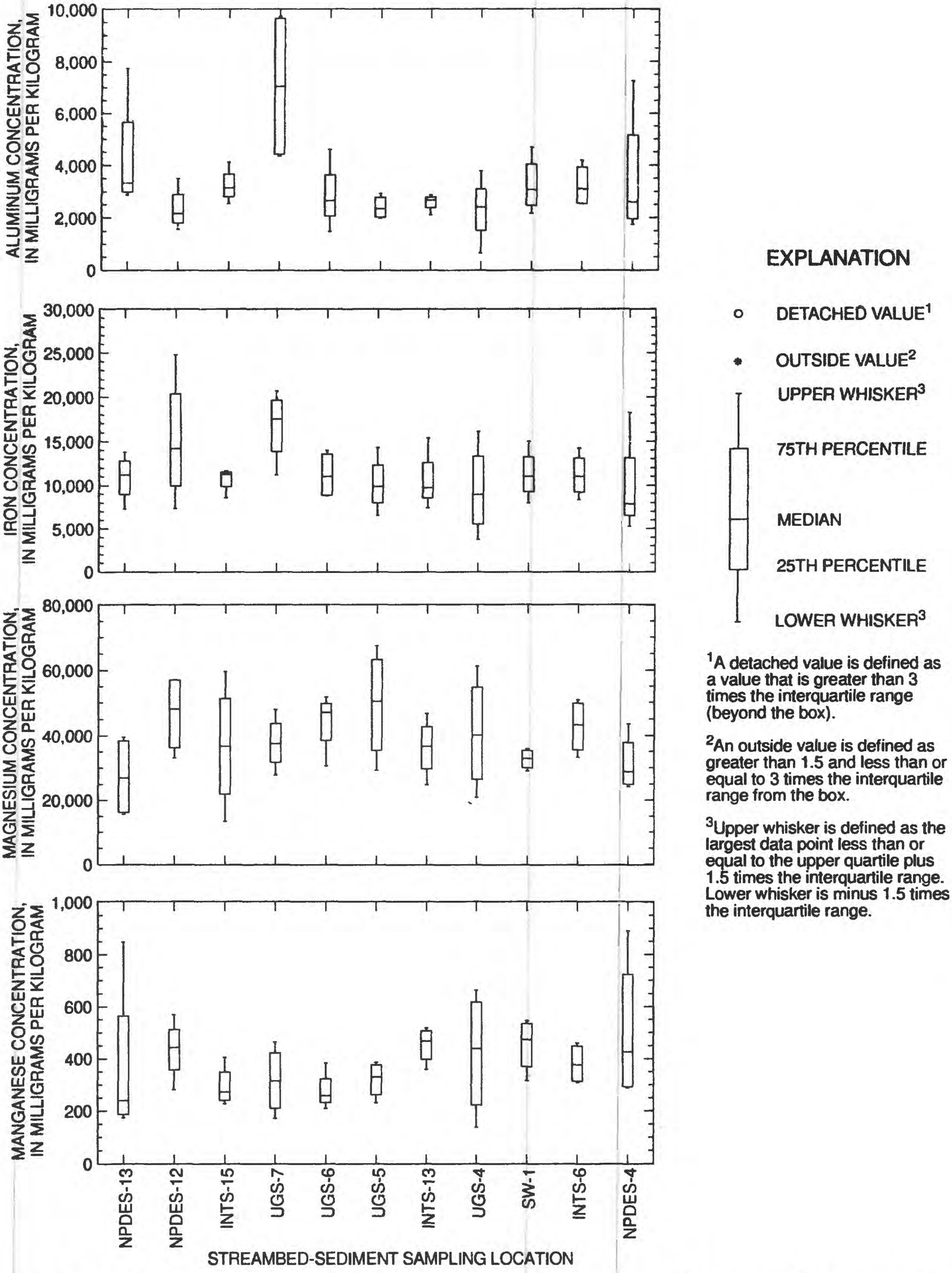


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 68. Concentrations of sodium, potassium, and calcium in streambed-sediment samples, all rounds, August 1993-September 1994, in the Mad River subsystem, Wright-Patterson Air Force Base, Ohio.

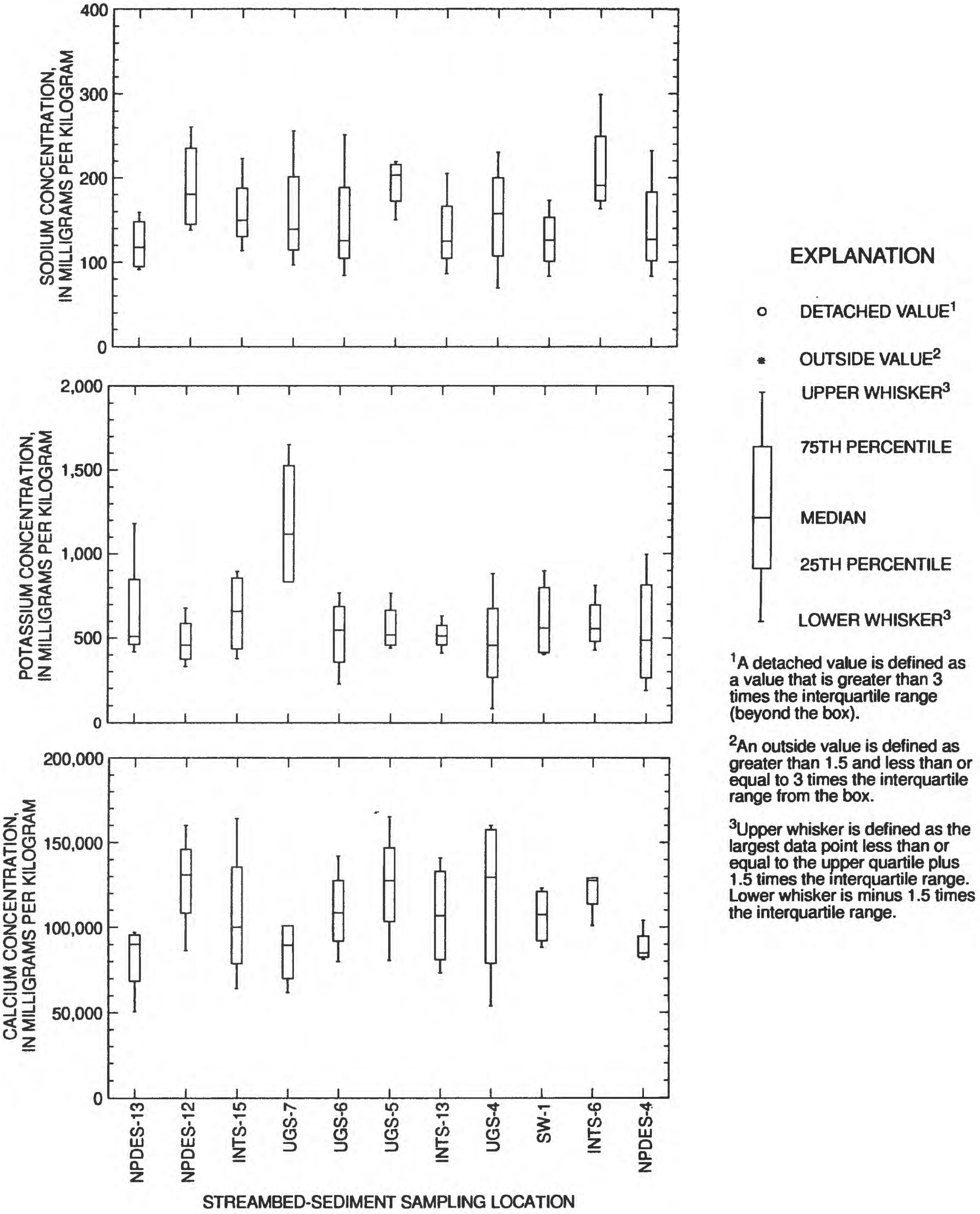


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 69. Concentrations of aluminum, iron, magnesium, and manganese in streambed-sediment samples, all rounds, August 1993-September 1994, in the Hebble Creek subsystem, Wright-Patterson Air Force Base, Ohio.

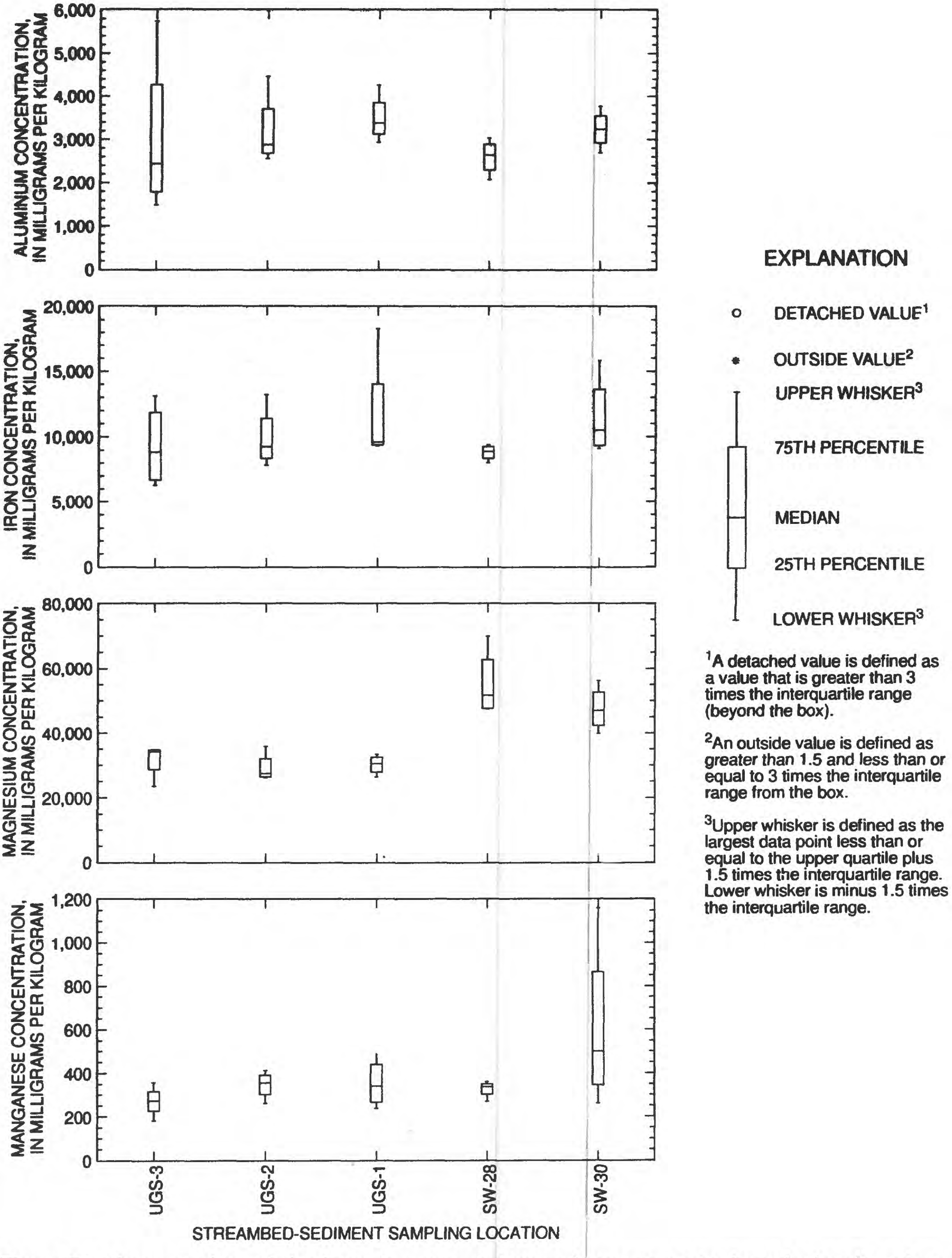


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 70. Concentrations of sodium, potassium, and calcium in streambed-sediment samples, all rounds, August 1993-September 1994, in the Hebble Creek subsystem, Wright-Patterson Air Force Base, Ohio.

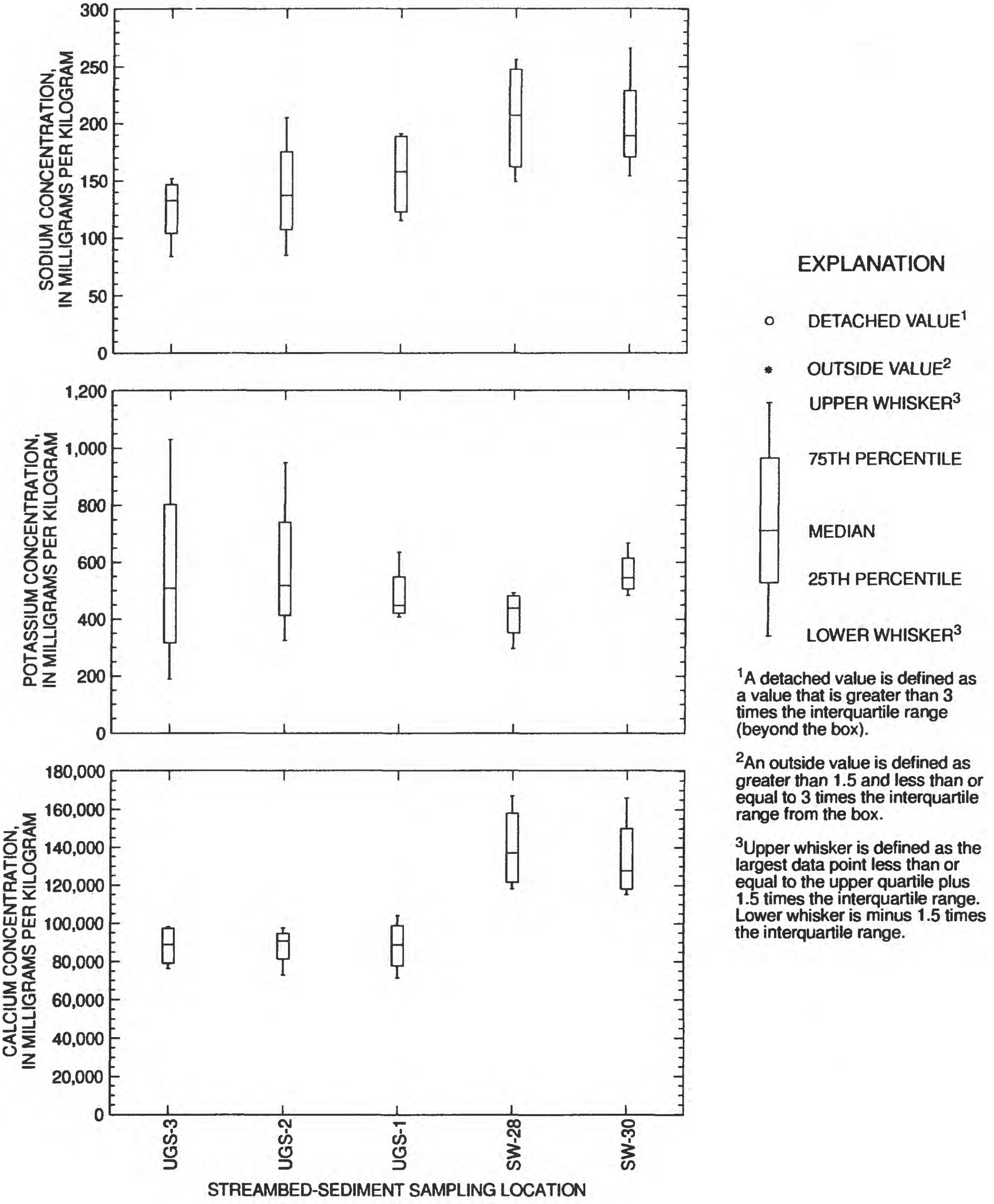


[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 71. Concentrations of aluminum, iron, magnesium, and manganese in streambed-sediment samples, all rounds, August 1993-September 1994, in the Lily Creek subsystem, Wright-Patterson Air Force Base, Ohio.



[1] A detached value is defined as a value that is greater than 3 times the interquartile range (beyond the box).

[2] An outside value is defined as greater than 1.5 and less than or equal to 3 times the interquartile range from the box.

[3] Upper whisker is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the interquartile range. Lower whisker is minus 1.5 times the interquartile range.

Figure 72. Concentrations of sodium, potassium, and calcium in streambed-sediment samples, all rounds, August 1993-September 1994, in the Lily Creek subsystem, Wright-Patterson Air Force Base, Ohio.

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date and type	Drilling method
UG1	* MT-249	MT-249	646759.	1545646.	800.5	802.95	250	200.3	190 - 200	2-in stainless steel	0.010-in slot, wire wrapped stainless steel	06/03/93	Rotasonic
	* MT-250	MT-250	646758.	1545658.	800.8	803.01	121.5	119.3	109 - 119	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/03/93	Rotasonic
	* MT-251	MT-251	646768.	1545659.	800.5	802.86	87	85.3	75 - 85	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/07/93	Rotasonic
	* MT-252	MT-252	646768.	1545648.	800.3	802.55	37	34.3	19 - 34	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/08/93	Rotasonic
UG2	* GR-433	GR-433	671684.	1572784.	826.2	828.38	250	192.3	182 - 192	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/23/93	Rotasonic
	GR-437	WP-NEA-MW05-1D	671668.	1572782.	826.4	827.81	37	29	22 - 27	2-in stainless steel	0.010-in slot stainless steel	08/19/92	Rotasonic
	GR-438	WP-NEA-MW05-2S	671675.	1572790.	825.5	827.22	20	20	7.5 - 17.4	2-in stainless steel	0.010-in slot stainless steel	10/05/92	Rotasonic
	GR-439	WP-NEA-MW05-3D	671678.	1572782.	825.8	827.67	88	88	81.2 - 85.9	2-in stainless steel	0.010-in slot stainless steel	10/09/92	Rotasonic
UG3	* GR-424	GR-424	675888.	1571297.	826.1	---	279	No well installed - borehole plugged			---	06/11/93	Rotasonic
	* GR-425	GR-425	675878.	1571299.	825.9	828.20	82	80.3	70 - 80	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/14/93	Rotasonic
	* GR-426	GR-426	675870.	1571300.	825.8	827.90	27	24.5	9.2 - 24.2	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/15/93	Rotasonic
UG8	* GR-412	GR-412	656390.	1561611.	831.5	833.86	107	80.3	70 - 80	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/26/93	Rotasonic
	*GR-413	GR-413	656389.	1561617.	831.4	834.00	37	33.3	18 - 33	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/26/93	Rotasonic
UG9	* GR-427	GR-427	664637.	1572425.	837.4	---	37	No well installed - borehole plugged			---	06/15/93	Rotasonic

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
UG10	* GR-423	GR-423	661556.	1569645.	840.4	---	22	No well installed - borehole plugged			---	06/08/93	Rotasonic
UG11	* GR-430	GR-430	664723.	1569969.	831.0	833.32	142	78.3	68 - 78	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/24/93	Rotasonic
	* GR-431	GR-431	664722.	1569960.	830.8	833.30	33	30.3	15 - 30	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/24/93	Rotasonic
DG1	* MT-234	MT-234	650766.	1542890.	784.7	787.23	38	36.9	21.6 - 36.6	2-in stainless steel	0.010-in slot wire wrapped stainless steel	03/23/93	Hollow stem auger
	* MT-239	MT-239	650733.	1542880.	784.7	786.93	247	215.3	205 - 215	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/14/93	Rotasonic
	* MT-240	MT-240	650728.	1542880.	784.7	786.56	45	42.3	37 - 42	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/17/93	Rotasonic
	* MT-241	MT-241	650721.	1542880.	784.8	786.65	130	128.8	118.5 - 128.5	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/18/93	Rotasonic
DG1A	* MT-235	MT-235	650305.	1542696.	781.8	783.85	38	33.4	18.1 - 33.1	2-in stainless steel	0.010-in slot wire wrapped stainless steel	03/25/93	Hollow stem auger
	* MT-236	MT-236	650315.	1542695.	781.7	---	246	No well installed - borehole plugged			---	05/03/93	Rotasonic
	* MT-237	MT-237	650315.	1542707.	781.8	784.08	58	54.8	44.5 - 54.5	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/06/93	Rotasonic
DG2	MT-231	EFDZ1-MW01B	651274.	1544481.	786.2	788.53	100	75	63 - 73	2-in stainless steel	0.010-in slot stainless steel	07/10/91	Rotasonic
	MT-232	EFDZ1-MW01C	651275.	1544470.	786.0	788.15	35	34	22 - 32	2-in stainless steel	0.010-in slot stainless steel	07/09/91	Rotasonic
	* MT-247	MT-247	651282.	1544483.	786.0	788.74	227	170.3	160 - 170	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/21/93	Rotasonic
DG3	* MT-238	MT-238	653699.	1545704.	781.5	784.18	37	35	19.7 - 34.7	2-in stainless steel	0.010-in slot wire wrapped stainless steel	03/29/93	Hollow stem auger

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
DG3	* MT-244	MT-244	653683.	1545720.	781.9	783.81	80	77.3	67 - 77	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/25/93	Rotasonic
	* MT-245	MT-245	653685.	1545705.	781.7	784.39	213	187.6	177.3 - 187.3	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/25/93	Rotasonic
	* MT-246	MT-246	653690.	1545712.	782.0	784.11	150	147.3	137 - 147	2-in stainless steel	0.015-in slot wire wrapped stainless steel	05/27/93	Rotasonic
DG4	* MT-242	MT-242	654594.	1546937.	785.2	787.77	137.5	75.3	65 - 75	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/18/93	Rotasonic
	* MT-243	MT-243	654590.	1546931.	785.1	787.85	37	33.3	18 - 33	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/19/93	Rotasonic
DG8	* MT-248	MT-248	657118.	1551428.	793.1	795.50	54	45.3	35 - 45	2-in stainless steel	0.010-in slot wire wrapped stainless steel	05/25/93	Rotasonic
	GR-287	19-564-M	657122.	1551437.	793.4	795.25	30	28.8	18.8 - 28.8	4-in stainless steel	0.010-in slot stainless steel	03/10/87	Hollow stem auger
DG10	* GR-418	GR-418	659081.	1554874.	791.0	---	23	No well installed - borehole plugged			---	06/07/93	Rotasonic
DG10A	* GR-428	GR-428	659448.	1554854.	790.8	792.97	67	59.3	49 - 59	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/17/93	Rotasonic
	* GR-429	GR-429	659438.	1554855.	790.9	793.08	27	25.3	10 - 25	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/17/93	Rotasonic
DG12	* GR-414	GR-414	662022.	1554578.	789.9	791.55	195	158.3	148 - 158	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/02/93	Rotasonic
	* GR-415	GR-415	662016.	1554580.	789.8	791.68	113	110.3	100 - 110	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/03/93	Rotasonic
	* GR-416	GR-416	662010.	1554581.	789.8	791.82	70	66.3	56 - 66	2-in stainless steel	0.015-in slot wire wrapped stainless steel	06/04/93	Rotasonic

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
DG12	* GR-417	GR-417	662004.	1554581.	789.6	791.92	17	16.3	6 - 16	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/04/93	Rotasonic
DG15	* GR-419	GR-419	662372.	1555025.	788.3	792.08	155	129.8	119.5 - 129.5	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/09/93	Rotasonic
	* GR-420	GR-420	662374.	1555020.	789.9	791.73	95	94.6	84.3 - 94.3	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/10/93	Rotasonic
	* GR-421	GR-421	662377.	1555017.	790.2	791.97	65.5	65.1	54.8 - 64.8	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/10/93	Rotasonic
	* GR-422	GR-422	662379.	1555013.	790.2	---	31	This well was plugged & abandoned			---	06/10/93	Rotasonic
	* GR-434	GR-434	662381.	1555009.	790.2	792.51	31.5	30.3	15 - 30	2-in stainless steel	0.010-in slot wire wrapped stainless steel	07/19/93	Rotasonic
DG16	GR-440	MW11A	666249.	1558944.	797.6	800.26	68	17	5 - 15	2-in stainless steel	0.010-in slot stainless steel	04/01/93	Rotasonic
USGS1	GR-315	GR-315	674693.	1566964.	814.8	816.81	267.5	267.5	262.5 - 267.5	4-in black steel	0.020-in slot wire wrapped stainless steel	12/20/88	Cable tool to bedrock, then rotary core
	GR-316	GR-316	674698.	1566960.	814.6	816.38	52.8	52.8	47.8 - 52.8	4-in stainless steel	0.010-in slot wire wrapped stainless steel	07/31/89	Air rotary with casing hammer
	GR-317	GR-317	674692.	1566958.	814.6	816.37	138	131.5	126 - 131.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	08/18/89	Air rotary with casing hammer
USGS2	GR-314	GR-314	668233.	1570208.	821.9	824.11	242.6	242	232 - 242	4-in black steel	0.020-in slot wire wrapped stainless steel	12/07/88	Cable tool to bedrock, then rotary core
	GR-318	GR-318	668231.	1570192.	821.7	823.93	48.4	48.4	43.4 - 48.4	4-in stainless steel	0.010-in slot wire wrapped stainless steel	10/10/89	Air rotary with casing hammer
	GR-319	GR-319	668218.	1570201.	822.0	824.19	160.5	160.5	150.5 - 160.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	10/27/89	Air rotary with casing hammer

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
USGS3	GR-303	GR-303	669706.	1562041.	803.6	805.79	61.9	61.4	51.4 - 61.4	4-in black steel	0.020-in slot wire wrapped stainless steel	11/06/88	Cable tool to bedrock, then rotary core
	GR-320	GR-320	669705.	1562047.	803.5	805.36	21.8	21.8	16.8 - 21.8	4-in stainless steel	0.010-in slot wire wrapped stainless steel	07/24/89	Air rotary with casing hammer
USGS4	GR-304	GR-304	665008.	1561560.	798.5	800.82	225.7	225.7	215.7 - 225.7	4-in black steel	0.020-in slot wire wrapped stainless steel	02/18/89	Cable tool to bedrock, then rotary core
	GR-321	GR-321	665003.	1561576.	798.6	800.22	45.7	42.6	37.1 - 42.6	4-in stainless steel	0.010-in slot wire wrapped stainless steel	08/24/89	Air rotary with casing hammer
	GR-322	GR-322	664992.	1561564.	798.7	800.21	147.2	147.2	137.2 - 147.2	4-in stainless steel	0.010-in slot wire wrapped stainless steel	11/03/89	Air rotary with casing hammer
USGS5	GR-305	GR-305	662614.	1557785.	796.8	799.36	158	157.6	147.6 - 157.6	4-in stainless steel	0.020-in slot wire wrapped stainless steel	11/20/88	Cable tool to bedrock, then rotary core
	GR-323	GR-323	662627.	1557792.	796.6	798.47	56.5	50.6	45.6 - 50.6	4-in stainless steel	0.010-in slot wire wrapped stainless steel	08/30/89	Air rotary with casing hammer
	GR-324	GR-324	662627.	1557777.	796.8	798.26	130.6	127.7	117.7 - 127.7	4-in stainless steel	0.010-in slot wire wrapped stainless steel	09/13/89	Air rotary with casing hammer
USGS6	GR-306	GR-306	660822.	1568734.	839.9	841.74	238.2	238.2	228.2 - 238.2	4-in black steel	0.020-in slot wire wrapped stainless steel	03/07/89	Cable tool to bedrock, then rotary core
	GR-330	GR-330	660830.	1568740.	839.9	841.80	49.5	49.5	39.5 - 49.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	05/16/90	Cable tool
	GR-331	GR-331	660837.	1568733.	839.9	841.19	115	115	105 - 115	4-in stainless steel	0.010-in slot wire wrapped stainless steel	05/22/90	Cable tool
USGS6	GR-332	GR-332	660829.	1568726.	840.0	841.56	196	195.5	185.5 - 195.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	05/15/90	Cable tool

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
USGS6	* GR-432	GR-432	660845.	1568740.	839.6	841.65	92	86.3	76 - 86	2-in stainless steel	0.010-in slot wire wrapped stainless steel	06/28/93	Rotasonic
USGS7	GR-307	GR-307	657587.	1565664.	838.7	840.89	277.6	277.6	267.6 - 277.6	4-in black steel	0.020-in slot wire wrapped stainless steel	02/28/90	Cable tool to bedrock, then rotary core
	GR-326	GR-326	657596.	1565676.	838.9	841.05	38.6	38.6	33.6 - 38.6	4-in stainless steel	0.010-in slot wire wrapped stainless steel	09/20/89	Air rotary with casing hammer
	GR-327	GR-327	657599.	1565655.	838.6	840.81	153.8	153.8	143.8 - 153.8	4-in stainless steel	0.010-in slot wire wrapped stainless steel	10/09/89	Air rotary with casing hammer
	GR-328	GR-328	657608.	1565667.	838.4	840.88	249.8	244.5	239.5 - 244.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	01/22/90	Air rotary with casing hammer
USGS8	GR-308	GR-308	658289.	1556681.	800.0	802.01	27.6	27.6	5 - 27.6	6-in black steel	Open hole	02/14/89	Cable tool to bedrock, then rotary core
USGS9	GR-309	GR-309	653999.	1555158.	976.7	978.75	116.6	104	44 - 104	6-in black steel	Open hole	03/27/89	Mud rotary to bedrock, then rotary core
	GR-312	GR-312	653984.	1555154.	976.6	978.51	135.9	135.9	116.3 - 135.9	6-in black steel	Open hole	03/27/89	Mud rotary to bedrock, then rotary core
USGS10	GR-310	GR-310	650637.	1555527.	974.1	976.05	51.7	51.7	41.7 - 51.7	4-in black steel	0.020-in slot wire wrapped stainless steel	03/07/89	Cable tool to bedrock, then rotary core
USGS11	GR-311	GR-311	664656.	1566794.	812.7	814.62	287.3	287.3	277.3 - 287.3	4-in black steel	0.020-in slot wire wrapped stainless steel	03/09/89	Cable tool to bedrock, then rotary core
	GR-333	GR-333	664657.	1566808.	812.7	814.84	35.5	35.1	25.1 - 35.1	4-in stainless steel	0.010-in slot wire wrapped stainless steel	04/16/90	Cable tool
	GR-334	GR-334	664648.	1566801.	812.8	814.23	155	155	145 - 155	4-in stainless steel	0.010-in slot wire wrapped stainless steel	04/25/90	Cable tool

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
USGS11	GR-335	GR-335	664663.	1566800.	812.8	814.77	235	234.5	224.5 - 234.5	4-in stainless steel	0.010-in slot wire wrapped stainless steel	05/01/90	Cable Tool
	GR-436	WP-NEA-MW38-1I	664665.	1566789.	812.5	814.52	57	55	45 - 55	2-in stainless steel	0.010-in slot stainless steel	01/04/93	Rotasonic
USGS12	MT-133	MT-133	649890.	1546893.	792.1	794.34	241.7	241.7	231.7 - 241.7	4-in black steel	0.020-in slot wire wrapped stainless steel	03/19/89	Cable tool to bedrock, then rotary core
	MT-152	MT-152	649879.	1546893.	792.3	794.41	36	36	26 - 36	4-in stainless steel	0.010-in slot wire wrapped stainless steel	04/11/90	Cable tool
	MT-153	MT-153	649885.	1546884.	792.0	794.10	90.2	90.2	80.2 - 90.2	4-in stainless steel	0.010-in slot wire wrapped stainless steel	04/13/90	Cable tool
USGS13	GR-313	GR-313	651978.	1551019.	807.6	809.44	94.3	94.3	84.3 - 94.3	4-in black steel	0.020-in slot wire wrapped stainless steel	03/16/89	Cable tool to bedrock, then rotary core
	GR-329	GR-329	651968.	1551023.	807.2	809.33	55	55	45 - 55	4-in stainless steel	0.010-in slot wire wrapped stainless steel	04/11/90	Cable tool
1	GR-283	00-501-M	649891.	1551685.	825.8	827.89	20	20	5 - 20	4-in stainless steel	0.010-in slot stainless steel	03/17/87	Cable tool
2	GR-288	00-500-M	666028.	1570391.	833.7	835.34	32	32	17 - 32	4-in stainless steel	0.010-in slot stainless steel	03/04/87	Cable tool
	GR-289	00-600-M	666022.	1570393.	833.7	834.98	90.4	90.4	80.4 - 90.4	4-in stainless steel	0.010-in slot stainless steel	03/04/87	Cable tool
	GR-435	WP-NEA-MW40-1I	666021.	1570382.	833.2	835.01	55.5	55.5	43.1 - 53.1	2-in stainless steel	0.010-in slot stainless steel	04/02/93	Rotasonic
33	GR-214	05-DM-123S-M	664888.	1558206.	795.4	798.30	15	15	5 - 15	4-in stainless steel	0.010-in slot stainless steel	05/22/86	Auger
	GR-215	05-DM-123I-M	664872.	1558200.	795.7	798.18	24.75	24.75	19.75 - 24.75	4-in stainless steel	0.010-in slot stainless steel	06/01/86	Auger
	GR-216	05-DM-123D-M	664862.	1558199.	795.5	797.83	31.8	31.8	26.8 - 31.8	4-in stainless steel	0.010-in slot stainless steel	06/01/86	Auger

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
34	GR-280	12-548-M	667374.	1560373.	801.2	803.13	23.1	23.1	8.1 - 23.1	4-in stainless steel	0.010-in slot stainless steel	02/21/87	Cable tool
35	GR-278	12-622-M	667077.	1560294.	803.9	805.98	50.5	49.9	39.9 - 49.9	4-in stainless steel	0.010-in slot stainless steel	03/19/87	Hollow stem auger
38	GR-234	11-542-M	657082.	1562274.	816.2	818.06	18.1	18.1	8.1 - 18.1	4-in stainless steel	0.010-in slot stainless steel	01/15/87	Hollow stem auger
	GR-242	11-618-M	657076.	1562269.	816.1	818.04	65.5	65.1	55.1 - 65.1	4-in stainless steel	0.010-in slot stainless steel	01/14/87	Cable tool
42	GR-236	11-544-M	658546.	1561582.	804.4	806.28	20	17.1	7.1 - 17.1	4-in stainless steel	0.010-in slot stainless steel	01/13/87	Hollow stem auger
	GR-244	11-620-M	658547.	1561588.	804.3	805.70	66.6	66.6	56.6 - 66.6	4-in stainless steel	0.010-in slot stainless steel	01/27/87	Cable tool
60	GR-256	14-626-M	671769.	1571165.	822.3	824.16	75.2	75.2	65.2 - 75.2	4-in stainless steel	0.010-in slot stainless steel	01/31/87	Cable tool
	GR-257	14-553-M	671775.	1571167.	822.3	824.04	20	18.3	8.3 - 18.3	4-in stainless steel	0.010-in slot stainless steel	01/14/87	Hollow stem auger
80	GR-264	08-522-M	660586.	1555857.	791.2	793.35	15	14.3	4.3 - 14.3	4-in stainless steel	0.010-in slot stainless steel	01/05/87	Hollow stem auger
81	MT-125	10-532-M	649276.	1543754.	785.7	787.70	27	27	17 - 27	4-in stainless steel	0.010-in slot stainless steel	02/18/87	Cable tool
	MT-129	10-616-M	649291.	1543757.	785.5	787.15	54	53.8	43.8 - 53.8	4-in stainless steel	0.010-in slot stainless steel	02/17/87	Cable tool
83	MT-126	10-534-M	649797.	1542530.	780.9	782.72	30	26.7	11.7 - 26.7	4-in stainless steel	0.010-in slot stainless steel	03/05/87	Cable tool
89	GR-275	13-624-M	674252.	1572497.	829.1	831.15	106	106	96 - 106	4-in stainless steel	0.010-in slot stainless steel	02/11/87	Cable tool
	GR-299	13-551-M	674254.	1572490.	829.3	831.05	23	22.2	12.2 - 22.2	4-in stainless steel	0.010-in slot stainless steel	03/09/87	Cable tool
91	GR-286	22-575-M	651491.	1553550.	882.3	883.91	15.4	15.4	5.4 - 15.4	4-in stainless steel	0.010-in slot stainless steel	04/01/87	Hollow stem auger
97	GR-298	23-578-M	662705.	1569711.	838.1	840.05	43	41.5	31.5 - 41.5	4-in stainless steel	0.010-in slot stainless steel	03/05/87	Hollow stem auger

Table 4. Borehole and construction details of wells in the Basewide Monitoring Program, Wright-Patterson Air Force Base, Ohio—*Continued*

[*, drilled as part of Basewide Monitoring Program; USGS, U.S. Geological Survey; IRP, Installation Restoration Program; MP, measuring point; TD, total depth; ft-bls, feet below land surface; ft-asl, feet above sea level. Northings and eastings are in State-plane coordinates, 1927 datum . --, no data]

Cluster name	USGS well number	IRP well number	Northing (feet)	Easting (feet)	Ground altitude (ft-asl)	MP altitude (ft-asl)	Borehole TD (ft-bls)	Well TD (ft-bls)	Screened interval (ft-bls)	Casing diameter and type	Screen size and type	Date completed	Drilling method
CW1	MT-222	CW1-27	655533.	1548179.	786.9	789.46	30	27	17 - 27	2-in stainless steel	0.010-in slot stainless steel	09/10/90	Hollow stem auger
	MT-223	CW1-35	655539.	1548190.	787.2	789.38	44	35.5	25.5 - 35.5	2-in stainless steel	0.010-in slot stainless steel	09/09/90	Hollow stem auger
	MT-224	CW1-121	655523.	1548158.	787.2	789.50	150	121	111 - 121	2-in stainless steel	0.010-in slot stainless steel	09/26/90	Cable tool
CW2	MT-225	CW2-35	656366.	1549567.	791.7	793.45	50	35	15 - 35	2-in stainless steel	0.010-in slot stainless steel	09/10/90	Hollow stem auger
	MT-226	CW2-44	656374.	1549582.	791.5	793.76	50	44.25	34.25 - 44.25	2-in stainless steel	0.010-in slot stainless steel	09/12/90	Hollow stem auger
	MT-227	CW2-90	656383.	1549596.	791.6	793.65	150	90	80 - 90	2-in stainless steel	0.010-in slot stainless steel	09/25/90	Cable tool
CW3	MT-228	CW3-27	656889.	1550744.	788.8	791.21	30	27.33	7.33 - 27.33	2-in stainless steel	0.010-in slot stainless steel	09/11/90	Hollow stem auger
	MT-229	CW3-35	656896.	1550758.	788.9	791.20	42	35	25 - 35	2-in stainless steel	0.010-in slot stainless steel	09/11/90	Hollow stem auger
	MT-230	CW3-77	656905.	1550781.	789.1	791.26	106	76.8	66.8 - 76.8	2-in stainless steel	0.010-in slot stainless steel	09/24/90	Cable tool
LF08-01	GR-401	LF08-MW01C	654124.	1557144.	904.0	905.92	17	15	7.2 - 15	2-in stainless steel	0.010-in slot stainless steel	02/19/91	Cable tool
	GR-402	LF08-MW01A	654132.	1557154.	903.7	905.69	42.2	29.4	23.8 - 29.4	2-in stainless steel	0.010-in slot stainless steel	02/19/91	Cable tool

Table 12. Characteristics of wells sampled in the first year (1993-94) of the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio

[WT, water table; IN, intermediate; DP, deep; glac, glacial aquifer; bed, bedrock aquifer; I, interior; U, upgradient; D, downgradient]

Well	Cluster	Altitude (feet above sea level)	Total depth (feet)	Depth to top of screen (feet)	Length of screen (feet)	Aquifer	Aquifer-depth code	Position code
GR-283	1	825.9	20.0	5.0	15.0	glac	WT	I
GR-288	2	833.7	32.0	17.0	15.0	glac	WT	U
GR-289	2	833.7	90.4	80.4	10.0	glac	IN	U
GR-435	2	833.2	55.5	42.5	10.0	glac	IN	U
GR-214	33	795.4	15.0	5.0	10.0	glac	WT	D
GR-215	33	795.7	24.8	19.8	5.0	glac	IN	D
GR-216	33	795.5	31.8	26.8	5.0	glac	IN	D
GR-280	34	801.2	23.1	8.1	15.0	glac	WT	D
GR-278	35	803.8	49.9	39.9	10.0	glac	IN	D
GR-234	38	816.2	18.1	8.1	10.0	glac	WT	I
GR-242	38	816.1	65.1	55.1	10.0	glac	IN	I
GR-236	42	804.4	17.1	7.1	10.0	glac	WT	I
GR-244	42	804.3	66.6	56.5	10.1	glac	IN	I
GR-256	60	822.3	75.2	65.2	10.0	glac	IN	I
GR-257	60	822.3	18.3	8.3	10.0	glac	WT	I
GR-264	80	791.2	15.0	4.3	10.7	glac	WT	I
MT-125	81	785.6	27.0	17.0	10.0	glac	WT	I
MT-129	81	785.5	53.8	43.6	10.2	glac	IN	I
MT-126	83	780.9	30.0	11.7	15.0	glac	WT	D
GR-275	89	828.8	106.0	96.0	10.0	glac	IN	I
GR-299	89	829.0	22.2	12.2	10.0	glac	WT	I
GR-286	91	882.0	15.4	5.4	10.0	glac	WT	I
GR-298	97	838.3	41.5	31.5	10.0	glac	WT	I
MT-222	CW1	786.9	27.0	17.0	10.0	glac	WT	D
MT-223	CW1	787.2	35.5	25.5	10.0	glac	IN	D
MT-224	CW1	787.2	121.0	111.0	10.0	glac	IN	D
MT-225	CW2	791.7	35.0	25.0	10.0	glac	WT	D
MT-226	CW2	791.5	44.2	34.2	10.0	glac	IN	D
MT-227	CW2	791.6	90.0	80.0	10.0	glac	IN	D
MT-228	CW3	788.8	27.3	7.3	20.0	glac	WT	D
MT-229	CW3	788.9	35.0	25.0	10.0	glac	IN	D
MT-230	CW3	789.1	76.8	66.8	10.0	glac	DP	D
MT-234	DG1	784.7	36.9	21.6	15.0	glac	WT	D
MT-239	DG1	784.7	215.3	205.0	10.0	glac	DP	D
MT-240	DG1	784.7	42.3	37.0	5.0	glac	IN	D
MT-241	DG1	784.8	128.8	118.5	10.0	glac	IN	D
GR-428	DG10A	790.8	59.3	49.0	10.0	glac	DP	D
GR-429	DG10A	790.9	25.3	10.0	15.0	glac	WT	D
GR-414	DG12	789.9	158.3	148.0	10.0	glac	DP	D
GR-415	DG12	789.8	110.3	100.0	10.0	glac	IN	D

Table 12. Characteristics of wells sampled in the first year (1993-94) of the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio—*Continued*

Well	Cluster	Altitude (feet above sea level)	Total depth (feet)	Depth to top of screen (feet)	Length of screen (feet)	Aquifer	Aquifer-depth code	Position code
GR-416	DG12	789.8	66.3	56.0	10.0	glac	IN	D
GR-417	DG12	789.6	16.3	6.0	10.0	glac	WT	D
GR-419	DG15	788.4	129.8	119.5	10.0	glac	DP	D
GR-420	DG15	789.9	94.6	84.3	10.0	glac	IN	D
GR-421	DG15	790.2	65.1	54.8	10.0	glac	IN	D
GR-422	DG15	790.2	30.9	20.6	10.0	glac	IN	D
GR-434	DG15	790.2	30.3	15.0	15.0	glac	WT	D
GR-440	DG16	797.6	17.0	5.0	10.0	glac	WT	D
MT-235	DG1A	781.8	33.4	18.1	15.0	glac	WT	D
MT-237	DG1A	781.8	54.8	44.5	10.0	glac	IN	D
MT-231	DG2	786.2	75.0	63.0	10.0	glac	IN	D
MT-232	DG2	786.0	34.0	22.0	10.0	glac	WT	D
MT-247	DG2	786.0	170.3	160.0	10.0	glac	IN	D
MT-238	DG3	781.5	35.0	19.7	15.0	glac	WT	D
MT-244	DG3	781.9	77.3	67.0	10.0	glac	IN	D
MT-245	DG3	781.7	187.8	177.3	10.0	glac	DP	D
MT-246	DG3	782.0	147.3	137.0	10.0	glac	IN	D
MT-242	DG4	785.2	75.3	65.0	10.0	glac	IN	D
MT-243	DG4	785.1	33.5	18.0	15.0	glac	WT	D
GR-287	DG8	793.4	28.8	18.8	10.0	glac	WT	D
MT-248	DG8	793.1	45.3	35.0	10.0	glac	DP	D
GR-401	LF08-01	904.0	17.0	7.2	7.8	glac	WT	U
GR-402	LF08-01	903.7	29.4	23.8	5.6	glac	DP	U
MT-249	UG1	800.5	200.5	190.0	10.0	glac	IN	U
MT-250	UG1	800.8	119.5	109.0	10.0	glac	IN	U
MT-251	UG1	800.5	85.3	75.0	10.0	glac	IN	U
MT-252	UG1	800.3	34.5	19.0	15.0	glac	WT	U
GR-430	UG11	831.0	78.3	68.0	10.0	glac	IN	I
GR-431	UG11	830.8	30.3	15.0	15.0	glac	WT	I
GR-433	UG2	826.2	192.3	182.0	10.0	glac	IN	I
GR-437	UG2	826.4	29.0	22.0	5.0	glac	IN	I
GR-438	UG2	825.5	20.0	7.5	10.0	glac	WT	I
GR-439	UG2	825.8	88.0	81.2	4.7	glac	IN	I
GR-425	UG3	825.9	80.3	70.0	10.0	glac	IN	U
GR-426	UG3	825.8	24.5	9.2	15.0	glac	WT	U
GR-412	UG8	831.5	80.5	70.0	10.0	glac	DP	U
GR-413	UG8	831.4	33.5	18.0	15.0	glac	WT	U
GR-315	USGS1	814.8	268	258.0	10.0	bed	bed	U
GR-316	USGS1	814.6	52.8	47.8	5.0	glac	IN	U
GR-317	USGS1	814.6	131.0	126.0	5.0	glac	IN	U
GR-310	USGS10	974.1	51.6	41.6	10.0	bed	bed	U

Table 12. Characteristics of wells sampled in the first year (1993-94) of the Basewide Monitoring Program at Wright-Patterson Air Force Base, Ohio—*Continued*

Well	Cluster	Altitude (feet above sea level)	Total depth (feet)	Depth to top of screen (feet)	Length of screen (feet)	Aquifer	Aquifer-depth code	Position code
GR-311	USGS11	812.7	287.0	277.3	10.0	bed	bed	I
GR-333	USGS11	812.7	35.1	25.1	10.0	glac	WT	I
GR-334	USGS11	812.8	155.0	145.0	10.0	glac	IN	I
GR-335	USGS11	812.8	234.0	224.0	10.0	glac	IN	I
GR-436	USGS11	812.5	57.0	45.0	10.0	glac	IN	I
MT-133	USGS12	792.1	241.0	231.0	10.0	bed	bed	I
MT-152	USGS12	792.3	36.0	26.0	10.0	glac	WT	I
MT-153	USGS12	792.0	90.2	80.2	10.0	glac	IN	I
GR-313	USGS13	807.6	94.3	84.3	10.0	bed	bed	I
GR-329	USGS13	807.2	55.0	45.0	10.0	glac	IN	I
GR-314	USGS2	821.9	243.0	233.0	10.0	bed	bed	I
GR-318	USGS2	821.7	48.4	43.4	5.0	glac	IN	I
GR-319	USGS2	822.0	160.0	150.0	10.0	glac	IN	I
GR-303	USGS3	803.6	62.0	52.0	10.0	bed	bed	D
GR-320	USGS3	803.5	21.7	16.7	5.0	glac	WT	D
GR-304	USGS4	798.5	226.0	216.0	10.0	bed	bed	I
GR-321	USGS4	798.6	42.6	37.1	5.5	glac	IN	I
GR-322	USGS4	798.7	147.0	137.0	10.0	glac	IN	I
GR-305	USGS5	796.8	158.0	148.0	10.0	bed	bed	I
GR-323	USGS5	796.7	50.6	45.1	5.5	glac	IN	I
GR-324	USGS5	796.8	128.0	116.0	12.0	glac	IN	I
GR-306	USGS6	839.9	238.0	228.0	10.0	bed	bed	U
GR-330	USGS6	839.9	49.5	39.5	10.0	glac	WT	U
GR-331	USGS6	839.9	115.0	105.0	10.0	glac	IN	U
GR-332	USGS6	840.0	195.0	185.0	10.0	glac	DP	U
GR-432	USGS6	839.6	86.3	76.0	10.0	glac	IN	U
GR-307	USGS7	838.7	278.0	268.0	10.0	bed	bed	U
GR-326	USGS7	838.9	38.6	33.6	5.0	glac	WT	U
GR-327	USGS7	838.6	154.0	144.0	10.0	glac	IN	U
GR-328	USGS7	838.4	244.0	239.0	5.0	glac	DP	U
GR-308	USGS8	800.0	27.6	10.7	16.9	bed	bed	I
GR-309	USGS9	976.7	105.0	44.0	60.0	bed	bed	I
GR-312	USGS9	976.6	136.0	116.0	20.0	bed	bed	I

Table 25. Minor constituents (unfiltered) by administrative area and position along the regional ground-water gradient, rounds 1 and 2, August 1993 - Jauary 1994, glacial wells, Wright-Patterson Air Force Base, Ohio

[All concentrations in micrograms per liter; D, downgradient; I, interior; U, upgradient; --, no detections]

Constituent	Position Code	Areas A and C					Area B				
		Minimum	Maximum	Number of detects	Mean	Median	Minimum	Maximum	Number of detects	Mean	Median
Aluminum	D	16.3	178	6	49.8	26.2	15.6	731	20	158	62.2
	I	44.3	5,750	13	712	233	31	32.8	2	31.9	31.9
	U	18.7	960	10	156	64.4	34.3	1,580	6	517	202
Antimony	D	29.3	36.9	2	33.1	33.1	33.8	47.9	6	38.7	37.8
	I	--	--	--	--	--	35.9	35.9	1	--	--
	U	32.2	32.2	1	--	--	38.9	38.9	1	--	--
Arsenic	D	1.9	18.3	16	8.9	10.3	2.4	11.2	10	4.6	3.4
	I	0.5	20.4	26	7.1	6.7	3.4	7.6	2	5.5	5.5
	U	1.5	7.4	12	4.8	4.9	2.7	14.3	6	8.4	6.9
Barium	D	74.8	395	34	206	159	40.4	333	54	147	122
	I	50.0	913	60	226	158	110	279	13	184	166
	U	35.2	308	35	174	153	81.5	462	12	301	310
Bromide	D	200	240	2	220	220	100	300	7	240	300
	I	42	310	6	210	295	100	360	4	240	245
	U	29,200	29,200	1	--	--	--	--	--	--	--
Chromium	D	--	--	--	--	--	3.9	323	15	56.1	16.0
	I	4.0	1,310	10	152	13.6	3.6	126	4	37.2	9.7
	U	5.6	162	9	28.2	8.0	4.8	25.9	5	13.8	10.7
Cobalt	D	--	--	--	--	--	7.6	34.2	7	15.0	9.9
	I	--	--	--	--	--	7.7	7.7	1	7.7	7.7
	U	8	8	1	--	--	--	--	--	--	--
Copper	D	4.1	4.3	2	4.2	4.2	4.8	13.3	5	7.32	5.3
	I	21.4	21.4	1	--	--	9.5	13	2	11.3	11.25
	U	2.7	7.2	4	4.53	4.1	4.2	28.7	4	14.1	11.8
Cyanide	D	57	57	1	--	--	13	13	1	13	13
	I	--	--	--	--	--	--	--	--	--	--
	U	10	10	1	--	--	--	--	--	--	--

Table 25. Minor constituents (unfiltered) byadministrative area and position along the regional ground-water gradient, rounds 1 and 2, August 1993 - January 1994, glacial wells, Wright-Patterson Air Force Base, Ohio—*Continued*

Constituent	Position Code	Areas A and C					Area B				
		Minimum	Maximum	Number of detects	Mean	Median	Minimum	Maximum	Number of detects	Mean	Median
Iron	D	9.5	10,900	31	1,990	1,620	10.4	5,910	49	1,170	305
	I	60.9	9,880	51	1,910	1,680	6.8	2,310	13	491	236
	U	57.8	3,920	30	1,230	686	111	4,520	12	2,060	2,350
Lead	D	0.8	13.2	8	3.1	1.7	1.3	6.5	4	3.1	2.3
	I	1.1	4.2	9	1.8	1.2	1.8	1.8	1	--	--
	U	1.3	2.5	3	1.8	1.5	1.1	3.6	3	2.7	3.3
Manganese	D	2.9	917	33	218	116	2.3	56	44	121	72.2
	I	1.6	1,390	54	141	81.7	2.1	1,160	13	191	26.1
	U	1.6	211	29	65.9	62.9	4.1	214	12	72.8	25.5
Nickel	D	23.3	34.3	2	28.8	28.8	15.4	135	8	62.9	51.3
	I	25.5	239	10	75.7	65.4	21.2	45.6	3	33.5	33.6
	U	11.8	85.4	7	40.2	32.7	26.5	41.4	3	33.8	33.5
Nitrate	D	1,000	1,600	2	1,300	1,300	100	3,800	25	2,000	2,100
	I	800	5,600	16	2,400	2,000	400	900	5	700	780
	U	310	4,200	10	2,400	2,550	290	3,600	3	2,000	2,200
Selenium	D	--	--	--	--	--	2.3	3.1	2	2.7	2.7
	I	2.6	15	6	6.5	5.6	--	--	--	--	--
	U	--	--	--	--	--	--	--	--	--	--
Silver	D	--	--	--	--	--	2.2	2.2	1	--	--
	I	19.4	19.4	--	--	19.4	--	--	--	--	--
	U	--	--	--	--	--	1.8	1.3	1	--	--
Thallium	D	1.1	1.1	1	--	--	3.2	3.2	1	--	--
	I	1.4	2.1	2	1.8	1.8	--	--	--	--	--
	U	2.5	2.5	1	--	--	--	--	--	--	--
Vanadium	D	4.8	4.9	2	4.9	4.9	0.7	2.3	5	1.4	1.3
	I	2	5.6	7	3.2	2.8	--	--	--	--	--
	U	--	--	--	--	--	--	--	--	--	--
Zinc	D	6.6	6.6	1	--	--	1.8	12.7	6	7.7	8.1
	I	2.6	57.3	15	12.7	9.4	3.2	3.2	1	--	--
	U	1.8	27.3	8	11.2	4.7	3.2	3.2	1	--	--

Table 46. Elevated concentrations of arsenic, cadmium, mercury, and lead in streambed-sediment samples from Wright-Patterson Air Force Base, Ohio, August 1993 - September 1994

[Elevated defined by Kelly and Hite (1984). Units are mg/kg, milligram per kilogram; --, not detected or detected below "elevated" concentration]

Location	Arsenic (elevated concentration = 11 mg/kg)	Cadmium (elevated concentration = 1.0 mg/kg)	Mercury (elevated concentration = 0.1 mg/kg; extremely elevated concentration = 0.37 mg/kg)	Lead (highly elevated concentration = 63 mg/kg)
DGS-5	11.8	1.80	0.21, 0.15	--
DGS-6	--	1.20	--	--
DGS-7	14.9	7.40	0.23, 0.10	117
DGS-8	--	2.90	0.23	328
INTS-6	11.3	--	--	--
INTS-15	--	1.50	0.24, 0.20, 0.16, 0.13	127
NPDES-5	--	5.30, 3.10, 2.90, 2.10	0.34, 0.26, 0.20, 0.19	433, 249, 236, 214
NPDES-6	--	16.5, 14.7, 13.4, 8.0	0.27, 0.24, 0.21, 0.16	564, 472, 455, 269
NPDES-12	--	--	0.13	120
NPDES-13	--	--	--	123, 70.3, 67.7
SW-1	11.6	--	0.25	--
SW-30	--	--	--	134
UGS-4	--	1.40	--	--
UGS-5	14.1	1.40	--	--
UGS-6	11.0	--	--	70.7
UGS-7	--	2.20, 1.20	0.10	145, 72.8

Table 55. Highest concentrations of selected pesticides in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in micrograms per kilogram; J, estimated; -- not applicable]

Location	Sample round	Pesticide	Concentration, in µg/kg	Qualifier
UGS-4	3	Heptachlor epoxide	190	--
UGS-7	3	Endrin ketone	120	J
NPDES-5	3	4,4'-DDT	57.0	J
NPDES-5	3	Endrin	40.0	J
NPDES-5	3	4,4'-DDD	36.0	J
NPDES-5	3	Endrin ketone	32.0	J
UGS-4	3	Endrin	27.0	J
NPDES-6	3	Endrin aldehyde	24.0	J
UGS-4	3	Methoxychlor	16.0	J
DGS-7	3	4,4'-DDT	15.0	J
NPDES-12	3	Endrin	14.0	J
UGS-4	3	Heptachlor	14.0	J
NPDES-6	3	Endosulfan II	12.0	J
DGS-7	3	Endrin	12.0	J
NPDES-5	3	4,4'-DDE	11.0	J
INTS-15	1	Methoxychlor	11.0	J
NPDES-6	3	Endrin	9.50	J
NPDES-5	1	4,4'-DDD	8.60	J
NPDES-5	4	Endrin	7.40	J
NPDES-6	3	4,4'-DDT	7.20	J
NPDES-5	1	4,4'-DDT	6.60	J
UGS-7	4	Endrin aldehyde	6.40	J
NPDES-6	3	Endosulfan sulfate	6.30	J

Table 56. Highest concentrations of petroleum hydrocarbons in streambed-sediment samples, all rounds, August 1993–September 1994, Wright-Patterson Air Force Base

[All concentrations in milligrams per kilogram]

Location	Sample round	Concentration
NPDES-6	1	1,100
NPDES-6	2	910
UGS-6	2	900
NPDES-12	2	830
UGS-7	1	690
UGS-10	2	400
NPDES-5	1	350
NPDES-13	2	310
NPDES-12	1	300
UGS-6	1	300
UGS-7	2	300
INTS-15	2	240
INTS-15	1	160
NPDES-5	2	160
UGS-8	1	100
UGS-8	2	100

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