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Use of Environmental Tracers to Evaluate Ground-Water Age and Water-Quality Trends in a Buried-Valley Aquifer, Dayton Area, Southwestern Ohio

Water-Resources Investigations Report 99-4113

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

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By Gary L. Rowe, Jr., Stephanie Dunkle Shapiro, and Peter Schlosser

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Miami Conservancy District

Columbus, Ohio

U.S. DEPARTMENT OF THE INTERIOR
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Columbus, Ohio
1999

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17–30. Graphs showing:

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED UNITS OF MEASURE

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter
inch (in)	25,400	micrometer
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
gallons per minute (gal/min)	3.785	liter per minute
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	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:

$$°F = 1.8(°C) + 32$$

Vertical Datum: 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.

Other abbreviated 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).

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. Redox potential (Eh) is given in millivolts (mV).

Activities of tritium are presented in tritium units (TU) where 1 TU = 3.24 picocuries per liter (pCi/L).

Dissolved gas concentrations are presented in units of mg/L or as cubic centimeters of gas at standard temperature and pressure per gram water (ccSTP/g H_2O). Excess-air content is given in cubic centimeters per kilogram of water (cm^3/kg H_2O).

Concentrations of chlorofluorocarbons in water are given in units of picograms per kilogram (pg/kg), and concentrations of chlorofluorocarbons in air are given in units of parts per trillion by volume (pptv).

Use of Environmental Tracers To Evaluate Ground-Water Age and Water-Quality Trends in a Buried-Valley Aquifer, Dayton Area, Southwestern Ohio

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ABSTRACT

Chlorofluorocarbons (CFC method) and tritium and helium isotopes (^{3}H-^{3}He method) were used as environmental tracers to estimate ground-water age in conjunction with efforts to develop a regional ground-water flow model of the buried-valley aquifer in the Dayton area, southwestern Ohio. This report describes results of CFC and water-quality sampling, summarizes relevant aspects of previously published work, and describes the use of ^{3}H-^{3}He ages to characterize temporal trends in ground-water quality of the buried-valley aquifer near Dayton, Ohio.

Results of CFC sampling indicate that approximately 25 percent of the 137 sampled wells were contaminated with excess CFC's that rendered the ground water unsuitable for age dating. Evaluation of CFC ages obtained for the remaining samples indicated that the CFC compounds used for dating were being affected by microbial degradation. The degradation occurred under anoxic conditions that are found in most parts of the buried-valley aquifer. As a result, ground-water ages derived by the CFC method were too old and were inconsistent with measured tritium concentrations and independently derived ^{3}H-^{3}He ages. Limited data indicate that dissolved methane may play an important role in the degradation of the CFC's. In contrast, the ^{3}H-^{3}He technique was found to yield ground-water ages that were chemically and hydrologically reasonable.

Ground-water ages derived by the ^{3}H-^{3}He technique were compared to values for selected water-quality characteristics to evaluate temporal trends in ground-water quality in the buried-valley aquifer. Distinct temporal trends were not identified for pH, alkalinity, or calcium and magnesium because of rapid equilibration of ground-water with calcite and dolomite in aquifer sediments. Temporal trends in which the amount of scatter and the number of outlier concentrations increased as ground-water age decreased were noted for sodium, potassium, boron, bromide, chloride, ammonia, nitrate, phosphate, sulfate, and organic carbon. Elevated concentrations of these constituents in shallow ground water are probably related to human activities. Temporal trends in which concentrations declined as ground-water age increased may reflect natural processes that reduce constituent concentrations to low levels. For example, the absence of nitrate detections in ground water recharged before 1980 may indicate natural removal of nitrate by bacterially mediated denitrification. Temporal trends observed for dissolved oxygen, iron, nitrate and silica indicate that these constituents may help identify recently (post-1990) recharged ground water.

INTRODUCTION

Glacial outwash deposits that fill the Great Miami River Valley are the main source of water for the city of Dayton and many surrounding communities in southwestern Ohio. The regional buried-valley aquifer system was classified as a sole-source aquifer in 1988 by the U.S. Environmental Protection Agency (USEPA) (1993). Because of past land use and waste-disposal practices, however, the area in and around Dayton includes many sites identified by USEPA under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). Although numerous site-specific hydrogeologic studies have been done in the Dayton area, no comprehensive study of the regional hydrogeology of the buried-valley aquifer has been done since the mid-1960's (Norris and Spieker, 1966).

The City of Dayton and other municipalities that produce water from the Great Miami buried-valley aquifer have developed, or are in the process of developing, comprehensive wellhead-protection plans to safeguard municipal well fields from contamination. Ground-water flow models used to evaluate various wellhead-protection plans, and all USEPA CERCLA activities, are site specific in their scope. Therefore, the regional effects of chemical spills or future development on the buried-valley aquifer as a whole are largely unknown. To address such regional issues, USEPA entered into a cooperative agreement with the U.S. Geological Survey (USGS) in 1991 to develop a regional ground-water flow model and hydrogeologic data base of the Great Miami buried-valley aquifer near Dayton. Because of widespread local interest in the regional model, a cooperative agreement between the USGS, the Miami Conservancy District (MCD), the City of Dayton, and 21 other municipal and private entities was reached to provide additional support for development of the regional ground-water flow model. A description of methods and data used to construct the regional flow model is given by Dumouchelle (1998a, b).

Because many aquifer-management decisions are based on numerical models, assessing model accuracy is important. Model evaluations are traditionally done by visual or statistical comparisons of simulated water-level and flow data with measured water-level and flow data. Alternatively, environmental-tracer techniques that involve measurements of chlorofluorocarbon compounds (CFC method) and tritium and helium isotopes (^{3}H-^{3}He method) have been used to estimate the age of ground water in shallow unconsolidated aquifers. Ground-water ages obtained at multiple locations and depths in an aquifer can be used to estimate rates and directions of ground-water flow, which can then be compared with results of numerical simulations to assess model accuracy. Therefore, as part of the agreement reached with MCD and its cooperators, an environmental tracer study was done during 1993–96 to obtain information about the age of ground water in the buried-valley aquifer.

Specific objectives of the environmental tracer study were to (1) use environmental-tracer techniques to estimate the age of ground water at selected locations in the Great Miami buried-valley aquifer, (2) apply estimates of ground-water age to the calibration and refinement of existing numerical flow models of selected parts of the aquifer, and (3) characterize temporal trends in ground-water quality of the aquifer. Results of ground-water age dating by use of the ^{3}H-^{3}He technique and the application of ground-water ages to calibration of flow models of selected parts of the buried-valley aquifer are given by Shapiro and others (1998) and Sheets and others (1998), respectively. (See "Previous Investigations" section.)

Purpose and scope

This report describes results of CFC and water-quality sampling done as part of the environmental tracer study, summarizes relevant aspects of previously published work, and characterizes temporal trends in ground-water quality of the buried-valley aquifer on the basis of environmental-tracer ages.

Previous investigations

The hydrogeology of the Great Miami buried-valley aquifer near Dayton is summarized in several reports, including those by Norris and others (1948, 1950, and 1952), Walton and Scudder (1960), Norris and Spieker (1966), Spieker, (1968), Fidler (1975), CH2M-Hill (1986a, b; 1989), Geraghty & Miller (1987), Dumouchelle and others (1993), Cunningham and others (1994), Sheets (1994), and Ritzi and others (1994, 1995). Water-quality data for ground water pumped from the selected parts of the buried-valley aquifer within the study area are reported in

Norris and Spieker, (1966), Evans (1977), Pennino (1984), CH2M Hill (1986a, b; 1989), Geraghty & Miller (1987), Dumouchelle and others (1993), and Rowe (in Schalk and others, 1996).

Reports by Norris and Spieker (1966) and Spieker (1968) contain the most comprehensive description of regional ground-water resources in the Dayton area. These reports include detailed sections on the geology and hydrology of the glacial outwash deposits, aquifer-test data for several major well fields, and maps detailing surface geology, bedrock-surface-elevation contours, and potentiometric surface. More recently, Ritzi and others (1994, 1995) used geostatistical methods to quantify and predict physical heterogeneity in selected parts the buried-valley aquifer, including the distribution of low-permeability tills south of Dayton. Yost (1995) presents synoptic water-level, streambed-permeability, and streamflow data for the Dayton area collected in September 1993. A map showing water levels and flow directions in the Great Miami buried-valley aquifer based on the September 1993 data set is given by Dumouchelle (1998a). These and other hydrogeologic data were used by Dumouchelle (1998b) to develop and calibrate a steady-state, regional ground-water flow model of the Great Miami buried-valley aquifer near Dayton, Ohio.

Site-specific hydrogeologic descriptions of selected parts of the buried-valley aquifer can be found in reports that describe ground-water flow models developed for water-resource management purposes or for predicting rates and directions of contaminant migration from known or suspected pollution sources. These include reports by Fidler (1975), CH2M-Hill (1986a, b; 1989), Geraghty & Miller (1987), Field (1991), Dames & Moore and others (1992), Dumouchelle and others (1993), Cunningham and others (1994), Sheets (1994), and the U.S. Department of Energy and EG&G Mound Applied Technology Corporation (1995).

The use of environmental tracer methods to estimate ground-water age, including the CFC, ^{3}H, and ^{3}H-^{3}He methods, is reviewed by Plummer and others (1993). Additional recent studies that describe the use of the CFC and ^{3}H-^{3}He methods for estimating ground-water age include those by Dunkle and others (1993), Solomon and others (1993, 1995), Ekwurzel and others (1994), Bohlke and Denver (1995), Cook and others (1995), Katz and others (1995), Solomon and others (1995), and Szabo and others (1996). Studies examining the use of environmental tracers to improve the calibration of ground-water-flow models include those by Reilly and others (1994), Katz and others (1995), Solomon and others (1993, 1995), and Szabo and others (1996).

Data and analytical methods used to determine the ^{3}H-^{3}He ages of ground-water samples collected for this study are discussed by Shapiro and others (1998). These researchers reported several complications to successful application of the ^{3}H-^{3}He method for age dating ground water in the Great Miami buried-valley aquifer, including (1) sampling in parts of the aquifer affected by heavy pumping and induced infiltration of river water, (2) the presence of tritium contamination in some parts of the aquifer, and (3) elevated concentrations of radiogenic helium, which affects interpretation of the ^{3}H-^{3}He ages, in a significant percentage of the samples. Shapiro and others (1998) evaluated the ^{3}H-^{3}He ages for geochemical and hydrogeologic consistency. Consistency of the ^{3}H-^{3}He ages with known tritium geochemistry was evaluated by comparing the sum of tritium and tritiogenic helium-3 [^{3}H+^{3}He$_{trit}$] against the estimated tritium-input function for rainwater in southwestern Ohio. In general, close agreement was found between [^{3}H+^{3}He$_{trit}$] and estimated tritium concentrations in rainwater. Deviations from initial tritium concentrations were explained by (1) dispersion that causes lower reconstructed peak tritium values, (2) mixing at discharge areas that caused some samples with low [^{3}H+^{3}He$_{trit}$] values to have younger ages than expected, and (3) local sources of tritium that resulted in affected samples having [^{3}H+^{3}He$_{trit}$] concentrations in excess of those predicted by the rainwater input curve. Hydrologic consistency of the ^{3}H-^{3}He ages was evaluated by examining trends in ^{3}H-^{3}He ages as a function of depth and distance along ground-water flowpaths near the Miami and North Miami Well Fields and the Wright-Patterson Air Force Base-Mad River Well Field area. With few exceptions, ground-water age increased with depth and increasing distance along the regional flowpath. Ground water also became younger as the distance between the recharge area and the major pumping centers decreased (Shapiro and others, 1998).

Sheets and others (1998) used the ^{3}H-^{3}He ages reported by Shapiro and others (1998) to calibrate and improve numerical flow models of selected parts of the Great Miami buried-valley aquifer. Reverse particle tracking was done with two existing steady-state ground-water flow models: a two-layer model of the buried-valley aquifer near the Mound Plant, and a regional model of the buried-valley aquifer underlying the Wright-Patterson Air Force Base-Mad River Well Field area. Results of the initial comparisons showed that ^{3}H-^{3}He ages for ground-water samples from shallow and intermediate-depth wells were in close agreement with the simulated ages derived by reverse-particle tracking. Significant differences were common, however, between the two sets of ages for wells screened in deeper parts of the buried-valley aquifer; at several wells, simulated traveltimes of several decades or more were clearly incompatible with ^{3}H-^{3}He ages of 30 years or less. Hydrologically reasonable modifications to the flow model of Wright-Patterson Air Force Base were shown by Sheets and others (1998) to result in improved agreement between the ^{3}H-^{3}He ages and simulated traveltimes.

Acknowledgments

The authors thank the following persons and agencies for allowing access to monitoring wells, providing logistical support during ground-water sampling, and furnishing hydrogeologic and water-quality data: The Miami Conservancy District; personnel of the City of Dayton, including Lawrence Blossom and others at the Department of Water Supply and Treatment; Douglas Hall, Assistant City Manager, and James P. Shoemaker, Office of Environmental Protection; Wright-Patterson Air Force Base; the Ohio Department of Natural Resources, Division of Water; the Ohio Environmental Protection Agency, Southwest District; the Miami Valley Regional Planning Commission; the U.S. Department of Energy; Alec Bray and other personnel of E.G.&G. Mound Applied Technologies; and Roger McCready and Brent Huntsman of Terran Corporation.

ENVIRONMENTAL SETTING

General area

The study area is in southwestern Ohio and is restricted to areas underlain by the Great Miami buried-valley aquifer near Dayton (fig. 1). Highly productive parts of the buried-valley aquifer that are used for water supply are found along the drainages of the Great Miami, Mad, Stillwater, and Little Miami Rivers. The study area is centered on Dayton, which is about 50 mi northeast of Cincinnati and about 65 mi west of Columbus. About 250 mi^2 of the study area, including most of Montgomery County and parts of southwestern Clark County and northwestern Greene County, are underlain by the buried-valley aquifer (fig. 1).

Census data compiled for 1990 indicate that Montgomery County had a total population of 573,809 (U.S. Bureau of the Census, 1991). Within the study area, approximately 460,000 people live in Dayton and surrounding communities. Dayton is a major industrial center for southwestern Ohio; factories in and around Dayton produce automobile parts, air-conditioning units, business machines, computer equipment, paper, and chemical products. The study area is home to Wright-Patterson Air Force Base (8,500 acres) which is northeast of downtown Dayton and employs about 35,000 military and civilian personnel. Past industrial activities in the area included production of refrigerators at a large plant near downtown Dayton. Because CFC compounds were the main refrigerants used in refrigerators and air conditioners in the years prior to this study, past industrial activity may have affected the concentration of CFC compounds in air and water in the Dayton area.

The study area is in the north temperate climate zone. Long-term precipitation data for 12 rain gages maintained by MCD and (or) the National Oceanic and Atmospheric Administration (NOAA) indicate that mean annual precipitation throughout the study area is about 39 in/yr. Mean annual rainfall for the downtown Dayton station (period of record 1883–1991) was 37.6 in., with a standard deviation of 6.1 in. The maximum annual rainfall of 55.3 in. was recorded in 1990, and the minimum annual rainfall of 23.7 in. was recorded in 1934 (Miami Conservancy District, written commun., 1992). Mean monthly rainfall data indicate that precipitation is relatively evenly distributed throughout the year. In June, the wettest month, precipitation normally ranges from 3.8 to 4.4 in.; in October, the driest month, precipitation normally ranges from 2.0 to 2.2 in. Mean annual temperature at downtown Dayton and at the Dayton International Airport (about 10 mi north of downtown Dayton) during 1951–91 was approximately 12°C (54°F) and 11°C (52°F), respectively (National Oceanic and Atmospheric Administration, written commun., 1992). Long-term temperature records indicate that July is the warmest month (mean temperature 24 to 25°C) and January is the coldest (mean temperature -2 to -3°C). Annual snowfall in the study area typically ranges from 20 to 30 in. (Harstine, 1991).

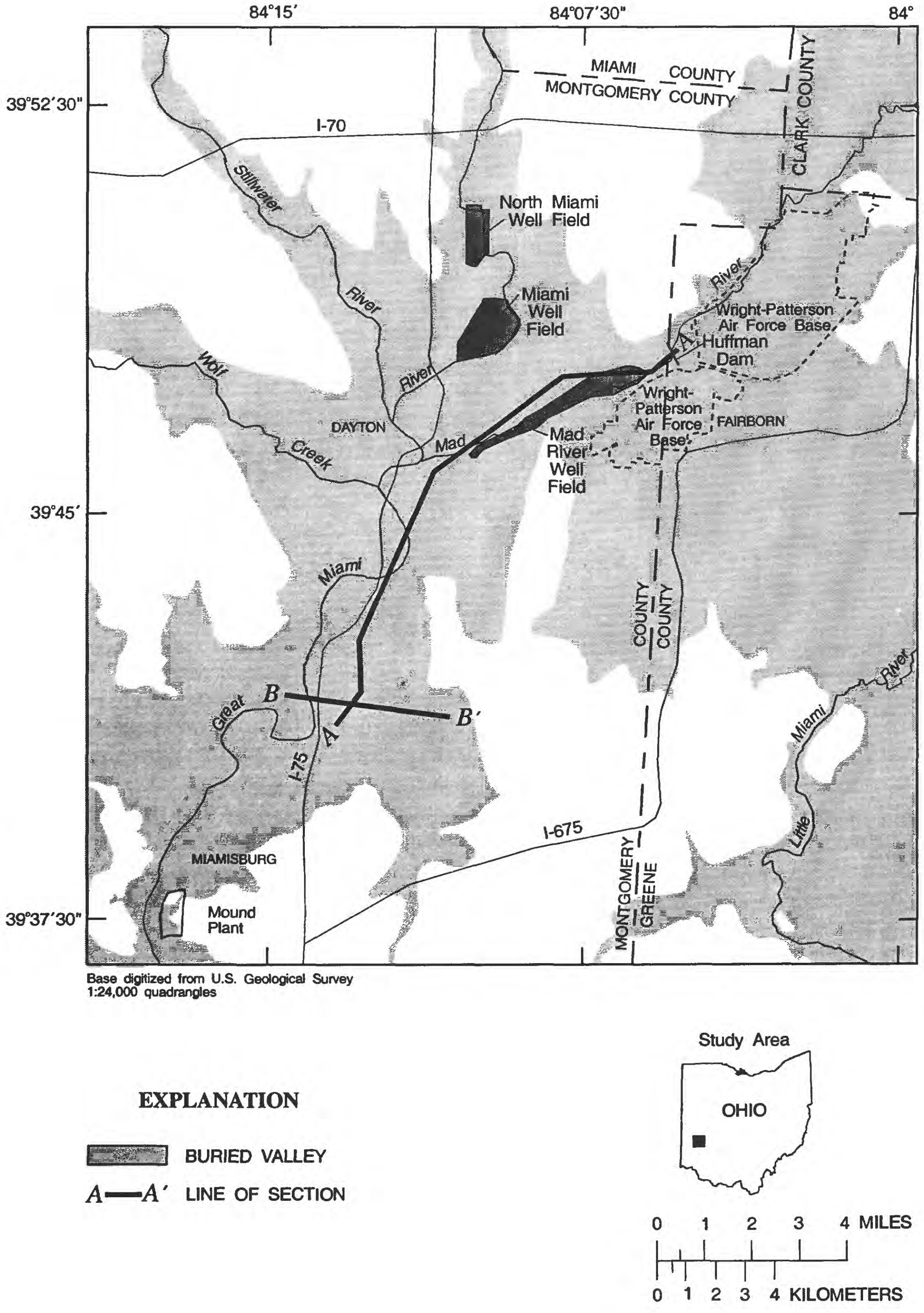


Figure 1. Location of study area.

The study area is in the Till Plains section of the Central Lowland Physiographic Province (Fenneman, 1938). Present-day topography of the Till Plains is the result of continental glaciation during the Pleistocene epoch. Valleys incised into uplifted Silurian and Ordovician bedrock by preglacial drainage systems were buried by sediments deposited by advancing glaciers (glacial tills) or filled in by sediments deposited by glacial meltwaters (outwash deposits). The result is a land surface that is flat to gently rolling. Land elevation across the study area ranges from 690 ft to more than 1,000 ft above sea level. The relatively flat flood plains of the major rivers range from 690 ft to 790 ft above sea level along the Great Miami River to a maximum of 860 ft above sea level in the northeast corner of the study area along the Mad River. Dayton is at the confluence of the Great Miami, Stillwater, and Mad Rivers at an altitude of about 750 ft above sea level.

The buried-valley aquifer near Dayton is composed of a heterogeneous mixture of coarse and fine-grained sediments and is underlain by Ordovician bedrock consisting of a poorly permeable sequence of interbedded shale and limestone (Norris and Spieker, 1966). The Ordovician bedrock is generally considered to be impermeable to regional ground-water flow. More permeable Silurian carbonate formations crop out along valley walls; small springs, which are common along the contact between Silurian and Ordovician bedrock, represent localized sources of recharge to the buried-valley aquifer. Glacial sediments that comprise the buried-valley aquifer range in thickness from about 150 to 300 ft and have been subdivided into three distinct layers (fig. 2). These include upper and lower outwash deposits composed of massive or cross-bedded sands and gravels deposited by glacial meltwaters and an intervening till-rich layer composed of clay and silt-rich sediments (Norris and Spieker, 1966; Ritzi and others, 1995). The till-rich zone ranges in thickness from 0 to 50 ft and is laterally discontinuous throughout the study area (fig. 2). Where present, the till layer can cause confined or semiconfined conditions in the lower aquifer. In many areas thin, laterally discontinuous lenses of clay or silt-rich sediment are found throughout the entire thickness of the aquifer. Many of these lenses have gradational contacts with adjacent sand and gravel beds, making stratigraphic correlation at distances greater than tens or hundreds of feet extremely difficult (Dumouchelle and others, 1993; Ritzi and others, 1995).

On a regional scale, potentiometric contours mimic surface topography except where water levels have been affected by heavy pumping (Dumouchelle, 1998a). Near bedrock valley walls, ground-water flowpaths are typically towards the centers of the valleys but then become parallel or subparallel to streams in the centers of the valleys. Regional ground-water flow tends to follow the gradient of bedrock valleys carved out by the preglacial drainage system, which is generally to the south-southwest (Dumouchelle, 1998a). Recharge by infiltration of precipitation occurs in the upland areas and in areas covered by more permeable soils and glacial sediments; recharge is also induced from streams and rivers by pumping near major well fields. Some recharge occurs where bedrock-valley walls contact valley-fill deposits; ground-water discharge usually occurs at or adjacent to major streams. During periods of low streamflow, sustained ground-water discharge (base flow) can be the predominant source of water to the stream, as in the Mad River (Koltun, 1995). During periods of high streamflow, however, flow reversals occur and infiltration of streamwater through freshly scoured streambeds and adjacent, permeable bank sediments can be a significant temporary source of recharge to the buried-valley aquifer (Norris and Spieker, 1966; Dumouchelle, 1998b). In most parts of the study area, the water table is within 10 to 20 ft of land surface except near major well fields or in upland areas, where depth to water can be 50 ft or more (Yost, 1995).

The buried-valley aquifer is the primary source of water for Dayton and surrounding communities. Ground-water withdrawals in the Dayton area for municipal, commercial, and industrial water supply totaled about 135 Mgal/d in September 1993 (Dumouchelle, 1998b). About 55 percent of the total supply in the Dayton area is obtained from production wells at the Miami and Mad River Well Fields operated by the City of Dayton (fig. 1). Both of the these well fields have artificial recharge systems that rely on induced infiltration of streamwater diverted from the Great Miami and Mad Rivers, respectively.

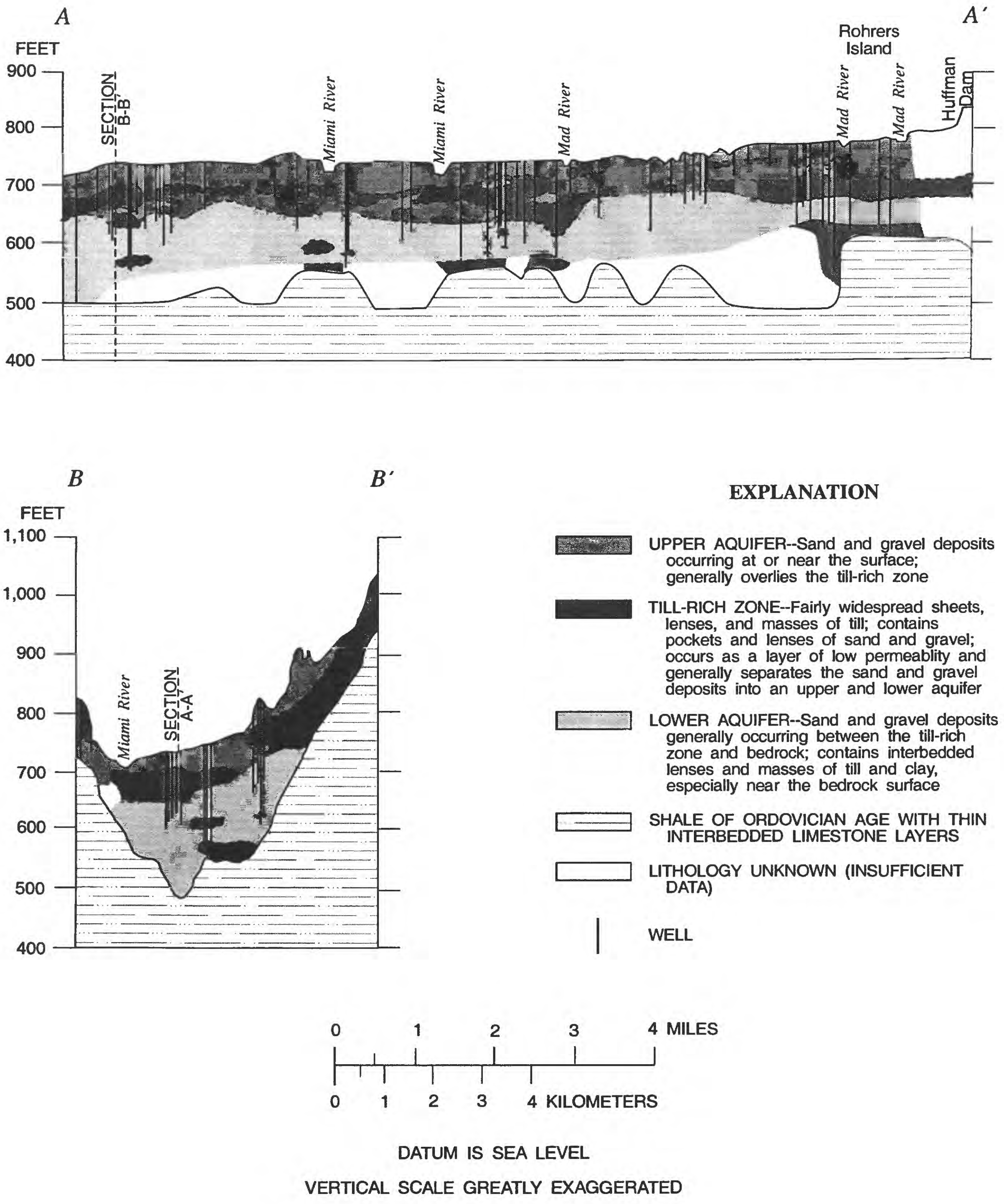


Figure 2. Geologic sections *A-A′* and *B-B′* through selected parts of the buried-valley aquifer, Dayton area, southwestern Ohio. Sections modified from those given in Norris and Spieker, 1966. (Section lines shown in fig. 1.)

Subregional study areas

Environmental tracer sampling was concentrated in three areas where detailed hydrogeologic information and extensive networks of monitoring wells already existed: (1) Wright-Patterson Air Force Base (WPAFB)-Mad River Well Field in the northeastern part of the study area, (2) Miami and North Miami Well Fields north of downtown Dayton, and (3) Mound Plant near Miamisburg, Ohio (fig. 1). Additional samples were collected throughout the entire study area during a reconnaissance survey at the beginning of the project.

Wright-Patterson Air Force Base-Mad River Well Field. WPAFB overlies the buried-valley aquifer associated with the Mad River Valley. This part of the aquifer is heavily used for water supply and contains well fields operated by the cities of Dayton and Fairborn, WPAFB, and local industry. The largest withdrawals are at the Mad River Well Field, which is west of WPAFB and just downstream from Huffman Dam. The Mad River Well Field typically withdraws 30 to 50 Mgal/d, mostly from shallow supply wells on the Rohrer's Island artificial-recharge facility. At Rohrer's Island, the City of Dayton maintains a 20-acre network of ditches and lagoons that are used to facilitate direct recharge of the buried-valley aquifer by water diverted from the Mad River. This artificial-recharge system originated as a series of ditches constructed in the early 1900's; the current configuration of recharge lagoons has been in operation since the late 1930's (James P. Shoemaker, City of Dayton, oral commun., 1998). Waste-disposal practices associated with operation of WPAFB have contaminated ground water, primarily with low levels of volatile organic compounds (VOC's). This contamination has affected supply wells at WPAFB and at the Mad River Well Field, which is downgradient from WPAFB (Geraghty & Miller, 1987; Schalk and others, 1996).

The hydrogeology of the Mad River aquifer near WPAFB and the Mad River Well Field has been described by Norris and others (1948), Norris (1959), Norris and Spieker (1966), Geraghty & Miller (1987), and Dumouchelle and others (1993). Major hydrogeologic features of this part of the buried-valley aquifer include a sharp narrowing of the bedrock valley near Huffman Dam and the presence of a thick, laterally extensive till sheet (fig. 2). The top of the till, whose thickness is about 75 ft, is found at depths of 30 to 50 ft. The till clearly separates the buried-valley aquifer into upper and lower aquifers near the Mad River Well Field, but it is discontinuous north of Rohrer's Island (Norris and Spieker, 1966). Regional ground-water flow is towards the west-southwest except near the Mad River Well Field, where the regional flow gradient is towards the well field (Schalk, 1992).

Miami and North Miami Well Fields. The Miami and North Miami Well Fields are north of Dayton, adjacent to the Great Miami River (fig. 1). The Miami Well Field is about 3 mi north of downtown Dayton and has been operated since the 1950's. Direct recharge to the aquifer is provided by a series of recharge lagoons that receive water pumped from the Great Miami River. Pumpage at the Miami Well Field varies from 15 to 30 Mgal/d, depending on the season. The North Miami Well Field is about 5 mi north of downtown Dayton and is being developed by Dayton to meet increasing water demands. At the time of sampling (1993, 1994), wells in the North Miami Well Field were not being pumped, so the flow system in this part of the aquifer was relatively undisturbed when environmental tracer samples were collected for this study. The two well fields are in a designated well-field protection zone; however, land use in upland areas adjacent to the well fields is mixed commercial and residential, and ground-water contamination has been found in several monitoring wells on the northern boundaries of both well fields (CH2M Hill, 1986, 1989).

The hydrogeology of the buried-valley aquifer near the Miami and North Miami well fields is similar to that described for WPAFB. Glacial valley-fill deposits are highly heterogeneous, with extreme lithologic variation over short distances and with depth. Clay and silt-rich zones are interbedded with sand and gravel deposits but are laterally discontinuous, especially near the Miami Well Field. More continuous tills are found east of the Great Miami River near the edge of bedrock valley wall (Norris and Spieker, 1966; CH2M-Hill, 1986a, 1989). Regional ground-water flow is towards the south except near the edge of the valley and near the Miami Well Field, where a cone of depression has developed.

Mound Plant. The Mound Plant in Miamisburg, Ohio, is an integrated research, development, and production facility operated by a private company for the U.S. Department of Energy (DOE) in support of Federal weapons and energy programs. The plant began operations in 1949. Remedial investigations related to historical disposal practices and release of contaminants to the environment led to the Mound Plant's being placed on the National Priorities List (Superfund) in November 1989 (U.S. Environmental Protection Agency, 1989). Contaminants affecting ground water are mainly VOC's; however, both airborne and liquid releases of tritium occurred in the past, and these have affected tritium concentrations in ground water at locations both downgradient and downwind of the Mound Plant (U.S. Department of Energy, 1991, 1995). The prevailing wind direction across the Mound Plant is towards the northeast (Dames and Moore, 1973).

The Mound Plant was built on a bedrock high on the east bank of the Great Miami River. The bedrock is a poorly permeable Ordovician shale; however, bedding-plane and vertical fractures associated with an upper weathered zone facilitate ground-water flow through the upper 50–60 ft of the sequence. The fracture zone is above the contact with the glacial sediments in the valley; therefore, direct recharge of the buried-valley aquifer by ground water flowing through these fractures does not occur. However, a small tributary valley filled with fine silt and sand that trends east and northeast across the central part of the Mound Plant provides a hydraulic connection to the main part of the buried-valley aquifer and a potential path for contaminant migration. The hydrogeology of the main bedrock valley west of the Mound Plant is similar to that in other parts of the buried-valley aquifer described previously (Norris and Spieker, 1966). Total thickness of the main buried-valley aquifer near the Mound plant approaches 180 ft; width of the bedrock valley directly west of the Mound Plant is about half a mile. Regional ground-water flow is towards the south and is nearly parallel to bedrock valley walls except where deflected by pumping associated with supply wells operated by the City of Miamisburg (west bank Great Miami River) and the Mound Plant (east bank Great Miami River) (U.S. Department of Energy, 1995).

METHODS OF DATA COLLECTION AND ANALYSIS

In this section, methods used to collect and analyze environmental samples for the environmental tracer study are described. Site-selection criteria and construction data pertaining to wells used to obtain ground-water samples also are described.

Site-selection criteria

Site-selection criteria for the environmental tracer study reflect overall project objectives and method-specific considerations that are required to successfully apply the environmental tracer techniques used in this study.

Ground water. Sites used for water-quality and environmental tracer sampling were selected on the basis of the following criteria: (1) location, (2) depth, (3) relative position along regional and local flowpaths, (4) presence/absence of multidepth well clusters, (5) screen length, (6) presence/absence of supply pump, (7) well-construction materials, (8) availability of long-term water-level/water-quality data, and (9) site accessibility (including ability to obtain permission to sample well). Criteria 1 through 4 are related to the primary objectives of the environmental tracer study, which were to use environmental tracer techniques to estimate the age of ground water at selected depths and locations in the buried-valley aquifer and then apply those estimates to the calibration and refinement of ground-water flow models. Criteria 5 through 8 were used to minimize various factors associated with sampling existing wells that could affect the reliability the tracer-derived ages. Each of these criteria is discussed in more detail below. Ancillary information regarding wells sampled during this study, such as location, elevation, casing material, screen length, and water level at the time of sampling is available online at http://oh.water.usgs.gov/reports/daytonwells.html or as hard copy from the Columbus, Ohio, office of the USGS; locations of all wells and well clusters sampled are shown in figure 3.

Location and depth were the primary selection criteria for the 137 wells that were sampled as part of the environmental tracer study. Twenty-four wells were sampled as part of an initial reconnaissance survey in June 1993 to give a representative spatial and depth distribution throughout the study area (fig. 4). Total depths of individual wells in the initial reconnaissance group ranged from about 14 to 238 ft below land surface (bls). Wells in the reconnaissance group were constructed of black steel, stainless steel, or polyvinyl chloride (PVC) casing. Well screens (if present) were made of similar materials, were perforated or slotted, and were less than 10 ft in length.

Wells sampled in September–October 1993 and July–September 1994 were chosen to provide samples along known or inferred flowpaths at each of the three subregional study areas (Mound Plant, Miami-North Miami Well Fields, WPAFB-Mad River Well Field). At the Mound Plant, 30 wells were sampled (fig. 5). Mound Plant wells

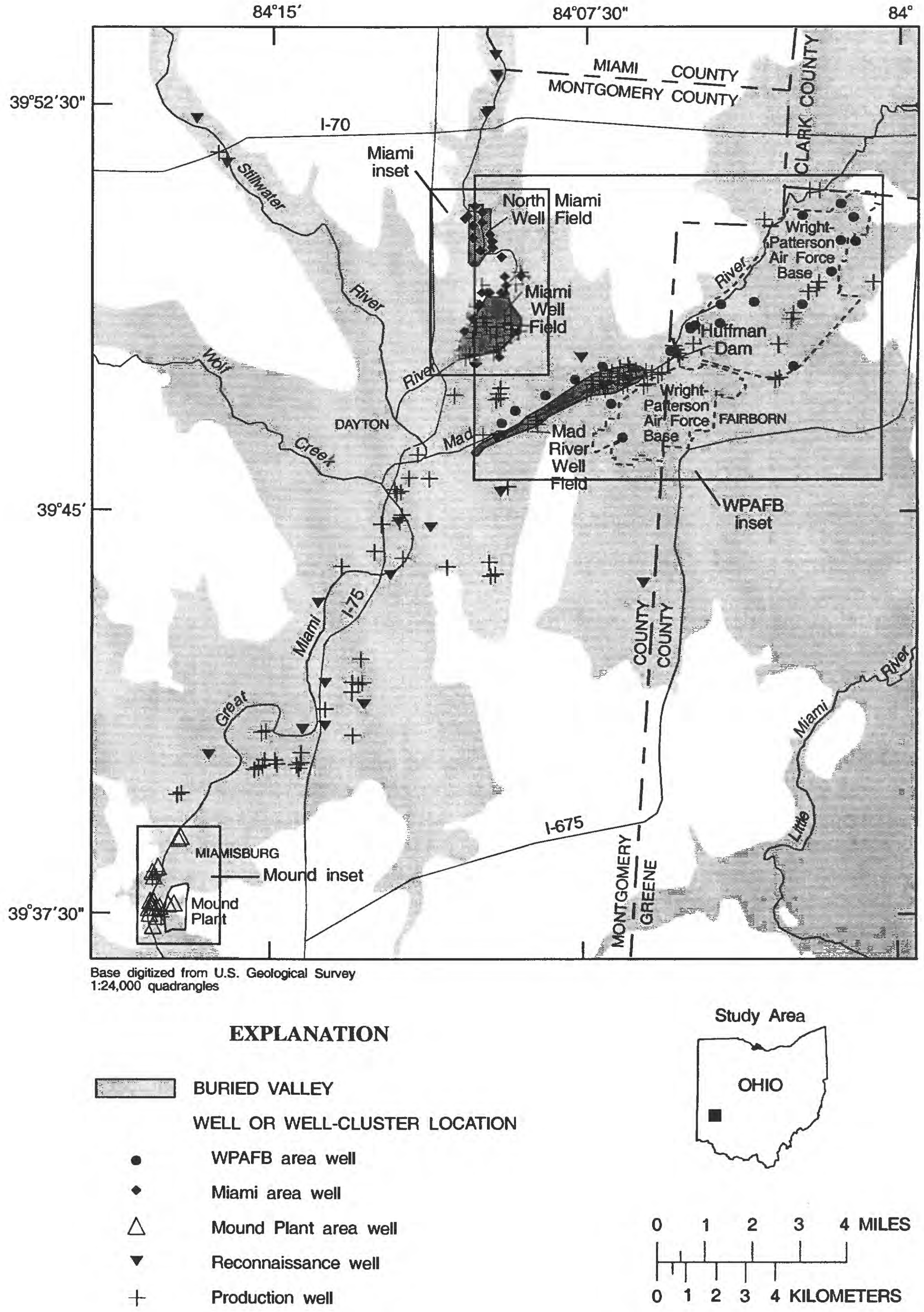
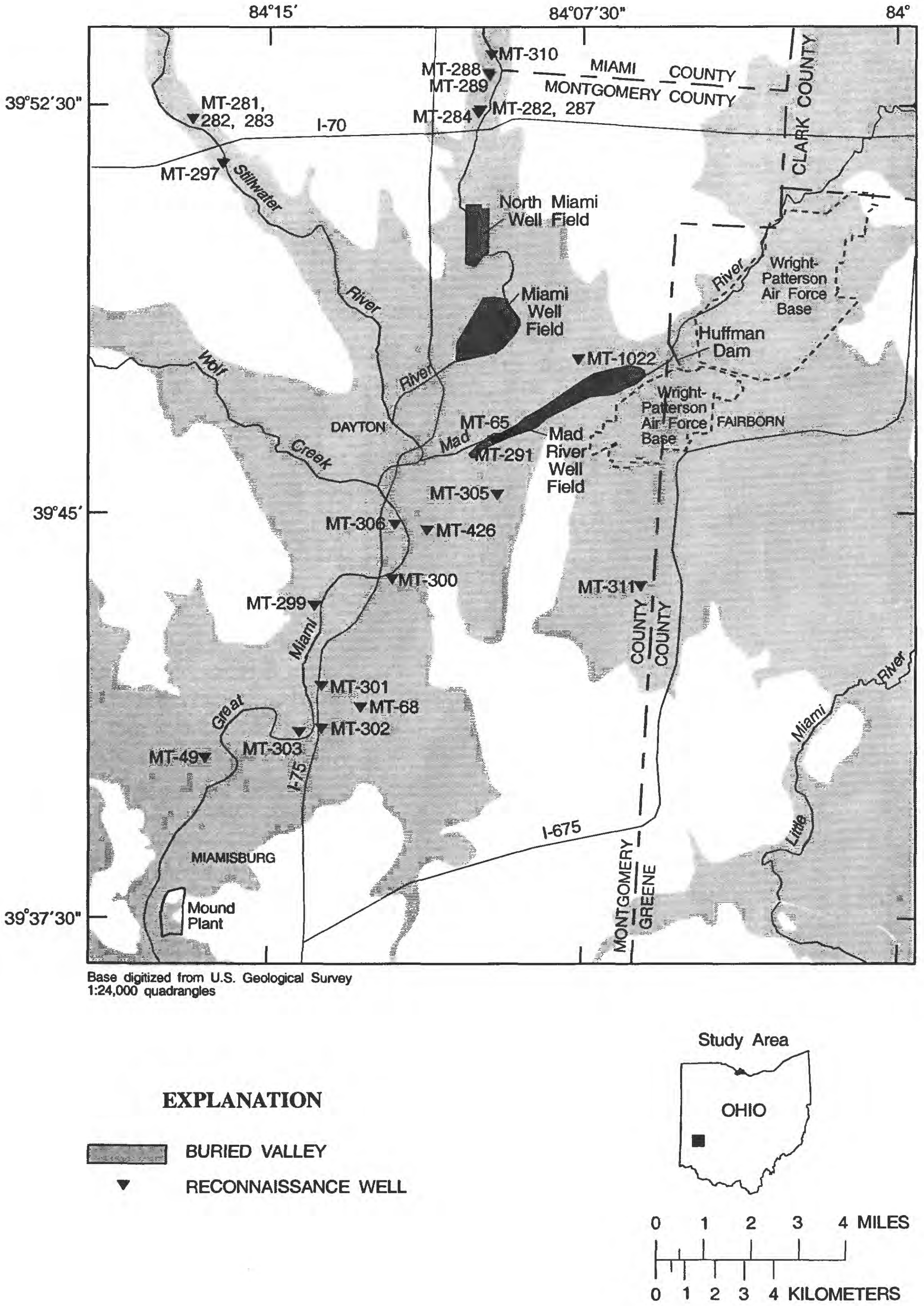


Figure 3. Areal distribution of all wells and well clusters sampled in the buried-valley aquifer, Dayton area, southwestern Ohio. (Locations of wells by well type and subarea are shown in figs. 4-7.)



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

Figure 4. Locations of reconnaissance wells sampled, Dayton area, southwestern Ohio.

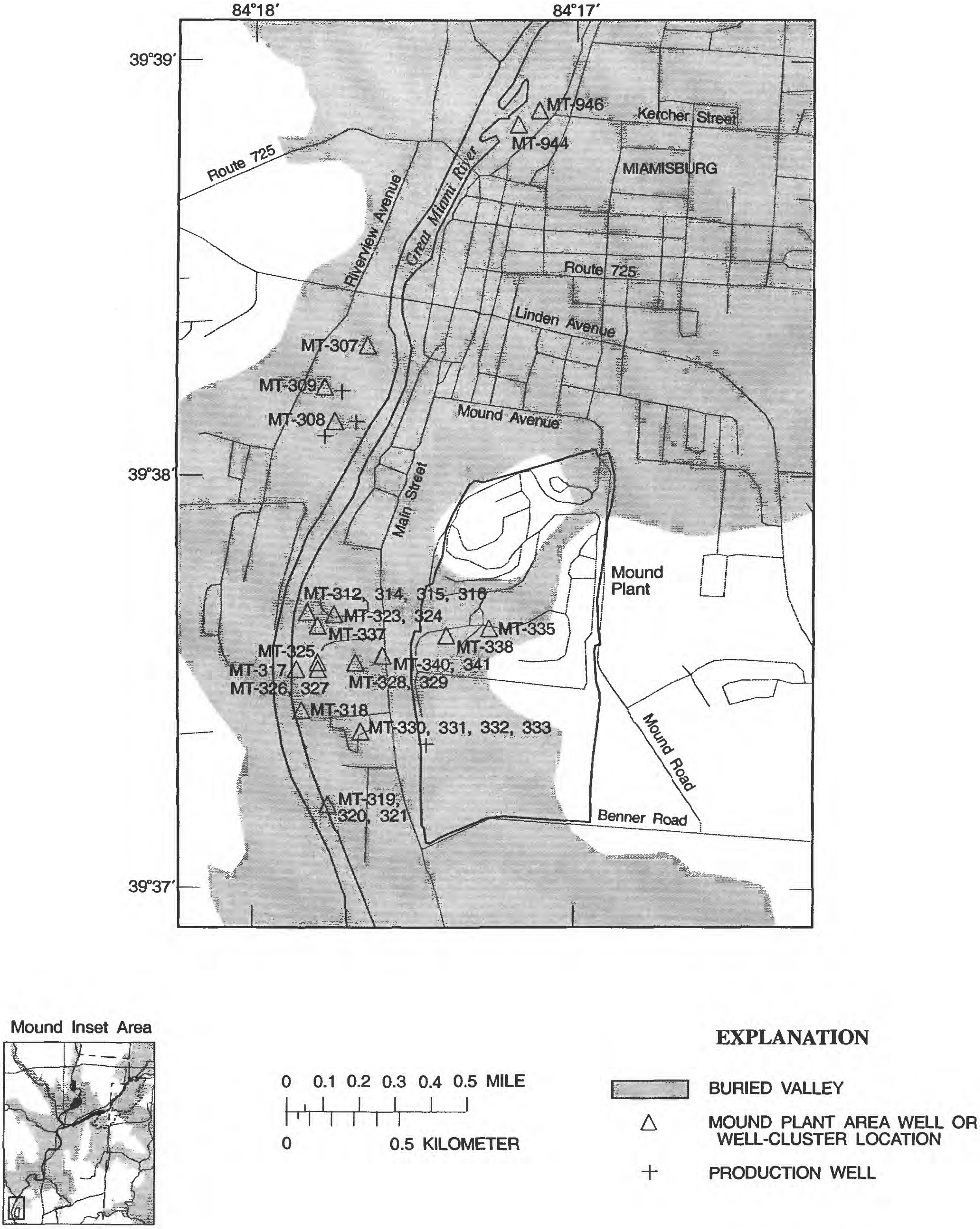


Figure 5. Locations of wells sampled on or near the Mound Plant, Dayton area, southwestern Ohio. (Relation of this subarea to other study subareas is shown in fig. 3.)

ranged in depth from 20 to 160 ft bls, although only 3 of the 30 were deeper than 100 ft. Casings and well screens were constructed of PVC or stainless steel, with screen lengths ranging from 2 to 10 ft (one well with no screen reported). Thirty-nine wells were sampled at the North Miami and Miami Well Fields area. Wells and well clusters selected for sampling were located along the regional flow direction, which is south towards the Miami Well Field (fig. 6). Most of the wells sampled were monitoring wells owned by the City of Dayton and consisted of shallow-deep well pairs. Shallow wells were screened at depths ranging from 40 to 70 ft bls, whereas deep wells were screened at depths of 100 to 150 ft bls. These wells, with few exceptions, were made of 4-in.-diameter PVC casing and had slotted screens ranging in length from 5 to 20 ft (most commonly 10 ft).

At the WPAFB-Mad River Well Field area, a total of 44 wells were sampled. Fourteen of these were shallow-deep well pairs installed by the City of Dayton to monitor water quality around the Mad River Well Field (fig. 7). Shallow wells were completed at depths from 24 to 60 ft bls, whereas deep wells were completed at depths from 110 to 152 ft bls. Screen lengths ranged from 10 to 23 ft. These wells were designed to sample ground water from well-defined upper and lower sand and gravel aquifers that are separated by the thick till layer that underlies Rohrer's Island at the Mad River Well Field (fig. 2). Wells sampled at WPAFB were constructed of 4-in.-diameter stainless-steel casing and had stainless-steel screens ranging in length from 5 to 15 ft. These wells were part of multidepth clusters of three to four wells that were screened at depths ranging from 15 to 25 ft bls (at the water table) to 180 ft bls (Dumouchelle and de Roche, 1991). Wells from WPAFB were grouped with those near the Mad River Well Field because regional ground-water flow from Areas A and C and Area B of WPAFB is towards the Mad River Well Field (Dumouchelle and others, 1993; Cunningham and others, 1994; Dumouchelle, 1998a).

For the subregional studies, wells or well clusters along regional or local ground-water flowpaths were targeted for sampling. Wells or well clusters along the perimeter of major well fields also were targeted. Along flowpaths, wells at recharge and discharge areas were sampled. Shallow wells were preferred for sampling in recharge areas and multidepth well clusters were preferred along the flowpath and at discharge areas. Ground-water flow directions were identified by examination of published and unpublished water-level data available for the Mound Plant, WPAFB-Mad River Well Field, and Miami and North Miami Well Fields. At WPAFB, results of reverse particle-tracking analysis (Cunningham and others, 1994) done with the ground-water-flow model developed by Dumouchelle and others (1993) were used to calculate traveltimes from the screened interval of existing monitoring wells to corresponding recharge areas. Wells whose simulated traveltimes were within the 40- to 50-year limit of the ^{3}H-^{3}He and CFC methods were then targeted for environmental tracer sampling.

Paired shallow-deep wells or well clusters consisting of three or more wells were targeted for environmental tracer sampling to provide information about age-depth relations in the buried-valley aquifer. Wells with long (>10 ft) screens were also generally avoided because long well screens increase the potential for mixing of old and young waters that may have significantly different concentrations of CFC's or tritium (Sheets and others, 1998). In all, 18 wells (mostly monitoring wells owned by the City of Dayton) had screens greater than 10 ft long (11 to 23 ft); the remaining wells sampled in this study had screen lengths of 10 ft or less. Wells that contained dedicated pumps, such as domestic or industrial supply wells, were avoided because such pumps usually have parts made of rubber, nylon, or other materials that can affect CFC concentrations (Busenberg and others, 1992).

Wells where long-term water-level or water-quality data had been collected were preferred for sampling because these data provided information regarding general flow directions and the occurrence of contaminants that could affect the concentration of environmental tracers. Long-term water-level records were used to help define the relative position of a well in the regional flow system and, for sites with multiple wells, the vertical hydraulic gradient between adjacent wells. Average vertical hydraulic gradients were used to determine whether the site was in a recharge or discharge area in the buried-valley aquifer (downward gradient corresponds to a recharge area; upward gradient corresponds to a discharge area) because this would affect the expected age distribution observed at the site. Available water-quality data were also examined to determine the hydrogeochemistry of the aquifer at the well site and to identify wells contaminated with VOC's. Wells known to be contaminated with VOC's were generally avoided because ground water that has detectable concentrations of VOC's often has levels of CFC's too high to be useful for age-dating. However, some wells known to contain detectable concentrations of VOC's were sampled because of their position along identified flowpaths and because VOC's do not affect the ^{3}H-^{3}He method of dating.

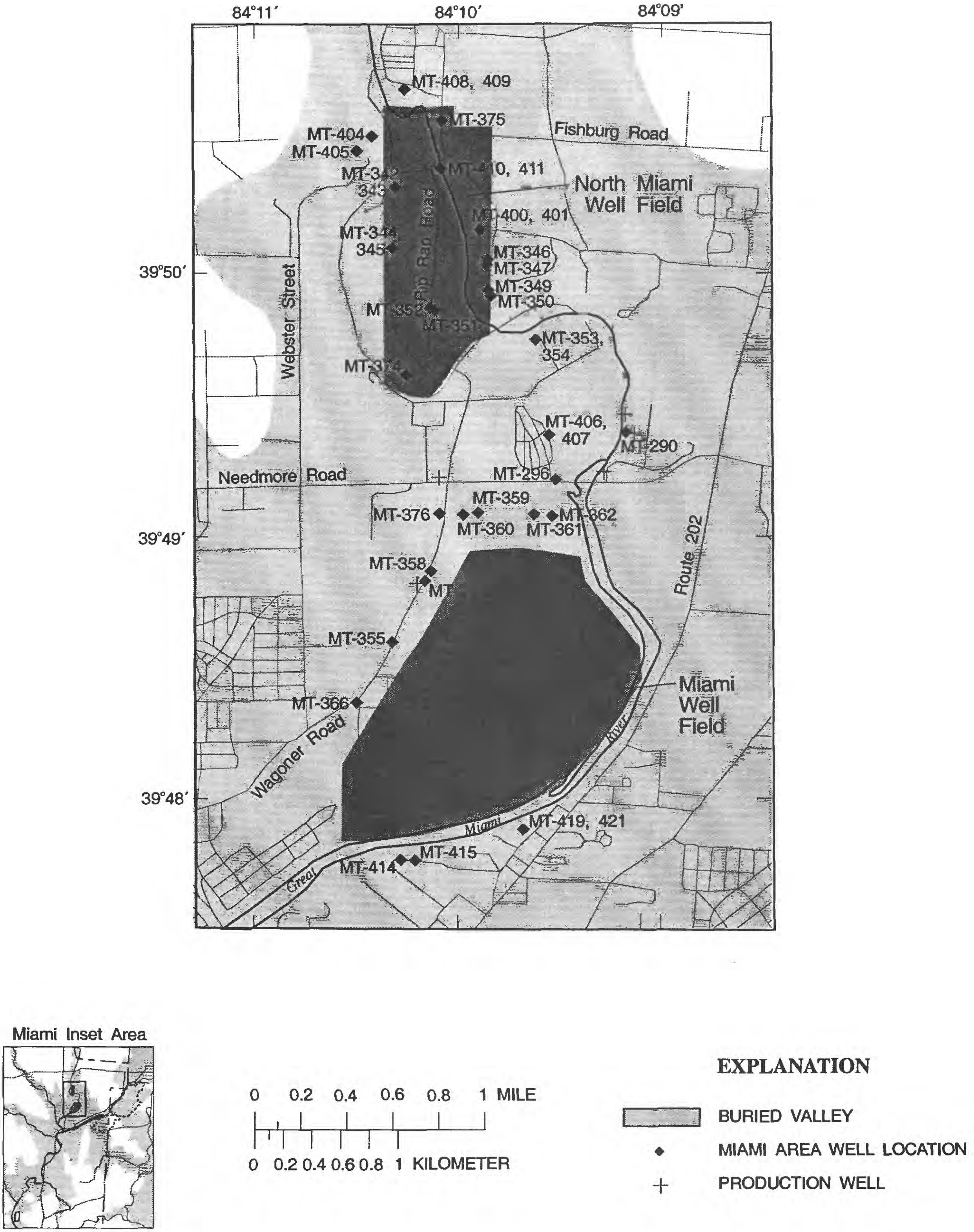


Figure 6. Locations of wells sampled in or near the Miami well fields, Dayton area, southwestern Ohio. (Relation of this subarea to other study subareas is shown in fig. 3.)

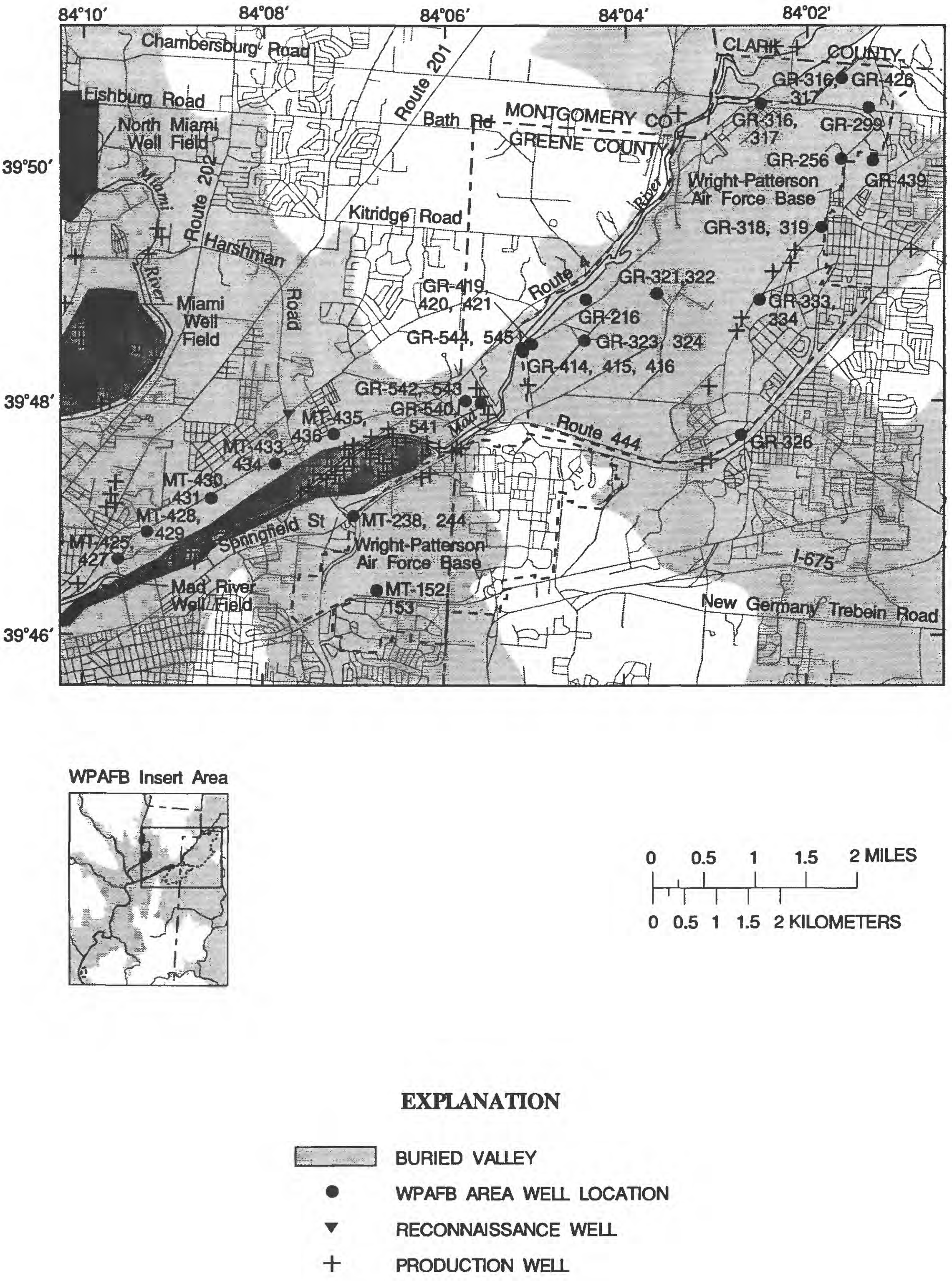


Figure 7. Locations of well sampled in or near Wright-Patterson Air Force Base-Mad River Well Field, Dayton area, southwestern Ohio. (Relation of this subarea to other study subareas is shown in fig. 3).

Issues pertaining to site accessibility were the final set of criteria applied to deciding which wells would be sampled for the environmental tracer study. These include obtaining permission from the well owner to sample the well and being able to access the wellhead. At many locations, it was necessary to temporarily remove dedicated sampling pumps so that the specialized pump used to collect environmental tracer samples could be inserted in the well. Removal and replacement of existing pumps required an additional set of permissions from the well owner.

Surface water. Twenty-one surface-water sites were sampled for dissolved major ions and CFC's in September 1995 to assess CFC concentrations in major streams in the study area (fig. 8). The purpose of this reconnaissance sampling was to evaluate the occurrence and distribution of CFC's in streams and their relation to the distribution of major industrial and wastewater-treatment plant effluent. Such effluent has been shown to be a significant source of CFC's in surface water (Busenberg and Plummer, 1992). Because many discharge locations are upstream from well fields affected by induced infiltration of surface water, it was important to determine whether high concentrations of CFC's in streamwater could be affecting CFC concentrations in shallow ground water in and around these well fields. Surface-water sampling for CFC's was therefore done at easily accessible sites both upstream and downstream from major industrial and wastewater-treatment plant discharge locations (fig. 8). Flow-duration data given by Johnson and Metzker (1981) indicate that for September–November, streamflows recorded on the Great Miami, Mad, and Stillwater Rivers at the time of sampling are equaled or exceeded 25 to 31 percent of the time. This statistic indicates that the surface-water samples collected in September 1995 contained a significant component of surface-water runoff.

Air. Air samples for CFC analysis were collected at three sites over three consecutive days in October 1995 to examine spatial and temporal trends in the three CFC compounds of interest in this study (fig. 8). The northernmost sampling site (Air-1) was at the base of Taylorsville Dam near well MT-287 in a largely rural setting. Site Air-2 was adjacent to the water-treatment facility at the Miami Well Field and near well MT-366 about 2 mi north of Dayton. Land use in the area around the well field is mixed among commercial, industrial, and residential uses. Site Air-3 was at well MT-302 in the southern part of the study area, where land use is also a mixture of commercial, industrial, and residential uses.

Collection and analysis of water-quality samples

In this section, apparatus and procedures used to collect and analyze water-quality samples are described.

Ground water. Wells were purged before sampling with a submersible stainless steel pump placed 5 to 10 ft below the water table. Purging was done at rates that varied from 1 to 4 gal/min depending on the borehole volume. During purging, temperature, pH, specific conductance, redox potential, and dissolved-oxygen (DO) concentrations were monitored with probes placed in a flowthrough chamber attached to a 1/2-in.-diameter polypropylene discharge line. Purging was considered complete after a minimum of three borehole volumes had been pumped and after temperature, pH, specific conductance, and DO had stabilized (Wood, 1976). Total purge time ranged from less than 20 minutes for shallow, 2-in. piezometers to several hours for deep wells with 6- or 8-in.-diameter casing.

After purging was completed, water was filtered with a 142-mm-diameter nitrocellulose plate filter (0.45 µm nominal pore diameter), and water samples were collected for the determination of nutrients (N species and PO_4), major ions (Na, K, Ca, Mg, F, Cl, SO_4), and selected trace elements (Fe, Mn, B, and Br). Additional filtered samples were collected for field analysis of ferrous and total iron by spectrophotometric techniques (Hach Company, 1993). Unfiltered water samples were then collected for the field determination of alkalinity and laboratory analyses of total iron and manganese. Filtered and unfiltered samples collected for dissolved and total iron and manganese analyses were acidified in the field to a pH less than 2 with trace-metal-grade nitric acid. Samples collected for dissolved organic carbon (DOC) analysis were filtered with a silver filter (0.45 µm nominal pore diameter) by use of a stainless steel nitrogen-pressurized filter chamber. Nutrient and DOC samples were placed in insulated, ice-filled coolers, chilled to 4°C, and then shipped to the U.S. Geological Survey National Water Quality Laboratory (NWQL) for analysis. Nutrients, DOC, major cations, anions and other constituents were analyzed by the NWQL using methods described in Fishman and Friedman (1989).

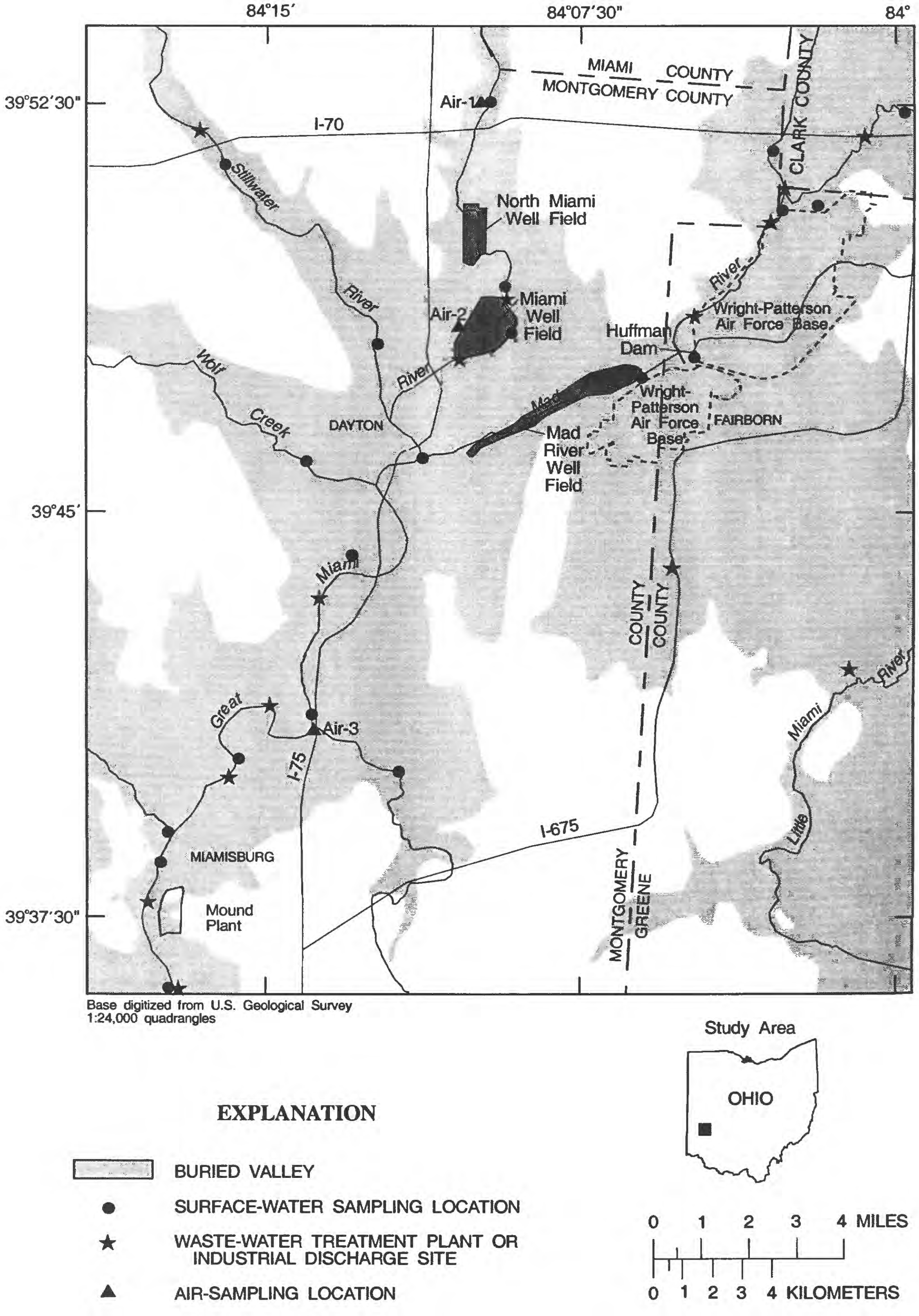


Figure 8. Locations of surface-water-quality and air-sampling sites, Dayton area, southwestern Ohio.

About 5 percent of the total water-quality samples collected and submitted to NWQL were quality-assurance/quality-control samples that were either field blanks or replicates. These were used to assess contamination during sampling and analysis and to check the precision and reproducibility of sampling and analytical methods used to collect water-quality samples. Levels of contamination indicated by the blank analyses were negligible. One exception was iron, where 20-30 µg/L of dissolved iron was found in the blanks. Replicate results agreed within 10 percent for most constituents with the exception of dissolved iron, total iron, and fluoride, where discrepancies of as much as 50 percent were reported. Problems with the iron data may reflect either variable entrainment of iron hydroxide dislodged from the casing during purging or, alternatively, filtration effects, because some colloid-sized iron-hydroxide particles would be small enough to pass through the 0.45-µm plate filter. Large discrepancies in the fluoride data reflect a lack of analytical sensitivity at the low fluoride concentrations found in ground water and resulting rounding effects (for example, 0.2 as opposed to 0.3 mg/L F).

Water-quality samples were not collected concurrently with environmental-tracer samples at 36 monitoring wells that were sampled in September–October 1993. These wells were already being sampled on a regular (quarterly) basis by the City of Dayton Department of Water Supply and Treatment. Samples collected from these wells were analyzed by the Department of Water Supply and Treatment laboratory. As part of this program, Dayton monitoring wells are sampled quarterly for major ions, nutrients, trace metals, total organic carbon (TOC), and various synthetic organic chemicals including VOC's. Major-ion, nutrient, trace-metal, and TOC data reported herein are for the quarterly sample collected closest to the date the well was sampled for environmental tracers. TOC concentrations are substituted for DOC concentrations for these samples because the City of Dayton does not analyze for DOC. Charge-balance errors were evaluated for major-ion data supplied by the Dayton laboratory and were, with one exception (MT-429), less than 15 percent, an acceptable level for the purposes of this study. Concentratons of nutrients, dissolved iron and manganese, and TOC were consistent with quarterly data reported by Dayton for previous sampling rounds and were within limits considered reasonable for the buried-valley aquifer.

Surface water. Surface-water-quality samples were collected by lowering an air-piston pump into the stream near or at the centroid of flow. During purging of the pump discharge line, specific conductance, pH, temperature, and DO were monitored with a four-parameter water-quality meter and were recorded immediately prior to sampling. After 10 tubing volumes were purged, aliquots filtered with a 142-mm-diameter nitrocellulose plate filter (0.45 mm nominal pore diameter) were collected for the determination of major ions, nutrients, dissolved iron, manganese, boron, and bromide. Preservation, handling, and shipping procedures were as described above.

Collection and analysis of chlorofluorocarbon samples

Specialized apparatus and techniques used in the collection of water and air samples for chlorofluorocarbon analysis are described in this section.

Ground water. Immediately after collection and processing of the water-quality samples, the submersible pump was pulled from the well casing and an air-piston pump fitted with a refrigeration-grade 1/4-in. copper-tubing discharge line was inserted into the well. The pump was placed near the top of the well screen or 2 to 3 ft above the bottom of the cased interval for wells with no screen. The pump and discharge line were purged of a minimum of 10 discharge-line volumes (at least 5 gal) and then sampled by use of methods described by Busenberg and Plummer (1992).

Four to six CFC glass ampules were collected at each well; these ampules were sealed by use of a blowtorch at the sampling site and then shipped to the USGS CFC Laboratory in Reston, Va. Two (numbers 2 and 4) or three (numbers 1, 3, 5) ampules from each well were analyzed by use of a purge and trap gas chromatograph equipped with an electron-capture detector (Busenberg and Plummer, 1992). Additional ampules were analyzed if results of the initial analyses differed significantly. CFC concentrations were determined for three CFC compounds: trichlorofluoromethane (CCl_3F, F-11, Freon 11, or CFC-11), dichlorodifluoromethane (CCl_2F_2, F-12, Freon 12, or CFC-12), and trichlorotrifluoroethane ($C_2Cl_3F_3$, F-113, Freon 113, or CFC-113). The detection limit for each of the three CFC compounds is about 1 picogram per kilogram (pg/kg).

The electron-capture detector used to detect and quantify CFC compounds also gives qualitative responses to nitrous oxide (N_2O), reduced-sulfur compounds (hydrogen sulfide (H_2S) and methyl sulfide (CH_3SH)), and halogenated VOC's such as methylene chloride, methyl chloride, carbon tetrachloride, trichloroethylene, and vinyl chloride.

Although the concentration of the above-listed compounds cannot be quantified, their presence or absence provides information about the redox state of the aquifer and the presence or absence of synthetic organic compuonds in the sample.

Surface water. Two to four CFC ampules were collected at each surface-water site. The samples were collected near the centroid of flow by use of an air-piston pump. Samples were collected just below the surface and near the midpoint between the river bottom and river surface. The samples were collected and analyzed by use of procedures discussed in the previous section (Busenberg and Plummer, 1992).

Air. Air samples were collected in preevacuated stainless steel gas cylinders with a nominal volume of 600 cm^3. The cylinders were attached to an air pump constructed of stainless steel. A piece of stainless steel tubing about 6 ft in length was attached to the inlet port and was extended vertically from the pump during sampling. The pump was allowed to operate for several minutes to purge previously enclosed air. After purging was completed, the valve was opened and the gas cylinder was filled with air until cylinder pressure reached 25–30 lb/in^2. At all three sites, the pump and cylinder were placed on top of the well casing so that air was sampled at a height of 8 to 10 ft above ground surface. After sampling, the cylinder valve was closed and the sample was shipped to the USGS CFC Laboratory in Reston, Va., for analysis.

Collection and analysis of ground-water samples for dissolved gases

Twelve wells were sampled for dissolved gases (N_2, Ar, O_2, CO_2, CH_4) using 500-mL sidearm chamber (SAC) bottles (Hobba and others, 1977; Pearson and others, 1978). Samples were collected by connecting the SAC bottle to the pump discharge line with flexible tubing. Ground water filled the chamber from the bottom, forcing air out of the chamber. Flushing was continued for several minutes, and then the upper and lower valves were closed. After both chamber valves were closed, the valve to the sidearm was opened, allowing dissolved gases to enter the newly created headspace. In the laboratory, the SAC bottle was attached to a gas chromatograph and the headspace gases were analyzed by methods described in Busenberg and others (1993). By use of measured temperature, sidearm pressure, and sample-volume data and appropriate Henry's Law constants, the concentrations of dissolved gases in the sample were calculated. All analyses of samples collected with sidearm chambers were completed within 2 weeks of sample collection.

In addition, unused CFC ampules collected at 21 wells were analyzed for methane at the USGS CFC Laboratory in December 1995. These analyses were done on samples from wells where degradation of CFC's was suspected. Methane analyses were done by inserting a glass ampule into a rubber sleeve attached to a gas chromatograph. The neck of the ampule was broken off under vacuum, and headspace gases were analyzed for methane by gas chromatography. Measured pressure and temperature, an estimate of headspace volume in the ampule, and the appropriate Henry's Law constant were used to calculate the approximate methane concentration of the sample. Because of the large uncertainty in the estimate of headspace volume, reported methane concentrations are qualitative (accuracy estimated to be $\pm$ 50 percent). The analytical detection limit for methane by this method is 0.003 mg/L.

The representativeness of the methane data obtained from the CFC samples with respect to actual aquifer conditions at the time of sampling must be assessed in view of the long interval between sample collection and analysis. This interval ranged from 16 to 30 months (2.5 years), depending on when the sample was originally collected. During this time, microbial reactions with dissolved organic compounds or colloidal organic material in the sample could have produced methane. Production of methane during sample storage is indicated by comparison of methane data obtained for wells where both SAC and unused CFC ampules were analyzed for methane. At two wells (MT-296 and MT-297), methane concentrations were lower in the initial SAC sample than in the later CFC ampules, although the observed difference in CFC ampule data from well MT-296 was within the analytical precision of the ampule analyses. Ground water from MT-296 is also known to be contaminated with a variety of VOC's, whereas no VOC's (halocarbons) were detected on the CFC chromatogram for the ground-water sample collected from MT-297. Ground water sampled from MT-286, which had an on-site DO concentration of 0.5 mg/L, did not yield detectable quantities of methane in either analysis.

Collection and analysis of ground-water samples for tritium, helium, and neon

Ground-water samples for analysis of tritium, helium isotopes, and neon were collected in 3-ft sections of 1/4-in.-diameter copper tubing (nominal volume 40 cm^3). The copper tube was attached to the pump discharge line by a short length of polypropylene tubing secured by stainless steel hose clamps. The copper tube was mounted in a metal holder with stainless steel pinch-off clamps at each end; these clamps were crimped shut at both ends of the tube after sampling was completed. Two copper tubes were filled at each well. Additional water samples were collected in 1-L glass or high-density polyethylene bottles for tritium analysis in the event of leakage from the copper tubes. Samples were shipped to the Lamont-Doherty Earth Observatory Noble Gas Facility for gas extraction and analysis. Methodology and analytical precision associated with tritium, neon, and helium isotope analyses are described by Shapiro and others (1998).

Estimation of ground-water age

In the following sections, the basic theory and assumptions used to estimate the recharge age of ground water by use of environmental tracers are briefly described. The two environmental tracers used to estimate ground-water age for this study are the chlorofluorocarbons (CFC's) and tritium-helium 3 (^{3}H-^{3}He). Because of various uncertainties and assumptions that are associated with sampling, analysis, and interpretation of the environmental tracer data, ground-water ages estimated by use of the CFC and ^{3}H-^{3}He methods are regarded as apparent ages and must be carefully reviewed to ensure that they are geochemically consistent and hydrologically realistic.

Chlorofluorocarbon method. CFC's are manufactured VOC's that have been used extensively use as refrigerants, aerosol propellants, cleaning solvents, and blowing agents in a variety of industries. The concentrations of CFC's in air have steadily increased since CFC's were first introduced in the 1930's. However, CFC's are also believed to catalyze the destruction of atmospheric ozone and are a known greenhouse gas (Rowland, 1991). As a result, worldwide controls have been instituted in an effort to reduce global atmospheric CFC concentrations. Data reported through the mid-1990's (E. Busenberg, U.S. Geological Survey, written commun., 1996) indicate that concentrations of CFC-11 and CFC-113 in air are starting to level off or decline in response to the new controls; hence, CFC dating of modern ground water will become less precise in the future as concentrations of CFC compounds used for dating decline further.

The use of CFC's as a dating tool is based on the more or less steady increase in northern troposphere CFC concentrations that has accompanied the large-scale use of CFC compounds in various industries. CFC's released into the atmosphere are partitioned into rainwater. The equilibrium solubility of individual CFC compounds in water (C_{CFC}) is governed by gas-liquid exchange equilibria, which are expressed in terms of Henry's Law:

$$C_{CFC} = K_{CFC(T,S)} \times P_{CFC}, \qquad (1)$$

where K is the Henry's Law constant for the individual CFC compound at a known temperature (T) and salinity (S), and P is the atmospheric partial pressure of the CFC compound. Henry's Law constants for CFC-11, CFC-12, and CFC-113 as a function of temperature and salinity have been compiled (Warner and Weiss, 1985; Bu and Warner, 1995). Concentrations of CFC-11, CFC-12, and CFC-113 in continental U.S. air from 1940 to the present have been reconstructed from CFC production records (McCarthy and others, 1977; Chemical Manufacturers Association, 1992) and atmospheric measurements that began in the mid-1970's (Busenberg and others, 1993; Elkins and others, 1993; Fisher and Midgley, 1993; and E. Busenberg, written commun., 1996). Concentrations of CFC-11, CFC-12, and CFC-113 in air and water in equilibrium at 10°C are shown in figure 9.

To calculate the age of a ground-water sample (or recharge year, if age is subtracted from the date of sampling), concentrations of the individual CFC compounds in ground water are divided by the appropriate Henry's Law constant to give the partial pressure of the CFC compound in air at the time the sample was isolated from the atmosphere. Because the Henry's Law constants are temperature dependent, an estimate of the recharge temperature is needed. The recharge temperature is the temperature at the base of the unsaturated zone and is usually close to the mean annual air temperature. Recharge temperatures can be estimated independently by a variety of techniques; the average recharge temperature of 10°C used in this study (see section on dissolved gases and recharge temperature) was estimated by use of oxygen and deuterium isotope data, dissolved-gas (N_2/Ar) ratios, and long-term air temperature records for the study area. The calculated partial pressure is then compared with the atmospheric concentration curves (fig. 9) to derive the age of the sample. It is assumed that CFC concentrations in recharge waters are in equilibrium with the soil atmosphere and, more importantly, that CFC concentrations in the soil gas are equal to those found in air (Busenberg and others, 1993). These assumptions are reasonable for the study area because depth to the water table is generally 20 ft or less, and most soils in recharge areas are moderately to highly permeable.

Ground-water ages derived by the CFC technique are considered to be minimum ages because trace-level contamination by small amounts of CFC compounds introduced during sampling or mixing of ground water of different ages can never be completely excluded. Trace-level contamination affects the reliability of older recharge

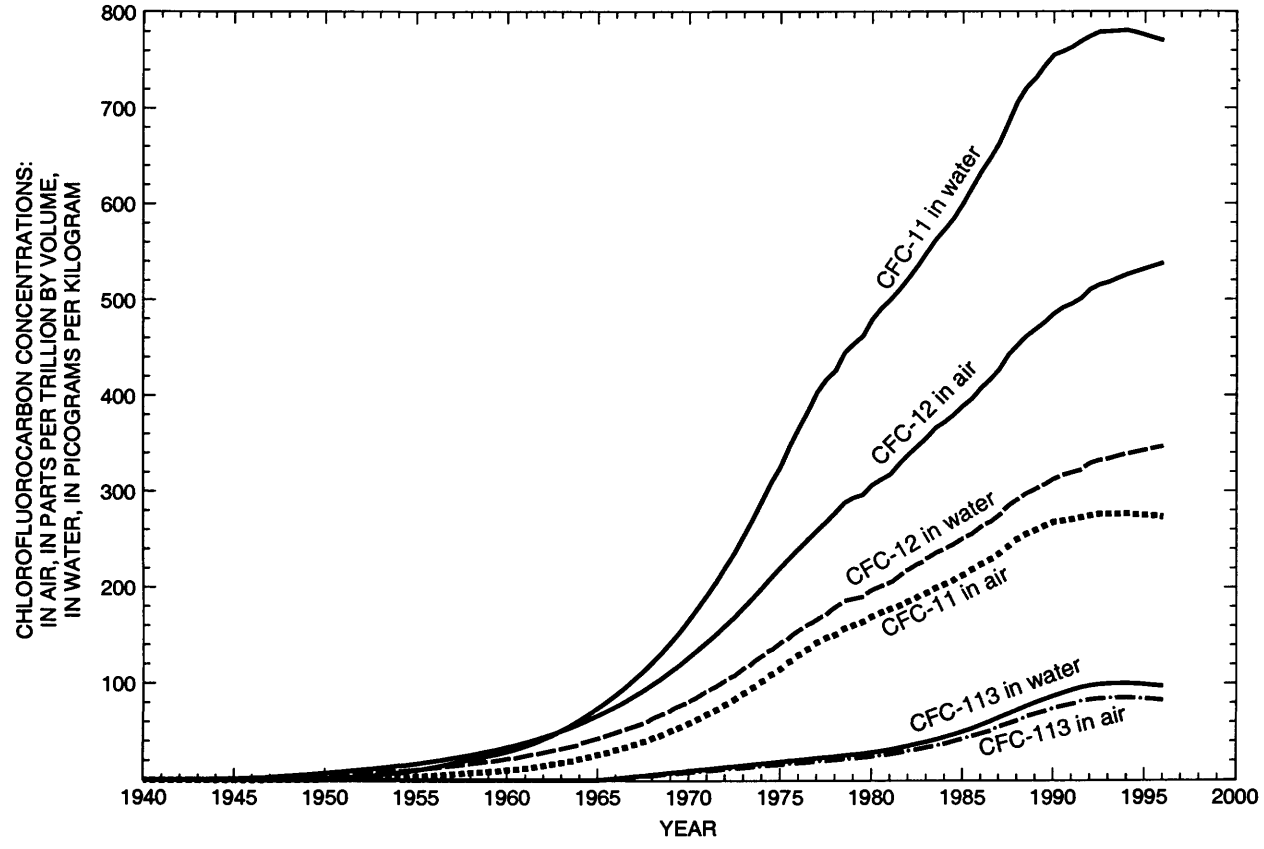


Figure 9. Concentrations of chlorofluorocarbon compounds CFC-11, CFC-12, and CFC-113 in air and water at equilibrium at 10°C and 760 feet above sea level. (Data from E. Busenberg, U.S. Geological Survey, written commun., 1996.)

ages to a greater degree because of lower CFC concentrations in older waters (fig. 9). Other processes that can affect the reliability of CFC ages include gross contamination, sorption, microbial degradation, hydrodynamic dispersion, and diffusion in the unsaturated zone (Weeks and others,1982; Russell and Thompson, 1983; Busenberg and Plummer, 1992; Lovley and Woodward, 1992; Busenberg and others, 1993; Dunkle and others, 1993; Plummer and others, 1993; Reilly and others, 1994; and Katz and others, 1995). Uncertainty in the recharge temperature affects the recharge age to a varying extent. Uncertainty of several degrees Celsius causes an uncertainty of less than a year in waters recharged prior to 1975. For waters recharged in the 1980's, an uncertainty of 2°C results in an uncertainty of 2 to 3 years. For post-1989 waters, a 2°C uncertainty in the recharge temperature can cause errors of several years or more (Busenberg and Plummer, 1992; Plummer and others, 1993).

Tritium-helium-3 method. Tritium (^3H), the radioactive isotope of hydrogen, has been used extensively as a hydrologic tracer and dating tool. Although tritium is produced naturally in the upper atmosphere, its use as a hydrologic tracer is related to the injection of large quantities of tritium into the atmosphere during atomic-weapons testing in the 1950's and early 1960's. Peak tritium activities in southwestern Ohio rainwater are believed to have approached 2,000 tritium units (TU; 1 TU equals 3.24 picocuries per liter or 1 tritium atom per 10^{18} hydrogen atoms) (fig. 10). The atmospheric-testing peak therefore provides an absolute time marker from which to estimate ground-water age. However, because radioactive decay and hydrodynamic dispersion have greatly reduced maximum tritium concentrations in ground water, identification of the 1960's atmospheric-testing peak has become increasingly difficult. Therefore, tritium by itself is used only as a qualitative indicator of ground-water age; detectable concentrations of tritium ($\geq$ 1-2 TU) indicate that some fraction of the water recharged the aquifer after 1952.

The ^3H-^3He dating method is based on the decay of tritium to its daughter product, the noble gas helium 3 ($^3He_{trit}$, tritiogenic helium). The sum of tritium and its daughter product ($^3H+^3He_{trit}$) represents a conservative quantity equivalent to the amount of tritium in rainwater at the time of recharge, assuming that helium produced by tritium decay is not lost by upward diffusion to the unsaturated zone. This assumption is considered valid for aquifers where vertical flow velocities exceed approximately 1.5 ft/yr (Schlosser and others, 1988, 1989; Poreda and others, 1988). Because helium in ground water is derived from several sources, however, a detailed evaluation of the various components of the helium budget is required to obtain accurate ^3H-^3He ages. Procedures used to evaluate and correct the helium data for nontritiogenic sources of ^3He in samples collected during this study are described by Schlosser and others (1988, 1989) and Shapiro and others (1998).

Once the amount of tritiogenic ^3He is known, the ^3H-^3He age is then calculated from the daughter/parent ratio ($^3He_{trit}/^3H$) by use of the standard decay equation:

$$\tau = \frac{T_{1/2}}{\ln 2} \cdot \ln\left(1 + \frac{^3He_{trit}}{^3H}\right), \qquad (2)$$

where τ is the ^3H-^3He age, in years; $^3He_{trit}$ is the amount of ^3He derived from tritium decay, in TU; ^3H is the measured tritium concentration, in TU; and $T_{1/2}$ is the half-life of tritium (12.43 years) (Schlosser and others, 1988, 1989; Solomon and Sudicky, 1991; Solomon and others, 1993). In simple terms, the concentration of tritiogenic ^3He will increase as tritium decays; thus, older waters will have higher $^3He_{trit}/^3H$ ratios. The age derived by use of this technique represents the time elapsed after rainwater or infiltrating surface water was confined below the water table; it is further assumed that diffusion, dispersion, contamination, or mixing at the well screen have not affected the concentrations of ^3H or ^3He in the sample. Apart from radioactive decay of tritium, ^3H and ^3He are both chemically inert and therefore are unaffected by microbial degradation or sorption, processes known to affect the reliability of the CFC dating method.

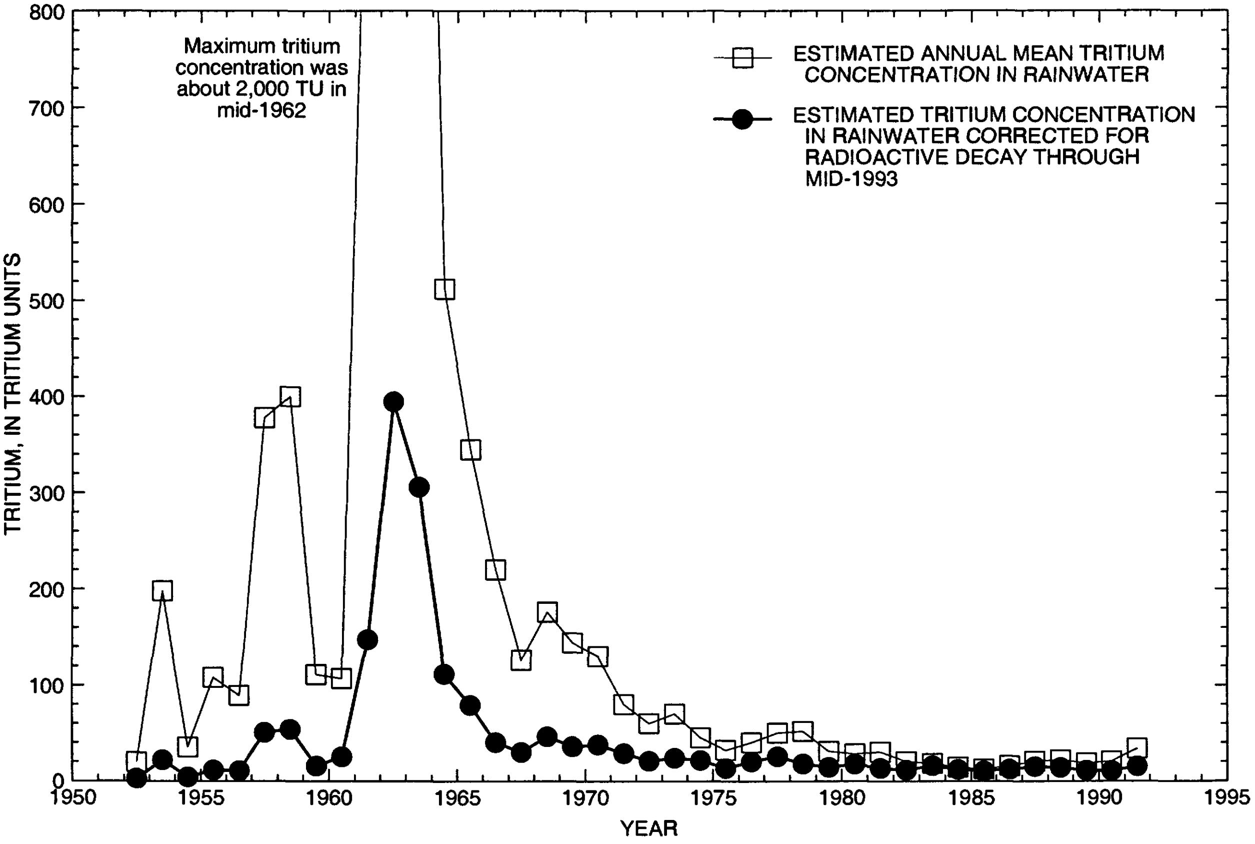


Figure 10. Estimated annual mean tritium concentration in rainwater, 1952-91, southwestern Ohio. (Tritium concentrations in original rainwater based on tritium deposition estimates given by Michel, 1989, and R.L. Michel, U.S. Geological Survey, written commun., 1991.)

RESULTS OF ANALYSES

This section describes the analytical results obtained for water-quality and environmental-tracer samples collected for this study. Ages of ground-water samples estimated by use of the CFC and ^{3}H-^{3}He methods also are summarized.

Onsite water-quality measurements, major ions, and selected trace constituents

Ground-water-quality samples were collected to assess geochemical conditions in the aquifer at the time of environmental-tracer sampling and to assess relations between ground-water ages and ground-water quality in the buried-valley aquifer. The ground-water-quality data are used to characterize redox conditions in the buried-valley aquifer because the reliability of the CFC dating technique is known to be adversely affected by anoxic conditions in an aquifer (Dunkle and others, 1993; Katz and others, 1995). Additional water-quality data were obtained for surface-water samples collected during the CFC reconnaissance survey of streams and rivers in the Dayton area.

Ground water. Construction, water-level, onsite, and laboratory-derived water-quality data for the 137 wells sampled during this study are available online at http://oh.water.usgs.gov/reports/daytonwells.html or as hard copy from the Columbus, Ohio, office of the USGS. Onsite analyses done immediately prior to collection of water-quality samples yielded a median temperature of 14°C,a median pH of 7.2, a median specific conductance near 800 µs/cm, a median DO concentration of 0.1 mg/L (the reporting limit), and a median redox (oxidation-reduction) potential of about 140 mV (reported relative to the Standard Hydrogen Electrode or SHE) (fig. 11). Of these data, the distribution of DO is particularly noteworthy because it indicates that the majority of wells sampled in this study were screened in anoxic, and hence chemically reduced, parts of the buried-valley aquifer (DO $\leq$ 10 µmol O_2 or 0.3 mg/L).

On the basis of major-ion chemistry, nearly all of the ground-water samples are classified as a calcium-magnesium-bicarbonate waters. This is illustrated on a trilinear diagram (fig. 12), which graphically plots water types on the basis of the milliequivalent percentages of major cations and anions in the water. The cation and anion triangles both show relatively linear trends towards more sodium- and chloride-rich compositions. Such trends could be caused by the presence of deicing salts in winter and spring runoff that recharges the buried-valley aquifer, or they could represent mixing with slightly saline sodium-chloride-type waters from bedrock shales (Dumouchelle and others, 1993). Several of the most sodium- and chloride-rich samples are from shallow Mound Plant wells that were screened at or near the contact between the buried-valley aquifer and bedrock shales.

Boxplots of major-ion data confirm that calcium, bicarbonate, and, to a lesser extent, magnesium, are the dominant ions in the ground water (fig. 13). The boxplots indicate a near-normal distribution for these constituents that is probably related to rapid dissolution and equilibration with calcite and dolomite, which are common in aquifer sediments. The distributions of sodium and chloride data are the most positively skewed; outlier data (as defined in fig. 13) reflect addition of these elements to ground water from road salt applied at the surface or saline water from bedrock shales. The data distributions of nearly all the trace and minor constituents appear positively skewed because several have median concentrations that are at or near their respective detection limits. The median dissolved-iron concentration, about 0.55 mg/L, exceeds the Secondary Maximum Contaminant Level for drinking water set by the U.S. and Ohio Environmental Protection Agencies (U.S. Environmental Protection Agency, 1991). At concentrations near or above this limit, iron imparts a metallic taste to the water and may cause staining of laundry, utensils, and bathroom fixtures.

Data for redox-sensitive chemical species show that DO concentrations indicating oxic or suboxic conditions are rarely found at depths greater than 40 ft below the water table (fig. 14). In comparison, nitrate concentrations of a few milligrams per liter or less persist to depths approaching 60 ft below the water table. Below this depth, detectable amounts of nitrate ($\geq$ 0.05 mg/L NO_3^- as N) are uncommon, an indication of possible removal of nitrate by denitrification. Further evidence of denitrification is the occurrence of nitrous oxide (N_2O) peaks in the CFC chromatograms and dissolved-nitrogen (N_2) concentrations much greater than those expected for gas-water equilibrium at the range of recharge temperatures expected for the study area. (See sections on other species and dissolved gases.) Dissolved-iron concentrations show no consistent trend with depth. Onsite analysis of dissolved-iron speciation by spectrophotometric techniques (Hach, 1993) indicated that nearly all dissolved iron in anoxic ground water is present as ferrous (Fe^{2+}) iron. The majority of ground-water samples lacking detectable concentrations of dissolved iron were collected from shallow wells that yielded ground water with detectable amounts of DO. At the near-neutral pH of ground water in the buried-valley aquifer, oxidation of ferrous iron to ferric (Fe^{3+}) iron would occur quickly in the presence of measurable DO. The low solubility of ferric hydroxide [$Fe(OH)_3$] would then prevent dissolved-iron concentrations from exceeding the analytical detection limit of 3 µg/L (Hem, 1989).

In contrast, sulfate concentrations remain fairly uniform with depth (fig. 14), an indication that sulfate reduction is not an important redox process in the buried-valley aquifer. Although the odor of H_2S was only rarely noted during sampling, peaks present in chromatograms produced during analysis of the CFC samples (see below) indicate very small quantities of H_2S (or methyl sulfide) in about 30 percent of the anoxic ground-water samples.

Reducing conditions are also indicated by the presence of dissolved methane in anoxic ground-water samples. Detectable concentrations of methane indicate reducing conditions. Methane can be of natural origin, or it can be produced by microbial degradation of organic chemicals (hydrocarbons, VOC's) of human origin. Of the 25 samples that had detectable methane concentrations, 5 also had detections of non-CFC halocarbons of human origin. This finding suggests that methane in the majority of the samples is of natural origin. Methane concentrations show no distinct trend with depth (fig. 8).

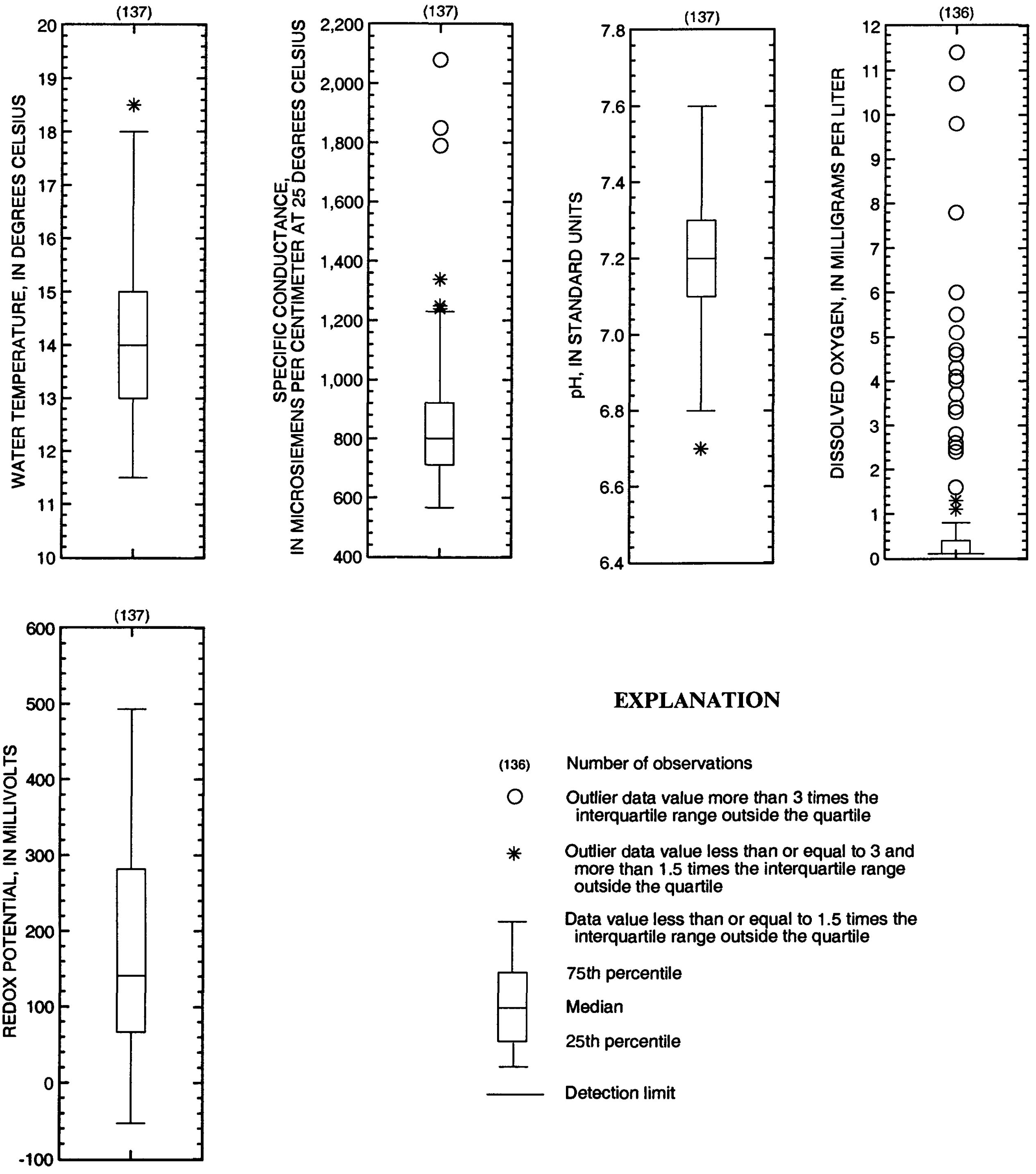
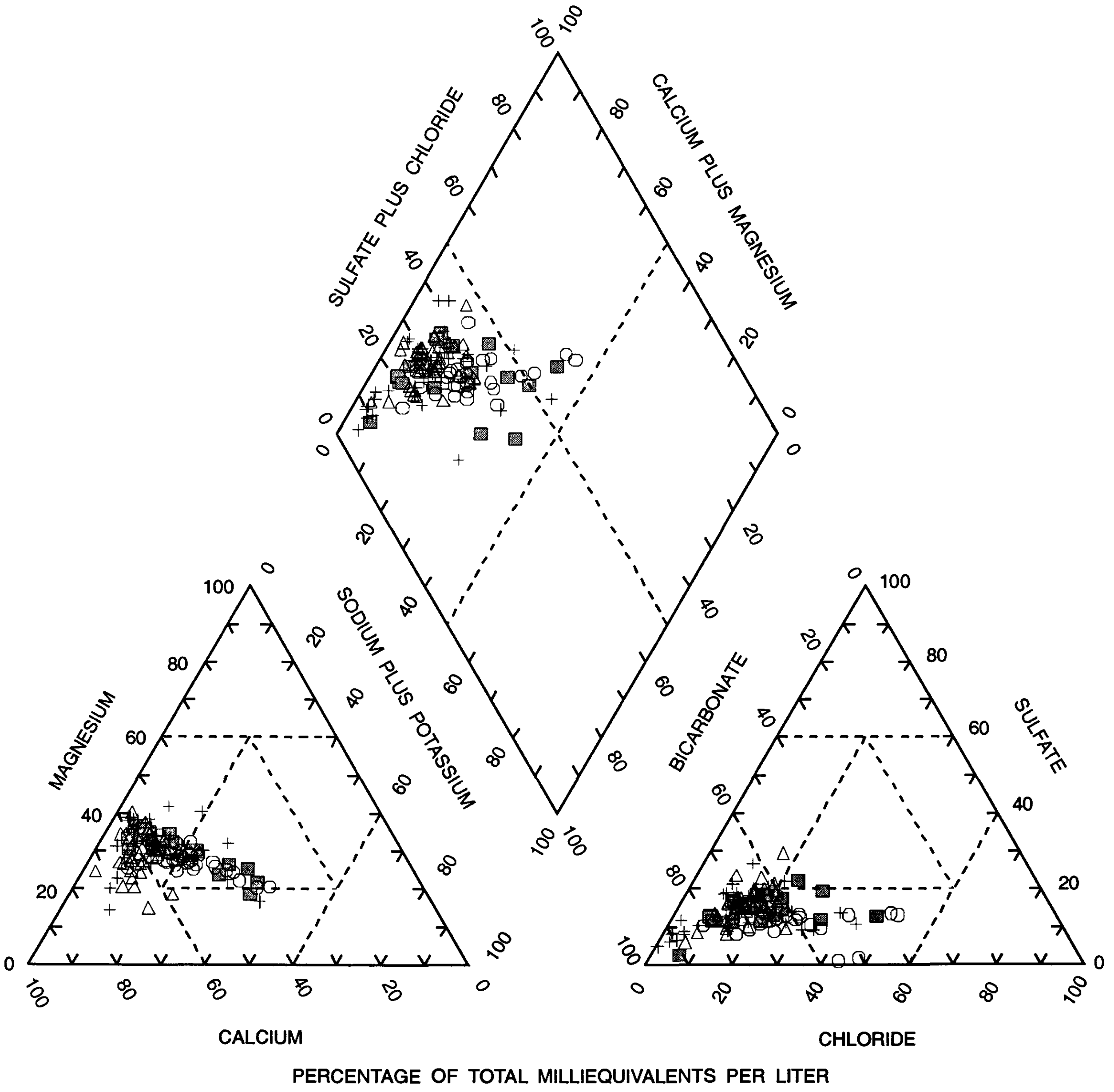


Figure 11. Distribution of temperature, specific-conductance, pH, dissolved-oxygen, and redox-potential data for the buried-valley aquifer, Dayton area, southwestern Ohio.



EXPLANATION

SAMPLES FROM WELL OR WELL FIELD INDIRECTED:

+ Wright-Patterson and Mad River well field area

△ Miami well field area

○ Mound plant

▨ Reconnaissance

Figure12. Trilinear diagram illustrating major-ion data from the buried-valley aquifer, Dayton area, southwestern Ohio.

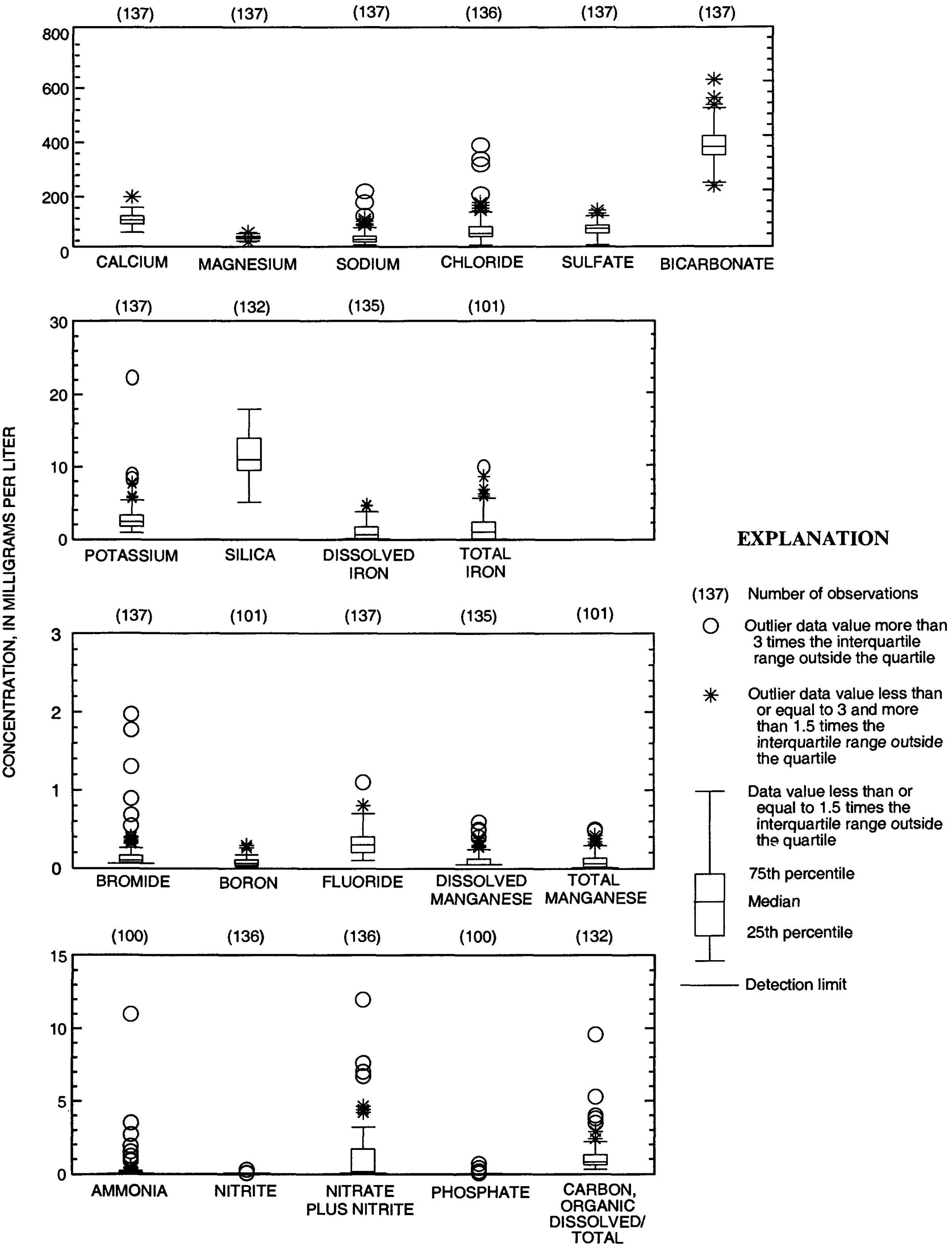


Figure 13. Distribution of major- and minor-ion data for the buried-valley aquifer, Dayton area, southwestern Ohio.

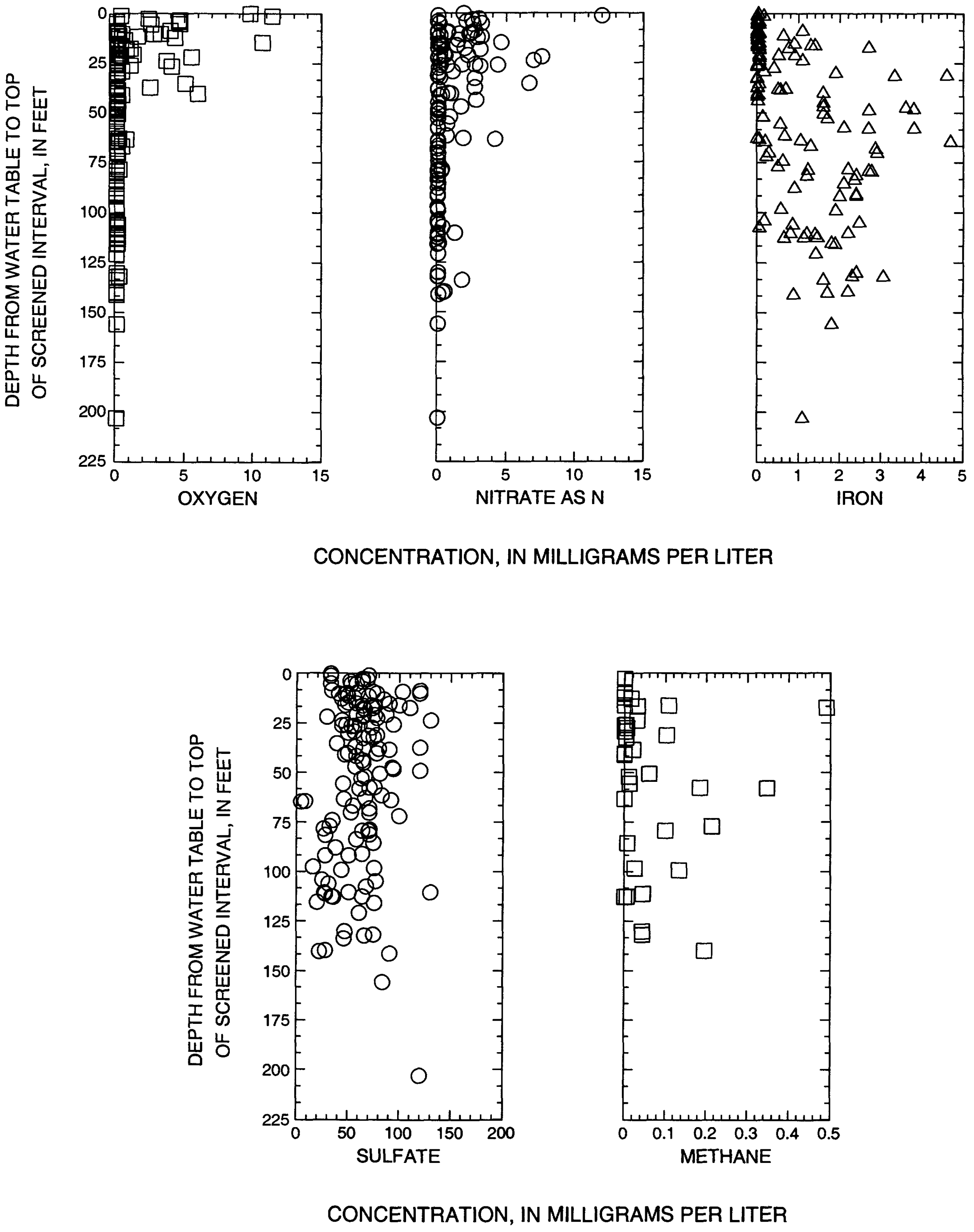


Figure 14. Concentrations of dissolved oxygen, nitrate-N, iron, sulfate, and methane as a function of depth from the water table to top of screened interval in the buried-valley aquifer, Dayton area, southwestern Ohio.

Evaluation of the ground-water analyses by use of the equilibrium speciation program WATEQ4F (Ball and Nordstrom, 1991) indicates that most ground water in the buried-valley aquifer is saturated with respect to dolomite ($CaMg(CO_3)_2$) and saturated to supersaturated with respect to calcite ($CaCO_3$). Ground water is generally supersaturated with respect to the ferrous iron-carbonate mineral siderite ($FeCO_3$) and various forms of silica (SiO_2), including quartz and chalcedony. Ground water is undersaturated with respect to fluorite (CaF_2) and gyspum ($CaSO_4$-$2H_2O$). As will be discussed later, the degree of saturation of ground water in the buried-valley aquifer with respect to certain minerals is related to apparent ground-water age.

Surface water. Compared to ground-water, data for the 21 surface-water samples collected in September 1995 indicate higher pH (median pH = 8.2), slightly lower specific conductance (median specific conductance = 725 µs/cm), and oxic conditions (percent DO saturation values range from 70 to 140 percent; median DO = 8.6 mg/L) (table 1, back of report). Boxplot summaries of major-ion data indicate that the majority of surface-water samples are classified as calcium-magnesium-bicarbonate waters (fig. 15), although samples from the Great Miami River downstream from the Dayton wastewater-treatment plant are classified as mixed cation-mixed anion waters because of elevated sodium and chloride concentrations that are probably derived from wastewater-treatment-plant effluent.

Compared to ground water, surface water in the Dayton area has lower dissolved silica, iron, manganese, and ammonia concentrations but higher nitrite plus nitrate concentrations. Despite these differences, the major-ion composition of surface water and ground water in the Dayton area are quite similar. This similarity reflects the fact that a significant percentage of the flow in area streams is ground water discharged from the buried-valley aquifer.

Chlorofluorocarbons

Concentrations of the CFC compounds CFC-11, CFC-12, and CFC-113 were determined on ground-water samples collected from 135 wells, surface-water samples collected at 20 locations, and air samples collected at 3 sites.These data are summarized in the following sections.

Ground water. CFC concentrations were highly variable in ground water, ranging from below the detection limit (≤1 pg/L for all three CFC compounds) to maximum concentrations of 28,650, 40,880, and 90,240 pg/L of CFC-11, CFC-12, and CFC-113, respectively (table 2, at back of report). Highly elevated concentrations indicate that addition of CFC compounds from nonatmospheric sources has occurred, as concentrations of CFC-11, CFC-12, and CFC-113 in water equilibrated with 1994 air would be about 780, 340, and 100 pg/L, respectively. These concentrations are based on CFC-11, CFC-12, and CFC-113 concentrations in air of 277, 526, and 85.3 parts per trillion by volume, respectively (fig. 9), and air-water equilibration at a temperature of 10°C at an elevation of 760 ft (the average surface elevation of wells sampled for this study).

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Ground-water samples with CFC concentrations that were only slightly above (less than 5 percent) the 1994 air-water equilibrium concentrations were considered to be modern waters that probably recharged the buried-valley aquifer in a year or less. However, samples that had CFC concentrations greater than 5 percent above the equilibrium concentrations probably represent contamination of the sample by CFC's from nonatmospheric sources. Such samples cannot be used to estimate ground-water age. The percentage of samples suitable for dating by the CFC method varied for the three CFC compounds: 83 percent for CFC-11; 67 percent for CFC-12, and about 79 percent for CFC-113. The data indicate that nearly a third of the wells sampled had CFC-12 concentrations above the range suitable for dating by the CFC method. The relatively large percentage of samples (18 to 33 percent) that could not be dated because of contamination with excess CFC's is not surprising given the many potential sources of these compounds in urban and industrial parts of the Dayton area. Calculated recharge years for ground-water samples that had CFC concentrations suitable for estimating ground-water ages are reported in table 2 (at back of report).

Surface Water. CFC concentrations were determined on 20 of the 21 surface-water samples collected over a 2-week period from September 11 to 25, 1995 (samples from the 21st site were broken in transit) (table 3). As discussed previously, streamflow data for the sampling period indicate a substantial component of surface runoff derived from basinwide rainstorms (> 0.2 in. per day) on September 9, 13, and 20, 1995.

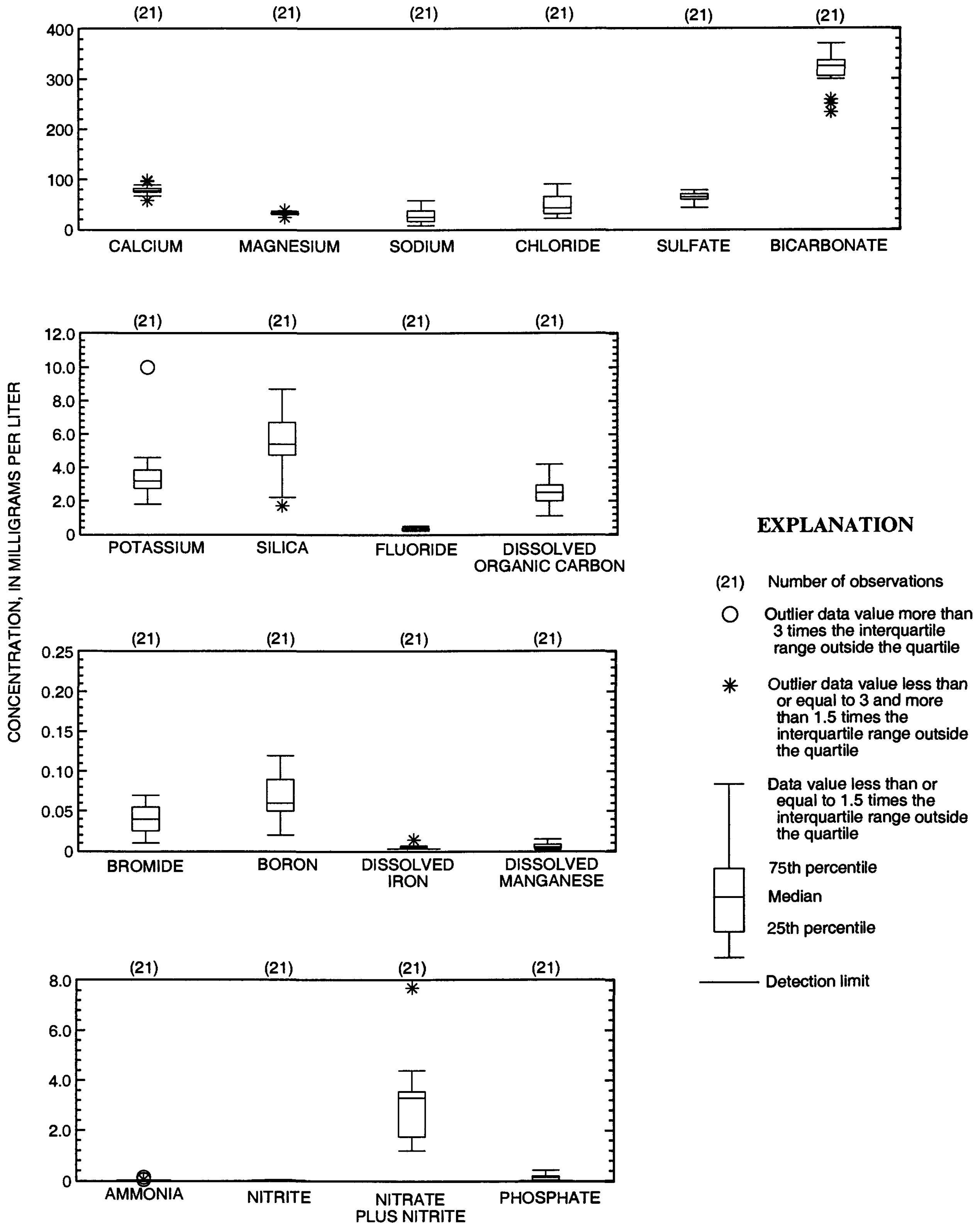

Figure 15. Distribution of major- and minor-ion data for surface-water samples, Dayton area, southwestern Ohio.

Using temperature data collected at the time of sampling and appropriate gas-water partitioning coefficients, CFC concentrations measured in surface-water samples were converted to equivalent partial pressures and divided by the CFC concentration in 1995 NH mean annual air to yield percent saturation values (table 3). Strictly speaking, only saturation values exactly equal to 100 percent would be saturated with respect to 1995 NH mean annual air; however, because of uncertainties in measured temperature, air-water equilibration rates, and applicability of the 1995 NH mean annual air value to the study area, saturation values in the range of 80 to 120 percent are considered representative of saturated or near-saturated conditions. Saturation values greater than 120 percent are assumed to indicate the addition of CFC's from nonatmospheric sources.

Data in table 3 indicate that the majority of surface-water samples were supersaturated with respect to one or more CFC compounds; most samples had 2 to 5 times the equilibrium solubility concentration. A few samples had extremely high CFC concentrations, such as the sample from Wolf Creek, which had a CFC-113 concentration more than 2,200 times greater than the 1995 air-water equilibrium concentration. Surface-water samples with the highest CFC concentrations were collected from main-stem reaches of the Great Miami, Mad, and Stillwater Rivers near or south of downtown Dayton (fig. 16). Interestingly, large concentrations of CFC's were not found downstream from wastewater-treatment plants despite the fact that sewage effluent has been shown to be a major source of CFC's in surface water at other locations (Busenberg and Plummer, 1993). Smaller tributary streams sampled at sites in rural or nonindustrialized parts of the study area, such as Bear Creek, Holes Creek, Mud Creek, and Mud Run, were approximately saturated with respect to all three CFC compounds.

Air. CFC-11, CFC-12, and CFC-113 concentrations in air samples collected at three sites in October 1995 are summarized in table 4.

Data for each of the three air-sampling sites were evaluated by calculating CFC excess values relative to the NH mean annual air concentrations for 1995 (E. Busenberg, U.S. Geological Survey, written commun., 1996). Positive excess percentages indicate that CFC concentrations recorded at the site were higher than the NH mean annual air values, whereas negative excess percentages indicate that values were lower than the NH mean annual air values.

Data in table 4 indicate that fluctuations in CFC concentrations in air in the Dayton area vary by individual CFC compound, sampling date, and location. Samples from site Air 1, which is in a largely rural setting north of metropolitan Dayton, had CFC concentrations that showed the least variation from day to day and were closest to 1995 NH mean air concentrations. Site Air 2, just north of downtown Dayton, and site Air 3, south of Dayton in the heavily industrialized Moraine area, had more variable CFC-11 and CFC-12 concentrations with maximum CFC-11 and CFC-12 excesses of about 33 and 15 percent. In contrast, CFC-113 concentrations in air at all three sites were close to the NH mean air value for CFC-113, with no CFC-113 excess values greater than 5 percent. Local deviations from NH mean air concentrations are commonly observed in urban and industrialized areas (Prather, 1985; Clarke and others, 1995); average monthly CFC-11 and CFC -12 excesses of 10 to 15 percent were recently reported for the New York-Long Island metropolitan area (Ho and others, 1998). Such CFC excesses result in estimated CFC ages that are younger than the actual ground-water age. The limited air data obtained indicate that the 5-percent limit used to determine whether ground-water samples have been contaminated by local sources of CFC's is conservative in that excesses of 10 or even 15 percent may characterize modern air in the Dayton area. However, without local long-term records of such variations, it is impossible to correct the CFC input functions used to estimate ground-water age; hence, the NH mean annual air concentrations were used to calculate the CFC recharge years given in table 3.

Table 3. Chlorofluorocarbon concentrations in surface-water samples from selected sites near Dayton, Ohio

[Site locations shown in fig. 8. Abbreviations: Cr, creek; R, River; Brdg, bridge; deg C, degrees Celsius; ft, feet; pg/kg, picograms per kilogram]

Site ID	Site description	Date	Water temperature (deg C)	Land-surface altitude (ft)	Number of ampules analyzed	Average chlorofluorocarbon concentation in water (pg/kg)			Average percent of 1995 air-water equilibrium[1]		
						CFC-11	CFC-12	CFC-113	CFC-11 (%)	CFC-12 (%)	CFC-113 (%)
395122084031100	Mud Creek at Valley Pike	95/09/25	13.0	820	4	491	341	93	75	114	113
395042084021700	Mud Run at Medway Road	95/09/25	17.0	820	2	490	302	77	91	120	118
394755084050400	Hebble Creek at South Boundary of Wright-Patterson Air Force Base	95/09/19	20.5	790	4	502	356	92	109	164	168
3271000	Wolf Creek at Bridge Street	95/0/912	18.5	740	2	3,730	746	138,200	738	316	227,700
394014084121200	Holes Creek at Alexanderville-Bellbrook Pike	95/09/11	21.5	715	2	390	200	66	88	95	127
393910084172300	Bear Creek at Soldiers Home Road	95/09/11	20.0	690	2	600	341	1,530	127	153	2,710
3263000	Great Miami River at Taylorsville Dam	95/09/12	21.0	760	4	1,740	291	75	386	137	141
394910084092300	Great Miami River at Needmore Road	95/09/18	22.0	750	2	523	239	61	121	117	121
394809084092100	Great Miami River at Miami Well field	95/09/19	17.5	745	2	931	272	70	176	111	109
394352084125700	Great Miami River at Broadway	95/09/12	22.0	720	2	910	2,430	1,300	210	1,190	2,570
394116084135200	Great Miami River at Sellars Avenue	95/09/12	22.5	710	2	700	1,140	966	165	569	1,950
394027084154100	Great Miami River at Miami Avenue	95/09/12	21.5	690	2	509	683	498	115	326	956
393826084173100	Great Miami R at Linden Avenue Brdg	95/09/11	25.5	680	2	651	695	457	173	384	1,060
3271601	Great Miami River at Chautauqua Road	95/09/11	18.5	670	2	683	658	429	135	278	705
395226083594600	Mad River at I-675	95/09/19	19.5	835	2	450	271	99	94	120	173
395035084030200	Mad River at SR235	95/09/19	19.5	805	1	509	240	81	106	106	140
394731084061800	Mad River at Rohrer's Island Inlet Gates	95/0919	19.5	775	1	559	3,240	108	116	1430	188
394605084110600	Mad River at Webster Street	95/09/18	21.0	730	1	1,000	395	5,200	222	185	9730
395117084155900	Stillwater River at Heathcliff Road	95/09/13	25.0	780	2	450	228	60	118	124	135
394753084122500	Stillwater River at Siebenthaler Road	95/09/13	21.0	735	2	3,130	756	2,610	694	354	4,880

[1] Concentrations of CFC-11, CFC-12, and CFC-113 in mid-1995 air used to calculate percent saturation values were 274, 535, and 83.5 parts per trillion by volume, respectively. Chlorofluorocarbon concentrations in 1995 air from E. Busenberg, (U.S. Geological Survey, written commun., 1996).

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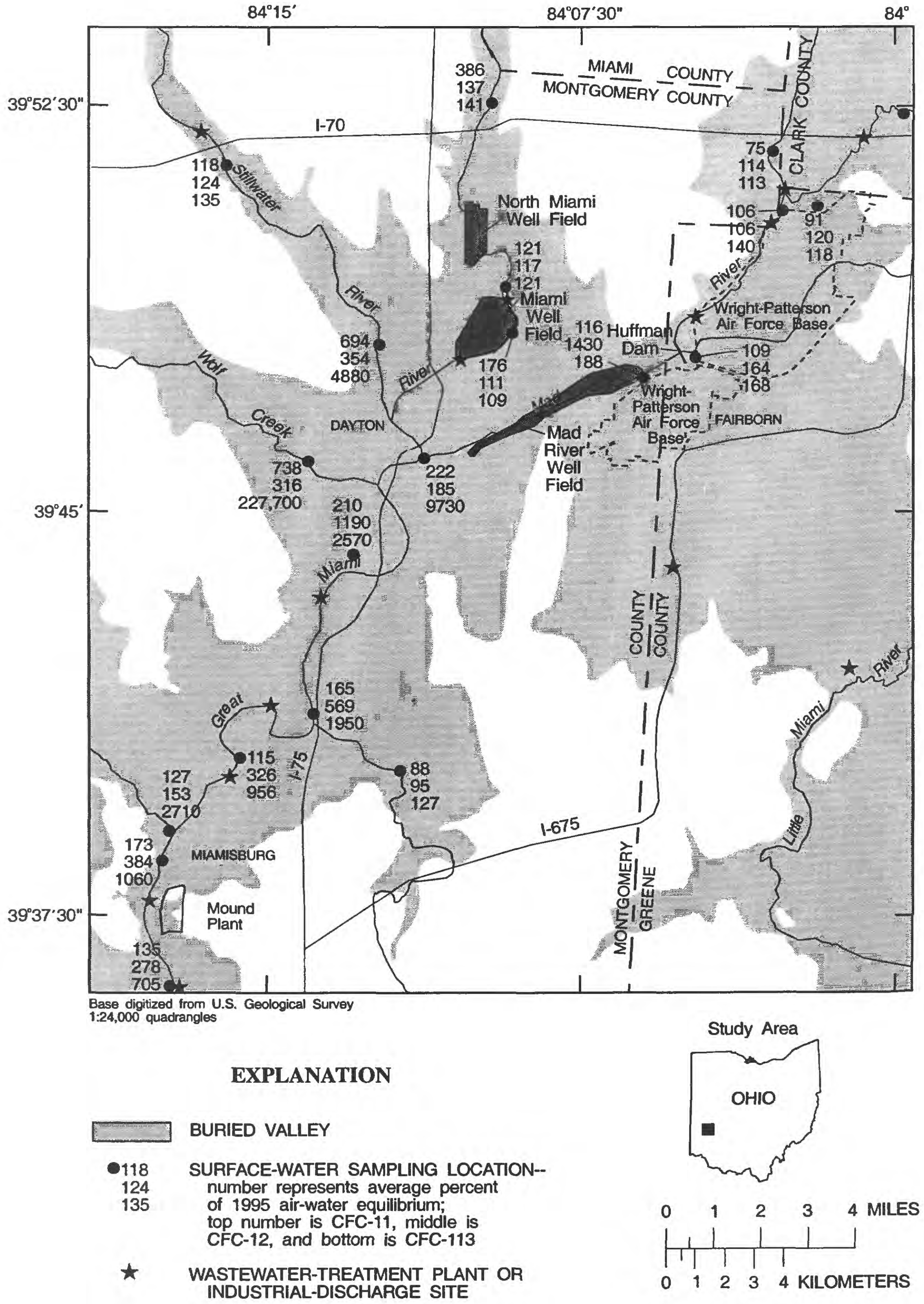

Figure 16. Chlorofluorocarbon concentrations in surface water, September 1995, Dayton area, southwestern Ohio.

Table 4. Chlorofluorocarbon concentrations and percent excess relative to Northern Hemisphere mean air[1] for air samples collected near Dayton, Ohio, October 1995

[pptv, parts per trillion by volume; %, percent]

Date	Time	CFC-11 (pptv)	CFC-11 excess (%)	CFC-12 (pptv)	CFC-12 excess (%)	CFC-113 (pptv)	CFC-113 excess (%)
Air 1 at well TU-287							
951710	1150	275.2	0.4	548.2	2.5	82.3	-1.4
951810	1125	269.2	-1.8	551.3	3.0	80.0	-4.2
951910	1155	280.8	2.5	593.3	10.9	83.3	-0.2
Air 2 near well MT-366							
951710	1115	274.8	0.2	578.1	8.0	81.9	-1.9
951810	1040	287.8	5.0	591.1	10.5	84.6	1.3
951910	1110	363.3	32.6	613.3	14.6	81.2	-2.7
Air 3 at well MT-302							
951710	1045	277.8	1.3	555.3	3.8	82.4	-1.3
951810	1000	322.4	17.7	589.3	10.1	82.5	-1.2
951910	0935	285.3	4.1	576.7	7.8	82.9	-0.7

[1] CFC-11, CFC-12, CFC-113 concentrations in Northern Hemisphere 1995 mean annual air used to calculate percent excess values were 274, 535, and 83.5 pptv, respectively. CFC concentrations in 1995 air from E. Busenberg (U.S. Geological Survey, written commun., 1996).

Other compounds

CFC chromatographs were reviewed for peaks indicating the presence of other compounds in the groundwater samples (table 5, at back of report). These compounds include nitrous oxide (N_2O), reduced sulfur compounds such as hydrogen sulfide (H_2S) and methyl sulfide (CH_3SH), and halogenated VOC's such as methylene chloride, methyl chloride, carbon tetrachloride, trichloroethylene, and vinyl chloride. These determinations were qualitative and only indicated the presence or absence of these compounds in the sample. The presence or absence of the compounds provides information regarding the redox potential of the sample and whether halogenated VOC's of human origin are present.

The electron-capture detector used for the CFC analyses is highly sensitive to halogenated VOC's and has detection limits that are an order of magnitude or more below standard gas chromatography techniques used for the analysis of VOC's in drinking water. Because of this enhanced sensitivity, more frequent detections of trace amounts of halogenated VOC's is likely. However, the enhanced detection frequency could also be due to trace levels of VOC's introduced during sampling or leached from PVC well casing. Because many of the wells sampled for environmental tracers were part of existing monitoring networks operated by the City of Dayton, Wright-Patterson Air Force Base, and the Mound Plant, VOC detections recorded during CFC analyses could be compared with VOC data reported by other agencies for the same well. As noted above, the methods used for VOC analysis by other agencies are less sensitive than the method used for CFC analysis; therefore, detection of VOC's in two independent samples from the same well supports the assertion that ground water in that part of the buried-valley aquifer contains VOC's derived from human activities. For wells where other-agency data were not available, VOC data collected by other agencies at upgradient or adjacent wells could be used to identify areas where detection of trace amounts fo VOC's in ground water would be reasonable (table 5).

Results of CFC analyses indicated that halogenated VOC's were detected at low levels in 45 percent (61) of the wells. For 22 of the 45 wells where halogenated VOC's were detected during CFC analysis, VOC detections were reported in ground-water samples that had been collected and analyzed by other agencies as part of their water-quality monitoring programs. The most commonly detected halogenated VOC was methylene chloride, which is an ingredient in paint stripper and PVC cement. Carbon tetrachloride (also an ingredient of PVC cement), methyl chloride, tetrachloroethylene, chloroform, and vinyl chloride were less commonly detected. About two-thirds of the wells with detections of halogenated VOC's were screened at depths less than 50 ft below the water table.

Nitrous oxide peaks were detected in 27 percent of the wells sampled. More than 86 percent of the nitrous oxide detections were in wells screened at depths less than 50 ft below the water table. Detections of nitrous oxide, which is an intermediate product in the breakdown of nitrate, were associated with oxic conditions in the aquifer: about 75 percent of the wells where nitrous oxide was detected produced water with DO concentrations greater than 0.3 mg/L. DO can produce a response similar to that of nitrous oxide, and some of the nitrous oxide detections (especially those where DO concentrations are several milligrams per liter or more) could be suspect.

Reduced-sulfur compounds (H_2S or CH_3SH), indicative of highly reducing conditions in the aquifer, were detected in about 30 percent of the wells sampled. Reduced-sulfur detections were relatively evenly distributed with depth throughout anoxic parts of the buried-valley aquifer.

Dissolved gases and evaluation of recharge temperature

Dissolved-gas data were collected to assess recharge temperatures for calculation of CFC partial pressures and to determine whether methane was in ground-water samples that yielded discordant CFC ages. Nitrogen and argon data were plotted against nitrogen-argon solubilities calculated for a total pressure of 760 mm Hg and excess-air contents of 0 to 20 $cm^3/kg\ H_2O$ using solubility data from Weiss (1970) (fig. 17). Nitrogen and argon data in table 6 were normalized to a barometric pressure of 760 mm Hg prior to plotting to facilitate direct estimation of recharge temperature. The excess-air values range from 2 to about 15 $cm^3/kg\ H_2O$; such quantities of excess air imply recharge temperatures from about 10 to 30°C, with most data clustering around 20°C. An average recharge temperature of 20°C is unreasonable given that the mean annual air temperature across the study area is between 11 and 12°C (National Oceanic and Atmospheric Administration, written commun., 1992) and that mean ground-water temperature for the 137 wells sampled in this study is 14°C. It is also inconsistent with temperature estimates derived from oxygen and hydrogen isotope data and deuterium-excess values (see p. 37), which indicate that most recharge to the buried-valley aquifer occurs during the fall and winter months.

The dissolved-gas data are more reasonably interpreted as being affected by denitrification. The effects of excess nitrogen produced by bacterially mediated denitrification can be removed by extrapolating back to the air-water equilibrium curve for zero excess air along a horizontal line equal to the normalized argon concentration of the sample (fig. 17). This procedure results in a more restricted range of recharge temperatures between about 5 and 16°C. The sample with the highest recharge temperature (16°C) was collected from a shallow well (MT-290) located between the Great Miami River and a small well field operated by a private water company. Ground water from this well has an ^3H-^3He age of only a few months and is probably being recharged by pumpage-induced infiltration of nearby river water. Therefore, its elevated temperature is probably reasonable; N_2/Ar ratios of most other wells imply recharge temperatures between 10-12°C, close to the mean annual air temperature for the study area. The difference between the sample with the highest observed N_2 concentration (30.7 mg/L N_2; well GR-317) and that of air-saturated water with the same Ar concentration ($\approx$17 mg/L N_2) implies denitrification of about 14 mg/L of nitrate (as N). Although elevated, this nitrate concentration is comparable to the maximum nitrate concentration observed in this study (12.0 mg/L nitrate as N, well MT-289, located in a cornfield) and is in the upper range of nitrate concentrations observed in shallow ground water underlying agricultural areas elsewhere in the United States (Hamilton and Helsel, 1995).

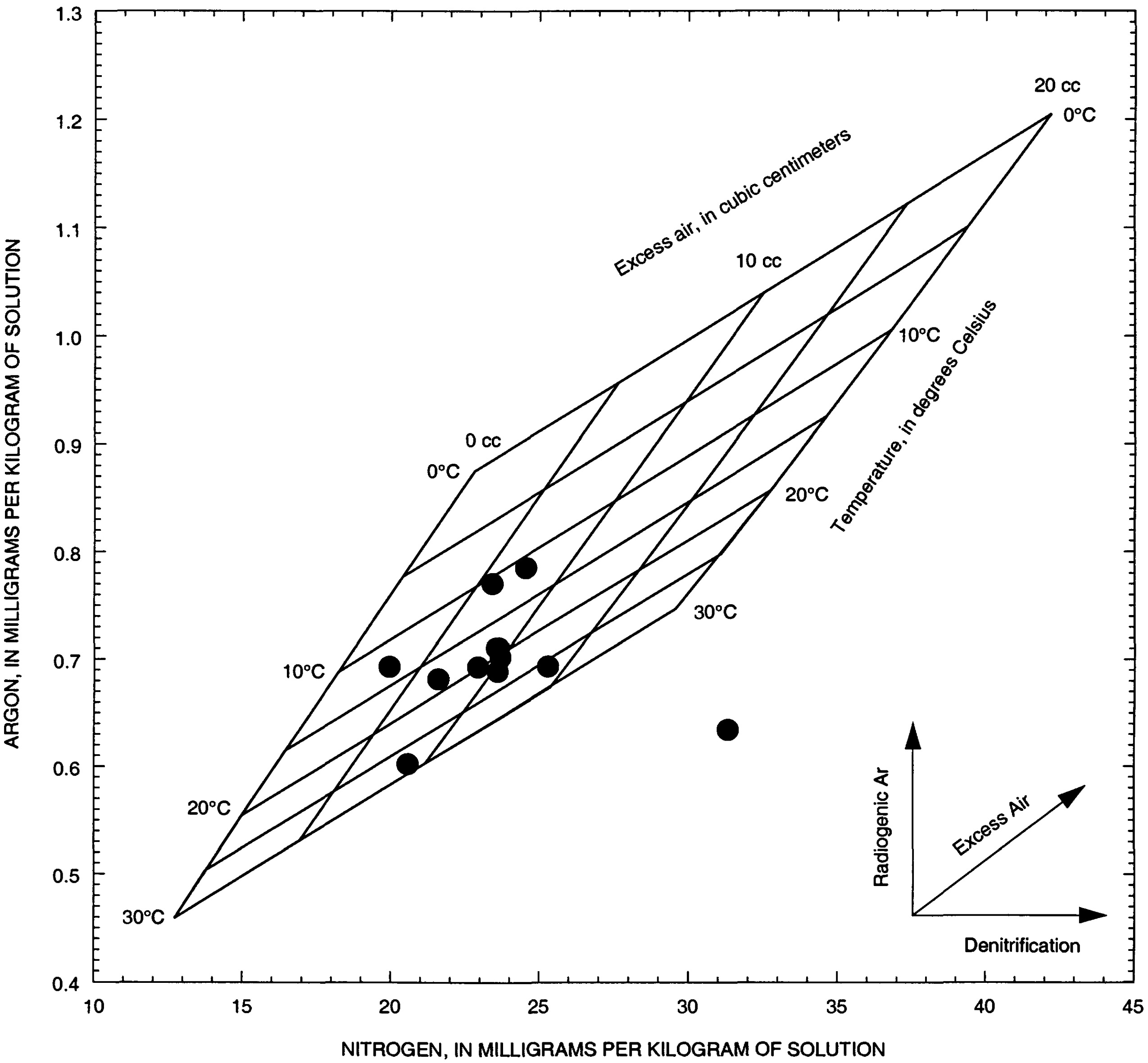

Figure 17. Concentrations of dissolved nitrogen and argon in the buried-valley aquifer, Dayton area, southwestern Ohio.

Stable-isotope data indicate recharge temperatures between 8 and 11°C. Median δD and $\delta^{18}O$ values for 21 ground-water samples collected from wells in the buried-valley aquifer underlying WPAFB were -46.5 and -7.65 per mil (Dumouchelle and others, 1993). Based on the latitudinal temperature dependence of stable-isotope data (Van der Straaten and Mook, 1983), the median δD and $\delta^{18}O$ values for WPAFB area indicate ground-level air temperatures of 9.1°C (range for all WPAFB data =7.6 to 9.8°C) and 10.6°C (range for WPAFB data = 9.2 to 11.2°C), respectively. The deuterium excess parameter d ($d = \delta D - 8\delta^{18}O$) calculated from the median isotopic composition given above is +14.7 and ranges from +12.2 to +20.2 for all WPAFB data. The deuterium-excess parameter d represents the y-intercept on a δD-$\delta^{18}O$ plot and is known to vary regionally as well as seasonally (Van der Stratton and Mook, 1983); d can therefore be used to infer not only sources but also timing of recharge. Deuterium-excess values calculated for monthly δD and $\delta^{18}O$ precipitation data collected during 1966–71 at the International Atomic Energy Agency monitoring station at Coshocton, Ohio, show strong seasonal variations: average deuterium-excess values calculated for the 6-month periods April–September and October–March were +10.3 and +15.0, respectively (International Atomic Energy Agency, 1971, 1973, 1975). Although the Coshocton station is approximately 125 mi east-northeast of the study area, seasonal isotopic variations there are likely to be similar to those in southwestern Ohio. The deuterium-excess values observed for the WPAFB data indicate that most recharge to the buried-valley aquifer occurs during fall and winter.

On the basis of dissolved-gas and stable-isotope data, most ground water in the buried-valley aquifer appears to have been recharged at temperatures between 9 and 11°C, with recharge occurring primarily in the fall and winter. Hence, an average recharge temperature of 10°C is used to calculate CFC ages throughout the study area. Recharge at temperatures outside of this range surely occurs, especially in shallow parts of the aquifer recharged by pumping-induced infiltration of river water or during summer or winter floods, but such recharge can be considered regionally and temporally atypical.

Tritium, helium, and neon

Results of tritium, helium, and neon analyses of ground-water samples from 101 wells are discussed by Shapiro and others (1998) and are reproduced in table 7 (at back of report) with tritium data for samples from an additional 17 wells where noble gas and helium isotope data were not obtained. Also reported in table 7 are tritium data for 13 wells sampled at or near the Mound Plant. For these samples, qualitative tritium determinations by Mound Plant personnel indicated that these samples contained several hundred to several thousand TU. Because such high tritium concentrations could contaminate the Lamont-Doherty analytical equipment, more precise analyses of the tritium and helium isotopic composition of these samples were not attempted.

Results of $^{3}He/^{4}He$ isotope ($\delta^{3}He$) analyses reported by Shapiro and others (1998) are also included in table 7, along with calculated values of several other parameters used for ^{3}H-^{3}He dating (including $\Delta^{4}He$, a measure of ^{4}He supersaturation; $^{4}He_{rad}$, the calculated amount of radiogenic ^{4}He in the sample; and $^{3}H+^{3}He$, the calculated sum of tritium and tritiogenic ^{3}He). Recharge-year estimates calculated from the ^{3}H-^{3}He ages reported by Shapiro and others (1998) were obtained for 95 of the 101 wells for which complete tritium, neon, and helium analyses were available (table 7).

Shapiro and others (1998) reported that most wells screened near the water table in the buried-valley aquifer yield water with tritium concentrations between 10 and 15 TU, a range consistent with that expected for modern precipitation. In deeper wells considered to be unaffected by local sources of tritium (such as landfills and the Mound Plant), concentrations of tritium range from near zero to about 30 or 40 TU. Water samples from wells downwind or downgradient from known or suspected tritium sources may have tritium concentrations of several tens, hundreds, or thousands of tritium units. Shapiro and others (1998) showed that water from the buried-valley aquifer that contains excess tritium from local sources can be identified by plotting the sum of tritium and tritiogenic helium 3 [$^{3}H+^{3}He_{trit}$] against the ^{3}H-^{3}He recharge year. The addition of tritium from local sources is readily discerned on such a graph because such samples will plot above the tritium-input curve for southwestern Ohio precipitation (see fig. 3 in Shapiro and others, 1998; fig. 22, this report).

Table 6. Concentration of dissolved gases in water samples from wells screened in the buried-valley aquifer near Dayton, Ohio

[SAC, Sidearm chamber analysis done within two weeks of sampling date; AMP, Analysis done in December 1995 on unused flame-sealed 62-milliliter borosilicate glass ampule collected for chlorofluorocarbon analysis; mg/L, milligrams per liter; --, no data available. Methane data marked with asterisk were from analyses of unused chlorofluorocarbon ampules]

Well name	Sampling date	Sampling method[2]	CH_4 in mg/L	CO_2 in mg/L	O_2 in mg/L	N_2 mg/L	Ar in mg/L
GR-316	93/06/21	SAC	0.000	11.64	4.54	19.55	0.680
GR-317	93/06/21	SAC	0.000	25.60	0.09	30.69	0.622
GR-333	93/06/22	SAC	0.000	30.44	5.33	21.15	0.668
GR-540	93/06/23	SAC	0.000	15.61	1.21	23.12	0.675
MT-281	93/06/24	SAC	0.000	37.99	2.37	22.46	0.679
MT-282	93/06/24	SAC	0.000	37.46	1.10	23.21	0.688
MT-283	93/06/23	SAC	0.000	38.41	0.05	24.78	0.680
MT-296	93/06/24	SAC/AMP	0.201, 0.356* 0.337*	17.50	0.02	23.16	0.697
MT-297	93/06/24	SAC/AMP	0.020, 0.099*	31.66	0.05	23.09	0.697
MT-286	93/06/25	SAC/AMP	0.000, 0.000*	21.76	0.03	24.05	0.770
MT-287	93/06/25	SAC	0.000	26.42	0.04	22.94	0.755
MT-290	93/06/25	SAC	0.000	11.16	0.16	20.15	0.591
GR-334	93/06/22	AMP	0.044	--	--	--	--
GR-324	93/06/22	AMP	0.045	--	--	--	--
GR-323	93/06/22	AMP	0.021	--	--	--	--
MT-303	93/08/11	AMP	0.168, 0.197	--	--	--	--
MT-68	93/08/13	AMP	0.025	--	--	--	--
MT-311	93/08/13	AMP	0.097, 0.107	--	--	--	--
MT-305	93/08/13	AMP	0.491	--	--	--	--
MT-288	93/08/16	AMP	0.010	--	--	--	--
MT-347	93/10/07	AMP	0.006	--	--	--	--
MT-327	94/08/01	AMP	0.133	--	--	--	--
MT-318	94/08/03	AMP	0.016	--	--	--	--
MT-333	94/08/04	AMP	0.195	--	--	--	--
MT-337	94/08/10	AMP	0.030	--	--	--	--
MT-153	94/08/19	AMP	0.012	--	--	--	--
GR-319	94/08/23	AMP	0.044	--	--	--	--
MT-343	94/08/30	AMP	0.007	--	--	--	--
MT-342	94/08/30	AMP	<0.003	--	--	--	--
MT-344	94/08/30	AMP	0.006	--	--	--	--
MT-360	94/08/31	AMP	0.060	--	--	--	--
MT-376	94/08/31	AMP	0.107	--	--	--	--
MT-355	94/08/31	AMP	<0.003	--	--	--	--
MT-375	94/09/01	AMP	<0.003	--	--	--	--
MT-404	94/09/01	AMP	0.031	--	--	--	--
MT-405	94/09/01	AMP	0.213	--	--	--	--

Of the 95 wells for which complete gas and isotopic analyses were available, Shapiro and others (1998) reported that the concentrations of neon were fairly uniform with depth but were higher than those expected for solubility equilibrium with the atmosphere. The range of reported neon concentrations indicates excess-air concentrations of 0 to 13 $cm^3/kg\ H_2O$ (mean = 3.2 $cm^3/kg\ H_2O$), a range that is consistent with the excess-air concentrations indicated by the N_2/Ar data (fig. 17). In contrast, concentrations of ^4He ranged from near atmospheric equilibrium to values several orders of magnitude greater than those expected for air-water equilibrium. Shapiro and others (1998) reported that the average percent supersaturation of ^4He above solubility equilibrium is about 37 percent for shallow wells and 274 percent for deeper wells. Although low degrees of ^4He supersaturation are probably related to excess air, substantially higher values indicate the presence of excess (radiogenic) ^4He derived from the decay of uranium and thorium-bearing minerals in shale-rich bedrock or lithic fragments in glacial sediments. The presence of significant amounts of radiogenic helium complicates the determination of the ^{3}H-^{3}He age. Shapiro and others (1998) reported that nearly 60 percent of the ground-water samples required corrections for radiogenic helium before reasonable ^{3}H-^{3}He ages could be calculated.

RELIABILITY OF GROUND-WATER AGES

Ground-water ages estimated by use of the CFC and ^{3}H-^{3}He methods are regarded as apparent ages and require careful review in the geochemical and hydrologic context of the study area. In the following sections, the reliabilities of CFC- and ^{3}H-^{3}He-derived ground-water ages are evaluated in view of current understanding of ground-water flow and hydrogeology in the buried-valley aquifer.

Chlorofluorocarbon ages. To evaluate the reliability of age estimates derived by the CFC technique, ground-water ages (expressed as recharge years) obtained for CFC-11, CFC-12, and CFC-113 were compared by means of scatterplots. Under ideal conditions, ages derived from all three CFC compounds would be identical, and paired data sets would plot along a 1:1 correspondence line. CFC ages obtained for this study are full of inconsistencies, however, and for many samples estimated recharge years calculated for different CFC compounds differ by 30 years or more (fig. 18). For CFC-11 and CFC-12, the ages of about 20 percent of the samples are in reasonable agreement. Most samples, however, particularly those collected from anoxic parts of the buried-valley aquifer (DO less than 0.3 mg/L) plot below the 1:1 line (fig. 18). The downward shift, reflecting CFC-11 ages that are significantly older than CFC-12 ages, is a pattern observed in other aquifers where microbial degradation of CFC-11 under anoxic conditions is suspected (Dunkle and others; 1993, Cook and others, 1995). Data points that plot above

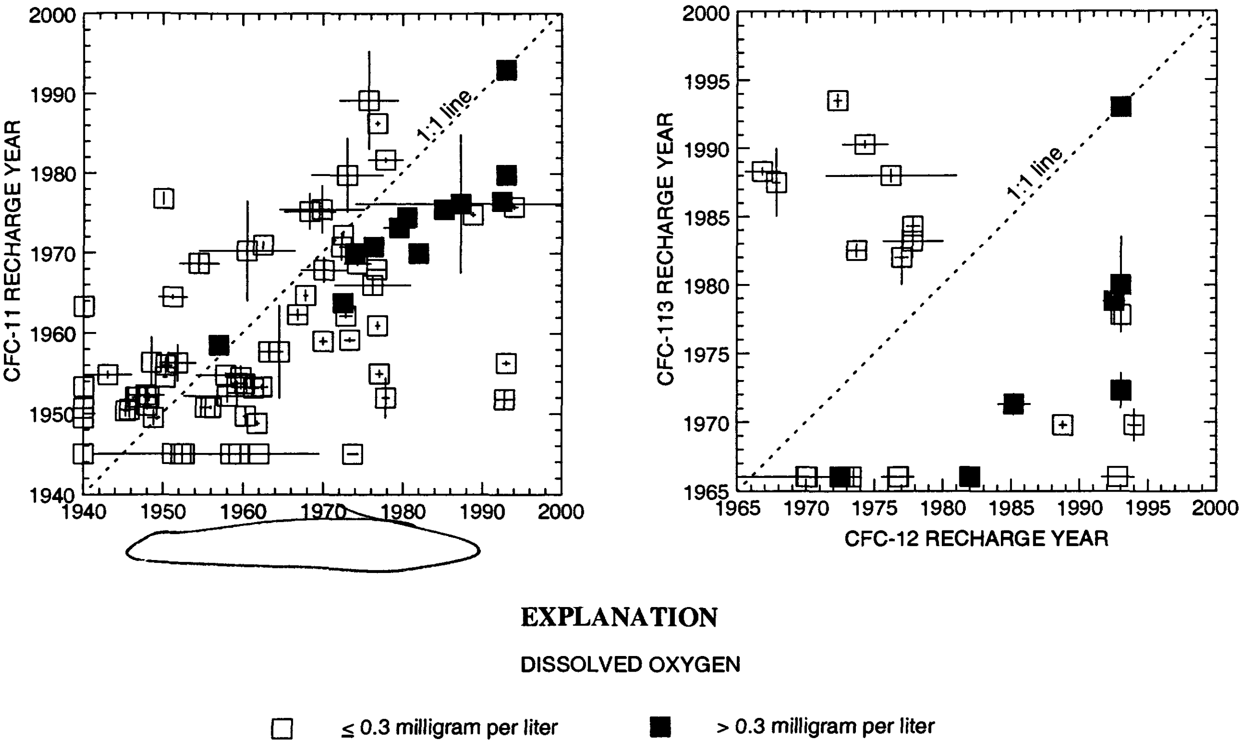

Figure 18. CFC-11 and CFC-113 recharge year as a function of CFC-12 recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (Error bars reflect CFC age errors reported in table 3).

the 1:1 correspondence line may indicate degradation of CFC-12 relative to CFC-11 or CFC-113; however, because CFC-12 has been shown to be the most resistant to microbial degradation under anoxic conditions (Lovely and Woodward; 1992, Katz and others, 1995), these data points probably reflect minor contamination of the samples, resulting in younger CFC-11 and CFC-113 ages relative to the CFC-12 ages.

Another check on the consistency of the CFC ages is to compare CFC recharge years with measured tritium concentrations, as is done for CFC-12 ages in fig. 19. If the CFC-12 ages are reliable, then the data points in fig. 19 should plot on or near the tritium-input curve for southwestern Ohio rainwater. Although some data points plot near the curve (particularly those with measurable DO concentrations recharged after 1975), several samples with elevated tritium concentrations (10-58 TU) have pre-1950 CFC-12 ages. Such elevated tritium concentrations are not reasonable for waters that recharged the buried-valley aquifer prior to the start of atomic weapons testing in the early 1950's. These observations support the hypothesis that microbial degradation of the CFC-12 has occurred. A final chemical check on the consistency of the CFC-12 ages is to compare them to the ^{3}H-^{3}He ages reported by Shapiro and others (1998). This comparison provides further support that microbial degradation of CFC-12 occurred because nearly all of the anoxic ground-water samples plot below the 1:1 correspondence line (fig. 20). Agreement is closer between CFC-12 and ^{3}H-^{3}He ages where the ground water has measurable DO, but even a few of these samples show marked disagreement (fig. 20)

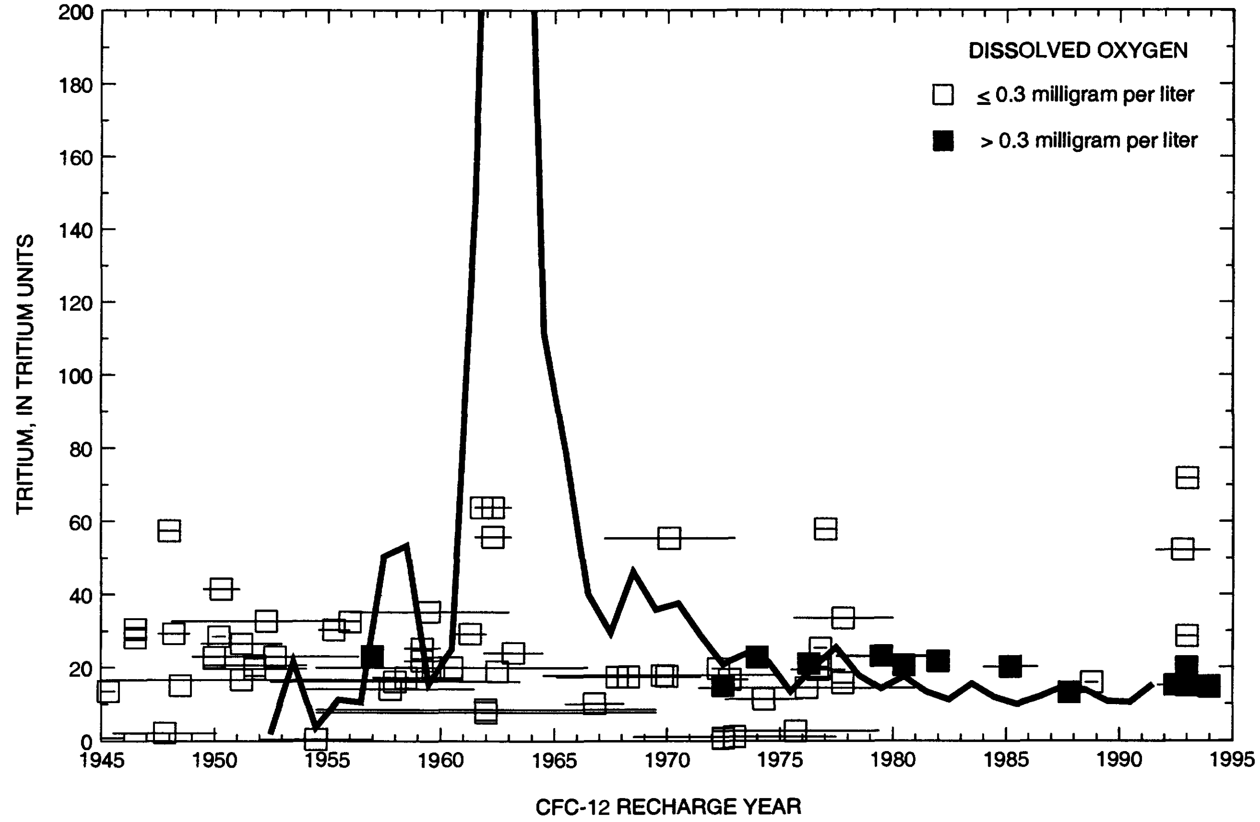

Figure 19. Tritium concentrations as a function of CFC-12 recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (Horizontal bars reflect CFC-12 age error as given in table 3. Bold line gives estimated concentration of tritium in rainwater from southwest Ohio, corrected for radioactive decay through mid-1993.)

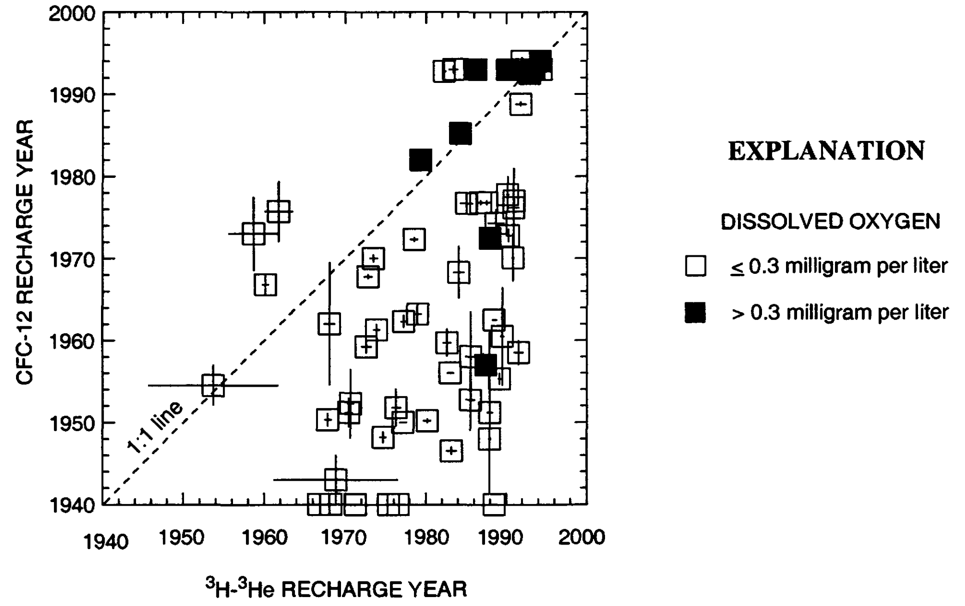

Figure 20. CFC-12 recharge year as a function of ^{3}H-^{3}He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He recharge year from Shapiro and others, 1998. Horizontal bars reflect age errors reported by Shapiro and others, 1998, and shown in table 7; vertical bars reflect CFC-12 age errors reported in table 3).

The data highlighted in the preceding discussion indicate that redox conditions in the buried-valley aquifer are affecting the reliability of the CFC ages. Agreement between the CFC-12 and ^{3}H-^{3}He ages is usually close when ground water contains measurable concentrations of DO and nitrate (fig. 21). As concentrations of oxygen and nitrate drop below detection limits, however, the difference between the two ages exceeds the analytical uncertainty. There is no distinct correlation between the concentration of dissolved iron and the difference between the two ages; however, it appears that when methane concentrations are greater than 0.05 mg/L, complete degradation of CFC-12 occurs, resulting in age differences as high as 30 or 40 years (fig. 21). Difference between ^{3}H-^{3}He ages and CFC-12 ages is negative for a few samples, probably because of contamination that results in CFC-12 ages that are too young.

Tritium-helium-3 ages. Unlike CFC's, the concentration of tritium and its daughter product, helium-3, are not affected by microbial degradation; however, processes such as hydrodynamic dispersion or the addition of radiogenic helium can affect the reliability of ^{3}H-^{3}He ages (Solomon and Sudicky, 1991; Shapiro and others, 1998). Hence, the consistency of the ^{3}H-^{3}He ages must be assessed. As reported by Shapiro and others (1998), the first check on the consistency of the ^{3}H-^{3}He ages is to compare the sum of tritium and tritiogenic helium [^{3}H+^{3}He$_{trit}$] with the estimated tritium concentrations for southwestern Ohio rainwater as a function of ^{3}H-^{3}He recharge year. If the calculated ^{3}H-^{3}He ages are accurate, then the [^{3}H+^{3}He$_{trit}$] concentrations should reflect the amount of tritium in rainwater at the time of recharge to the buried-valley aquifer and should therefore plot on or close to the tritium-input curve. Because [^{3}H+^{3}He$_{trit}$] values for most samples plot on or near the tritium-input curve, particularly for waters recharged after 1970 (fig. 22), the correction procedure developed by Shapiro and others (1998) seems reasonable. These workers also report that samples of water recharged after 1980 that plot above the tritium-input curve were probably affected by tritium releases to the atmosphere or land surface from local sources, such as the Mound Plant or waste-disposal facilities. Samples that plot below the curve are either affected by hydrodynamic dispersion or are pre-atmospheric-testing waters that have mixed with small amounts of younger, tritiated ground water (Shapiro and others, 1998).

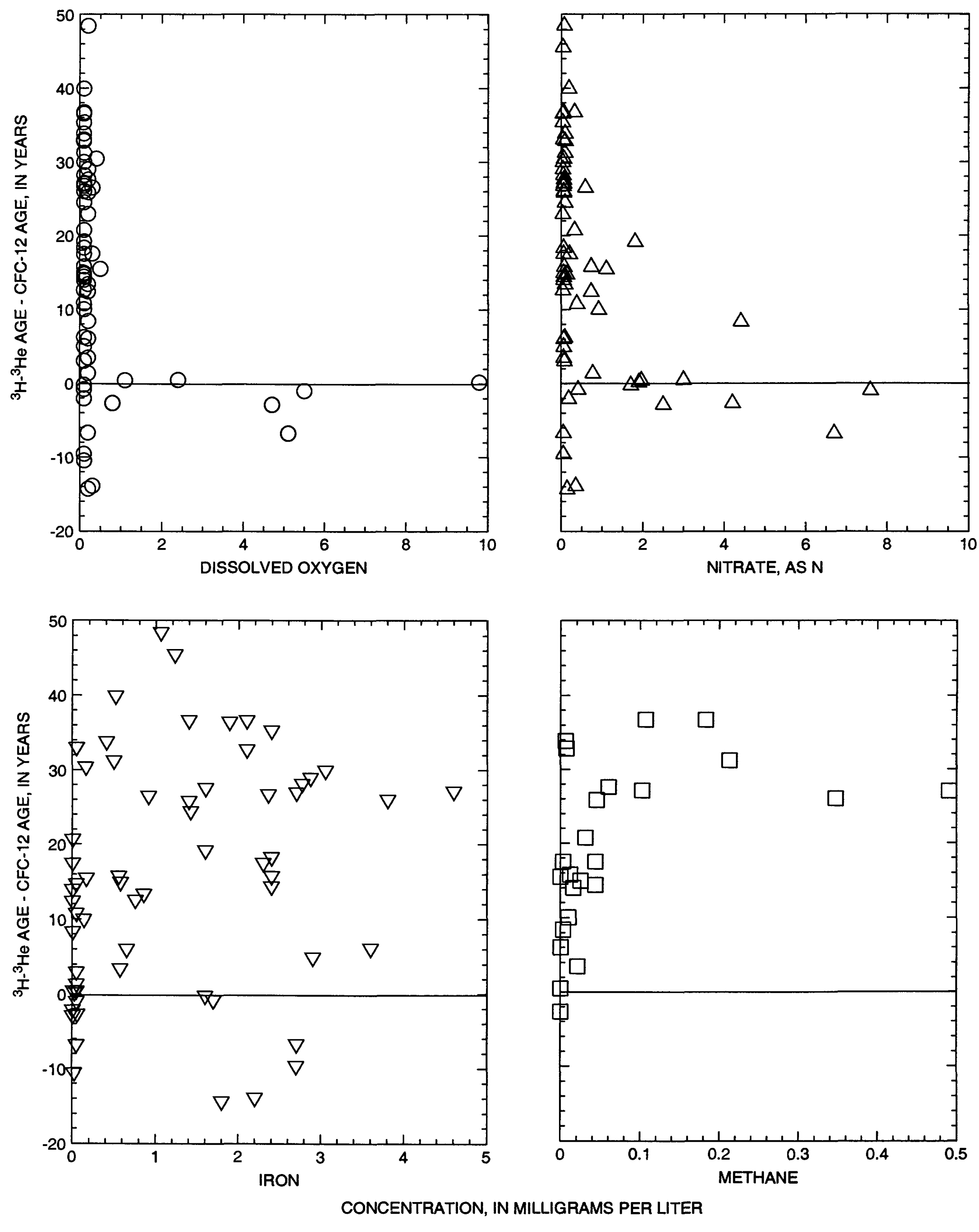

Figure 21. Concentration of dissolved oxygen, nitrate-N, iron, and methane as a function of the difference between ^{3}H-^{3}He age and CFC-12 age for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio.

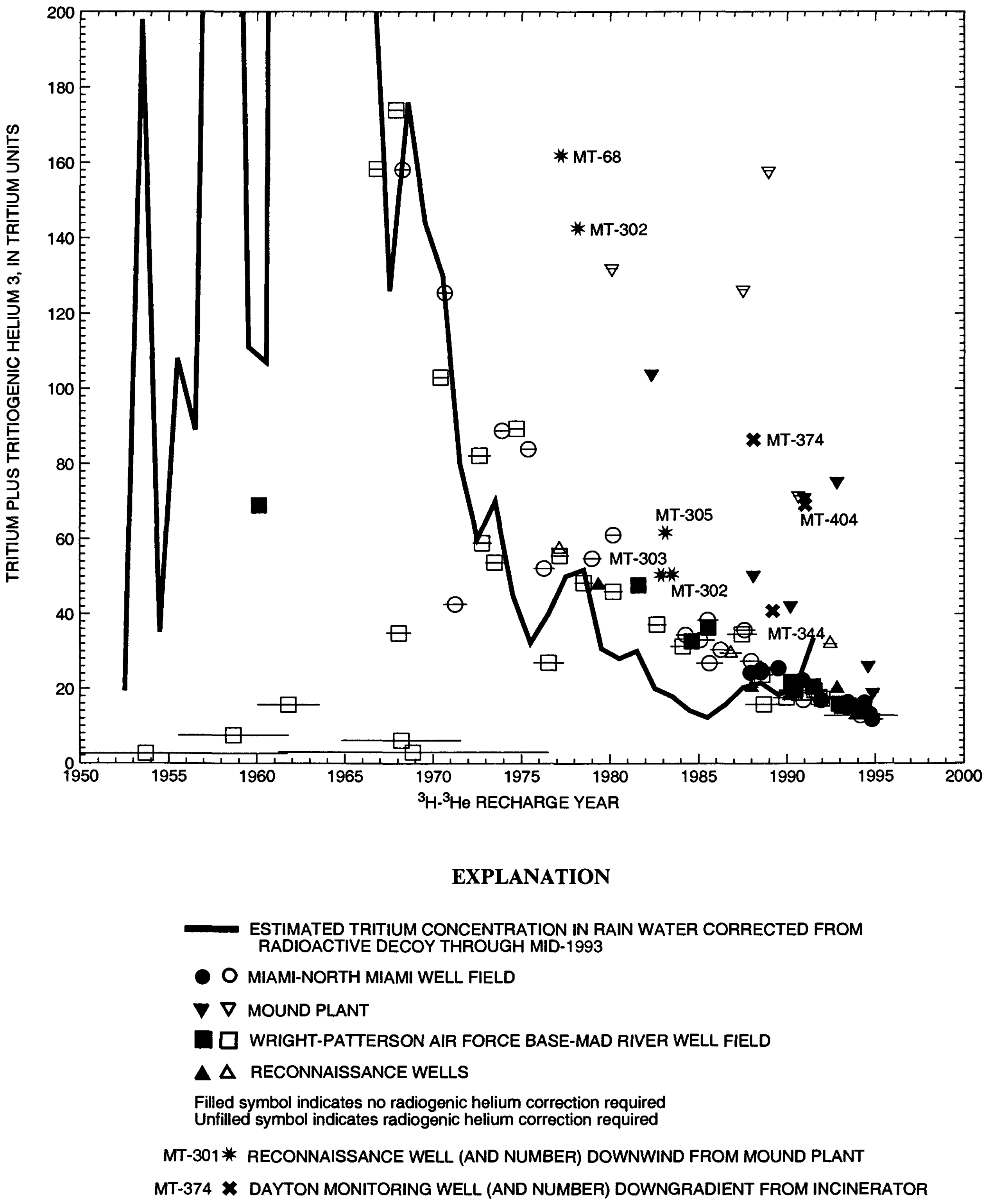

Figure 22. Sum of tritium and tritiogenic helium 3 [^{3}H+^{3}He] as a function of ^{3}H-^{3}He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (Horizontal bars reflect age errors reported by Shapiro and others, 1998, and shown in table 7; figure modified from Shapiro and others, 1998).

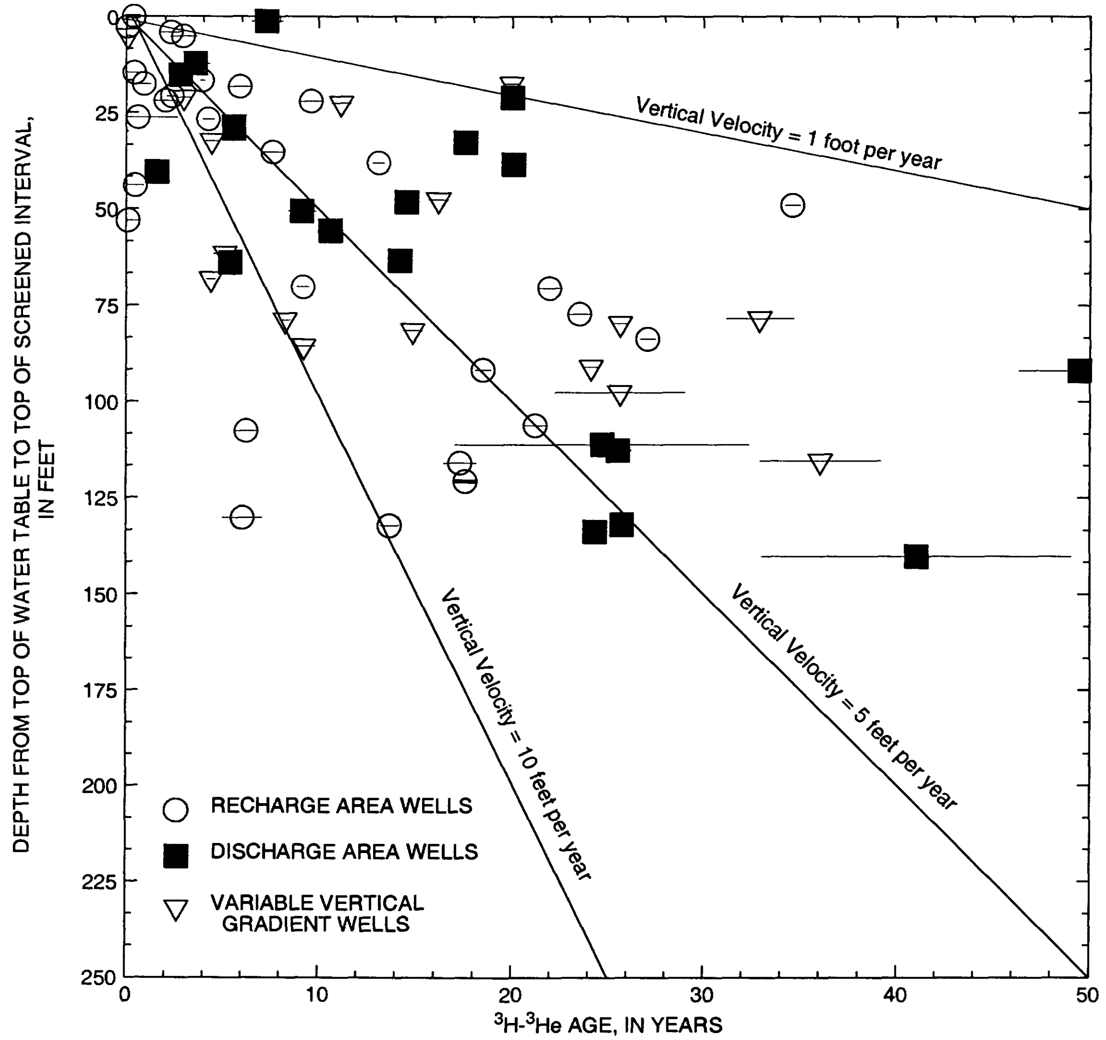

Figure 23. ^{3}H-^{3}He age as a function of depth from water table to top of screened interval for the buried-valley aquifer, Dayton area, southwestern Ohio. (Horizontal bars reflect age errors reported by Shapiro and others, 1998 and shown in table 7; figure modified from Shapiro and others 1998).

Shapiro and others (1998) also evaluated the ^{3}H-^{3}He ages for consistency with current knowledge of hydrologic processes and ground-water flow in the buried-valley aquifer. This was done in a general way by examining the relation between ^{3}H-^{3}He age and depth for the entire study area. It was found, as expected, that ground-water age generally increases with depth (fig. 23). Most of the data shown on the age-depth plot indicate vertical velocities in the range of 1 to 5 ft/yr, flow velocities that are consistent with existing data on aquifer recharge rates and sediment porosity (Dumouchelle and others, 1993; Dumouchelle, 1998).

Shapiro and others (1998) provide detailed discussions of age-depth relations in selected parts of the buried-valley aquifer including the Miami-North Miami Well Fields, the WPAFB-Mad River Well Field area, and the Mound Plant. With some exceptions, the geologic sections provided by Shapiro and others (1998) show that ^{3}H-^{3}He ages increase with increasing depth and distance along major flowpaths in these areas. Exceptions to this trend are commonly related to pumping effects; for instance, Shapiro and others (1998) reported that ^{3}H-^{3}He ages decrease as flowpaths approached major pumping centers. In addition, monitoring wells between production wells and streams often yielded very young ground water (^{3}H-^{3}He ages less than 1 year) because of the combined effects of drawdown and induced infiltration of surface water.

A final check on the hydrogeologic consistency of the ^{3}H-^{3}He ages is provided by the work of Sheets and others (1998), who used the ^{3}H-^{3}He ages reported by Shapiro and others (1998) to evaluate and improve numerical flow models of the buried-valley aquifer in the Dayton area. Traveltimes obtained by particle-tracking analysis were compared with ^{3}H-^{3}He ages reported for 44 wells in parts of the buried-valley aquifer for which two previous ground-water flow models had been calibrated. The modeled areas included (1) a 5.6-mi^2 area adjacent to the Mound Plant near Miamisburg, Ohio (U.S. Department of Energy, 1995), and (2) an approximately 100-mi^2 area that encompasses the buried-valley aquifer and adjacent bedrock uplands in the WPAFB-Mad River Well Field area (Dumouchelle and others, 1993). Both models were calibrated to existing water-level, aquifer-test, and streamflow data.

Sheets and others (1998) reported that agreement between ^{3}H-^{3}He ages and the simulated traveltimes was generally good and that most data obtained for the Mound Plant and WPAFB-Mad River Well Field area plotted near the 1:1 correspondence line (fig. 24). Particularly close correspondence was found for shallow wells at both sites, where mean absolute errors (MAE) between simulated traveltimes and the ^{3}H-^{3}He ages were a few years or less (Sheets and others, 1998). The close correspondence is not unexpected because particle-tracking analyses for wells screened in the shallow layers of both models are constrained by abundant water-level and aquifer test data. However, Sheets and others (1998) reported that agreement between simulated traveltimes and the ^{3}H-^{3}He ages was much poorer for deeper parts of the buried-valley aquifer, with MAE's of 17.2 and 255 years for layers 2 and 3 of the WPAFB-Mad River well-field model, respectively (fig. 24). Sheets and others (1998) ascribed these differences to the lack of hydrogeologic data for deeper parts of the buried-valley aquifer and then went on to demonstrate that hydrologically reasonable modifications to model parameters would improve agreement between the simulated traveltimes and the ^{3}H-^{3}He ages. On the whole, however, results of the initial comparison between the two independent methods of estimating ground-water age provides further evidence that the ^{3}H-^{3}He method does yield reliable estimates of ground-water age in the buried-valley aquifer near Dayton.

RELATIONS BETWEEN GROUND-WATER AGE AND QUALITY

Selected properties and constituents of water samples are compared with ^{3}H-^{3}He ages to determine whether temporal trends in ground-water quality can be identified in the buried-valley aquifer near Dayton. Such trends may be related to natural processes (such as attainment of water-mineral equilibrium and hydrodynamic dispersion) or to human factors (such as changes in land use or rates at which manufactured chemicals such as pesticides, fertilizers, or organic solvents are used). A combination of natural and anthropogenic processes may affect temporal distribution of some constituents in the aquifer. For example, trends in nitrate concentration may reflect rates of bacterially mediated denitrification under anoxic conditions or changes in fertilizer application rates or both. Trends in ground-water quality, if they exist, provide qualitative information about rates of water-rock reactions or rates of contaminant loading and removal. In addition, temporal trends of water properties and constituents may be useful as qualitative indicators of ground-water age. Locally weighted scatterplot smoothing, or LOWESS (Cleveland, 1979), is used to illustrate apparent temporal trends in subsequent data plots.

A potential source of bias in the age distributions discussed in the following paragraphs is the depth distribution of wells sampled for this study. Because existing wells were used, detailed sampling along ground-water flowpaths as a function of depth was not always possible. Moreover, although most production wells completed in the buried-valley aquifer near Dayton are screened at depths 50 to 150 ft below land surface, most monitoring wells are screened at or above these depths to monitor for potential contamination. In addition, proportionately more shallow wells are available for sampling because many wells are constructed specifically for monitoring shallow ground-water quality. Of the 95 wells for which ^{3}H-^{3}He ages were obtained, 57 of the wells (60 percent) are screened at depths less than 50 ft below the water table (fig. 25). The predominance of shallow wells is reflected in the distribution of ^{3}H-^{3}He ages: for most samples (69 percent), the estimated age is 15 years or less (fig. 25). As a result, apparent trends in ground-water quality noted in subsequent discussions are influenced by the relatively young ages of most ground-water samples collected for this study.

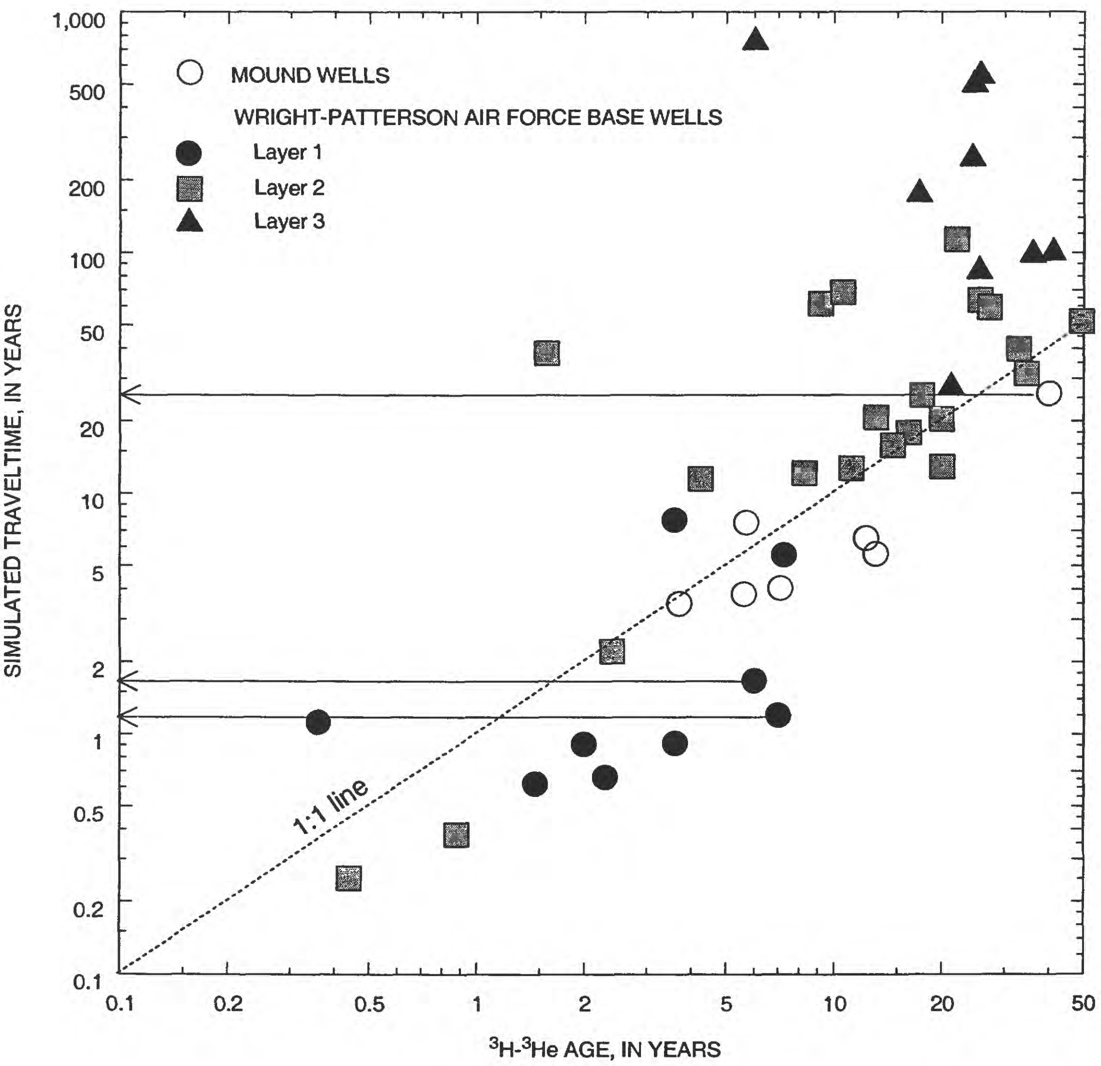

Figure 24. Simulated traveltimes as a function of ^{3}H-^{3}He age for selected wells at the Mound Plant and Wright-Patterson Air Force Base-Mad River Well Field, Dayton area, southwestern Ohio. (The ages for the three data points with left-pointing arrows are maximum age estimates based on reported tritium and chlorofluorocarbon concentrations. Note difference in log scales. Modified from Sheets and others, 1998.)

Another factor that influenced observed ground-water-quality trends was the varied land-use setting of wells sampled in this study. Samples from wells in urban or industrial settings are more likely to contain organic contaminants, whereas samples from wells in agricultural settings are more likely to be affected by fertilizers or pesticides. Categorizing the land-use settings of wells sampled for environmental tracers was beyond the scope of this study. In addition, data for describing temporal trends for many trace elements and synthetic organic chemicals were insufficient for detailed analysis. As a result, the study focused on assessing temporal trends of onsite water-quality measurements (temperature, pH, specific conductance, DO), major ions, and selected trace elements. Temporal trends of saturation indices of minerals that may be affecting the concentrations of some constituents in ground water also were examined. The age distribution of ground-water samples where halogenated VOC's other than CFC's were detected also was evaluated.

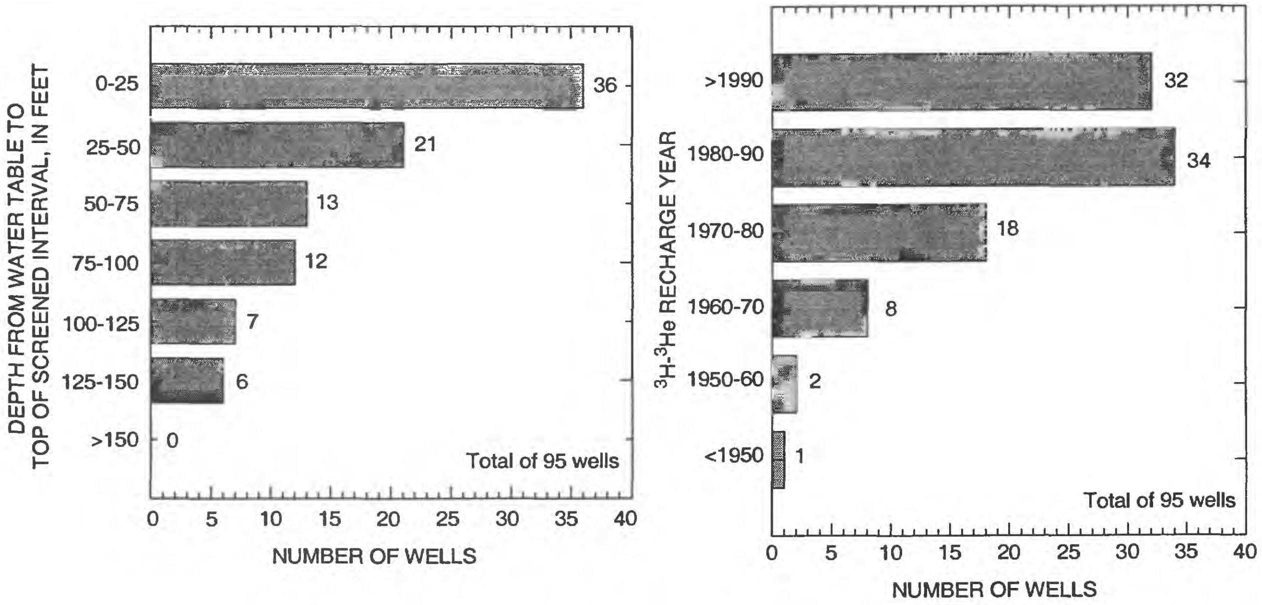

Figure 25. Distribution of well depth (depth from water table to top of screened interval) and ^{3}H-^{3}He age for ground-water samples from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He ages from Shapiro and others, 1998).

Onsite water-quality measurements

Results of onsite measurements of temperature, pH, specific conductance, and DO as a function of ^{3}H-^{3}He age indicate slight trends toward lower temperature and higher pH with increasing ground-water age (fig. 26). The trend indicated for specific conductance is for lower values in waters recharged prior to 1965; post-1965 ground water is generally characterized by higher specific conductance, albeit with a slight tendency toward lower specific conductance in the most recently recharged samples. Because of substantial scatter in the temperature, pH, and specific-conductance data, these apparent trends may not be meaningful. Nevertheless, the older ground-water samples (recharged prior to 1965) tend to have similar temperature, pH, and specific conductance; these values differ only slightly from the median value for the entire data set. For instance, with the exception of one sample recharged in 1960, specific conductance of older ground-water samples is close to 600 µs/cm, whereas the median for all 137 ground-water samples collected for this study is about 800 µs/cm (fig. 11). Although not shown on fig. 26, redox-potential data indicate a similar trend, with all pre-1965 samples having redox potentials between 40 and 60 mV.

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In contrast, measurable concentrations of DO are rarely observed in ground water recharged prior to 1990. Based on the observed distribution, a DO concentration greater than 1 mg/L is a reliable indicator of recent (post-1990) recharge in the buried-valley aquifer. The reverse, however, is not true: very young ground water with no detectable DO was found at several sites. The rapid disappearance of DO from ground water at most locations indicates that DO-consuming reactions—for example, bacterially mediated oxidation of organic matter—occur quickly in the buried-valley aquifer. It also indicates that the organic-matter content of most aquifer sediments is sufficient to remove DO early in the flowpath.

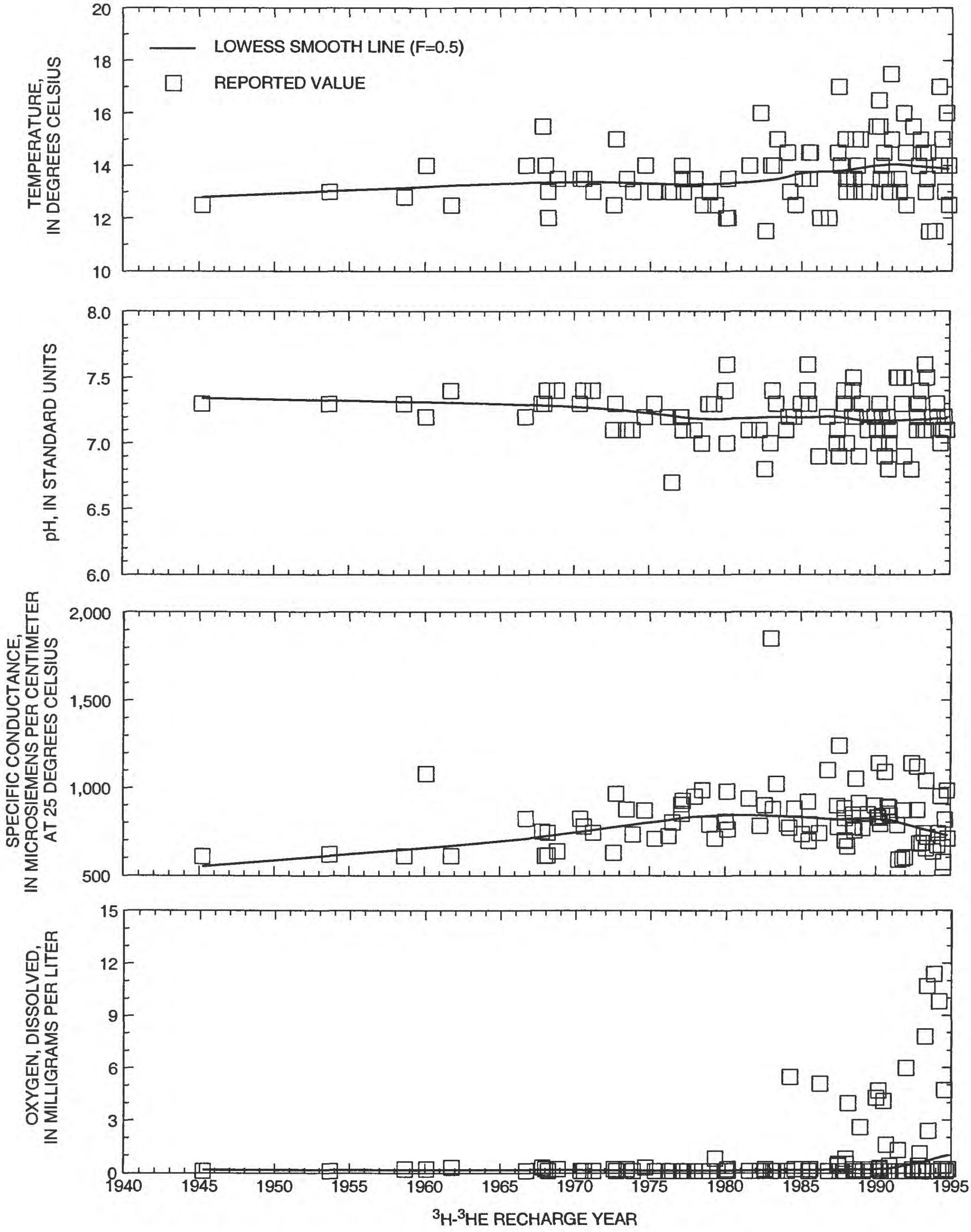

Figure 26. Temperature, pH, specific conductance, and dissolved-oxygen concentration as a function of ^{3}H-^{3}He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He recharge year from Shapiro and others, 1998.)

Major ions and selected trace constituents

Several patterns can be observed when selected major and trace constituent data are plotted against the ^3H-^3He ages. For calcium, magnesium, and alkalinity, the pattern is similar to that for pH; no particular trend is evident in the data, particularly for waters recharged after 1965 (fig. 27). For older, pre-1965 waters, scatterpoints for these constituents tend to cluster around a central value. These patterns suggest an approach to equilibrium with carbonate minerals in aquifer sediments. This hypothesis is supported by temporal trends in the saturation indices of the two main carbonate minerals found in buried-valley aquifer sediments, dolomite and calcite (fig. 27). In both cases, young ground water quickly approaches saturation or supersaturation with respect to calcite. Furthermore, with increasing age, ground water appears to reach equilibrium with dolomite while becoming slightly supersaturated with respect to calcite. Because pH and alkalinity also are controlled by carbonate equilibria, temporal trends in these properties are similar to those observed for calcium and magnesium. Alkalinity, pH, and hardness of older buried-valley aquifer ground water will therefore vary within a limited range that is controlled by water-rock reactions. Deviation from these trends is probably related to chemical changes in the buried-valley aquifer caused by infiltration of alkaline landfill leachate, organic contaminants, or acidic waste fluids.

The most common temporal trend observed in the major-ion and trace-constituent data is that the number of outliers and overall scatter in the data increase with decreasing ground-water age; most outliers tend to be associated with ground water recharged after 1980. Examples of this general pattern include sodium, chloride, nitrate, organic carbon, and boron (fig. 28). Other constituents not shown that have similar trends are ammonia, bromide, phosphate, potassium, and sulfate. This pattern probably reflects the effects of various human activities on the quality of recharge to the buried-valley aquifer in recent years. For instance, elevated concentrations of sodium, potassium, bromide, and chloride are probably related to application of deicing salts or leakage of septic-tank effluent, particularly for shallow wells. Similarly, elevated concentrations of boron may be related to infiltration of treated sewage effluent or landfill leachate, whereas high nitrate concentrations may be related to increased use of nitrate-based fertilizers. The tendency towards lower concentrations and few if any outliers in the older (pre-1960) ground-water samples for this group of constituents suggests that water this old has not been directly influenced by human activities.

But only 4 samples

An alternative hypothesis is that hydrodynamic dispersion or other natural processes in the buried-valley aquifer have attenuated previously elevated concentrations of these constituents to background levels. In the case of nitrate, measurable concentrations of nitrate are rarely found in ground water recharged prior to the mid-1970's. Excess nitrogen found in dissolved-gas samples (see fig. 17) strongly indicates denitrification in the buried-valley aquifer. Denitrification will occur after DO has been consumed (Korom, 1992), a fact consistent with the observation that measurable DO is rarely found in ground water recharged prior to 1980. Denitrification is also consistent with previous findings that nitrate is rarely present at detectable concentrations in anoxic parts of the buried-valley aquifer below WPAFB (Rowe, 1996). The data shown in fig. 28 indicate that, given sufficient time (10 to 20 years), denitrification in the buried-valley aquifer can reduce the concentration of nitrate derived from human activities to levels that will not affect human health. However, in areas where induced infiltration is used to augment ground-water production from the buried-valley aquifer, traveltimes will likely be too short to allow the complete breakdown of dissolved nitrate in streamwater.

The final temporal trend of note involves constituents that are found at reduced or nondetectable concentrations in very young ground water. As ground-water age increases, constituent concentrations may increase sharply and erratically, as is the case for dissolved iron, or may increase gradually with time, as is true for dissolved silica (fig. 29). Other constituents that have similar sharp or gradual temporal trends are manganese and fluoride. For both iron and silica, concentrations in the older waters approach a restricted range of values. On the basis of saturation-index calculations, the temporal trends for iron and silica seem to be related to gradual equilibration with a ferrous iron carbonate mineral (siderite) and microcrystalline quartz (chalcedony), respectively. For both iron and silica, a fairly constant degree of supersaturation is observed for waters recharged prior to the mid-1970's, indicating that a state of metastable equilibrium has been achieved (fig. 29).

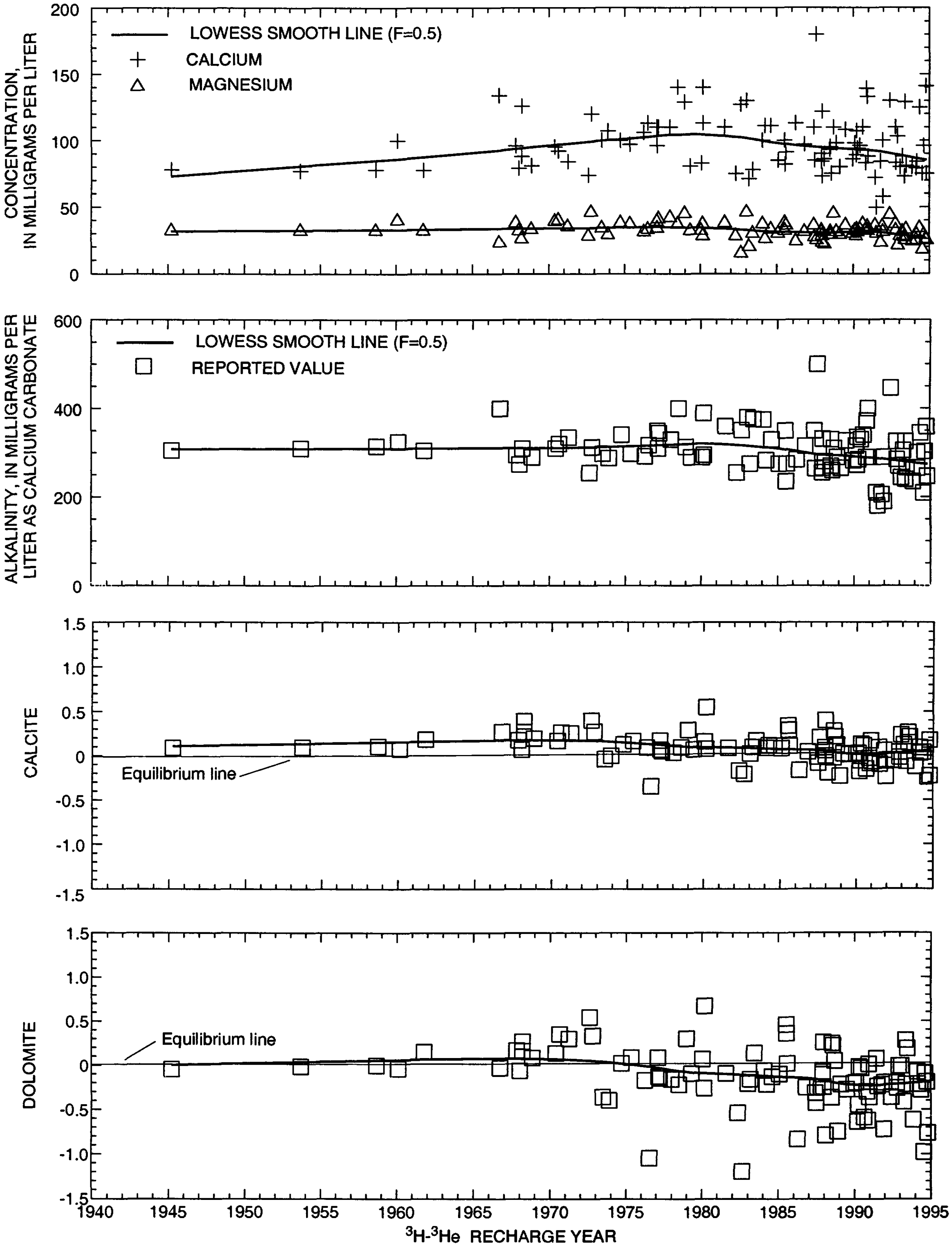

Figure 27. Calcium and magnesium concentrations, alkalinity, and saturation indices of calcite and dolomite as a function of ^{3}H-^{3}He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He ages from Shapiro and others, 1998.)

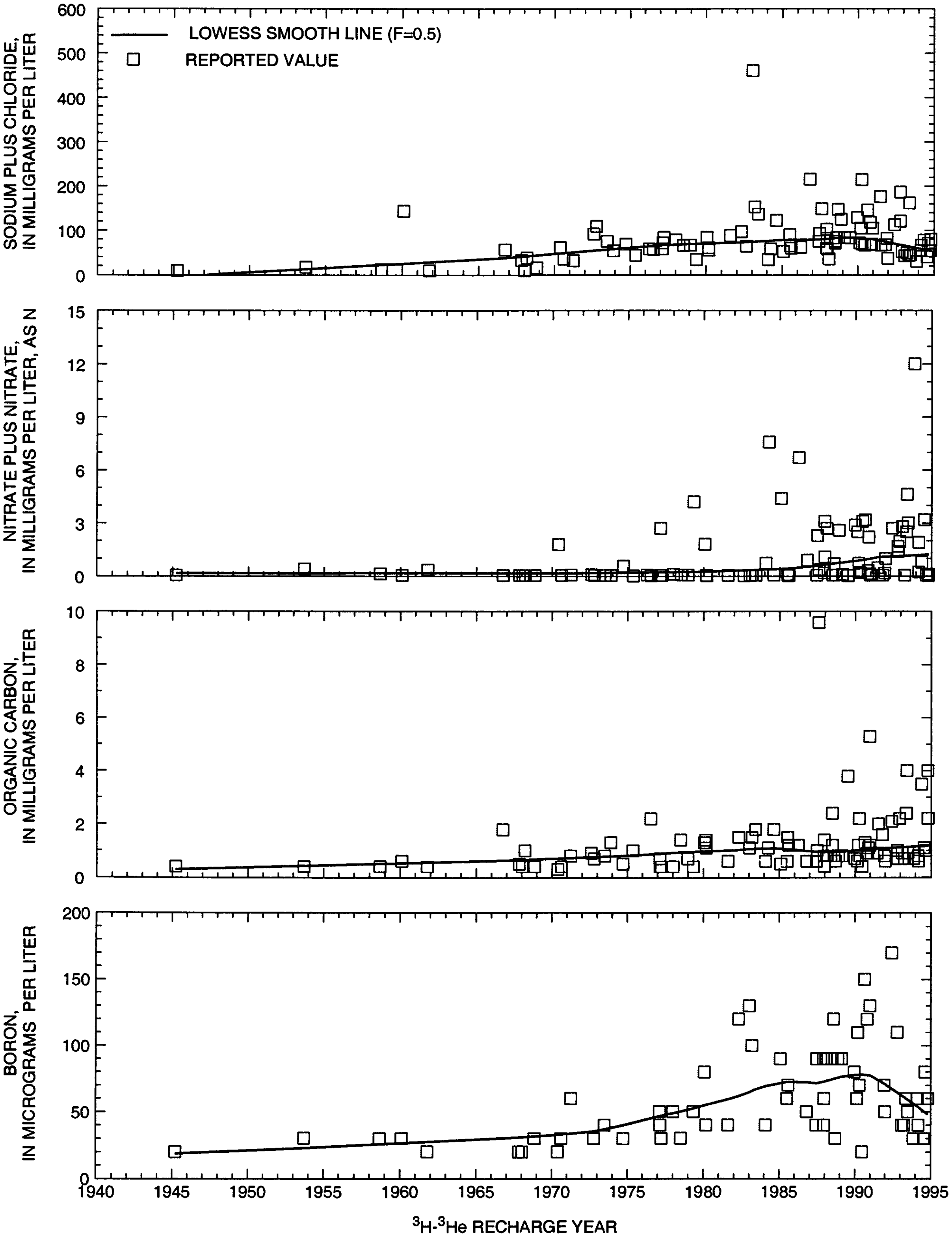

Figure 28. Sodium plus chloride, nitrate plus nitrite, dissolved or total organic carbon, and boron concentrations as a function of ^3H-^3He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^3H-^3He ages from Shapiro and others, 1998.)

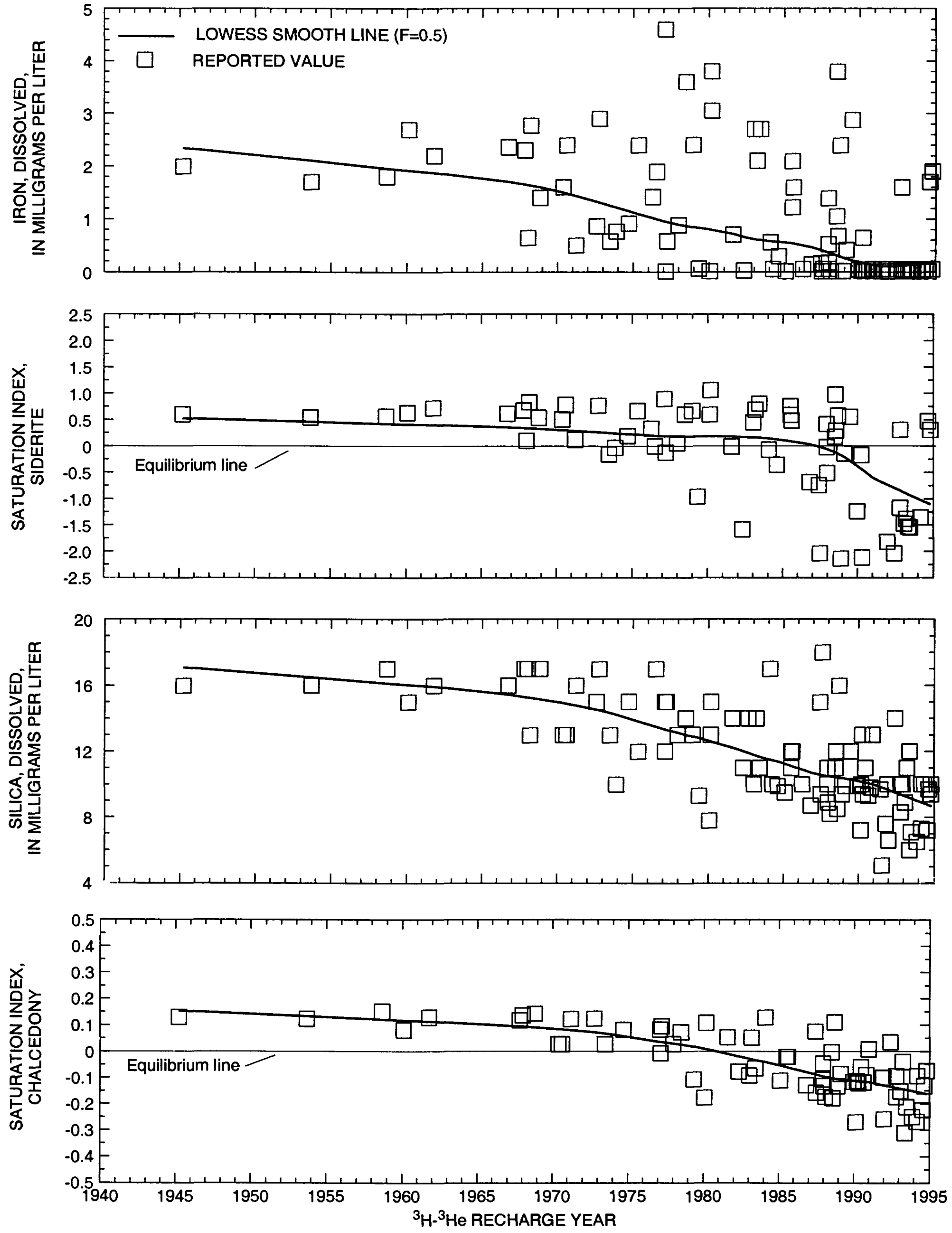

Figure 29. Iron concentration, saturation index of siderite, silica concentration, and saturation index of chalcedony as a function of ^{3}H-^{3}He recharge year for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He ages from Shapiro and others, 1998.)

For iron (and to a lesser extent manganese), measurable concentrations are found only in anoxic ground water. Thus, ground water that does not contain measurable concentrations of dissolved iron is likely to be very young because, as shown previously, oxic ground water in the buried-valley aquifer also tends to be very young. As a result, the approach to equilibrium with respect to siderite partly reflects the transition from oxic to anoxic conditions that occurs as ground water flows through the aquifer. With regard to silica, very young (post-1990) ground water tends to have concentrations between 5 and 10 mg/L. Several very young ground-water samples were collected from shallow wells adjacent to large streams where induced infiltration of river water was believed to be occurring. These samples all had silica concentrations less than 8 mg/L, consistent with the observation that silica concentrations in river water in the study area are generally low; the median silica concentration for all surface-water samples collected during September–October 1995 for this study was 5.8 mg/L (fig. 15). Long-term data collected at the USGS National Stream-Quality Accounting Network station on the Great Miami River at New Baltimore, Ohio (approximately 30 mi downstream from Dayton), show a median silica concentration of 5.2 mg/L for 131 quarterly samples collected between 1974 and 1993 (range = <0.1 to 10.0 mg/L). Therefore, low silica concentrations appear to be a good indicator of ground water affected by significant amounts of recharge from adjacent streams or river-fed artificial-recharge lagoons.

The data in fig. 29 show that a constant rate of supersaturation with respect to chalcedony is reached within 15 to 20 years after recharge and that waters recharged prior to 1970 are characterized by dissolved silica concentrations of about 16 mg/L. Similar correlations between silica concentration and ground-water age have been reported for shallow sand and gravel aquifers of the Delmarva Peninsula in northeastern Maryland (Bohlke and Denver, 1995). It should be noted that waters affected by landfill leachate or alkaline waste fluids will contain artificially high silica concentrations because the solubility of glass and most silica-bearing minerals increases sharply at $pH > 9$. Despite such exceptions, silica concentration seems to be an inexpensive indicator for distinguishing between recently recharged ground water and ground water recharged more than 20 or 30 years ago, especially when combined with other qualitative indicators of ground-water age such as nitrate and DO.

Halogenated volatile organic compounds

Of the 95 wells for which hydrologically reasonable ^3H-^3He ages are available, 41 wells (43 percent) produced water with detectable concentrations of halogenated VOC's such as methylene chloride, trichloroethylene, or vinyl chloride. The observed age distribution indicates that most VOC detections (34 out of 41 wells, about 83 percent) are associated with young or very young ground water—water that recharged the aquifer after 1980 (fig. 30). This result is not surprising given that 60 percent of the wells with hydrologically reasonable ^3H-^3He ages are screened at depths 50 ft or less below the water table, and a plot of all samples for which ^3H-^3He ages are available as a function of depth confirms that most VOC detections are associated with shallow wells (fig. 30). Nevertheless, for some wells where saturated thicknesses above the intake were greater than 140 ft, samples also had detectable concentrations of VOC's. Rowe (1996) reported similar depth distributions for VOC's and other contaminants at WPAFB.

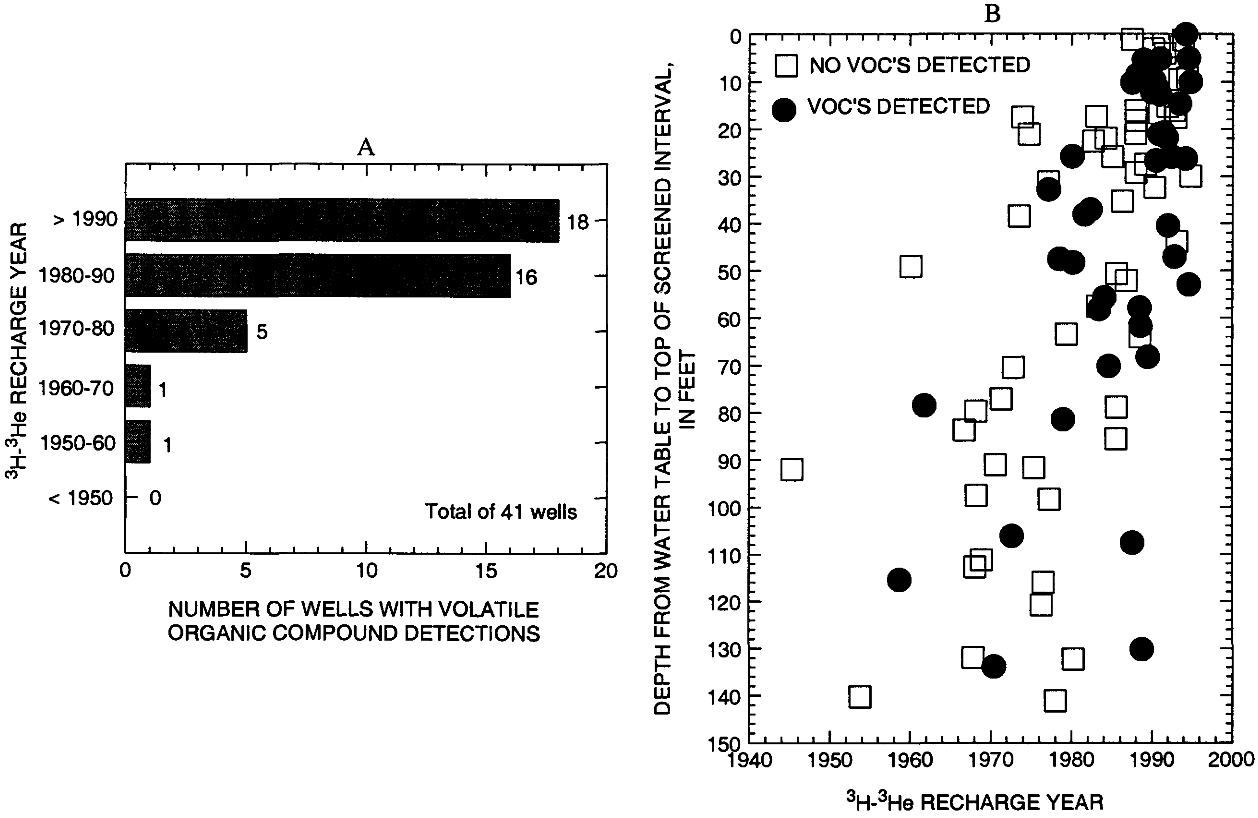

Figure 30. (A) Ground-water age distribution among wells where halogenated volatile organic compounds (VOC'S) were detected and (B) distribution of halogenated-VOC detections and nondetections in relation to well depth and ^{3}H-^{3}He age for ground water from the buried-valley aquifer, Dayton area, southwestern Ohio. (^{3}H-^{3}He ages from Shapiro and others, 1998.)

SUMMARY AND CONCLUSIONS

An environmental tracer study was done in conjunction with efforts to develop a regional ground-water flow model of the buried-valley aquifer in the Dayton area in southwestern Ohio. Objectives of the environmental tracer study were to (1) use newly developed environmental tracer techniques to estimate the age of ground water in the buried-valley aquifer, (2) apply estimates of ground-water age to the calibration and refinement of numerical flow models of selected parts of the buried-valley aquifer, and (3) characterize temporal trends in the quality of water in the buried-valley aquifer. Dating methods based on the measurement of chlorofluorocarbons (CFC method) and tritium and helium isotopes (^{3}H-^{3}He method) were used to estimate the age of ground water collected from 137 wells. Most of these wells were in three main areas near Dayton: (1) the WPAFB-Mad River Well Field area, (2) the Miami and North Miami Well Fields north of downtown Dayton, and (3) the Mound Plant near Miamisburg, Ohio.

Results of environmental-tracer sampling indicate that the CFC method is unreliable as an dating technique in the buried-valley aquifer because of ground-water contamination by local sources of CFC's or microbial degradation. On average, about 25 percent of the samples had concentrations of one or more CFC compounds that were above those expected for the air-water equilibrium value at the time of sampling. CFC ages obtained for anoxic ground-water samples unaffected by contamination were inconsistent with measured tritium concentrations. In several instances, ground-water samples that lacked detectable concentrations of CFC-12 (indicative of a pre-1945 recharge year) contained 20 to 30 tritium units, and therefore a significant component of post-1952 recharge. Anoxic conditions, which are found throughout most of the buried-valley aquifer, appear to be responsible for enhanced microbial degradation of the CFC compounds. Limited dissolved-gas data indicate that when methane concentrations exceed 0.05 mg/L, rapid degradation of all CFC compounds occurs. Further research is needed to define the origin and distribution of methane in the buried-valley aquifer and its role in the degradation of CFC's.

In contrast, Shapiro and others (1998) reported that ground-water ages obtained by the ^{3}H-^{3}He method were, for the most part, consistent with known tritium geochemistry. For most samples, the sum of tritium and tritiogenic helium-3 [^{3}H+^{3}He$_{trit}$] plotted as a function of ^{3}H-^{3}He age was in close agreement with the estimated tritium-input function for southwestern Ohio rainwater. Deviations from the rainwater curve were attributed to (1) dispersive effects that lowered reconstructed peak tritium values, (2) mixing at discharge areas that caused some WPAFB samples with low [^{3}H+^{3}He$_{trit}$] values to have ages that were less than expected, and (3) local tritium contamination that caused some samples to have [^{3}H+^{3}He$_{trit}$] concentrations above the tritium-input curve for southwestern Ohio rainwater. The latter included water samples collected from wells near the Mound Plant and waste-disposal facilities. This finding is important because it provides a method for identifying ground water that has been affected by small, local releases of tritium as either vapor or liquid.

Hydrologic consistency of the ^{3}H-^{3}He ages was also evaluated by examining trends in ^{3}H-^{3}He ages as a function of depth and distance along flowpaths delineated by use of existing water-level data or particle-tracking analysis. Shapiro and others (1998) constructed schematic geologic sections along regional flowpaths near the Miami-North Miami Well Fields area and the WPAFB-Mad River Well Field area. With few exceptions, these sections show that ground-water age increases with depth and increased distance along the flowpaths. Ground-water age decreased as the distance from large well fields decreased because of the combined effects of pumping and induced infiltration.

The fact that ^{3}H-^{3}He ages were, for the most part, geochemically and hydrologically consistent is an important finding because successful application of the ^{3}H-^{3}He method in the buried-valley aquifer depended on overcoming several complications that were either not present or were not addressed in previous investigations: (1) the size and hydrogeologic complexity of the buried-valley aquifer, (2) the mostly anoxic conditions that prevented comparison of the ^{3}H-^{3}He ages with largely unreliable CFC ages, (3) the use of existing wells with variable screen lengths and diameters, (4) the high rates of pumping and induced infiltration, and (5) the local tritium contamination in several parts of the buried-valley aquifer. In addition, nearly 60 percent of the ^{3}H-^{3}He samples required corrections for excess radiogenic helium before hydrologically reasonable ages could be calculated. However, Shapiro and others (1998) showed that the corrected ^{3}H-^{3}He ages of samples that had excess radiogenic helium were as consistent as those derived from samples that did not have excess helium. Although some data support the hypothesis that excess radiogenic helium is derived from underlying Ordovician shales, other data indicate that it may be generated by the decay of uranium and thorium contained in lithic fragments in glacial sediments. Further research will be needed to clarify the origin of the excess radiogenic helium in the buried-valley aquifer.

After the chemical and hydrologic consistency of the ^{3}H-^{3}He ages was established, the ages could then be applied to the calibration and refinement of ground-water flow models. Application of the ^{3}H-^{3}He ages reported by Shapiro and others (1998) to the calibration and refinement of numerical ground-water flow models of the buried-valley aquifer near Dayton is described by Sheets and others (1998). These workers showed that initial agreement between simulated traveltimes and ^{3}H-^{3}He ages was close, particularly for shallow parts of the buried-valley aquifer. In deeper parts of the aquifer where significant discrepancies between the simulated traveltimes and the ^{3}H-^{3}He ages were observed, these investigators describe procedures for making hydrologically reasonable adjustments to the numerical models that yielded improved agreement between the simulated traveltimes and ^{3}H-^{3}He ages. Such improvements can lead to increased confidence in model-based predictions concerning the fate and transport of ground-water contaminants such as VOC's or trace elements. These procedures can also be used to evaluate and improve the recently completed regional ground-water flow model of the buried-valley aquifer described by Dumouchelle (1998).

^{3}H-^{3}He ages were plotted against selected properties and constituents in ground-water samples to determine whether temporal trends in ground-water quality of the buried-valley aquifer could be identified. Distinct temporal trends were not identified for pH, temperature, specific conductance, redox potential, calcium, magnesium, or alkalinity. The absence of trends in pH, alkalinity, and calcium and magnesium concentrations was attributed to equilibration of water with carbonate minerals in aquifer sediments. Temporal trends in which the number of outliers and degree of scatter in the data increased as ground-water age decreased were characteristic of several constituents including sodium, potassium, boron, bromide, chloride, ammonia, nitrate, phosphate, sulfate, and organic carbon. Elevated concentrations of these constituents are probably related to human activities. For many of these constituents, however, ground water recharged prior to 1970 is characterized by distinctly lower concentrations and reduced scatter in the data. Temporal trends in which constituent concentrations decline as ground-water age increases could also reflect natural processes that reduce constituent concentrations to low levels. For example, the absence of measurable nitrate concentrations in ground water recharged prior to 1980 probably reflects removal of nitrate by bacterially mediated denitrification.

Temporal trends of DO, iron, nitrate, and silica indicate that these constituents may be useful for identifying wells receiving recent (post-1990) recharge, particularly if combined with tritium measurements. Lower concentrations of dissolved silica tend to be associated with ground water recharged after the mid-1970's, whereas older (pre-1970's) ground water appears to have reached a state of metastable equilibrium with respect to siderite and chalcedony. Silica may also be a useful indicator of wells affected by induced infiltration of surface water. Further research is required to evaluate the reliability of the above-listed constituents as qualitative age-dating tools and to determine their applicability to other buried-valley aquifers in glaciated parts of the United States.

Perhaps the principal finding of the environmental tracer study is that ground water in the buried-valley aquifer near Dayton is relatively young, with ages ranging from a few months to a few years in shallow parts of the aquifer and from a few years to a few decades in the deeper parts of the aquifer. The presence of young ground water throughout the regional hydrogeologic system reflects natural as well as human factors: it is consistent with the high transmissivity of the sand and gravel deposits that make up the aquifer and the high pumping rates that induce infiltration of large amounts of surface water. Temporal trends in ground-water quality indicate that the effects of human activities are readily discerned in shallow parts of the aquifer, that overall vulnerability of the buried-valley aquifer to contamination is high, and that ongoing efforts to protect the aquifer will need to continue in order to preserve the current ground-water quality.

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Table 1. Water-quality data for surface-water samples from selected sites near Dayton, Ohio

[Site locations shown in fig. 8. Abbreviations: ft, feet; µs/cm, microsiemens per centimeter at 25 degrees Celsius; mm Hg, millimeters of mercury; deg C, degrees Celsius; mg/L, milligrams per liter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; - - no data reported or not analyzed for; Cr, creek; Pk, Pike; R, river; Brdg, bridge; WPAFB, Wright-Patterson Air Force Base]

Site number	Date	Latitude	Longitude	Site description	Water temperature (deg C)	Land-surface altitude (ft)	Air temperature (deg C)	Barometric pressure (mm Hg)	Specific conductance, field (µS/cm)	Oxygen, dissolved, field (mg/L)	pH, field (standard units)
395122084031100	95/09/25	39°51'22"	84°03'11"	Mud Creek at Valley Pike	13.0	820	15.5	743	752	9.3	8.1
395042084021700	95/09/25	39°50'42"	84°02'17"	Mud Run at Medway Road	17.0	820	19.5	742	721	9.1	8.2
394755084050400	95/09/19	39°47'55"	84°05'04"	Hebble Creek at S. Boundary of WPAFB	20.5	790	27.0	749	867	9.1	8.0
3271000	95/09/12	39°46'00"	84°14'10"	Wolf Creek at Bridge Street	18.5	740	--	--	817	6.5	7.8
394014084121200	95/09/11	39°40'14"	84°12'12"	Holes Cr at Alexanderville-Bellbrook Pk	21.5	715	--	--	823	8.2	8.2
393910084172300	95/09/11	39°39'10"	84°17'23"	Bear Creek at Soldiers Home Road	20.0	690	--	--	843	9.6	8.0
3263000	95/09/12	39°52'27"	84°09'45"	Great Miami River at Taylorsville Dam	21.0	760	--	--	705	8.6	8.2
394910084092300	95/09/18	39°49'10"	84°09'23"	Great Miami River at Needmore Road	22.0	750	22.5	751	704	10.5	8.4
394809084092100	95/09/19	39°48'09"	84°09'21"	Great Miami River at Miami Wellfield	17.5	745	12.0	752	725	8.2	8.3
394352084125700	95/09/12	39°43'52"	84°12'57"	Great Miami River at Broadway	22.0	720	--	--	565	8.0	8.2
394116084135200	95/09/12	39°41'16"	84°13'52"	Great Miami River at Sellars Ave.	22.5	710	--	--	799	7.6	8.3
394027084154100	95/09/12	39°40'27"	84°15'41"	Great Miami River at Miami Ave.	21.5	690	--	--	867	7.6	8.2
393826084173100	95/09/11	39°38'26"	84°17'31"	Great Miami R at Linden Ave. Brdg	25.5	680	--	--	867	10.0	8.4
3271601	95/09/11	39°36'24"	84°17'23"	Great Miami River at Chautauqua Rd.	18.5	670	--	--	888	8.2	8.4
395226083594600	95/09/19	39°52'26"	83°59'46"	Mad River at I-675	19.5	835	23.0	747	714	10.6	8.2
395035084030200	95/09/19	39°50'35"	84°03'02"	Mad River at SR235	19.5	805	23.5	745	712	9.6	8.3
3270000	95/09/25	39°47'50"	84°05'19"	Mad River at Huffman Dam	13.5	785	16.0	746	696	9.1	8.1
394731084061800	95/0919	39°47'31"	84°06'18"	Mad River at Rohrer's Island Inlet Gates	19.5	775	20.0	750	732	7.6	8.0
394605084110600	95/09/18	39°46'05"	84°11'06"	Mad River at Webster Street	21.0	730	20.0	752	723	12.3	8.4
395117084155900	95/09/13	39°51'17"	84°15'59"	Stillwater River at Heathcliff Road	25.0	780	--	--	705	7.4	8.1
394753084122500	95/09/13	39°47'53"	84°12'25"	Stillwater River at Siebenthaler Road	21.0	735	--	--	702	6.4	7.9

Table 1. Water-quality data for surface-water samples from selected sites near Dayton, Ohio—Continued

[Site locations shown in fig. 8. Abbreviations: ft, feet; µs/cm, microsiemens per centimeter at 25 degrees Celsius; mm Hg, millimeters of mercury; deg C, degrees Celsius; mg/L, milligrams per liter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; - - no data reported or not analyzed for; Cr, creek; Pk, Pike; R, river; Brdg, bridge; WPAFB, Wright-Patterson Air Force Base]

Site number	Date	pH, lab (standard units)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Bicarbonate, field (mg/L as HCO_3^-)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)
395122084031100	95/09/25	8.0	400	98	37	8.4	1.8	299	365	22	76	0.2
395042084021700	95/09/25	8.0	340	76	37	14	10	276	337	31	52	0.2
394755084050400	95/09/19	7.9	400	96	38	25	3.7	304	371	53	55	0.2
3271000	95/09/12	7.8	340	81	34	34	2.7	272	332	66	64	0.4
394014084121200	95/09/11	8.1	320	71	34	47	2.5	206	251	91	44	0.2
393910084172300	95/09/11	7.9	380	89	38	28	2.8	296	361	52	79	0.4
3263000	95/09/12	8.1	320	77	30	23	3.4	260	317	40	61	0.5
394910084092300	95/09/18	8.2	320	78	30	26	3.5	254	310	41	65	0.4
394809084092100	95/09/19	8.1	320	78	30	27	3.5	258	315	43	65	0.5
394352084125700	95/09/12	8.0	240	58	24	20	2.9	192	234	34	48	0.2
394116084135200	95/09/12	8.2	310	74	31	41	4	246	300	65	68	0.4
394027084154100	95/09/12	8.1	320	76	32	53	4.6	248	304	76	74	0.5
393826084173100	95/09/11	8.3	330	77	33	58	4.4	252	308	83	78	0.4
3271601	95/09/11	8.2	330	77	33	57	4.4	254	310	83	75	0.4
395226083594600	95/09/19	8.2	350	84	34	14	2.6	272	332	27	65	0.2
395035084030200	95/09/19	8.1	340	82	34	15	2.7	270	329	29	65	0.3
3270000	95/09/25	8.0	340	81	34	16	2.8	267	326	31	63	0.2
394731084061800	95/09/19	8.0	350	83	34	17	3	276	337	32	65	0.2
394605084110600	95/09/18	8.3	340	82	34	19	3.3	274	334	36	64	0.2
395117084155900	95/09/13	8.1	310	68	34	25	3.2	212	259	46	62	0.3
394753084122500	95/09/13	7.9	300	67	33	25	3.2	278	339	47	59	0.3

Table 1. Water-quality data for surface-water samples from selected sites near Dayton, Ohio—Continued

[Site locations shown in fig. 8. Abbreviations: ft, feet; µs/cm, microsiemens per centimeter at 25 degrees Celsius; mm Hg, millimeters of mercury; deg C, degrees Celsius; mg/L, milligrams per liter; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; µg/L, micrograms per liter; - - no data reported or not analyzed for; Cr, creek; Pk, Pike; R, river; Brdg, bridge; WPAFB, Wright-Patterson Air Force Base]

Site number	Date	Silica, dis-solved (mg/L as SiO_2)	Nitrogen, ammonia (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorous, dissolved orthophos-phate (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Mangen-ese, dissolved (µg/L as Mn)	Sum of dissolved solids (mg/L)	Bromide, dissolved (mg/L as Br)
395122084031100	95/09/25	7.1	<0.015	0.01	3.8	0.02	1.1	20	<3	5	447	0.05
395042084021700	95/09/25	7.4	<0.015	<0.01	4.4	0.02	2.2	30	<3	3	413	0.03
394755084050400	95/09/19	8.7	<0.015	0.02	7.7	0.04	1.5	50	4	15	496	0.06
3271000	95/09/12	4.7	0.02	0.01	1.2	<0.01	1.6	70	6	9	456	0.07
394014084121200	95/09/11	7.6	0.02	<0.01	1.7	0.01	2.5	50	<3	4	428	0.05
393910084172300	95/09/11	7.1	0.02	<0.01	1.6	0.02	1.5	20	<3	3	481	0.05
3263000	95/09/12	5.4	<0.015	0.01	2.0	0.19	2.9	80	6	2	406	0.02
394910084092300	95/09/18	4.8	<0.015	0.01	1.8	0.15	2.8	80	4	4	410	0.01
394809084092100	95/09/19	4.8	<0.015	0.01	1.9	0.16	2.8	80	<3	2	416	0.03
394352084125700	95/09/12	3.3	0.14	0.02	2.0	0.12	4.2	70	7	10	315	0.01
394116084135200	95/09/12	4.7	0.04	0.01	3.4	0.32	2.9	100	<3	6	452	0.04
394027084154100	95/09/12	5.1	0.05	0.02	3.5	0.37	3.5	120	14	5	488	0.07
393826084173100	95/09/11	5.3	<0.015	0.02	3.4	0.42	3.8	120	<3	5	507	0.06
3271601	95/09/11	4.9	<0.015	0.01	3.3	0.39	3.9	60	<3	2	503	0.07
395226083594600	95/09/19	6.2	<0.015	0.02	3.7	0.17	2.1	60	6	1,010	413	0.03
395035084030200	95/09/19	6.3	<0.015	0.01	3.6	0.19	2.0	50	3	7	413	0.04
3270000	95/09/25	5.8	0.02	0.01	3.2	0.14	2.0	60	6	8	409	0.04
394731084061800	95/09/19	6.3	0.02	0.02	3.5	0.14	2.1	60	5	10	422	0.04
394605084110600	95/09/18	5.9	<0.015	0.03	3.3	0.13	2.2	60	7	5	424	0.04
395117084155900	95/09/13	1.7	0.03	0.01	1.3	0.06	3.0	120	4	5	374	0.02
394753084122500	95/09/13	2.2	0.02	<0.01	1.3	0.07	2.9	100	4	4	410	0.02

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon concentrations exceed 1994 air-water equilibrium value by more than 5 percent at assumed recharge temperature; - - no data available; ND, not detected]

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temperature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
MT-296	MI	93/06/24	57.88	8.5	2	214, 209	1971.0±0.5	34, 33	1962.5±0.0	--, --	--
MT-290	MI	93/06/25	9.56	16.0	2	219, 224	1974.0±0.5	451, 458	Contam.	90, 98	Contam.
MT-419	MI	93/09/30	14.63	10.0	3	2,807; 3,357; 4,413	Contam.	900; 966; 1,161	Contam.	876; 1,041; 99	Contam.
MT-421	MI	93/09/30	107.64	10.0	3	41, 33, 36	1961.0±0.5	172, 166, 171	1976.8±0.3	--, --, --	--
MT-408	MI	93/10/06	18.21	10.0	3	879, 851, 860	Contam.	1,765; 1,767; 1,769	Contam.	7.9, 7.3, 7.5	1969.5±0.0
MT-409	MI	93/10/06	132.29	10.0	3	ND, 9.1, 9.7	1954.5±0.0#	4.7, 5.1, 5.5	1950.2±0.3	ND, 17.7, 19.7	1975.0±0.5#
MT-411	MI	93/10/06	104.18	10.0	3	ND,ND,ND	<1945.0	ND, 2.9, ND	<1940.0#	ND, ND, ND	<1966.0
MT-410	MI	93/10/06	23.75	10.0	3	264, 276, 280	1973.2±0.3	177, 201, 207	1979.5±2.0	--, --, 9.0	--#
MT-400	MI	93/10/06	21.95	10.0	3	352, 359, 357	1975.5±0.0	240, 264, 261	1985.2±1.2	12, 9.6, 12	1971.3±0.8
MT-401	MI	93/10/06	91.79	10.0	3	ND, ND, ND	<1945.0	1.4, ND, ND	<1940.0#	ND, ND, ND	<1966.0
MT-346	MI	93/10/07	35.33	10.0	3	482, 482, 472	1979.8±0.3	351, 377, 363	1993.0±0.5&	15, 15, 11	1972.3±1.3
MT-347	MI	93/10/07	112.61	10.0	3	1.8, 2.6, 1.9	1950.3±0.7	ND, 1.0, 1.3	1945.3±0.3#	ND, ND, ND	<1966.0
MT-349	MI	93/10/07	31.52	10.0	3	ND, 1.2, 0.7	1948.3±0.3#	431, 479, 487	Contam.	ND, ND, ND	<1966.0
MT-350	MI	93/10/07	104.98	10.0	3	ND 1.3, 1.5	1949.5±0.0#	2.3, ND, ND	<1940.0#	ND, ND, ND	<1966.0
MT-351	MI	93/10/07	17.52	10.0	3	4.6, 6.3, 7.7	1953.2±0.8	25, 25, 29	1961.3±0.7	ND, ND, ND	<1966.0
MT-352	MI	93/10/07	79.71	10.0	3	ND, ND, ND	<1945.0	ND, ND, ND	<1940.0	ND, ND, ND	<1966.0
MT-406	MI	93/10/08	21.10	10.0	3	532, 546, 495	1981.7±1.2	1,812; 1,445; 1,315	Contam.	--, --, --	--
MT-407	MI	93/10/08	81.5	10.0	3	19, 21, 24	1957.7±0.8	28, 30, 44	1963.2±1.3	498, 221, 13	Contam.
MT-353	MI	93/10/08	5.14	10.0	3	105, 83, 89	1966.0±1.0	206, 123, 130	1976.2±4.8	132, 78, 76	1988.0±0.5#
MT-354	MI	93/10/08	120.79	10.0	3	19, 21, 8.4	1956.3±2.3	9.4, 5.8, 5.6	1951.8±2.3	9.8, 8.4, ND	1968.8±2.8
MT-361	MI	93/10/28	10.00	10.0	3	23, 27, 34	1959.7±1.3	2,998; 2,716; 2,573	Contam.	41, 41, 75	1984.7±3.3
MT-362	MI	93/10/28	68.27	10.0	3	283, 273, 64	1970.3±6.3	21, 10, 62	1960.5±6.0	--, --, --	--
MT-357	MI	93/10/28	9.19	10.0	3	15,970; 15,730; 15,880	Contam.	368, 356, 372	1993.0±0.5&	11, 38, 30	1977.8±6.3
MT-358	MI	93/10/28	64.04	10.0	3	62, 65, 51	1963.3±0.8	ND, 1.1, ND	<1940.0#	7.3, 9.6, 7.0	1969.8±0.8
MT-343	MI	94/08/30	85.65	10.0	3	ND, ND, ND	<1945.0	10, 3.8, 11	1952.7±3.7	ND, ND, ND	<1966.0

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temperature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
MT-342	MI	94/08/30	32.36	10.0	3	44, 46, 44	1962.2±0.3	119, 106, 127	1972.8±0.8	ND, ND, ND	<1966.0
MT-344	MI	94/08/30	27.51	10.0	3	1.0, 3.1, 3.8	1950.8±1.3	12, 11, 13	1955.3±0.7	6.7, 4.9, 6.2	1968.7±0.7
MT-345	MI	94/08/30	91.045	10.0	3	ND, ND, ND	<1945.0	14, 2.8, 7.8	1952.3±4.2	ND, ND, ND	<1966.0
MT-359	MI	94/08/31	15.27	10.0	3	378, 382, 365	1975.8±0.3	367, 348, 338	1994.0±0.5&	5.0, 9.8, 10	1969.8±1.2
MT-360	MI	94/08/31	50.66	10.0	3	5.5, 3.2, 4.1	1952.2±0.8	7.7, 25, 25	1958.0±5.5	ND, ND, ND	<1966.0
MT-376	MI	94/08/31	16.16	10.0	3	10, ND, ND	<1945.0#	1.7, 1.5, 26	1951.2±9.8	ND, ND, ND	<1966.0
MT-355	MI	94/08/31	16.09	10.0	3	9.8, 10, 12	1954.8±0.3	9.5, 27, 18	1957.8±3.7	6.8, 8.0, 7.8	1969.5±0.5
MT-375	MI	94/09/01	25.88	10.0	3	128, 130, 132	1968.0±0.0	150, 162, 179	1976.7±1.2	ND, ND, ND	<1966.0
MT-374	MI	94/09/01	20.96	10.0	3	2.1, 3.0, 2.5	1951.0±0.5	3.3, 3.0, 2.7	1948.0±0.5	ND, ND, ND	<1966.0
MT-404	MI	94/09/01	16.63	10.0	8	143, 122, 160 156, 112, 111 109, 108	1967.9±1.6	94, 79, 120, 93 71, 88, 64, 82	1970.1±2.9	ND, ND, ND ND	<1966.0
MT-405	MI	94/09/01	77.15	10.0	3	ND, ND, ND	<1945.0	ND, ND, 0.8	<1940.0#	ND, ND, ND	<1966.0
MT-366	MI	94/09/02	10.25	10.0	3	709, 693, 633	1987.0±1.5	1,354; 1,337; 1,349	Contam.	1,852; 1,857; 1,792	Contam.
MT-414	MI	94/09/02	26.26	10.0	3	559, 437, 466	1980.2±2.8	824, 807, 810	Contam.	734, 50, 606	Contam.#
MT-415	MI	94/09/02	53.04	10.0	3	--, --, --	--	474, 485, 467	Contam.	1,066; 1,084; 1,006	Contam.
MT-309	MO	93/08/10	62.92	10.0	2	669, 635	1986.5±0.5	780, 741	Contam.	224, 191	Contam.
MT-307	MO	93/08/10	25.79	10.0	2	270, 278	1973.3±0.3	973, 992	Contam.	258, 261	Contam.
MT-308	MO	93/08/10	8.61	10.0	2	4098, 4050	Contam.	617, 501	Contam.	173, 176	Contam.
MT-944	MO	93/08/10	11.60	10.0	2	17,460; 16,270	Contam.	414, 401	Contam.	--, --	--
MT-946	MO	93/08/11	47.05	10.0	2	10,270; 10,195	Contam.	365, 351	1993±0.5&	410, 3350	Contam.
MT-316	MO	94/07/18	87.92	10.0	3	ND, ND, ND	<1945.0	133, 119, 130	1973.7±0.7	36, 35, 40	1982.5±0.5
MT-315	MO	94/07/18	74.24	10.0	3	161, 157, 159	1969.5±0.0	847, 839, 841	Contam.	73, 72, 73	1987.5±0.0
MT-314	MO	94/07/18	45.11	10.0	3	6.4, 8.4, 8.7	1953.8±0.3	934, 882, 961	Contam.	ND, ND, ND	<1966.0

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temperature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
MT-312	MO	94/07/18	15.13	10.0	3	2.6, 2.4, 9.5	1952.0±2.5	177, 178, 180	1977.8±0.5	54, 48, 47	1984.3±0.7
MT-321	MO	94/07/19	40.20	10.0	3	ND, ND, ND	<1945.0	1,007; 1,049; 1,070	Contam.	ND, ND, ND	<1966.0
MT-320	MO	94/07/19	29.98	10.0	3	ND, 0.3, ND	<1945.0#	378, 390, 401	Contam.#	ND, ND, ND	<1966.0
MT-319	MO	94/07/19	5.05	10.0	3	1,077; 1,110; 1,096	Contam.	1,167; 1,210; 1,205	Contam.	299, 224, 219	Contam.
MT-325	MO	94/07/19	9.77	10.0	3	513, 522, 531	1981.7±0.3	175, 152, 191	1977.8±2.2	49, 37, 41	1983.2±1.3
MT-329	MO	94/07/29	64.83	10.0	3	57, 12, 7.6	1957.7±5.8	43, 46, 40	1964.5±0.5	28, 30, 28	1979.7±0.3
MT-326	MO	94/08/01	37.08	10.0	3	3.2, 2.9, 5.9	1951.8±1.2	329, 407, 348	1992.8±1.2#	ND, ND, ND	<1966.0
MT-327	MO	94/08/01	99.21	10.0	3	6.7, 2.1, 3.7	1952.0±1.5	1.8, 2.1, 1.8	1946.8±0.3	ND, ND, ND	<1966.0
MT-328	MO	94/08/02	5.39	10.0	4	19,480; 19,730; 19,810; 19,200	Contam.	771, 774, 748 703	Contam.	2,782; 2,769; 2,624; 2,428	Contam.
MT-323	MO	94/08/02	10.15	10.0	3	16,530; 16,200; 15,750	Contam.	654, 656, 639	Contam.	1,523; 1,515; 1,489	Contam.
MT-324	MO	94/08/03	64.58	10.0	3	28, 9.5, 10	1956.3±3.2	3.4, 3.5, 3.6	1948.5±0.0	ND, ND, ND	<1966.0
MT-318	MO	94/08/03	12.64	10.0	3	11, 13, 10	1955.0±0.5	171, 167, 175	1977.0±0.5	46, 38, 30	1982.0±2.0
MT-330	MO	94/08/04	15.96	10.0	3	193, 188, 198	1970.8±0.3	416, 445, 404	Contam.	11, 7.4, 6.8	1969.8±1.2
MT-331	MO	94/08/04	41.69	10.0	3	1.6, 3.9, 2.9	1950.8±1.3	460, 442, 478	Contam.	ND, ND, ND	<1966.0
MT-333	MO	94/08/04	139.77	10.0	3	1.1, 0.8, 0.8	1948.8±0.3	31, 29, 28	1961.8±0.3	40, 44, 46	1983.5±1.0
MT-332	MO	94/08/08	81.74	10.0	3	1.2, 0.8, 3.0	1949.7±1.2	22, 24, 23	1960.3±0.3	8.3, 12, 9.6	1970.8±1.2
MT-335	MO	94/08/09	13.26	10.0	3	7,108; 6,955; 6,735	Contam.	8,929; 9,108; 8,826	Contam.	508, 498, 488	Contam.
MT-337	MO	94/08/10	23.68	10.0	3	5.5, 8.1, 8.3	1953.7±0.7	22, 25, 23	1960.2±0.3	12, 17, 14	1972.8±1.7
MT-338	MO	94/08/10	8.73	10.0	3	27, 28, 26	1959.2±0.3	118, 133, 130	1973.3±0.7	ND, ND, ND	<1966.0
MT-317	MO	94/08/11	66.88	10.0	3	499, 497, 116	1976.2±8.7	385, 383, 136	1987.3±13.3	535, 501, 74	Contam.#
MT-283	RE	93/06/23	40.97	10.0	2	178, 176	1970.0±0.5	132, 135	1974.0±0.5	--, --	--
MT-282	RE	93/06/24	26.15	10.0	2	192, 199	1970.8±0.5	158, 163	1976.3±0.5	--, --	--
MT-281	RE	93/06/24	10.19	10.0	2	320, 318	1974.5±0.5	203, 202	1980.5±0.5	--, --	--
MT-297	RE	93/06/24	79.41	10.0	2	20, ND	<1945.0*	34, 13	1959.5±3.5	--, ND	<1966.0*
MT-284	RE	93/06/25	3.11	10.0	2	793, 795	1993.0±0.5&	373, 365	1993.0±0.5&	42, 23	1980.0±3.5

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temper-ature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
MT-287	RE	93/06/25	63.41	10.0	2	172, 167	1970.0±0.5	223, 220	1982.0±0.5	ND, ND	<1966.0
MT-286	RE	93/06/25	29.25	10.0	2	65, 60	1963.8±0.5	119, 108	1972.5±0.5	ND, ND	<1966.0
MT-1022	RE	93/08/09	110.47	10.0	2	12, 7.2	1954.5±0.5	1,307; 1,301	Contam.	4.2, ND	<1966.0*
MT-302	RE	93/08/11	141.20	10.0	2	3,208; 3,080	Contam.	2,703; 2,693	Contam.	ND, 1.1	<1966.0*
MT-303	RE	93/08/11	57.58	10.0	2	3.8, 3.9	1952.0±0.0	2.2, 1.5	1946.5±0.5	9.4, 2.2	1968.8±1.8
MT-300	RE	93/08/12	16.14	10.0	2	4,171; 3,967	Contam.	1,340; 1,352	Contam.	70, 72	1987.0±0.0
MT-49	RE	93/08/12	203.20	10.0	2	5.6, 3.3	1952.3±0.8	1.2, 4.7	1947.8±2.3	ND, ND	<1966.0
MT-68	RE	93/08/13	98.41	10.0	2	7.4, 5.4	1953.3±0.3	27, 34	1962.3±0.8	--, --	--
MT-311	RE	93/08/13	31.26	10.0	2	383, 407	1976.8±0.8	4.8, 4.7	1950.0±0.0	6.3, ND	<1966.0*
MT-305	RE	93/08/13	17.35	10.0	2	2.3, 2.4	1950.8±0.2	13, 13	1956.0±0.0	11, 8.8	1970.8±0.8
MT-310	RE	93/08/16	226.97	10.0	2	3.1, 1.3	1950.5±1.0	2.1, 0.9	1945.8±1.3	ND, 3.2	<1966.0*
MT-288	RE	93/08/16	52.13	10.0	2	650, 640	1986.3±0.3	172, 166	1976.8±0.3	0.3, ND	<1966.0*
MT-289	RE	93/08/16	1.16	10.0	2	796, 797	1993.0±0.5&	388, 396	Contam.	63, 64	1986.3±0.8
MT-301	RE	93/08/17	58.13	10.0	2	15, 17	1956.3±0.3	342, 332	1993±0.5	--, --	--
MT-426	RE	93/08/18	110.45	10.0	2	17,220; 17,500	Contam.	2,363; 2,422	Contam.	2,573; 2,653	Contam.
MT-306	RE	93/08/18	72.02	10.0	2	12, 8.6	1954.8±0.8	515, 486	Contam.	23, 13	1974.8±2.3
MT-299	RE	93/08/19	25.83	10.0	2	22,560; 23,890	Contam.	3,003; 2,909	Contam.	--, 212	Contam.
GR-317	WP	93/06/21	112.77	14.5	2	ND, 4.5	<1945.0*	8.2, 63	1962.0±7.5	ND, ND	<1966.0
GR-316	WP	93/06/21	40.47	10.5	2	6,415; 815	<1993.0*	1,364; 1,666	Contam.	4,873; 183	Contam.
GR-334	WP	93/06/22	131.97	10.0	2	10, 19	1956.0±1.0	4.2, 5.7	1950.3±0.8	8.9, ND	<1966.0*
GR-333	WP	93/06/22	12.18	10.0	2	26,980; 28,650	Contam.	895, 852	Contam.	19,670; 23,460	Contam.
GR-324	WP	93/06/22	111.24	10.0	2	11, 9.9	1954.8±0.5	ND, 1.4	1943.0±3.0	ND, ND	<1966.0
GR-323	WP	93/06/22	38.52	10.0	2	24, 27	1959.0±0.5	85, 83	1970.0±0.5	ND, ND	<1966.0
GR-540	WP	93/06/23	2.62	9.0	2	1,090; 1,066	Contam.	395, 405	1993.0±0.5&	107, 110	1993.0±0.5&
GR-541	WP	93/06/23	43.87	9.0	2	859, 856	1993.0±0.5&	406, 425	Contam.	103, 100	1990.8±0.5
MT-65	WP	93/08/17	156.01	10.0	2	2.3, 0.7	1949.5±1.0	4.0, 1.8	1948.8±0.8	ND, ND	<1966.0

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temperature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
MT-291	WP	93/08/17	61.66	10.0	2	79, 67	1964.5±0.5	40,380; 40,880	Contam.	43, 13	1978.0±5.5
MT-427	WP	93/09/27	78.93	10.0	3	13, 4.7, 2.5	1953.0±2.0	1.9, ND, ND	<1940.0#	17, 6.7, ND	1972.3±2.3#
MT-425	WP	93/09/27	11.14	10.0	3	521, 527, 530	1981.8±0.5	11,710; 11,350; 11,580	Contam.	--, --, --	--
MT-429	WP	93/09/28	106.21	10.0	2	8.2, 6.4	1953.8±0.3	23, 19	1959.2±0.8	61, 69	1986.5±0.5
MT-428	WP	93/09/28	20.75	10.0	3	3,264; 4,641; 4,910	Contam.	34,890; 37,830; 38,740	Contam.	133, 170, 195	Contam.
MT-435	WP	93/09/28	21.84	10.0	3	339, 322, 344	1974.8±0.3	292, 307, 303	1988.8±0.3	8.4, 8.4, 8.0	1969.8±0.3
MT-436	WP	93/09/28	70.22	10.0	3	902, 843, 878	Contam.	13,150; 12,230; 13,030	Contam.	25, 27, 15	1976.8±3.8
MT-430	WP	93/09/28	4.07	10.0	3	ND, ND, 7.6	<1945.0#	21, 23, 13	1958.5±1.5	5.0, ND, 6.2	1968.8±0.3#
MT-431	WP	93/09/28	112.56	10.0	3	1.4, 2.3, ND	<1945.0#	ND, ND, ND	<1940.0	ND, ND, ND	<1966.0
MT-433	WP	93/09/29	9.33	10.0	3	56, 24, 24	1960.2±3.3	690, 558, 725	Contam.	24, ND, ND	<1966.0#
MT-434	WP	93/09/29	83.75	10.0	3	1.7, 3.1, 3.3	1950.7±0.8	ND, ND, ND	<1940.0	6.4, ND, ND	<1966.0#
GR-542	WP	93/09/29	17.54	10.0	3	393, 392, 399	1976.5±0.0	337, 331, 330	1992.5±0.8	25, 25, 32	1978.8±1.7
GR-543	WP	93/09/29	115.97	10.0	3	ND, ND, ND	<1945.0	ND, ND, ND	<1940.0	ND, ND, ND	<1966.0
GR-544	WP	93/09/30	22.57	10.0	3	9.3, 14, 6.2	1954.5±1.5	22, 27, 17	1959.7±1.7	97, 115, 92	1990.5±0.5#
GR-545	WP	93/09/30	97.61	10.0	3	6.2, 7.9, 6.1	1953.3±0.7	ND, ND, ND	<1940.0	ND, 6.6, ND	<1966.0#
GR-419	WP	94/08/17	115.46	10.0	3	588, 431, 413	1979.8±4.7	179, 92, 87	1973.0±4.5	1,832; 914; 818	Contam.
GR-420	WP	94/08/17	78.52	10.0	3	812, 762, 558	1989.2±6.2	184, 170, 107	1975.7±3.7	1,907; 1,699; 992	Contam.
GR-421	WP	94/08/17	47.55	10.0	3	240, 170, 178	1970.8±1.7	114, 105, 107	1972.3±0.3	198, 100, 105	1993.5±0.5#
GR-416	WP	94/08/18	48.29	10.0	3	310, 284, 319	1974.2±0.7	1,741; 1,448; 1,887	Contam.	51,180; 3,834; 55,900	Contam.
GR-415	WP	94/08/18	92.02	10.0	3	152, 92, 940	1967.5±1.5#	1,270; 584; 681	Contam.	18,120; 7,821; 97	Contam.#
GR-414	WP	94/08/18	140.28	10.0	3	176, 126, 119	1968.7±1.3	15, 7.8, 9.5	1954.5±2.5	95, 44, 43	1985.8±4.7
GR-216	WP	94/08/18	21.08	10.0	3	4.3, 5.1, 3.4	1952.0±0.5	3.5, 2.5, 3.4	1948.2±0.7	19, 14, 14	1973.8±1.7
MT-153	WP	94/08/19	55.7	10.0	3	320, 290, 425	1975.2±2.3	62, 51, 99	1968.3±3.2	733, 620, 434	Contam.
MT-152	WP	94/08/19	1.08	10.0	3	27, 23, 22	1958.5±1.0	16, 16, 14	1957.0±0.5	7.5, ND, ND	<1966.0#
MT-238	WP	94/08/19	0	10.0	2	1,099; 1,100	Contam.	366, 350	1994.0±0.5	789, 785	Contam.
MT-244	WP	94/08/19	38.04	10.0	3	266, 255, 258	1973.0±0.0	2,306; 2,142; 2,084	Contam.	90,240; 84,550; 83,310	Contam.

Table 2. Concentration of dissolved chlorofluorocarbon compounds and average recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[Well locations shown in figs. 4-7. Abbreviations: MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; pg/kg, picograms per kilogram; CFC-11, chlorofluorocarbon-11; CFC-12, chlorofluorocarbon-12; CFC-113, chlorofluorocarbon-113; ft, feet; deg C, degrees Celsius; Contam., chlorofluorocarbon

Well name	Group code	Date	Saturated thickness[1] (ft)	Assigned recharge temperature[2] (deg C)	Number of ampules analyzed[3]	Concentration of CFC-11[4] (pg/kg)	CFC-11 Average recharge year ± age error[5]	Concentration of CFC-12[4] (pg/kg)	CFC-12 Average recharge year ± age error[5]	Concentration of CFC-113[4] (pg/kg)	CFC-113 Average recharge year ± age error[5]
GR-299	WP	94/08/22	0	10.0	3	3,527; 3,512; 3,470	Contam.	2,135; 2,130; 2,223	Contam.	71, 52, 59	1985.7±1.3
GR-439	WP	94/08/22	70.45	10.0	3	77, 76, 65	1964.7±0.7	65, 65, 64	1967.8±0.3	45, 74, 83	1987.5±2.5
GR-256	WP	94/08/22	49.04	10.0	3	42, 46, 53	1962.3±0.7	59, 46, 64	1966.8±1.3	132, 82, 76	1988.3±0.3#
GR-326	WP	94/08/23	3.96	10.0	3	699, 704, 708	1987.8±0.3	435, 436, 445	Contam.	74, 73, 72	1987.5±0.0
GR-319	WP	94/08/23	130.26	10.0	3	141, 137, 144	1968.7±0.3	158, 114, 140	1974.3±1.7	93, 95, 106	1990.3±0.3#
GR-318	WP	94/08/23	26.59	10.0	3	2,136; 2,383; 2,293	Contam.	534, 545, 518	Contam.	71, 31, 43	1983.8±3.7
GR-426	WP	94/08/23	0	10.0	3	19,100; 19,060; 18,540	Contam.	320, 324, 326	1987.8±0.3	191, 139, 108	Contam.
GR-323	WP	94/08/24	38.15	10.0	3	448, 237, 347	1975.5±3.0	144, 42, 82	1969.8±5.3	1,539; 405; 831	Contam.
GR-324	WP	94/08/24	110.71	10.0	3	244, 247, 233	1972.3±0.3	115, 112, 110	1972.5±0.0	418, 429, 360	Contam.
GR-321	WP	94/08/24	32.76	10.0	3	8,420; 7,943; 8,120	Contam.	1,141; 1,573; 1,586	Contam.	438, 80, 21	1982.3±0.3
GR-322	WP	94/08/24	133.82	10.0	3	86, 71, 60	1964.5±0.3	8.2, 6.0, 4.3	1951.2±1.8	57, 45, 38	1984.0±1.5

[1] Saturated thickness is distance from water table to top of screened interval. For wells where depth to top of screen minus depth to water table is negative (for example, water table is within screened interval) the saturated thickness is reported as zero.

[2] Assigned recharge temperature is 10°C, which is based on dissolved-gas and stable-isotope data. Exceptions are those samples whose concentrations of dissolved nitrogen and argon indicate other temperatures. See figure 17 and text for details.

[3] Because of interference by unknown compounds, the number of reported concentrations may be less than the number of ampules analyzed.

[4] Chlorofluorocarbon concentration data are given in relative collection order from left to right.

[5] Average model year ± age error is based on the average of the model years calculated from the given analytical data. The age error does not represent a true standard deviation and instead covers the range of model ages calculated from the given CFC concentration data.

* Either one ampule had CFC concentration greater than concentration expected for air-water equilibrium with 1993 or 1994 air, or one of two ampules measured had no detectable CFC's. In either case, the model year is based on of ampule with lowest observed CFC concentration and therefore represents a minimum age (that is, water could be older if the lowest measured CFC concentration resulted from contamination).

For two out of three ampules, (1) CFC concentrations were greater than those expected for air-water equilibrium with 1993 or 1994 air, (2) CFC's were not detected, or (3) CFC concentrations were within the suitable range for age dating. For (1), the sample is designated contaminated with respect to the individual CFC compound. For (2), the model year is set to the minimum possible value (for example, <1945 for CFC-11; <1940 for CFC-12, < 1966 for CFC-113). For (3), the model year is based on the average recharge year calculated from the given analytical data.

& CFC concentrations were a few percent or less above concentrations xpected for air-water equilbrium with 1993 or 1994 air at the given recharge temperature. Although this could represent contamination, uncertainties in the recharge temperature and the effect of industrial activity on concentrations of individual CFC compounds in air in the study area indicate recharge within a year or less of the sampling date.

Table 5. Summary of nitrous oxide, reduced sulfur, and halogenated volatile organic compound detections in wells screened in the buried-valley aquifer near Dayton, Ohio

[MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; mg/L,milligrams per liter; Y, yes, compound or group of compounds present; N, no, compound or group of compounds not present;VOC, volatile organic compound; CFC, chlorofluorocarbon; --, no data available]

Well name	Group code	Date	Saturated thickness (ft[1])	Dissolved oxygen (mg/L)	Nitrous oxide detected	Reduced sulfur detected[2]	Halogenated VOC's detected on CFC chromatographs	VOC's detected in samples collected by other agencies	Source of other agency VOC data[3]
MT-296	MI	930624	57.88	<0.1	N	Y	Y	Y	OE
MT-290	MI	930625	9.56	0.1	Y	Y	N	ND	ND
MT-419	MI	930930	14.63	10.7	N	N	Y	N	DY
MT-421	MI	930930	107.64	0.1	N	N	Y	Y	DY
MT-408	MI	931006	18.21	0.8	Y	N	N	N	DY
MT-409	MI	931006	132.29	0.1	Y	N	N	N	DY
MT-411	MI	931006	104.18	<0.1	N	N	N	N	DY
MT-410	MI	931006	23.75	3.7	Y	N	N	N	DY
MT-400	MI	931006	21.95	5.5	Y	N	N	N	DY
MT-401	MI	931006	91.79	0.1	N	Y	N	N	DY
MT-346	MI	931007	35.33	5.1	Y	N	N	N	DY
MT-347	MI	931007	112.61	0.1	N	N	N	N	DY
MT-349	MI	931007	31.52	0.1	N	N	N	N	DY
MT-350	MI	931007	104.98	<0.1	N	N	N	N	DY
MT-351	MI	931007	17.52	<0.1	N	N	N	N	DY
MT-352	MI	931007	79.71	<0.1	N	N	N	N	DY
MT-406	MI	931008	21.1	0.4	N	N	Y	Y	DY
MT-407	MI	931008	81.5	0.1	N	N	Y	Y	DY
MT-353	MI	931008	5.14	<0.1	Y	Y	Y	N	DY
MT-354	MI	931008	120.79	0.1	N	N	N	N	DY
MT-361	MI	931028	10	0.2	N	N	Y	N	DY
MT-362	MI	931028	68.27	0.2	N	N	Y	N	DY
MT-357	MI	931028	9.19	0.2	Y	N	N	N	DY
MT-358	MI	931028	64.04	0.2	N	N	N	N	DY
MT-343	MI	940830	85.65	<0.1	N	Y	N	N	DY
MT-342	MI	940830	32.36	<0.1	N	N	N	N	DY
MT-344	MI	940830	27.51	0.1	N	N	N	N	DY
MT-345	MI	940830	91.04	0.1	N	N	N	N	DY
MT-359	MI	940831	15.27	0.1	Y	N	N	N	DY
MT-360	MI	940831	50.66	0.2	N	N	N	N	DY

Table 5. Summary of nitrous oxide, reduced sulfur, and halogenated volatile organic compound detections in wells screened in the buried-valley aquifer near Dayton, Ohio—Continued

[MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; mg/L,milligrams per liter; Y, yes, compound or group of compounds present; N, no, compound or group of compounds not present;VOC, volatile organic compound; CFC, chlorofluorocarbon; --, no data available]

Well name	Group code	Date	Saturated thickness (ft[1])	Dissolved oxygen (mg/L)	Nitrous oxide detected	Reduced sulfur detected[2]	Halogenated VOC's detected on CFC chromatographs	VOC's detected in samples collected by other agencies	Source of other agency VOC data[3]
MT-376	MI	940831	16.16	0.1	N	N	N	N	DY
MT-355	MI	940831	16.09	0.2	N	N	N	N	DY
MT-375	MI	940901	25.88	0.2	Y	N	N	N	DY
MT-374	MI	940901	20.96	0.1	N	N	N	N	DY
MT-404	MI	940901	16.63	0.1	N	N	N	N	DY
MT-405	MI	940901	77.15	0.1	N	N	N	N	DY
MT-366	MI	940902	10.25	2.8	N	N	Y	Y	DY
MT-414	MI	940902	26.26	0.1	N	N	Y	Y	DY
MT-415	MI	940902	53.04	<0.1	N	N	Y	Y	DY
MT-309	MO	930810	62.92	0.3	N	N	Y	Y	MI
MT-307	MO	930810	25.79	0.1	N	N	Y	Y	MI
MT-308	MO	930810	8.61	4.0	Y	N	Y	N	MI
MT-944	MO	930810	11.6	1.6	Y	N	Y	--	--
MT-946	MO	930811	47.05	0.1	Y	N	Y	--	--
MT-316	MO	940718	87.92	0.1	N	Y	Y	--	--
MT-315	MO	940718	74.24	0.1	N	Y	Y	--	--
MT-314	MO	940718	45.11	0.1	N	Y	Y	--	--
MT-312	MO	940718	15.13	<0.1	N	N	Y	--	--
MT-321	MO	940719	40.2	0.2	N	Y	Y	--	--
MT-320	MO	940719	29.98	0.2	N	Y	N	--	--
MT-319	MO	940719	5.05	4.7	Y	N	Y	--	--
MT-325	MO	940719	9.77	0.2	N	Y	Y	N	MO
MT-329	MO	940729	64.83	0.1	N	N	N	Y	MO
MT-326	MO	940801	37.08	<0.1	N	N	Y	--	--
MT-327	MO	940801	99.21	<0.1	N	Y	N	N	MO
MT-328	MO	940802	5.39	2.6	Y	N	Y	Y	MO
MT-323	MO	940802	10.15	0.5	Y	N	Y	Y	MO
MT-324	MO	940803	64.58	<0.1	N	Y	N	N	MO
MT-318	MO	940803	12.64	<0.1	N	Y	Y	N	MO
MT-330	MO	940804	15.96	0.1	N	N	Y	Y	MO
MT-331	MO	940804	41.69	<0.1	N	N	Y	--	--
MT-333	MO	940804	139.77	<0.1	N	Y	N	N	MO

Table 5. Summary of nitrous oxide, reduced sulfur, and halogenated volatile organic compound detections in wells screened in the buried-valley aquifer near Dayton, Ohio—Continued

[MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; mg/L,milligrams per liter; Y, yes, compound or group of compounds present; N, no, compound or group of compounds not present;VOC, volatile organic compound; CFC, chlorofluorocarbon; --, no data available]

Well name	Group code	Date	Saturated thickness (ft^1)	Dissolved oxygen (mg/L)	Nitrous oxide detected	Reduced sulfur detected^2	Halogenated VOC's detected on CFC chromatographs	VOC's detected in samples collected by other agencies	Source of other agency VOC data^3
MT-332	MO	940808	81.74	<0.1	N	N	N	N	MO
MT-335	MO	940809	13.26	0.7	Y	N	Y	N	MO
MT-337	MO	940810	23.68	0.1	N	N	Y	N	MO
MT-338	MO	940810	8.73	0.1	N	N	Y	N	MO
MT-317	MO	940811	66.88	0.5	N	Y	Y	--	--
MT-283	RE	930623	40.97	0.5	N	Y	Y	--	--
MT-282	RE	930624	26.15	1.1	Y	N	N	--	--
MT-281	RE	930624	10.19	3.3	Y	N	N	--	--
MT-297	RE	930624	79.41	0.1	N	Y	N	--	--
MT-284	RE	930625	3.11	4.7	Y	N	N	--	--
MT-287	RE	930625	63.41	0.8	N	N	N	--	--
MT-286	RE	930625	29.25	0.5	N	Y	N	--	--
MT-1022	RE	930809	110.47	0.1	N	Y	N	--	--
MT-302	RE	930811	141.2	<0.1	Y	Y	N	--	--
MT-303	RE	930811	57.58	<0.1	N	Y	N	--	--
MT-300	RE	930812	16.14	0.4	Y	N	N	--	--
MT-49	RE	930812	203.2	0.1	N	Y	N	--	--
MT-68	RE	930813	98.41	0.1	N	Y	N	--	--
MT-311	RE	930813	31.26	<0.1	N	Y	N	--	--
MT-305	RE	930813	17.35	<0.1	N	Y	N	--	--
MT-310	RE	930816	226.97	0.1	N	N	N	--	--
MT-288	RE	930816	52.13	0.1	Y	Y	N	--	--
MT-289	RE	930816	1.16	11.4	Y	N	N	--	--
MT-301	RE	930817	58.13	<0.1	N	Y	Y	--	--
MT-426	RE	930818	110.45	0.2	Y	Y	Y	--	--
MT-306	RE	930818	72.02	0.1	N	Y	N	--	--
MT-299	RE	930819	25.83	0.2	N	N	Y	--	--
GR-317	WP	930621	112.77	0.2	N	Y	N	N	US
GR-316	WP	930621	40.47	6.0	N	N	Y	N	US
GR-334	WP	930622	131.97	0.3	N	Y	N	Y	US
GR-333	WP	930622	12.18	4.3	Y	N	Y	Y	US
GR-324	WP	930622	111.24	0.2	N	N	N	Y	US

Table 5. Summary of nitrous oxide, reduced sulfur, and halogenated volatile organic compound detections in wells screened in the buried-valley aquifer near Dayton, Ohio—Continued

[MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; mg/L,milligrams per liter; Y, yes, compound or group of compounds present; N, no, compound or group of compounds not present;VOC, volatile organic compound; CFC, chlorofluorocarbon; --, no data available]

Well name	Group code	Date	Saturated thickness (ft[1])	Dissolved oxygen (mg/L)	Nitrous oxide detected	Reduced sulfur detected[2]	Halogenated VOC's detected on CFC chromatographs	VOC's detected in samples collected by other agencies	Source of other agency VOC data[3]
GR-323	WP	930622	38.52	0.2	N	N	N	N	US
GR-540	WP	930623	2.62	2.4	N	N	N	--	--
GR-541	WP	930623	43.87	0.2	Y	Y	N	--	--
MT-65	WP	930817	156.01	0.1	N	N	N	--	--
MT-291	WP	930817	61.66	<0.1	N	N	Y	--	--
MT-427	WP	930927	78.93	ND	N	Y	N	N	DY
MT-425	WP	930927	11.14	0.3	Y	Y	Y	Y	DY
MT-429	WP	930928	106.21	0.2	N	N	Y	N	DY
MT-428	WP	930928	20.75	1.3	Y	N	Y	Y	DY
MT-435	WP	930928	21.84	<0.1	N	N	Y	Y	DY
MT-436	WP	930928	70.22	0.2	N	N	Y	N	DY
MT-430	WP	930928	4.07	<0.1	N	Y	N	N	DY
MT-431	WP	930928	112.56	<0.1	N	N	N	N	DY
MT-433	WP	930929	9.33	0.2	N	N	Y	N	DY
MT-434	WP	930929	83.75	0.1	N	N	N	N	DY
GR-542	WP	930929	17.54	1.1	N	N	N	N	DY
GR-543	WP	930929	115.97	0.1	N	N	N	N	DY
GR-544	WP	930930	22.57	0.2	N	Y	N	N	DY
GR-545	WP	930930	97.61	0.1	N	N	N	N	DY
GR-419	WP	940817	115.46	0.2	N	Y	Y	Y	US
GR-420	WP	940817	78.52	0.3	N	N	Y	N	US
GR-421	WP	940817	47.55	0.1	N	N	Y	N	US
GR-416	WP	940818	48.29	0.2	N	Y	Y	N	US
GR-415	WP	940818	92.02	0.1	N	Y	N	N	US
GR-414	WP	940818	140.28	0.1	N	N	N	N	US
GR-216	WP	940818	21.08	0.3	N	N	N	N	US
MT-153	WP	940819	55.7	0.1	Y	N	Y	N	US
MT-152	WP	940819	1.08	0.4	N	N	N	N	US
MT-238	WP	940819	0	9.8	Y	N	Y	Y	US
MT-244	WP	940819	38.04	<0.1	N	Y	Y	Y	US
GR-299	WP	940822	0	7.8	Y	N	N	N	US
GR-439	WP	940822	70.45	0.1	N	N	N	N	US

Table 5. Summary of nitrous oxide, reduced sulfur, and halogenated volatile organic compound detections in wells screened in the buried-valley aquifer near Dayton, Ohio—Continued

[MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; mg/L,milligrams per liter; Y, yes, compound or group of compounds present; N, no, compound or group of compounds not present;VOC, volatile organic compound; CFC, chlorofluorocarbon; --, no data available]

Well name	Group code	Date	Saturated thickness (ft[1])	Dissolved oxygen (mg/L)	Nitrous oxide detected	Reduced sulfur detected[2]	Halogenated VOC's detected on CFC chromato-graphs	VOC's detected in samples col-lected by other agencies	Source of other agency VOC data[3]
GR-256	WP	940822	49.04	0.2	N	N	N	N	US
GR-326	WP	940823	3.96	4.6	Y	N	Y	N	US
GR-319	WP	940823	130.26	0.1	N	N	Y	N	US
GR-318	WP	940823	26.69	4.1	Y	N	Y	Y	US
GR-426	WP	940823	0	3.4	Y	N	Y	N	US
GR-323	WP	940824	38.15	0.1	N	N	Y	N	US
GR-324	WP	940824	110.71	<0.1	N	N	Y	Y	US
GR-321	WP	940824	32.76	0.1	Y	N	Y	Y	US
GR-322	WP	940824	133.82	<0.1	N	N	Y	N	US

[1] Saturated thickness is distance from water table to top of screened interval. For wells where depth to top of screen minus depth to water table is negative (for example, water table is within screened interval), the saturated thickness is reported as zero.

[2] Electron capture detector responds to hydrogen sulfide (H_2S) and methly sulfide (CH_3SH).

[3] DY, Dept. of Water Supply and Treatment, City of Dayton, written commun. (1995); MI, CH2M Hill Inc. (1991); MO, U.S. Department of Energy (1995); OE, Ohio Environmental Protection Agency cited in CH2M Hill Inc. (1989); US, Wright-Patterson Air Force Base Basewide Monitoring Program, unpublished data on file at Ohio District office of USGS.

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	$\Delta\,^4He$[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
Radiogenic helium correction not required for age estimate													
MT-296	930624	MI	57.88	18.9	0.21	2.46	6.05	33.0	16.88	0.153	25.0	1988.5	0.3
MT-290	930625	MI	9.56	14.8	0.13	1.95	4.70	6.59	-1.06	0.034	14.9	1993.4	0.3
MT-419	930930	MI	14.63	15.9 13.6*	0.09 0.8*	2.63	6.53	44.6	-0.20	0.092	16.3	1993.4	0.4
MT-406	931008	MI	21.10	18.8	0.27	3.20	8.14	80.2	6.52	0.047	22.2	1990.9	0.4
MT-361	931028	MI	10.00	21.3	0.16	3.17	7.76	71.8	-2.44	-0.235	11.7	1994.8	0.7
MT-362	931028	MI	68.27	19.9	0.23	2.01	4.60	1.81	19.88	-0.060	25.4	1989.5	0.2
MT-357	931028	MI	9.19	16.6	0.24	2.56	6.21	37.6	-2.52	-0.039	16.1	1994.4	0.4
MT-358	931028	MI	64.04	18.0 17.7*	0.13 0.9*	3.01	7.30	61.7	14.46	-0.246	24.3	1988.5	0.4
MT-342	940830	MI	32.36	16.5	0.10	2.44	5.89	30.4	12.82	-0.007	21.2	1990.3	0.3
MT-344	940830	MI	27.51	30.2	0.15	2.36	5.64	24.9	33.94	-0.029	41.3	1989.1	0.2
MT-359	940831	MI	15.27	14.4	0.09	3.21	7.35	62.8	4.89	-0.075	16.9	1991.9	0.5
MT-376	940831	MI	16.16	16.6	0.10	3.11	7.36	63.0	17.61	-0.480	24.2	1987.9	0.4
MT-374	940901	MI	20.96	57.4	0.23	2.40	5.60	23.9	83.42	-0.176	83.8	1987.9	0.2
MT-404[e]	940901	MI	16.63	55.8	0.19	2.45	5.65	25.0	41.58	-0.320	68.8	1990.8	0.1
MT-415	940902	MI	53.04	13.0	0.09	3.30	7.73	71.0	-0.87	-0.657	13.1	1994.7	0.6
MT-308	930810	MO	8.61	37.0	0.20	2.79	7.02	54.9	33.37	0.106	50.4	1988.1	0.2
MT-946	930811	MO	47.05	71.7	0.48	2.24	5.35	18.2	10.49	0.037	75.3	1992.8	0.1
MT-320	940719	MO	29.98	19.1	0.11	2.53	5.83	28.8	-2.02	-0.313	18.9	1994.8	0.3
MT-319	940719	MO	5.05	26.0	0.13	2.75	5.95	31.3	-1.06	-0.843	26.0	1994.6	0.2
MT-325	940719	MO	9.77	33.4	0.16	2.08	5.00	10.3	30.14	0.152	42.2	1990.2	0.2

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	Δ ^4He[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
MT-326	940801	MO	37.08	52.2	0.22	2.46	6.16	36.0	149.5	0.213	103.9	1982.3	0.2
MT-318	940803	MO	12.64	57.9	0.23	2.15	4.91	8.39	46.47	-0.142	71.0	1991.0	0.1
MT-284	930625	RE	3.11	14.8	0.08	2.41	5.76	27.6	8.38	-0.036	17.9	1990.1	0.4
MT-287	930625	RE	63.41	21.6	0.24	2.51	6.16	36.4	74.92	0.052	47.7	1979.3	0.3
MT-286	930625	RE	29.25	14.9	0.18	2.64	6.44	42.8	13.96	-0.037	20.3	1988.0	0.4
MT-300	930812	RE	16.14	19.0	0.27	2.40	5.73	26.6	1.60	-0.052	20.0	1992.8	0.3
MT-289	930816	RE	1.16	12.7 11.4*	0.07 0.80*	3.01	7.49	66.0	-1.32	-0.043	12.7	1993.9	0.6
GR-540	930623	WP	2.62	15.3	0.22	2.61	6.16	35.9	-1.13	-0.202	15.3	1993.5	0.4
GR-541	930623	WP	43.87	14.9	0.22	2.57	6.20	36.8	-0.18	-0.024	15.3	1993.1	0.4
MT-427	930927	WP	78.93	22.9	0.20	2.45	5.42	20.0	43.02	-0.508	36.3	1985.5	0.3
MT-425	930927	WP	11.14	17.8*	0.9*	2.43	5.78	28.0	10.86	-0.085	21.7	1990.2	0.3
MT-428	930928	WP	20.75	18.0	0.22	2.20	5.31	17.5	7.05	0.108	20.5	1991.5	0.3
MT-436	930928	WP	70.22	19.5	0.11	2.90	7.14	58.1	31.85	-0.078	32.6	1984.6	0.3
GR-542	930929	WP	17.54	15.1	0.24	2.34	5.62	24.5	1.05	<-0.001	15.8	1992.9	0.4
MT-238	940819	WP	0	14.7	0.09	2.06	4.79	6.10	-0.48	-0.024	15.0	1994.2	0.3
MT-244	940819	WP	38.04	22.9	0.12	2.66	6.08	34.6	71.78	-0.441	47.6	1981.6	0.3
GR-299	940822	WP	0	14.2	0.09	2.33	5.16	14.5	2.69	-0.411	16.4	1993.3	0.4
GR-256	940822	WP	49.04	10.0	0.07	2.41	6.08	33.9	174.3	0.215	69.0	1960.1	0.4
GR-318	940823	WP	26.69	15.3	0.10	2.36	5.37	19.2	12.27	-0.304	19.4	1990.5	0.3

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	Δ ^4He[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
Radiogenic helium correction required for age estimate													
MT-421	930930	MI	107.64	25.2	0.21	2.77	10.6	134	-17.20	3.72	35.6	1987.6	0.6
MT-408	931006	MI	18.21	19.7*	0.9*	2.21	7.29	61.3	-9.72	2.06	27.4	1988.0	0.6
MT-409	931006	MI	132.29	28.5	0.20	2.64	15.6	244	-19.72	9.10	61.1	1980.2	0.5
MT-400	931006	MI	21.95	21.0	0.24	2.30	6.46	43.1	23.78	0.971	34.3	1984.3	0.6
MT-401	931006	MI	91.79	29.9	0.16	2.05	21.4	373	-30.58	16.6	83.8	1975.4	0.4
MT-346	931007	MI	35.33	19.9	0.30	2.41	6.26	38.6	21.78	0.459	30.4	1986.2	0.6
MT-351	931007	MI	17.52	29.2	0.18	2.23	6.27	38.9	154.2	0.989	88.8	1973.9	0.4
MT-352	931007	MI	79.71	37.8 34.9*	0.52 1.3*	2.53	21.9	384	28.62	15.7	158.1	1968.2	0.4
MT-407	931008	MI	81.50	23.9	0.34	2.52	9.18	103	27.46	3.04	54.8	1979.0	0.5
MT-353	931008	MI	5.14	14.3	0.21	1.91	4.65	2.92	2.28	0.278	16.8	1990.9	0.7
MT-354	931008	MI	120.79	19.6	0.14	2.62	17.7	291	-29.21	11.2	52.1	1976.3	0.6
MT-343	940830	MI	85.65	22.9	0.25	2.69	7.98	76.6	17.14	1.37	38.3	1985.5	0.6
MT-345	940830	MI	91.04	32.9	0.15	2.41	17.7	292	28.4	11.9	125.4	1970.6	0.4
MT-360	940831	MI	50.66	16.1	0.10	2.61	7.15	58.3	15.51	0.756	26.7	1985.6	0.7
MT-375	940901	MI	25.88	19.2	0.13	2.44	9.63	113	-12.95	3.74	32.9	1985.1	0.8
MT-405	940901	MI	77.15	11.5	0.08	2.82	14.3	216	-15.02	7.87	42.5	1971.2	0.7
MT-414	940902	MI	26.26	12.3	0.19	4.12	11.0	143	-2.04	0.226	12.7	1994.2	2.1
MT-307	930810	MO	25.79	61.6	0.83	2.07	7.31	61.5	138.4	2.49	131.9	1980.1	0.3
MT-944	930810	MO	11.6	60.3*	2.2*	2.65	6.84	50.9	23.32	0.350	71.5	1990.6	0.3

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	Δ ^4He[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
MT-328	940802	MO	5.39	114.3	0.40	2.47	6.36	40.4	115.4	0.392	157.7	1988.9	0.2
MT-323	940802	MO	10.15	84.6	0.31	2.43	6.37	40.7	108.8	0.506	126.3	1987.5	0.2
MT-302	930811	RE	141.20	58.6	0.79	4.35	20.5	353	28.17	9.13	140.6	1978.0	0.5
MT-303	930811	RE	57.58	28.1 30.4*	0.39 1.5*	3.89	10.3	128	35.79	0.257	50.5	1983.2	0.7
MT-68	930813	RE	98.41	63.8 55.8*	0.33 1.9*	3.06	13.1	189	91.25	5.38	159.8	1977.2	0.4
MT-311	930813	RE	31.26	22.8	0.32	1.99	5.36	19.2	100.77	0.753	57.3	1977.1	0.5
MT-305	930813	RE	17.35	32.5	0.46	2.24	6.03	33.6	65.74	0.723	58.9	1983.0	0.4
MT-288	930816	RE	52.13	20.1 19.5*	0.11 0.9*	2.49	7.54	67.0	1.94	1.51	29.5	1986.8	0.6
MT-301	930817	RE	58.13	28.5	0.39	3.27	8.76	93.6	38.96	0.486	50.5	1983.4	0.6
MT-299	930819	RE	25.83	29.3	0.40	1.94	4.78	5.65	0.05	0.323	31.5	1992.4	0.4
GR-317	930621	WP	112.77	8.4 7.6*	0.05 0.6*	2.20	12.7	187	-19.59	7.37	34.8	1968.0	0.7
GR-316	930621	WP	40.47	15.8	0.19	1.91	4.87	8.17	-5.75	0.475	17.2	1992.0	0.7
GR-334	930622	WP	131.97	41.4	0.56	2.44	10.4	130	186.9	4.47	173.9	1967.8	0.4
GR-333	930622	WP	12.18	14.4	0.21	2.05	5.03	11.4	4.90	0.256	17.5	1990.0	0.7
GR-324	930622	WP	111.24	0.7 0.5*	0.04 0.6*	2.60	26.7	491	-72.91	20.3	2.9	1968.9	7.7
GR-323	930622	WP	38.52	17.5	0.25	2.18	8.97	98.7	30.01	3.83	53.7	1973.5	0.6
MT-291	930817	WP	61.66	17.8	0.25	2.10	10.4	130	-41.76	5.46	23.7	1988.6	0.6

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	Δ ^4He[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
MT-429	930928	WP	106.21	25.2 21.7*	0.13 1.0*	2.46	55.8	1134	-68.62	49.8	82.2	1972.6	0.6
MT-435	930928	WP	21.84	15.8	0.11	1.97	4.87	7.76	-1.05	0.320	17.7	1991.8	0.7
MT-430	930928	WP	4.07	17.1	0.21	1.91	4.64	2.80	1.32	0.288	19.5	1991.5	0.6
MT-434	930929	WP	83.75	38.2*	1.6*	2.77	7.93	75.6	265.2	1.07	158.2	1966.7	0.5
GR-543	930929	WP	115.97	10.3	0.16	2.56	15.4	241	-39.01	9.18	26.9	1976.5	0.9
GR-544	930930	WP	22.57	19.9	0.14	2.16	5.78	28.0	40.52	0.698	37.1	1982.6	0.5
GR-545	930930	WP	97.61	1.5	0.01	2.50	22.7	403	-67.97	16.6	6.1	1968.2	3.4
GR-419[e]	940817	WP	115.46	1.0	0.03	2.48	26.6	489	-71.33	20.7	7.4	1958.7	3.1
GR-420	940817	WP	78.52	2.5	0.04	2.48	31.7	602	-71.64	25.7	15.6	1961.8	1.8
GR-421	940817	WP	47.55	19.6	0.11	2.40	7.64	69.2	42.81	1.87	48.3	1978.5	0.5
GR-416	940818	WP	48.29	20.4	0.11	2.39	7.07	56.8	45.76	1.31	45.9	1980.2	0.5
GR-415[e]	940818	WP	92.02	0.5	0.01	2.47	26.1	478	-70.7	20.2	7.1	1945.2	3.2
GR-414[e]	940818	WP	140.28	0.3	0.02	2.48	23.9	429	-71.37	17.9	2.6	1953.7	8.0
GR-216	940818	WP	21.08	29.2	0.13	2.45	6.35	40.8	161.8	0.438	89.2	1974.7	0.4
MT-153	940819	WP	55.70	17.3	0.10	2.67	9.47	110	-4.16	2.91	31.3	1984.1	0.7
MT-152	940819	WP	1.08	23.0	0.14	2.79	7.90	75.1	13.07	0.988	34.5	1987.4	0.8
GR-439	940822	WP	70.45	17.2	0.10	2.47	8.76	94.4	53.2	2.77	58.8	1972.8	0.5
GR-319	940823	WP	130.26	11.2	0.07	2.43	10.2	126	-34.0	4.31	15.7	1988.7	1.0
GR-321	940824	WP	32.76	20.8	0.10	2.42	6.62	46.6	81.66	10.8	55.5	1977.2	0.5
GR-322	940824	WP	133.82	26.5	0.13	2.48	23.4	418	-13.83	17.4	102.9	1970.4	0.5

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	$\Delta\,^4He$[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
Radiogenic helium concentration too high for age estimate													
MT-324	940803	MO	64.58	15.0	0.09	2.45	3,490	76,891	-94.46	3,480	--	--	--
MT-49	930812	RE	203.2	2.3	0.02	3.42	79.1	1,648	-90.52	70.5	--	--	--
Samples affected by gas fractionation													
MT-355[e]	940831	MI	16.09	14.0	0.09	3.07	7.05	56.2	-1.84	-0.638	--	--	--
MT-366	940902	MI	10.25	13.8	0.19	3.00	6.72	48.8	-2.7	-0.800	--	--	--
MT-321	940719	MO	40.20	17.5	0.09	2.43	6.10	34.6	-7.66	0.223	--	--	--
GR-326	940823	WP	3.96	15.4	0.20	2.44	8.26	83.3	-33.81	2.37	--	--	--
Helium sample lost during extraction or analysis													
MT-411	931006	MI	104.18	1.9 1.6*	0.02 0.5*	--	--	--	--	--	--	--	--
MT-410	931006	MI	23.75	23.0 22.9*	0.33 1.0*	--	--	--	--	--	--	--	--
MT-347	931007	MI	112.61	13.4 13.5*	0.20 0.5*	--	--	--	--	--	--	--	--
MT-349	931007	MI	31.52	17.3	0.09	--	--	--	--	--	--	--	--
MT-309	930810	MO	62.92	73.1	0.98	--	--	--	--	--	--	--	--
MT-330	940804	MO	15.96	68.2	0.27	--	--	--	--	--	--	--	--
MT-283	930623	RE	40.97	22.6	0.12	--	--	--	--	--	--	--	--
MT-282	930624	RE	26.15	20.8	0.30	--	--	--	--	--	--	--	--
MT-281	930624	RE	10.19	20.4	0.29	--	--	--	--	--	--	--	--
MT-297	930624	RE	79.41	35.1	0.27	--	--	--	--	--	--	--	--

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	Δ ^4He[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
MT-1022	930809	RE	110.47	35.0	0.18	--	--	--	--	--	--	--	--
MT-426	930818	RE	110.45	18.0	0.32	--	--	--	--	--	--	--	--
MT-431	930928	WP	112.56	35.8	0.19	--	--	--	--	--	--	--	--
MT-433	930929	WP	9.33	15.3	0.23	--	--	--	--	--	--	--	--
MT-312	940718	MO	15.13	15.6	0.10	--	--	--	--	--	--	--	--
MT-333	940804	MO	139.77	63.8	0.30	--	--	--	--	--	--	--	--
GR-426	940823	WP	0	13.1	0.09	--	--	--	--	--	--	--	--
						Tritium concentration too high for tritium/helium analysis							
MT-316	940718	MO	87.92	320**	--	--	--	--	--	--	--	--	--
MT-315	940718	MO	74.24	280**	--	--	--	--	--	--	--	--	--
MT-314	940718	MO	45.11	270**	--	--	--	--	--	--	--	--	--
MT-329	940729	MO	64.83	2900**	--	--	--	--	--	--	--	--	--
MT-327	940801	MO	99.21	1300**	--	--	--	--	--	--	--	--	--
MT-331	940804	MO	41.69	200**	--	--	--	--	--	--	--	--	--
MT-332	940808	MO	81.74	670**	--	--	--	--	--	--	--	--	--
MT-341	940809	MO	37.4	1500**	--	--	--	--	--	--	--	--	--
MT-340	940809	MO	0	1200**	--	--	--	--	--	--	--	--	--
MT-335	940809	MO	13.26	500**	--	--	--	--	--	--	--	--	--
MT-337	940810	MO	23.68	1500**	--	--	--	--	--	--	--	--	--
MT-338	940810	MO	8.73	670**	--	--	--	--	--	--	--	--	--
MT-317	940811	MO	66.88	220**	--	--	--	--	--	--	--	--	--

Table 7. Concentrations of tritium (^3H), neon (Ne), and helium (^4He) and ^3H-^3He recharge year for water samples from the buried-valley aquifer near Dayton, Ohio—Continued

[All tritium, neon, and helium concentrations and related data are from Shapiro and others (1998) except where noted. MI, Miami and North Miami well fields area; MO, Mound Plant area; WP, Wright-Patterson Air Force Base-Mad River well field area; RE, Reconnaissance wells; ft, feet; TU, tritium units; cc STP/g H_2O, cubic centimeter at standard temperature and pressure per gram water; %, percent; --, no data available or not determined]

Well name	Date	Group code	Saturated thickness[a] (ft)	[^3H] (TU)	[^3H] error (TU)	Ne_{total} (10^{-7} cc STP/g H_2O)	$^4He_{total}$ (10^{-8} cc STP/g H_2O)	$\Delta\,^4He$[b] (%)	δ^3He[c] (%)	$^4He_{rad}$[d] (10^{-8} cc STP/ g H_2O)	^3H+$^3He_{trit}$[d] (TU)	^3H-^3He recharge year[d]	^3H-^3He age error (years)
Duplicate tritium sample-helium isotope sample not analyzed													
GR-323	940824	WP	38.15	17.7	0.09	--	--	--	--	--	--	--	--
GR-324	940824	WP	110.71	0.7	0.03	--	--	--	--	--	--	--	--

[a] Saturated thickness is distance from water table to top of screened interval. For wells where depth to top of screen minus depth to water table is negative (for example, water table is within screened interval),7 the saturated thickness is reported as zero.

[b] $\Delta\,^4He$ is computed percent saturation of ^4He relative to air-water equilibrium value for temperature at assumed recharge temperature of 10°C.

[c] $\delta\,^3He$ is the percent deviation the $^3He/^4He$ ratio of a sample from the $^3He/^4He$ ratio of helium in air, where $\delta\,^3He = [(R_{sample} - R_{air})/R_{air}] \times 100$ and $R_{air} = 1.38\times10^{-6}$ (Clarke and others, 1976).

[d] All data and computed values shown for well MT-404 are average values from four consecutive samples collected at 5-foot intervals at depths of 25, 30, 35, and 40 feet below land surface. Note that well MT-404 is screened from 25 to 45 feet below land surface and that samples were collected at very low pumping rates (100 mL/min) in an effort to prevent mixing of waters from different parts of the screen. However, water-quality data indicate that mixing did occur. See Shapiro and others (1998) for complete data set.

[e] All data and computed values shown for these wells (except for tritium data) are average of original and replicate sample analyses.

* Tritium data for duplicate samples analyzed by the U.S. Geological Survey Tritium Laboratory in Menlo Park, Calif.

** Tritium data from Alec Bray (E.G.&G. Mound Applied Technologies Corporation, written commun., 1994).