Prepared in cooperation with the
West Virginia Bureau for Public Health Office of Environmental Health Services

Relation of Chlorofluorocarbon Ground-Water Age Dates to Water Quality in Aquifers of West Virginia

Scientific Investigations Report 2006-5221

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

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By Kurt J. McCoy and Mark D. Kozar

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Conversion Factors, Datums, and Abbreviated Units of Measure

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3,785	milliliters (mL)
	Flow rate	
gallon per minute (gal/min)	3.785	liter per minute (L/min)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Mass	
picogram (pg)	1×10^{-12}	gram (g)

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

°F=(1.8×°C)+32

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

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

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

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

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/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 chlorofluorcarbons 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).

Relation of Chlorofluorocarbon Ground-Water Age Dates to Water Quality in Aquifers of West Virginia

By Kurt J. McCoy and Mark D. Kozar

Abstract

The average apparent age of ground water in fractured-bedrock aquifers in West Virginia was determined using chlorofluorocarbon (CFC) dating methods. Since the introduction of CFC gases as refrigerants in the late 1930s, atmospheric concentrations have increased until production ceased in the mid-1990s. CFC dating methods are based on production records that date to the early 1940s, and the preservation of atmospheric CFC concentrations in ground water at the time of recharge. As part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) and Ambient Ground-Water Monitoring Network (AGN) programs in West Virginia from 1997 to 2005, 80 samples from the Appalachian Plateaus Physiographic Province, 27 samples from the Valley and Ridge Physiographic Province, and 5 samples from the Ohio River alluvial aquifers were collected to estimate ground-water ages in aquifers of West Virginia.

Apparent CFC ages of water samples from West Virginia aquifers ranged from 5.8 to 56 years. In the Appalachian Plateaus, topographically driven ground-water flow is evident from apparent ages of water samples from hilltop, hillside, and valley settings (median apparent ages of 12, 14, and 25 years, respectively). Topographic setting was the only factor that was found to be related to apparent ground-water age in the Plateaus at the scale of this study. Similar relations were not found in Valley and Ridge aquifers, indicating that other factors such as bedding or geologic structure may serve larger roles in controlling ground-water flow in that physiographic province.

Degradation of CFCs was common in samples collected from methanogenic/anoxic aquifers in the Appalachian Plateaus and suboxic to anoxic aquifers in the Valley and Ridge. CFC contamination was most common in Ohio River alluvial aquifers and carbonate units of the Valley and Ridge, indicating that these highly transmissive surficial aquifers are the most vulnerable to water-quality degradation and may contain wastewater from domestic or industrial sources with CFC concentrations greater than modern atmospheric levels. However, based on a lack of detections of the volatile organic compounds analyzed for in most of the water samples collected for this and similar USGS investigations, ground-water resources of West Virginia used for public and private consumption do not appear to be routinely affected by anthropogenic activities despite their young apparent age.

Introduction

Shallow fractured-bedrock aquifers of the Appalachian Plateaus and Valley and Ridge Physiographic Provinces are common sources of water supply for most rural homeowners and some municipalities throughout the State of West Virginia (fig. 1). With additional supplies withdrawn from alluvial terraces along the Ohio River in West Virginia, ground water accounts for approximately 33 percent of the State's consumptive water use (Wheeler, 1995). Because ground water is a major source of potable water for West Virginia residents, an understanding of the potential for industrial or domestic waste contaminants to reach subsurface water supplies is essential. To address this issue, the U.S. Geological Survey (USGS) has conducted several assessments of ground-water quality and availability at the large (greater than 1,000 mi^2) watershed or county-wide scale since the 1940s (Schwietering, 1981; Mathes and others, 1998). As a result, conceptualization of ground-water flow in West Virginia's aquifers has been well documented; however, less attention has been focused on the age of ground water and the applications that such data may provide for protecting the State's fractured-bedrock and alluvial aquifers.

Like all other states, West Virginia was required by the 1996 amendments to the Safe Drinking Water Act to adopt a Source Water Assessment and Protection (SWAP) program to assess the source of water used for surface- and ground-water public supplies. The goal of the SWAP program is to prevent degradation of source waters and ensure the availability of safe water in sufficient quantity to users. The mandate outlined in Section 1428(e) of the Safe Drinking Water Act is enforced by State and Federal regulatory agencies and requires public ground-water suppliers to delineate recharge areas through which contaminants are reasonably likely to move toward and reach a well or well field. Many of the recharge and wellhead protection areas (WHPAs) are delineated by establishing a generalized radius of influence for each well using simplified

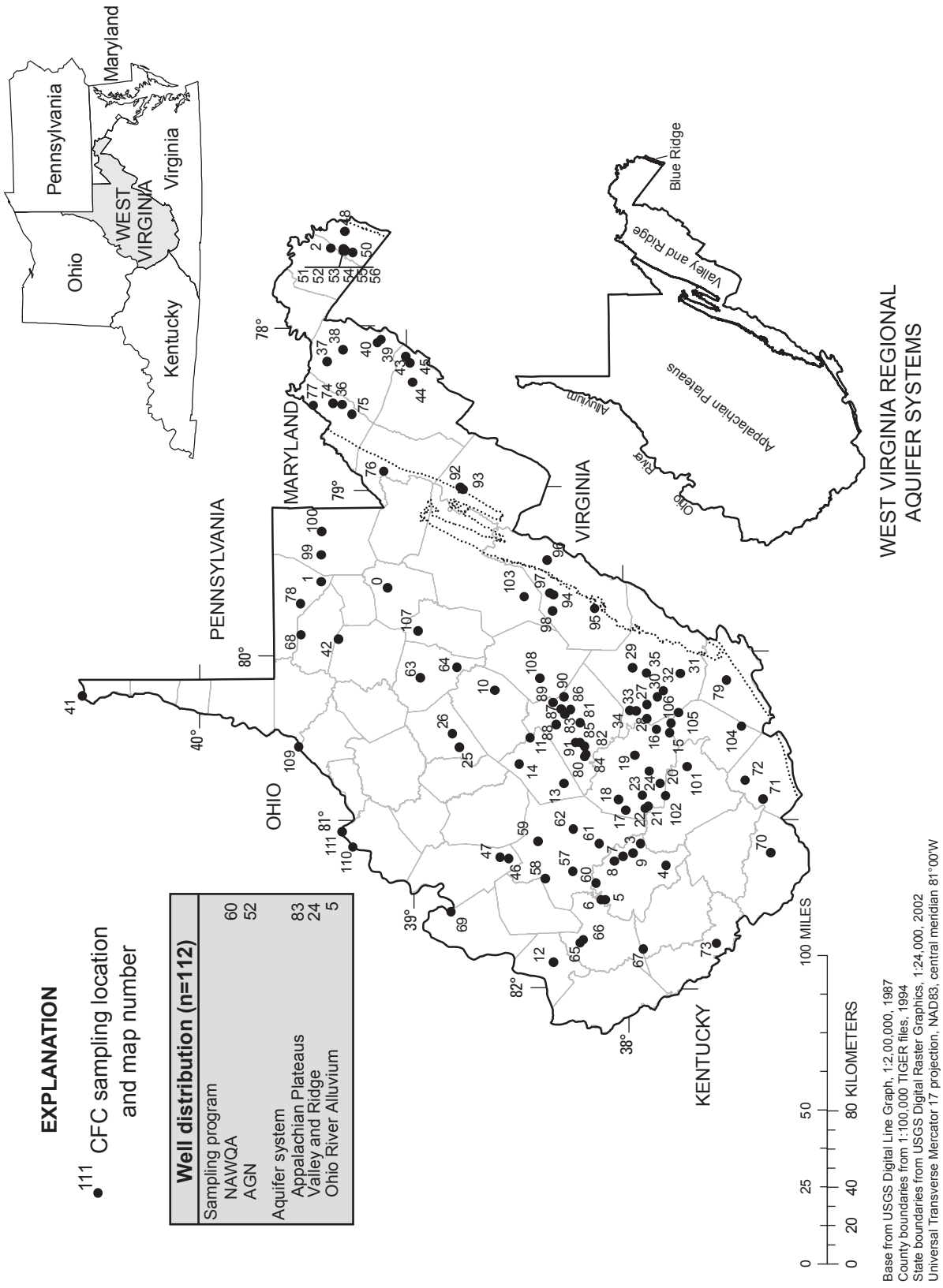

Figure 1. Regional aquifer systems and chlorofluorocarbon (CFC) sampling locations in West Virginia, 1997-2005. (NAWQA, National Water-Quality Assessment Program; AGN, Ambient Ground-Water Network)

analytical ground-water flow models. Although such simplified analytical models provide a first approximation of potential WHPAs, they typically fail to accurately describe ground-water flow in complex hydrogeologic settings and quantify the potential for anthropogenic disturbance of an aquifer. Ground-water resource managers can benefit from knowing the time required for ground water to flow from recharge areas to wells or springs used for drinking-water supplies. Previous attempts have been made to estimate rates of ground-water flow on the basis of hydraulic properties of respective aquifers; however, the complexity of fractured-rock ground-water systems typically resulted in rough estimates at best.

Chlorofluorocarbons (CFCs) can be used as environmental tracers to assess the residence time, or apparent age, of ground water recharged after about 1940. The term "apparent age" is defined as the approximate time elapsed since a water sample was isolated from air in the unsaturated zone (Plummer and Busenberg, 2000). Apparent age of a ground-water sample is a model-calculated approximation based on the measured concentrations of an environmental tracer, and its validity increases with the number of tracers used. According to Plummer and Busenberg (2000), the apparent ages must be determined with consideration of chemical sorption, biodegradation, and physical mixing processes that can alter age interpretations. Understanding these processes and classifying an aquifer in terms of vulnerability often require the multiple-tracer approach. In two studies done in the neighboring states of Ohio (Rowe and others, 1999) and Virginia (Nelms and others, 2003), the multiple-tracer approach was used to determine and assess temporal trends in ground-water quality. Nelms and others (2003) used a threshold value for CFC concentrations of 5 picograms per kilogram as a guideline for establishing aquifer vulnerability. Sites exceeding this threshold value were deemed vulnerable to anthropogenic affects.

To improve the understanding of West Virginia's aquifers, the USGS in cooperation with the West Virginia Bureau for Public Health collected water samples from 112 wells across the State and analyzed them for CFCs and other water-quality constituents. The CFC analyses were used to determine the apparent ground-water age of the State's public and domestic supplies using a single-tracer approach. In the absence of data from multiple age-dating tracers, the conclusions of previous studies in similar hydrogeologic settings are extremely useful in establishing guidelines for West Virginia. The data for the present study were collected as part of routine USGS National Water-Quality Assessment (NAWQA) and the USGS and West Virginia Department of Environmental Protection cooperative Ambient Ground-Water Monitoring Network (AGN) sampling programs in West Virginia from 1997 to 2005. Further evaluation of selected water-quality constituents provided additional validation of apparent CFC ground-water ages by helping to determine whether the samples contained anthropogenic signatures of young water (less than 60 years of age).

Purpose and Scope

This report describes results of CFC and selected water-quality-constituent analyses of 112 ground-water samples collected as part of the NAWQA and AGN programs in West Virginia from 1997 to 2005. The intent of the analysis was to determine the apparent ground-water age, with a single environmental tracer approach, of selected public and domestic ground-water supplies throughout West Virginia. Comparisons of selected water-quality-constituent concentrations and apparent ground-water ages are used to assess the effect of anthropogenic activity on those supplies. CFC concentrations and resulting apparent ages of water samples from three aquifer systems in West Virginia are also compared to assess regional variance.

Chlorofluorocarbon Age Dating

CFCs are stable, volatile organic compounds (VOCs) commonly used as refrigerants and solvents since their development in the late 1930s. CFC production steadily increased such that measurable atmospheric concentrations were prevalent by 1940. Also known as freons, CFCs are detectable at very low concentrations using purge-and-trap gas chromatography with an electron-capture detector (Busenberg and Plummer, 1992). Three CFC compounds, trichlorofluoromethane (CFC-11), dichlorodifluoromethane (CFC-12), and trichlorotrifluoroethane (CFC-113), are commonly used as environmental tracers in ground-water investigations. Historical curves of atmospheric concentrations of these three compounds have been reconstructed on the basis of production records (Chemical Manufacturers Association, 1983) and rates of release to the atmosphere (McCarthy and others, 1977; Gamlen and others, 1986; Szabo and others, 1996) (fig. 2). Because CFCs are relatively stable in an aquifer under ideal conditions, ground water preserves a record of the prevailing CFC atmospheric concentrations at the time infiltration reaches the water table. Therefore, the apparent CFC recharge date of the water sample is computed by comparing calculated partial pressures of CFCs in solubility equilibrium with the sample to historical concentrations of CFCs in the North American atmosphere from about 1940 to the present (Busenberg and Plummer, 1992).

Because CFCs were used as refrigerants and solvents in industrial and domestic applications, contamination of ground water with CFCs, in terms of age-dating technique, is common where such near-surface or atmospheric sources are prevalent. If a well has been contaminated by one CFC compound, concentrations of the other CFCs that are within the dating range typically can be used to estimate the apparent ground-water age. Gross contamination is readily recognized because calculated concentrations of a particular CFC in equilibrium with the atmosphere will be much larger than the highest concentration of the CFC used in developing the air-concentration curves in figure 2. On the other hand, trace-level contamina-

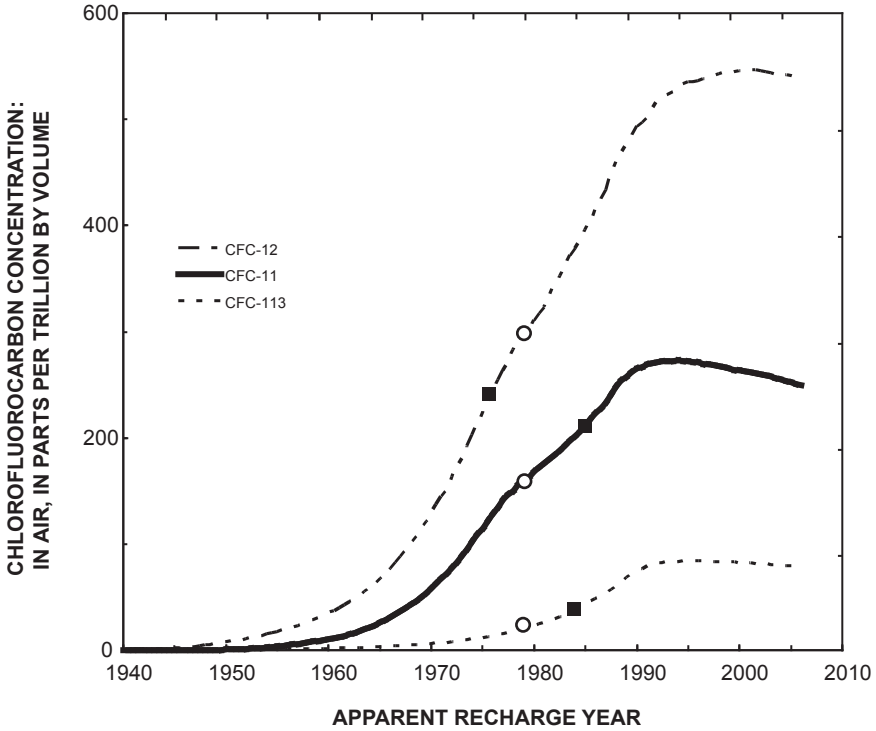

Figure 2. Concentrations of chlorofluorocarbons CFC-11, CFC-12, and CFC-113 in the northern troposphere. Piston flow is indicated by the agreement among apparent CFC recharge years determined from concentrations for all three compounds (open circles). Discordance of one or more CFC concentrations indicative of binary mixtures is shown by the filled squares. (Modified from Plummer and Busenberg, 2000).

tion can easily be overlooked; therefore, CFC dating results are considered to be minimum ages (Rowe and others, 1999).

Ground-water age dating with CFCs is based on partitioning of CFCs between the gas phase and the liquid phase at the base of the unsaturated zone. This partitioning is governed by Henry's Law of solubility and requires some knowledge of ground-water salinity and recharge temperatures (Busenberg and Plummer, 1992). Detailed methodology of CFC dating can be found in Busenberg and Plummer (1992), Plummer and others (1993), and Plummer and Busenberg (2000).

For a 2 °C error in estimated recharge temperature, apparent CFC ages for ground waters that are more than 30, 20 to 30, 10 to 20, and less than 10 years old will vary by ± 0, 1, 2, and 2 to 3 years, respectively (Busenberg and Plummer, 1992). Excess air is another factor that can affect apparent CFC age determinations for ground water because it can increase the dissolved-gas and CFC concentrations in a water sample, thus causing ground-water age to appear younger than its actual age (Heaton, 1981). However, extensive sampling of ground water throughout the United States indicates that excess-air content rarely exceeds 5 cm^3/kg H_2O and does not usually affect CFC age determinations (Busenberg and Plummer, 1992).

Initially, CFC recharge dates are evaluated using piston, or unmixed flow models. Piston flow models represent a slug of water moving from recharge to discharge zones along a defined flow path without dispersive mixing in the direction of flow (Busenberg and Plummer, 1992). These models are based on CFC concentration alignment in atmospheric growth curves (fig. 2) and the assumption that infiltrating waters are in equilibrium with the troposphere at the time they reach the saturated zone. The assumption is generally valid in areas where the unsaturated thickness does not exceed 30 ft (Cook and Solomon, 1995). If one or more of the CFC concentrations are not in concordance, then the sample either is contaminated, is degraded, or can be described as a binary mixture of young and old (pre-CFC) fractions (Plummer and Busenberg, 2000). In the case of binary mixtures, one of the CFCs appears to give the sample a younger age than that indicated by a piston flow model. The ratio of any two CFCs (CFC-11/CFC-12, CFC-11/CFC-113, and CFC-113/CFC-12) can be used to determine apparent young age and young-age fractions of uncontaminated binary mixtures.

Interpreting mixtures in methanogenic environments is difficult because CFC-11 and CFC-113 are typically completely degraded, whereas CFC-12 is only partially degraded (Happell and others, 2003; Böhlke and Krantz, 2003). In these reducing environments where CFCs are degraded primarily by dechlorination reactions that produce hydrochlorofluorocarbons (HCFCs), the CFC method results in apparent ages that are older than the actual age of the sample. Measurement of other environmental tracer compounds is often helpful to support CFC age interpretations in methanogenic environments.

Aquifer Systems of West Virginia

West Virginia's aquifers can be divided into three regional systems on the basis of physiographic province and aquifer type. The locations of the Appalachian Plateaus, Valley and Ridge, and Ohio River alluvial aquifer systems are shown in figure 1. Despite similar lithologic characteristics, each system possesses different structural and topographic characteristics that provide a unique opportunity to compare apparent ground-water ages at the statewide scale.

Appalachian Plateaus Aquifer System

The Appalachian Plateaus Physiographic Province of West Virginia covers an area of 19,960 mi^2 and is underlain by an aquifer system of nearly horizontal, consolidated sedimentary rocks. The bedrock aquifer system is typically composed of alternating layers of sandstone, siltstone, shale, limestone, and coal. Ground-water flow in these aquifers is primarily through fractures, bedding-plane separations, and, in limestone or dolomite rock, through solution openings (Ferrell, 1988). Recharge occurs primarily in topographically high areas (ridges) and flows laterally and downward through shallow fractures in the bedrock (Harlow and LeCain, 1993). Streams have eroded bedrock to form steep hills and deeply incised valleys. The result is a dendritic surface drainage pattern with coincident, well-defined surface- and ground-water drainage divides (Kozar and Brown, 1995).

Conceptual models of ground-water flow in the Appalachian Plateaus have been presented by Wyrick and Borchers (1981), Harlow and LeCain (1993), and Sheets and Kozar (2000). In the model of Wyrick and Borchers, ground-water flow in the Appalachian Plateaus occurs primarily in bedding-plane separations beneath valley floors and in nearly vertical and horizontal stress-relief fractures along valley walls. Near-surface flow in valley and hillside settings is a result of a network of fractures formed by the unloading of compressional stresses. Expanding on the work of Wyrick and Borchers, Sheets and Kozar (2000) presented a model of topographically driven ground-water flow that incorporated apparent CFC ages for the southern Appalachian Plateaus in West Virginia. Using packer tests, Harlow and LeCain (1993) found ground-water flow in coal seams of the Appalachian Plateaus to be a result of higher hydraulic conductivity of the strata in the horizontal direction, rather than a result of vertical connections with adjacent sandstone, siltstone, or shale layers. Where vertical and horizontal hydraulic conductivity are variable, ground water flows in a stair-step pattern, alternating among vertical joints, faults, and fractures and horizontal bedding-plane separations.

Valley and Ridge Aquifer System

The Valley and Ridge Physiographic Province of West Virginia covers an area of 4,200 mi^2 and is underlain by an aquifer system of sedimentary rocks that have been complexly folded and faulted into long, northeast-southwest-trending mountains and valleys. Elevations range from about 247 ft above NGVD of 1929 where the Shenandoah River joins the Potomac River to near 4,800 ft above NGVD of 1929 along resistant sandstone ridges in Pocahontas County. Surface drainage patterns generally reflect the occurrence of less resistant siltstone, shale, and carbonate units in valleys, and form right-angle intersections in a rectangular or trellis drainage-pattern network.

Ground water in Valley and Ridge aquifers flows mostly along fractures and bedding planes in all rock types and in solution conduits that were formed in the carbonate rocks after deposition (Trapp and Horn, 1997); primary porosity is low. The local flow systems are typically limited to within a few hundred feet of the surface and receive recharge through the regolith on the tops or flanks of ridges. In some cases, deep circulation (>1,000 ft below land surface) and geothermal heating of waters has been noted in areas adjacent to faults (Hobba and others, 1979). Faults, cleavage, and high-angle bedding planes form structural and lithologic barriers to cross-strike flow. Commonly, ground water is forced along strike, seemingly parallel to gradient, until flow is permitted to move across structural and lithologic barriers along a complex network of joints, cleavage, and fractures.

Ohio River Alluvial Aquifer System

The Ohio River alluvial aquifer system consists of a heterogeneous sequence of unconsolidated sediments ranging from gravels to clays overlying Pleistocene sands and gravels. Below the Pleistocene deposits and along valley walls, Lower Permian- and Pennsylvanian-age bedrock of the Ohio River Valley consists of cyclic groups of interbedded shales, sandstones, limestones, clays, and coals (Cross and Schemel, 1956). Generally, the alluvium thickens away from the valley walls and near the mouths of tributary streams.

Induced infiltration is likely where the aquifer is pumped close to the Ohio River, although local heterogeneity of river-bottom sediments may reduce the connection (Jeffords, 1945; Mathes and others, 1995). Jeffords (1945) found a large proportion of recharge at high stage is derived from the Ohio River, a conclusion later supported by Kozar and McCoy (2004). During normal base-flow conditions, however, hydraulic gradients typically indicate flow in the direction of the river. Tributaries may provide additional recharge as they flow across gravel deltas near their mouths on the main channel (Mathes and others, 1995).

Methods of Ground-Water Sample Collection and Analysis

Sample wells were selected on the basis of the following criteria: (1) age of well typically less than 25 years, (2) well casing not rusted or allowing surface contaminants to enter well bore, (3) yield minimum of 5 gallons per minute, (4) adequate plumbing system, and (5) submersible pump in place. Well and site characteristics including well depth, water level, and casing length were obtained during a site visit, from drilling logs, or from well-owner records (where available). The minimum parameters collected at each site were well depth, length of casing, location (latitude/longitude), and contributing geologic unit. Well information is provided in table 1. Sample collection and analytical methods are presented in the following sections.

Water-Quality Constituents

Ground water from 112 CFC sampling locations in West Virginia (fig. 1) was analyzed for trace elements, nutrients, pesticides, VOCs, and major ions. Approximately half of the ground-water samples were from rural, private-household wells; the remainder were from production wells.

All wells were fitted with preexisting submersible pumps and were purged daily through routine use by the well owner or utility operator. Water samples were collected after additional rigorous purging of the well, in most instances of an amount equal to a minimum of at least three well volumes. Dissolved-oxygen concentration, pH, specific conductance, water temperature, turbidity, and redox potential were monitored continuously during purging using a multiparameter water-quality monitor. The discharge line from the wellhead to sample containers was isolated from contact with ambient air. Measurements and samples were taken from spigots located as close to the wellhead as possible, ahead of treatment or filtration systems, and usually from taps on the pressure tanks or frost-free hydrants adjacent to the well. Samples were collected only after the measured field parameters had stabilized according to USGS NAWQA sampling protocols (Koterba and others, 1995). Nelms and Harlow (2003) provide a complete discussion of specific collection procedures and analytical methods for measuring cations, anions, trace elements, and nutrient compounds.

Quality-assurance and quality-control guidelines and protocols described by Koterba and others (1995) were followed to provide representative and accurate water-quality data and to assess sampling and analytical variability. Sheets and Kozar (2000) describe the quality-assurance analyses associated with the data-collection process for the 60 wells sampled as part of NAWQA from 1997 to 1998. For the AGN data set, ground-water samples were collected from 52 wells from 1999 to 2005. Quality-assurance blanks were collected 13 times during the AGN project and analyzed for trace elements, major ions, nutrients, pesticides, VOCs, and dissolved organic carbon. Most constituents were not detected in the blanks; however, calcium (0.02 mg/L) and sodium (0.2 mg/L) were detected in one major-ion blank. Aluminum and iron were each detected in two blanks, at concentrations near the minimum reporting levels of 3 and 2 μg/L, respectively. Dissolved organic carbon was detected in one blank sample at a concentration of 0.4 mg/L. No pesticides or VOCs were detected in any of the blank samples analyzed. No bias in the data set is indicated by the quality-assurance data.

Dissolved Gases

Ground-water samples were collected for analysis for dissolved gases at 100 of the 112 CFC sampling sites to estimate ground-water recharge temperatures and quantities of "excess air." In many aquifers, air bubbles can be entrained in recharge water or percolate along casings, eventually dissolve in the water, and result in the addition of atmospheric gases, known as excess air, to ground water. Samples were collected by placing a silicone rubber discharge tube from the well discharge line into the bottom of a 160-mL glass serum bottle. The 160-mL bottle was then placed in the bottom of a 2-L container and allowed to overflow until completely submerged. While submerged, the bottle was capped with a rubber stopper to prevent gas exchange between the sample and atmosphere. One to four samples were collected at each sampling site.

Concentrations of dissolved N_2, Ar, O_2, CO_2, and CH_4 were measured by gas chromatography at the USGS Dissolved Gas Laboratory in Reston, Virginia. Concentrations of dissolved N_2 and Ar generally agree to within less than 1 percent, and concentrations of O_2, CH_4, and CO_2 agree to within 1 to 2 percent in replicate samples (Busenberg and others, 1998). However, microbial degradation in the sample bottle can cause uncertainties of as much as 20 percent in the results of O_2, CH_4, and CO_2 analyses.

Chlorofluorocarbons

Water samples were collected for CFC analysis in a 62-mL borosilicate glass ampule in the field using an apparatus designed to completely isolate the ampule from atmospheric contamination (Busenberg and Plummer, 1992). The apparatus was connected to sample taps by 0.25-in. refrigeration-grade copper tubing, and both the apparatus and ampule were flushed with ultra-pure nitrogen before the sample was collected. Once the ampule was filled with ground water, it was sealed by fusing the stem with a gas torch. One to five sequential duplicate samples were sent to the USGS CFC laboratory for analysis. Upon receipt by the laboratory, the samples were analyzed for CFCs by use of purge-and-trap gas chromatography with an electron-capture detector (GC/ECD) (Busenberg and Plummer, 1992). Detection limits for CFC-11 and CFC-12 are near 0.3 pg/kg and for CFC-113 are near 1.0 pg/kg (Plummer and Busenberg, 2000).

Chlorofluorocarbon Ground-Water Age Dates

The data collected from the 112 sample wells were used to assess water quality and ground-water age trends in aquifers of West Virginia. The data are summarized in tables 2-4 and are described in the following sections of the report.

Estimates of Recharge Temperature Based on Dissolved-Gas Concentration

For air-equilibrium CFC concentrations in a sample to be calculated it is critical that the temperature of water recharging the aquifer be measured or estimated as accurately as possible from N_2-Ar solubility data (Heaton, 1981). Recharge temperature estimates are calculated by plotting N_2-Ar solubilities at total pressures of 760 mm Hg and excess-air contents of 0 to 20 $cm^3/kg\ H_2O$ against N_2- and Ar-concentration data collected from the CFC sample wells (Weiss, 1970) (fig. 3). Dissolved-gas data for 100 of the CFC sample sites in West Virginia are presented by White and Mathes (2006). Excess-air content ranged from -1.3 to 31.1 $cm^3/kg\ H_2O$. Corresponding recharge temperature estimates ranged from -0.13 to 50 °C, an unlikely range of values. Of the 100 samples, estimates for 90 samples cluster between 5 and 15 °C and most are thought reasonable values given mean annual air temperatures of 9 to 13 °C and elevation ranges of 400 to 4,800 ft above NGVD of 1929 in West Virginia. For the 12 sites without dissolved-gas data and 10 sites without reasonable recharge-temperature estimates, mean annual air temperatures were used (Owenby and others, 1992) and excess-air content was assumed to be 0.0 $cm^3/kg\ H_2O$ (Nelms and Harlow, 2003) (table 2).

Some of the recharge temperatures in excess of mean annual air temperature ranges are thought to be a result of bacterially mediated denitrification. Denitrification can account for excess nitrogen in a sample, and its effects can be removed by extrapolating excess-air content back to zero along a horizontal line equal to the normalized Ar concentration in the sample. This procedure restricts the maximum recharge temperatures of the CFC data set to about 25 °C; however, recharge temperatures greater than 20 °C are unrealistic and indicate that denitrification alone is insufficient in accounting for excess air in all the samples. Recharge estimates outside the upper limits of mean annual temperature ranges and negative excess-air values are more likely the result of uncertainty in recharge elevation, analytical error, or sample degassing (Plummer and others, 1993).

Like the N_2 and Ar data, dissolved-methane concentrations can be used to identify samples for which input parameters into CFC-age calculations need careful consideration. Dissolved methane was detected at 67 of the 100 sites with dissolved-gas data, at concentrations that ranged from 2 x 10^{-4} to 30 mg/L. Methane can be of natural origin in reducing environments or produced from microbial degradation of VOCs. Of those 67 samples containing methane, VOCs were detected in 34 with either the GC/ECD (Shapiro and others, 2003), the gas chromatograph/mass spectrometer (GC/MS) (Ward and others, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005), or both. Thirty of the 34 wells were located in the southern Appalachian Plateaus coalfields. Although all VOC concentrations in wells in this study were below U.S. Environmental Protection Agency (USEPA) maximum contaminant levels, trace detections can provide early warning of potential adverse aquifer conditions (Shapiro and others, 2003).

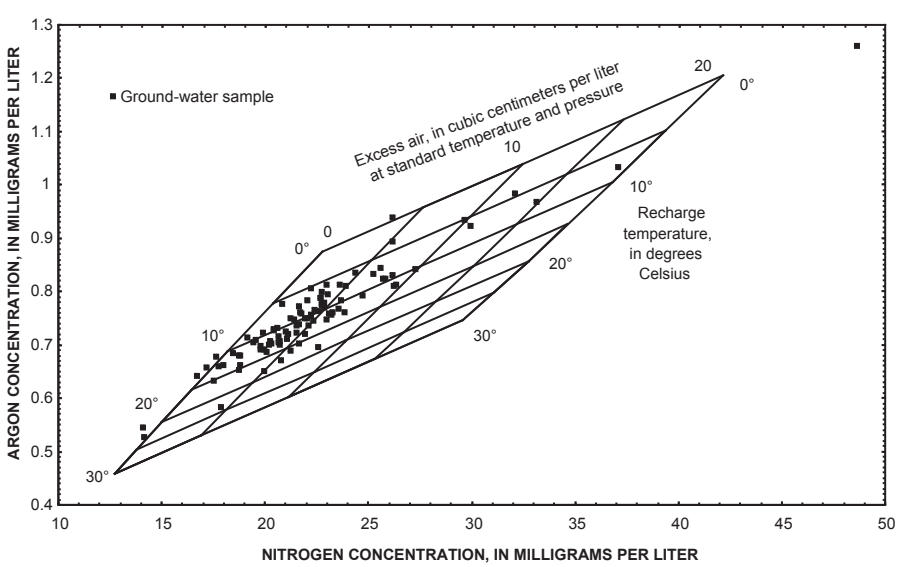

Figure 3. Concentrations of dissolved nitrogen and argon in water samples from aquifers of West Virginia.

Table 4. Percent of water samples from aquifers of West Virginia contaminated with chlorofluorocarbons, by aquifer system.

Aquifer system	Percent of samples contaminated		
	CFC-11	CFC-12	CFC-113
Appalachian Plateaus	3	5	11
Valley and Ridge			
Carbonates	88	88	33
Siliciclastics	0	18	0
Ohio River alluvium	80	80	20

Apparent Ground-Water Ages

CFC concentrations were highly variable and ranged from below the detection limit for all CFC compounds to calculated partial pressures of 5,303, 116,715, and 405 pptv (parts per trillion by volume) of CFC-11, CFC-12, and CFC-113, respectively (table 2). Contamination is evident in samples containing concentrations above maximum partial pressures of 273 (CFC-11), 546 (CFC-12), and 84 (CFC-113) pptv at 10 °C air-water equilibrium, and such samples cannot be used to calculate apparent ages. Contamination can occur from introduction of domestic or industrial waste to the ground water, or from atmospheric sources, and was found in 13, 22, and 12 percent of all the CFC-11, CFC-12, and CFC-113 samples, respectively. Nearly all CFC concentrations from the current study in West Virginia exceeded the 5-pg/kg threshold value established by Nelms and others (2003) for aquifer vulnerability in Virginia.

Variations in CFC concentrations also result from microbial degradation under anoxic or methanogenic conditions. CFC-11 is particularly susceptible to degradation in aquifers of the Appalachian Plateaus, where reducing environments are common. Degradation is suspected when dissolved-oxygen concentrations are lower than about 0.3 mg/L and (or) methane concentrations are higher than about 1 mg/L and can only be quantitatively confirmed by examination of individual chromatograms for degradation by-products. A qualitative confirmation can be obtained by comparing calculated partial pressures of CFC-11 and CFC-12 from each well (fig. 4). Because most of the samples in the data set fall below the envelope of values expected for either model, CFC-11 is considered degraded with respect to CFC-12. As a result, CFC-11 was unsuitable for ground-water age dating in most cases, although single-tracer age interpretations were possible by model design. Degradation of CFC-11 is ascribed to either microbial degradation in samples containing less than 1 mg/L dissolved oxygen or mixing of aerobic and anaerobic waters in the borehole at the time of sampling (Burton and others, 2002).

In a similar comparison, 30 of the CFC-113 and CFC-12 sample mixing ratios plot within the envelope defined by the piston flow and binary mixing models (fig. 5). For the remain-

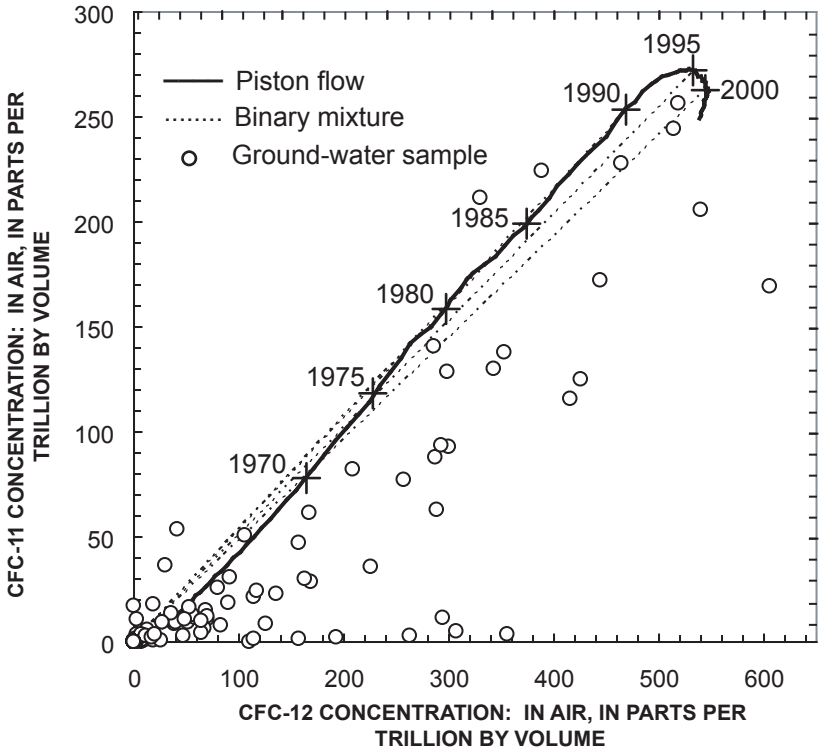

Figure 4. Relation of CFC-11 concentration to CFC-12 concentration with piston-flow model and binary mixing models for water samples from aquifers of West Virginia.

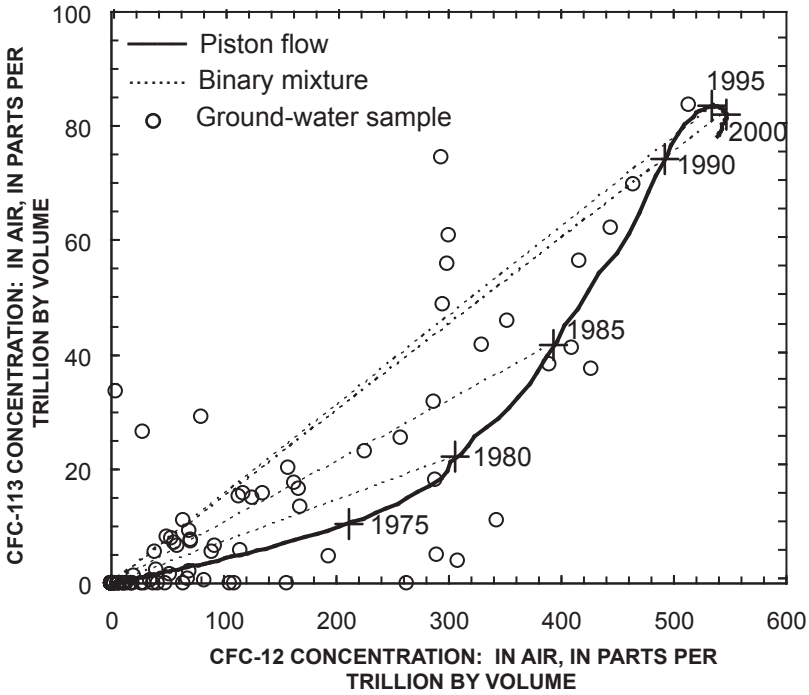

Figure 5. Relation of CFC-113 concentration to CFC-12 concentration with piston-flow model and binary mixing models for water samples from aquifers of West Virginia.

ing samples, a majority of the calculated CFC-113 partial pressures fall below expected model boundaries. This result indicates that CFC-113 has also been degraded by microbial activity or exposure to a reducing environment, albeit to a much lesser degree than CFC-11. CFC-12 and CFC-113 have been shown in prior investigations to be more resistant to degradation in anoxic environments than CFC-11 (Plummer and Busenberg, 2000); this conclusion is supported by the present data.

The variability in ranges of apparent CFC ground-water ages for the replicate samples was fairly low; most sites had less than a 2-year variation. Where variability was greater, it is possible that water of different ages, from separate fracture zones, was intercepted by the well at various times during the purging and sampling cycle. For example, three replicates from well Kan-0935 showed a gradual progression of younger waters entering the borehole during sampling although all field parameters, with the exception of dissolved-oxygen concentration, were stable. In this case, dissolved-oxygen concentration increased abruptly from 0.24 mg/L at the time of sampling to 1.27 mg/L by the time pumping ceased, although no note of cascading water in the well was recorded. To account for variance in apparent CFC ground-water ages as shown by Kan-0935, CFC concentrations for all wells were evaluated individually for trends prior to averaging. Final apparent ages shown in table 3 were determined only after careful analysis of trends.

Final apparent CFC ground-water age determinations were based on (1) mixing ratios if any combination of the three CFC compounds fell within respective mixing and piston-flow boundaries and were not degraded or contaminated; (2) piston-flow models, if data plotted along the piston-flow line; or (3) piston-flow models, if only a single tracer was suitable for dating. CFC recharge date uncertainties attributed to ±2 °C variations in N_2-Ar recharge temperatures and ±10 percent variations in CFC-11, CFC-12, and CFC-113 concentrations are shown in figures 6a and 6b; these variations generally represent twice the standard deviation of replicate analyses (Burton and others, 2002). Recharge date uncertainties in excess of 10 years were found for all three CFC compounds, particularly in samples that contained water recharged after 1975. Scatter-plot comparisons for each CFC compound pair should, under ideal conditions in unmixed samples, plot along a 1:1 line indicative of identical age determinations. In the CFC-11:CFC-12 plot (fig. 6a), most samples fall below the 1:1 line, implying older CFC-11 ages than those determined from CFC-12. This pattern is common in aquifers where microbial degradation of CFC-11 in anoxic waters is suspected (Happell and others, 2003). For the CFC-113:CFC-12 comparison (fig. 6b), most samples fall above the 1:1 line. The plot shows that for most aquifer conditions in West Virginia, CFC-113 analyses result in younger apparent ages than CFC-12 analyses. Data that fall above the 1:1 line in either plot likely represent the prevalence of mixing of young and old waters in West Virginia's aquifers or minor degradation of CFC-11 and CFC-113, as CFC-12 is the most resistant of the three compounds to microbial degradation (Rowe and others, 1999).

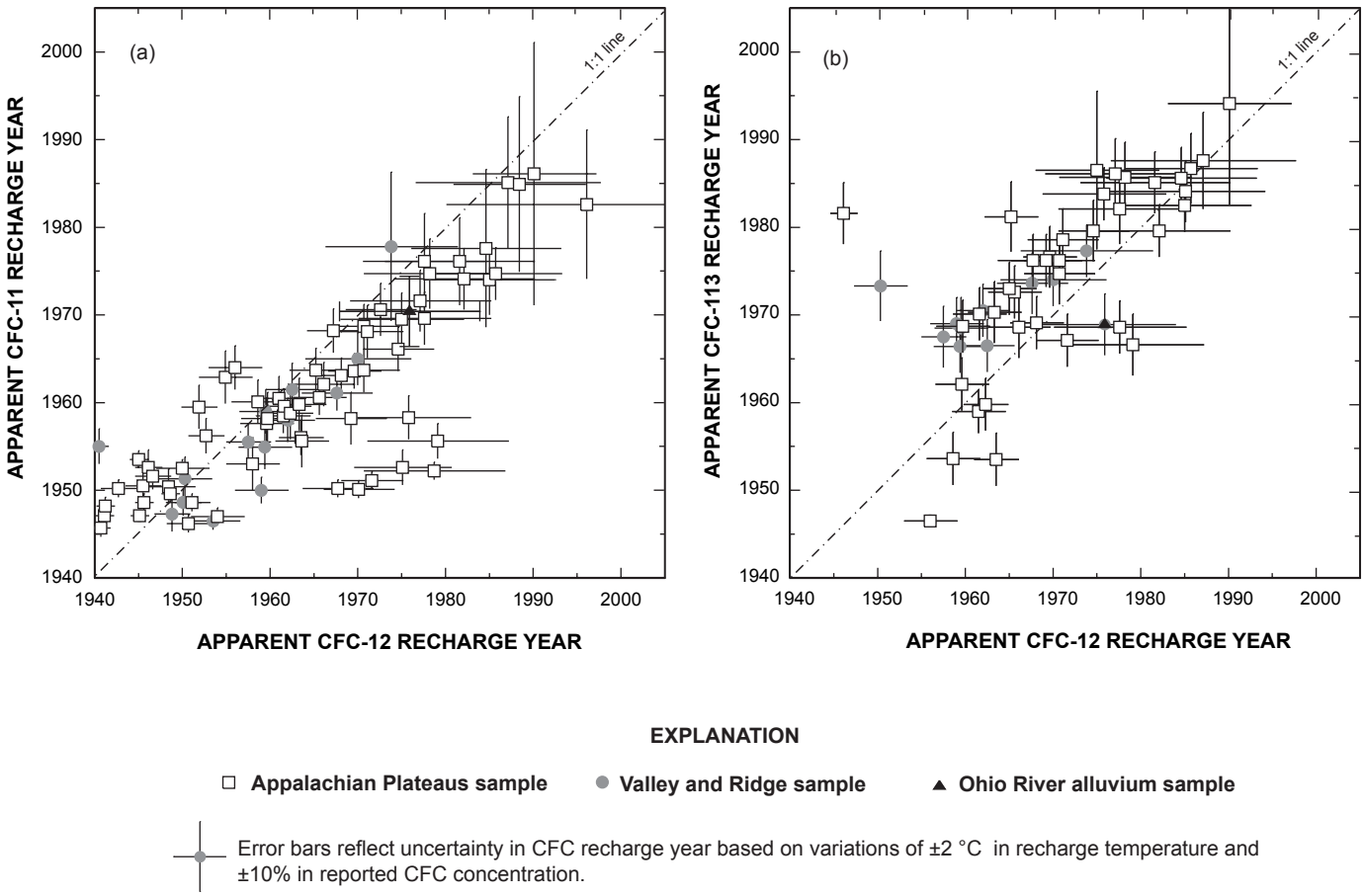

Figure 6. Error-bar plot of apparent (a) CFC-11 and (b) CFC-113 recharge year as a function of apparent CFC-12 recharge year for water samples from aquifers of West Virginia.

Statewide Assessment of Apparent Ages

The wide range in CFC-11, CFC-12, and CFC-113 concentrations shown in figure 7 is indicative of the high variability not only in ground-water ages but also in aquifer conditions in the three regional aquifer systems and the difficulty in using such data for detailed aquifer conceptualization at a statewide scale. Median concentrations for all CFCs were lowest in the Appalachian Plateaus, where CFC degradation in reducing environments is common; in contrast, CFC contamination was most common at sites in the highly transmissive, surficial aquifers of the Ohio River alluvium and Valley and Ridge carbonate units (table 4). These sites coincide with densely populated areas of West Virginia. CFC contamination in West Virginia's highly transmissive aquifers points to a higher degree of vulnerability when compared to less transmissive units in the State.

The apparent CFC ground-water age in aquifers of West Virginia ranged from 5.9 (Poc-258) to 56 years (Cab-0233). Median age of all the samples was 19 years; median ages of water in the Appalachian Plateaus, Valley and Ridge, and Ohio River alluvial aquifer systems were 21, 13, and 20 years, respectively (fig. 8). The young ages indicate that all three aquifer settings are vulnerable to contaminant sources in a time span of less than 30 years. The median percent young water was lowest in the Appalachian Plateaus aquifers, indicating that a larger portion of mixed samples collected from that aquifer system than from the others are pre-CFC water. Additionally, all dated samples from the Ohio River alluvium were evaluated as piston flow and attributed with 100 percent young water for model consistency. The wide range in both apparent age and percent young fraction for the Appalachian Plateaus and Valley and Ridge aquifers reflects the heterogeneity of the fractured-rock environments of West Virginia.

In typical sequences of sandstone, siltstone, shale, and coal throughout the Appalachian Plateaus, vertical hydraulic conductivity varies by orders of magnitude (Harlow and LeCain, 1993) as a result of lithologic control of ground-water flow patterns. Horizontal hydraulic conductivity is similarly variable such that downgradient flow is forced to alternate among vertical joints, faults, fractures, and horizontal bedding-plane separations. This type of topographically driven flow,

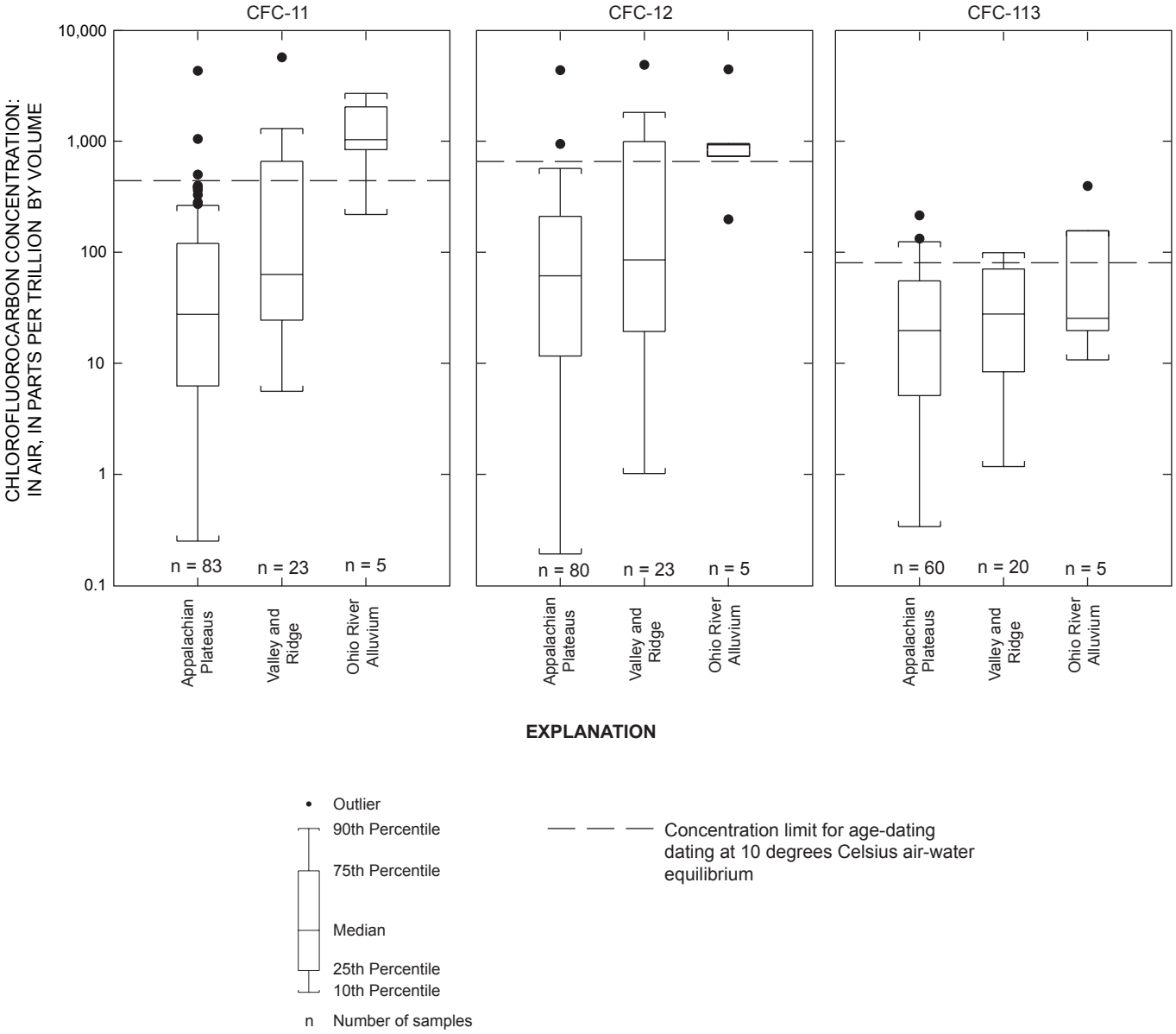

Figure 7. Box plots of CFC-11, CFC-12, and CFC-113 concentrations in water samples from aquifers of West Virginia.

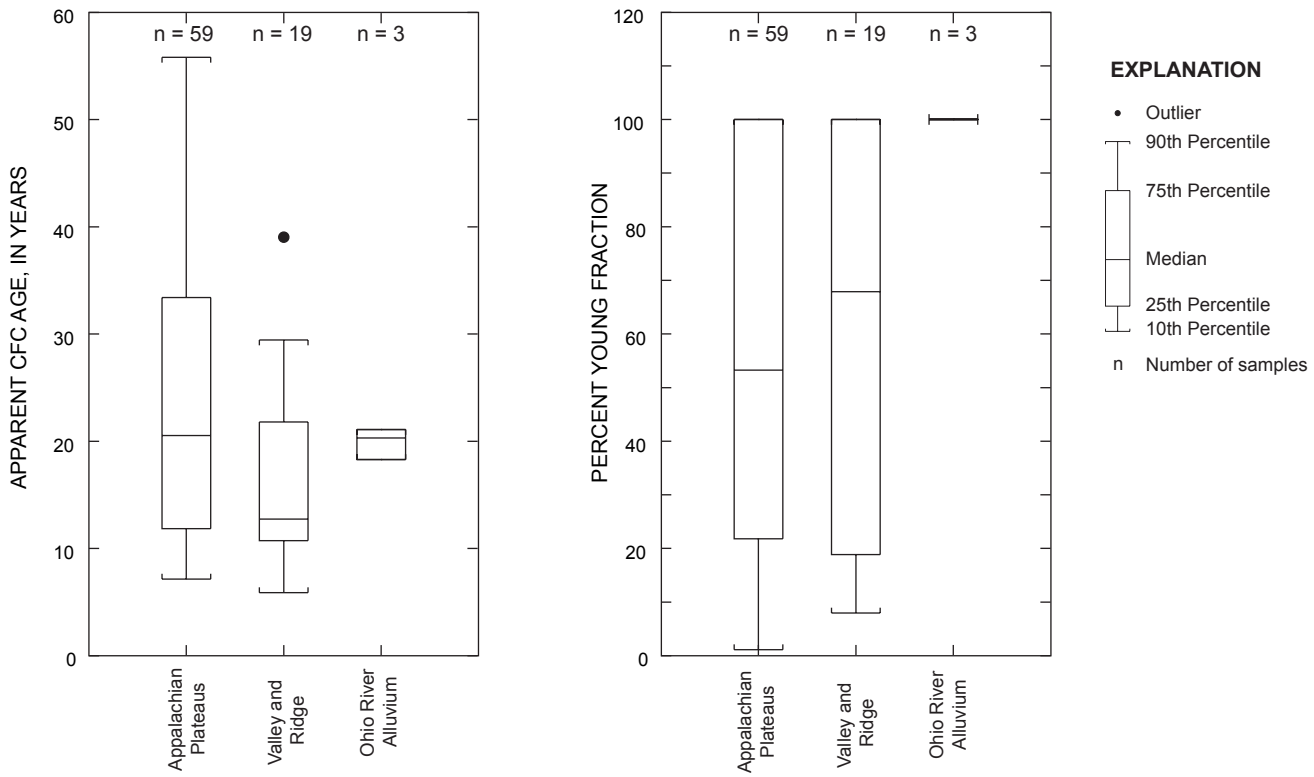

Figure 8. Box plots of apparent CFC age and percent young fraction for water samples from aquifers of West Virginia.

conceptualized by Wyrick and Borchers (1981), is supported by ground-water age-dating results (table 5). Median apparent ages of ground water for all hilltop, hillside, and valley wells indicate that ground water flowing in fractured-bedrock aquifers of the Appalachian Plateaus is younger than previously thought (Sheets and Kozar, 2000).

In mined areas, the conceptual models of ground-water flow by Wyrick and Borchers (1981) and Harlow and LeCain (1993) are only partly applicable because of the substantial effect of mining on the natural hydrology of an area. Underground coal mining has been shown to cause fracturing in overburden strata, resulting in increased hydraulic conductivity of the overburden and increased ground-water recharge to underground mines (Schubert, 1980; Su and Hasenfus, 1987; Hasenfus and others, 1988). Because CFC tracers are often compromised in reducing environments such as abandoned workings, their utility to refine conceptual models of flow in these environments is limited. One well in this data set that was completed in abandoned coal workings (Mcd-0109) has an associated apparent ground-water age of 33 years based on a CFC-12 piston flow model; degradation of CFC-11 and CFC-113 is apparent. Underground workings commonly provide storage for large quantities of water, and mixing of ground waters of various ages is probable. Assumptions of piston flow in the case of sites like Mcd-0109 are likely erroneous; therefore, ages based on CFC-12 alone in such environments represent a maximum age and should be considered with caution.

Topographic influences on ground-water flow patterns are less apparent in the present data set in Valley and Ridge aquifers than in Appalachian Plateaus aquifers. Other factors, such as bedding, cleavage, joints, or fault planes, exert strong control in the Valley and Ridge aquifers and serve to concentrate and apparently force ground water to travel parallel to strike until it breaches impermeable lithologic barriers along

Table 5. Ages of water samples from aquifers of West Virginia, by aquifer system and topographic setting.

Setting	Median age of young fraction (years)	Average percent young fraction	Total number of samples	Number of binary mixtures
Appalachian Plateaus				
Hilltop	12	85	3	2
Hillside	14	52	20	16
Valley	25	57	32	19
Valley and Ridge				
Hilltop	18	66	4	2
Hillside	21	62	6	4
Valley	13	61	13	8
Ohio River alluvium				
Valley	20	100	3	0

cross-strike joints or faults and moves downgradient (Jones, 1991). The role of bedding in Valley and Ridge aquifers has been supported by results of ground-water flow simulations (Burton and others, 2002; Gburek and Folmar, 1999; Gburek and others, 1998); investigations of surface-water/ground-water interaction (Kozar and others, 1991; Shultz and others, 1995; Trainer and Watkins, 1975); aquifer tests (McCoy and others, 2005; Trainer and Watkins, 1975); age dating (Burton and others, 2002); and dye-tracing experiments (Jones, 1991). Precipitation falling on upland ridges and hillsides can percolate to great depths along bedding contacts and, in some cases, can flow into adjacent basins (Hobba and others, 1979). In non-carbonate areas, however, a large percentage of precipitation falling on upland areas is immediately discharged to tributary streams as surface runoff, some of which infiltrates colluvial wedges at the hillslope margin (Trapp and Horn, 1997). Therefore, it is not surprising that ground water in valley settings is typically younger than ground water in adjacent hillslopes and ridges in the Valley and Ridge province.

Relation of Ground-Water Age to Water Quality

To assess whether temporal trends in water quality can be identified, selected sample constituents and field parameters were compared to associated apparent CFC recharge year. Temporal trends may indicate anthropogenic effects or natural variation in the aquifer, as well as provide a further qualitative assessment of apparent ground-water age.

Temperature, pH, specific conductance, and dissolved-oxygen concentration show only a slight increase in scatter with CFC recharge date (fig. 9), most noticeably in the dissolved-oxygen concentration data from the Valley and Ridge samples. Although noticeable trends are largely absent in the field-parameter data, all four parameters show consistency among dated samples and limited variation from median concentrations of the entire data set (pH, 6.9; temperature, 13.4 °C; specific conductance, 389 μS/cm; and dissolved-oxygen concentration, 1.1 mg/L). Additionally, when compared to apparent CFC recharge year, none of the major-ion and trace-metal constituent concentrations show expected deviations or increased scatter in younger samples (figs. 10-11) with the exception of a few outliers likely related to site-specific land-use practices. This pattern is observed in nearly all comparisons of apparent CFC recharge year and water-quality constituent concentrations.

For the nutrient species, comparisons of apparent CFC recharge year with concentrations of ammonia and dissolved organic carbon show slightly more scatter in data for samples containing young-water fractions recharged after about 1985 than for samples containing young-water fraction recharged prior to 1985 (fig. 12). In a subset of 49 wells tested for pesticide compounds, only 9 wells produced water with detectable concentrations of either atrazine or carbofuran, the latter in only one of the nine. All detections were below USEPA maximum contaminant levels of 0.003 mg/L and 0.04 mg/L for atrazine and carbofuran, respectively. Reasonable apparent ground-water ages, available for six of the nine wells, ranged from 8.6 to 22 years. Although this range of ages is indicative of young ground water, pesticide detections are more likely the result of higher agricultural activity in carbonate regions of the State than in areas underlain by other lithologies.

VOCs were detected in 60 of 106 wells using GC/ECD or GC/MS techniques. Results from the two methods generally were in agreement; of 49 wells initially interpreted to be VOC-free by the GC/MS analyses, only 17 had trace concentrations later found in GC/ECD chromatograms. GC/MS detection limits were most frequently exceeded by toluene and trichloromethane, although all reported concentrations for any VOC compound in the data set were below USEPA maximum contaminant levels. The distribution of CFC recharge years for samples with VOC detections indicates that 76 percent of these samples are associated with recharge after 1970 (fig. 13), wells completed to shallow depths (<200 ft), and greater fractions of young water in comparison to samples in which VOCs were not detected (fig. 14).

These age/constituent-concentration relations indicate that, for most public and private ground-water supplies included in this investigation, based on the constituents analyzed for, either (1) ground water has not been directly or adversely affected by human activities, (2) natural attenuation processes have lowered constituent concentrations, or (3) the signatures of recent land-use practices have yet to reach subsurface water supplies.

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the West Virginia Bureau for Public Health, evaluated chlorofluorocarbon (CFC) and water-quality data from 112 production and domestic supply wells to assess apparent ground-water ages in West Virginia's aquifers. Ground-water withdrawals in West Virginia account for a substantial portion of public and domestic water consumption statewide. Therefore, ground-water resource managers can benefit from knowing the time required for ground water to flow from recharge areas to wells or springs used for drinking-water supplies. Previous attempts have been made to estimate rates of ground-water flow on the basis of hydraulic properties of respective aquifers; however, the complexity of fractured-rock ground-water systems typically resulted in rough estimates at best. Ground-water samples collected as part of the USGS National Water-Quality Assessment program and the West Virginia Department of Environmental Protection Ambient Ground-Water Monitoring Network (1997-2005) were analyzed for CFCs and dissolved gases. The CFC and dissolved-gas data were analyzed to quantify apparent ground-water ages in Ohio River alluvial sediments and fractured-bedrock aquifers of the

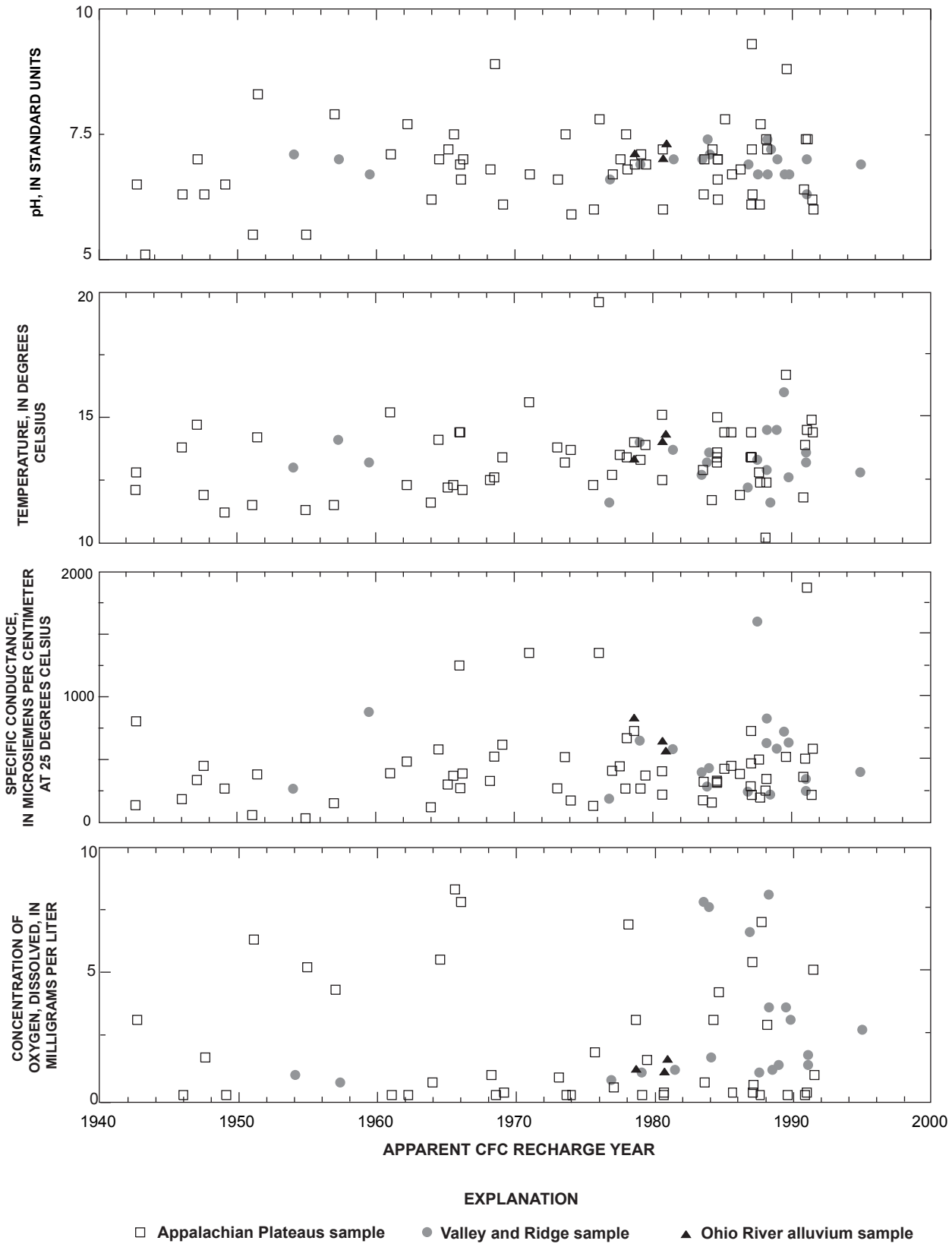

Figure 9. Field parameters, pH, temperature, specific conductance, and dissolved-oxygen concentration as a function of apparent CFC recharge year in water samples from aquifers of West Virginia.

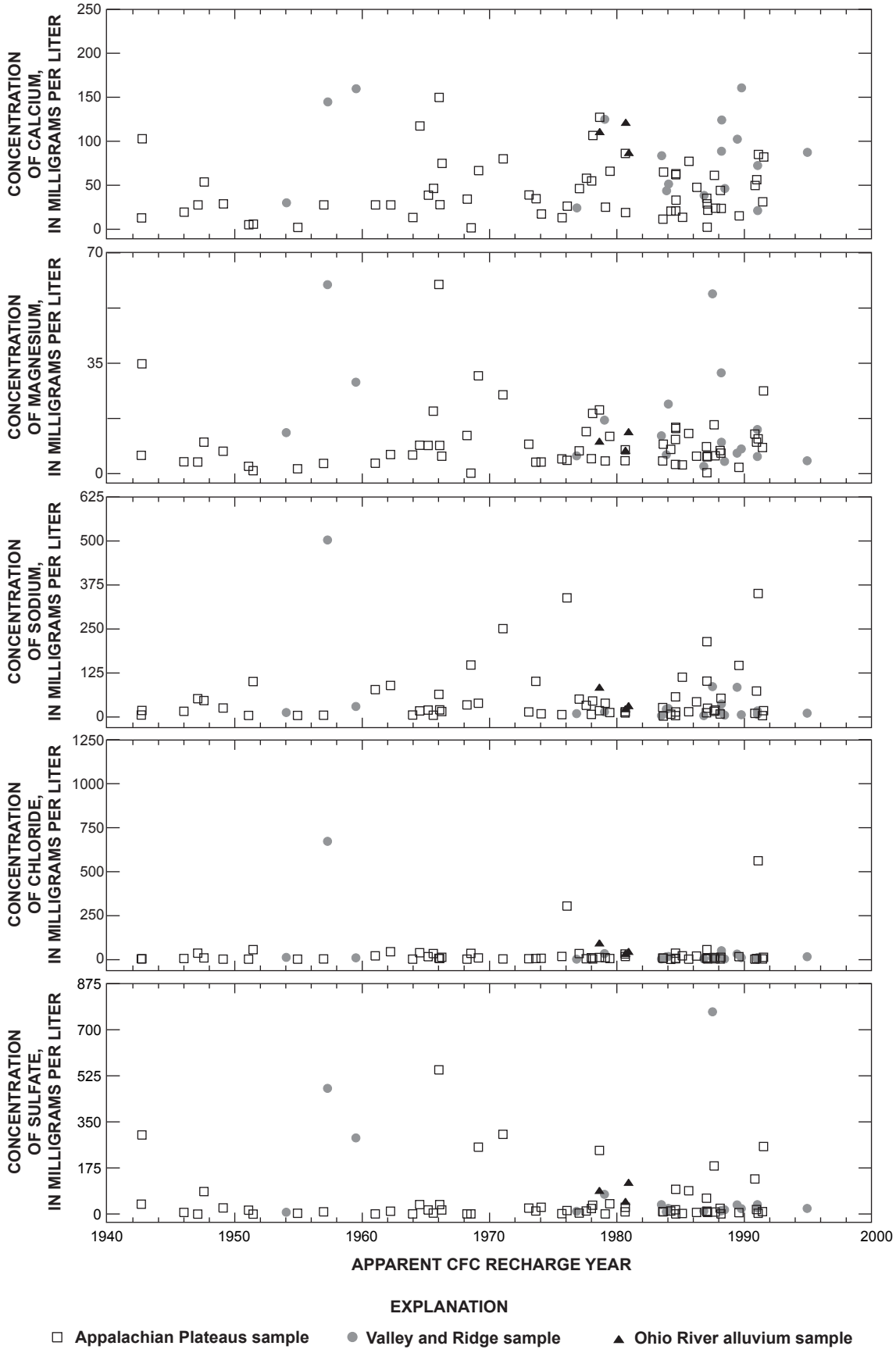

Figure 10. Major-ion concentrations as a function of apparent CFC recharge year in water samples from aquifers of West Virginia.

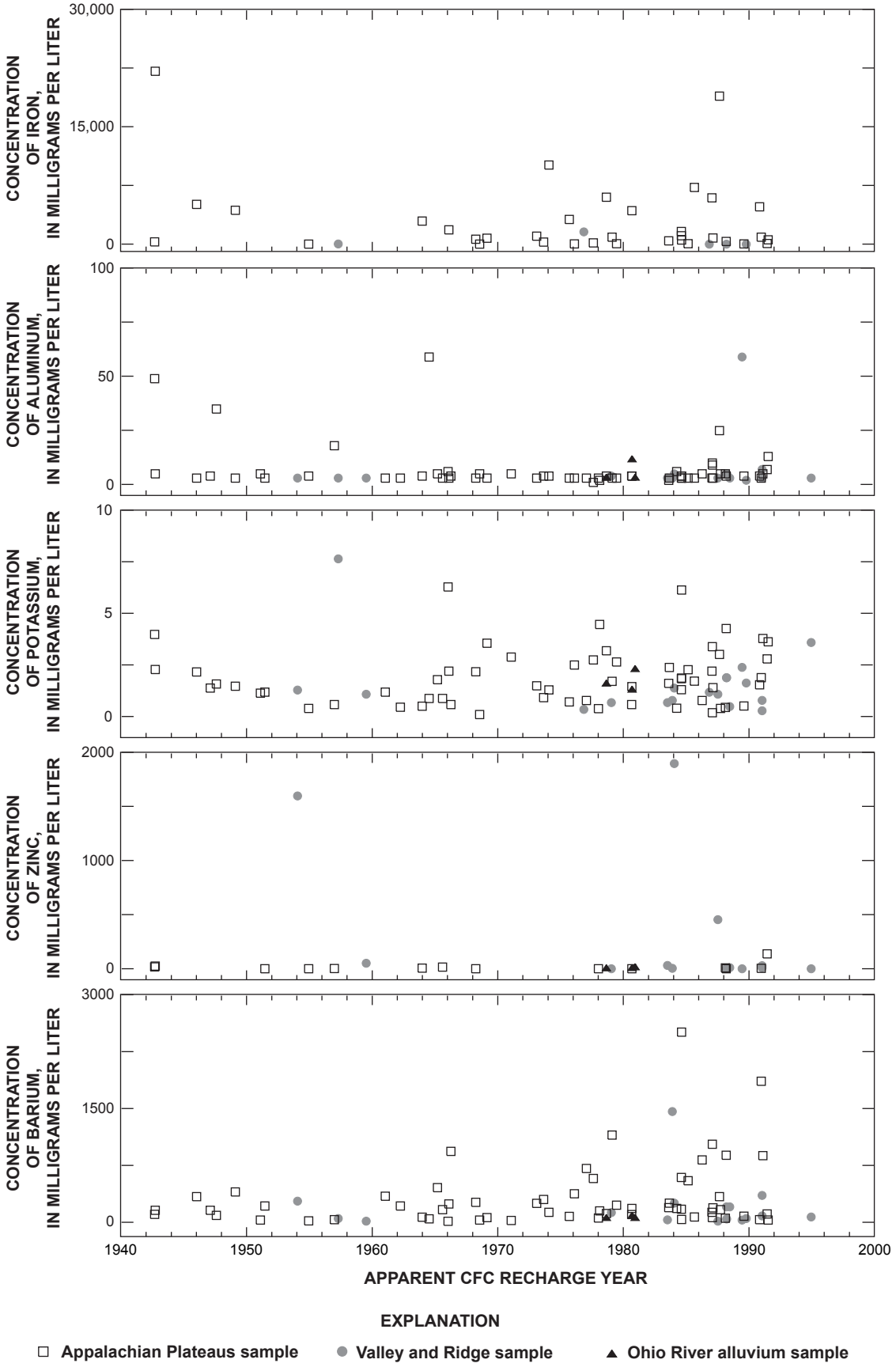

Figure 11. Trace-metal concentrations as a function of apparent CFC recharge year in water samples from aquifers of West Virginia.

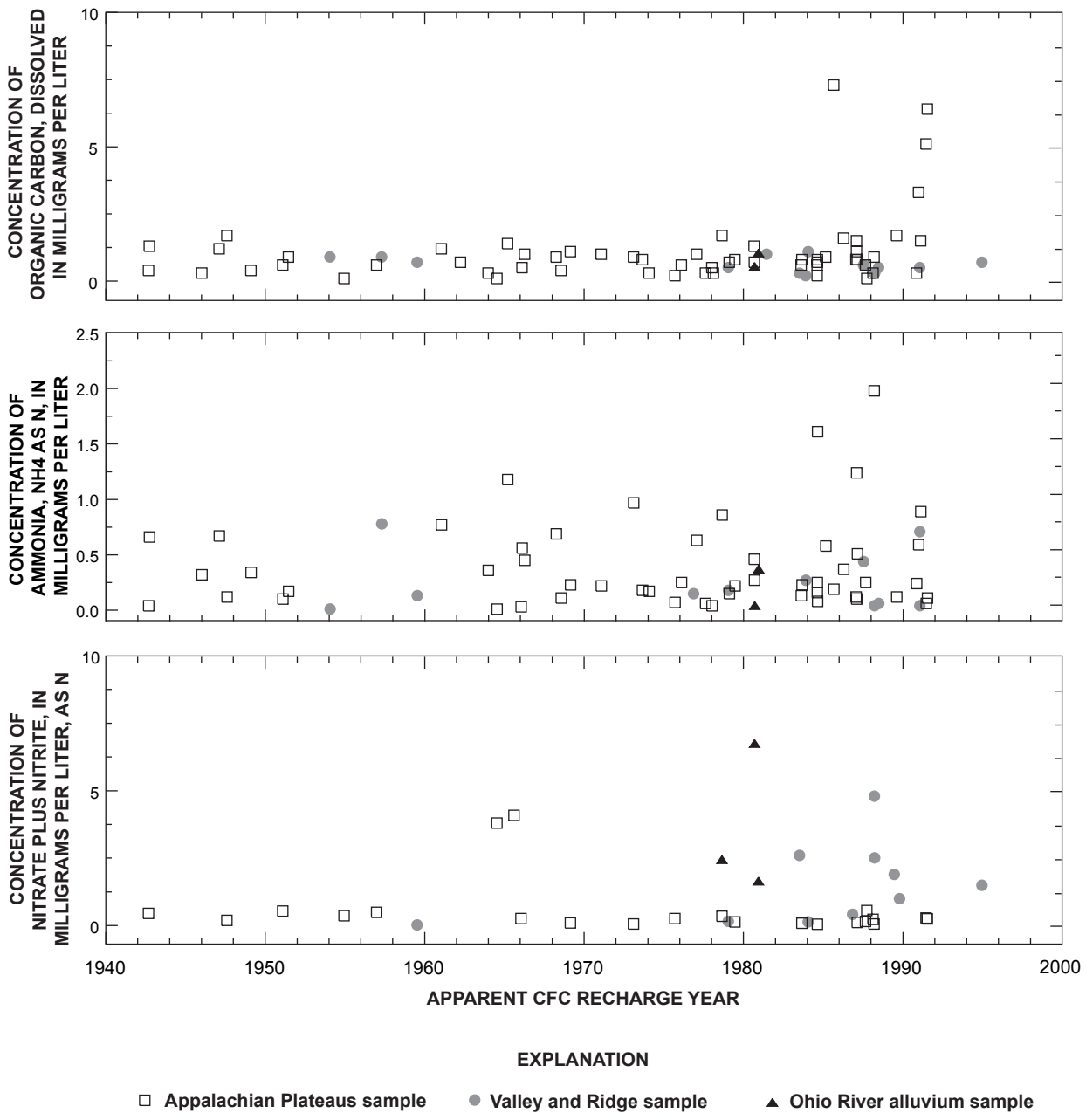

Figure 12. DOC and nutrient compound concentrations as a function of apparent CFC recharge year of young-water fractions in water samples from aquifers of West Virginia.

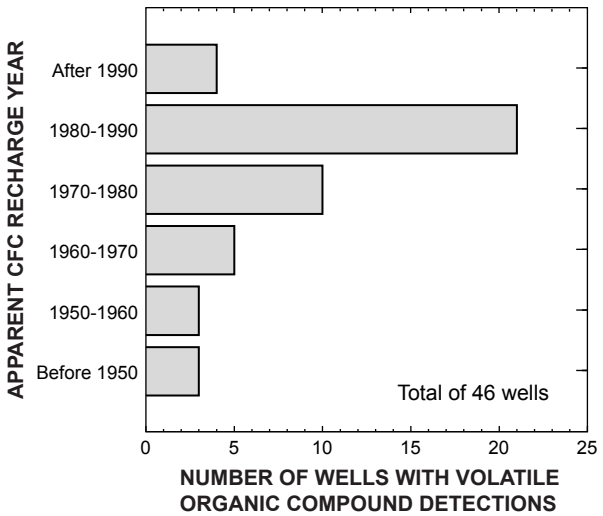

Figure 13. Distribution of apparent CFC recharge year for water samples from aquifers of West Virginia with volatile organic compound detections.

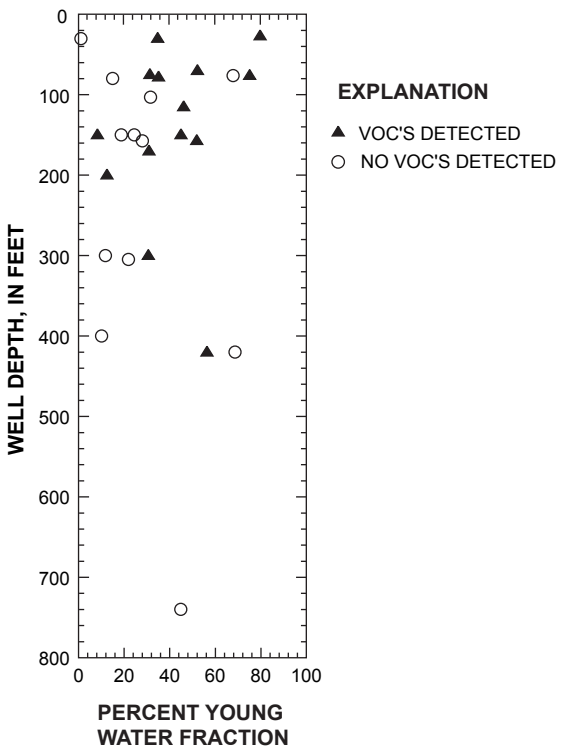

Figure 14. Comparison of well depth and percent young-water fraction of binary mixtures in water samples from aquifers in West Virginia analyzed for volatile organic compounds.

Appalachian Plateaus and Valley and Ridge Physiographic Provinces in West Virginia.

Using CFC dating methods, ground water in aquifers of West Virginia ranged in age from 5.9 (Poc-258) to 56 years (Cab-0233). Median age of all the samples was 19 years; median ages of water in the Appalachian Plateaus, Valley and Ridge, and Ohio River alluvial aquifers systems were 21, 13, and 20 years, respectively. Frequent occurrence of CFC contamination in samples collected from the Ohio River alluvium and Valley and Ridge carbonate units restricted dating techniques to CFC-12 piston-flow models. It is likely that the highly transmissive surficial aquifers contain mixtures of ground water of varying age, possibly including modern fractions contaminated with CFCs. Sites at which a threshold value for CFC concentrations of 5 picograms per kilogram, used in an earlier study of similar fractured-rock settings in Virginia as a guideline for establishing aquifer vulnerability, was exceeded were deemed vulnerable to anthropogenic influences. Nearly all CFC concentrations from the current study in West Virginia exceeded the threshold value. However, current CFC contamination in West Virginia's highly transmissive aquifers points to a higher degree of vulnerability when compared to less transmissive units in the State. Because aquifers readily transmit water, surface or subsurface contaminants can be transported great distances in relatively short periods of time, potentially affecting large areas.

Variations in apparent CFC ages for individual well locations are a result of (1) degradation of the CFC due to anoxic or methanogenic conditions, (2) contamination of a water sample by high concentrations of a particular CFC, or (3) variability in the water contributed to a well from multiple water-bearing zones. Microbial degradation under anoxic or methanogenic conditions common in the Appalachian Plateaus results in the degradation of CFCs in samples from this aquifer system and limits interpretations derived from their analysis.

Because most of the ground water sampled and analyzed in this study is young, the potential for anthropogenic activities to adversely affect ground-water quality in West Virginia is high. However, comparisons of apparent ground-water age and concentrations of selected water-quality constituents show little degradation of water quality in younger samples. The young ages do generally indicate, however, that the State's aquifers are vulnerable to contaminant sources in a time span of less than 30 years.

Acknowledgments

The authors thank the owners of the residential and municipal water systems who allowed access to their wells and well fields. The data on which this report is based were collected as a result of the voluntary participation of homeowners and plant operators of municipal, state park, restaurant, hospital, and other commercial water systems across the State of West Virginia. This report could not have been completed without their support. The authors also thank William Toomey of the West Virginia Bureau for Public Health and David Watkins of the West Virginia Department of Environmental Protection. Their support for the statewide Ambient Ground-Water Monitoring Network is primarily responsible for the majority of the data that were collected in support of this investigation.

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Tables 1-3

Table 1. Location and construction information for wells sampled for chlorofluorocarbons in West Virginia.

[Site locations shown in fig. 1. Abbreviations: Alt, altitude; ft, feet; ft-blsd, feet below land-surface datum; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system]

Map Number	Station Name	USGS Site Identifier	County	Latitude	Longitude	Datum	Alt (ft)	Date of Construction	Well Depth (ft blsd)	Casing Depth (ft blsd)	Sample Interval Top (ft blsd)	Sample Interval Bottom (ft blsd)	Regional Aquifer System	Aquifer
0	Bar-0147	391103079582901	Barbour	39°11′03″	79°58′29″	NAD83	1,460	--	51.0	18.6	18.6	51.0	AP	Pottsville
1	Bar-0148	390353079555601	Barbour	39°03′53″	79°55′58″	NAD83	1,700	--	90.0	18.5	18.5	90.0	AP	Conemaugh
2	Ber-0150	392453077543501	Berkeley	39°24′53″	77°54′35″	NAD27	489	1943	300.0	--	0.0	300.0	VR	Beekmantown
3	Boo-0253	375943081304601	Boone	37°59′43″	81°30′46″	NAD83	1,035	11/1977	94.0	61.4	61.4	94.0	AP	Kanawha
4	Boo-0254	375232081382701	Boone	37°52′32″	81°38′27″	NAD83	1,060	1/12/1994	146.0	110.0	110.0	146.0	AP	Kanawha
5	Boo-0256	380939081504801	Boone	38°09′38″	81°50′46″	NAD83	805	7/1997	130.0	21.9	50.6	130.0	AP	Kanawha
6	Boo-0257	381048081504801	Boone	38°10′48″	81°50′49″	NAD83	675	1973	120.0	60.0	60.0	120.0	AP	Kanawha
7	Boo-0258	380444081351401	Boone	38°04′44″	81°35′15″	NAD83	845	1980	64.0	6.0	7.1	64.0	AP	Kanawha
8	Boo-0259	380708081370201	Boone	38°07′09″	81°37′01″	NAD83	715	1945	105.0	40.0	44.3	105.0	AP	Kanawha
9	Boo-0260	380153081341101	Boone	38°01′54″	81°34′11″	NAD83	780	--	73.0	20.0	20.0	73.0	AP	Kanawha
10	Brx-0269	384057080354101	Braxton	38°40′57″	80°35′41″	NAD83	1,160	11/19/1995	90.0	18.2	18.2	90.0	AP	Allegheny
11	Brx-0270	383101080525401	Braxton	38°31′01″	80°52′54″	NAD83	1,540	10/30/1995	172.0	64.0	74.0	172.0	AP	Conemaugh
12	Cab-0233	382631082143001	Cabell	38°26′31″	82°14′30″	NAD83	576	--	70.0	--	0.0	70.0	AP	Conemaugh
13	Cla-0141	382131081091501	Clay	38°21′31″	81°09′15″	NAD83	910	5/15/1990	50.0	10.3	28.0	50.0	AP	Kanawha
14	Cla-0142	383405081022701	Clay	38°34′05″	81°02′27″	NAD83	840	1986	46.0	19.0	19.0	46.0	AP	Allegheny
15	Fay-0233	375209080515502	Fayette	37°51′36″	80°51′16″	NAD27	2,430	1980	400.0	40.0	40.0	400.0	AP	Mauch Chunk
16	Fay-0234	375523080495601	Fayette	37°55′23″	80°49′56″	NAD27	2,460	--	250.0	--	0.0	250.0	AP	Mauch Chunk
17	Fay-0267	380403081185001	Fayette	38°04′03″	81°18′50″	NAD83	1,160	1940	55.0	25.0	28.7	55.0	AP	Kanawha
18	Fay-0270	380607081145801	Fayette	38°06′08″	81°14′58″	NAD83	855	--	27.0	13.0	13.0	27.0	AP	New River
19	Fay-0272	380131080591301	Fayette	38°01′32″	80°59′12″	NAD83	2,305	1977	225.0	9.0	30.0	225.0	AP	New River
20	Fay-0274	375420081091301	Fayette	37°54′22″	81°09′14″	NAD83	1,684	1984	47.5	11.3	12.7	47.5	AP	New River
21	Fay-0275	375739081171801	Fayette	37°57′39″	81°17′19″	NAD83	1,585	1968	21.2	8.0	8.0	21.2	AP	New River
22	Fay-0276	375829081180801	Fayette	37°58′30″	81°18′08″	NAD83	1,450	1997	102.0	12.9	12.9	102.0	AP	New River
23	Fay-0279	375915081132501	Fayette	37°59′16″	81°13′26″	NAD83	1,706	1980	30.0	11.0	11.0	30.0	AP	Kanawha
24	Fay-0282	375727081044601	Fayette	37°57′27″	81°04′46″	NAD83	1,080	--	255.0	--	0.0	255.0	AP	Pocahontas
25	Gil-0045	385103080561801	Gilmer	38°51′03″	80°56′18″	NAD27	740	1939	104.0	--	0.0	104.0	AP	Conemaugh
26	Gil-0198	385254080512701	Gilmer	38°52′54″	80°51′27″	NAD83	760	12/21/1979	63.0	30.2	30.2	63.0	AP	Conemaugh
27	Grb-0167	375802080411201	Greenbrier	37°58′02″	80°41′12″	NAD27	2,450	--	157.0	--	53.0	157.0	AP	Hinton
28	Grb-0208	375803080460901	Greenbrier	37°58′03″	80°46′09″	NAD27	2,390	1984	200.0	80.0	80.0	200.0	AP	Mauch Chunk
29	Grb-0280	380202080275801	Greenbrier	38°02′02″	80°27′58″	NAD83	2,620	6/1/1989	305.0	68.7	110.0	305.0	AP	Mauch Chunk

Table 1. Location and construction information for wells sampled for chlorofluorocarbons in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: Alt, altitude; ft, feet; ft-blsd, feet below land-surface datum; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system]

Map Number	Station Name	USGS Site Identifier	County	Latitude	Longitude	Datum	Alt (ft)	Date of Construction	Well Depth (ft blsd)	Casing Depth (ft blsd)	Sample Interval Top (ft blsd)	Sample Interval Bottom (ft blsd)	Regional Aquifer System	Aquifer
30	Grb-0281	375503080382301	Greenbrier	37°55’03″	80°38’23″	NAD83	2,510	1958	123.0	35.2	61.4	123.0	AP	Hinton
31	Grb-0282	374836080300601	Greenbrier	37°48’36″	80°30’06″	NAD83	2,040	4/2/1991	523.0	41.8	417.0	523.0	AP	Greenbrier
32	Grb-0283	375320080360801	Greenbrier	37°53’20″	80°36’08″	NAD83	2,565	1980	205.0	20.6	139.3	205.0	AP	Mauch Chunk
33	Grb-0284	380106080432801	Greenbrier	38°01’06″	80°43’28″	NAD83	2,807	1950	112.0	30.0	30.0	112.0	AP	New River
34	Grb-0285	380253080431901	Greenbrier	38°02’53″	80°43’19″	NAD83		1929	137.0	--	0.0	137.0	AP	New River
35	Grb-0287	375804080294601	Greenbrier	37°58’04″	80°29’46″	NAD83	2,190	1975	300.0	248.4	248.4	300.0	AP	Greenbrier
36	Grt-0106	391137079160401	Grant	39°11’37″	79°16’04″	NAD83	3,260	--	197.0	--	0.0	197.0	AP	Conemaugh
37	Har-0172	392458080165301	Harrison	39°24’58″	80°16’53″	NAD83	970	--	96.0	21.0	38.0	96.0	AP	Monongahela
38	Hmp-0379	392654078355101	Hampshire	39°26’54″	78°35’51″	NAD83	1,230	9/7/1999	740.0	--	215.3	740.0	AP	Upper-Middle Devonian
39	Hmp-0380	392217078314801	Hampshire	39°22’17″	78°31’48″	NAD83	1,200	2000	600.0	48.8	48.8	600.0	VR	Upper-Middle Devonian
40	Hmp-0382	391125078282401	Hampshire	39°11’25″	78°28’24″	NAD83	1,190	1989	400.0	--	77.1	400.0	VR	Upper-Middle Devonian
41	Hmp-0383	391231078292901	Hampshire	39°12’31″	78°29’29″	NAD83	890	6/1992	300.0	58.8	58.8	300.0	VR	Marcellus
42	Hnc-0042	403716080363001	Hancock	40°37’18″	80°36’27″	NAD27	685	1907	76.0	56.0	56.0	76.0	ORA	Quaternary
43	Hrd-0019	390443078345101	Hardy	39°04’43″	78°34’49″	NAD27		--	--	--	0.0		VR	Marcellus
44	Hrd-0300	390254078441001	Hardy	39°02’54″	78°44’10″	NAD83	1,320	1981	103.0	20.7	26.2	103.0	VR	Oriskany
45	Hrd-0301	390333078370801	Hardy	39°03’33″	78°37’08″	NAD83	1,165	2/11/2004	160.0	58.0	58.0	160.0	VR	Helderberg
46	Jac-0165	383657081362501	Jackson	38°36’57″	81°36’25″	NAD83	720	4/1987	60.0	20.0	20.0	60.0	AP	Monongahela
47	Jac-0166	383920081355401	Jackson	38°39’20″	81°35’54″	NAD83	775	8/1996	73.0	33.0	33.0	73.0	AP	Dunkard
48	Jef-0312	392045077484401	Jefferson	39°20’45″	77°48’44″	NAD27	500	--	325.0	--	224.0	325.0	VR	Elbrook
49	Jef-0327	392110077555201	Jefferson	39°21’10″	77°55’52″	NAD27	460	--	--	--	0.0	0.0	VR	Beekmantown
50	Jef-0579	391839077563101	Jefferson	39°18’39″	77°56’31″	NAD83	552	--	205.0	--	0.0	205.0	VR	Beekmantown
51	Jef-0581	392117077554501	Jefferson	39°21’17″	77°55’45″	NAD83	495	--	155.0	--	0.0	155.0	VR	Beekmantown
52	Jef-0585	392117077550302	Jefferson	39°21’17″	77°55’03″	NAD83	530	9/10/2003	326.0	39.0	285.3	326.0	VR	Beekmantown
53	Jef-0590	392101077554901	Jefferson	39°21’01″	77°55’49″	NAD83	478	9/23/2003	160.0	38.5	38.5	160.0	VR	Beekmantown
54	Jef-0592	392117077550301	Jefferson	39°21’17″	77°55’03″	NAD83	529	9/10/2003	321.0	38.0	138.4	141.2	VR	Beekmantown
55	Jef-0603	392119077554701	Jefferson	39°21’19″	77°55’47″	NAD83	490	10/16/2002	475.0	56.0	56.0	475.0	VR	Upper Cambrian
56	Jef-0659	392049077554601	Jefferson	39°20’49″	77°55’46″	NAD83	479	--	--	--	0.0	0.0	VR	Beekmantown
57	Kan-0927	381852081404401	Kanawha	38°18’52″	81°40’44″	NAD83	640	--	65.0	4.3	32.8	65.0	AP	Kanawha
58	Kan-0928	382636081432801	Kanawha	38°26’36″	81°43’28″	NAD83	600	9/18/1987	73.0	40.0	40.0	73.0	AP	Conemaugh
59	Kan-0932	382845081300301	Kanawha	38°28’45″	81°30’03″	NAD83	740	--	75.0	20.0	33.9	75.0	AP	Conemaugh

Table 1. Location and construction information for wells sampled for chlorofluorocarbons in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: Alt, altitude; ft, feet; ft-blsd, feet below land-surface datum; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system]

Map Number	Station Name	USGS Site Identifier	County	Latitude	Longitude	Datum	Alt (ft)	Date of Construction	Well Depth (ft blsd)	Casing Depth (ft blsd)	Sample Interval Top (ft blsd)	Sample Interval Bottom (ft blsd)	Regional Aquifer System	Aquifer
60	Kan-0934	381216081450101	Kanawha	38°12’16″	81°45’01″	NAD83	640	1966	80.0	21.2	30.7	80.0	AP	Kanawha
61	Kan-0935	381125081304701	Kanawha	38°11’27″	81°30’45″	NAD83	810	1989	100.0	30.0	30.0	100.0	AP	Kanawha
62	Kan-0938	381847081254201	Kanawha	38°18’47″	81°25’42″	NAD83	825	1979	105.0	30.0	30.0	105.0	AP	Kanawha
63	Lew-0219	390201080311301	Lewis	39°01’59″	80°31’05″	NAD83	1,070	--	85.0	19.1	19.1	85.0	AP	Conemaugh
64	Lew-0220	385131080272501	Lewis	38°51’30″	80°27’26″	NAD83	1,110	8/1997	112.0	28.3	110.3	112.0	AP	Conemaugh
65	Lin-0179	381631082061602	Lincoln	38°16’31″	82°06’16″	NAD27	650	5/17/1967	135.0	--	30.0	135.0	AP	Allegheny
66	Lin-0180	381545082050801	Lincoln	38°15’45″	82°05’08″	NAD83	653	--	89.0	--	0.0	89.0	AP	Allegheny
67	Log-0198	375842082082101	Logan	37°58’42″	82°08’21″	NAD27	670	--	78.0	10.0	10.0	78.0	AP	Kanawha
68	Mar-0296	393530080151501	Marshall	39°35’30″	80°15’15″	NAD27	1,050	--	107.0	--	0.0	107.0	AP	Monongahela
69	Mas-0917	385304081554501	Mason	38°53’05″	81°55’45″	NAD27	600	8/25/1981	57.0	52.0	52.0	57.0	ORA	Quaternary
70	Mcd-0109	372259081334101	Mcdowell	37°23’01″	81°33’39″	NAD27	1,400	--	130.0	128.0	128.0	130.0	AP	Pocahontas
71	Mer-0163	372519081144203	Mercer	37°25’19″	81°14’42″	NAD27	2,380	10/1/1976	240.0	--	0.0	240.0	AP	Pocahontas
72	Mer-0170	373020081075601	Mercer	37°30’20″	81°07’56″	NAD83	1,858	1970	144.0	62.4	62.4	144.0	AP	Bluestone/Princeton
73	Mig-0140	373810082055601	Mingo	37°38’10″	82°05’56″	NAD83		--	--	--	0.0	0.0	AP	Kanawha
74	Min-0168	392538078510301	Mineral	39°25’38″	78°51’04″	NAD83	700	--	75.0	--	0.0	75.0	VR	Upper-Middle Devonian
75	Min-0169	392014078551801	Mineral	39°20’14″	78°55’18″	NAD83	750	--	150.0	--	0.0	150.0	VR	Upper-Middle Devonian
76	Min-0170	392304078512901	Mineral	39°23’04″	78°51’28″	NAD83	690	--	150.0	--	0.0	150.0	VR	Upper-Middle Devonian
77	Min-0171	393106078513401	Mineral	39°31’06″	78°51’34″	NAD83	1,500	--	420.0	--	0.0	420.0	VR	Oriskany
78	Mng-0584	393533080035501	Monongahela	39°35’35″	80°03’52″	NAD83	1,140	--	40.7	19.5	19.5	40.7	AP	Monongahela
79	Mnr-0148	373528080323302	Monroe	37°35’28″	80°32’33″	NAD27	2,050	1974	398.0	10.0	60.0	398.0	AP	Greenbrier
80	Nic-0207	381533080593401	Nicolas	38°15’33″	80°59’34″	NAD83	1,220	12/1994	200.0	197.0	197.0	200.0	AP	Kanawha
81	Nic-0208	381652080473501	Nicolas	38°16’52″	80°47’35″	NAD83	2,105	1984	208.0	17.0	40.0	208.0	AP	Allegheny
82	Nic-0209	381539080560201	Nicolas	38°15’40″	80°56’01″	NAD83	1,525	1973	50.0	40.0	40.0	50.0	AP	Kanawha
83	Nic-0211	382113080442701	Nicolas	38°21’11″	80°44’30″	NAD83	1,995	1945	80.0	20.0	22.5	80.0	AP	Kanawha
84	Nic-0212	381513080584401	Nicolas	38°15’14″	80°58’44″	NAD83	1,289	1959	25.5	10.0	10.0	25.5	AP	Kanawha
85	Nic-0213	381656080543301	Nicolas	38°16’57″	80°54’33″	NAD83	1,540	1989	48.4	22.0	22.0	48.4	AP	Kanawha
86	Nic-0214	381931080425401	Nicolas	38°19’32″	80°42’55″	NAD83	2,250	1992	47.6	40.0	40.0	47.6	AP	Kanawha
87	Nic-0215	382011080424501	Nicolas	38°22’12″	80°42’45″	NAD83	2,250	1965	375.0	42.0	42.0	375.0	AP	Kanawha
88	Nic-0217	382340080481301	Nicolas	38°23’40″	80°48’13″	NAD83	1,880	1982	100.0	15.0	15.0	100.0	AP	Kanawha
89	Nic-0218	382434080401401	Nicolas	38°24’34″	80°40’15″	NAD83	2,250	--	90.0	20.0	35.0	90.0	AP	Kanawha

Table 1. Location and construction information for wells sampled for chlorofluorocarbons in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: Alt, altitude; ft, feet; ft-blsd, feet below land-surface datum; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system]

Map Number	Station Name	USGS Site Identifier	County	Latitude	Longitude	Datum	Alt (ft)	Date of Construction	Well Depth (ft blsd)	Casing Depth (ft blsd)	Sample Interval Top (ft blsd)	Sample Interval Bottom (ft blsd)	Regional Aquifer System	Aquifer
90	Nic-0219	382123080381701	Nicolas	38°21’26″	80°38’15″	NAD83	2,250	1974	57.0	8.0	8.0	57.0	AP	Kanawha
91	Nic-0220	381814080543901	Nicolas	38°18’14″	80°54’39″	NAD83		1969	104.0	--	0.0	104.0	AP	Kanawha
92	Pen-0163	385003079222601	Pendleton	38°50’03″	79°22’26″	NAD83	1,550	--	76.0	--	0.0	76.0	VR	Upper-Middle Devonian
93	Pen-0164	384915079231201	Pendleton	38°49’15″	79°23’12″	NAD83	1,660	--	150.0	--	0.0	150.0	VR	Upper-Middle Devonian
94	Poc-0257	382416080013701	Pocahontas	38°24’16″	80°01’37″	NAD83	3,170	9/1992	175.0	40.1	71.7	175.0	VR	Greenbrier
95	Poc-0258	381233080063801	Pocahontas	38°12’33″	80°06’38″	NAD83	2,530	3/21/1987	300.0	42.0	68.0	300.0	VR	Greenbrier
96	Poc-0262	382553079491201	Pocahontas	38°25’53″	79°49’12″	NAD83	2,740	1994	175.0	30.0	30.0	175.0	VR	Upper-Middle Devonian
97	Poc-0263	382525080005601	Pocahontas	38°25’25″	80°00’56″	NAD83	3,260	--	140.0	--	0.0	140.0	VR	Mauch Chunk
98	Poc-0265	382435080072301	Pocahontas	38°24’35″	80°07’23″	NAD83	2,700	--	50.0	--	0.0	50.0	VR	Greenbrier
99	Pre-0169	392917079460501	Preston	39°29’40″	79°46’05″	NAD83	1,790	--	41.0	26.0	26.0	41.0	AP	Allegheny
100	Pre-0170	392924079374601	Preston	39°29’24″	79°37’46″	NAD83	1,290	6/4/1988	110.0	39.2	68.1	110.0	AP	Conemaugh
101	Ral-0220	374645081030701	Raleigh	37°46’45″	81°03’07″	NAD83	2,800	1970	226.0	100.0	100.0	226.0	AP	New River
102	Ral-0221	375246081133401	Raleigh	37°52’47″	81°13’35″	NAD83	2,010	1984	49.5	20.0	23.4	49.5	AP	Kanawha
103	Ran-0278	383235080020701	Randolph	38°32’35″	80°02’07″	NAD83	2,380	--	100.0	--	0.0	100.0	AP	Upper-Middle Devonian
104	Sum-0099	373123080484801	Summers	37°31’23″	80°48’48″	NAD83	1,540	1994	200.0	20.2	48.0	200.0	AP	Bluestone/Princeton
105	Sum-0103	374908080435601	Summers	37°49’08″	80°43’56″	NAD83	2,455	8/1996	170.0	59.0	59.0	170.0	AP	Mauch Chunk
106	Sum-0105	375115080474901	Summers	37°51’14″	80°47’49″	NAD83	2,950	1988	115.0	30.0	46.6	115.0	AP	Pocahontas
107	Ups-0180	390227080145801	Upshur	39°02’29″	80°14’16″	NAD83	1,430	--	68.0	19.2	20.7	68.0	AP	Conemaugh
108	Web-0237	382817080313501	Webster	38°28’17″	80°31’35″	NAD83	1,840	4/3/1986	100.0	50.0	50.0	100.0	AP	Kanawha
109	Wet-0111	393618080560601	Wetzel	39°36’18″	80°56’06″	NAD27	630	--	83.0	68.0	68.0	83.0	ORA	Quaternary
110	Woo-0185	392055081322901	Wood	39°20’55″	81°32’29″	NAD83		--	82.0	--	0.0	82.0	ORA	Quaternary
111	Woo-0196	392359081270001	Wood	39°23’59″	81°27’00″	NAD27	630	1977	83.0	63.0	63.0	83.0	ORA	Quaternary

Table 2. Summary of recharge data and chlorofluorocarbon (CFC) concentrations in West Virginia.

[Site locations shown in fig. 1. Abbreviations: °C, degrees Celsius; Rech. elev., recharge elevation; ft, feet; ccSTP/L, cubic centimeters per liter at standard temperature and pressure; pg/kg. picograms per kilogram; pptv, calculated parts per trillion by volume; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system. Italicized recharge-temperature values are estimates from mean annual temperature; italicized excess-air values are estimates.]

Map Number	Station Name	Regional Aquifer System	Sample Date	Water Temp (°C)	Rech. Elev. (ft)	Assigned Recharge Temperature (°C)	N_2-Ar Excess Air (ccSTP/L)	Number of CFC Ampules Analyzed	Average Concentration, in pg/kg			Average Calculated Atmospheric Mixing Ratio, in pptv		
									CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
0	Bar-0147	AP	10/21/1997	12.8	1460	*10.30*	*0.00*	3	69.7	50.8	34.3	25.9	81.7	30.0
1	Bar-0148	AP	10/8/1997	14.4	1700	8.77	3.79	3	4.3	8379.7	0.0	1.6	13042.1	0.0
2	Ber-0150	VR	4/14/1999	14.5	520	12.14	5.56	3	13454.4	3282.5	74.5	5303.0	5390.6	68.4
3	Boo-0253	AP	6/3/1997	14.2	2150	*11.20*	*0.00*	3	0.0	4.3	0.0	0.0	7.3	0.0
4	Boo-0254	AP	5/7/1997	14.4	2200	11.70	1.08	3	14.0	7.3	--	5.8	13.1	--
5	Boo-0256	AP	5/4/1998	13.4	1160	11.78	3.47	3	71.3	99.9	14.3	28.4	168.2	13.4
6	Boo-0257	AP	5/29/1998	15	1180	*11.20*	*0.00*	2	2.3	--	--	0.8	--	--
7	Boo-0258	AP	5/6/1998	13.6	1640	10.19	1.25	3	347.0	186.1	64.2	129.6	301.4	56.6
8	Boo-0259	AP	6/23/1998	14.2	1560	*11.20*	*0.00*	3	7.2	6.2	0.0	2.7	9.9	0.0
9	Boo-0260	AP	5/15/1998	13.2	1760	5.12	1.79	3	0.8	1.8	0.0	0.3	2.9	0.0
10	Brx-0269	AP	6/10/1997	13.4	1400	8.68	3.85	4	1.9	4.4	0.0	0.7	6.5	0.0
11	Brx-0270	AP	6/9/1997	13.5	1564	11.80	1.22	1	339.8	201.6	47.5	138.2	352.1	46.0
12	Cab-0233	AP	4/9/1999	14.5	900	11.24	4.51	3	2.1	0.6	0.0	0.8	1.0	0.0
13	Cla-0141	AP	5/8/1997	12.9	1400	11.22	-0.59	2	58.6	78.9	16.6	23.1	135.4	15.7
14	Cla-0142	AP	6/4/1997	13.3	1220	*10.60*	*0.00*	3	1.0	1.4	0.0	0.3	2.2	0.0
15	Fay-0233	AP	7/20/2000	13.4	3040	9.22	3.52	4	7.8	7.2	0.0	2.9	11.5	0.0
16	Fay-0234	AP	4/28/1999	11.8	2880	*10.30*	*0.00*	3	2.5	788.7	0.0	1.0	1313.5	0.0
17	Fay-0267	AP	6/2/1997	13.4	2345	10.01	3.48	3	53.5	67.8	6.3	20.2	109.6	5.6
18	Fay-0270	AP	5/22/1998	13.7	2000	11.73	5.35	2	4.5	111.8	5.0	1.8	190.3	4.7
19	Fay-0272	AP	5/13/1998	12.6	2480	8.75	2.36	3	37.1	35.3	8.5	13.2	54.3	7.1
20	Fay-0274	AP	5/21/1998	15	2000	12.01	0.26	3	491.3	299.0	218.7	205.9	541.1	219.5
21	Fay-0275	AP	5/12/1998	11.5	2440	8.92	0.48	3	685.8	327.8	99.8	246.2	516.8	84.3
22	Fay-0276	AP	5/8/1998	13.4	2400	11.67	2.07	3	197.8	117.8	122.0	82.2	209.2	120.0
23	Fay-0279	AP	5/26/1998	11.2	2240	8.96	7.01	3	0.8	0.6	0.0	0.3	0.9	0.0
24	Fay-0282	AP	8/4/2000	14.8	1840	13.43	2.97	3	81.6	16.1	0.0	36.3	30.0	0.0

Table 2. Summary of recharge data and chlorofluorocarbon (CFC) concentrations in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: °C, degrees Celsius; Rech. elev., recharge elevation; ft, feet; ccSTP/L, cubic centimeters per liter at standard temperature and pressure; pg/kg. picograms per kilogram; pptv, calculated parts per trillion by volume; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system. Italicized recharge-temperature values are estimates from mean annual temperature; italicized excess-air values are estimates.]

Map Number	Station Name	Regional Aquifer System	Sample Date	Water Temp (°C)	Rech. Elev. (ft)	Assigned Recharge Temperature (°C)	N_2-Ar Excess Air (ccSTP/L)	Number of CFC Ampules Analyzed	Average Concentration, in pg/kg			Average Calculated Atmospheric Mixing Ratio, in pptv		
									CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
25	Gil-0045	AP	7/7/2000	15.2	1160	10.29	-0.66	4	8.2	4.0	0.0	3.0	6.1	0.0
26	Gil-0198	AP	7/6/2000	14.2	1060	12.31	2.91	3	1.8	15.1	0.0	0.7	26.1	0.0
27	Grb-0167	AP	4/26/1999	12.1	3440	6.66	5.38	3	4.6	80.9	20.5	1.8	133.6	18.5
28	Grb-0208	AP	4/27/1999	11.9	3080	9.18	6.66	3	9.6	210.3	161.1	3.5	326.2	135.5
29	Grb-0280	AP	5/13/1997	11.7	2850	6.79	2.30	3	33.2	49.6	10.2	12.8	82.5	9.2
30	Grb-0281	AP	5/12/1997	12.3	2600	9.67	4.22	3	168.1	181.1	5.8	62.8	288.6	5.0
31	Grb-0282	AP	5/21/1997	13.5	2845	*10.00*	*0.00*	3	46.2	51.9	5.8	17.8	86.3	5.3
32	Grb-0283	AP	5/19/1997	12.4	2680	10.65	0.45	3	353.6	165.3	33.6	141.1	286.6	31.9
33	Grb-0284	AP	6/16/1998	12.3	3320	6.38	9.25	2	1996.6	52.3	12.9	770.5	83.2	11.3
34	Grb-0285	AP	4/27/1999	12.2	3500	5.69	3.88	3	0.6	0.6	0.0	0.2	1.0	0.0
35	Grb-0287	AP	7/13/2000	15.1	2440	12.42	6.11	4	35.8	39.1	2.1	15.3	69.3	2.1
36	Grt-0106	AP	6/25/2003	9.7	860	11.04	5.18	3	157.4	29.0	0.0	65.6	50.7	0.0
37	Har-0172	AP	9/30/1997	14	970	*9.70*	*0.00*	3	26.5	33.8	1.9	9.7	53.2	1.6
38	Hmp-0379	VR	6/11/2001	13.6	1240	5.55	0.68	3	82.7	104.7	20.7	30.1	166.4	17.8
39	Hmp-0380	VR	6/12/2001	13	1220	9.55	5.16	3	5.7	11.0	--	2.0	16.5	--
40	Hmp-0382	VR	6/13/2001	13.2	1220	4.27	11.09	3	30.0	31.8	9.7	10.7	46.4	7.8
41	Hmp-0383	VR	6/13/2001	13.6	1700	7.25	2.21	3	10.9	40.5	12.8	3.4	56.2	9.4
42	Hnc-0042	ORA	7/23/2002	14.3	1200	10.29	3.84	3	353.1	218.8	12.9	129.7	342.8	11.0
43	Hrd-0019S	VR	2/25/2004	12.2	2110	*9.70*	*0.00*	2	565.4	206.0	47.8	212.2	333.5	42.1
44	Hrd-0300	VR	6/14/2001	14	1780	10.50	6.40	3	83.2	59.2	7.7	31.4	93.6	6.7
45	Hrd-0301	AP	2/25/2004	11.6	2110	*9.70*	*0.00*	2	8.8	12.8	1.4	3.3	20.7	1.2
46	Jac-0165	AP	5/29/1997	13.2	1000	*9.70*	*0.00*	3	14.0	75057.4	2.5	5.0	116715.0	2.1
47	Jac-0166	AP	5/27/1997	13.9	960	8.76	3.00	4	14.8	211.7	5.0	5.0	307.2	3.9
48	Jef-0312	VR	4/15/1999	12.9	480	6.68	3.89	3	2793.6	910.1	76.4	987.6	1375.3	62.9
49	Jef-0327S	VR	9/14/2004	13.7		12.61	3.84	--	--	--	--	--	--	--

Table 2. Summary of recharge data and chlorofluorocarbon (CFC) concentrations in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: °C, degrees Celsius; Rech. elev., recharge elevation; ft, feet; ccSTP/L, cubic centimeters per liter at standard temperature and pressure; pg/kg. picograms per kilogram; pptv, calculated parts per trillion by volume; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system. Italicized recharge-temperature values are estimates from mean annual temperature; italicized excess-air values are estimates.]

Map Number	Station Name	Regional Aquifer System	Sample Date	Water Temp (°C)	Rech. Elev. (ft)	Assigned Recharge Temperature (°C)	N_2-Ar Excess Air (ccSTP/L)	Number of CFC Ampules Analyzed	Average Concentration, in pg/kg			Average Calculated Atmospheric Mixing Ratio, in pptv		
									CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
50	Jef-0579	VR	7/15/2002	12.9	600	13.85	1.97	3	912.9	367.9	93.8	398.2	677.4	97.9
51	Jef-0581	VR	7/16/2002	16	540	14.87	2.25	3	1922.4	529.6	69.6	880.3	1015.4	76.4
52	Jef-0585	VR	7/21/2004	13.7	540	14.81	5.12	2	1007.2	22543.5	28.3	456.3	41874.1	30.2
53	Jef-0590	VR	9/16/2004	12.6	500	13.15	3.65	3	2061.6	1216.0	77.9	860.0	2125.7	76.7
54	Jef-0592	VR	7/27/2004	14.5	540	15.94	5.01	2	884.3	9873.5	89.4	423.6	19244.8	101.4
55	Jef-0603	VR	9/16/2004	14.1	510	11.40	8.60	2	24.9	17.9	30.9	9.4	27.7	26.6
56	Jef-0659S	VR	9/16/2004	13.3	500	12.61	3.84	2	1313.6	513.7	94.1	532.5	874.7	89.9
57	Kan-0927	AP	5/28/1997	13.4	1000	9.36	2.90	4	135.6	104.9	25.0	47.1	157.2	20.2
58	Kan-0928	AP	5/29/1997	14.8	700	11.16	3.23	4	2.3	47079.8	0.4	0.9	75898.7	0.3
59	Kan-0932	AP	5/5/1997	13.4	1120	11.29	5.27	3	300.6	257.3	63.1	115.9	416.2	56.5
60	Kan-0934	AP	5/6/1997	13.4	870	12.18	-0.71	4	21.3	70.9	15.3	8.6	125.1	15.0
61	Kan-0935	AP	5/5/1998	13.8	1440	10.75	3.46	3	161.3	103.5	18.7	61.4	167.8	16.7
62	Kan-0938	AP	6/22/1998	14.4	1580	11.33	2.83	3	9.2	1.8	0.0	3.6	3.0	0.0
63	Lew-0219	AP	10/9/1997	16.7	1070	11.25	3.55	4	22.5	23.2	6.0	8.8	38.4	5.5
64	Lew-0220	AP	8/27/1998	19.6	1300	*10.70*	*0.00*	3	28.8	172.0	51.9	10.5	276.5	45.2
65	Lin-0179	AP	4/6/1999	14.5	660	*11.30*	*0.00*	3	0.9	8.9	0.0	0.3	13.4	0.0
66	Lin-0180	AP	4/5/1999	14.4	1000	9.88	3.88	3	0.2	72.1	0.0	0.1	109.9	0.0
67	Log-0198	AP	4/8/1999	14.7	1300	*11.20*	*0.00*	3	4.5	1.1	0.0	1.6	1.7	0.0
68	Mar-0296	AP	6/27/2000	11.9	1440	12.22	4.02	3	227.3	169.9	77.3	93.4	293.4	74.6
69	Mas-0917	ORA	5/11/1999	15.7	620	12.58	2.51	3	4038.4	610.9	165.0	1647.0	1056.0	159.6
70	Mcd-0109	AP	5/19/1999	15.6	2240	11.76	4.32	3	18.2	47.6	0.5	7.5	82.6	0.5
71	Mer-0163	AP	7/18/2000	12.7	2680	12.27	2.62	4	41.8	10.4	--	18.1	19.1	--
72	Mer-0170	AP	5/14/1997	12.6	2600	*11.70*	*0.00*	4	0.0	0.0	0.0	0.0	0.0	0.0
73	Mig-0140	AP	5/18/1999	14.4	1800	12.35	0.60	3	408.0	244.8	61.5	172.6	445.2	62.3
74	Min-0168	VR	6/24/2003	13.2	840	7.31	13.72	3	7.2	29.2	0.0	2.2	36.3	0.0

Table 2. Summary of recharge data and chlorofluorocarbon (CFC) concentrations in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: °C, degrees Celsius; Rech. elev., recharge elevation; ft, feet; ccSTP/L, cubic centimeters per liter at standard temperature and pressure; pg/kg. picograms per kilogram; pptv, calculated parts per trillion by volume; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system. Italicized recharge-temperature values are estimates from mean annual temperature; italicized excess-air values are estimates.]

Map Number	Station Name	Regional Aquifer System	Sample Date	Water Temp (°C)	Rech. Elev. (ft)	Assigned Recharge Temperature (°C)	N_2-Ar Excess Air (ccSTP/L)	Number of CFC Ampules Analyzed	Average Concentration, in pg/kg			Average Calculated Atmospheric Mixing Ratio, in pptv		
									CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
75	Min-0169	VR	6/24/2003	13	960	4.92	9.09	3	40.1	2.5	0.0	14.2	3.7	0.0
76	Min-0170	VR	6/25/2003	13.3	3600	11.27	8.52	3	64.2	72.8	18.3	24.3	113.4	15.8
77	Min-0171	VR	6/26/2003	12.7	1960	9.65	3.98	3	213.1	165.7	30.2	77.7	258.3	25.5
78	Mng-0584	AP	9/23/1997	14.4	1140	9.19	-0.30	3	104.0	393.0	0.0	37.6	596.0	0.0
79	Mnr-0148	AP	7/19/2000	14.1	2240	12.33	3.14	4	601.2	287.9	126.5	256.5	518.6	127.3
80	Nic-0207	AP	6/5/1997	13.8	1600	7.43	3.30	3	1.3	7.3	0.0	0.4	10.1	0.0
81	Nic-0208	AP	6/16/1997	12.5	2200	6.40	2.83	4	33.0	27.4	0.0	12.4	44.3	0.0
82	Nic-0209	AP	6/8/1998	11.8	1880	7.52	3.29	3	3.5	112.6	0.0	1.1	158.4	0.0
83	Nic-0211	AP	6/10/1998	12.5	2480	9.81	-0.62	3	24.7	23.8	2.7	9.4	39.8	2.4
84	Nic-0212	AP	5/19/1998	13	1680	9.31	1.84	2	258.8	192.6	72.3	92.0	297.6	60.2
85	Nic-0213	AP	5/28/1998	13.8	2200	9.79	8.48	2	7.6	170.3	0.0	2.8	259.8	0.0
86	Nic-0214	AP	6/3/1998	12.8	2440	13.22	4.60	2	6.5	2.1	31.9	2.9	4.0	33.6
87	Nic-0215	AP	6/2/1998	12.4	2440	3.26	4.56	1	880.5	341.8	66.6	332.7	548.7	58.4
88	Nic-0217	AP	6/12/1998	12.5	2520	9.03	6.63	3	38.3	23.4	0.8	13.7	35.3	0.6
89	Nic-0218	AP	6/17/1998	12.1	2560	12.75	2.56	3	281.3	227.7	35.8	124.4	425.6	37.5
90	Nic-0219	AP	6/4/1998	12.5	2800	7.42	3.48	3	6.0	3.3	0.0	2.0	4.7	0.0
91	Nic-0220	AP	4/28/1999	12.8	2120	8.44	2.66	3	6.6	3281.8	0.0	2.3	4901.5	0.0
92	Pen-0163	VR	7/18/2002	12.8	2840	9.65	1.89	3	479.8	1410.3	64.2	181.5	2311.4	56.9
93	Pen-0164	VR	8/6/2002	13.2	2840	*9.40*	*0.00*	4	31.4	42.7	8.4	12.1	71.1	7.6
94	Poc-0257	AP	5/20/1997	10.2	3900	5.46	2.48	3	283.6	209.7	25.6	113.7	361.5	24.1
95	Poc-0258	AP	5/21/1997	12.3	3160	*9.30*	*0.00*	2	411.5	347.5	52.4	160.5	584.7	48.0
96	Poc-0262	VR	7/11/2000	11.6	3360	7.29	4.13	4	49.5	36.2	10.1	16.6	52.8	7.7
97	Poc-0263	AP	7/8/2003	9.5	4700	7.28	5.11	3	28.9	42.1	0.0	10.2	63.8	0.0
98	Poc-0265	AP	7/9/2003	11.5	3600	9.91	1.19	3	621.8	474.9	86.8	246.0	816.1	80.9
99	Pre-0169	AP	9/24/1997	14	1790	*10.00*	*0.00*	3	438.2	522.4	44.1	165.6	851.8	39.1

Table 2. Summary of recharge data and chlorofluorocarbon (CFC) concentrations in West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: °C, degrees Celsius; Rech. elev., recharge elevation; ft, feet; ccSTP/L, cubic centimeters per liter at standard temperature and pressure; pg/kg. picograms per kilogram; pptv, calculated parts per trillion by volume; --, no data reported; AP, Appalachian Plateau aquifer system; VR, Valley and Ridge aquifer system; ORA, Ohio River alluvial aquifer system. Italicized recharge-temperature values are estimates from mean annual temperature; italicized excess-air values are estimates.]

Map Number	Station Name	Regional Aquifer System	Sample Date	Water Temp (°C)	Rech. Elev. (ft)	Assigned Recharge Temperature (°C)	N_2-Ar Excess Air (ccSTP/L)	Number of CFC Ampules Analyzed	Average Concentration, in pg/kg			Average Calculated Atmospheric Mixing Ratio, in pptv		
									CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
100	Pre-0170	AP	9/29/1997	13.9	1290	*10.00*	*0.00*	3	32.0	38.1	7.7	12.2	62.7	6.9
101	Ral-0220	AP	5/13/1997	11.3	2850	9.10	1.20	4	10526.7	255.1	47.7	3870.6	409.5	41.2
102	Ral-0221	AP	5/27/1998	14.9	2584	14.95	1.02	3	463.3	223.4	58.9	230.7	469.5	70.9
103	Ran-0278	AP	7/9/2003	14.2	2800	11.43	2.35	3	45.4	--	0.0	18.9	--	0.0
104	Sum-0099	AP	5/22/1997	14.1	1956	9.44	2.05	3	98.3	144.1	27.3	35.6	226.0	23.2
105	Sum-0103	AP	6/18/1997	11.7	2658	10.03	3.73	3	0.3	0.0	0.0	0.1	0.0	0.0
106	Sum-0105	AP	6/18/1998	11.6	2380	8.75	16.14	3	19.4	49.1	0.9	6.9	69.6	0.7
107	Ups-0180	AP	10/20/1997	13.9	1430	*10.50*	*0.00*	3	139.8	67.2	0.0	51.6	107.1	0.0
108	Web-0237	AP	6/11/1997	12	2640	*10.00*	*0.00*	2	18.2	41961.4	4.3	7.0	69275.2	3.9
109	Wet-0111	ORA	5/3/1999	14.4	1220	11.26	5.43	3	5864.2	3072.1	451.2	2264.4	4974.1	404.5
110	Woo-0185	ORA	5/6/1999	13.3	700	8.76	4.13	3	1812.5	908.3	26.4	600.0	1294.7	20.2
111	Woo-0196	ORA	4/29/1999	14	780	12.51	3.33	3	1862.9	769.7	27.0	760.2	1324.4	26.0

Table 3. Summary of apparent chlorofluorocarbon (CFC) ages and uncertainties for water samples from aquifers of West Virginia.

[Site locations shown in fig. 1. Abbreviations: C, contaminated; NP, not possible; nd, not determined; modern, ground water recharged after 1995; P, piston flow; M, binary mixture]

Map Number	Station Name	Sample Date	Apparent Age and Uncertainty, in Years						Apparent Age Young Fraction, in Years	Percent Young Water	Model	Basis of Apparent Age
			CFC-11	CFC-12	CFC-113	CFC-11/ CFC-12	CFC-113/ CFC-11	CFC-113/ CFC-12				
0	Bar-0147	10/21/1997	33.3 ± 2.5	31.8 ± 3.0	15.8 ± 4.0	NP	NP	NP	31.8	~100	P	CFC-12
1	Bar-0148	10/8/1997	45.3 ± 1.0	C	nd	NP	NP	NP	nd	nd	nd	nd
2	Ber-0150	4/14/1999	C	C	10.8 ± 4.5	NP	NP	NP	10.8	~100	P	CFC-113
3	Boo-0253	6/3/1997	nd	47.9 ± 1.0	nd	NP	NP	NP	nd	nd	nd	nd
4	Boo-0254	5/7/1997	40.8 ± 2.0	44.3 ± 2.0	nd	24.3	NP	NP	24.3	7.2	M	CFC-11/CFC-12
5	Boo-0256	5/4/1998	33.3 ± 2.5	26.3 ± 4.0	22.3 ± 3.5	NP	NP	17.3	17.3	52.2	M	CFC-113/CFC-12
6	Boo-0257	5/29/1998	47.9 ± 1.0	nd	nd	NP	NP	NP	nd	nd	nd	nd
7	Boo-0258	5/6/1998	22.3 ± 4.0	18.8 ± 7.5	11.3 ± 4.0	NP	NP	NP	18.8	~100	P	CFC-12
8	Boo-0259	6/23/1998	44.5 ± 1.0	47.0 ± 3.0	nd	37.5	NP	NP	37.5	25.0	M	CFC-11/CFC-12
9	Boo-0260	5/15/1998	49.9 ± 0.0	51.9 ± 1.0	nd	43.4	NP	NP	43.4	17.0	M	CFC-11/CFC-12
10	Brx-0269	6/10/1997	47.4 ± 1.0	48.4 ± 1.0	nd	42.4	NP	NP	42.4	38.0	M	CFC-11/CFC-12
11	Brx-0270	6/9/1997	20.9 ± 5.0	15.4 ± 8.5	11.9 ± 3.5	NP	NP	9.9	9.9	79.6	M	CFC-113/CFC-12
12	Cab-0233	4/9/1999	48.8 ± 1.0	55.8 ± 1.0	nd	NP	NP	NP	55.8	~100	P	CFC-12
13	Cla-0141	5/8/1997	33.4 ± 2.0	27.4 ± 3.0	20.4 ± 3.5	NP	NP	11.9	11.9	34.7	M	CFC-113/CFC-12
14	Cla-0142	6/4/1997	48.4 ± 1.0	51.4 ± 1.0	nd	40.4	NP	NP	40.4	9.0	M	CFC-11/CFC-12
15	Fay-0233	7/20/2000	46.6 ± 2.0	48.6 ± 3.0	nd	40.1	NP	NP	40.1	31.0	M	CFC-11/CFC-12
16	Fay-0234	4/28/1999	48.3 ± 1.0	C	nd	NP	NP	NP	nd	nd	nd	nd
17	Fay-0267	6/2/1997	33.9 ± 2.0	28.9 ± 3.0	27.9 ± 3.0	NP	7.9	22.9	22.9	51.8	M	CFC-113/CFC-12
18	Fay-0270	5/22/1998	45.9 ± 1.0	25.4 ± 3.5	29.9 ± 3.0	NP	NP	NP	25.4	~100	P	CFC-12
19	Fay-0272	5/13/1998	37.4 ± 2.0	35.4 ± 3.0	26.9 ± 3.0	NP	NP	10.9	10.9	12.4	M	CFC-113/CFC-12
20	Fay-0274	5/21/1998	14.4 ± 8.5	0.9 ± 16	C	NP	NP	NP	nd	nd	nd	nd
21	Fay-0275	5/12/1998	10.9 ± 15	6.9 ± 7.0	2.9 ± 11.5	NP	NP	NP	nd	nd	nd	nd
22	Fay-0276	5/8/1998	26.4 ± 3.0	24.4 ± 4.0	C	NP	NP	NP	24.4	~100	P	CFC-12
23	Fay-0279	5/26/1998	49.9 ± 0.0	55.9 ± 1.0	nd	32.4	NP	NP	32.4	1.1	M	CFC-11/CFC-12
24	Fay-0282	8/4/2000	34.1 ± 3.0	42.1 ± 3.0	nd	NP	NP	NP	nd	nd	nd	nd
25	Gil-0045	7/7/2000	46.5 ± 1.5	51.5 ± 2.0	nd	24.0	NP	NP	24.0	2.4	M	CFC-11/CFC-12
26	Gil-0198	7/6/2000	50.0 ± 1.0	43.0 ± 3.0	nd	NP	NP	NP	43.0	~100	P	CFC-12
27	Grb-0167	4/26/1999	46.8 ± 1.0	29.3 ± 4.0	20.8 ± 3.0	NP	NP	10.8	10.8	28.0	M	CFC-113/CFC-12

Table 3. Summary of apparent chlorofluorocarbon (CFC) ages and uncertainties for water samples from aquifers of West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: C, contaminated; NP, not possible; nd, not determined; modern, ground water recharged after 1995; P, piston flow; M, binary mixture]

Map Number	Station Name	Sample Date	Apparent Age and Uncertainty, in Years						Apparent Age Young Fraction, in Years	Percent Young Water	Model	Basis of Apparent Age
			CFC-11	CFC-12	CFC-113	CFC-11/ CFC-12	CFC-113/ CFC-11	CFC-113/ CFC-12				
28	Grb-0208	4/27/1999	44.8 ± 1.0	18.3 ± 8.0	C	NP	NP	NP	18.3	~100	P	CFC-12
29	Grb-0280	5/13/1997	36.4 ± 2.0	31.4 ± 3.0	24.4 ± 3.0	NP	NP	12.4	12.4	21.8	M	CFC-113/CFC-12
30	Grb-0281	5/12/1997	27.4 ± 3.0	19.4 ± 7.5	28.4 ± 3.0	NP	NP	NP	27.9	~100	P	CFC-11, CFC-113
31	Grb-0282	5/21/1997	34.9 ± 2.5	30.9 ± 3.5	28.4 ± 3.5	NP	6.4	19.4	19.4	30.6	M	CFC-113/CFC-12
32	Grb-0283	5/19/1997	20.9 ± 5.5	19.4 ± 7.0	14.9 ± 4.0	NP	10.9	12.4	12.4	75.0	M	CFC-113/CFC-12
33	Grb-0284	6/16/1998	C	32.0 ± 3.0	24.0 ± 3.0	NP	NP	10.5	10.5	18.5	M	CFC-113/CFC-12
34	Grb-0285	4/27/1999	51.3 ± 1.0	56.3 ± 1.0	nd	39.3	NP	NP	39.3	2.9	M	CFC-11/CFC-12
35	Grb-0287	7/13/2000	38.5 ± 2.0	35.5 ± 3.0	38.0 ± 2.5	NP	20.5	NP	20.5	9.2	M	CFC-113/CFC-11
36	Grt-0106	6/25/2003	33.0 ± 2.5	41.0 ± 3.0	50.5 ± 0.0	NP	NP	NP	nd	nd	nd	nd
37	Har-0172	9/30/1997	38.2 ± 3.0	34.7 ± 2.5	37.2 ± 3.0	NP	15.2	NP	34.7	~100	P	CFC-12
38	Hmp-0379	6/11/2001	35.9 ± 2.0	29.4 ± 4.0	23.4 ± 3.5	NP	NP	16.9	16.9	44.9	M	CFC-113/CFC-12
39	Hmp-0380	6/12/2001	48.4 ± 1.5	46.9 ± 2.0	nd	45.4	NP	NP	46.9	~100	P	CFC-12
40	Hmp-0382	6/13/2001	41.5 ± 2.0	39.5 ± 2.5	29.5 ± 3.5	NP	NP	10.0	10.0	10.2	M	CFC-113/CFC-12
41	Hmp-0383	6/13/2001	47.0 ± 1.5	38.0 ± 3.0	28.0 ± 3.0	NP	NP	10.0	10.0	11.7	M	CFC-113/CFC-12
42	Hnc-0042	7/23/2002	26.6 ± 4.0	21.1 ± 8.0	28.1 ± 3.5	NP	NP	NP	21.1	~100	P	CFC-12
43	Hrd-0019S	2/25/2004	19.2 ± 8.5	23.2 ± 7.5	19.7 ± 3.0	NP	NP	17.2	17.2	77.6	M	CFC-113/CFC-12
44	Hrd-0300	6/14/2001	35.5 ± 3.0	34.5 ± 3.0	30.5 ± 3.0	NP	16.0	22.0	22.0	31.6	M	CFC-113/CFC-12
45	Hrd-0301	2/25/2004	49.7 ± 2.0	48.2 ± 2.0	nd	47.2	NP	27.2	27.2	8.0	M	CFC-113/CFC-12
46	Jac-0165	5/29/1997	41.4 ± 2.0	C	34.4 ± 3.0	NP	NP	NP	nd	nd	nd	nd
47	Jac-0166	5/27/1997	41.4 ± 2.0	17.9 ± 8.0	30.4 ± 3.5	NP	NP	NP	17.9	~100	P	CFC-12
48	Jef-0312	4/15/1999	C	C	11.3 ± 4.0	NP	NP	NP	11.3	~100	P	CFC-113
49	Jef-0327S	9/14/2004	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
50	Jef-0579	7/15/2002	C	C	C	NP	NP	NP	nd	nd	nd	nd
51	Jef-0581	7/16/2002	C	C	12.5 ± 13.5	NP	NP	NP	12.5	~100	P	CFC-113
52	Jef-0585	7/21/2004	C	C	22.6 ± 4.0	NP	NP	NP	22.6	~100	P	CFC-113
53	Jef-0590	9/16/2004	C	C	14.2 ± 13.5	NP	NP	NP	14.2	~100	P	CFC-113
54	Jef-0592	7/27/2004	C	C	C	NP	NP	NP	nd	nd	nd	nd
55	Jef-0603	9/16/2004	45.7 ± 2.5	46.7 ± 3.0	23.7 ± 4.0	38.7	NP	NP	38.7	35.7	M	CFC-11/CFC-12

Table 3. Summary of apparent chlorofluorocarbon (CFC) ages and uncertainties for water samples from aquifers of West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: C, contaminated; NP, not possible; nd, not determined; modern, ground water recharged after 1995; P, piston flow; M, binary mixture]

Map Number	Station Name	Sample Date	Apparent Age and Uncertainty, in Years						Apparent Age Young Fraction, in Years	Percent Young Water	Model	Basis of Apparent Age
			CFC-11	CFC-12	CFC-113	CFC-11/ CFC-12	CFC-113/ CFC-11	CFC-113/ CFC-12				
56	Jef-0659S	9/16/2004	C	C	C	NP	NP	NP	nd	nd	nd	nd
57	Kan-0927	5/28/1997	28.9 ± 3.0	25.9 ± 4.0	18.4 ± 3.5	NP	NP	9.9	9.9	35.1	M	CFC-113/CFC-12
58	Kan-0928	5/29/1997	46.4 ± 1.0	C	nd	NP	NP	NP	nd	nd	nd	nd
59	Kan-0932	5/5/1997	22.3 ± 3.0	11.3 ± 7.5	10.3 ± 4.0	NP	NP	9.3	9.3	92.3	M	CFC-113/CFC-12
60	Kan-0934	5/6/1997	38.8 ± 3.0	27.8 ± 4.0	20.8 ± 3.0	NP	NP	11.3	11.3	31.2	M	CFC-113/CFC-12
61	Kan-0935	5/5/1998	28.3 ± 2.5	26.3 ± 4.0	20.8 ± 3.0	NP	9.3	14.3	14.3	44.9	M	CFC-113/CFC-12
62	Kan-0938	6/22/1998	43.5 ± 1.0	52.0 ± 1.0	nd	NP	NP	NP	52.0	~100	P	CFC-12
63	Lew-0219	10/9/1997	38.8 ± 3.0	37.3 ± 3.0	28.3 ± 3.0	NP	NP	9.3	9.3	8.3	M	CFC-113/CFC-12
64	Lew-0220	8/27/1998	38.7 ± 2.5	21.2 ± 7.0	13.2 ± 3.0	NP	NP	7.2	7.2	56.3	M	CFC-113/CFC-12
65	Lin-0179	4/6/1999	50.8 ± 1.0	46.3 ± 2.5	nd	NP	NP	NP	nd	nd	nd	nd
66	Lin-0180	4/5/1999	nd	30.8 ± 3.0	nd	NP	NP	NP	nd	nd	nd	nd
67	Log-0198	4/8/1999	46.8 ± 1.0	54.3 ± 2.0	nd	NP	NP	NP	nd	nd	nd	nd
68	Mar-0296	6/27/2000	27.5 ± 3.0	22.0 ± 7.0	10.5 ± 9.0	NP	NP	NP	22.0	~100	P	CFC-12
69	Mas-0917	5/11/1999	C	C	C	NP	NP	NP	nd	nd	nd	nd
70	Mcd-0109	5/19/1999	41.4 ± 3.0	33.4 ± 3.0	nd	NP	NP	NP	33.4	~100	P	CFC-12
71	Mer-0163	7/18/2000	37.5 ± 2.5	45.1 ± 2.0	nd	NP	NP	NP	nd	nd	nd	nd
72	Mer-0170	5/14/1997	nd	nd	nd	NP	NP	NP	nd	nd	nd	nd
73	Mig-0140	5/18/1999	19.4 ± 9.0	12.4 ± 8.5	11.4 ± 3.5	NP	NP	10.9	10.9	95.7	M	CFC-113/CFC-12
74	Min-0168	6/24/2003	50.5 ± 1.0	43.5 ± 3.0	nd	NP	NP	NP	43.5	~100	P	CFC-12
75	Min-0169	6/24/2003	42.0 ± 2.0	56.5 ± 1.0	nd	NP	NP	NP	nd	nd	nd	nd
76	Min-0170	6/25/2003	39.0 ± 2.5	35.0 ± 3.0	26.5 ± 3.0	NP	NP	15.0	15.0	24.4	M	CFC-113/CFC-12
77	Min-0171	6/26/2003	32.0 ± 3.0	27.0 ± 6.0	23.0 ± 3.0	NP	NP	19.5	19.5	68.7	M	CFC-113/CFC-12
78	Mng-0584	9/23/1997	30.7 ± 2.5	C	nd	NP	NP	NP	nd	nd	nd	nd
79	Mnr-0148	7/19/2000	12.1 ± 10	8.6 ± 7.5	C	NP	NP	NP	8.6	~100	P	CFC-12
80	Nic-0207	6/5/1997	48.4 ± 1.0	45.9 ± 2.0	nd	NP	NP	NP	45.9	~100	P	CFC-12
81	Nic-0208	6/16/1997	36.5 ± 2.5	36.0 ± 3.0	nd	NP	NP	NP	36.0	~100	P	CFC-12
82	Nic-0209	6/8/1998	46.9 ± 1.0	26.9 ± 4.0	nd	NP	NP	NP	26.9	~100	P	CFC-12
83	Nic-0211	6/10/1998	39.4 ± 3.0	37.4 ± 3.0	34.9 ± 3.0	NP	9.9	20.9	20.9	15.0	M	CFC-113/CFC-12

Table 3. Summary of apparent chlorofluorocarbon (CFC) ages and uncertainties for water samples from aquifers of West Virginia.—Continued

[Site locations shown in fig. 1. Abbreviations: C, contaminated; NP, not possible; nd, not determined; modern, ground water recharged after 1995; P, piston flow; M, binary mixture]

Map Number	Station Name	Sample Date	Apparent Age and Uncertainty, in Years						Apparent Age Young Fraction, in Years	Percent Young Water	Model	Basis of Apparent Age
			CFC-11	CFC-12	CFC-113	CFC-11/ CFC-12	CFC-113/ CFC-11	CFC-113/ CFC-12				
84	Nic-0212	5/19/1998	25.4 ± 3.5	19.9 ± 8.0	10.9 ± 4.0	NP	NP	NP	nd	nd	nd	nd
85	Nic-0213	5/28/1998	44.4 ± 2.0	21.9 ± 5.5	nd	NP	NP	NP	nd	nd	nd	nd
86	Nic-0214	6/3/1998	44.4 ± 2.0	50.9 ± 1.5	15.4 ± 3.5	NP	NP	NP	nd	nd	nd	nd
87	Nic-0215	6/2/1998	C	C	10.9 ± 3.5	NP	NP	NP	nd	nd	nd	nd
88	Nic-0217	6/12/1998	36.9 ± 2.5	38.4 ± 3.0	43.4 ± 3.0	29.4	NP	NP	29.4	30.9	M	CFC-11/CFC-12
89	Nic-0218	6/17/1998	23.0 ± 4.0	12.0 ± 7.5	14.5 ± 3.0	NP	6.5	NP	6.5	46.1	M	CFC-113/CFC-11
90	Nic-0219	6/4/1998	45.4 ± 1.5	50.4 ± 2.0	nd	27.4	NP	NP	27.4	3.3	M	CFC-11/CFC-12
91	Nic-0220	4/28/1999	45.8 ± 1.0	C	nd	NP	NP	NP	nd	nd	nd	nd
92	Pen-0163	7/18/2002	21.0 ± 9.0	C	15.5 ± 3.5	NP	7.1	NP	7.1	67.9	M	CFC-113/CFC-11
93	Pen-0164	8/6/2002	42.1 ± 2.5	37.6 ± 3.0	30.6 ± 3.0	NP	NP	18.1	18.1	18.8	M	CFC-113/CFC-12
94	Poc-0257	5/20/1997	22.9 ± 3.5	14.9 ± 8.0	17.4 ± 3.0	NP	11.9	NP	11.9	53.3	M	CFC-113/CFC-11
95	Poc-0258	5/21/1997	18.4 ± 8.0	C	11.9 ± 3.0	NP	5.9	NP	5.9	59.7	M	CFC-113/CFC-11
96	Poc-0262	7/11/2000	38.0 ± 2.5	37.5 ± 3.0	28.5 ± 3.5	35.5	NP	11.5	11.5	11.3	M	CFC-113/CFC-12
97	Poc-0263	7/8/2003	44.0 ± 3.0	39.0 ± 3.0	nd	NP	NP	NP	39.0	~100	P	CFC-12
98	Poc-0265	7/9/2003	16.0 ± 15	C	12.0 ± 4.5	NP	NP	NP	12.0	~100	P	CFC-113
99	Pre-0169	9/24/1997	18.2 ± 8.5	C	13.7 ± 3.5	NP	10.7	NP	10.7	72.2	M	CFC-113/CFC-11
100	Pre-0170	9/29/1997	37.2 ± 3.0	33.7 ± 3.0	26.7 ± 3.5	NP	NP	12.7	12.7	16.4	M	CFC-113/CFC-12
101	Ral-0220	5/13/1997	C	11.9 ± 9.0	12.9 ± 3.5	NP	NP	NP	12.4	~100	P	CFC-12, CFC-113
102	Ral-0221	5/27/1998	11.9 ± 7.5	9.9 ± 10.5	9.4 ± 5.5	NP	3.4	8.4	8.4	95.1	M	CFC-113/CFC-12
103	Ran-0278	7/9/2003	40.5 ± 2.0	nd	nd	NP	NP	NP	nd	nd	nd	nd
104	Sum-0099	5/22/1997	30.9 ± 2.5	22.4 ± 4.0	17.4 ± 3.5	NP	NP	13.4	13.4	62.6	M	CFC-113/CFC-12
105	Sum-0103	6/18/1997	51.0 ± 1.0	nd	nd	NP	NP	NP	nd	nd	nd	nd
106	Sum-0105	6/18/1998	41.0 ± 2.0	33.5 ± 2.5	43.5 ± 3.0	NP	24.0	NP	24.0	6.4	M	CFC-113/CFC-11
107	Ups-0180	10/20/1997	28.8 ± 2.5	29.8 ± 3.0	nd	21.8	NP	NP	21.8	43.8	M	CFC-11/CFC-12
108	Web-0237	6/11/1997	39.9 ± 2.0	C	30.4 ± 3.5	NP	NP	NP	nd	nd	nd	nd
109	Wet-0111	5/3/1999	C	C	C	NP	NP	NP	nd	nd	nd	nd
110	Woo-0185	5/6/1999	C	C	20.3 ± 3.5	NP	NP	NP	20.3	~100	P	CFC-113
111	Woo-0196	4/29/1999	C	C	18.3 ± 3.5	NP	NP	NP	18.3	~100	P	CFC-113

For additional information, write to:
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