Hydrogeology and Water Quality of the West Valley Creek Basin, Chester County, Pennsylvania

By Lisa A. Senior, Ronald A. Sloto, and Andrew G. Reif

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
	0.003785	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.000063	cubic meter per second
million gallons (Mgal)	3,785	cubic meter
million gallons per day per square mile [(Mgal/d)/mi^2]	0.0169	cubic meters per second per square kilometer
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.000207	cubic meter per second per meter
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day
	Temperature	
degree Fahrenheit (°F)	5/9 (°F-32) = °C	degree Celsius (°C)
	Other Abbreviations	
gram (g)		milligrams per liter (mg/L)
kilogram (kg)		milliliter (ml)
micrograms per kilogram (µg/kg)		parts per million (ppm)
micrograms per liter (µg/L)		picocuries per liter (pCi/L)

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

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ABSTRACT

The West Valley Creek Basin drains 20.9 square miles in the Piedmont Physiographic Province of southeastern Pennsylvania and is partly underlain by carbonate rocks that are highly productive aquifers. The basin is undergoing rapid urbanization that includes changes in land use and increases in demand for public water supply and wastewater disposal. Ground water is the sole source of supply in the basin.

West Valley Creek flows southwest in a 1.5-mile-wide valley that is underlain by folded and faulted carbonate rocks and trends east-northeast, parallel to regional geologic structures. The valley is flanked by hills underlain by quartzite and gneiss to the north and by phyllite and schist to the south. Surface water and ground water flow from the hills toward the center of the valley. Ground water in the valley flows west-southwest parallel to the course of the stream. Seepage investigations identified losing reaches in the headwaters area where streams are underlain by carbonate rocks and gaining reaches downstream. Tributaries contribute about 75 percent of streamflow. The ground-water and surface-water divides do not coincide in the carbonate valley. The ground-water divide is about 0.5 miles west of the surface-water divide at the eastern edge of the carbonate valley. Underflow to the east is about 1.1 inches per year. Quarry dewatering operations at the western edge of the valley may act partly as an artificial basin boundary, preventing underflow to the west.

Water budgets for 1990, a year of normal precipitation (45.8 inches), and 1991, a year of sub-normal precipitation (41.5 inches), were calculated. Streamflow was 14.61 inches in 1990 and 12.08 inches in 1991. Evapotranspiration was estimated to range from 50 to 60 percent of precipitation. Base flow was about 62 percent of streamflow in both years. Exportation by sewer systems was about 3 inches from the basin and, at times, equaled base flow during the dry autumn of 1991. Recharge was estimated to be 18.5 inches in 1990 and 13.7 inches in 1991.

Ground-water quality in the basin reflects differences in lithology and has been affected by human activities. Ground water in the carbonate rocks is naturally hard, has a near neutral pH, and contains more dissolved solids and less dissolved iron, manganese, and radon-222 than ground water in the non-carbonate rocks, which is soft, with moderately acidic to acidic pH. Regional contamination by chloride and nitrate and local contamination by organic compounds and metals was detected. Natural background concentrations are estimated to be about 1 milligram per liter for nitrate as nitrogen and less than 3 milligrams per liter for chloride. Ground water in unsewered areas and agricultural areas of the basin has median concentrations of nitrate that are greater than those in ground water from other areas; septic system effluent and fertilizer are probable sources of elevated nitrate. Water samples from wells in urbanized areas contain greater concentrations of chloride than samples from wells in residential areas; road salt is the probable source of elevated chloride. Organic solvents, especially trichloroethylene, were detected in 30 percent of the wells sampled in the urbanized carbonate valley. Most of the organic solvents and some of the metals in ground water were detected near old industrial sites.

Base-flow stream quality of West Valley Creek was determined at 15 sites from monthly sampling for 1 year. Differences in stream quality reflect differences in lithology, land use, and point sources in tributary subbasins and mainstem reaches. The chemical composition of base flow in the mainstem is dominated by ground-water discharge from carbonate rocks. Elevated concentrations of nitrate (greater than 3 milligrams per liter as nitrogen) in base flow were measured in a tributary draining agricultural land and in a tributary draining an unsewered residential area. Elevated concentrations of phosphate

(greater than 0.5 milligrams per liter as phosphorus) were measured in a stream that receives treated sewage effluent. Discharge of water containing elevated sulfate (about 250 milligrams per liter) from quarry dewatering operations contributes to the increase in sulfate concentration (of 10 to 40 milligrams per liter) in base flow downstream from the quarry. The chloride load at all stream sites is greater than the load contributed by precipitation and mineral weathering to the basin, indicating anthropogenic sources of chloride throughout the basin.

The diversity index of the benthic invertebrate community has increased since 1973 at the long-term biological monitoring site on West Valley Creek, indicating an improvement in stream quality. The improvement probably is related to controls on discharges and banning of pesticides, such as DDT, in the 1970's. Concentrations of dissolved constituents, except for chloride, determined for base flow in the autumn do not appear to have changed since 1971. Application of the seasonal Kendall test for trend indicates that concentrations of chloride in base flow have increased since 1971; this increase may be related to the increase in urbanization in the basin. The benthic community structure at the West Valley Creek site in 1991 indicates slight nutrient enrichment.

Lithium was detected in ground water and surface water downgradient from two lithium-processing facilities. Until 1991, lithium was discharged into a losing reach of West Valley Creek, thus introducing lithium into the ground-water system. The potential for cross-contamination between the ground-water and surface-water systems is great, as demonstrated by the detection of lithium in ground water and surface water downstream and downgradient from the two lithium-processing facilities. The lithium that was discharged into the creek acts as a conservative tracer in gaining reaches of West Valley Creek, maintaining a mass balance and characteristic isotopic signature. Lithium-7/lithium-6 ratios were greater in streams that are affected by sewage and by lithium-processing discharges and in ground water downgradient from the lithium-processing facilities than natural background lithium isotopic ratios.

INTRODUCTION

The center of the West Valley Creek Basin is underlain by carbonate rocks that are some of the most productive aquifers in Chester County, Pa. The basin is a major source of water for public water supplies, and the demand for ground water is increasing because of rapid residential and commercial development. Population has increased between 25 and 100 percent in the principal townships in the basin during 1980-90 (Chester County Planning Commission, 1991a) and continued commercial growth is projected for the area (Chester County Planning Commission, 1988). However, chemical contamination has reduced the availability of potable ground water. A study to assess the effects of urbanization (Sloto, 1987) pointed out the vulnerability of carbonate rocks to ground-water contamination.

West Valley Creek is one of several streams that are named Valley Creek in Chester County; the term "west" is used to differentiate the stream from another Valley Creek that drains the adjacent basin to the east. West Valley Creek is designated a cold-water, migratory fishery by the Pennsylvania Department of Environmental Resources (PaDER) (Pennsylvania Department of Environmental Resources, 1991). Broad Run, the largest tributary to West Valley Creek, is designated a high quality cold-water fishery. Some industrial, commercial, and municipal discharges to streams are regulated by PaDER according to stream designation. At present, discharges to West Valley Creek include storm runoff from roads and commercial and industrial sites, effluent from a small sewage-treatment plant, and pumpage and runoff from a quarry. Past discharges to the stream have included industrial wastewater and effluent from other sewage-treatment plants.

Ground water discharges to and is recharged by streams in carbonate rocks in southeastern Pennsylvania. Therefore, a thorough understanding of the ground-water-flow system and ground-water/surface-water relations is necessary for prudent management of the ground-water and surface-water resources.

This study was done in cooperation with the Chester County Water Resources Authority. The Chester County Health Department contributed funding for many of the water-quality analyses. Additional funding was provided by East Bradford and West Whiteland Townships.

Purpose and Scope

This report presents baseline water-quality data and quantifies water resources in the West Valley Creek Basin. These data may be used in the future to evaluate effects of urbanization or other changes in the basin. Further, a basic understanding of the hydrogeological system is provided to aid in management of the water resources in the basin. This report describes the hydrogeology of the West Valley Creek Basin and includes a description of the aquifers and ground-water/surface-water relations. Water budgets and recharge are calculated for the West Valley Creek Basin above the streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown, Pa., for 1990-91.

Ground-water and surface-water quality in the West Valley Creek Basin are described by use of both data collected for and prior to this study. Data on ground-water quality and contamination in the basin collected since 1980 are summarized. This report presents results of analysis of monthly base-flow surface-water-quality data collected during August 1990 - July 1991. Surface-water quality is related to ground-water quality in the basin. Trends in surface-water quality are described by use of a biological indicator (benthic invertebrate diversity index) developed at a long-term monitoring station on West Valley Creek.

Description of the Study Area

The West Valley Creek Basin, in eastern Chester County in southeastern Pennsylvania (fig. 1), is part of the Piedmont Physiographic Province (fig. 2). West Valley Creek, a tributary to the East Branch Brandywine Creek, drains 20.9 mi^2 and is a subbasin in the lower Delaware River Basin. The center of the basin is underlain mostly by easily eroded limestone and dolomite, which form Chester Valley (pl. 1). Chester Valley, shown as the Lowland Section of the Piedmont on figure 2, trends east-northeast across Chester County. The northern part of the Valley Creek Basin is underlain by resistant quartzites and gneiss that form the North Valley Hills; the southern part of the Valley Creek Basin is underlain by resistant phyllite, schist, and gneiss that form the South Valley Hills (fig. 3). The hills rise about 400 ft above the gently rolling valley floor.

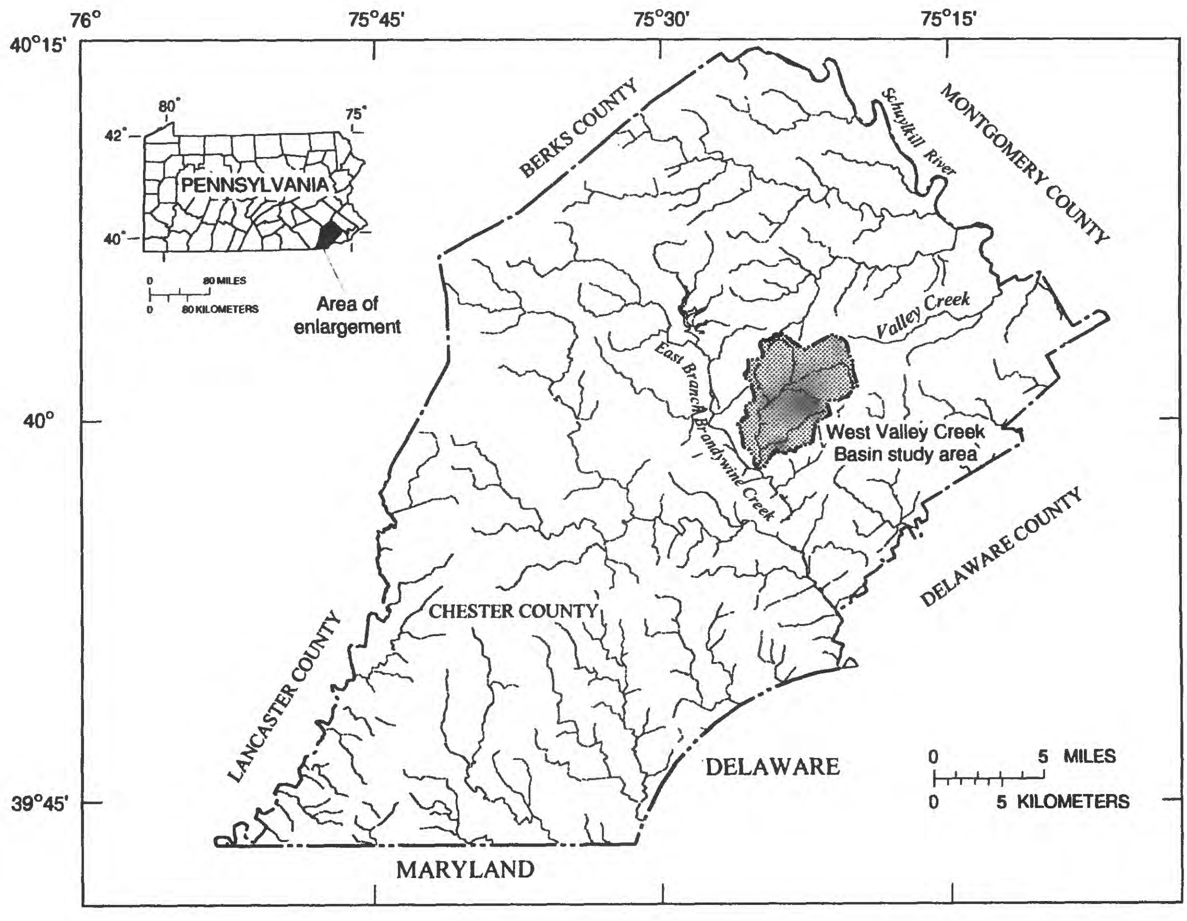


Figure 1. Location of the West Valley Creek Basin, Chester County, Pennsylvania.

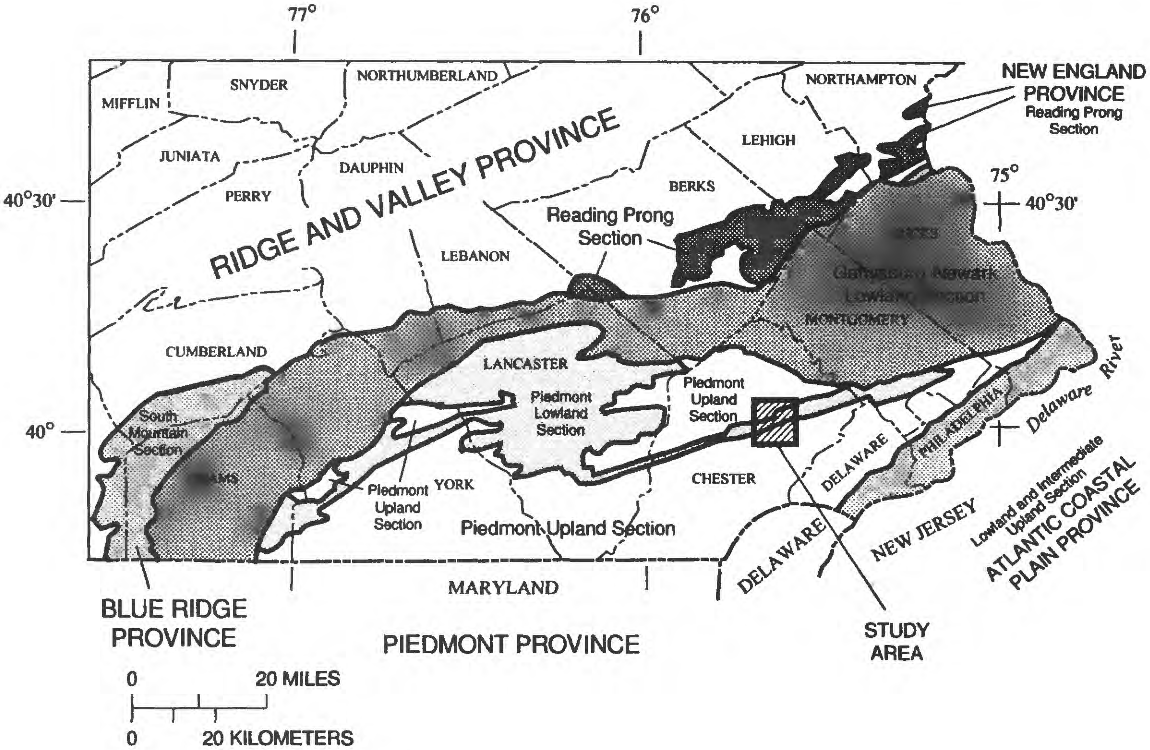


Figure 2. Physiographic provinces, southeastern Pennsylvania. (From Berg and others, 1989.)

The principal headwaters of West Valley Creek are in the South Valley Hills (fig. 3, pl. 1). The headwaters drain to the mainstem, which flows about 5.5 mi west-southwest along the axis of the Chester Valley (parallel to the trend of the valley) before abruptly turning south (perpendicular to the valley) to cut through the South Valley Hills. East of the West Valley Creek Basin, Valley Creek flows eastward, also parallel to the Chester Valley, and discharges to the Schuylkill River. West of the West Valley Creek Basin, East Branch Brandywine Creek flows south across Chester Valley and eventually joins the Delaware River. The main streams in Chester County flow south and do not necessarily follow present topography. For example, only relatively small streams (tributaries) flow parallel to the low-lying Chester Valley. The drainage pattern was probably established before the present geomorphology of Chester Valley and is related to an earlier erosional surface (Bascom and Stose, 1932).

Streamflow draining 14.5 mi^2 of the basin is measured at streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown (fig. 3). Broad Run, the major tributary to West Valley Creek, drains 4.6 mi^2 and is confluent with West Valley Creek below the streamflow-measurement station. Thirty-two percent of the entire basin (46 percent of the basin above the streamflow-measurement station) is underlain by carbonate rocks and 68 percent of the entire basin (54 percent of the basin above the streamflow-measurement station) is underlain by noncarbonate rocks that include phyllite, schist, quartzite, and gneiss.

The village of Exton is in the center of the West Valley Creek Basin at the intersections of U.S. Route 30 and Pennsylvania State Route 100. Much of the West Valley Creek Basin lies within West Whiteland Township, with successively smaller areas in East Bradford, Uwchlan, East Whiteland, and West Goshen Townships (pl. 1). Most of the past and present commercial and industrial development is near Routes 30 and 100, especially in the valley underlain by carbonate rocks. Residential development is concentrated largely in the hills and at the edges of the valley.

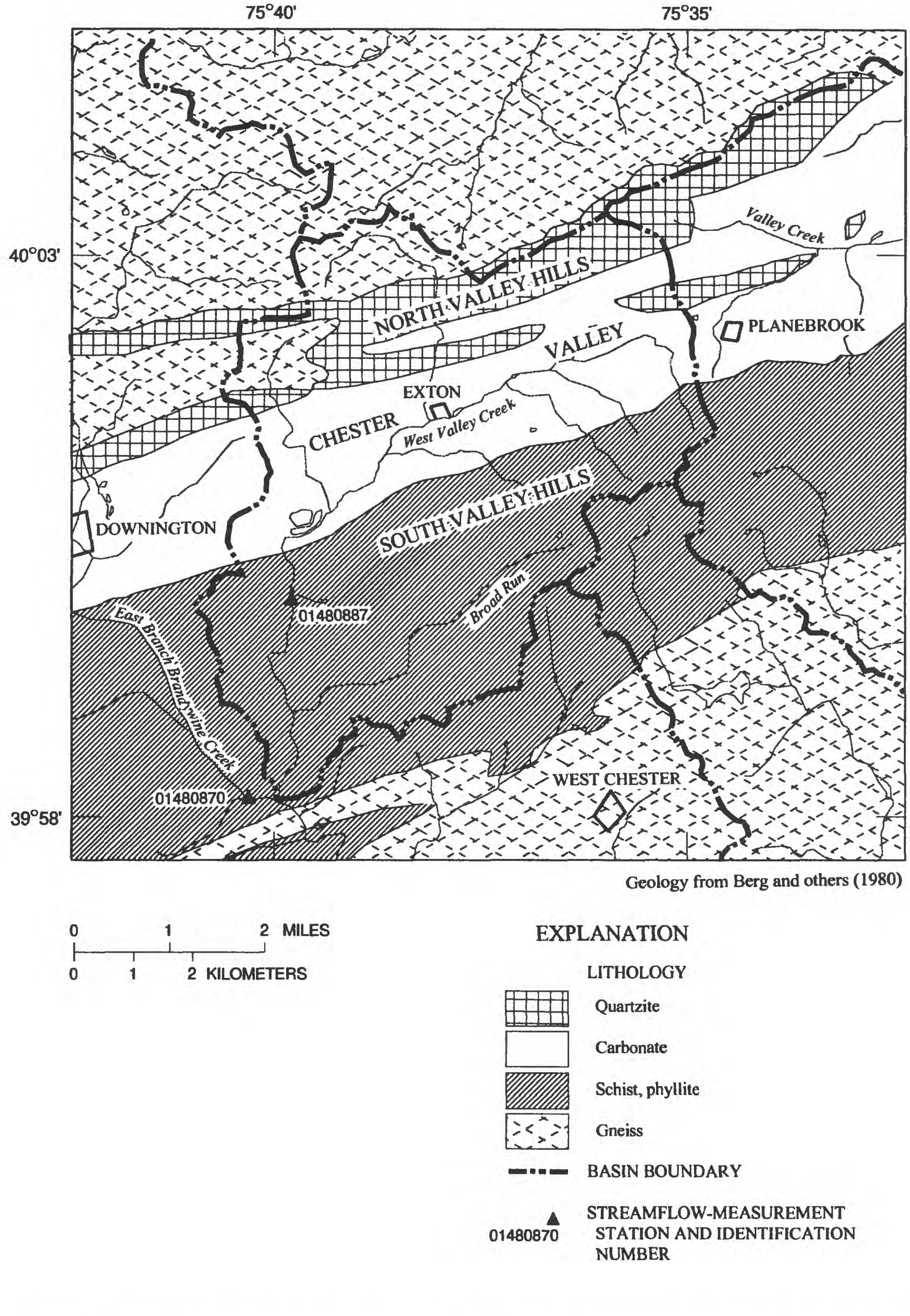


Figure 3. Generalized geology of the West Valley Creek Basin, Pennsylvania, and location of streamflow-measurement stations.

The climate in Chester County is a humid, modified continental climate characterized by warm summers and moderately cold winters. The normal (1961-90) mean annual temperature at West Chester, about 2 mi southeast of the West Valley Creek Basin, is 52.9°F (11.5°C) (National Oceanic and Atmospheric Administration, 1992). The normal (1961-90) temperature for January, the coldest month, is 29.5°F (-1.2°C), and the normal temperature for July, the warmest month, is 74.8°F (23.8°C). The normal annual (1961-90) precipitation at West Chester is 45.88 in. Precipitation is fairly evenly distributed throughout the year, although slightly more falls in May through August than in the other months.

Well-Numbering System

The well-numbering system in this report consists of a county abbreviation prefix followed by a sequentially-assigned local well number. The prefix CH denotes a well in Chester County. The prefix CH-SP denotes a spring in Chester County. In addition to the local well number, each well or spring is assigned a unique 15-digit site identification number, usually on the basis of the latitude and longitude (in degrees, minutes, and seconds) of the well and a site sequence number. Locations of selected wells and springs are shown on plate 1. Data for wells and springs shown on plate 1 are listed in table 24 in numerical sequence by local well number for each aquifer underlying the study area. Additional data on wells is given by Sloto (1989).

Previous Investigations

The geology of the West Valley Creek Basin was mapped and described by Bascom and others (1909), Bascom and Stose (1932 and 1938), Huntsman (1975), and Demmon (1977). Geologic-quadrangle maps for the study area were published by Berg and Dodge (1981). Part of the basin is included in the geologic map of Lyttle and Epstein (1987).

Hydrologic studies of Chester County, and particularly the Brandywine Creek to which West Valley Creek is tributary, include ground-water and surface-water investigations. Hall (1934) briefly discussed the water-bearing characteristics of the principal geological formations of southeastern Pennsylvania. Wolman (1955), as part of a stream channel study for the Brandywine Creek, measured discharge along the mainstem of West Valley Creek in August 1951. Olmsted and Hely (1962) described the relation between ground water and surface water in the Brandywine Creek Basin. The hydrology of the igneous and metamorphic rocks of central Chester County were described by Poth (1968). McGreevy (1974) made a seepage study of streams crossing the Chester Valley. Sloto (1987) described the effect of urbanization on the water resources of eastern Chester County. Sloto (1989) presented ground-water data for Chester County. Sloto (1990) used a digital computer model to simulate ground-water flow and the water budget of the adjacent Valley Creek Basin. Sloto (1994) described the ground-water resources of Chester County; this report supersedes McGreevy and Sloto (1977).

The water table was mapped in the carbonate rocks in eastern Chester Valley by Sloto (1987, pl. 2) and in central Chester Valley by Wood (1984). The water table was mapped in the noncarbonate rocks of the South Valley Hills by Garges (1986; 1988) and part of the North Valley Hills by McManus (1992).

Surface-water quality was described and discussed by Miller and others (1971), who collected surface-water samples for 2 years in two small basins adjacent the West Valley Creek Basin. Murphy and others (1982) evaluated results of continuous water-quality monitoring for pH, dissolved oxygen, specific conductance, and temperature at three sites on the Brandywine Creek. Moore (1987) calculated benthic-invertebrate indices and determined water-quality trends for 46 sites on streams, including one site in West Valley Creek Basin, in Chester County. Stream chemistry and benthic invertebrate data for the 46 stream sites in Chester County were reported by Moore (1989) and Lium (1976; 1977).

Acknowledgments

The cooperation of well owners, who made their wells accessible for water samples, water-level measurements, and geophysical logging, is greatly appreciated. The authors are grateful to municipal and private water purveyors, especially the Uwchlan Township Municipal Authority and West Whiteland Municipal Services Commission, which contributed essential data.

The assistance of volunteer raingage observers, who collected data on daily precipitation for 2 years, was extremely valuable and greatly appreciated. The volunteer observers were Joseph Salisbury, Uwchlan Township Municipal Authority, Waterloo Gardens, and Jeffrey Holton at the Church Farm School.

Others who contributed information and assisted in the study or who provided site access are Gene Webster, Dave Williams, and Rodney George at the General Crushed Stone Company, the Church Farm School, Devereux Foundation, and Transcontinental Gas Pipeline Corporation (Transco). Their assistance is gratefully acknowledged.

HYDROGEOLOGY

The West Valley Creek Basin is underlain by carbonate and noncarbonate rocks. All geologic units in the West Valley Creek Basin are considered to be aquifers. The geologic units are sometimes referred to as "bedrock aquifers." The geologic units generally are unconfined, fractured-rock aquifers that are recharged by precipitation and discharge locally to streams. Ground-water discharge to streams comprises more than half of streamflow, and most streams are perennial, although some reaches may go dry during periods of drought or because of seasonal fluctuations in the water table.

Geology

The rocks that underlie West Valley Creek Basin are folded, faulted, and metamorphosed clastic and carbonate rocks of Paleozoic age and igneous rocks of Precambrian age (pl. 1). The topography of the basin reflects the susceptibility of each lithology to erosion and the structure of the rocks. The Chester Valley, which cuts through the center of the basin, is underlain by limestone and dolomite of Cambrian and Ordovician age. Basal quartzite in the sedimentary sequence and Precambrian felsic gneiss underlie the North Valley Hills to the north of Chester Valley. Ordovician or older schists underlie the South Valley Hills to the south of Chester Valley.

The rocks that comprise the Chester Valley sedimentary sequence were deposited by continental margin sedimentation during the Upper Precambrian, Cambrian, and Ordovician; during that time, this area was the eastern edge of the North American continent (Rodgers, 1968, p. 141-148), and the continental basement comprised Precambrian felsic gneiss and other rocks that had been metamorphosed to amphibolite facies earlier during the Grenville orogeny (Crawford and Hoersch, 1984). Depositional environments include intertidal sand flat, subtidal channel, and tidal flat pond for the Chickies Quartzite (Goodwin and Anderson, 1974) and shallow to deep seas for the carbonate rocks (Bascom and Stose, 1938). Kauffman and Frey (1979) interpret the Antietam Quartzite as a line of barrier islands fronting the continent during early Cambrian time. Schwab (1970) interprets the Harpers Phyllite as a vertical repetition of (1) nearshore and shallow marine platform sands and (2) offshore, fine-grained, deep-water turbidite deposits. The phyllites and schists to the south of Chester Valley were deposited during the early Paleozoic time as oceanic sediments east of the North American continental edge (Crawford and Crawford, 1980; Wagner and Srogi, 1987, p. 123-124).

The rock units of the Piedmont Physiographic Province of Pennsylvania have been divided into three parts, reflecting their origin and history: (1) Precambrian gneisses of the Honeybrook Upland; (2) carbonate and clastic rocks of Paleozoic age in the Chester Valley; and (3) metamorphosed sediments, volcanic rocks, and plutonic bodies of the Glenarm Terrain (Crawford and Crawford, 1980). The stratigraphic relations of these units are given in table 1. The Paleozoic cover rocks of the Piedmont are divided into a northern and southern sequence (Lyttle and Epstein, 1987). Geologic descriptions below were taken from Bascom and Stose (1938), Lyttle and Epstein (1987), and Berg and others (1980). The nomenclature used in this report is that of Lyttle and Epstein (1987, table 1). The nomenclature of the Pennsylvania Geological Survey (table 1) has been used for previous reports on the ground-water resources of Chester County (Sloto, 1987; 1990; 1994).

Table 1. *Stratigraphic section of geologic units in the West Valley Creek Basin, Pennsylvania*

SYSTEM AND ERA	SERIES	GEOLOGIC UNIT: Lyttle and Epstein (1987)				GEOLOGIC UNIT: Berg and others (1986)		
Ordovician	Middle Ordovician						Wissahickon "Octoraro" Schist	Peters Creek Schist
Ordovician	Lower Ordovician	Conestoga Limestone				Conestoga Formation	Wissahickon "Octoraro" Schist	Peters Creek Schist
Cambrian	Upper Cambrian	Conestoga Limestone	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Conestoga Formation	Wissahickon "Octoraro" Schist	Peters Creek Schist ? / Wissahickon Formation
Cambrian	Middle Cambrian	Elbrook Formation	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Elbrook Formation	Wissahickon "Octoraro" Schist	Wissahickon Formation
Cambrian	Middle Cambrian	Ledger Dolomite	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Ledger Formation	Wissahickon "Octoraro" Schist	Wissahickon Formation
Cambrian	Lower Cambrian	Kinzers Formation	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Kinzers Formation	Wissahickon "Octoraro" Schist	Wissahickon Formation
Cambrian	Lower Cambrian	Vintage Dolomite	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Vintage Formation	Wissahickon "Octoraro" Schist	Wissahickon Formation
Cambrian	Lower Cambrian	Antietam Quartzite and Harpers Phyllite, undivided	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Antietam Formation and Harpers Formation, undivided	Wissahickon "Octoraro" Schist	Wissahickon Formation
Cambrian	Lower Cambrian	Chickies Quartzite	Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Antietam Formation and Harpers Formation, undivided	Wissahickon "Octoraro" Schist	Wissahickon Formation
Proterozoic	Late Proterozoic		Octoraro Schist	Peters Creek Schist	Wissahickon Formation	Chickies Formation	Wissahickon "Octoraro" Schist ?	Wissahickon Formation ?
Proterozoic	Middle Proterozoic	Gneiss and schist				Gneiss		

The rocks that underlie the West Valley Creek Basin were deformed and metamorphosed to variable degrees. During the early Paleozoic, a tectonic collision at the eastern edge of the North American continent caused folding of continental shelf rocks and thrusting of oceanic sediments and magmatic arc rocks west over the Grenville basement and the clastic and carbonate rocks (Wagner and Srogi, 1987, p. 122). The Chester Valley Cambrian and Ordovician quartzite and carbonate rocks were metamorphosed to greenschist facies, and the South Valley Hill schists were metamorphosed to amphibolite facies (Crawford and Crawford, 1980). The general structure of the carbonate rocks that underlie the center of the West Valley Creek Basin and the noncarbonate rocks that underlie the North Valley Hills is a south-dipping anticline (fig. 4). Within this anticline are smaller synclinal structures in the carbonate rocks and anticlinal structures that expose the Chickies Quartzite as slices within the valley (Bascom and Stose, 1938); in places, the rocks dip very steeply to the south. The contact between the noncarbonate rocks that underlie the South Valley Hills and the carbonate rocks of Chester Valley has been mapped as a thrust fault that is part of a regional fault structure called the Martic Line (Bascom and Stose, 1938). South of the Martic Line, the structures of rocks in the Glenarm Terrain were caused by complex deformation that was accompanied by metamorphism (Crawford and Crawford, 1980; Wagner and Srogi, 1987). The regional structures and the thrust contact between the noncarbonate rocks to the south of Chester Valley trends east-northeast. Other smaller faults offset regional structures; nearly north-south trending faults have been mapped as cutting across the Chester Valley at Downingtown, about 2 mi west of West Valley Creek Basin, and near Frazer, about 1.5 mi east of the West Valley Basin (Bascom and Stose, 1938).

Carbonate Rocks

A series of carbonate rocks of Cambrian and Ordovician age underlies Chester Valley. The principal formations are the Ledger Dolomite, Elbrook Formation, and Conestoga Limestone. The Vintage Dolomite and Kinzers Formation, which crop out in a narrow band, are thin and of relatively small areal extent.

Vintage Dolomite

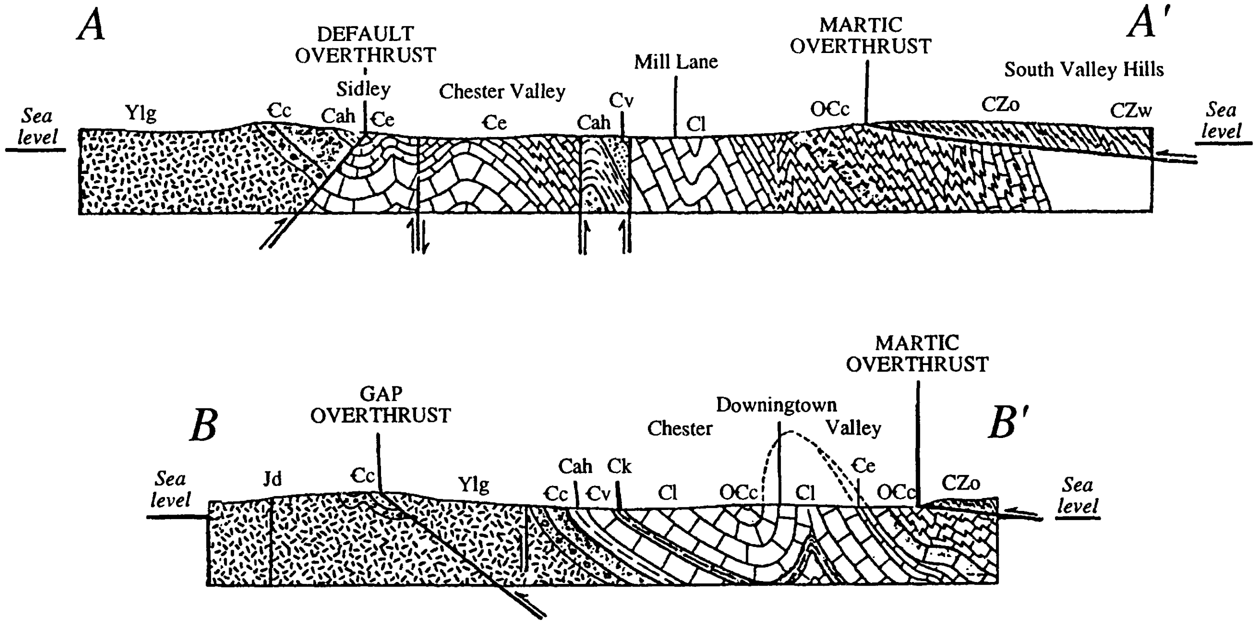
The Vintage Dolomite crops out in a narrow band in eastern Chester Valley. The Vintage is a dark-gray, granular dolomite with a wavy texture. A white marble is present at the base. The lower part of the Vintage is a fine-grained, thin- to medium-bedded, argillaceous to sandy dolomite with abundant mica on the bedding planes. The upper part is a light gray, fine- to coarse-grained, thick-bedded dolomite. The Vintage grades into the underlying Antietam Quartzite and Harpers Phyllite. The Vintage is 200 to 300 ft thick in Chester Valley.

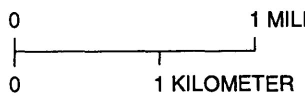
Kinzers Formation

The Kinzers Formation crops out adjacent to the Vintage Dolomite. The Kinzers is a gray, micaceous limestone and calcareous mica schist with interbeds of dark-gray shale, dark-gray argillaceous limestone, and spotted gray to white marble. The Kinzers grades downward into the Vintage Dolomite. The Kinzers is less than 30 ft thick in Chester Valley.

Ledger Dolomite

The Ledger Dolomite is a white to light gray, massive to thick-bedded, granular, relatively pure dolomite with a high magnesium content. The dolomite is interbedded with some siliceous beds and laminated limestone. The Ledger contains a few beds of marble with a high calcium content. The lower contact is gradational with the Kinzers Formation. The Ledger is 660 to 1,000 ft thick. This formation is quarried in the Chester Valley because of its high purity.





EXPLANATION

(Geologic nomenclature from Lyttle and Epstein, 1987)

Jd - diabase
OꞒc - Conestoga Limestone
Ꞓe - Elbrook Formation
Cl - Ledger Dolomite
Ck - Kinzers Formation
Ꞓv - Vintage Dolomite
Cah - Harpers Phylite and Antietam Quarztite, undivided
Cc - ChickiesQuartzite
Ylg - felsic to intermediate gneiss
CZo - Octoraro Phyllite
CZw - Wissahickon Formation

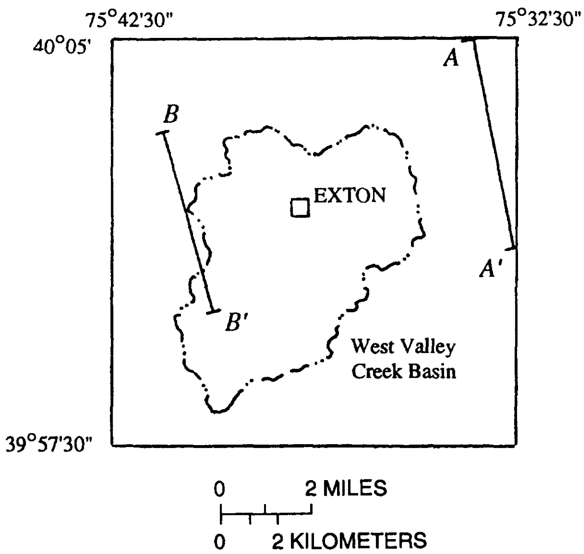


Figure 4. Structural cross sections of Chester Valley, Pennsylvania. Section lines A - A' and B - B' are shown on plate 1. (From Bascom and Stose, 1938, pl. 1.)

Elbrook Formation

The Elbrook Formation is a light-gray to white, finely laminated, fine-grained, interbedded limestone and marble. Concentrations of coarse-grained mica on parting planes are a pressure-solution residue parallel to regional cleavage. The Elbrook, 300 to 800 ft thick, forms low hills in Chester Valley. The lower contact is gradational with the Ledger Dolomite. The unit mapped as the Elbrook in Chester County may not be the same unit mapped as the Elbrook to the west of Chester County (R.T. Faill, Pennsylvania Geological Survey, written commun., 1991).

Conestoga Limestone

The Conestoga Limestone (Lyttle and Epstein, 1987) crops out along the southern edge of Chester Valley. The Conestoga is a blue-gray, thin-bedded, argillaceous limestone with intervals of a purer, granular limestone. Mica coats most of the bedding and cleavage planes. The impure part of the Conestoga has thin-bedded alterations of dark-gray, clayey, silty, slaty, micaceous layers and medium-gray, argillaceous limestone that imparts a characteristic banded appearance to the rock. Some of the basal beds are a coarse limestone conglomerate containing large pebbles and irregular masses of coarse white marble in a gray limestone. The Conestoga Limestone is 500 to 800 ft thick and unconformably overlies the Elbrook Formation. The upper contact of the Conestoga may be marked by a thrust fault with the Octoraro Phyllite overlying the Conestoga.

Noncarbonate Rocks

The area underlain by noncarbonate rocks is divided by Chester Valley. North of Chester Valley, the North Valley Hills are underlain by the Chickies Quartzite, Antietam Quartzite and Harpers Phyllite (undifferentiated) of Cambrian ages, and Precambrian leucocratic and intermediate felsic gneiss. South of Chester Valley, the South Valley Hills are underlain by Late Proterozoic to Cambrian Octoraro Phyllite, Peters Creek Schist, and Wissahickon Schist. The Peters Creek Schist and Wissahickon Schist are in the southern Piedmont sequence, and the other units are in the northern Piedmont sequence (Lyttle and Epstein, 1987).

Leucocratic and Intermediate Felsic Gneiss

The Precambrian leucocratic and intermediate felsic gneiss is a fine- to medium-grained, white to gray, microcline-microperthite-quartz gneiss associated with biotite-oligoclase-microperthite-quartz gneiss and is interlayered with amphibolite. These rocks form rolling hills that are part of the Honeybrook upland (Crawford and Crawford, 1980).

Chickies Quartzite

The Chickies Quartzite is a white to light-gray, thin- to thick-bedded, cross-bedded, medium-grained quartzite with interbeds of quartzose schist and sandy mica schist. The basal Hellam Member, which is not mapped as a separate unit in Chester County, is a coarse-grained, black-tourmaline-bearing quartzite and arkosic pebble conglomerate. The Chickies Quartzite unconformably overlies Precambrian gneissic rocks. The Chickies Quartzite is about 500 ft thick and is a very resistant unit that forms prominent hills.

Antietam Quartzite and Harpers Phyllite

The Antietam Quartzite and Harpers Phyllite are not mapped as separate units in Chester County. In general, they consist of gray, thin- to thick-bedded, laminated quartzite, quartzose schist, and sandy micaceous schist that conformably overlie the Chickies Quartzite. The Antietam Quartzite is a gray, laminated quartzite and quartzose schist that is no thicker than 200 ft thick in Chester Valley (Bascom and Stose, 1938, p. 52) and grades downward into the Harpers. The Harpers Phyllite is a gray, sandy, micaceous schist with interbeds of quartz schist and thin-bedded quartzite and is no thicker than 500 ft in the Chester Valley (Bascom and Stose, 1938, p. 51). The Antietam Quartzite and Harpers Phyllite underlie slopes of the North Valley Hills.

Octoraro Phyllite

The South Valley Hills are underlain by the Octoraro Phyllite (called the albite-chlorite facies of the Wissahickon Formation by Bascom and Stose, 1938). The Octoraro Phyllite is a bluish-gray to greenish-gray, well-foliated, quartz-muscovite-chlorite phyllite with lustrous, smooth laminae. It commonly contains quartz lenses parallel to the laminae around which the foliation wraps. The Octoraro is finer grained to the north. Small plagioclase crystals are common in some of the layers. Along the northern edge of its outcrop area, the Octoraro Phyllite may be thrust over the Conestoga Limestone. The contact between the Octoraro Phyllite and the Peters Creek Schist and Wissahickon Formations to the south has been interpreted as thrust fault (Lyttle and Epstein, 1987).

Wissahickon Formation

The Wissahickon Formation (called the oligoclase-mica facies of the Wissahickon Formation by Bascom and Stose, 1938) underlies the southern boundary of the West Valley Creek Basin. The Wissahickon Formation is a fine- to medium-grained, medium- to dark-gray to black, aluminous, pelitic schist, and feldspathic metagraywacke that weathers brownish-gray to rusty. It contains lenses or pods of altered ultramafic rocks and thin interbeds of amphibolites. Near the fault contact with the Octoraro Phyllite, it is a highly crenulated, coarse-grained, garnet-mica schist. The metamorphic grade of the formation ranges from greenschist through upper amphibolite facies.

Peters Creek Schist

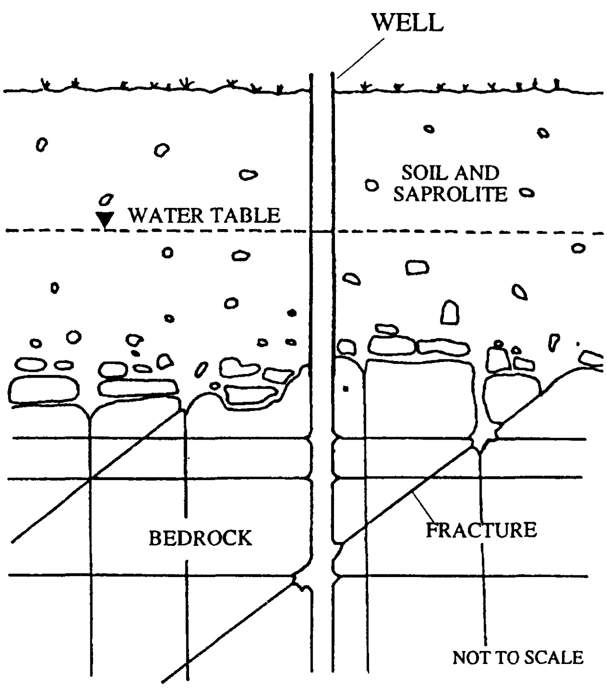
In the South Valley Hills, the Peters Creek Schist underlies Broad Run, the main tributary to West Valley Creek. The Peters Creek Schist may be in fault contact with and crops out between the Octoraro Phyllite (to the north) and the Wissahickon Formation (to the south). The Peters Creek Schist is a metagraywacke, metasemipelite, and pelite rich in quartz and magnetite. The metagraywacke and metasemipelite are fine- to medium-grained, light to medium gray and weather yellowish to reddish-brown. The metapelite is fine-grained, lustrous, greenish-gray to gray and weathers reddish brown. The metagraywacke is well bedded with graded beds. The metasemipelite and metapelite are phyllite (metapelite only), schist, and gneiss. The unit contains tectonic slivers of serpentinite.

Hydrology

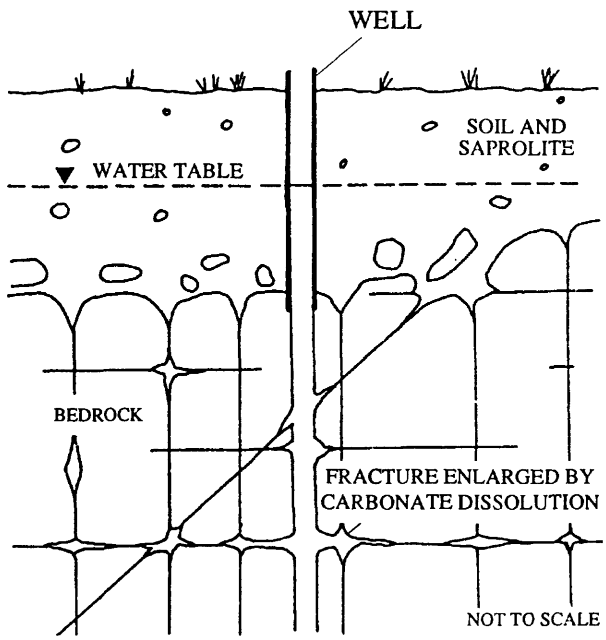
In the West Valley Creek Basin, geologic characteristics, such as structure and lithology, that affect the direction and character of ground-water and surface-water flow and the extent and nature of stream-aquifer interaction. The bedrock aquifers generally are under unconfined (water-table) conditions and are recharged by precipitation and discharge to streams. In the West Valley Creek Basin, the ground-water divides coincide with the surface-water divides (basin boundary) along topographic highs in the non-carbonate rocks but do not coincide with the surface-water divides in the carbonate rocks.

Ground Water

Ground water in bedrock aquifers flows through a network of interconnected secondary openings that include joints, faults, bedding planes, and fractures (fig. 5). The number and size of the water-bearing openings determines the secondary porosity of the rock; the number, size, and degree of interconnection of the openings determines the secondary permeability. Primary porosity in the rocks of the West Valley Creek Basin is insignificant. In carbonate rocks, these secondary openings commonly are enlarged by solution. Permeability of carbonate rock is predominately the result of solution-enlarged fractures. Some fractures enlarged by solution are several feet wide; however, most are only a fraction of an inch wide, but large quantities of water can be transmitted through these fractures. Where solution



Sketch of well tapping fractured noncarbonate rock.



Sketch of well tapping solution openings in fractured carbonate rock.

Figure 5. Water-bearing openings in noncarbonate and carbonate fractured-rock aquifers. (Modified from McGreevy and Sloto, 1977, fig. 5.)

has been active, permeability may be high; elsewhere, the same unit may be nearly impermeable. In the crystalline rocks, ground water moves through intergranular openings in the saprolite zone and through a network of interconnecting secondary openings (fractures and joints) in the underlying unweathered rock. The permeability of fractured crystalline rock depends on the number of fractures, the size of the fracture openings, and the degree of interconnection of the fractures.

The primary weathering processes are dissolution of calcite and dolomite in carbonate rock and mineral weathering in noncarbonate rock. Mineral dissolution and weathering generally are most active above and within the zone of water-table fluctuation where water movement is relatively rapid and recharge water is acidic. Below the zone of water-table fluctuation, water movement is much slower. In carbonate rocks, clay and unconsolidated material sometimes move downward from the surface, plugging openings. This plugging results in decreased well yields and turbid ground-water discharge from some wells. Some of the water that infiltrates through the soil is stored in the weathered zone of bedrock aquifers.

The depth of weathering in carbonate rocks is highly variable. Deeply weathered zones can be found adjacent to outcrops. Pinnacle weathering, caused by solution along bedding planes and fractures in dipping strata, is common in carbonate rock in Chester County. As solution enlargement moves downward in the formation, the solid rock between the weathered areas is left as pinnacles. Weathering in the noncarbonate rocks generally is less variable than in carbonate rocks. Many hand-dug wells have been completed to the bottom of the weathered zone.

The ground-water system generally is unconfined (under water-table conditions) in carbonate rock, although confined ground water is present locally. Confined conditions have been observed in wells in the Elbrook Formation in the center of Chester Valley (Sloto, 1990). Ground-water flow in carbonate rock has both local and regional components. Locally, ground water discharges to gaining reaches of streams. Regionally, ground water flows beneath surface-water divides, resulting in underflow to or from adjacent surface-water basins. In the West Valley Creek Basin, ground-water and surface-water divides do not coincide in the carbonate valley. Also, computer model simulations show that wells pumping near a surface-water divide in one surface-water basin can reduce base flow in an adjacent surface-water basin (Sloto, 1990).

The ground-water flow system in crystalline rock is local with streams acting as drains. Flow paths are short, and ground water flows from areas of higher elevation to adjacent streams. Ground-water and surface-water divides generally coincide. The hydrologic system generally is unconfined, and the water-table surface is a subdued replica of the land surface. Semi-confined ground water may occur locally. A few wells flow; these wells penetrate water-bearing zones with hydraulic heads greater than land-surface altitude.

The direction of ground-water flow is controlled by the hydraulic gradient and spatial variability of hydraulic conductivity. Transport of contaminants in a fractured-rock aquifer is greatest in highly permeable fractures; the orientation of fractures partially directs ground-water flow.

Water-bearing zones

Ground water flows through a network of interconnected secondary openings that comprise the water-bearing zones that provide water to wells. Generally, the larger and more numerous the openings, the greater the yield of a well. The frequency of water-bearing zones commonly decreases with depth.

The distribution of reported water-bearing zones was analyzed for 28 wells completed in carbonate rock with 4,000 ft of uncased borehole and well depths to 500 ft and 44 wells completed in noncarbonate rock with 3,876 ft of uncased borehole and depths to 300 ft in the West Valley Creek Basin (table 2). The frequency of water-bearing zones is expressed in units of water-bearing zones per 100 ft of uncased borehole. Most reported water-bearing zones are within 100 ft of land surface in both carbonate and noncarbonate aquifers. Water-bearing zones at depths greater than 200 ft are reported more frequently for carbonate-rock wells than noncarbonate-rock wells, although data for depths below 200 ft are not exactly comparable because more wells are drilled to greater depths in the carbonate rocks than in noncarbonate rocks.

Table 2. *Number of water-bearing zones reported per 100 feet of uncased borehole drilled in carbonate and noncarbonate rocks, West Valley Creek Basin, Pennsylvania*

[ft, feet; --, no data]

Interval (ft below land surface)	Carbonate rock (28 wells)			Noncarbonate rock (44 wells)		
	Number of water-bearing zones			Number of water-bearing zones		
	Total	Per 100 ft of borehole	Footage drilled (ft)	Total	Per 100 ft of borehole	Footage drilled (ft)
0 - 50	13	2.77	469	11	2.51	438
51-100	22	2.12	1,038	41	2.62	1,565
101-150	5	.63	795	19	1.93	985
151-200	4	.65	617	5	1.19	421
201-250	5	1.24	404	2	.67	299
251-300	0	0	294	2	1.19	168
301-500	4	1.04	383	--	--	--
Total (mean)	53	(1.33)	4,000	80	(2.11)	3,876

The number and depth of water-bearing zones intercepted by a well do not necessarily limit well yield or specific capacity. In the West Valley Creek Basin, high-yielding public supply wells in carbonate rocks commonly have only one or two major producing zones. On the average, fewer water-bearing zones per 100 ft of uncased borehole are reported in wells that penetrate carbonate rocks than noncarbonate rocks (table 2); data for the West Valley Creek Basin are similar to those for Chester County (Sloto, 1994). Geophysical logs for wells drilled for public supply show that high-yielding water-bearing zones are encountered from less than 80 ft to as deep as 500 ft below land surface in carbonate rocks in the West Valley Creek Basin. Well CH-4147 is a 500-ft deep well with major water-bearing zones below 400 ft, as shown by the fracture openings on the caliper log and inflections in the single-point-resistance log (fig. 6). Although well CH-4147 has some minor water-bearing openings between 100 ft and 250 ft, yields from deeper fractures are much greater; during drilling, well yield increased from 3 gal/min at 250 ft to 35 gal/min at 400 ft, 60 gal/min at 402 ft, 150 gal/min at 450 ft, 200 gal/min at 490 ft, and 300 gal/min at 515 ft.

Aquifer and well characteristics

Some of the aquifer characteristics that can be used to describe ground-water flow and assess the productivity of an aquifer under unconfined conditions are hydraulic conductivity, saturated aquifer thickness, well yield, and specific yield. Additionally, hydraulic conductivity partly determines the potential for contaminant transport in an aquifer because the ability of water and contaminants to move through an aquifer is controlled by the permeability of aquifer materials and ground-water velocity, as well as on aquifer dispersivity and chemical properties.

Hydraulic conductivity.—Hydraulic conductivity (K) is the rate at which a unit volume of a fluid is transmitted through a unit cross-sectional area of aquifer in a direction perpendicular to flow under a unit hydraulic gradient, per unit thickness of saturated aquifer material (Lohman, 1972). Units of hydraulic conductivity are length cubed per length squared which reduces to length per time, such as feet per day. Transmissivity (T) is the rate at which a fluid is transmitted through a unit width of the aquifer under a unit hydraulic gradient; transmissivity is hydraulic conductivity multiplied by the saturated thickness of an aquifer (Lohman, 1972). Units of transmissivity are length squared per time, such as feet squared per day. The magnitude of K varies spatially in a heterogeneous or anisotropic aquifer. The saturated thickness of the aquifers in the West Valley Creek Basin is at least 500 ft. However, as indicated by water-bearing zone data, the hydraulic conductivity may decrease with depth. Thus, estimates of T from aquifer tests represent vertically averaged hydraulic conductivities.

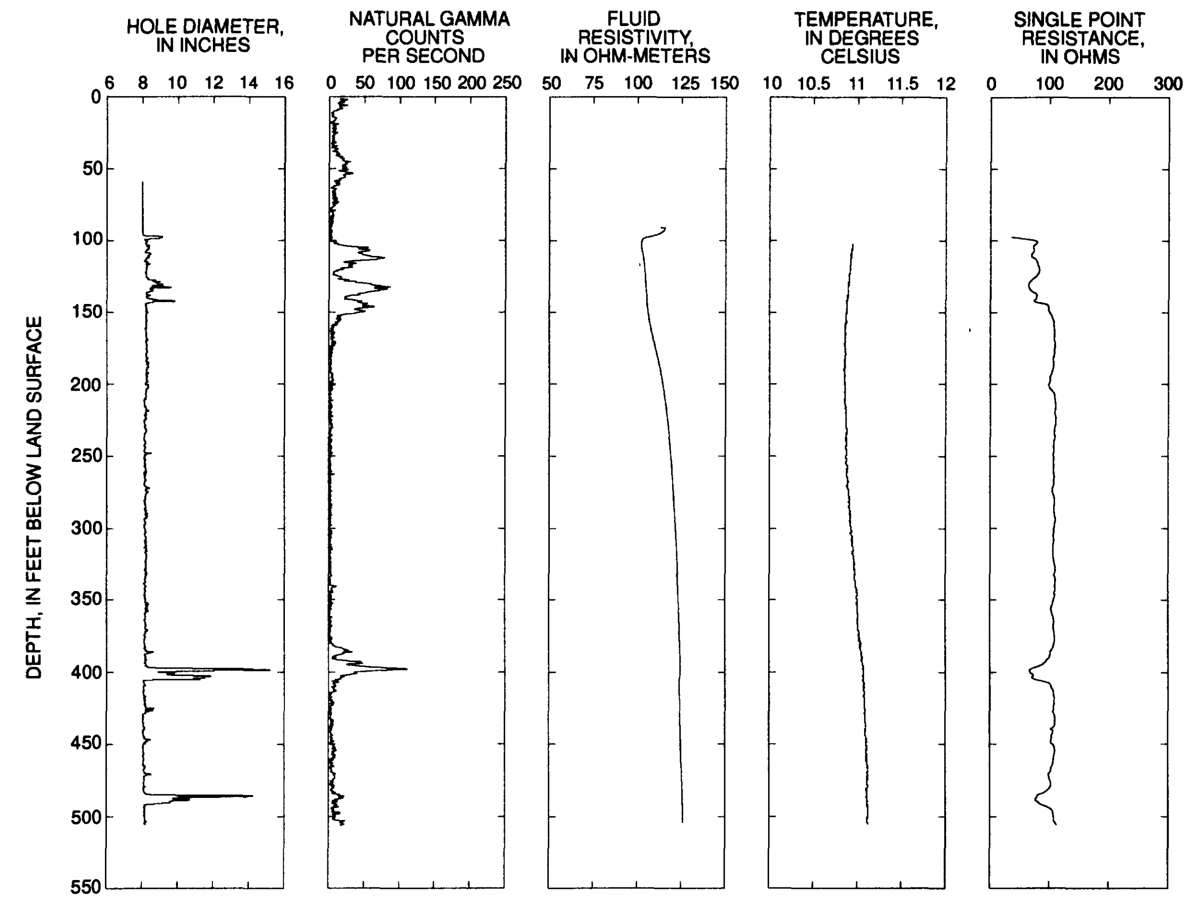


Figure 6. Geophysical logs for well CH-4147 completed in carbonate rock, West Valley Creek Basin, Pennsylvania.

Aquifer tests that involve pumping wells or slug tests can be used to calculate T, K, and the storage coefficient (S) from data for specific wells. Estimates of K from slug tests in wells completed in carbonate rock range from 0.01 to 28.8 ft/d (median, 0.73 ft/d) at the Foote Mineral facility in Planebrook (R.F. Weston, 1991), and from 0.1 to 182 ft/d (median, 3.6 ft/d) at the AIW/Frank National Priority List (NPL) Superfund site (R.W. Conger, U.S. Geological Survey, written commun., 1992). Results of aquifer tests at the Foote Mineral facility in Planebrook were interpreted to show that the Ledger Dolomite is anisotropic; the orientation of the greatest hydraulic conductivity is parallel to regional and valley structure (R.F. Weston, Inc., 1991). T_x, corrected for anisotropy, was estimated to be 17,000 ft^2/d in the east-north-east direction, and is about 14 times greater than the T_y of 1,200 ft^2/d in the north-west-north direction. Such anisotropy affects the direction of ground-water flow and indicates that ground water preferentially flows parallel to regional structure.

Regional aquifer characteristics for application in simulating ground-water flow can be derived during calibration of the models. Estimates of K for the carbonate rocks reported by Sloto (1990, p. 39) for ground-water-flow simulation in the Valley Creek Basin to the east range from to 6 to 45 ft/d. The value of K was estimated to be 45 ft/d for the Ledger Dolomite, 10 ft/d for the Conestoga Limestone, and 7 ft/d for the Elbrook Formation. Estimates of K for the noncarbonate rocks reported by Sloto (1990) range from 3 to 5 ft/d.

Specific yield.—For aquifers under confined conditions, the storage coefficient (S) is defined as the volume of water released from (or taken into) storage per unit surface area of an aquifer per unit change in head (Lohman,1972). For aquifers under unconfined conditions, the ratio of the volume of water drained by gravity to the volume of aquifer material (rock and soil) is the specific yield (Sy) (Lohman, 1972). Sy can vary with depth to water. By use of the change in water levels in a carbonate-rock well and streamflow during dry periods, Sloto (1990, p. 26) showed that Sy decreased non-linearly from about 0.11 to 0.04 over a 4-ft (seasonal) decline of the water table. Estimates of average Sy for aquifers in the Brandywine Basin range from 0.075 to 0.10 (Olmsted and Hely, 1962). An average Sy of 0.08 was used by Sloto (1990, p. 38) to calculate water budgets in the Valley Creek Basin to the east of the study area.

Specific capacity and well yield.—Specific capacity is a better measure of aquifer productivity than well yield because it can be related directly to aquifer transmissivity. Specific capacity is calculated by dividing the pumping rate of a well by the drawdown and reflects combined efficiency of the well and aquifer transmissivity. Specific capacity for a well pumped at a constant yield decreases with time. Specific capacity data from single-well aquifer tests can be used to estimate T (Theis, 1963).

Reported specific capacities for wells in the West Valley Creek Basin are summarized in table 3. The specific-capacity data are determined from aquifer tests performed by drillers, water purveyors, and consultants. Few or no data are available for the Elbrook Formation, Kinzers Formation, Vintage Dolomite, Harpers Phyllite, and Antietam Quartzite. Specific-capacity data for these and other formations elsewhere in Chester County are given by Poth (1968), McGreevy and Sloto (1977), and Sloto (1994). Table 3 combines data for domestic and other wells because most of the wells open to geologic units other than the Ledger Dolomite are 6-in. diameter domestic or commercial wells. For the carbonate rocks, the greatest median specific capacity was calculated for the Ledger Dolomite, and the least for the Conestoga Limestone. Median specific capacity reported for the Conestoga Limestone in the West Valley Creek Basin is less than that for the formation as a whole in Chester County (Sloto, 1994). For the noncarbonate rocks, the greatest median specific capacity was calculated for the Peters Creek Schist and the least for the Octoraro Phyllite.

***Table 3.** Minimum, maximum, and median reported specific capacity for wells in the West Valley Creek Basin, Pennsylvania*

[(gal/min)/ft, gallons per minute per foot of drawdown; <, less than]

Geologic unit	Number	Specific capacity [(gal/min)/ft]		
		Minimum	Maximum	Median
Felsic gneiss	2	0.45	1.86	1.12
Chickies Quartzite	9	.06	1.67	.26
Conestoga Limestone	9	<.01	.38	.01
Ledger Dolomite, all wells	26	.03	80	4.78
Domestic (6-in. diameter)	13	.03	6	.35
Nondomestic (8-20-in. diameter)	13	3.55	80	15
Octoraro Phyllite	16	.01	2.27	.12
Peters Creek Schist	6	.08	5.83	.94
Wissahickon Formation	7	<.01	2.17	.29

Because public supply and industrial wells are drilled and constructed for high yields, nondomestic wells generally have greater specific capacities than domestic wells. The maximum specific capacities listed in table 3 for the felsic gneiss, Chickies Quartzite, Wissahickon Formation, and Ledger Dolomite are from aquifer tests of public supply wells. For the Ledger Dolomite, large diameter (8-20 in.) public supply and industrial wells have much greater specific capacities than 6-in. diameter domestic and commercial wells (table 3).

In a statistical evaluation of variation in specific capacity in fractured rocks in the Piedmont, Valley and Ridge, and Blue Ridge Physiographic Provinces in Pennsylvania, Knopman and Hollyday (1993) determined that casing diameter, water use, duration of aquifer test, lithology topographic setting, casing depth, and well depth are important variables in accounting for observed variations in specific capacity. Knopman and Hollyday (1993) also found in statistical evaluation of aquifer tests using 4,391 wells in Pennsylvania that median specific capacities were greatest (by as much as an order of magnitude) for tests in wells completed in dolomite than for test in wells completed in other lithologies and were successively less in wells completed in limestone, siliciclastic rocks, metamorphic rocks, and diabase. In the West Valley Creek Basin, the median specific capacities of the geologic units (table 3) are similar in magnitude to those listed by Knopman and Hollyday (1993) for a larger area in Pennsylvania.

Specific capacities, together with available drawdowns, provide a reasonable basis for estimating well yields. This information can be used to determine which geologic units produce the most water and which units produce the least. In the West Valley Creek Basin, the Ledger Dolomite is the highest-yielding unit, and some wells have high yields in most of the other units with the possible exception of the Elbrook Formation, which was noted as a low-yielding unit in the eastern end of the Chester Valley by McGreevy and Sloto (1977).

Reported well yield is the discharge of a well measured during pumping and does not necessarily represent long-term yield for the well. Well construction, well-bore storage, pumping rate, and pumping duration can affect the reported well yield. The yield of nondomestic wells provides a better measure of maximum aquifer yield than the yield of domestic wells because the nondomestic wells are generally drilled for high yield and because aquifer tests and discharge measurements commonly are done with greater care for nondomestic than domestic wells.

Reported well-yield data for wells in the West Valley Creek Basin are given in table 4. Few or no data are available for the Elbrook Formation, Kinzers Formation, Vintage Dolomite, Harpers Phyllite, and Antietam Quartzite, which, except for the Elbrook, are thin in Chester Valley. Data for these units elsewhere in Chester County is reported by Poth (1968), McGreevy and Sloto (1977), and Sloto (1994). The relative magnitudes of median well yields in different geologic units (table 4) are similar to those of median specific capacities (table 3). Thus, both the well yield and specific-capacity data indicate that the Ledger Dolomite is the most productive aquifer in the West Valley Creek Basin.

Table 4. *Minimum, maximum, and median reported well yield and depth for domestic and nondomestic wells in the West Valley Creek Basin, Pennsylvania*

[gal/min, gallons per minute; ft, feet; <, less than]

Geologic unit	Number	Well yield (gal/min)		
		10th percentile[1]	Median	90th percentile[2]
Felsic gneiss	5	4	12	167
Chickies Quartzite	12	5	13	91
Conestoga Limestone	11	1	2	92
Ledger Dolomite	29	3	100	725
Octoraro Phyllite	21	1	10	75
Peters Creek Schist	7	6	25	60
Wissahickon Formation	5	12	20	250

Geologic unit	Number	Well depth (ft)		
		10th percentile	Median	90th percentile
Felsic gneiss	5	145	235	288
Chickies Quartzite	14	61	143	398
Conestoga Limestone	18	111	200	387
Ledger Dolomite	33	25	140	406
Octoraro Phyllite	25	100	150	332
Peters Creek Schist	7	66	105	145
Wissahickon Formation	5	56	75	237

[1] For small data sets (number < 10), 10th percentile is the minimum.

[2] For small data sets (number < 10), 90th percentile is the maximum.

Well yield does not correlate with well depth. Wells are drilled to depths where water-bearing zones are penetrated and commonly are drilled deeper until greater or sufficient yields are obtained. Because contributions from fractures vary, the apparent decreasing frequency of water-bearing zones with depth (table 2) does not determine well yield. However, some deep wells intersect few or no high-yielding water-bearing zones.

Water levels

Water levels measured in wells in an aquifer under unconfined conditions indicate the level of the water table. In aquifers under confined conditions, water levels measured in wells indicate the level of the potentiometric surface. Water levels commonly are measured as the depth to water from land surface and are expressed as the altitude of the water level above sea level. The altitude of the water table or potentiometric surface indicates potential energy or head. Static water levels in an aquifer that is not being pumped or stressed by other anthropogenic activities reflect natural conditions. Water levels rise in response to recharge and decline in response to discharge (pumping, evapotranspiration, and discharge to streams and springs). The magnitude of seasonal fluctuations and changes in water levels is related to specific yield and hydraulic conductivity.

Depth to water.—Under natural conditions in an aquifer under unconfined conditions, water levels generally are closest to land surface in valleys near streams (discharge areas) and deepest below land surface on hilltops (recharge areas). Median depth to water is greatest for quartzite and schist (table 5), which are the resistant, ridge-forming geologic units of the North and South Valley Hills. Median depth to water is least for carbonate rocks that underlie Chester Valley and for the felsic gneiss that underlies uplands of low relief. The median depth to water reflects the regional topographic setting (hill, valley, or slope) associated with the geologic units; the range of water levels reflects the local topographic setting of the geologic units. Commonly, the water table more closely replicates topography in aquifers with low permeability and storage than in aquifers with high permeability and storage.

***Table 5.** Minimum, maximum, and median reported depth to water in wells in the West Valley Creek Basin, Pennsylvania*

Geologic unit	Number	Depth to water (feet below land surface)		
		Minimum	Median	Maximum
Felsic gneiss	4	10	17	41
Chickies Quartzite	13	12	34	60
Conestoga Limestone	26	5.6	20	60
Ledger Dolomite	41	3.6	22	75
Octoraro Phyllite	48	2.5	39	87
Peters Creek Schist	15	3	35	61
Wissahickon Formation	11	3	33	74

Fluctuations.—Water levels fluctuate in response to recharge to the ground-water system from precipitation and discharge from the ground-water system to pumping wells and quarries, to the atmosphere by ground-water evapotranspiration, and to streams. Water levels generally rise during the late fall, winter, and early spring when ground-water and soil-moisture evapotranspiration is at a minimum and recharge is at a maximum. Water levels generally decline during the late spring, summer, and early fall when ground-water evapotranspiration and soil-moisture evapotranspiration is at a maximum, and recharge is at a minimum. Water levels in observation wells in different geologic units in the West Valley Creek Basin (fig. 7) were measured monthly during 1990-91 and similar patterns of response (fig. 8) to seasonal changes in recharge and evapotranspiration were indicated. Figure 9 shows that water levels decline in the summer and fall despite precipitation because recharge is offset by evapotranspiration.

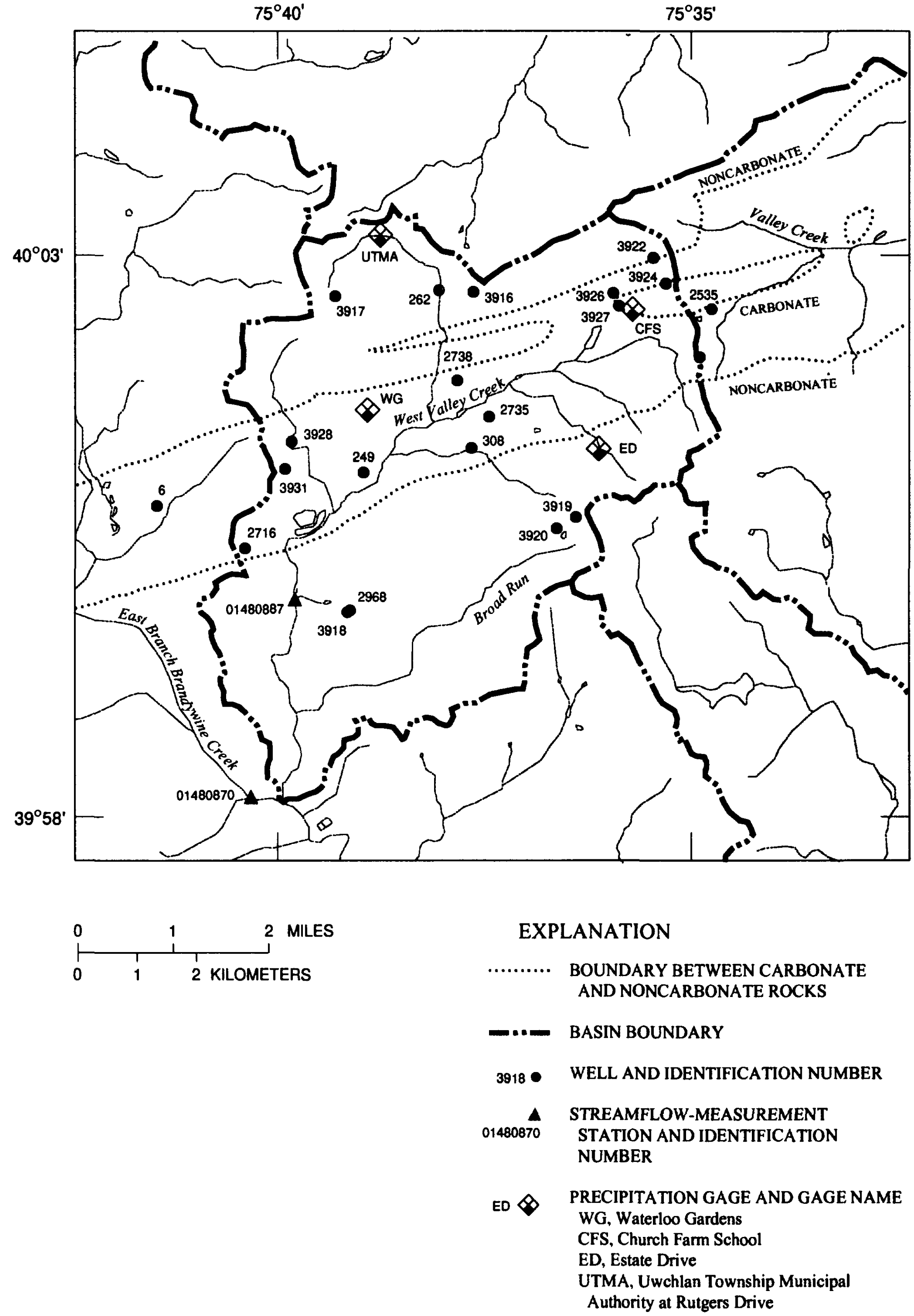
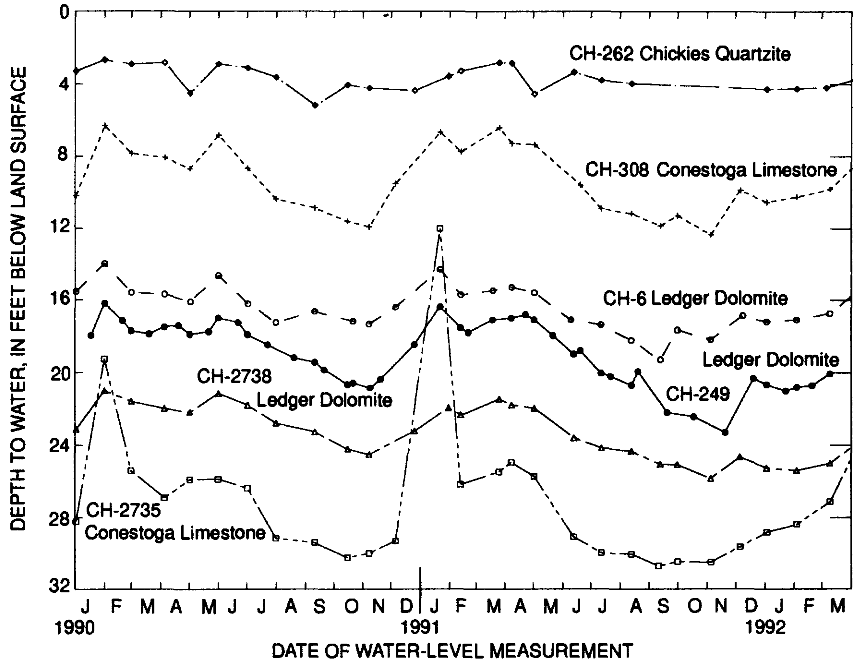
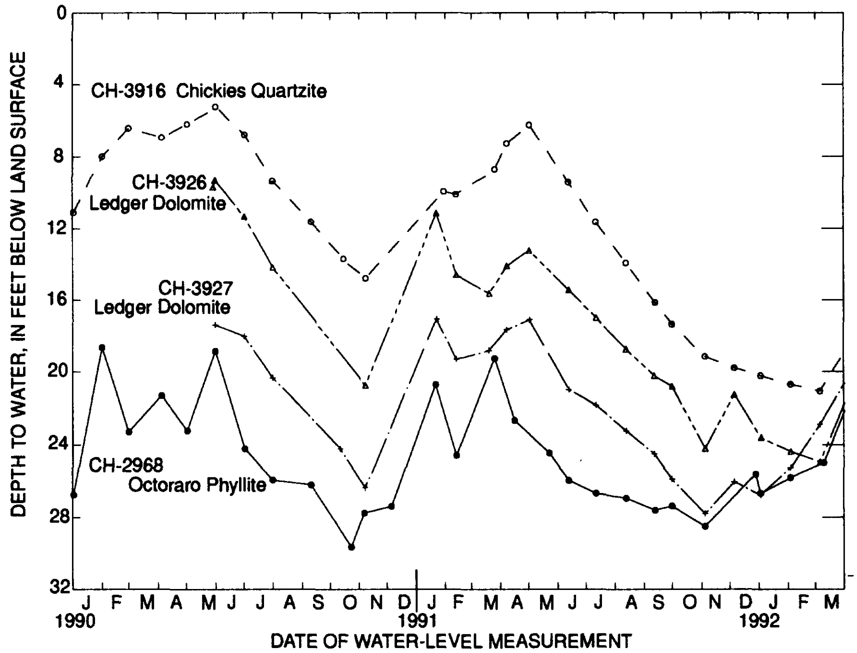


Figure 7. Location of observation wells and precipitation gages, West Valley Creek Basin, Pennsylvania.



A. Wells with seasonal fluctuations of 10 feet or less; well CH-2735 shows brief, transient rises in water levels following some recharge periods



B. Wells with seasonal fluctuations of more than 10 feet

Figure 8. Water-level fluctuations in observation wells completed in carbonate and noncarbonate rocks, West Valley Creek Basin, Pennsylvania, January 1990 - January 1992.

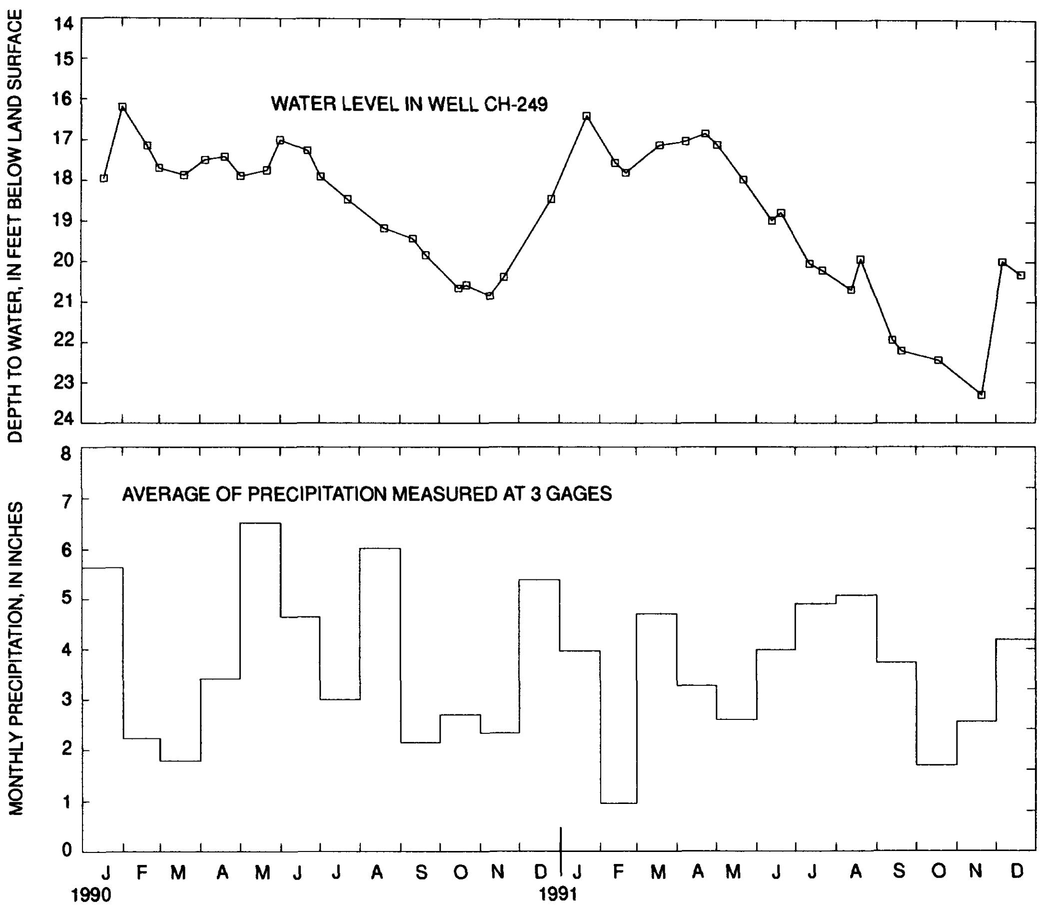


Figure 9. Relation between precipitation and the water levels measured in well CH-249, West Valley Creek Basin, Pennsylvania, 1990-91.

The relative magnitude of water-level changes depends on the hydrologic setting, infiltration rates, hydraulic conductivity, and specific yield of the rock units. Water levels in geologic units with a small specific yield (less than 0.10, for example) show a greater change in response to recharge and discharge than those with a large specific yield (greater than 0.15). Also, the water-table rise may be sustained longer in aquifers with low hydraulic conductivity than in those with high hydraulic conductivity. In the West Valley Creek Basin, the annual fluctuation is greatest (up to 14 ft) for wells in the hills underlain by noncarbonate rocks (wells CH-2968 and CH-3916) and least (as little as 3 ft) for wells in the ground-water discharge zone near streams (wells CH-308 and CH-262) underlain by carbonate and noncarbonate rocks (fig. 8). Well CH-262, an unused public supply well, is probably drilled through the Chickies Quartzite into carbonate rocks. Local hydrologic setting affects the range of annual fluctuations in water levels. For example, the annual fluctuation in the Ledger Dolomite varied within 6 ft for wells near the center of the basin (wells CH-249 and CH-2738) but up to 12 ft for wells near the eastern ground-water divide (wells CH-3926 and CH-3927).

Although the seasonal fluctuations in water levels are similar from year to year, changes in climatic conditions affect the seasonal pattern. Superposition of cumulative precipitation and the hydrographs for well CH-3916 for 1990 and 1991 show that less precipitation was received by June 1991 than by June 1990 and that water levels declined earlier in 1991 than 1990 (fig. 10). On the average, the basin received 4 in.

less precipitation in 1991 than in 1990, and February, May, and June 1991 were comparatively dry months. Because precipitation during winter months contributes more to recharge than precipitation in other seasons when the evapotranspiration rate is higher, a series of dry winters may result in lower-than-normal ground-water levels despite normal annual precipitation. However, lower-than-normal precipitation in seasons other than winter also can result in water-level decline, such as the dry spring of 1990 (fig. 10).

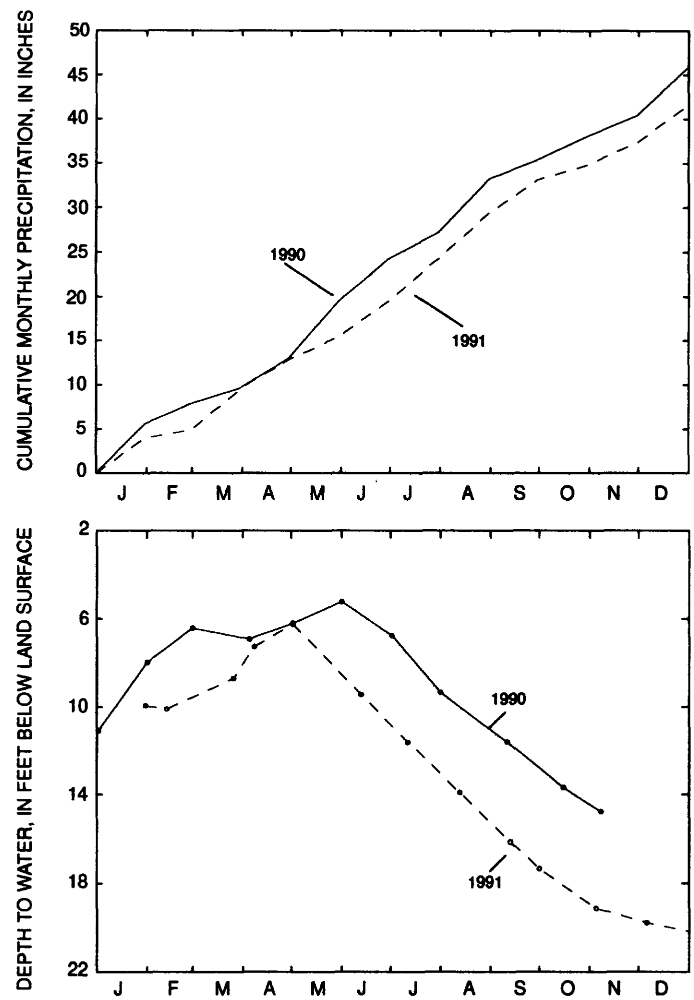


Figure 10. Precipitation and water levels in well CH-3916, West Valley Creek Basin, Pennsylvania, 1990-91.

Water levels in wells that tap aquifers under confined or semi-confined conditions can fluctuate in response to earth tides. Earth tides are characterized by semidiurnal fluctuations and are caused by the force of gravity exerted by the sun and moon on the earth and by centrifugal forces produced by the revolution of the earth and moon around their common center of gravity (Robinson, 1939). Daily peaks occur at low tide when the earth is compressed; because of increased pressure on confined ground water, water levels rise. The hydrograph from well CH-2738 in the Ledger Dolomite shows the daily patterns of earth tides (fig. 11), indicating that the aquifer is locally semi-confined. The well is 76 ft deep with 72 ft of casing, and the reported depth to bedrock is 66 ft. The 66-ft thick zone of clay-rich saprolite acts as a semi-confining unit. The rise in water level in well CH-2738 after precipitation shows that recharge is rapid (on the order of 1 day) (fig. 11).

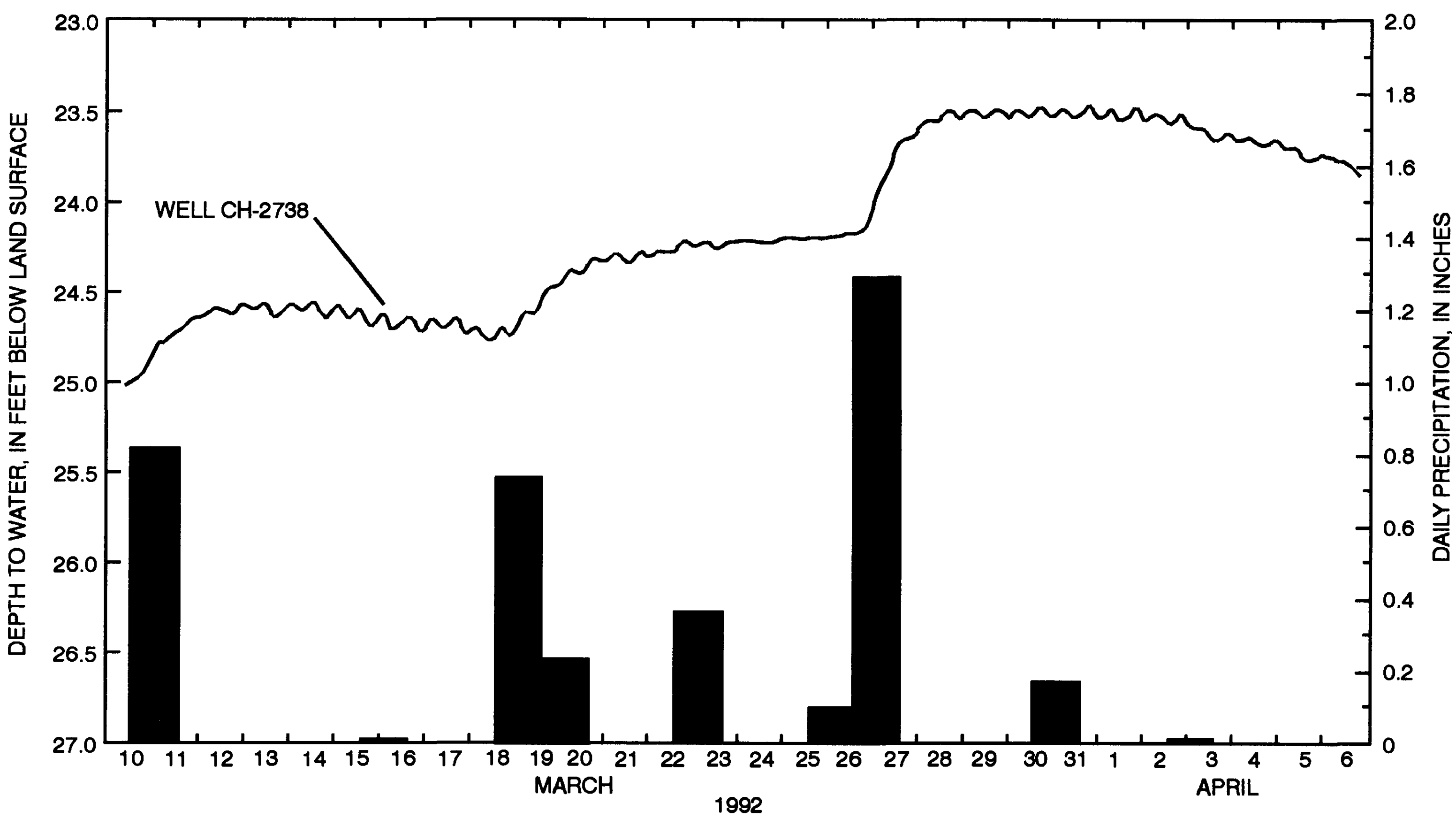


Figure 11. Hydrograph of well CH-2738 and daily precipitation, March 10-April 6, 1992, West Valley Creek Basin, Pennsylvania.

Regional flow

Because ground water flows from higher to lower head, the general direction of ground-water flow can be estimated from a map of the water table or potentiometric surface. In isotropic aquifers, the direction of flow is perpendicular to hydraulic gradient, but in anisotropic aquifers, the direction of flow is at some angle from perpendicular to the hydraulic gradient. Water-table maps prepared by Wood (1984), Sloto (1987), Garges (1986 and 1988), and McManus (1992), which cover most of the West Valley Creek Basin, show that ground water flows from the hills to the north and south toward the center of the carbonate valley and westward along the axis of the valley, nearly parallel to West Valley Creek. Generalized flow directions interpreted from maps made from 1984-92 water-level data show that ground water discharges to West Valley Creek, and that underflow may occur at the east and west ends of the basin in the carbonate rocks (fig. 12). Comparison of water levels measured in 1992 with water levels measured in the same wells in 1984 indicates changes in water levels are less than 10 ft in most parts of the basin.

Ground-water flow directions at the eastern and western edges of the basin in the carbonate valley probably shift seasonally and in response to changes in regional recharge and discharge. On the eastern side of the West Valley Creek Basin, the ground-water divide is about 0.5 mi east of the surface-water divide. Some ground water flows eastward to the adjacent Valley Creek Basin. Sloto (1990) estimated that the underflow from the West Valley Creek Basin to the east is about 0.75 Mgal/d.

The hydraulic gradient can reflect relative permeabilities of aquifers under unconfined conditions. Under identical flow conditions, the change in head over distance is less in aquifers with high permeability than in aquifers with low permeability. The water table mapped by Wood (1984) in carbonate rocks shows that the hydraulic gradient is steeper (water-table contours are more closely spaced) at the southern edge of the valley which is underlain by the Elbrook Formation and Conestoga Limestone than in the center which is underlain by the Ledger Dolomite and Conestoga Limestone (fig. 13). In the noncarbonate rocks, the water-table contours are more closely spaced than in the carbonate rocks and closely reflect topography.

Water levels decline (depth to water increases) in areas of ground-water withdrawal. The magnitude of the decline depends on the characteristics of the aquifer. The zone of water-level decline around a pumping well is called the cone of depression, which is conical only in isotropic, homogeneous aquifers that are unaffected by hydrologic boundaries, such as impermeable or less permeable units and recharge and discharge areas. At the western end of the West Valley Creek Basin, ground-water withdrawals for dewatering at the General Crushed Stone quarry causes a cone of depression (fig. 13). The water-level decline caused by quarry dewatering operations increased from about 250 ft below land surface in 1984 to about 300 ft below land surface in 1992 because the quarry was deepened.

The cone of depression caused by quarry dewatering is quite steep (fig. 13) as indicated by water levels in wells at the quarry and nearby. Depth to water is about 30 ft below land surface in wells at the quarry (wells CH-2724, CH-2753, and CH-2348), 1,800 ft south of the pit. The steep cone of depression indicates that the Conestoga Limestone is not very permeable in the areas to the north and south of the quarry. The quarry is in the Ledger Dolomite. East and west of the quarry, the cone of depression may be less steep and extend to greater distance from the quarry than mapped, although few data were available to accurately define the cone of depression in that direction. Because of quarry dewatering at the western edge of the basin, ground water that may have otherwise discharged to streams or left the basin as underflow to the west is intercepted by the cone of depression around the quarry.

In West Valley Creek Basin, vertical flow in the carbonate rocks probably is slower than horizontal flow. Borehole-flow measurements made in three wells (CH-249, CH-308, and CH-4147) completed in the carbonate rock in West Valley Creek Basin indicated no or extremely slow vertical movement between water-bearing fractures. The low gradient shown in the temperature log for well CH-4147 (fig. 6) suggests that the direction of ground-water flow may be vertical or have a vertical component between zones at 400 and 500 ft below land surface.

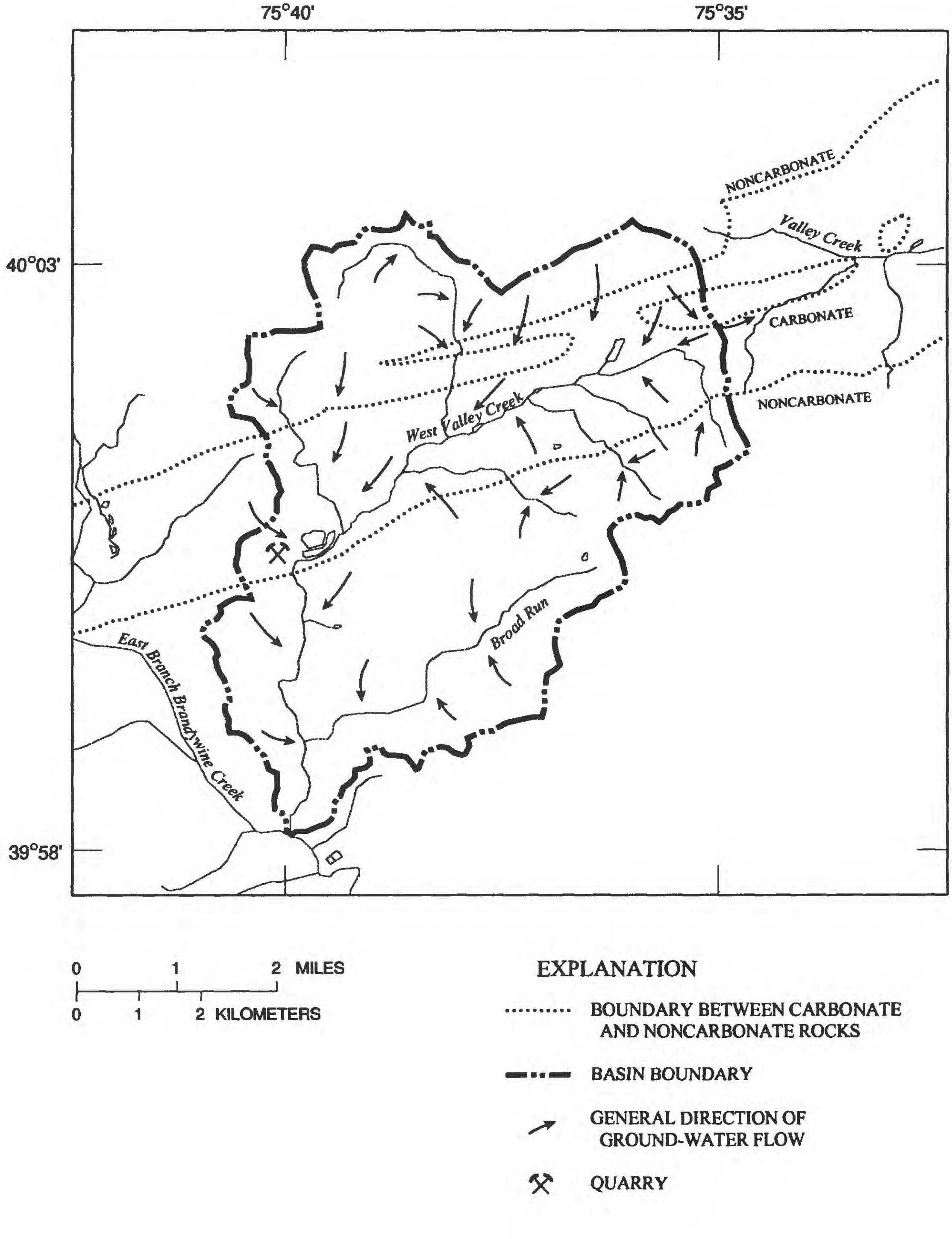
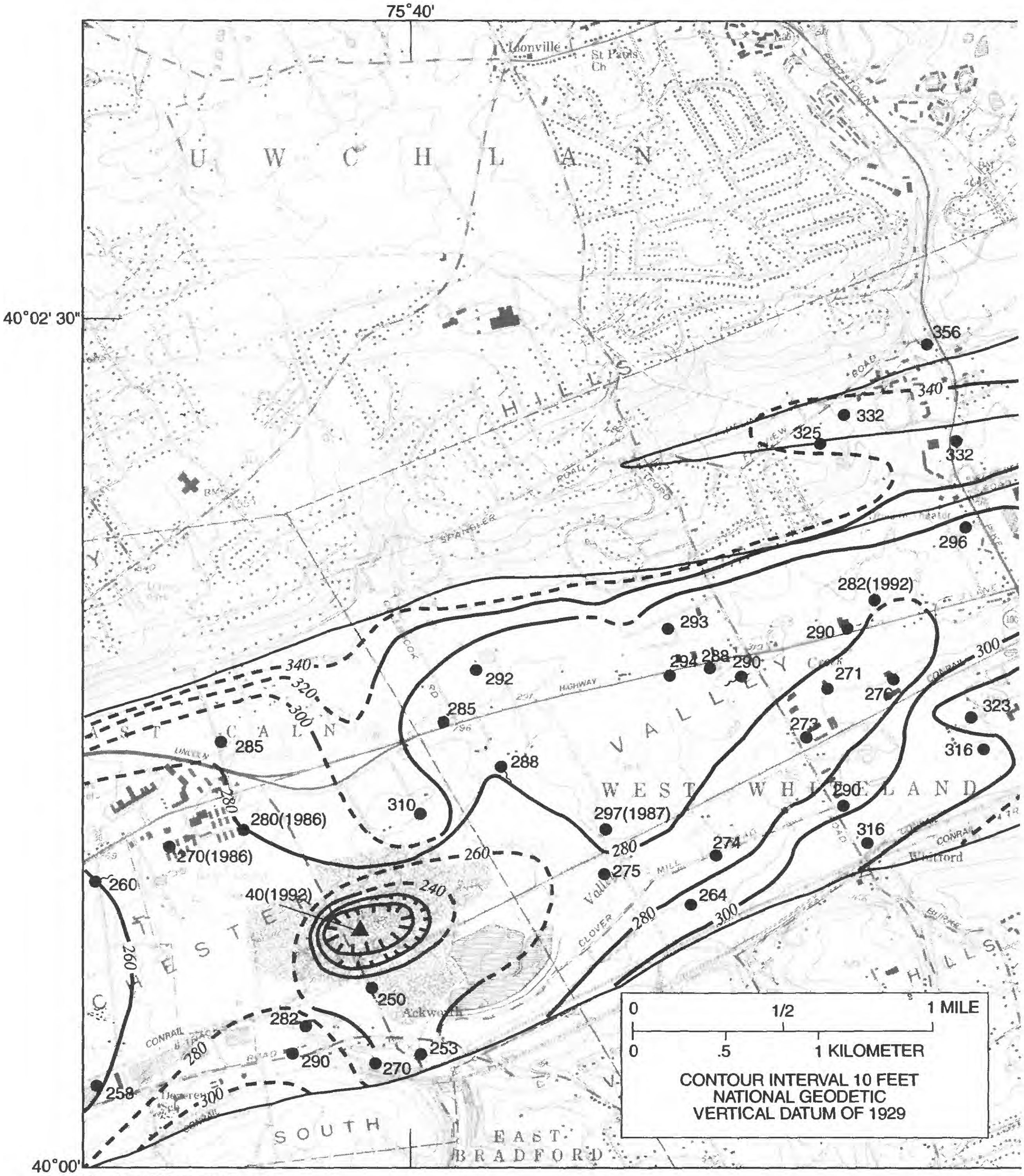


Figure 12. Generalized regional ground-water flow directions, West Valley Creek Basin, Pennsylvania.



Base from U.S.Geological Survey
Downingtown, Pa.,1983; Malvern, Pa.,1983
1:24,000

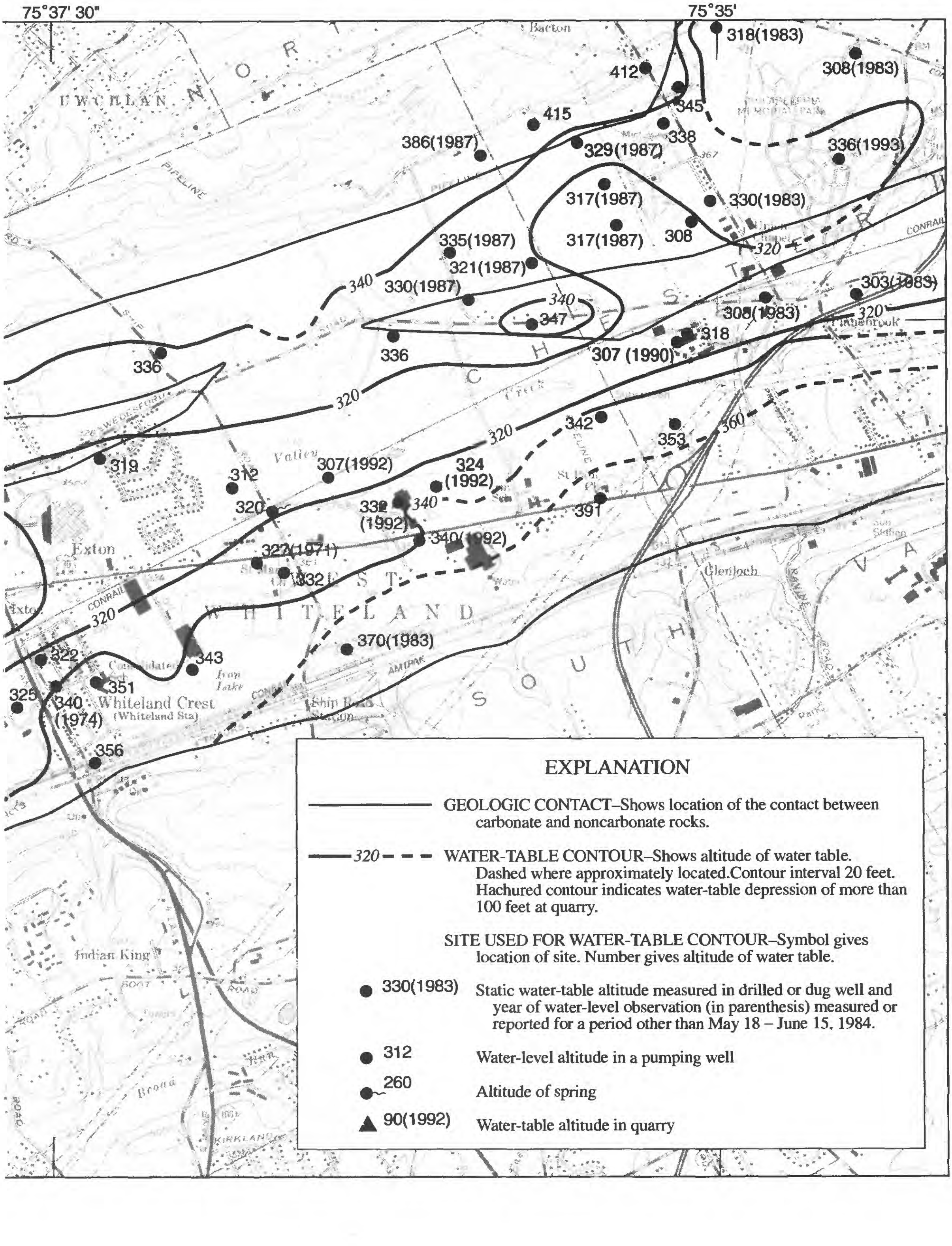


Figure 13. Altitude and configuration of the water-table determined from water levels measured May-June 1984, and in the fall of 1983, 1987, 1990, and 1992, West Valley Creek Basin, Pennsylvania. (Modified from Wood, 1984; Sloto, 1987; McManus and Sloto, 1993.)

Surface Water

Streamflow is composed of base flow and runoff. Base flow is ground water discharged to streams. After rainfall or snowmelt, water of atmospheric origin that does not infiltrate or evaporate enters streams as runoff. The proportions of streamflow that are base flow and runoff, as well as the relation between rainfall-runoff in a basin, depend on the hydrologic characteristics of the basin. Basins underlain by rocks with high permeability have relatively greater base flow (and less runoff) than basins underlain by rocks with low permeability (White and Sloto, 1990). Commonly, more runoff is observed in small basins with steep slopes and soils and rocks that have low permeability than in large basins with shallow slopes and soils and rocks that have high permeability. In urbanized areas, pavement or other land cover with low permeability reduces natural infiltration and can increase the intensity and volume of runoff relative to that in undeveloped areas.

Streamflow from 14.5 mi^2 of the West Valley Creek Basin has been measured since 1989 at streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown. The station is south of the valley underlain by carbonate rocks and downstream from the most urbanized and industrialized part of the basin. Streamflow as daily mean discharge for 1990-91 for West Valley Creek is shown with streamflow measured at the nearest streamflow-measurement station 0148070, East Branch Brandywine Creek below Downingtown (fig. 14). The area of the basin above the East Branch Brandywine Creek station is 89.9 mi^2 (6.2 times larger than the area above at the West Valley Creek station), is underlain by a greater percentage of noncarbonate rocks than the West Valley Creek Basin, and is less urbanized. Record from the two streamflow stations show similar seasonal changes in flow and responses to storms; the greater relative magnitude of the sharp rises following storms for West Valley Creek is probably caused by the greater degree of urbanization and smaller area of the West Valley Creek Basin.

Streamflow above the West Valley Creek station is affected by daily withdrawals from and discharges to the stream by the General Crushed Stone Quarry. The daily mean discharge measured at the station is a combination of natural streamflow and net quarry water usage. Water is withdrawn from West Valley Creek for processing crushed stone at the quarry during hours of operation while excess process water and quarry pumpage is discharged to the stream nearly continuously.

During the work week (Monday through Friday), stream withdrawals from the quarry operations reduce streamflow by several cubic feet per second between 7 a.m. and 5 p.m. daily. Quarry discharge to the stream is on a less regular schedule, commonly continuing 24 hours a day for several days or weeks. The typical weekly pattern of streamflow is shown by the variation in discharge measured at 15-minute intervals for October 1990 (fig. 15), where October 1-5 is the first 5-day work week, and October 6-7 is a weekend. Reported withdrawal rates averaged 3.32 ft^3/s for 17 days in October 1990. Discharge rates are estimated to be 3.12 ft^3/s for October 1-5 and 8-12, 1.56 ft^3/s for October 13-19 and 22-31, and zero (no discharge) for October 6-7 and 20-21 (two weekends). The hydrograph for October 1990 shows withdrawals (as troughs) of about 3 ft^3/s during the work days of the first week. Because 3.12 ft^3/s was continuously discharged during the first 5 days of October, the peaks on the hydrograph represent natural streamflow supplemented by quarry discharge. October 6-7 is a weekend during which no quarry withdrawal or discharge took place. During the weekend of October 27-28, no withdrawals took place, but an estimated 1.56 ft^3/s of water was discharged to the stream. For comparison, streamflow records are shown for December 1990 (fig. 15). In December 1990, water was withdrawn from the stream at the rate of 1.89 ft^3/s for only one working day (December 10) and discharge rates were estimated to be 3.12 ft^3/s on December 31, 1.56 ft^3/s on December 7-13 and 17-30, and zero on December 1-6 and 14-16.

Instantaneous discharge measured at the station on East Branch Brandywine Creek, which is not affected by quarry operations, superimposed on the hydrographs for West Valley Creek shows that the natural recession after storms at the West Valley Creek station is modified by quarry withdrawals and discharge during periods of typical quarry operation, such as October 1990 (fig. 15). The multiplication factor for discharge measured at the East Branch Brandywine Creek station was selected to obtain a visually good match in the hydrograph recession for the two stations in early December 1990.

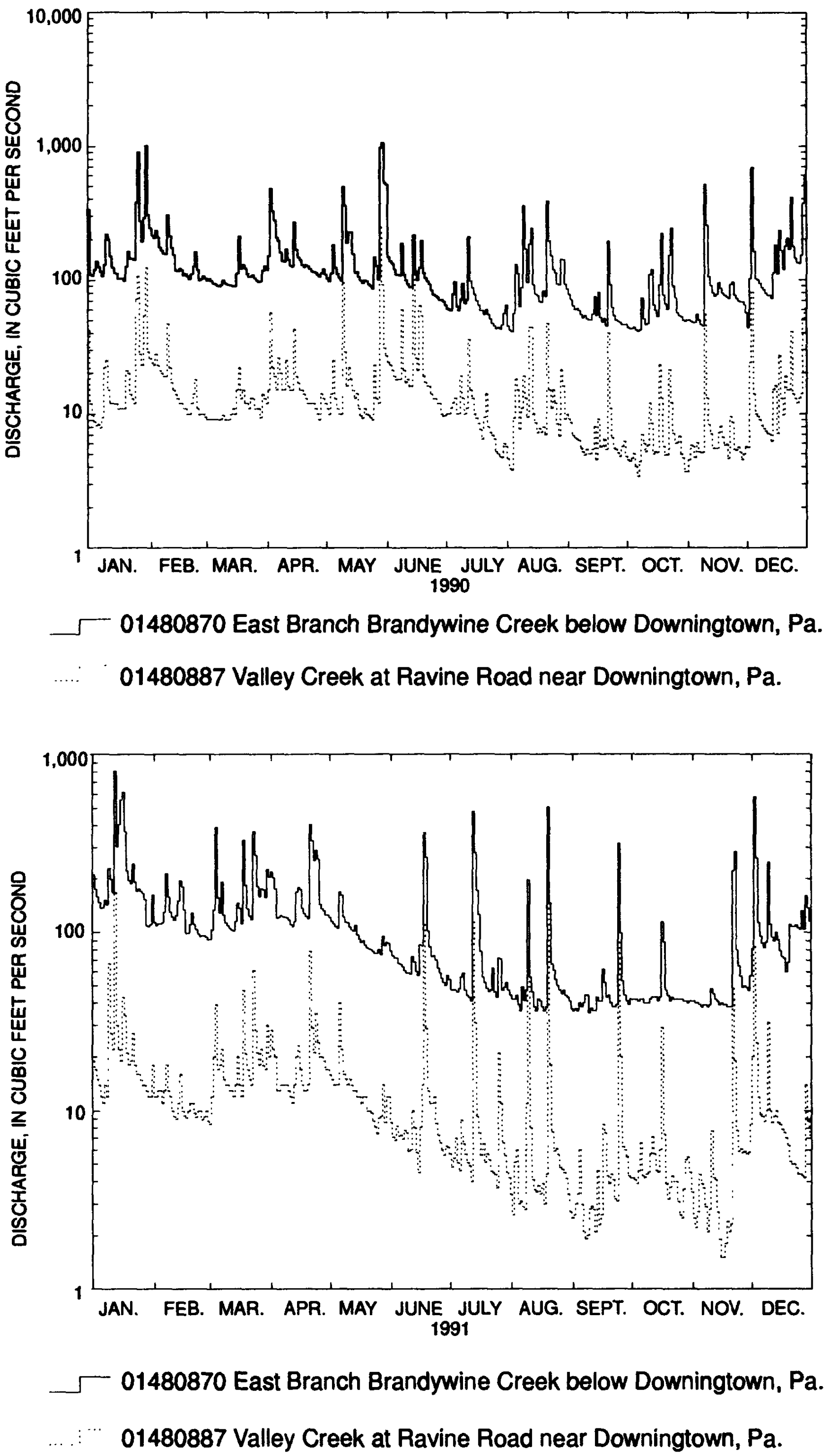
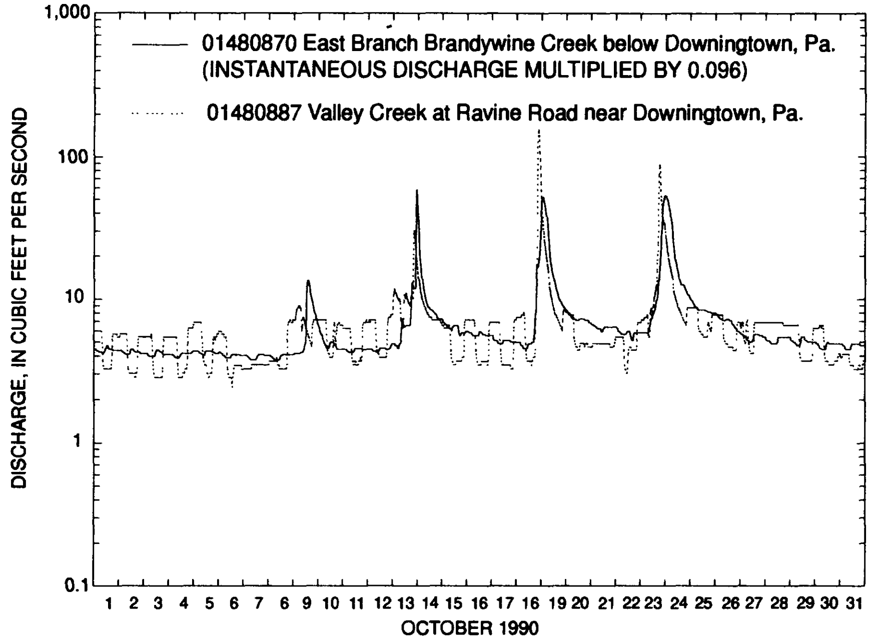
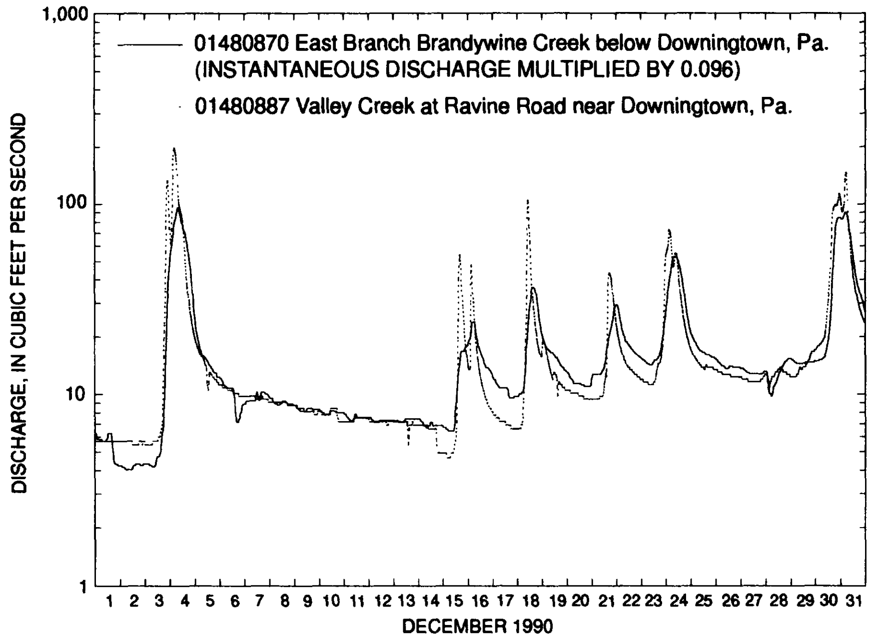


Figure 14. Daily mean discharge at streamflow-measurement stations 01480887, [West] Valley Creek at Ravine Road near Downingtown, and 01480870, East Branch Brandywine Creek below Downingtown, Pennsylvania, 1990-91.



A. October 1990 is a month with typical quarry withdrawals and discharges to West Valley Creek



B. December 1990 is a month with negligible quarry withdrawals but typical quarry discharges to West Valley Creek

Figure 15. Instantaneous discharge at 15-minute intervals at streamflow-measurement stations 01480887, [West] Valley Creek at Ravine Road near Downingtown, and 01480870, East Branch Brandywine Creek below Downingtown, Pennsylvania, October and December, 1990. Discharge at station 01480870 multiplied by 0.096.

The net effect of the quarry withdrawal from and discharge to the stream is an increase in streamflow of about 0.78 cfs on an average annual basis in 1990 and 1991. However, quarry dewatering may divert ground water that otherwise would have discharged to the stream.

Ground-Water/Surface-Water Relations

The ground-water and surface-water systems are well connected in the West Valley Creek Basin. Where West Valley Creek flows over fractured bedrock, the aquifer and the surface-water system are in direct contact. In most areas, ground water discharges to streams and makes up the base-flow component of streamflow. In some areas, stream reaches lose water to the ground-water system. Regional ground-water flow is from the hills to the center of the valley, with ground water discharging at the edges of the valley and to streams.

Streamflow is separated into base-flow and runoff components by use of hydrograph-separation techniques. Base-flow separations were made on hydrographs of West Valley Creek at the streamflow-measurement station by use of the computer program of Sloto (1991). A more detailed discussion of hydrograph separation for Pennsylvania streams is given by White and Sloto (1990). Figure 16 shows the streamflow and base-flow hydrographs of West Valley Creek for 1990-91. The local minimum method, which usually results in the most conservative estimate of base flow relative to other separation techniques (White and Sloto, 1990), was used.

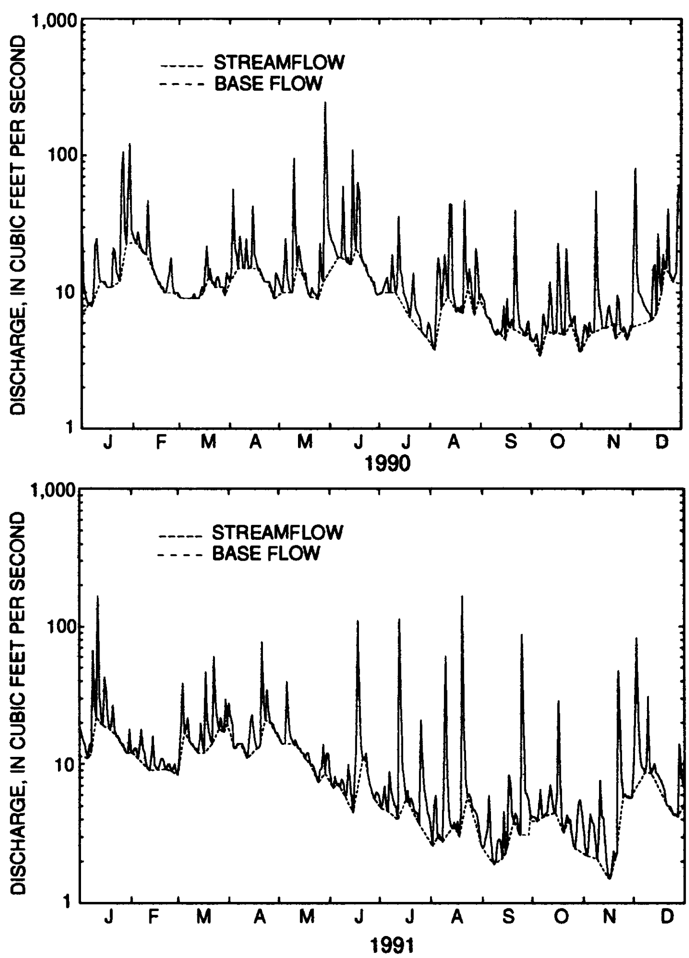


Figure 16. Base flow and streamflow, at streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown, Pennsylvania, 1990-91.

Ground-water discharge (base flow) comprised 40 to 91 percent of the monthly flow of West Valley Creek at the streamflow-measurement station during 1990 and 29 to 88 percent of monthly flow during 1991 (table 6). The average annual ground-water discharge was 62 percent of streamflow for 1990-91. Annual base flow of West Valley Creek was 7.48 in. in 1991 and 9.09 in. in 1990. The monthly base flow of West Valley Creek ranged from 0.21 in. in September 1991 to 1.25 in. in June 1990; the average was 0.62 in. in 1991 and 0.76 in. in 1990. Because quarry dewatering results in direct and nearly continuous discharge of ground water to West Valley Creek, the net water discharged by the quarry (quarry pumpage minus stream withdrawals) appears as base flow in the hydrograph separation. Quarry discharge contributed about 0.74 in. (8.1 percent) and 0.73 in. (9.7 percent) of total baseflow in 1990 and 1991, respectively.

In Pennsylvania, many basins predominantly underlain by carbonate rocks are characterized by a greater percentage of streamflow as base flow than are basins underlain by noncarbonate rocks (White and Sloto, 1990). The percentage of streamflow as base flow in the West Valley Creek Basin is similar to the percentage of streamflow as base flow for adjacent basins that are mostly or partly underlain by carbonate rocks. Annual base flow as a percentage of streamflow averaged 76 percent for 1983-87 in the Valley Creek Basin to the east (Sloto, 1990), which is underlain largely by the same carbonate rocks as the West Valley Creek Basin. Average annual base flow as a percentage of streamflow was estimated to be about 68 and 65 percent for two different periods (1928-31 and 1952-53) in the Brandywine Creek Basin (Olmsted and Hely, 1962).

***Table 6.** Monthly and annual streamflow and base flow at streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown, Pennsylvania, 1990-91*

[ft³/s, cubic feet per second; in., inches]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1990
Mean streamflow (ft^3/s)	25.1	16.7	11.4	17.2	28.7	24.3	10.4	13.7	7.5	7.1	7.7	18.4	15.6
Mean base flow (ft^3/s)	12.5	14.5	10.4	12.9	11.3	15.7	7.7	7.4	5.5	4.7	5.0	8.9	9.7
Total streamflow (in.)[1]	1.99	1.28	.91	1.37	2.06	1.93	.80	1.09	.58	.56	.61	1.41	[2]14.61
Total base flow (in.)[1]	1.00	1.11	.82	1.03	.81	1.25	.59	.59	.43	.38	.40	.68	[2]9.09
Percentage of streamflow as base flow	49.9	86.7	90.7	75.0	39.5	64.7	73.6	54.1	73.7	67.0	65.1	48.1	62.2

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1991
Mean streamflow (ft^3/s)	25.1	11.0	21.2	19.1	13.1	11.9	10.7	12.1	7.2	5.3	5.8	12.0	12.9
Mean base flow (ft^3/s)	15.2	9.6	14.8	14.9	10.9	6.8	4.3	3.5	2.8	3.7	3.0	6.4	8.0
Total streamflow (in.)[1]	2.00	.84	1.68	1.52	.94	.95	.83	.96	.55	.42	.47	.92	[3]12.08
Total base flow (in.)[1]	1.21	.74	1.18	1.18	.79	.54	.33	.28	.21	.29	.24	.49	[3]7.48
Percentage of streamflow as base flow	60.4	87.9	69.9	78.1	83.2	57.1	39.9	29.1	38.6	69.0	51.9	53.4	62.0

[1] Flow given in inches can be converted to millions of gallons per day per square mile by multiplying by 0.048.
[2] Includes net quarry discharge to stream of about 0.74 in. in 1990.
[3] Includes net quarry discharge to stream of about 0.73 in. in 1991.

The quantity of ground water discharged to streams is related to the altitude of the water table near the stream. Olmsted and Hely (1962, p. 9-16) found a linear relation between the monthly average ground-water level in index wells and the base flow of Brandywine Creek during winter months. Figure 17 shows the relation between ground-water levels in a well completed in carbonate rock (CH-249) and base flow in West Valley Creek during 1990-91. The shape of the base-flow and water-level hydrographs is very similar. Base flow generally declines as ground-water levels decline and increases when ground-water levels increase (fig. 17). The time of lowest base flow coincides with the lowest ground-water levels.

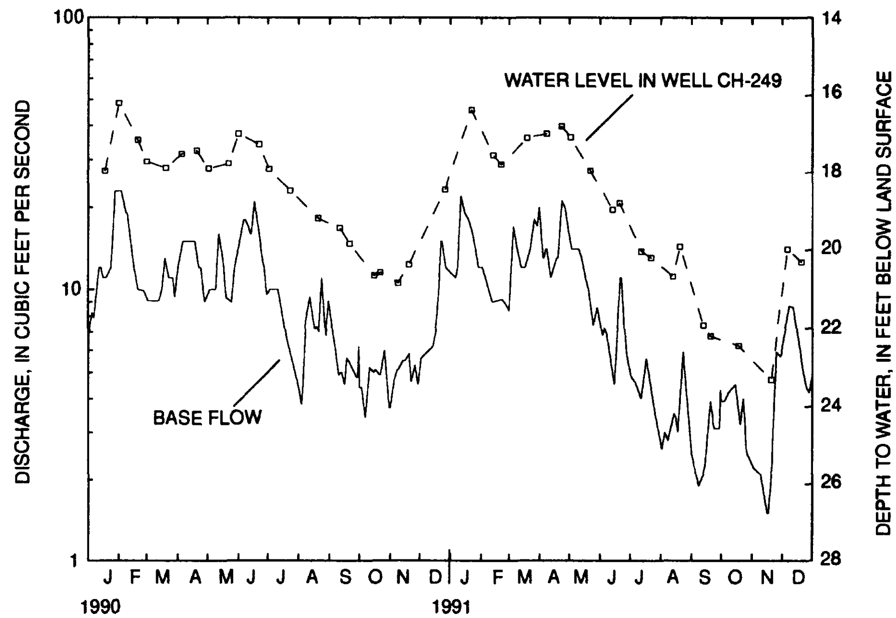


Figure 17. Base flow at streamflow-measurement station 01480887, [West] Valley Creek at Ravine Road near Downingtown and ground-water levels in a well (CH-249) completed in carbonate rocks, West Valley Creek Basin, Pennsylvania, 1990-91.

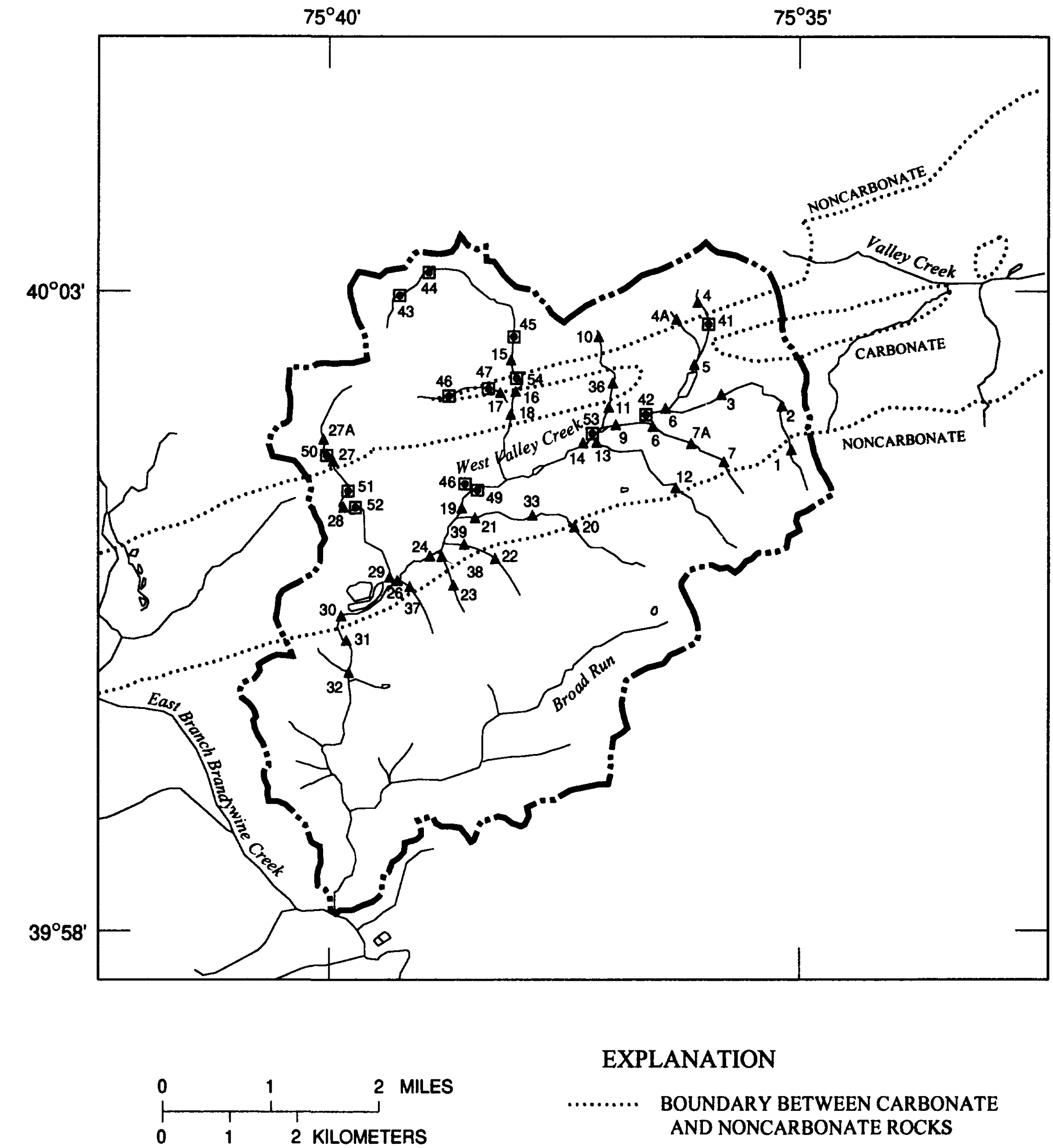
All tributaries to West Valley Creek have their headwaters in the crystalline rocks north and south of Chester Valley. Some streams lose water or become perched above the water table for a short distance after they cross the contact between the crystalline and carbonate rock. The hydraulic conductivity of carbonate rock is much higher than that of the crystalline rock, and the water table is generally lower in the carbonate rocks. The quantity of streamflow lost is small because the discharge of these headwater streams is small. McGreevy (1974) completed a seepage investigation of major streams that traverse Chester Valley and found that the streams initially lose water as they enter the valley, but have a net gain of water in the reaches underlain by carbonate rocks.

Temporal changes in stream loss or gain may reflect seasonal fluctuation of ground-water levels. When water levels are high, ground water may discharge to streams; when water levels are low, streams may lose water to the ground-water system. Potential losses from streams to the ground-water system are greatest when water levels are lowest, as they commonly are in autumn.

Seepage studies to define gaining and losing stream reaches were done during low base flow and low ground-water levels in October 1990 and 1991. Streamflow was measured at selected sites (some near geologic contacts) on the mainstem and tributaries (fig. 18). Tables 7 and 8 show that losses were measured in short reaches as tributaries enter the carbonate valley in the headwaters at the eastern end of the basin near the ground-water divide and possibly where West Valley Creek sharply turns south out of the carbonate valley. Because stream depths and velocities commonly were less than those specified for accurate discharge measurements by use of the Price pygmy meter (0.3 ft depth and 0.2 ft^3/s velocity) (Rantz and others, 1982), discharge measurements can only be considered estimates, especially for low values of discharge. In 1991, when precipitation in the summer and fall was below normal, ground-water levels were lower than in 1990 (fig. 10) and West Valley Creek was dry in the upper reaches. Streamflow gains were measured in tributaries underlain by noncarbonate rocks, at the geologic contact between the Conestoga Limestone and Ledger Dolomite, and in the mainstem along the mid-valley reach in carbonate rocks (above site 19 on figure 18). Gains to the mainstem represent less than 20 percent of total streamflow. The tributaries contribute the majority of flow to the mainstem, and tributaries generally are gaining streams. In some reaches, West Valley Creek neither gains nor loses and thus acts as a conduit for streamflow with little to no hydraulic connection between the surface-water and ground-water systems.

Streamflow is lost in reaches underlain by the Ledger Dolomite, but also can be lost in reaches underlain by the Elbrook Formation and Conestoga Limestone. The Ledger Dolomite is the most permeable unit in the basin. Ground water discharges as springs in several places in the basin near the contact between the Ledger Dolomite and Conestoga Limestone (pl. 1), suggesting a large difference between hydraulic conductivities of the two units. Springs also are found near the contact between noncarbonate and carbonate rocks at the edges of the valley, reflecting contrasting hydraulic conductivities. A series of temperature and specific-conductance measurements made in August 1990 identified water which was cooler (ground-water source) where gains were measured in the seepage investigations and near springs than in places where losses or no gains were measured (table 9).

Because ground water is pumped continuously as part of quarry dewatering operations and a cone of depression has developed around the quarry, loss of streamflow to the ground-water system might be expected. Large losses of streamflow to the ground-water system in the vicinity of the quarry are not indicated by data for the mainstem, although loss was measured in a tributary (sites 27a and 27 on figure 18) that traverses the valley near the quarry. The mainstem is underlain by the relatively less permeable (compared to the Ledger Dolomite) Elbrook Formation and Conestoga Limestone as it passes by the quarry, and this may account for the lack of significant streamflow loss. Nevertheless, quarry dewatering operations may divert ground water that otherwise would have discharged to West Valley Creek. In addition, quarry dewatering may create a sink to intercept underflow that, under natural conditions, would have discharged to the Brandywine Creek Basin.



EXPLANATION

··········	BOUNDARY BETWEEN CARBONATE AND NONCARBONATE ROCKS
▬··▬	BASIN BOUNDARY
▲22	DISCHARGE-MEASUREMENT SITE AND MAP-LOCATION NUMBER
▣41	RECONNAISSANCE WATER-QUALITY SITE AND MAP-LOCATION NUMBER

Figure 18. Location of discharge-measurement sites (October 1990 and 1991) and reconnaissance water-quality-measurement sites (August 1990), West Valley Creek Basin, Pennsylvania. See table 7 for information concerning the sites.

Table 7. *Discharge measurements in the West Valley Creek Basin, Pennsylvania, October 22 and 27, 1990*

[Measurement sites are shown on figure 18; --, no data; +, gain; -, loss]

Stream mile	Stream (stream sampling site number)	Site number	Discharge (cubic feet per second)				
			Tributary	Mainstem	Gain or loss in tributary	Gain or loss in mainstem	Total gain or loss in mainstem
October 22, 1990							
9.45	West Valley Creek	1	--	0.10	--	--	--
8.87	West Valley Creek	2	--	.15	--	+ 0.05	+ 0.05
8.20	West Valley Creek (WVC-2)	3	--	.13	--	-.02	+.03
	Unnamed tributary	4	0.03	--	--	--	--
	Unnamed tributary	4a	.01	--	--	--	--
7.61	Unnamed tributary (WVC-1)	5	.07	--	+ 0.03	--	--
7.61	West Valley Creek	6	--	.10	--	-.03	0
	Unnamed tributary	7	.08	--	--	--	--
	Unnamed tributary	7a	.20	--	+.12	--	--
7.33	Unnamed tributary (WVC-3)	8	.30	--	+.10	--	--
7.14	West Valley Creek (WVC-5)	9	--	.34	--	-.06	-.06
	Unnamed tributary	10	.03	--	--	--	--
6.99	Unnamed tributary (WVC-4)	11	.17	--	+.14	--	--
	Unnamed tributary	12	.36	--	--	--	--
6.80	Unnamed tributary (WVC-7)	13	.51	--	+.15	--	--
6.79	West Valley Creek (WVC-6)	14	--	.93	--	-.09	-.15
	Unnamed tributary	15	.68	--	--	--	--
	Unnamed tributary	16	.81	--	+.13	--	--
	Unnamed tributary	17	.01	--	--	--	--
5.90	Unnamed tributary (WVC-8)	18	1.05	--	+.23	--	--
5.30	West Valley Creek (WVC-9)	19	--	2.71	--	+.73	+.58
	Unnamed tributary (WVC-16)	20	.46	--	--	--	--
5.20	Unnamed tributary (WVC-10)	21	.58	--	+.12	--	--
4.79	Unnamed tributary	22	.27	--	--	--	-
4.74	Unnamed tributary	23	.11	--	--	--	--
4.54	West Valley Creek	24	--	3.54	--	-.13	+.45
	Unnamed tributary	27a	.21	--	--	--	--
	Unnamed tributary	27	.01	--	-.20	--	--
	Unnamed tributary	28	.08	--	+.07	--	--
October 27, 1990							
4.54	West Valley Creek	24	--	3.22	--	--	--
4.11	West Valley Creek (WVC-11)	26	--	3.63	--	[1]+.41	[1]+.41
	Unnamed tributary	28	.21	--	--	--	--
4.05	Unnamed tributary (WVC-12)	29	.04	--	-.17	--	--
3.37	West Valley Creek	30	--	7.05	--	[2]+3.38	[2]+3.79
3.15	West Valley Creek	31	--	7.73	--	+.68	+ 4.47
2.69	West Valley Creek (WVC-15)[3]	32	--	7.34	--	-.39	+ 4.08

[1] Net gain in this reach partly due to unmeasured tributary.
[2] Most or all of the net gain in this reach is process water discharged by quarry to West Valley Creek.
[3] Streamflow-measurement station 01480887.

Table 8. *Discharge measurements in the West Valley Creek Basin, Pennsylvania, October 9, 10, and 11, 1991*

[Measurement sites are shown on figure 18 and plate 1; --, no data; +, gain; -, loss]

Stream mile	Stream (stream sampling site number)	Site number	Discharge (cubic feet per second)			
			Tributary	Mainstem	Gain or loss in mainstem	Total gain or loss in mainstem
October 11, 1991						
9.45	West Valley Creek	1	--	0.07	--	--
8.87	West Valley Creek	2	--	.04	- 0.03	- 0.03
8.20	West Valley Creek (WVC-2)	3	--	dry	-.04	-.07
7.61	West Valley Creek	6	--	dry	0	[1]-.07
7.33	Unnamed tributary (WVC-3)	8	0.22	--	--	--
October 10, 1991						
7.14	West Valley Creek (WVC-5)	9	--	.24	[2]--	--
6.80	Unnamed tributary (WVC-7)	13	.26	--	--	--
6.79	West Valley Creek (WVC-6)	14	-	.63	[3]+.07	[3]+.07
5.90	Unnamed tributary (WVC -8)	18	.53	--	--	--
5.30	West Valley Creek (WVC-9)	19	--	1.37	+.21	+.28
October 9, 1991						
4.79	Unnamed tributary	39	.13	--	--	--
4.74	Unnamed tributary	38	.05	--	--	--
4.54	West Valley Creek	24	--	1.97	[4]--	--
4.17	Unnamed tributary	37	.01	--	--	--
4.11	West Valley Creek (WVC-11)	26	--	1.89	-.09	-.09
4.05	Unnamed tributary (WVC-12)	29	.05	--	--	--
3.37	West Valley Creek	30	--	1.63	-.31	-.40
3.15	West Valley Creek	31	--	1.82	+.19	-.21
2.69	West Valley Creek [5]	32	--	[6]2.27	[7]+.45	[7]+.24

[1] Total loss may be greater because tributary above this site goes dry before joining the mainstem.

[2] Represents a gain of about 0.02 cubic feet per second in the mainstem considering tributary discharge upstream (site 8), which was measured the next day, October 11, 1991.

[3] Gain is calculated by use of the discharge of 0.06 cubic feet per second at tributary site WVC-4 measured on October 7, 1992; no precipitation fell during October 9-11, 1991.

[4] Represents a gain of about 0.14 cubic feet per second applying discharge measurements of 1.37 cubic feet per second for the mainstem calculations (site 19) on October 10, 1991 and 0.28 cubic feet per second for an unnamed tributary (site 21) on October 4, 1991.

[5] Streamflow-measurement station 01480887.

[6] Discharge determined from stage-discharge relation at streamflow-measurement station.

[7] Streamflow-measurement station is downstream from two small tributaries whose discharge contribution is included in this mainstem gain.

Table 9. *Stream temperature and specific conductance at selected reconnaissance stream sites, West Valley Creek Basin, Pennsylvania, August 1-8, 1990*

[WVC, West Valley Creek stream-sampling site; °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not pertinent]

Mainstem stream site	Tributary stream site	Date measured	Mainstem temperature (°C)	Mainstem specific conductance (μS/cm)	Tributary temperature (°C)	Tributary specific conductance (μS/cm)
3 (WVC-2)		8-7-90	26.0	480	--	--
	41	8-1-90	--	--	16.8	58
	5 (WVC-1)	8-7-90	--	--	19.5	70
42		8-8-90	26.0	385	--	--
	8 (WVC-3)	8-7-90	--	--	21.0	415
9 (WVC-5)		8-7-90	23.0	425	--	--
	36 (WVC-20)	8-8-90	--	--	15.0	380
	11 (WVC-4)	8-7-90	--	--	17.0	380
53		8-7-90	24.0	375	--	--
	13 (WVC-7)	8-7-90	--	--	20.5	330
14 (WVC-6)		8-7-90	22.5	360	--	--
	43	8-8-90	--	--	23.0	290
	44	8-8-90	--	--	26.0	260
	45	8-1-90	--	--	21.5	340
	54	8-8-90	--	--	22.0	320
	46	8-8-90	--	--	18.0	168
	47	8-8-90	--	--	25.0	200
	18 (WVC-8)	8-3-90	--	--	23.5	340
49		8-3-90	21.0	400	--	--
	48	8-3-90	--	--	15.0	440
	33 (WVC-17)	8-1-90	--	--	18.0	320
	21 (WVC-10)	8-3-90	--	--	18.5	210
	37	8-3-90	--	--	18.5	235
26 (WVC-11)		8-3-90	21.5	370	--	--
	50	8-8-90	--	--	18.5	280
	51	8-1-90	--	--	24.5	275
	52	8-8-90	--	--	23.5	280
32 (WVC-13)		8-1-90	21.5	340	--	--

Water Budget

A water budget is an estimate of water entering and leaving a basin plus or minus changes in storage for a given period. Water enters as precipitation and leaves as streamflow, evapotranspiration, and diversions, such as ground-water pumpage. For a basin such as West Valley Creek, where ground-water divides and surface-water divides do not coincide, water also enters and leaves a basin as ground-water underflow. Water also is taken into and released from ground-water and soil-moisture storage. Recharge to the ground-water system can be determined from a ground-water budget that includes changes in ground-water storage, discharge to streams (base flow), ground-water evapotranspiration, ground-water withdrawals, and underflow.

Water use

In the West Valley Creek Basin, the major source of supply is ground water. Public water suppliers rely on withdrawals from wells completed in the carbonate rocks in the Chester Valley and in the schists of the South Valley Hills. The Exton Water Company (no longer in business) used wells completed in the felsic gneiss and Chickies Quartzite. The Church Farm School distributes water from a spring that issues from the Harpers Phyllite and Antietam Quartzite, as well as from wells in carbonate rocks. Surface water is used only by the General Crushed Stone Quarry, which withdraws water for processing from West Valley Creek.

Public water suppliers (table 10) supply most areas of the West Valley Creek Basin. A report by the Chester County Planning Commission (1991b) contains maps showing the areas served by public water. In 1990, approximately 20,000 people resided in the West Valley Creek Basin (Chester County Planning Commission, 1991a) and about 85 percent of the residents and businesses of the West Valley Creek Basin were served by public water supplies. Ground water is the sole source used for public supply. In the remainder of the basin, including residential areas in East Bradford Township in the South Valley Hills, a quarry, golf course, greenhouses, and businesses in the southwest part of the carbonate valley, on-site wells supply water.

Table 10. *Major water withdrawals in the West Valley Creek Basin, Pennsylvania, 1991*

[Data from the Pennsylvania Department of Environmental Resources and selected users]

Owner and well name	Local well or spring number or stream	Total annual withdrawal [1] (millions of gallons)
Public supply		
Church Farm School		
No. 1, 2 wells	CH-2739, 2740	4.75
spring	CH-SP-45	1.10
Philadelphia Suburban Water Company		
Pottstown Pike well	CH-1716	76.55
Highland Glen well	CH-1449	46.60
Uwchlan Township Municipal Authority [2]		
No. 3 Schoen Road well	CH-1228	91.16
No. 4 Schoen Road well	CH-1298	79.12
No. 5 Robert Dean well	CH-2670	136.90
No. 6 Robert Dean well	CH-2669	103.55
West Whiteland Township [2]		
No. 1 well	CH-1315	43.44
No. 2 well	CH-1316	29.60
Commercial and industrial		
Cyprus-Foote Mineral Company, Exton		
No. 3 well	CH-307	27.34
Exton Paper Company	CH-2412	39.10
General Crushed Stone Quarry		
No. 1, 2, 3 wells	CH-2753, 2724, 2348	2.05
quarry sumps		405.56
stream	West Valley Creek	154.90
Waterloo Gardens		
No. 1 well	CH-2497	43.44
No. 2 well	CH-2721	29.60
Whitford Flowers	CH-4149	1.08

[1] Total withdrawal is greater than net withdrawals because returns to ground water or surface water are not given here; data reported are for 1990 or 1991.

[2] In January 1993, the Philadelphia Suburban Water Company purchased the Uwchlan and West Whiteland Township water systems.

Most water pumped from the West Valley Creek Basin is exported from the basin to sewage-treatment facilities in other basins, except for water pumped at the quarry and where septic systems are used. A report by the Chester County Planning Commission (1991b) contains maps that show the areas served by public sewers. Water from the Chester Valley is sent to the Downingtown Area Regional Authority (DARA) treatment plant that discharges to the East Branch Brandywine Creek. Water from part of the South Valley Hills area is sent to the West Goshen treatment plant that discharges to Chester Creek.

A small sewage-treatment plant discharges to a tributary to West Valley Creek. This plant serves an apartment complex in Exton and is being phased out of operation (Jim Mahlon, West Whiteland Municipal Services Commission, oral commun., 1992). Until November 1991, the Foote Mineral facility discharged wastewater from lithium and other mineral processing to West Valley Creek under a National Pollution Elimination Discharge System (NPDES) permit.

Some industrial and commercial facilities have on-lot disposal systems or use water consumptively. These users include a quarry, rock crushing operations, a lithium battery manufacturer, a golf course, a nursery, and several greenhouses. In East Bradford Township in the South Valley Hills, private residences dispose of sewage with on-lot septic systems.

Basin budget

Because the water budgets in this report begin and end in winter when soil moisture is usually at field capacity, the change in soil moisture is equal to zero, and a soil-moisture term is not included in the water-budget equation. Surface-water storage is assumed to be negligible because the ponds in the basin are small. Therefore, a simple annual water budget for the West Valley Creek Basin can be expressed as

$$P = SF + GW + CGWS + ET + U, \qquad (1)$$

where P is precipitation,

SF is streamflow,

GW is ground-water withdrawals exported from the basin,

CGWS is change in ground-water storage,

ET is evapotranspiration, and

U is underflow.

All terms in the water-budget equation are known or can be estimated except evapotranspiration (ET); the equation is solved for ET. Deviations from the assumptions of the equation, such as changes in soil moisture and surface storage, and errors in other terms, therefore are included in ET.

Precipitation data for the West Valley Creek Basin are from four precipitation gages in the basin (fig. 7). Two precipitation gages are in the valley underlain by carbonate rocks, and one each are in the hills to the north and south. Less precipitation was measured in the valley gages than in the hill gages (table 11), and the data indicate that topography locally affects the distribution of precipitation. Differences in measurements at the gages also may be caused partly by differences in local setting, such as proximity to trees and buildings. The basin area above the streamflow-measurement station is about evenly divided between hills and valley; therefore, precipitation data were evenly weighted by area.

Streamflow was measured at the streamflow-measurement station [West] Valley Creek at Ravine Road near Downingtown, which is about 0.5 mi south of the valley underlain by carbonate rocks. Daily mean discharges were used to compute total annual streamflow. The daily mean discharges average the daily effects of quarry withdrawals and discharges. Base flow was separated from total flow by use of the local minimum hydrograph-separation technique in the computer program of Sloto (1991).

Table 11. *Annual precipitation in the West Valley Creek Basin, Pennsylvania, 1990-91*

[--, incomplete record]

Gage	Year	
	1990	1991
Waterloo Gardens	44.03	--
Estate Drive	48.13	45.11
Uwchlan Township Municipal Authority, Rutgers Drive	48.46	39.96
Church Farm School	42.55	39.61
Mean	45.79	[1]41.21

[1] Average of data from three gages, excluding Waterloo Gardens. The 1991 precipitation at Waterloo Gardens was probably similar to that at Uwchlan Township Municipal Authority and Church Farm School.

Water-level data from 12 observation wells in carbonate- and noncarbonate-rock aquifers were averaged to calculate the change in ground-water storage. Water-level measurements made in January of each year were used to calculate the annual change in water level, which was multiplied by 0.08, the specific yield of the zone of water-level fluctuation (McGreevy and Sloto, 1980, p. 18), to calculate the annual change in ground-water storage. Ground-water withdrawals from the basin for commercial, industrial, domestic and quarry pumpage are calculated from pumpage data supplied by PaDER and selected users, and include consumptive use. Thus, the total ground-water withdrawal is the sum of ground-water exportation and consumptive use. Records of pumpage from sumps and stream withdrawals at the General Crushed Stone Quarry were supplied by the quarry and PaDER; water pumped from sumps includes surface runoff and ground-water infiltration.

Water may leave a basin as ground-water underflow to another basin. Underflow from the West Valley Creek Basin results because the ground-water basin divide is at least 0.5 mi west of the surface-water divide at the eastern edge of the basin. By use of Darcy's Law and results of a ground-water flow simulation, Sloto (1990) estimated that about 1.1 in. of water annually flows from the West Valley Creek Basin east into the Valley Creek Basin as underflow. As much as three times that amount (3.3 in.) may be leaving the West Valley Creek Basin, on the basis of water levels measured in 1991, a relatively dry year. For the purposes of calculating water budgets, annual underflow is estimated to be 2.4 in. The ground-water divide shifts and underflow may vary from year to year.

The ground-water divide at the western edge of the basin in the carbonate valley is poorly defined because of the lack of available wells to measure water levels and because of the cone of depression caused by quarry dewatering. The quarry dewatering probably creates an artificial ground-water divide along at least part of the western edge and causes the natural ground-water divide to shift west, thus drawing water from the adjacent Brandywine Creek Basin. However, ground-water withdrawals from two public-supply wells just beyond this western edge on the north side of the valley could shift the ground-water divide to the east. These effects of the withdrawals are presumed to balance out.

Water budgets for 1990 and 1991 and an average water budget for both years are given in table 12. The water budget for 1990 probably more closely represents the long-term average than the water budget for 1991. Precipitation was near normal for 1990, but was about 4 in. less than normal in 1991.

***Table 12.** Basin water budget for West Valley Creek above streamflow-measurement station 01480887 at Ravine Road near Downingtown, Pennsylvania, 1990-91*

[Values are inches[1] per year]

Year	Precipitation (P)	Streamflow (SF)	Net ground- and surface-water withdrawals[2] (GW)	Change in ground-water storage (CGWS)	Evapotranspiration (ET)	Underflow (U)
1990	45.8	14.6	4.4	+ 0.6	23.8	2.4
1991	41.2	12.1	4.2	- 2.4	24.9	2.4
Mean (1990-91)	43.5	13.4	4.3	-.9	24.3	2.4

[1] Inches can be converted to million gallons per day per square mile by multiplying by 0.048.

[2] Includes ground-water infiltration to sewers, which is estimated to be up to 0.6 in. in 1990 and up to 0.3 in. in 1991.

Streamflow as a percentage of precipitation, and thus per unit area, appears to be lower in the West Valley Creek Basin than in many other basins in Chester County. For West Valley Creek, streamflow was 32 and 29 percent of precipitation in 1990 and 1991, respectively. Sloto (1994) calculated water budgets for the adjacent basins of East Branch Brandywine, Valley, Darby, and Crum Creeks by use of periods of record that ranged from 1974-88; for these basins, average streamflow as a percentage of average precipitation ranged from 41 to 48 percent.

Evapotranspiration is similar in the West Valley Creek and other basins in Chester County. In the West Valley Creek Basin, an estimated 52 and 60 percent of precipitation was lost as evapotranspiration in 1990 and 1991, respectively. Average annual evapotranspiration was estimated to be about 48 percent of precipitation in the adjacent Valley Creek Basin (Sloto, 1990), and up to 59 percent in the nearby Crum Creek Basin (Sloto, 1994).

Ground-water exportation depletes base flow in West Valley Creek Basin. Average base flow ranged from 12 to 13.6 in. in other basins in Chester County (Sloto, 1994) compared to 9.1 and 7.5 in. for West Valley Creek in 1990 and 1991, respectively. Net ground-water withdrawals of about 4 in. account for most of the difference in the average base flow between West Valley Creek and the other basins; differences range from about 3 to 4.5 in., assuming that 1990 represents an average year.

Sewers can export significant amounts of water out of the basin. In the West Valley Creek Basin, most of the water exported by sewers is ground water that was pumped for public supply. Exportation of ground water in sewers may reduce base flow (ground-water discharge to streams). During periods of low flow, sewer flow periodically equaled or exceeded the base flow of West Valley Creek (fig. 19). For example, sewer flow (2.4 ft^3/s or about 11 Mgal per week) was greater than streamflow (≤ 2 ft^3/s) during 1 or 2 weeks in August and November 1991. Exported water can include ground water that infiltrates sewers. The amount of ground-water infiltration partly depends on the position of the water table. In eastern Chester County, Sloto (1987, p. 24-30) showed a positive correlation between ground-water levels and discharge from sewage-treatment plants, and that when water levels were high, infiltrated ground water makes up a larger percentage of water discharged from sewers than does wastewater. In the West Valley Creek Basin, seasonal changes in sewer flow are similar to the seasonal changes in base flow (fig. 19), indicating seasonal changes in ground-water infiltration in sewers. Sewer flow increases as base flow increases, reflecting higher ground-water levels and probably indicating greater ground-water infiltration during the winter and spring than in the summer or fall (fig. 19). Ground-water infiltration to sewers during periods of high ground-water levels could account for as much as 25 percent of sewer flow. However, despite less infiltration, the ratio of sewer flow to base flow is greater during periods of low base flow than high base flow. The relative effect of ground-water exportation by sewers on base flow may be greatest during lowest base flow.

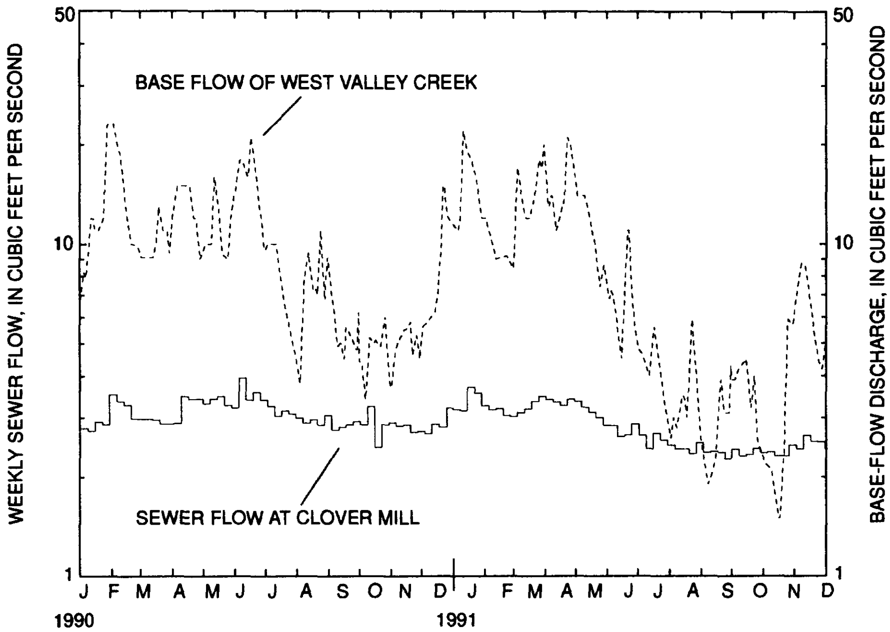


Figure 19. Base flow and exported sewer flow for the West Valley Creek Basin, Pennsylvania, 1990-91.

Recharge

Precipitation that infiltrates and does not replenish soil moisture recharges the ground-water system. Recharge to the ground-water system depends on many factors, including the duration and intensity of precipitation, antecedent soil-moisture conditions, slope, quantity of impervious surface areas associated with urbanization, and soil and bedrock characteristics. Because of climatic variability, recharge varies from year to year. Generally, recharge areas include hilltops and hillsides; topographic lows commonly are discharge areas.

Recharge was estimated by applying the following equation:

$$R = BF + GW + CGWS + GWET + U, \quad (2)$$

where R is recharge,

BF is base flow,

GW is ground-water withdrawals exported from the basin,

CGWS is change in ground-water storage,

GWET is ground-water evapotranspiration, and

U is underflow.

Calculations of base flow, ground-water withdrawals, change in ground-water storage, and underflow were described in the section on Basin Budgets. Ground-water evapotranspiration is evapotranspiration directly from the saturated zone. It is estimated to be 2 in. per year in the basin (Sloto, 1991).

Recharge in 1990 (18.5 in.) may more closely represent a long-term average for the basin than recharge in 1991 (13.7 in.) (table 13), which was a year of lower than normal precipitation. These recharge rates are similar to average recharge rates reported in nearby basins: 15.4 in. in the East Brandywine Creek Basin and 21 in. in the Valley Creek Basin for periods between 1974-88 and 1983-87, respectively (Sloto, 1994). Recharge as a percentage of precipitation was 40 and 33 percent in West Valley Creek in 1990 and 1991, respectively. Average recharge as a percentage of average precipitation was 32 percent for East Branch Brandywine Creek Basin and 44 percent for Valley Creek Basin (Sloto, 1994). The hydrogeology and land-use characteristics of West Valley Creek Basin are most similar to Valley Creek Basin to the east.

Table 13. *Estimated recharge to West Valley Creek Basin, Pennsylvania, 1990-91*

[Values are inches[1] per year; +, increase; -, decrease]

Year	Recharge (R)	Baseflow (BF)	Net ground-water withdrawals [2] (GW)	Change in ground-water storage (CGWS)	Ground-water evapotranspiration (GWET)	Underflow (U)
1990	18.5	9.1	4.4	+ 0.6	2	2.4
1991	13.7	7.5	4.2	- 2.4	2	2.4
Mean (1990-91)	16.1	8.3	4.3	-.9	2	2.4

[1] Inches can be converted to million gallons per day per square mile by multiplying by 0.048.

[2] Includes ground-water infiltration to sewers, which is estimated to be up to 0.6 in. in 1990 and up to 0.3 in. in 1991.

WATER QUALITY

The quality of water is determined primarily by the type and quantity of substances dissolved in it. As water moves through the hydrologic cycle, gases and minerals from the atmosphere, soil, and rock are dissolved. Additional substances may be added by anthropogenic activities. Nutrients from septic systems, sewage-treatment plants, or fertilizers; salts from road salting and septic systems, pesticides, and industrial solvents and chemicals can be introduced into ground water and surface water. Biological activity also can change the chemical composition of ground water and surface water.

Major ions dissolved from soil and rock make up most of the dissolved solutes in ground water and surface water; the remainder comes mostly from constituents dissolved in precipitation. Major cations (positively charged ions) are calcium (Ca^{+2}), sodium (Na^{+}), magnesium (Mg^{+2}), and potassium (K^{+}). Major anions (negatively charged ions) are bicarbonate (HCO_3^{-}), sulfate (SO_4^{-2}), chloride (Cl^{-}), nitrate (NO_3^{-}), and fluoride (F^{-}). Silica (SiO_2) is a major constituent that commonly is present as undissociated silicic acid (H_4SiO_4), an uncharged ion, below a pH of 10.

Precipitation is the primary source of water for the ground-water and surface-water systems in the basin. Precipitation contains trace and major elements that are scavenged from the atmosphere. The source of constituents in precipitation can be natural, such as sodium and chloride from the ocean, or anthropogenic, such as sodium and chloride from road salt. Without other anthropogenic sources, atmospheric precipitation commonly is a major source of chloride and nitrogen. The average concentration of selected major ions in precipitation measured at Valley Forge National Historical Park are given for 1982-91 in table 14. Valley Forge Park is about 5 mi east of the West Valley Creek Basin, and precipitation quality in the two areas should be similar.

Precipitation in southeastern Pennsylvania is acidic; the median pH was 4.24 at Valley Forge (table 14). The pH is a measurement of the activity of hydrogen ions in water and is expressed in logarithmic units with a pH of 7 considered neutral. Water with a pH less than 7 is acidic; water with a pH greater than 7 is basic. The pH of distilled water in contact with the atmosphere is about 5.6 because of dissolution of carbon dioxide. However, in southeastern Pennsylvania where emissions from combustion of fossil fuels contribute to acidity of atmospheric precipitation, the pH commonly is less than 5. Acidic

***Table 14.** Mean annual concentrations and loads of selected major constituents in precipitation at Valley Forge, Pennsylvania, 1982-91 (From Lynch and others, 1992)*

[mg/L, milligrams per liter; kg/ha, kilograms per hectare]

Constituent	Mean annual concentration (mg/L)	Mean annual load (kg/ha)
Calcium	0.136	1.59
Magnesium	.063	.50
Sodium	.187	1.99
Potassium	.033	.43
Chloride	.386	4.54
Sulfate	2.68	31.5
Ammonium (as NH_4)[1]	.286	3.34
Nitrate (as NO_3)[2]	1.75	20.59
Hydrogen (as pH)	[3] 4.24	.71

[1] To express ammonium as N (nitrogen), multiply ammonium as NH_4 by 0.7778.
[2] To express nitrate as N (nitrogen), multiply nitrate as NO_3 by 0.2258.
[3] Hydrogen concentration expressed as median pH.

precipitation can react aggressively with some minerals to accelerate mineral weathering. For typical precipitation at Valley Forge, the dominant anions are sulfate and nitrate, and the dominant cations are hydrogen and ammonium. Rain from summer storms is relatively enriched in sodium and chloride from the ocean, and precipitation from winter storms is relatively enriched by sulfur and nitrogen compounds from the burning of fossil fuels (Lynch and others, 1992). Temporal changes in precipitation quality can cause changes in ground-water and stream quality.

Water quality may be characterized by physical properties and the concentration of dissolved and suspended constituents. Physical properties and chemical constituents determined in the field include pH, specific conductance, hardness, alkalinity, and concentration of dissolved oxygen; these properties are unstable and are measured in the field at the time a water sample is collected. Specific conductance is a measurement of the ability of water to conduct an electric current and is expressed in units of microsiemens per centimeter at 25°C. Specific conductance is directly related to the concentration of dissolved solids; the higher the specific conductance, the greater the concentration of dissolved solids. Total dissolved solids (TDS) is a measurement of the total solutes in water. TDS can be calculated from the sum of the concentrations of dissolved major ions or measured by determining the mass of residue left after evaporation. The alkalinity of water is the capacity for solutes (bases) it contains to react with and neutralize acid and is expressed in terms of an equivalent amount of calcium carbonate. Alkalinity is produced by dissolution of minerals or reactions that generate bicarbonate, carbonate, or other basic anions. Bicarbonate alkalinity predominates in most natural ground and surface water.

The U.S. Environmental Protection Agency (USEPA) has set maximum contaminant levels (MCL's) and secondary maximum contaminant levels (SMCL's) for some constituents in drinking water (table 15). MCL's generally are set because elevated concentrations of these constituents may cause adverse health effects. SMCL's generally are set for aesthetic reasons; elevated concentrations of these constituents may impart an undesirable taste or odor to water.

***Table 15.** Primary and secondary maximum contaminant levels established by the U.S. Environmental Protection Agency for selected inorganic and organic constituents in drinking water (From U.S. Environmental Protection Agency, 1993)*

[MCL, maximum contaminant level; mg/L, milligrams per liter; pCi/L; picocuries per liter; --, no level established]

	Primary MCL (mg/L)	Secondary MCL (mg/L)
Inorganic constituents		
Aluminum	--	0.05 - 0.2
Antimony	0.006	--
Arsenic	.05	--
Barium	2	--
Beryllium	.004	--
Cadmium	.005	--
Chloride	--	250
Chromium (total)	.1	--
Copper	[1]--	1
Cyanide	.2	--
Fluoride	4	2
Iron	--	.3
Lead (at tap)	[2]--	--
Manganese	--	.05
Mercury	.002	--
Nickel	.1	--
Nitrate as N	10	--
Nitrite as N	1	--
Nitrate + Nitrite as N	10	--
pH	--	6.5 - 8.5 pH units
Selenium	.05	--
Silver	--	.1
Sulfate	--	250
Thallium	.002	--
Zinc	--	5
Total dissolved solids	--	500
Organic compounds		
Benzene	.005	--
Carbon tetrachloride	.005	--
1,1-dichloroethylene	.007	--
trans-1,2-dichloroethylene	.1	--
1,1,1-trichloroethane	.2	--
1,1,2-trichloroethane	.005	--
Trichloroethylene	.005	--
Radioactivity (pCi/L)		
Gross alpha particle activity	15	--
Ra-226 + Ra-228	[3]5	--

[1] Action level for copper is 1.3 mg/L.
[2] Action level for lead is 0.015 mg/L.
[3] Proposed MCL for either Ra-226 or Ra-228 is 20 pCi/L.

Ground Water

Ground-water composition evolves through a series of chemical interactions with minerals in the aquifer. Some of the chemical reactions are biologically mediated, such as denitrification, during which nitrate is reduced to nitrogen gas. The main chemical reactions are mineral dissolution and precipitation, mineral weathering, ion adsorption and exchange, and natural radioactive decay. Most of the strictly chemical reactions are thermodynamically and(or) kinetically controlled. Sources of many elements in natural waters and general and important chemical reactions governing water chemistry are summarized by Hem (1985).

Ground-water composition may change along a flow path. In the West Valley Creek Basin, the hills underlain by noncarbonate rocks are primarily recharge areas that discharge to the valley below underlain by carbonate rocks. Ground water in the noncarbonate rocks derives its composition by interaction with only those rocks, whereas ground water in the carbonate rocks is a mixture of water that infiltrates directly and ground water that flows from the noncarbonate rocks. In addition to water-rock interaction, the composition of ground water in both noncarbonate and carbonate rocks also can be affected by anthropogenic or biological activities.

In the noncarbonate rocks, silicate minerals are the most abundant minerals. These minerals can include feldspars, micas, and quartz. Other minerals that may be present are pyrite (a sulfide), secondary iron and manganese hydroxides, and trace-element oxides. The weathering of feldspars and micas causes an increase in alkalinity, pH, and concentrations of dissolved silica, sodium, calcium, magnesium, and (or) potassium. The weathering of pyrite can cause an increase in the concentration of dissolved sulfate and a decrease in pH. In the carbonate rocks, magnesium and calcium carbonates (dolomite and calcite) are the most abundant minerals. Dissolution of these carbonate minerals causes an increase in pH and concentrations of dissolved calcium, magnesium, and bicarbonate. The carbonate rocks in the West Valley Creek Basin also contain impurities (such as iron and manganese), and the Elbrook and Conestoga Formations contain phyllitic (mica-rich) beds.

Available data on ground-water composition for the West Valley Creek Basin is listed by geologic unit in tables 25 to 33. The data were collected by the U.S. Geological Survey over a period of more than 10 years as part of a ground-water-quality monitoring program in cooperation with the Chester County Water Resources Authority and the Chester County Health Department. Ground-water samples were analyzed at the National Laboratory of the U.S. Geological Survey in Denver, Colo. Many of the wells were sampled because of potential anthropogenic contamination. Where no contamination was detected, water samples may represent natural ground-water quality. Many inorganic compounds are from natural sources, but detection of industrial organic compounds and elevated concentrations of some inorganic constituents, such as chloride, are indicative of anthropogenic sources.

Most wells were sampled only once, but several wells were sampled multiple times. Ground-water quality can change over time; some changes are seasonal, and others may reflect changes in land use or other conditions affecting loads and geochemical processes. For example, seasonal changes in the concentration of sulfate were detected in water samples from wells near the West Valley Creek Basin; the greatest concentrations were measured in the late spring and early summer (Sloto, 1987; Senior and Vogel, 1995).

Physical Properties and Field-Determined Constituents

The range and median temperature, pH, specific conductance, hardness, alkalinity, and concentration of dissolved oxygen for general rock types in the West Valley Creek Basin are presented in table 16. The pH, alkalinity, dissolved-oxygen concentration measured using the azide modification of the iodometric method (American Public Health Works and others, 1985), specific conductance, and temperature of the ground-water samples were measured in the field according to established procedures (Wood, 1981). Where more than one analysis of water was available for a well, the most recent analysis was used for statistical analysis. Extreme values may represent anthropogenic contamination.

***Table 16.** Summary of ground-water physical properties and field-determined constituents for water samples from wells in the West Valley Creek Basin, Pennsylvania*

[Phyllite and schist includes the Octoraro Phyllite, Peters Creek Schist, and Wissahickon Formation; carbonate rocks include the Ledger Dolomite, Conestoga Limestone, Elbrook Formation; quartzite is the Chickies Quartzite; gneiss is felsic gneiss; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no or insufficient data]

Property or constituent and geologic group	Number of samples	Minimum	Median	Maximum
pH:				
Gneiss	5	5.1	6.2	7.1
Quartzite	10	4.3	5.2	6.0
Carbonate rocks	34	6.4	7.3	7.9
Phyllite and schist	13	5.8	6.0	6.7
Specific conductance (µS/cm):				
Gneiss	3	152	170	190
Quartzite	10	33	80	203
Carbonate rocks	32	290	645	1,020
Phyllite and schist	13	55	240	1,030
Alkalinity (mg/L as $CaCO_3$):				
Gneiss	4	10	45	64
Quartzite	10	0	12	27
Carbonate rocks	30	126	220	348
Phyllite and schist	11	13	18	40
Hardness[1] (mg/L as $CaCO_3$):				
Gneiss	4	29	64	76
Quartzite	8	7	27	61
Carbonate rocks	19	130	270	510
Phyllite and schist	5	25	51	80
Temperature (°C):				
Gneiss	2	11.5	12.5	13.5
Quartzite	10	11.5	12.5	17.5
Carbonate rocks	36	12	14	22
Phyllite and schist	13	10	13.5	14.5
Dissolved oxygen (mg/L):				
Gneiss	1	--	7.5	--
Quartzite	7	7.3	8.7	10.2
Carbonate rocks	20	.7	5.3	9.2
Phyllite and schist	3	2.8	8.7	11.6

[1] Includes some laboratory and computed determinations.

Most natural ground water is less acidic than precipitation, which has a median pH of about 4.24 (table 14), because mineral weathering reactions consume the hydrogen ions in recharge. The median pH of ground water from quartzite is the lowest (5.2 pH units) of the geologic groups because of the sparsity of easily dissolved minerals in this quartz-rich unit and perhaps because of acidifying reactions such as pyrite dissolution. The chemistry of the Chickies Quartzite is discussed in greater detail by Senior and Vogel (1992; 1995). The median pH of ground water from carbonate rocks is greater than water from noncarbonate rocks because carbonate minerals dissolve easily, and the pH from the reaction is buffered in the range between 6.2 and 10.3. The median pH of ground water from gneiss, schist, and phyllite is slightly acidic, but less acidic than ground water from quartzite. Gneiss, schist, and phyllite contain more soluble silicate minerals that react to increase pH than quartzite.

Ground water from carbonate rocks has a greater specific conductance than water from noncarbonate rocks because carbonate minerals dissolve more readily than silicate minerals. The differences in specific conductance largely reflect the differences in type and extent of mineral dissolution and weathering reactions among geologic units, and also differences in the extent of contamination by road salt and other soluble compounds.

Water from wells open to carbonate rocks has much greater alkalinity than ground water from noncarbonate rocks. Carbonate rocks are composed mainly of calcium and magnesium carbonate, and dissolution of these readily soluble minerals contributes to high alkalinity. Weathering of silicate minerals also increases alkalinity, but commonly to a lesser extent than carbonate minerals.

Hardness is a poorly defined property of water and is caused by the dissolved alkaline earth elements, chiefly calcium and magnesium. Hard water restricts the lathering and cleaning action of soap and causes the formation of encrustations when water is heated. Hardness usually is expressed in equivalent concentrations of calcium carbonate. Hardness is classified by Dufor and Becker (1964, p. 27) as: soft, 0-60 mg/L; moderately hard, 61-120 mg/L; hard, 121-180 mg/L; and very hard, more than 180 mg/L. According to this classification and median hardness, ground water from carbonate rocks is very hard, ground water from gneiss is moderately hard, and ground water from the other units generally is soft.

The median temperature of ground-water samples from wells in the West Valley Creek Basin ranges from 12.5 to 14.0°C (54.5 to 57.2°F). Ground-water temperature commonly is similar to mean annual air temperature. The mean annual air temperature is about 13.3°C (56°F). Ground-water temperatures measured monthly from December 1983 to December 1984 in six wells in different parts of Chester County had an average annual fluctuation range of about 3.3°C (6°F) (Sloto, 1987).

Dissolved oxygen in ground water indicates that infiltration of recharge is rapid and(or) that few biological and chemical reactions that consume oxygen have taken place. Oxygen can be consumed in the oxidation of organic and inorganic (including minerals) compounds. Ground water in fractured-rock aquifers in the Piedmont commonly contains some dissolved oxygen. For the range of ground-water temperature observed in the basin (10 to 22°C), the saturated concentration of dissolved oxygen ranges from 8.8 to 11.3 mg/L (American Public Health Association and others, 1985, p. 446). The median concentration of dissolved oxygen is lower in ground water from carbonate rocks (5.3 mg/L) than in ground water from the noncarbonate rocks (8.7 mg/L). Oxygen concentrations may be lower in ground water in carbonate rocks than in noncarbonate rocks because mineral oxidation is greater in ground water in the carbonate rocks, biological processes are more active in the soils that cover the carbonate rocks, and(or) soils are thicker and infiltration is slower for the carbonate rocks.

Major Ions and Constituents

The minimum, maximum, and median concentrations of major ions in water samples from wells in the West Valley Creek Basin are listed in table 17 by lithology; complete analyses are given in table 24. Maximum concentrations of some ions are the result of anthropogenic contamination of ground water. Because the number of water-quality analyses for wells in the noncarbonate rocks is small, these analyses may not represent water quality in the aquifers composed of these rocks, and differences in ground-water quality among lithologies were not tested statistically. Additional data on ground-water quality in the Chickies Quartzite is given by Senior and Vogel (1992; 1995) and in other formations in Chester County by Poth (1968) and Sloto (1990; 1994).

Ground water in the quartzite, which is resistant to weathering, is the most dilute and contains the lowest median concentration of TDS of the geologic units. Ground water in both the gneiss and the schist, which are composed of minerals that weather slowly but to a greater extent than the minerals in the quartzite, also contains low TDS. Readily soluble carbonate rocks contain the maximum concentration of TDS of the geologic units (table 17). Water from only 2 of 28 wells with reported TDS concentrations exceeded the USEPA SMCL of 500 mg/L for TDS; both samples were from wells open to carbonate rocks. The median reported concentration of TDS for water samples from 14 wells open to carbonate rocks is about 350 mg/L.

Table 17. *Summary of major ion concentrations in ground water, West Valley Creek Basin, Pennsylvania*

[Phyllite and schist includes the Octoraro Phyllite, Peters Creek Schist, and Wissahickon Formation; carbonate rocks include the Ledger Dolomite, Conestoga Limestone, Elbrook Formation; quartzite is the Chickies Quartzite; gneiss is felsic gneiss; --, no data; <, less than]

Ion and geologic group	Number of samples	Concentrations (milligrams per liter)		
		Minimum	Median	Maximum
Calcium:				
Gneiss	2	6.2	10.6	15
Quartzite	10	1.0	3.3	9.6
Carbonate rocks	17	42	75	130
Phyllite and schist	4	4.0	9.6	18
Magnesium:				
Gneiss	2	3.7	3.7	4
Quartzite	10	1	2.6	10
Carbonate rocks	18	11	21.5	51
Phyllite and schist	4	2.4	5.3	6.5
Sodium:				
Gneiss	2	5	9.5	14
Quartzite	10	1.6	4.1	19
Carbonate rocks	17	3.5	15	52
Phyllite and schist	14	2.8	7.5	11
Potassium:				
Gneiss	2	1.7	1.9	2.0
Quartzite	9	.5	2.5	11
Carbonate rocks	14	1.1	1.8	3.8
Phyllite and schist	4	.7	.9	1.0
Chloride:				
Gneiss	4	3.5	9.0	29
Quartzite	12	2.7	5.8	34
Carbonate rocks	27	3.3	22	110
Phyllite and schist	7	2.0	4.2	28
Sulfate:				
Gneiss	4	1.0	26	29
Quartzite	10	.9	7.5	37
Carbonate rocks	26	4.0	28	240
Phyllite and schist	7	1.2	4.3	14
Fluoride:				
Gneiss	2	.1	.1	.1
Quartzite	7	<.1	.1	.2
Carbonate rocks	9	<.1	.2	.5
Phyllite and schist	0	--	--	--
Silica:				
Gneiss	2	11	11.5	12
Quartzite	9	5.8	7.6	22
Carbonate rocks	14	6.4	8.7	15
Phyllite and schist	4	8.1	11	14

Mineral sources of calcium include calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$], and anorthite ($CaAl_2Si_2O_8$) or another calcium-bearing feldspar. Sources of magnesium include dolomite and chlorite [$Mg_5Al_2Si_3O_{10}(OH)_8$]. Concentrations of calcium and magnesium are greatest in water samples from carbonate rocks because of carbonate mineral dissolution. Median concentrations of calcium and magnesium in water samples from carbonate rocks are one order of magnitude greater than in water samples from other geologic units (table 17). Calcite and dolomite in the carbonate rocks weather more readily than the calcium- and magnesium-bearing minerals, such as feldspar and biotite, in gneiss, quartzite, and schist.

Mineral sources of potassium include mica [muscovite, $KAl_3Si_3O_{10}(OH)_2$ and biotite, $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$], and orthoclase, a potassium-bearing feldspar ($KAl_3Si_3O_8$), which are more abundant in noncarbonate rocks than in carbonate rocks; the difference in mineralogy may partly account for the greater concentrations of potassium in ground water from noncarbonate rocks than in ground water from carbonate rocks. Potassium is also a component in fertilizers.

Mineral sources of sodium include albite ($NaAl_3Si_3O_8$) or another sodium-bearing feldspar and clay mineral, which, if present, are more abundant in noncarbonate rocks than carbonate rocks. Road salt is a source of sodium and may produce elevated concentrations of sodium in ground water from carbonate rocks that underlie the valley. Two major highways traverse the West Valley Creek Basin; U.S. Route 30 lies in the carbonate valley, and Pennsylvania State Route 100 bisects the basin in a north-south direction and traverses both the carbonate valley and noncarbonate uplands.

The predominant natural source of chloride in the West Valley Creek Basin probably is precipitation. Chloride concentrations in precipitation (average is about 0.4 mg/L, table 14) can be increased by evaporation before infiltration. The minimum reported concentrations of chloride probably represent natural background concentrations (about 3 mg/L or less) in ground water (table 17). Elevated concentrations of chloride in the West Valley Creek Basin are probably caused by anthropogenic activities, such as input from road salt, fertilizers, and septic systems. Increases in chloride concentration commonly are accompanied by increases in sodium, indicative of road salt and septic-system waste containing salt from the human diet. A linear and direct relation between concentrations of sodium and chloride is evident for ground-water samples from all geologic units; concentrations of sodium and chloride are greatest in the carbonate rocks (fig. 20). If the sole source of sodium and chloride were salt as NaCl, the mass ratio of chloride to sodium should be the same in ground water as in salt (about 1.54), although cation exchange can affect ion ratios. Because the mass ratio is about 1.96 (slope of best fit line) for chloride to sodium, the data suggest sources of chloride other than salt. In southeastern Pennsylvania, both calcium chloride and sodium chloride salts are applied to roads in the winter months. None of the chloride concentrations in the ground-water samples exceeded the USEPA SMCL of 250 mg/L for chloride.

In a study of the effects of urbanization on the water resources of eastern Chester County, Sloto (1987, p. 66-68) compared the concentrations of selected constituents in early (1949-79) and later (1982-83) water samples collected from the same wells. Increases in the concentration of chloride and sodium were detected in developed areas. The source of increased concentrations of chloride and sodium probably is deicing salt.

Sulfate (SO_4^{-2}) is a common constituent of ground water that is derived from atmospheric precipitation and minerals. Sulfuric acid generated during coal combustion contributes to the acidity of rain in eastern Pennsylvania—the median concentration of sulfate is about 2.7 mg/L (table 14). Mineral sources of sulfur include gypsum ($CaSO_4 \cdot 2H_2O$), which may be present in the carbonate rocks, and metallic sulfides, such as pyrite (FeS_2), in carbonate rocks, quartzite, and schist. Sewage is another source of sulfate. Most sulfate in the ground water in the West Valley Creek Basin probably is from natural mineral sources. The median concentration of sulfate is greatest for ground water from carbonate rocks indicating that these rocks contain more abundant or soluble sources of sulfate than other rocks. The maximum reported concentration of sulfate (240 mg/L) is for a water sample from a well completed in carbonate rocks; this maximum concentration is close to the USEPA SMCL of 250 mg/L for sulfate.

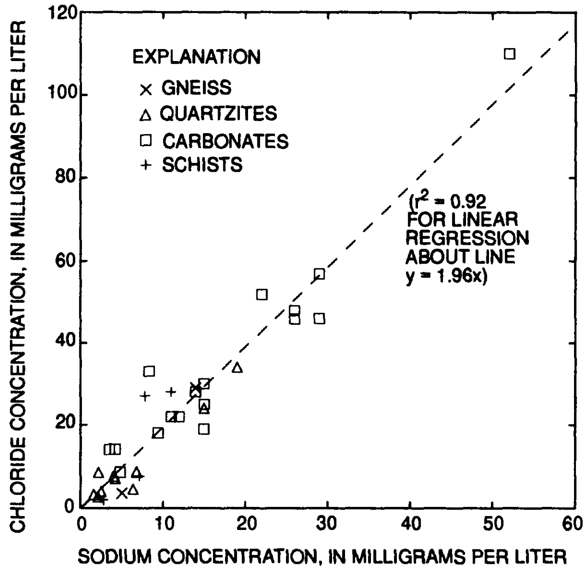


Figure 20. Relation between concentrations of sodium and chloride in ground water in the West Valley Creek Basin, Pennsylvania. (r^2 is the coefficient of determination or fraction of variance explained by regression.)

Nutrients in ground water include nitrogen and phosphorus species. Concentration of nutrients above natural background indicate pollution resulting from human activities. Sources of nutrients in ground water include fertilizers, storm runoff, animal wastes, and effluent from sewage-treatment plants and septic systems. The minimum, maximum, and median concentrations of nutrients in water samples from wells in the West Valley Creek Basin are listed by lithology in table 18; complete analyses are given in table 25.

Nitrogen is found in water principally as nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+). Nitrate is the most prevalent nitrogen species in ground water in the West Valley Creek Basin. Ammonium (NH_4^+) is the dominant form of ammonia (NH_3) in most natural waters. Ammonium commonly is oxidized to form nitrate and is rarely detected in uncontaminated ground water in concentrations greater than about 0.5 mg/L. Minimum reported concentrations of nitrate (table 18) probably are equivalent to background concentrations (about 1 mg/L as N) in ground water. Changes in laboratory analytical methods and sample collection and preservation techniques make comparison of nitrate data from different periods difficult.

***Table 18.** Summary of nutrient concentrations in ground water, West Valley Creek Basin, Pennsylvania*

[Phyllite and schist includes the Octoraro Phyllite, Peters Creek Schist, and Wissahickon Formation; carbonate rocks include the Ledger Dolomite, Conestoga Limestone, Elbrook Formation; quartzite is the Chickies Quartzite; gneiss is felsic gneiss; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; <, less than; --, no data]

Constituent and geologic group	Number of samples	Concentrations (milligrams per liter)		
		Minimum	Median	Maximum
Ammonia (as N): [1]				
Gneiss	2	0.04	0.10	0.16
Quartzite	3	.01	.02	.02
Carbonate rocks	27	<.01	.02	.38
Phyllite and schist	9	<.01	.01	4.2
Nitrite (as N):				
Gneiss	2	<.01	<.01	<.01
Quartzite	3	<.01	<.01	<.01
Carbonate rocks	27	<.01	<.01	.29
Phyllite and schist	9	<.01	<.01	.01
Nitrate plus nitrite (as N):				
Gneiss	2	.37	1.6	2.8
Quartzite	3	.98	1.6	3.3
Carbonate rocks	27	<.10	3.4	13.0
Phyllite and schist	9	.25	3.95	7.7
Phosphate (as P):				
Gneiss	3	<.01	.03	.41
Quartzite	0	--	--	--
Carbonate rocks	11	<.01	<.01	.06
Phyllite and schist	6	<8.1	.01	.03

[1] Ammonia plus ammonium.

The median and maximum concentrations of nitrate in water samples from carbonate rocks and schist were greater than median and maximum concentrations in water samples from gneiss and quartzite (fig. 21). Nitrate concentrations above background levels in ground water from carbonate rocks may reflect infiltration of fertilizer during past and present agricultural activities. The carbonate valley has been farmed for more than 200 years. In the past 25 years, agricultural areas have largely been urbanized; the most rapid change in land use has taken place in the last 10 years. Only two ground-water samples, both from wells in areas underlain by carbonate rocks where corn and soybean are grown, contained nitrate in concentrations that exceeded the USEPA MCL of 10 mg/L as nitrogen (N). Nitrate in water samples from schists may reflect past agricultural land use and the current use of septic systems in the residential areas of the South Valley Hills. Some areas underlain by fractured rocks with thin or unsuitable soils, such as the South Valley Hills, may be susceptible to contamination by septic systems. Soils in the carbonate valley generally are thicker than in the hills, and much of the carbonate valley is sewered. The median concentration of nitrate is lowest in ground-water samples from quartzite and gneiss; the area of the North Valley Hills underlain by these rocks has not been farmed extensively and is sewered.

Concentrations of ammonia or phosphate above background concentrations in ground water can indicate contamination, as can elevated concentrations of nitrate. The maximum reported concentration of 4.2 mg/L ammonia was measured in a water sample from a well (CH-2453) in an unsewered residential area underlain by the Wissahickon Formation in the Broad Run subbasin of the South Valley Hills. The elevated concentration of ammonia confirms an earlier elevated concentration measured in a sample from the same well and suggests contamination of the ground water by septic systems.

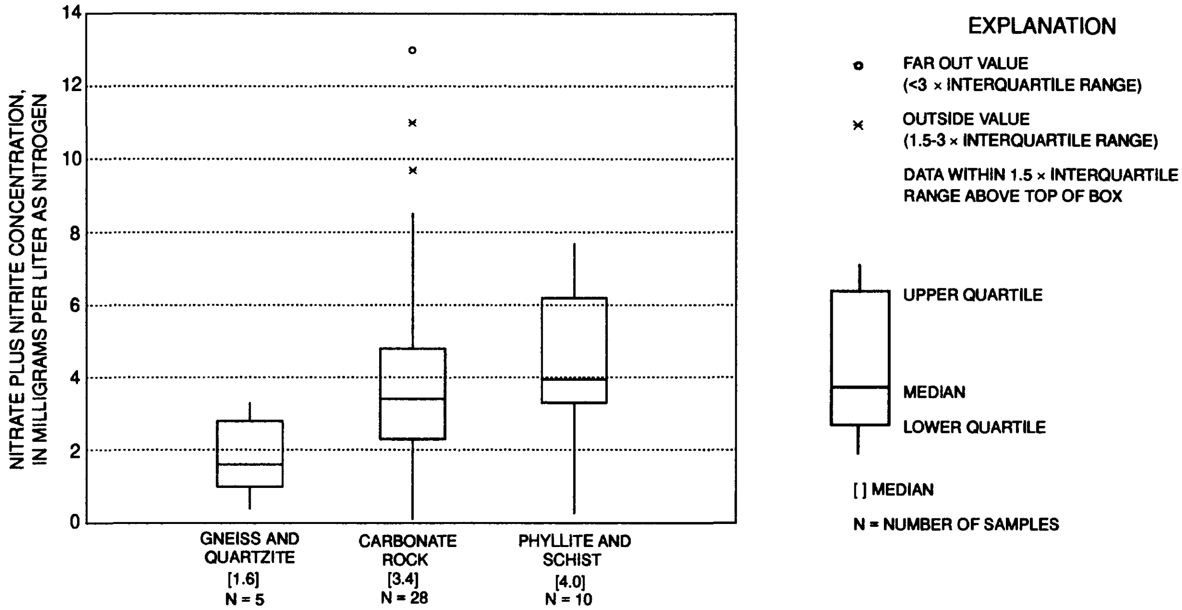
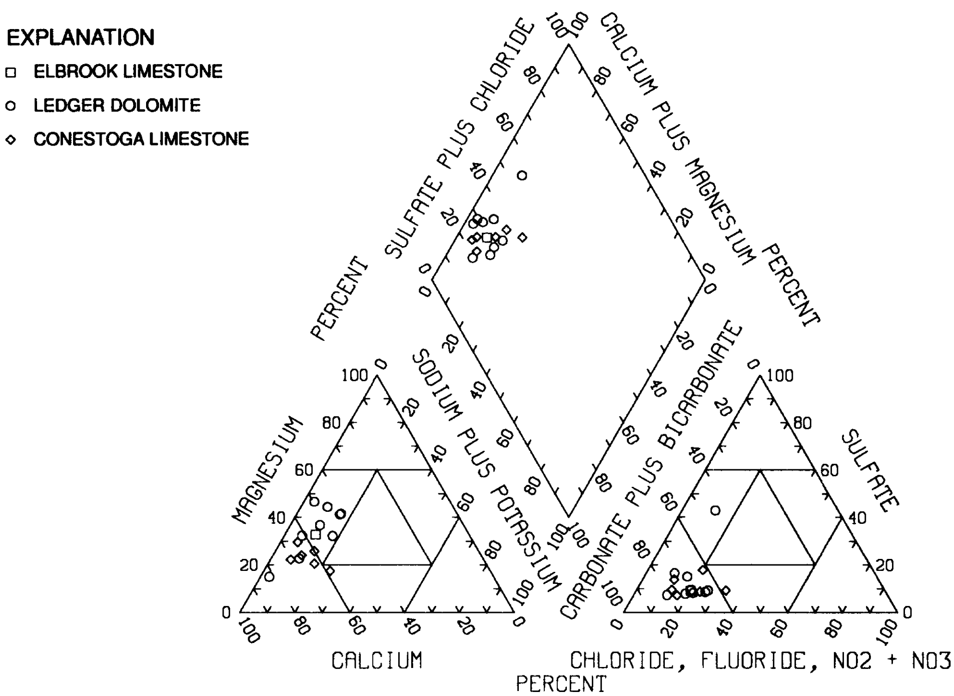


Figure 21. Distribution of concentrations of nitrite plus nitrate as nitrogen in ground water in the West Valley Creek Basin, Pennsylvania, grouped by lithology: 1) gneiss and quartzite; 2) carbonate rock; 3) phyllite and schist.

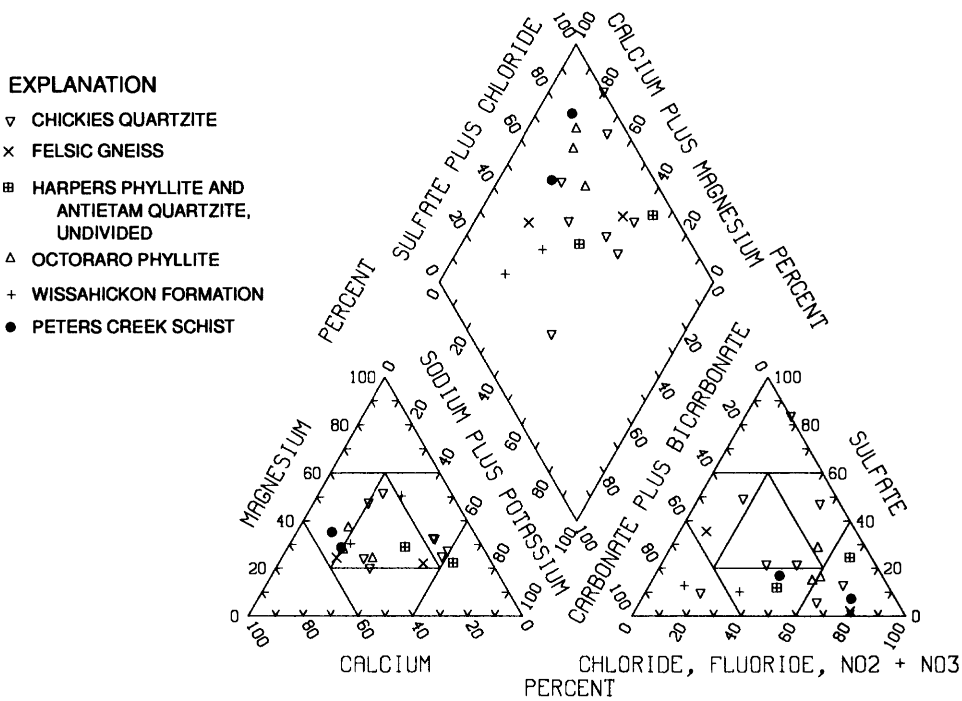
Concentrations of phosphate up to 0.41 mg/L were measured in a sample from one well in gneiss, but most samples contained concentrations below the level of detection (0.01 mg/L). Phosphate was detected most frequently in water samples from schist, possibly indicating contamination by effluent from septic systems.

Waters commonly are characterized by the relative percentage of major ions in solution. A trilinear diagram for cations and anions, known as a Piper diagram, shows ground-water compositions that reflect aquifer mineralogy and chemical loads to ground water. Predominant ions in ground water from the carbonate rocks are calcium, magnesium, and bicarbonate (fig. 22). Many of the ground-water samples are at or near saturation with calcite or dolomite, or both. The Ledger Dolomite contains relatively more magnesium than ground water from the other carbonate units because dolomite is richer in magnesium than limestone, in which calcite is the dominant mineral. The calcium/magnesium molar ratio should equal 1 in ground water in equilibrium with dolomite; this ratio is about equal to 1 in water samples from several wells in the Ledger dolomite (wells CH-1315, CH-1316, CH-2742, CH-2746, and CH-3926). For ground-water samples from the Conestoga Limestone, calcium is more abundant than magnesium and calcium/magnesium molar ratios range from 2.2 to 3.3 (wells CH-307, CH-2674, CH-2723, CH-2725, CH-2846, CH-4129, and CH-4292). Because some wells open to rocks near geologic contacts produce water from more than one formation, the calcium/magnesium molar ratios are greater than 1, as indicated by ratios that range from 1.4 to 5.5 for water samples collected near the contact between Ledger Dolomite and Conestoga Limestone (wells CH-249, CH-2161, CH-2730, CH-4293, and CH-SP-42).

Sodium, potassium, chloride, nitrate, and sulfate are relatively more dominant than other ions in ground water from gneiss, quartzite, and schist. In the relatively dilute ground water from noncarbonate rocks that result from slow weathering of silicate minerals, the chemical composition of recharge possibly contaminated by anthropogenic compounds easily can shift the natural relative ion concentrations. Although relative concentrations of sodium (plus potassium) are greater in samples from noncarbonate rocks than carbonate rocks (fig. 22), absolute concentrations of sodium are greatest in the samples from wells in carbonate rocks (table 17). The relative dominance of chloride and nitrate in several ground-water samples from schist and quartzite probably was caused by road-salt or septic-system contamination, or both.



A. CARBONATE ROCKS



B. NONCARBONATE ROCKS

Figure 22. Relative major ion concentrations for ground water from wells open to carbonate and noncarbonate rocks in the West Valley Creek Basin, Pennsylvania.

Metals and Other Trace Constituents

Metals and other trace constituents, such as arsenic and selenium, typically are present in concentrations less than 1 mg/L in natural waters. Some of these constituents, such as iron and manganese, are commonly determined and usually are present. Other constituents, such as beryllium and silver, are not commonly determined, and, if present, concentrations are generally below the detection limit of analytical instruments or procedures. The USEPA has established MCL's and SMCL's for some of these constituents in drinking water (table 16).

Most of the metals and other trace constituents in natural ground water underlying the basin are leached from the soil or dissolved from the underlying bedrock in minute quantities by circulating ground water. Precipitation also may contain some metals. Many metals are more soluble in acidic water than in water with neutral pH. Copper, lead, and zinc in tap water may be leached from household plumbing systems by acidic ground water. Copper leached from pipes commonly is deposited as blue or green precipitates on plumbing fixtures. Some industries or commercial activities use metals and generate waste that contains elevated concentrations of metals.

Table 19 is a summary of data on the concentration of metals and other trace constituents in ground water; complete analyses are given in table 26. Most metals and trace constituents do not pose a water-quality problem in the West Valley Creek Basin. Median concentrations of most metals and trace elements in table 19 represent natural background concentrations. Data for trace constituents are difficult to statistically evaluate because concentrations are commonly below detection limits. In addition, a constituent may have several detection limits. For example, detection limits for chromium data summarized in table 19 are 1 and 10 μg/L, and some concentrations are reported as 0 (below detection limit, detection limit not reported) or ND (not detected, detection limit not reported).

The maximum concentrations reported in table 19 for lithium, boron, bromide, and chromium represent ground-water contamination. These metals and constituents are associated with the two lithium-processing facilities in the West Valley Creek Basin. East of West Valley Creek Basin, elevated concentrations of lithium (up to 13,000 μg/L), boron (up to 20,000 μg/L), and chromium (up to 60 μg/L) were measured in water samples from wells near and east of a lithium-processing facility in Planebrook (Sloto, 1987). The ground-water divide at the eastern edge of the West Valley Creek Basin is in the vicinity of this plant. The site is on the USEPA National Priorities List (NPL). Elevated bromide, lithium, and chromium also are present in ground water west of this site and to the west of another facility near Exton.

Concentrations of mercury detected in samples (table 3) may not represent the actual concentration of mercury in ground water underlying the basin. Prior to 1985, water samples for analysis of mercury were collected and shipped to the lab in polyethylene bottles. Mercury can diffuse through polyethylene (Mahan and Mahan, 1977, p. 662-664) with a resultant loss of mercury from the water sample. Beginning in 1980, water samples for nutrient analysis were preserved with mercuric chloride and also were collected and shipped in polyethylene bottles. An increase in mercury in a water sample may result from contamination by mercuric chloride in nutrient samples previously shipped in the same container. Water samples from one well (CH-2724) contained a mercury concentration of 3 μg/L, which is greater than the USEPA MCL of 2 μg/L. This sample was collected in 1990 and shipped in a glass bottle and probably represents an accurate mercury concentration. Mercury was detected in ground-water samples from a nearby well (CH-2348) that was sampled in 1980 and 1981, which suggests that mercury may be persistent and present in low concentrations in the ground water underlying the area; the source of the mercury is unknown.

The maximum concentrations of lead, zinc, and copper were measured in water samples from wells completed in carbonate rocks and probably are caused by leaching of metals from plumbing. However, ground water in the carbonate rocks is not typically acidic or corrosive and lead and zinc deposits may naturally be present in carbonate rocks.

***Table 19.** Summary of concentrations of selected dissolved metals and trace constituents in ground water, West Valley Creek Basin, Pennsylvania. Concentrations of iron and manganese are listed by geologic unit*

[µg/L, micrograms per liter; ND, not detected, detection limit unknown; <, less than; --, no data]

Constituent	Number of samples	Concentration (µg/L)			Number of samples above detection level
		Minimum	Median	Maximum	
Arsenic	26	ND	<1	3	7
Barium	1	--	27	--	1
Boron	12	10	15	60	12
Bromide	4	.09	.21	2.0	4
Cadmium	26	ND	<1.0	3.0	2
Chromium	30	ND	<1	10	5
Copper	22	<1	7	43	20
Cyanide	7	<.01	<.01	.02	1
Lead	26	ND	<5	10	2
Lithium	14	<4	8	37	11
Mercury	23	<.1	<.1	3	4
Nickel	14	ND	2	7	10
Selenium	7	<1	<1	2	3
Strontium	4	64	145	300	4
Zinc	20	3	26	610	20
Iron					
Gneiss	4	<10	190	1,450	4
Quartzite	11	<3	15	2,500	9
Carbonate rocks	29	ND	<10	50	9
Phyllite and schist	10	<10	23	210	7
Manganese					
Gneiss	5	<1	31	350	4
Quartzite	11	4	24	180	11
Carbonate rocks	23	ND	2	100	13
Phyllite and schist	9	< 10	33	8,900	6

Concentrations of iron and manganese that exceed the USEPA SMCL's were measured in water samples from gneiss, quartzite, and schist, but not in water samples from carbonate rocks. Of the water samples from noncarbonate rocks that were analyzed for manganese and iron, 30 percent and 16 percent, respectively, exceeded the USEPA SMCL's. Sources of manganese in ground water include minerals in the bedrock, such as biotite and hornblende. Sources of iron in well water include minerals in the bedrock, such as pyroxenes, amphiboles, hematite, magnetite, and pyrite, and corrosion of iron well casings. Differences in concentrations of iron and manganese in ground water in the carbonate and noncarbonate rocks reflect different geochemical environments in the aquifers. Calculation of mineral equilibria by the use of the WATEQ4F computer program (Ball and others, 1987) indicates that ground water in the carbonate rocks is saturated with respect to some iron- and manganese-bearing minerals, but that ground water in the noncarbonate rocks is not. Concentrations of iron and manganese in ground water may be elevated in reducing and (or) acidic waters and by bacterial activity; reducing waters commonly have low concentrations of dissolved oxygen and can result from bacterial degradation of organic carbon in contaminated ground water. Elevated concentrations of iron and manganese in water above background levels may impart a bitter taste and stain laundry and plumbing fixtures.

Radionuclides

Radioactivity is the release of energy and energetic particles by changes in the structure of certain unstable elements as they break down to form more stable arrangements. Radioactive energy is released as (1) alpha radiation consisting of positively-charged helium nuclei, (2) beta radiation consisting of electrons or positrons, and (3) gamma radiation consisting of electromagnetic waves (Hem, 1985, p. 146-151).

Natural radioactivity in ground water is produced primarily by the radioactive decay of uranium-238 and thorium-232. They disintegrate in steps, forming a series of radioactive nuclide "daughter" products, mostly short lived, until a stable lead isotope is produced. The uranium-238 decay series produces the greatest amount of radioactivity in natural ground water. Uranium-238 has a half-life of 4.5×10^9 years. Its daughter products include radium-226 (half-life 1,620 years) and radon-222 (half-life 3.8 days). Radon-222 is a decay product of radium-226 and is a colorless, odorless, inert, alpha-emitting gas, which is soluble in water. Because it is a gas, radon also is found in air. The end product of the decay series is the stable isotope lead-206. Thorium-232 has a half-life of 1.39×10^{10} years. The thorium-232 decay series produces radium-228 (half-life 6.7 years). The end product of the decay series is the stable isotope lead-208.

Although radionuclides are natural in ground water, they may pose a health problem if elevated activities above a USEPA MCL (table 15, for example) are present. A commonly used unit for radioactivity in water is picocuries per liter. One curie is the activity of 1 gram of radium-226, which is equal to 3.7×10^{10} atomic disintegrations per second, a picocurie is 10^{-12} Curies. Activity refers to the number of particles emitted by a radionuclide per unit of time. The rate of decay is proportional to the number of atoms present and inversely proportional to half-life. Therefore, for example, an activity of 5 pCi/L of radium-226 is equal to a concentration of 5×10^{-3} μg/L, and an activity of 5 pCi/L of radium-228 is equal to a concentration of 1.9×10^{-8} μg/L. The USEPA has established an MCL of 5 pCi/L for combined radium-226 and radium-228 activity and 15 pCi/L for gross alpha-particle activity (table 16).

Activities of radionuclides in ground water are summarized in table 20; complete analyses are given in table 27. The activities of radium in ground water exceeded the USEPA MCL for combined radium-226 plus radium-228 in water samples from three of eight wells completed in quartzite, and from one of four wells completed in carbonate rock. Elevated radium was not measured in water samples from three wells completed in schist or one well in gneiss; elevated radium was not detected in these units elsewhere in Chester County (Sloto, 1994). The maximum radium-226 activity (98 pCi/L) was measured in a water sample from well CH-249 at the contact between the Ledger Dolomite and Conestoga Limestone. The highest radium-228 activity (32 pCi/L) was measured in a water sample from a well in the Chickies Quartzite. The activity of radium-228 generally exceeded the activity of radium-226 in water samples from the quartzite.

Natural radioactivity in ground water is related to the concentration of uranium and thorium in geologic materials and to a geochemical environment favorable for radionuclide mobility. The Chickies Quartzite contains slightly greater concentrations of thorium and uranium (with some thorium enrichment) compared to an average quartzite (Senior and Vogel, 1992; 1995). The generally low (less than detection limit) radioactivity in ground water in the carbonate rocks can be attributed to low concentrations of thorium and uranium in these rocks. However, carbonate rocks can contain elevated thorium and uranium. The uranium and thorium content of well cuttings from a borehole (well CH-249) drilled near the contact between the Ledger Dolomite and Conestoga Limestone were determined by delayed neutron activation analysis. A sample of dark gray carbonate rock contained 18.4 ppm of uranium, which is an anomalously elevated concentrations for carbonate rock, and 1.5 ppm of thorium. A sample of light gray carbonate rock contained 2.3 ppm uranium and 1.6 ppm thorium, which are close to reported average concentrations of 2.2 ppm uranium and 1.7 ppm thorium in carbonate rocks (Durrance, 1986). The elevated radioactivity in the water sample from well CH-249 is related to elevated uranium concentration in the rock. The dark gray cuttings came from 100 ft below land surface; the natural-gamma log for well CH-249 shows a high gamma count at this depth. Data from PaDER (John Wrobleski, Pennsylvania Department of Environmental Resources, written commun., 1987) and from Sloto (1990) indicate that a few ground-water samples from the Conestoga Limestone in Lancaster and Chester Counties contained detectable concentrations of radium.

Nonparametric Spearman rho correlations (r_s) between radium activities and chemical constituents and properties (Senior and Vogel, 1995) suggest that pH most strongly affects radium mobility and that dissolved organic carbon may increase radium mobility in low pH waters in the Chickies Quartzite. These factors may favor radium mobility by promoting a decrease in adsorption and an increase in solubility. Low pH decreases adsorption of radium and other ions by silica, kaolinite (Riese, 1982), and other mineral surfaces, such as iron and manganese hydroxides. All ground-water samples from the Chickies Quartzite in southeastern Pennsylvania that have a pH less than 4.8 contain combined activities of radium-226 and radium-228 greater than 5 pCi/L (Cecil and others, 1987; Senior and Vogel, 1995). Geochemical controls on radium in carbonate rock probably are different than those in quartzite.

Table 20. *Summary of radioactivity and uranium concentrations in ground water, West Valley Creek Basin, Pennsylvania*

[Phyllite and schist includes the Octoraro Phyllite, Peters Creek Schist, and Wissahickon Formation; carbonate rocks include the Ledger Dolomite, Conestoga Limestone, Elbrook Formation; quartzite is the Chickies Quartzite; gneiss is felsic gneiss; pCi/L, picocuries per liter; mg/L, micrograms per liter; <, less than; --, no data]

Constituent and geologic group	Number of samples	Minimum	Median	Maximum
Radium-226 (pCi/L):				
Gneiss	1	--	0.38	--
Quartzite	8	<0.10	1.1	8.7
Carbonate rocks	5	.10	.42	98
Phyllite and schist	2	.1	.4	.7
Radium-228 (pCi/L):				
Gneiss	1	--	<.7	--
Quartzite	9	<.05	2.9	32
Carbonate rocks	5	<1.0	<2.0	20
Phyllite and schist	2	<2.0	<2.0	<2.0
Uranium (μg/L):				
Gneiss	1	--	<.05	--
Quartzite	8	<.05	<.05	.09
Carbonate rocks	5	<.40	.56	97
Phyllite and schist	2	<.40	<.40	<.40
Radon-222 (pCi/L):				
Gneiss	1	--	3,800	--
Quartzite	12	335	1,350	18,000
Carbonate rocks	20	<80	510	5,810
Phyllite and schist	5	1,890	3,000	5,600
Gross alpha [1] (pCi/L):				
Gneiss	1	--	<1.0	--
Quartzite	9	<1.0	2.8	32
Carbonate rocks	5	1.9	2.6	52
Phyllite and schist	2	1.5	1.8	2.0
Gross beta (pCi/L as Cs-137):				
Gneiss	1	--	3.2	--
Quartzite	9	3.9	6.9	49
Carbonate rocks	5	1.6	2.8	58
Phyllite and schist	2	1.3	2.0	2.7

[1] Gross alpha-particle activities for some samples converted from μg /L as natural uranium to pCi/L for this table.

In waters with pH ranging from 7 to 8, phosphate and carbonate complexation increases uranium solubility (Langmuir, 1978). The water in carbonate aquifers contains bicarbonate and carbonate ions and has a pH between 7 and 8. Uranium was detected in three of four water samples from carbonate rock. A water sample from well CH-249 in the Ledger Dolomite had the highest measured uranium concentration (97 μg/L or 142 pCi/L). Uranium concentrations were below detection limits in water samples from 9 of 11 wells completed in noncarbonate rock.

Radon-222 is present where its parents, uranium-238 or radium-226, are present in the geologic unit. Radon-222 activities depend on radon-emanation rates, porosity and permeability of geologic unit, and the concentration and distribution of parent radionuclides in geologic unit. The greatest radon-222 activity, 18,000 pCi/L, was measured in a water sample from the Chickies Quartzite. Radon-222 concentrations may vary seasonally; maximum concentrations were measured in water samples collected in the autumn when depth to water is greatest (Senior and Vogel, 1995).

Gross alpha- and gross beta-particle activity are measurements of the total amount of alpha- or beta-particle activity detected from all radionuclides in a water sample. These measurements generally are used as screening tools for detection of elevated radionuclide activities. Measurements of gross alpha and beta activities do not identify specific radionuclides. For gross alpha-particle activity, the standard is uranium of natural isotopic composition, and results of gross alpha-particle activity measurements are reported as natural uranium. For gross beta-particle activity, the standard is cesium-137, and results of gross beta-particle activity measurements are reported as cesium-137. Water samples from two of eight wells sampled in the Chickies Quartzite and one of four wells in the Ledger Dolomite exceeded the USEPA MCL of 15 pCi/L for gross alpha-particle activity. Water from wells completed in gneiss and schist did not exceed the USEPA MCL for gross alpha-particle activities.

Organic Compounds

One of the most serious consequences of the urbanization of Chester County has been the introduction of anthropogenic organic compounds into the subsurface. Some of these compounds have been entering the ground-water system for decades, but awareness of contamination by organic compounds in drinking water supplies did not begin until the mid-1970's when analytical techniques became available for detection. The USEPA has classified 113 compounds, known as priority pollutants, as toxic organic compounds. These compounds are divided into four fractions by gas chromatography-mass spectroscopy analysis: (1) volatile, (2) acid, (3) base-neutral, and (4) pesticide. Laboratory analytical results for organic compounds are given in tables 28-33. Not all water samples collected in the basin were analyzed for all compounds.

Volatile organic compounds

Volatile organic compounds (VOC's) are extensively used in industrial, commercial, and household applications in the basin. VOC's in ground water presents a serious problem for public water suppliers, industries, and domestic well owners that rely on ground water. Many of the VOC's are confirmed or suspected human or animal carcinogens (Council on Environmental Quality, 1981, p. 64). They generally enter the ground-water system by spills, leakage from storage tanks, discharge from septic systems, and from lagoons and disposal sites. Once in the ground-water system, VOC's are difficult to remove, and treatment generally is expensive.

VOC's have been in use for many years. Analysis for VOC's in ground water in Chester County began in 1980. The precise length of time VOC's have been present in the ground water is unknown. Many of the VOC's detected in the ground water are industrial solvents or fuels. Trichloroethylene (TCE) is a commercial solvent and industrial metal degreaser, a common degreasing agent used since the 1920's, and in the dry cleaning industry since the 1930's (Petura, 1980). Awareness of TCE in ground water began in the late 1970's. TCE has been used as a septic tank cleaner, a solvent for paints and varnishes, and extensively in the dry cleaning, chemical, and pharmaceutical industries.

TCE, tetrachloroethylene, and 1,1,1-trichloroethane are commonly used as degreasers in the metals, electronics, and plastics industries. Tetrachloroethylene, also known as perchloroethylene (PCE), commonly is used in dry cleaning. Benzene, toluene, and xylene are fractional components of gasoline, diesel fuel, and fuel oil. Most compounds in gasoline and fuel oil float on water, but benzene, toluene, and xylene can dissolve. Benzene and toluene also are used as industrial solvents and in the manufacture of pharmaceuticals and organic chemicals.

Some of the organic compounds in a water sample are degradation products of chemical and microbial transformations in the soil and other geologic materials. Parsons and others (1984; 1985) found that PCE degrades by reductive chlorination under aerobic conditions to TCE, and TCE degrades to cis- and trans-1,2,-dichloroethylene. Other studies have shown significant biodegradability of benzene and other VOC's (Tabak and others, 1981, p. 1,514, for example).

Water samples for analysis of VOC's were collected from 33 wells and 1 spring during 1980-91. Compounds analyzed, maximum concentrations detected, and frequency of detection are summarized in table 21. The detection limit for VOC's is 1 μg/L for samples collected 1980-83, 3 μg/L for samples collected 1984-89, and 0.2 μg/L for samples collected 1990-92. The choice of wells for sampling was biased towards wells where the detection of VOC's in ground water was suspected.

Table 21. *Summary of volatile organic compounds detected in ground water, West Valley Creek Basin, Pennsylvania*

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

Compound	Number of wells with detected compounds [1]	Concentration		
		Minimum	Median	Maximum
Benzene	2	4	7.5	9
1,1-dichloroethane	1	--	7.0	--
1,1-dichloroethylene	3	4.1	5.0	63
Trans-1,2-dichloroethlyene	3	3.2	3.5	16
1,1,1-trichloroethane	5	.7	31	320
1,1,2-trichloroethane	1	--	7	--
Trichloroethylene	8	.2	25	770
Carbon tetrachloride	2	.3	.4	.5

[1] A total of 36 wells and 1 spring were sampled for volatile organic compounds.

VOC's were detected in the spring and in 9 of the 33 or about 30 percent of the wells sampled (table 28). Most of the wells sampled, and most of those that contained water with detectable concentrations of VOC's, are completed in the carbonate rocks. The distribution of VOC's in West Valley Creek Basin is related to the distribution of sources in the more urbanized carbonate valley.

Out of 37 compounds analyzed, 8 were detected. The most commonly detected compounds were TCE, 1,1,1-trichloroethane, 1,1-dichloroethane, and trans-1,2-dichloroethylene (table 5). Benzene was detected in water samples from two wells, carbon tetrachloride was detected in water samples from two wells, and 1,1-dichloroethylene was detected in a water sample from one well. Total VOC concentrations were as high as 1,500 μg/L; concentrations of a single compound, TCE, were as high as 770 μg/L. Water samples from 70 percent of the wells and the one spring in which VOC's were detected had more than one compound present. As many as five compounds were detected in one water sample. However, in the water samples that contained benzene, it was the only VOC detected.

Semivolatile organic compounds

Semivolatile organic compounds include acid-extractable and base-neutral compounds. Water samples from two wells were analyzed for the acid-extractable and base-neutral organic compounds listed in table 29. The wells sampled were near industrial areas where these compounds are possibly in ground water. No acid-extractable or base-neutral organic compounds were detected.

Pesticides

Pesticides are widely applied in both rural and urban areas of Chester County. Pesticides are divided into insecticides and herbicides on the basis of their use. Insecticides are used in agricultural areas to control crop-damaging insects and in urban areas to control household and garden insects. Herbicides are used to control weeds that compete with crops in agricultural areas and home gardens. Herbicides also are used to control broad-leaf weeds on lawns and turf and to defoliate utility, railroad, and highway rights-of-way. Sampling for herbicides generally was biased towards areas where herbicides were applied. Sampled wells were in or near cropland, orchards, and golf courses. Water samples were analyzed for the following classes of pesticides: organochlorine insecticides (15 wells), organophosphorus insecticides (3 wells), and triazine herbicides (5 wells).

Organochlorine insecticides have low solubility in water, are persistent in the environment, and are strongly bioaccumulated by many organisms. The use of many organochlorine insecticides has been prohibited or restricted to limited uses by the USEPA. Water samples from 15 wells were analyzed for organochlorine insecticides during 1980-91. None of the organochlorine compounds analyzed were measured in concentrations above the detection limit (table 30).

Organophosphorus insecticides have been used as substitutes for the banned organochlorine insecticides because they are less persistent in the environment and more selective in their targets. Water samples from three wells were analyzed for organophosphorus insecticides during 1980-91. None of the organophosphorus compounds analyzed were measured in concentrations above the detection limit (0.01 μg/L) (table 31).

Water samples from five wells were analyzed for triazine herbicides, and water samples from four wells were analyzed for alachlor and trifluralin. Compounds analyzed and concentrations are given in table 32. Triazine herbicides were detected in only one of five wells sampled. Two triazine compounds, atrazine and deethylatrazine, were present in concentrations above the detection limit in a water sample from a well drilled in a field where corn and soybean crops are rotated. The triazine herbicides mainly are used for preemergence applications on corn, soybeans, and other crops for control of grassy and broadleaf weeds. Atrazine, which is sold under various commercial names, is the most widely applied pesticide in Pennsylvania (Hartwig and others, 1980, p. 8-9). Atrazine commonly is used to control weeds in corn, soybeans, and hay crops in Chester County. Deethylatrazine is a microbial transformation degradation product of atrazine (Agertved and others, 1992). Atrazine, promotone, prometryne, propazine, and simazine have been detected in base flow in adjacent Lancaster County (Lietman and others, 1983, p. 31-32).

Other organic compounds

Determinations were made for gross phenols in water samples from 25 wells and for gross polychlorinated biphenyls (PCB) and gross polychlorinated napthalenes (PCN) in water samples from 15 wells during 1980-91 (tables 28 and 33). PCB and PCN were not detected in any water samples. Phenols, including phenol and several substituted phenols such as cresol, occur naturally in water at low concentrations (up to 1 mg/L), but are present in higher concentrations because of anthropogenic contamination (Thurman, 1985, p.143-144). Phenol is a toxic, caustic compound that is soluble in water (1 g of phenol will dissolve in 15 mL of water). Phenol is used as a general disinfectant and in the manufacture of resins, pharmaceuticals, and industrial organic compounds; cresol is used as a disinfectant, and other phenols have different industrial uses (Windholtz and others, 1976). Total phenols were detected at concentrations from 1 to 5 μg/L in water from 11 of the 25 wells (44 percent) sampled. Concentrations exceeded 2 μg/L in 4 (36 percent) of the 11 samples in which it was detected. The colorimetric method used to determine total phenols does not identify specific compounds.

Surface Water

The composition of surface water depends on the composition of water entering the stream and biological and chemical reactions that take place in the stream. Because relative proportions of base flow and runoff, biologic activity, and climactic conditions vary through time, stream chemistry is dynamic. Some variations occur at regular intervals, such as those that are seasonal or diurnal; others are sporadic, such as those that follow a storm. Runoff from storms carries trace metals and organic compounds from industrial and urban areas and pesticides, nutrients, and sediment from agricultural and urban areas.

This study does not address changes in the quality of streamwater in West Valley Creek caused by biological activity or storms; it is limited to describing the water quality under base-flow conditions. Transient water-quality conditions may be estimated by correlation with data from a nearby streamflow-measurement station equipped with a water-quality monitor. A water-quality monitor that continuously measures pH, temperature, specific conductance, and concentration of dissolved oxygen is maintained at the streamflow-measurement station, East Branch Brandywine Creek below Downingtown. The water-quality monitor is operated from March through November when low pH (below 6) and low concentrations of dissolved oxygen (below 4.0 mg/L) are most likely (Murphy and others, 1982).

Surface-water quality depends on the concentration of both dissolved and suspended substances. Streams transport relatively insoluble constituents as suspended or bedload sediment. Transport of solid particles (sediments) is more significant in streams than ground water. The amount of transported sediment increases as stream velocities increase, such as during storms when streamflow velocities are greatest. Although no sediment data were collected for the study, available data on stream sediments in West Valley Creek are summarized.

Base Flow

Base-flow samples for chemical analysis were collected monthly at seven sites on the mainstem of West Valley Creek and eight sites on tributaries (fig. 23) from August 1990 to July 1991. Additional samples at three of the eight sites on tributaries and five additional sites on tributaries were collected in October 1991. A description of the drainage area for the tributaries and mainstem is given in table 22. Sampling sites included the streamflow-measurement station and the long-term biological monitoring site on West Valley Creek. Local identification numbers with the prefix WVC (West Valley Creek) were assigned in approximate downstream order (although the tributary WVC-7 joins West Valley Creek above WVC-6).

Tributaries were sampled just above the confluence with the mainstem and were selected to characterize the water quality contributed by tributaries to West Valley Creek. Tributaries in the headwaters and most of the major tributaries downstream were chosen for sampling. Not all tributaries were sampled. The tributaries drain residential and relatively less developed areas underlain by noncarbonate rocks, but also cross the carbonate valley before joining the mainstem. The mainstem is underlain by carbonate rocks in the most urbanized area of the basin and then turns south and cuts through the residential South Valley Hills, which are underlain by noncarbonate rocks.

Discharge at the 15 sites was measured at the time of water-quality sampling (table 34) and was greatest in the spring and least in the late summer and autumn. Discharge at all sites increased and decreased in a seasonal pattern similar to discharge measured at the streamflow-measurement station, WVC-15 (fig. 16). The range of discharges measured under base-flow conditions is shown in figure 24. The relative proportion of discharge contributed by each tributary to discharge of the mainstem generally decreases downstream until Broad Run (WVC-14) joins West Valley Creek above site WVC-15. The discharge contributed by each tributary is not directly related to the area of each tributary subbasin and is affected by subbasin lithology, hydrology, and water use. The tributaries generally contribute more flow per unit basin area than the mainstem, except for two small spring-fed tributaries (sites WVC-1 and

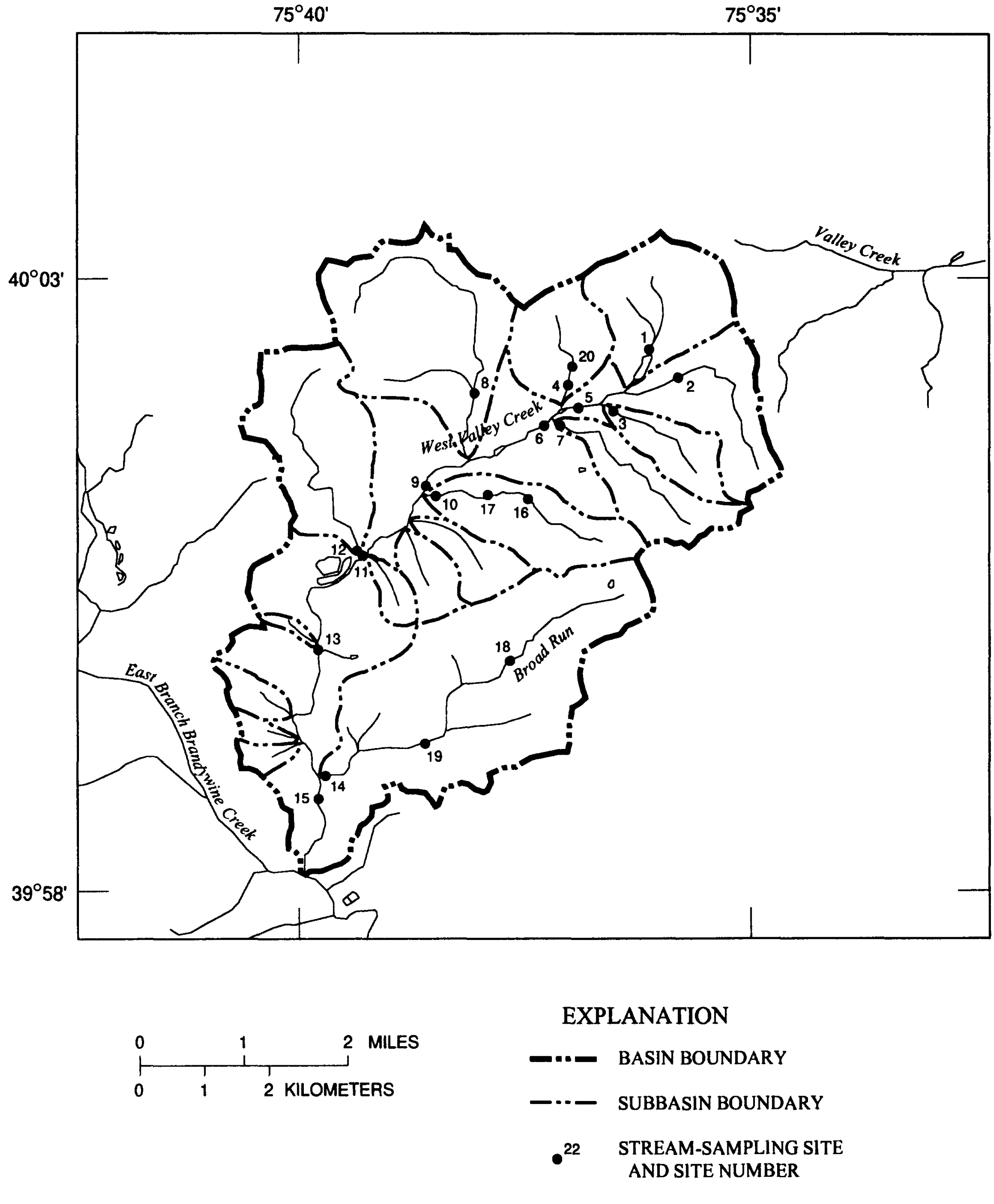


Figure 23. Location of stream-sampling sites in the West Valley Creek Basin, Pennsylvania.

Table 22. *Drainage area, stream sources, and land use for sampling sites in the West Valley Creek Basin, Pennsylvania*
[WVC, West Valley Creek; mi^2, square miles]

Site number	Drainage area (mi^2)	Source area or contributing tributaries	Predominant land use / type of point-source discharge
Tributary sites			
WVC-1	1.16	spring in quartzite	agricultural
WVC-3	.47	stream in phyllite and schist	commercial, industrial, institutional
WVC-4	.52	seep(s) in quartzite and carbonate rock	agricultural
WVC-7	1.00	stream in phyllite and schist	commercial, industrial, residential
WVC-8	2.26	stream in gneiss and quartzite	residential, commercial / sewage treatment plant effluent
WVC-10	1.18	stream in phyllite	industrial, commercial, residential
WVC-12	1.74	spring(s) in quartzite and carbonate rocks	residential, golf course, commercial
WVC-14	4.09	stream in schist	residential / small sewage effluent
Mainstem sites			
WVC-2	.98	headwaters in phyllite	industrial, residential, agricultural / lithium processing waste
WVC-5	3.28	WVC-1, 3	agricultural, residential, commercial
WVC-6	5.16	WVC-4, 7	residential, commercial
WVC-9	9.22	WVC-8	commercial
WVC-11	11.8	WVC-10	industrial, commercial, residential
WVC-13 [1]	14.5	WVC-12	industrial, residential / quarry discharge
WVC-15 [2]	20.4	WVC-14	residential

[1] WVC-13 is at the streamflow-measurement station, Valley Creek at Ravine Road near Downingtown (01480887).
[2] WVC-15 is at the biological sampling site, Valley Creek at Mullsteins Meadow (01480903).

WVC-12) at the northern edge of the valley. These tributaries receive little inflow from the carbonate rocks because of the hydrogeologic settings. WVC-1 is on a tributary near the eastern ground-water divide where the stream is perched above the water table. WVC-12 is on a tributary near the western ground-water divide downstream of where streamflow is diverted to golf course ponds, ground water is pumped for golf course irrigation, quarry dewatering operations lowers water levels, and losing reaches of the stream were identified; site WVC-12 was dry in the autumn of 1990.

During the period of sampling (August 1990 to October 1991), industrial, sewer, and quarry effluents were discharged continuously to West Valley Creek. A lithium-processing plant discharged wastewater into the mainstem of West Valley Creek above site WVC-2 for several years; the facility ceased discharging process water in November 1991, but stormwater from the facility was still discharged to the stream in 1992. A small sewage-treatment plant that serves an apartment complex in Exton discharges to a tributary to West Valley Creek above site WVC-8. The sewage-treatment plant may be phased out of operation in the next few years (Jim Mahlon, West Whiteland Township, oral commun., 1992). The General Crushed Stone Quarry discharges water from quarry-dewatering and crushing processes to the stream after the water flows through a series of three settling ponds that allow solid particles to settle out. The quarry discharges to and withdraws from West Valley Creek between mainstem sites WVC-11 and WVC-13.

Less continuous, episodic, or seasonal conditions also can affect streamwater quality. Stormwater from the urban and residential areas is discharged to West Valley Creek. Return flow from the golf course may affect the tributary above site WVC-12. The golf course diverts streamwater and pumps ground water to ponds which flow back to the stream; some water is lost by infiltration or evaporation, especially during warm summer months, before returning to the stream.

At each sampling site, the water sample was collected in midstream where velocities were greatest and the water well mixed. The streams are relatively small and complete mixing of the water in the stream channel was assumed. The pH, alkalinity, specific conductance, temperature, and concentration of dissolved oxygen of the samples were measured in the field according to established procedures (Wood,

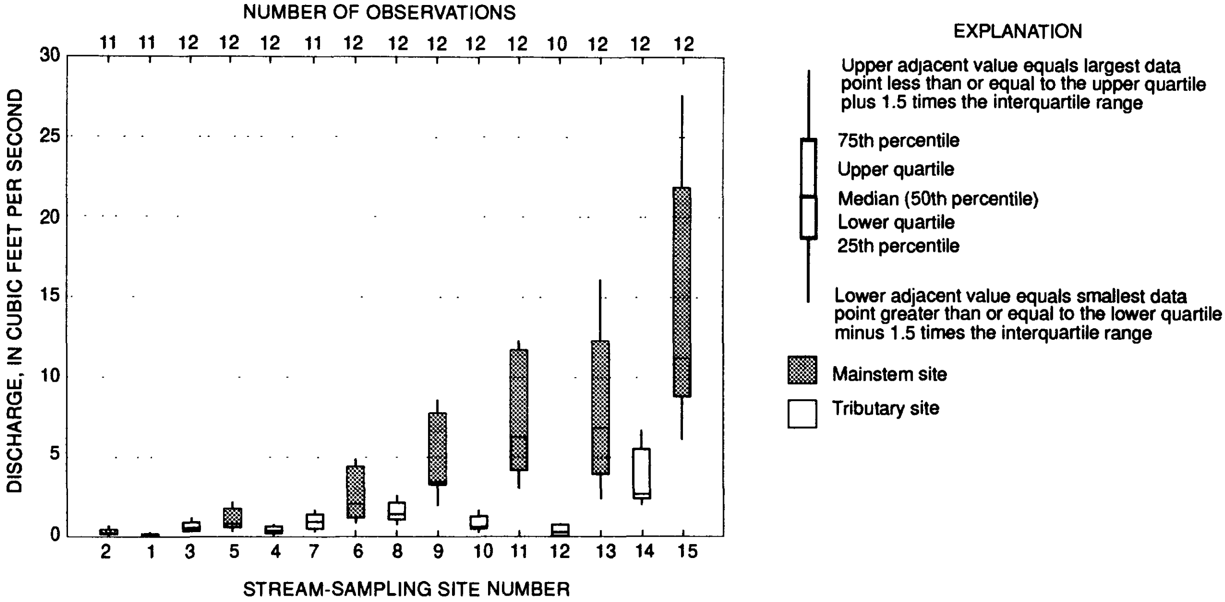


Figure 24. Distribution of discharge measured at 15 stream-sampling sites at time of sample collection, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991.

1981). Water samples were analyzed for dissolved major ions, iron, manganese, nutrients, and selected trace constituents including lithium and boron at the National Laboratory of the U.S. Geological Survey in Denver, Colo., by established methods (Fishman and Friedman, 1989). Water samples collected in November 1990 were analyzed for selected trace metals, and two samples were analyzed for VOC's. Complete results of chemical analyses and field measurements for stream samples are given in tables 34 and 35.

Although stream samples were collected monthly for a year, the data are insufficient to demonstrate statistically that concentrations of ions indicate seasonal changes or relation to discharge. Therefore, only a limited discussion of seasonality or relation to discharge is included. Correlations between concentrations of ions and discharge were computed by use of the nonparametric Spearman rho test statistic, a distribution-free statistical procedure that indicates monotonic relations that were accepted as significant at the 95-percent confidence interval. The data provide baseline concentrations of major ions that may be useful for future investigations, evaluations, and comparisons. The observed fluctuations in streamwater quality reflect natural and human processes. Anthropogenic discharges to the stream can change the natural water quality.

Physical properties and field-determined constituents

The temperature, pH, and concentration of dissolved oxygen of streams fluctuate daily because of diurnal cycles of solar heating and biological activity. Fluctuations in specific conductance and alkalinity largely reflect the changes in the concentrations of dissolved inorganic constituents. Temperature, pH, and concentration of dissolved oxygen generally increase from a minimum in the late night or early morning to a maximum in the afternoon. The range of these fluctuations depends on many variables characteristic of the stream and also depends upon season. The largest range in daily fluctuations is during summer months, and the smallest range is during winter months. For measurements made at the water-quality monitoring station (01480870) on the nearby East Branch Brandywine Creek from March through November when concentrations of dissolved oxygen are most likely to fall below 4.0 mg/L (Murphy and others, 1982), the typical range of daily fluctuation under base-flow conditions is about 10°C for temperature, 1.5 pH units for pH, 50 µS/cm for specific conductance, and 4 mg/L for dissolved oxygen concentration (U.S. Geological Survey, 1971-91).

The median and range of temperature, specific conductance, alkalinity, pH, and concentrations of dissolved oxygen differ among the 15 sites (fig. 25). Differences in reported physical properties and field measurements among the sites include differences related to hydrologic factors, such as lithology of rocks underlying drainage areas, and temporal differences, which may be diurual or seasonal, related to time of measurement. Temperature, alkalinity, and concentrations of dissolved oxygen correlate with discharge and change seasonally at many of the sites; for example, seasonal variations at site WVC-3 (fig. 26) are similar to those at most other sites. Changes in specific conductance and pH did not show a strong seasonal pattern or relation to discharge. Generally, base flow is greater during the winter and spring months when ground-water levels are high and temperatures low than in the summer and fall when ground-water levels are low and temperatures high.

The temperature of streamwater under base-flow conditions is affected by seasonal changes in air temperature. Stream temperatures were lowest during the winter months when base flow was high and greatest during the summer months when base flow was low. Because of these seasonal relations, stream temperature is inversely related to base-flow discharge. Differences in temperature among sites are apparent from the annual range for the sites and reflect the degree of contact with ground water and extent of solar (and other) heating for the stream reaches. Median stream temperatures were similar to mean annual air temperature (13.3°C) except at sites WVC-1, WVC-2, WVC-7, and WVC-8. Sites WVC-1 and WVC-2 are on streams with losing reaches that traverse open fields; site WVC-7 is on a stream near an urbanized area; and site WVC-8 could be affected by sewage-treatment discharge. The smallest range in temperature was measured at site WVC-4, which is a stream reach shaded in the summer and in contact with discharging ground water of cool and constant temperature. One of the largest ranges in temperature was measured at site WVC-2, which is downstream from thermal and chemical discharge, in an open field, and in a losing reach.

Differences in median concentrations of dissolved oxygen in the mainstem and tributaries were small (less than 2 mg/L), except for mainstem site WVC-15. The smallest concentration of dissolved oxygen measured was 5.7 mg/L at tributary site WVC-12 in July 1991. The greatest concentrations of dissolved oxygen measured were 17.1 and 17.3 mg/L at mainstem sites WVC-9 and WVC-11, respectively, in February 1991. Measurements of dissolved oxygen are not adjusted for daily fluctuations related to biological activity. Concentrations of dissolved oxygen increase as oxygen is produced by photosynthesis, but decrease as oxygen is consumed by respiration. Algal beds immediately upstream of site WVC-15 may increase concentrations of dissolved oxygen in the stream. Dissolved oxygen concentration also is inversely related to temperature (fig. 27), and a seasonal pattern of dissolved oxygen was observed with maximum concentrations measured in mid- to late winter and minimum concentration in late summer and early fall (fig. 28). The variability of concentration of dissolved oxygen is seasonal, in part because solubility of oxygen increases with decreases in temperature. Many samples contained concentrations of dissolved oxygen that are greater than saturation concentrations. Supersaturation can occur because of a rapid increase in temperature or active photosynthesis. Dissolved oxygen was directly related to base-flow discharge at mainstem sites WVC-5, WVC-6, WVC-9, and WVC-11 and tributary sites WVC-4, WVC-7, WVC-8, and WVC-10; the relation between dissolved oxygen and base-flow discharge is caused by coincident inverse relation between temperature and base-flow discharge.

The median pH of water samples from all sites ranged from 7 to 7.7. The pH of surface water commonly is in the range of 7.3 to 8.4 where in equilibrium with calcite (Drever, 1982, p. 47). The streamwaters were slightly to highly unsaturated with respect to calcite in samples from most sites, except for samples from site WVC-12, which were saturated with respect to calcite at low flow. Dissolution of calcite and silicate minerals is a reaction that can neutralize acid rain, which recharges the aquifers and supplies base flow in West Valley Creek, and generate alkalinity. The pH of stream samples did not correlate with alkalinity and, thus, is not solely related to mineral reactions. Biological processes can also affect pH; respiration causes a decrease in pH and photosynthesis increases pH. However, differences in pH between the mainstem stream sites were small, perhaps because of carbonate buffering. The median pH in samples from sites WVC-1 and WVC-14 was lower than the pH at the other sites (fig. 25) because these streams originate in noncarbonate rocks that have more acidic water and lower

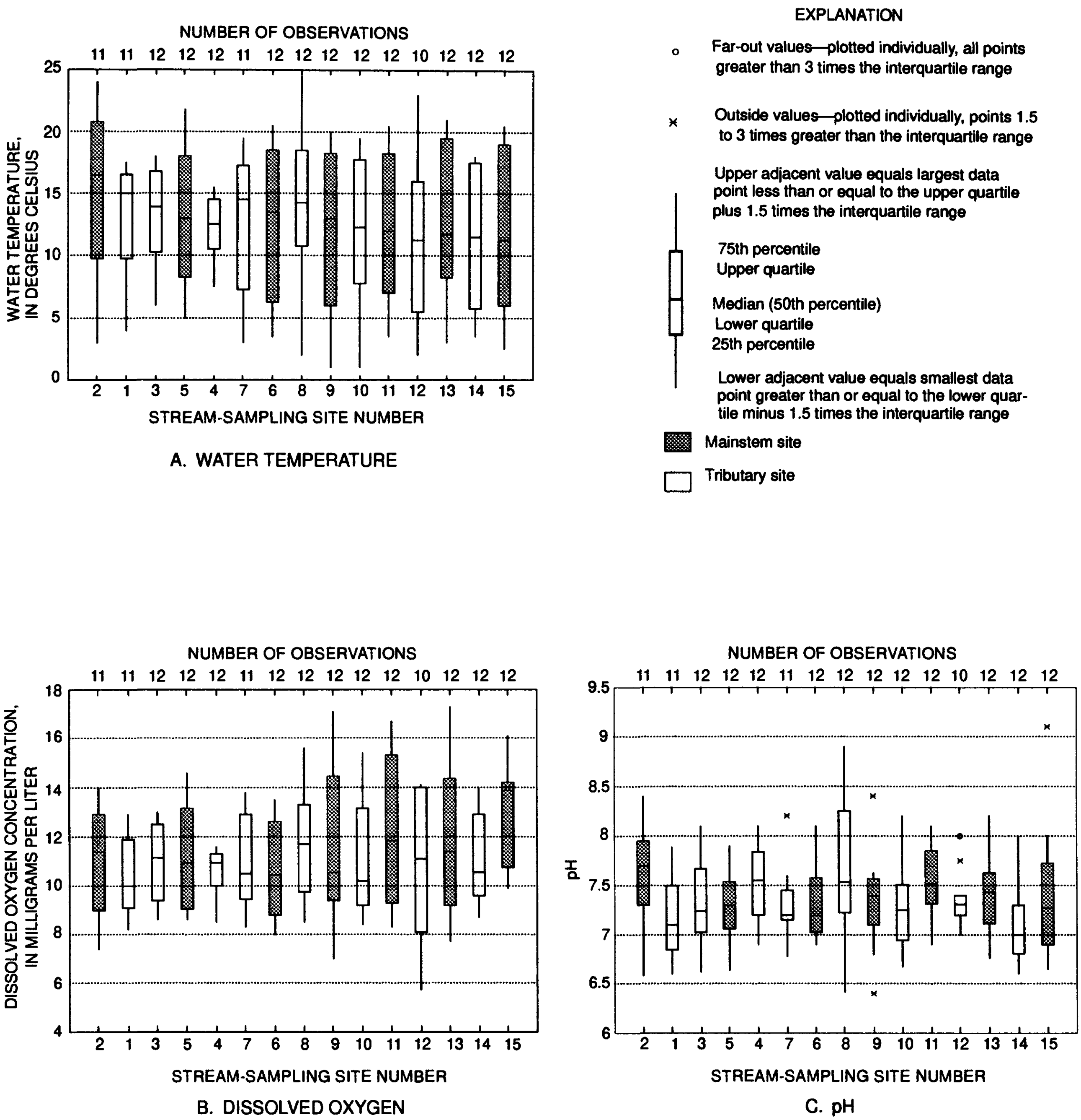
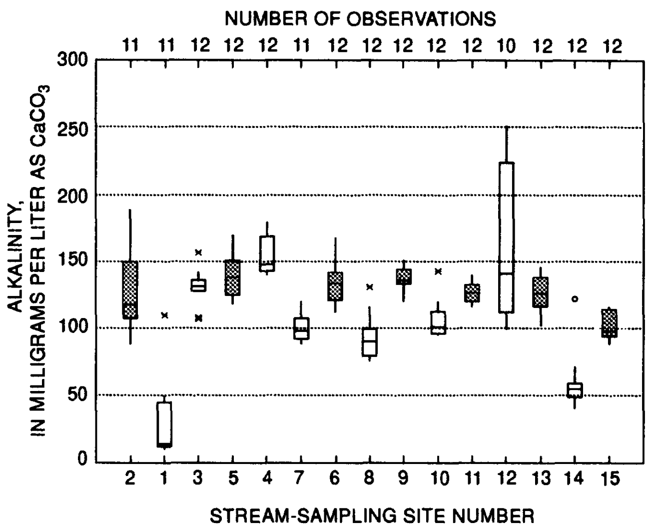
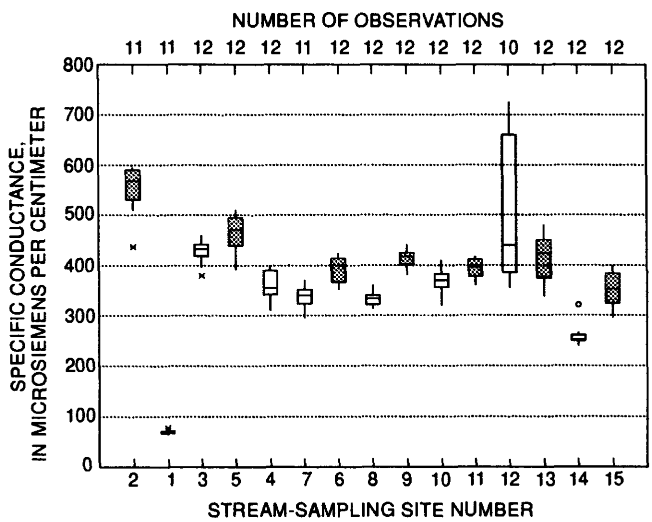


Figure 25. Distribution of monthly stream temperature, pH, alkalinity, specific conductance, and dissolved oxygen concentrations at 15 sampling sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.



D. ALKALINITY



E. SPECIFIC CONDUCTANCE

Figure 25. Distribution of monthly stream temperature, pH, alkalinity, specific conductance, and dissolved oxygen concentrations at 15 sampling sites on West Valley Creek, Pennsylvania, August 1990 - July 1991—Continued.

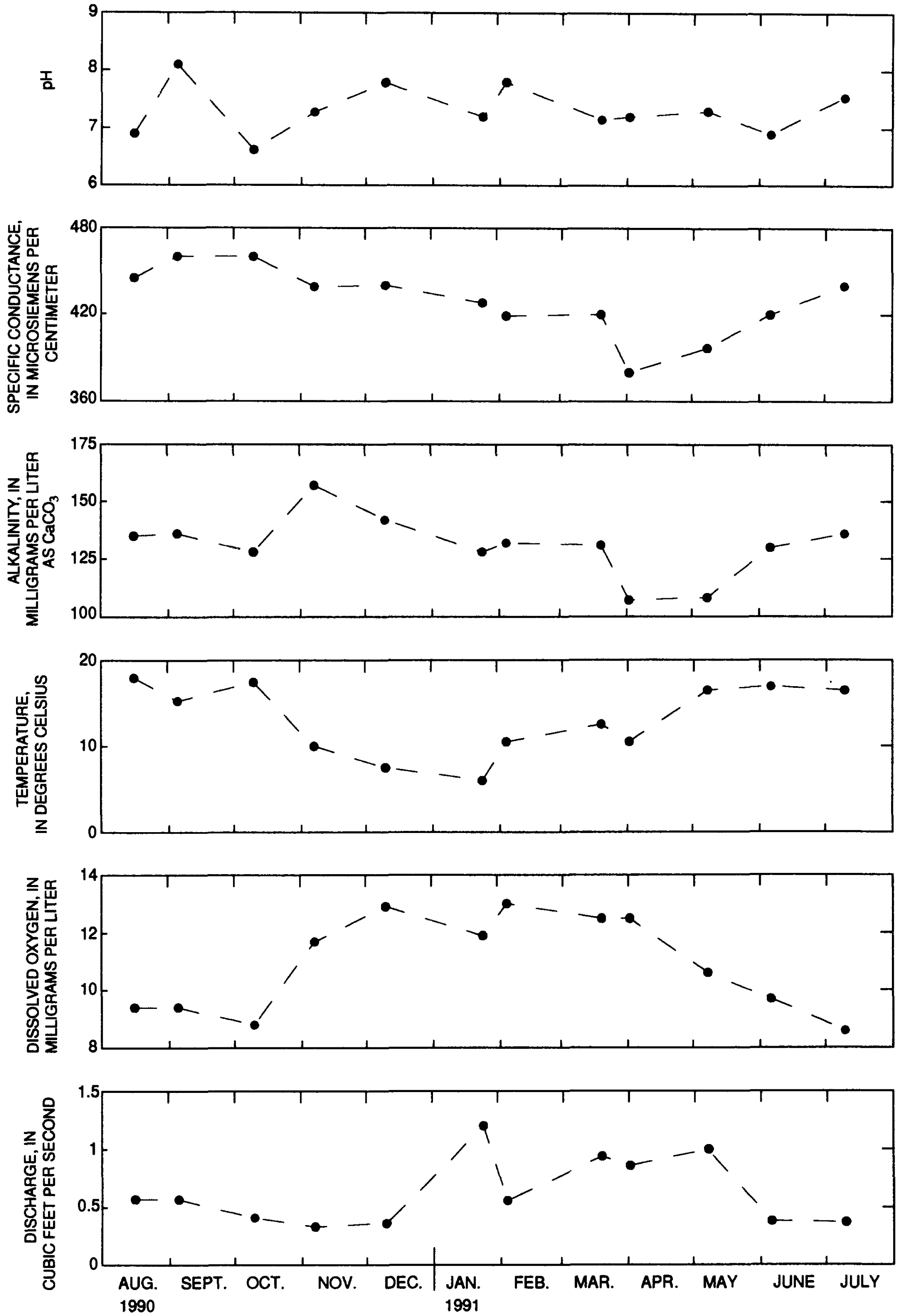


Figure 26. Seasonal variations in monthly base flow, dissolved oxygen concentrations, temperature, alkalinity, specific conductance, and pH at stream-sampling site WVC-3, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991.

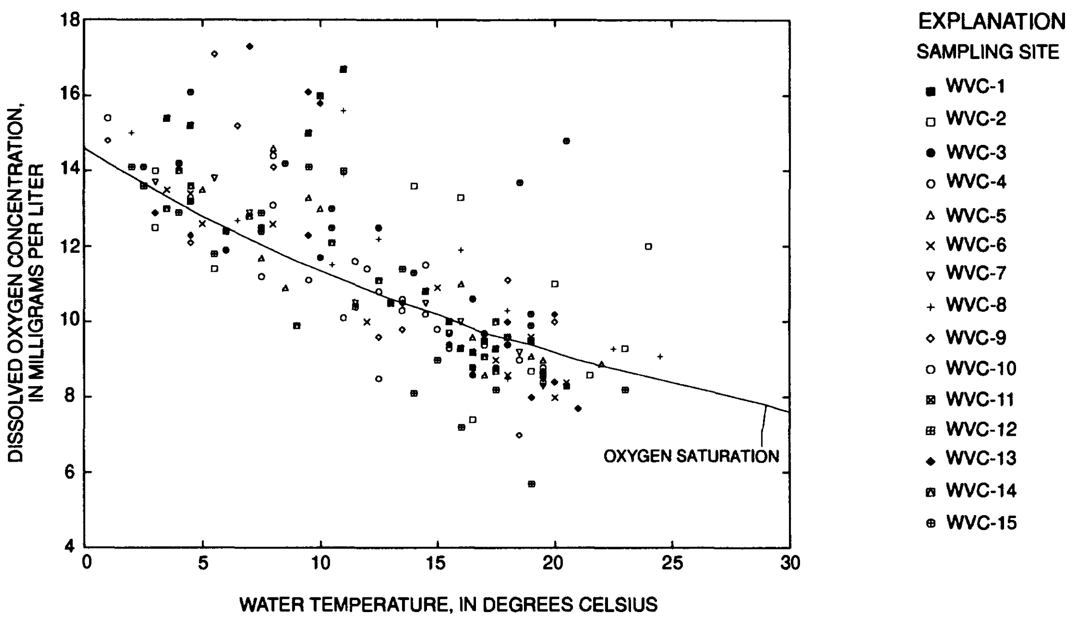


Figure 27. Relation between dissolved oxygen concentration and temperature in monthly base-flow samples at 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.

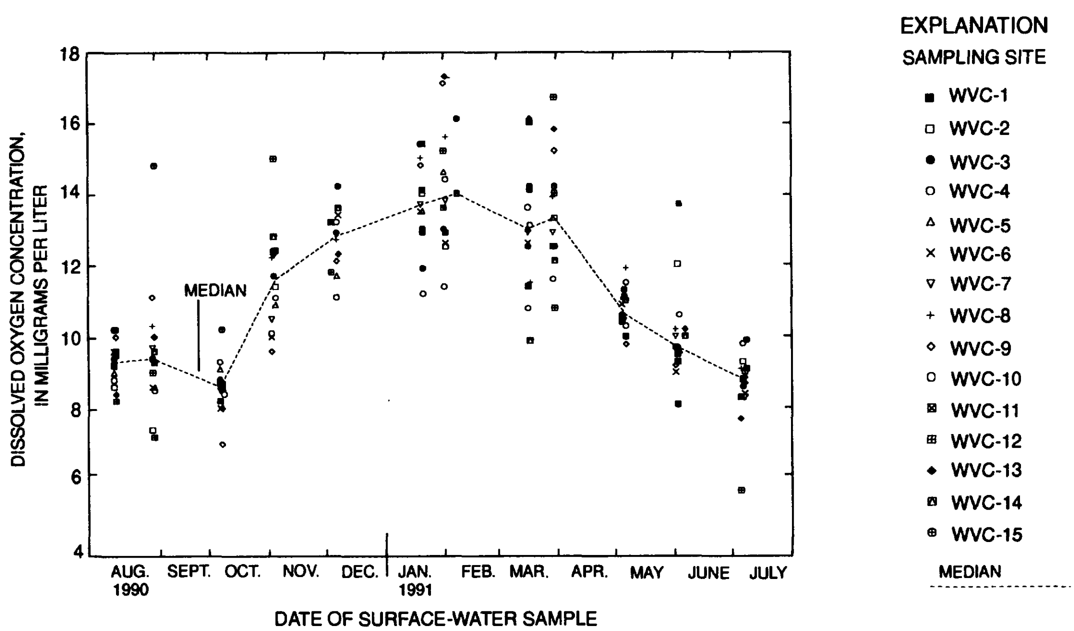


Figure 28. Concentrations of dissolved oxygen in monthly base-flow samples at 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.

buffering capacity than carbonate rocks. The lowest pH (6.4) was measured at mainstem sites WVC-8 and WVC-9 in October 1990; pH at site WVC-8 is possibly affected by variations in chemical composition of sewage effluent. WVC-9 is on the mainstem downstream but near the confluence of the tributary with the sewage treatment plant. The pH of 8 or greater measured in water samples from sites WVC-2 and WVC-8 could be caused by industrial and sewage-treatment effluent discharged into the streams above the sites. The maximum pH measured was 8.9 at tributary site WVC-8.

Alkalinity in the mainstem from WVC-2 downstream generally is greater than in the tributaries, except in streamwater at tributary sites WVC-4 and WVC-12 (fig. 25). Alkalinity is generated by the dissolution of carbonate rocks and to a lesser degree by silicate-mineral weathering. Water samples from tributary sites WVC-4 and WVC-12 have the greatest median alkalinity, 148 and 140 mg/L as $CaCO_3$, respectively. Base flow in these tributaries is predominately ground-water discharge from carbonate rocks, whereas base flow at other sites has a relatively greater component of ground-water discharge from noncarbonate rocks. Mainstem alkalinity decreases downstream from site WVC-5, reflecting the influx of lower alkalinity waters in the tributaries. Alkalinity is inversely related to discharge at tributary sites WVC-3, WVC-4, WVC-7, WVC-8, WVC-10, and WVC-14 and in the mainstem sites WVC-5 and WVC-6 (fig. 29). Alkalinities were lowest during the winter and spring when discharge was greatest. The inverse relation may result from dilution of base flow by recharge that has low alkalinity because of less extensive weathering related to a rapid rate of passage or short route to the stream in the winter and spring season and from concentration by evaporation during the summer and fall. This relation between alkalinity and discharge may not be observed in the mainstem because dissolution of carbonate rocks generates alkalinity more readily than reactions in noncarbonate rocks.

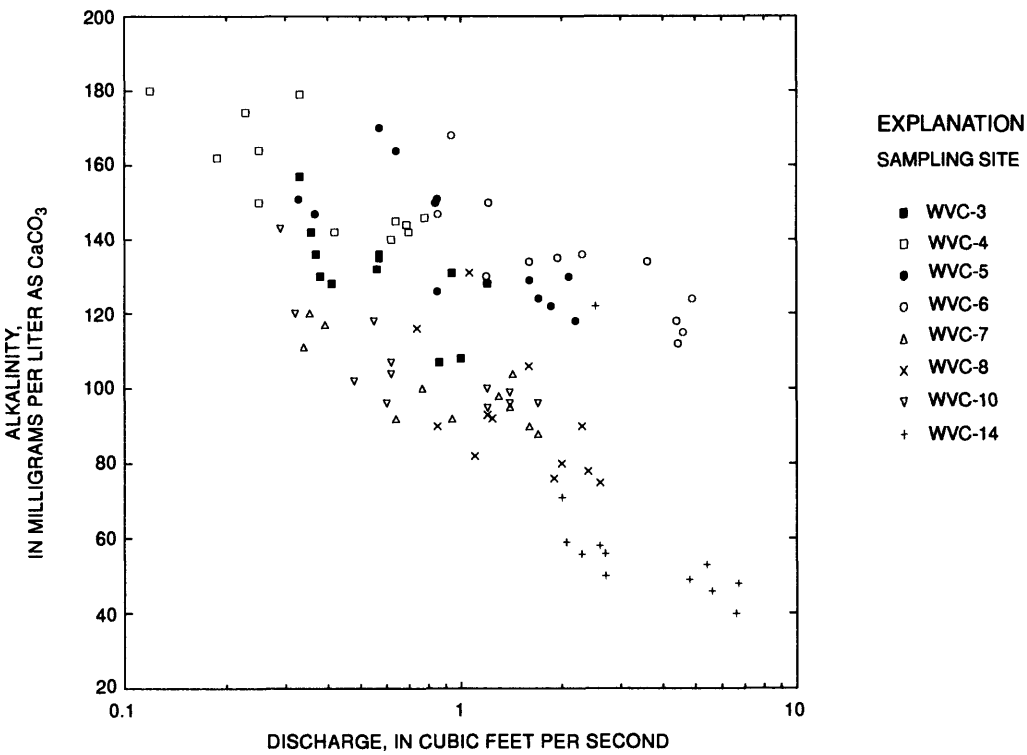


Figure 29. Relation between alkalinity and discharge in monthly base-flow samples at 8 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.

Median specific conductance ranged from 69 μS/cm in the tributaries to 565 μS/cm in the mainstem. The streamwater generally becomes more dilute downstream as tributaries draining noncarbonate rocks join the mainstem, except between sites WVC-11 and WVC-13 (fig. 25). Streamwater is most dilute (lowest specific conductance) at site WVC-1 and least dilute at sites WVC-2 and WVC-12. The site WVC-1 is on a tributary fed by a spring near the contact between the Chickies Quartzite and Harpers Phyllite and Antietam Quartzite, at the northern edge of the valley; ground water in these geologic units is more dilute than ground water in carbonate rocks. Site WVC-2 is below the surface-water discharge from the lithium-processing facility in Planebrook; the discharged effluent contains chloride, bromide, and other ions that increase specific conductance. The specific conductance increases downstream in the mainstem between sites WVC-11 and WVC-13 because of the input of high-conductance water from a tributary (WVC-12) and(or) quarry discharge water.

Major ions and constituents

Concentrations of the major ions calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and silica; nutrients; and turbidity were determined in monthly stream samples at most of the sites for 1 year (August 1990 to July 1991) and at some tributaries for a few months during that period. The distribution of concentrations of each ion are shown in figure 30. Differences in the median and range of major ion concentrations in base flow reflect both differences in lithology of contributing aquifers and in anthropogenic contributions to constituents, such as chloride and nitrate, that are associated with land uses. Because base flow primarily is ground water that has derived its chemical composition through mineral weathering, streams that drain more than one geologic unit will have a composition that is a mixture of different ground-water compositions. Tributaries may increase or decrease the concentrations of major ions in the mainstem, depending on the relative differences in ion concentrations.

Concentrations of major ions did not consistently correlate with discharge in samples from all 15 sites. However, the correlations, where significant, usually were inverse between discharge and concentrations of calcium, magnesium, potassium, and silica and direct between discharge and concentrations of sodium. Correlations between discharge and ion concentrations may not be comparable for all sites because the number of complete analyses differed among sites; correlations are most reliable for sites with the most data. Sites with the greatest and equal number of complete analyses (11) are WVC-5, WVC-6, WVC-8, WVC-9, WVC-10, WVC-14, and WVC-15; additionally, equal numbers of anion analyses were performed for WVC-11 and WVC-13.

Most calcium and magnesium in streamwater are derived from weathering of soils and geologic unit materials. Greater concentrations of calcium and magnesium are associated with water from carbonate rocks than from noncarbonate rocks. The concentrations of calcium and magnesium were lowest for water samples from site WVC-1 (median of 2.7 mg/L for calcium and 2.5 mg/L for magnesium), a spring-fed tributary that drains quartzite, and from site WVC-14 on Broad Run (median of 22 mg/L for calcium and 8.3 mg/L for magnesium), a tributary that drains the Peters Creek Schist. The concentrations of calcium were greatest in water samples from sites WVC-3 and WVC-12 (medians of 61 and 78 mg/L, respectively), streams in which the water derives its chemical composition from carbonate rocks. Water samples from site WVC-3, with relatively high alkalinity, contain relatively high concentrations of calcium, but relatively low concentrations of magnesium, indicating a $CaCO_3$ source, such as calcite in the Conestoga Limestone. The concentrations of magnesium are greatest in samples from sites WVC-4, WVC-12 and WVC-13 (medians of 25, 28, and 23 mg/L, respectively). Sites WVC-4 and WVC-12 are on streams that drain the magnesium-rich Ledger Dolomite. Water samples from site WVC-4 are saturated with respect to dolomite ($CaMg(CO_3)_2$). Quarry discharge, composed of ground water from the Ledger Dolomite and streamwater that has interacted with crushed dolomite, contributes magnesium to the mainstem below the quarry, as shown in samples from site WVC-13. Streams that receive significant ground-water discharge from both the noncarbonate and carbonate rocks have midrange concentrations of calcium (about 30 to 40 mg/L) and magnesium (about 10 to 14 mg/L), such as those observed in water samples from sites WVC- 7, WVC-8, and WVC-10. Concentration of calcium was directly related to alkalinity in samples from some sites (WVC-5, WVC-6, WVC-8, and WVC-10). In

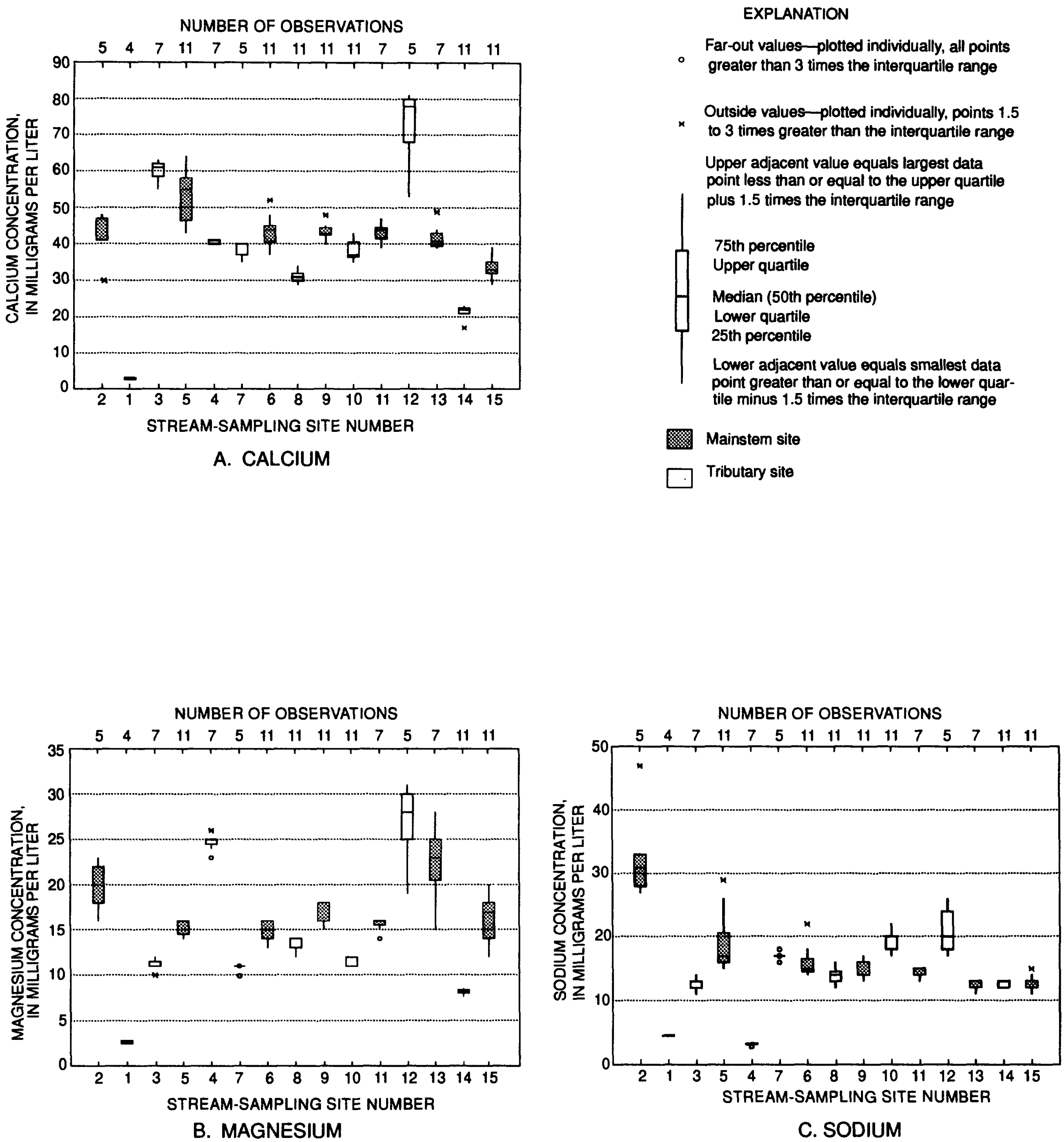
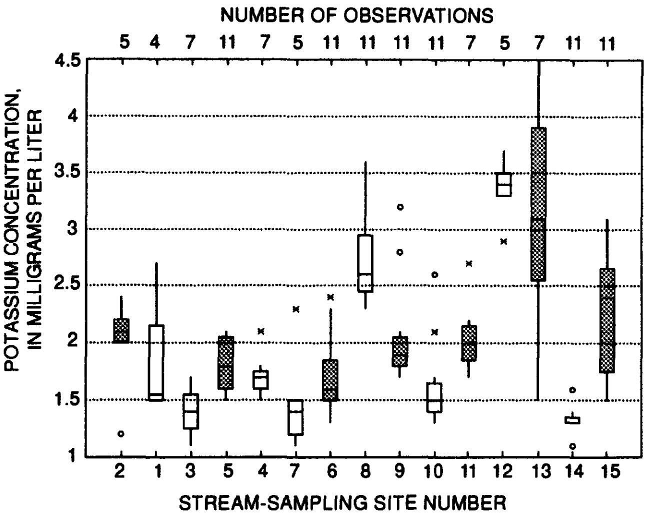
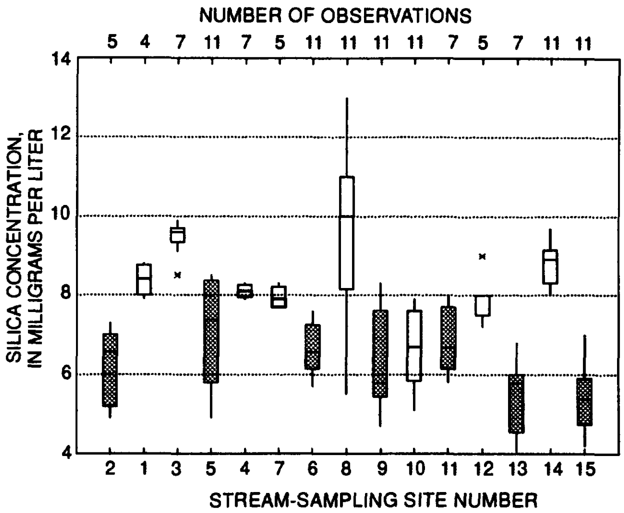


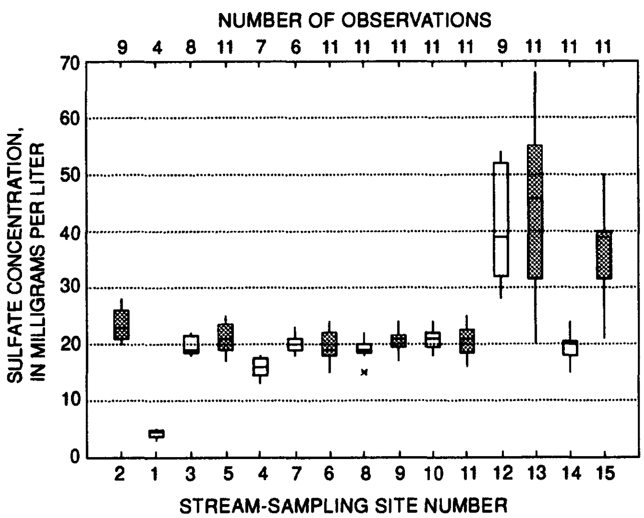
Figure 30. Distribution of selected dissolved major ion concentrations in monthly base-flow samples at 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.



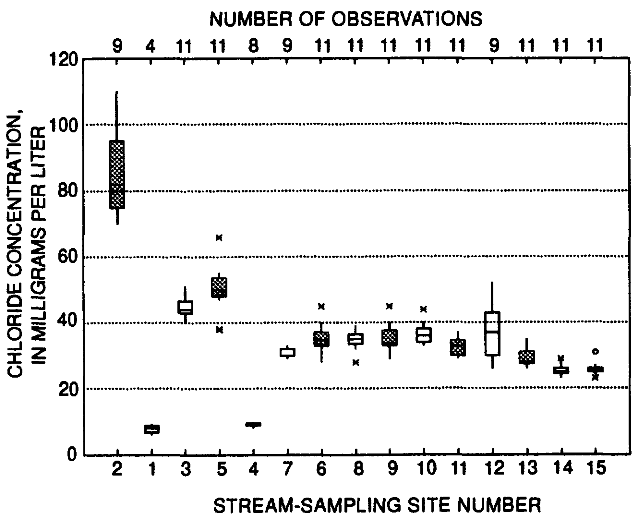
D. POTASSIUM



E. SILICA



F. SULFATE



G. CHLORIDE

Figure 30. Distribution of selected dissolved major ion concentrations in monthly base-flow samples at 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991—Continued.

samples from these sites and from site WVC-14, concentrations of calcium and alkalinity were inversely related to discharge. The lack of correlations between calcium concentration and alkalinity in water samples from other sites suggests that sources of calcium or alkalinity other than calcite are present. Calcium contributions from sources that include other calcium-bearing minerals and deicing salt may vary in the stream throughout the year.

Sodium is not naturally abundant in the West Valley Creek Basin and elevated concentrations of sodium above natural background levels (about 2 mg/L) indicate anthropogenic sources. The lowest sodium concentrations were in samples from sites WVC-1 (4 mg/L) and WVC-4 (3 mg/L), and probably represent nearly natural background concentrations. These streams drain principally agricultural areas. The greatest concentrations of sodium were in water samples from sites WVC-2, WVC-5, WVC-10, and WVC-12 (median concentrations of 31, 17, 18, and 20 mg/L, respectively). Discharge from the lithium-processing facility probably accounts for the elevated concentrations of sodium at sites WVC-2 and WVC-5. The sodium concentrations in the mainstem generally become lower downstream of site WVC-5 because of dilution (fig. 30). Elevated concentrations slightly above background levels at sites WVC-10 and WVC-12 may be related to road salt used on major highways (Routes 100 and 30, respectively) in the subbasins. However, sodium concentration was directly related to chloride concentration only in samples from sites WVC-8 and WVC-10. The stream reach above site WVC-8 receives sewage-treatment effluent, and the subbasin is developed and includes a major highway (Route 100). Concentrations of sodium were directly related to discharge in samples from sites WVC-5, WVC-6, and WVC-14, which may reflect seasonal and elevated concentrations from road salting during the winter.

Potassium is used as a nutrient in fertilizer and may be derived from weathering of rocks that contain minerals such as biotite, muscovite, and orthoclase. The median concentrations of potassium in samples from sites WVC-8, WVC-12, and WVC-13 (medians of 2.6, 3.4, and 3.1 mg/L, respectively) are greater than median concentrations in samples from other sites (fig. 30), and probably are partly from anthropogenic sources. Concentrations of potassium may be above background levels in the sewage-treatment effluent discharged above site WVC-8. Elevated concentrations of potassium in samples from site WVC-12 may be related to fertilizers applied on the golf course or cultivated fields in the subbasin; potassium may be further concentrated by evaporation in this small tributary, which has a very low discharge/drainage area ratio compared to other sites. Mainstem sites WVC-13 and WVC-15, downstream of site WVC-12, probably are affected by the elevated concentrations of potassium in the tributary. The lowest concentrations of potassium are in samples from sites WVC-3, WVC-7, WVC-10 and WVC-14 (medians ranging from 1.3 to 1.5 mg/L) that are on streams draining mostly residential areas in the South Valley Hills.

Concentrations of silica are greater in stream samples from tributaries that drain noncarbonate rocks than in samples from the mainstem (fig. 30), which is underlain by carbonate rocks. Median concentrations of silica ranged from 7.9 to 10 mg/L in samples from the tributaries and 5.3 to 7.1 mg/L in samples from the mainstem. Silicate minerals are sources of dissolved silica and are more abundant in noncarbonate rocks than carbonate rocks. Concentrations of silica inversely correlated with discharge in water samples from sites WVC-5, WVC-6, and WVC-10.

Sulfate concentrations were greatest in samples from sites WVC-12, WVC-13, and WVC-15 (medians of 39, 46, and 39 mg/L, respectively) and least in samples from site WVC-1 (median of 4.5 mg/L) (fig. 30). The highest concentrations of sulfate probably are caused by sulfate-rich ground water discharged naturally to the stream and from quarry dewatering operations. The sulfate concentration measured in a sample collected in autumn 1991 from the sump pond of the quarry was 130 mg/L. Possible mineral sources of sulfate are pyrite and gypsum in the dolomite that is quarried. Sulfate concentrations in quarry discharge water may be increased by enhanced dissolution of minerals related to the increased surface area of the crushed rock. Magnesium concentration was directly related to sulfate concentration in samples from sites WVC-13 and WVC-15, downstream of the quarry, suggesting concurrent dissolution of dolomite and a sulfate-containing mineral. Sulfate concentration was inversely related to discharge in samples from sites WVC-12, WVC-13, and WVC-15.

Chloride, like sodium, is not naturally abundant in the West Valley Creek Basin and concentrations above natural background level (about 3 mg/L or less) indicate anthropogenic sources. The chloride load in base flow estimated from concentrations at site WVC-13 for the stream (about 59 kg/ha) is much greater than the load contributed by precipitation to the basin (about 4.5 kg/ha). The highest concentrations of chloride (up to 110 mg/L) were measured in samples from site WVC-2, downstream of the lithium-processing facility effluent discharge. The concentrations of chloride generally decrease in the mainstem downstream of site WVC-2 (fig. 30) because of dilution. Similar to sodium, the lowest concentrations of chloride were in samples from sites WVC-1 (6 mg/L) and WVC-4 (8.9 mg/L), which are on streams that drain agricultural areas; these concentrations are only slightly greater than natural background concentrations. Concentrations of chloride (medians ranging from 25 to 89 mg/L) in samples from other stream sites are significantly greater than background concentrations indicating anthropogenic sources throughout the basin. In 1970, Miller and others (1971) determined streamwater quality in two small undeveloped (rural) basins north and northwest of the West Valley Creek Basin and reported background chloride concentrations of about 10 mg/L or less; where the area was affected by deicing salt, concentrations of chloride were about 25 mg/L.

Long-term increases in concentrations of chloride in base flow in West Valley Creek in autumn may be related to the increase in urbanization in the basin. For base-flow samples collected from West Valley Creek near Mullsteins Meadow (site WVC-15) in autumn, the seasonal Kendall test for trend (Hirsch and others, 1982) indicates that concentrations of chloride have increased since 1971 (fig. 31). Chloride is the only major constituent of those measured that has shown a significant change in concentration since 1971.

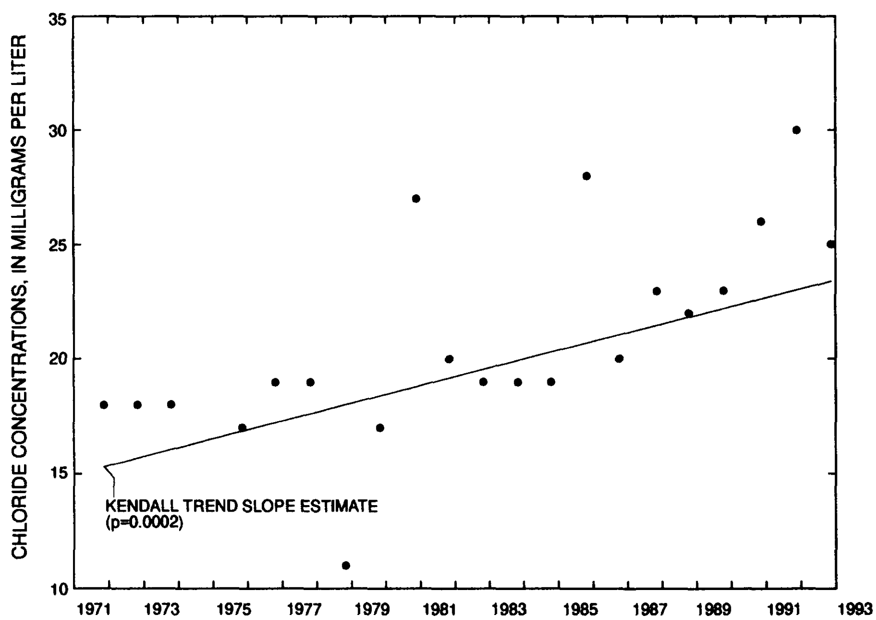


Figure 31. Concentrations of chloride in base-flow samples collected in autumn, 1971-93, at biological monitoring site 01480903 [West] Valley Creek at Mullsteins Meadow (WVC-15), Pennsylvania, and seasonal Kendall trend slope estimator. Significance of trend given by p-value = 0.0002.

Chloride concentrations in streamwater samples generally were greatest in February and March (fig. 32) (table 34), probably because of deicing salt applied to roads during winter. Chloride concentration did not indicate a consistent correlation with discharge; chloride concentrations directly correlated with discharge at sites WVC-1 and WVC-10, inversely correlated with discharge at site WVC-12, and did not significantly correlate with discharge elsewhere. Increases in concentrations of chloride in samples from sites WVC-2 and WVC-12 in months other than February and March have sources other than deicing salt; industrial effluent discharge affects the stream above site WVC-2, and evaporation and return irrigation flow during dry months affect the stream above site WVC-12.

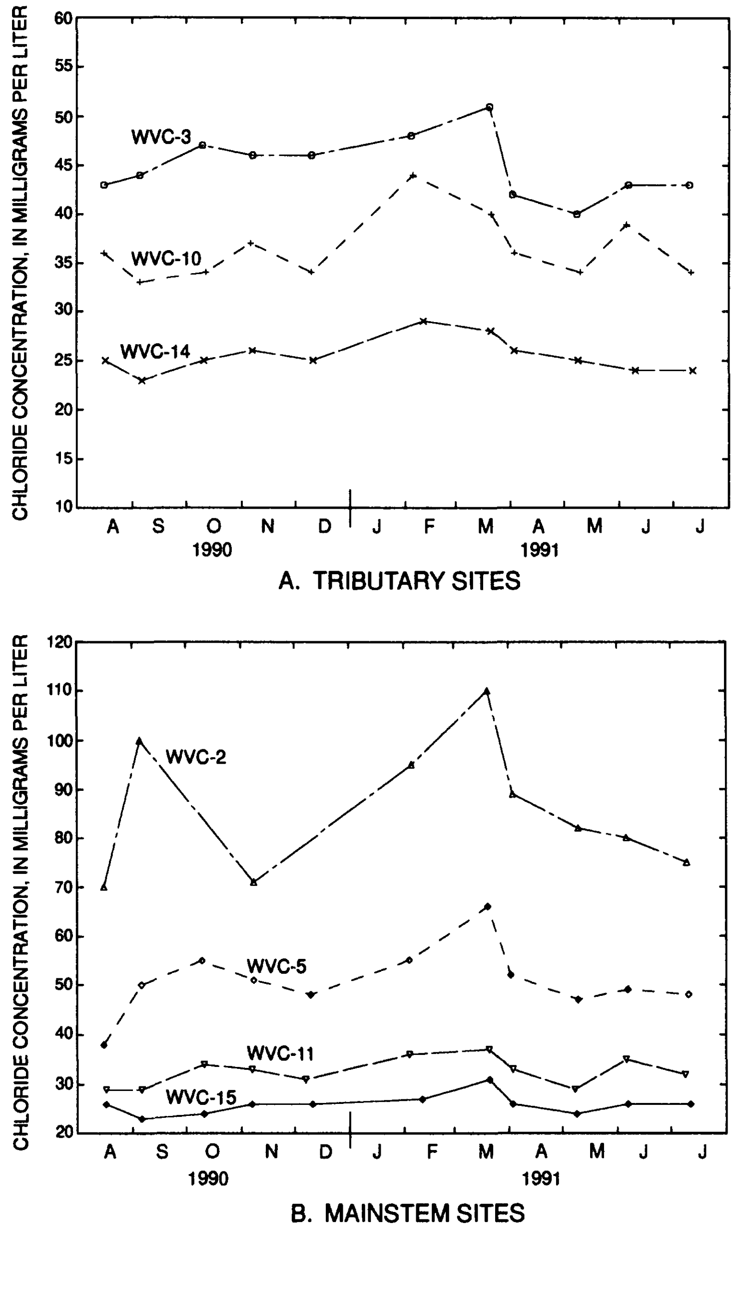


Figure 32. Seasonal variations in chloride concentrations in monthly base-flow samples from selected mainstem and tributary stream sites, West Valley Creek Basin, Pennsylvania.

The relative ion composition of streamwater is shown for samples collected September 5-6, 1990 (fig. 33). Differences in the water types for tributaries are shown by the greater spread of data points than the more tightly clustered data points for mainstem sites. All stream samples, except those from sites WVC-1, WVC-2, and WVC-14, are calcium-magnesium-bicarbonate type waters. Water samples from site WVC-2, near the headwaters in phyllite, are affected by sodium and chloride in the discharge from the lithium-processing facility. Streams at sites WVC-1 and WVC-14 are primarily fed by ground water from noncarbonate rocks. Water from mainstem sites becomes relatively more enriched in magnesium downstream, reflecting the dissolution of dolomite.

The relative ion compositions remained constant for samples from most sites with time. However, the relative concentrations of chloride increased in February and March at tributary and mainstem sites, except sites WVC-13 and WVC-15. These relative and absolute increases in chloride concentrations may reflect road salt loads to ground water and surface water in the winter. Water samples collected from sites WVC-13 and WVC-15 during autumn indicated relative increases in concentrations of magnesium and sulfate compared to samples collected in other seasons. Concentrations of sulfate and magnesium are higher in quarry discharge than in streamwater, and the effect of quarry discharge on stream composition is greatest at low-flow conditions in the autumn. Concentrations of magnesium and sulfate varied in stream samples from sites WVC-13 and WVC-15, and probably reflect varying proportions of quarry discharge water relative to natural streamflow.

The nutrients nitrogen and phosphorus are essential for life, and changes in natural concentrations of nutrients will affect the biological component in streams. Nutrients are biologically cycled, with uptake and release by organisms and plants throughout the year. In an evaluation of water quality by the use of diversity of benthic organisms as an indicator of stream quality, Moore (1987) suggested monitoring dissolved (rather than total) concentrations of nutrients in streams because the dissolved forms are most readily available for uptake by organisms and because laboratory analyses for total nitrogen and phosphorus compounds are unreliable. The range and median dissolved concentrations of ammonia, nitrite, nitrate plus nitrite, and orthophosphate in the stream samples in the basin are shown in figure 34. Concentrations of total and dissolved organic nitrogen and total and dissolved phosphorus were determined for selected samples and are given in table 34.

Concentrations of nitrate in stream samples from West Valley Creek were much greater than concentrations of other nitrogen species analyzed. Nitrate (NO_3^-) is the most stable of the nitrogen ions in oxygenated waters. Nitrite and ammonia are reduced forms of nitrogen. Background concentrations of nitrate, assuming no other sources but atmospheric precipitation and that all ammonia is converted to nitrate, would be about 0.67 mg/L nitrate as N. Near West Valley Creek, atmospheric precipitation contains about 0.32 mg/L nitrate as N and 0.25 mg/L of ammonia as N. Concentrations more than about 1.0 mg/L of nitrate as N in surface water and ground water probably represent sources other than atmospheric precipitation, such as fertilizer. The lowest concentrations of nitrate (as low as 0.7 mg/L as N) were measured in samples from site WVC-1, the spring-fed tributary that traverses an agricultural area but is not in hydraulic contact with ground water beneath the cultivated land. The greatest concentrations of nitrate (up to 6.3 mg/L as N) were measured in samples from site WVC-4 on a tributary that drains agricultural land and are probably a result of long-term applications of fertilizers to the land. Stream samples from site WVC-4 contained concentrations of nitrate that were consistently greater (median 6.0 mg/L as N) than concentrations at other stream sites (medians ranging from 0.8 to 3.2 mg/L as N). Stream samples from sites WVC-10 and WVC-14 contained concentrations of nitrate greater (medians of 2.8 and 3.2 mg/L, respectively) than concentrations in samples from sites other than WVC-4. The tributaries with sites WVC-10 and WVC-14 drain the unsewered part of the West Valley Creek Basin, and the observed concentrations of nitrate may be caused partly by nitrogen loading from septic tanks.

Nitrite concentrations generally were low (0.03 mg/L as N or less). Nitrite concentrations were lower in samples from tributary sites (medians near level of detection or less than 0.01 mg/L as N), except for site WVC-12, than in samples from mainstem sites (medians of 0.01 to 0.02 mg/L as N), suggesting that conditions in the mainstem may be more reducing or less oxidizing than in the tributaries. Ammonia is persistent only in reducing conditions because it is readily oxidized to nitrate

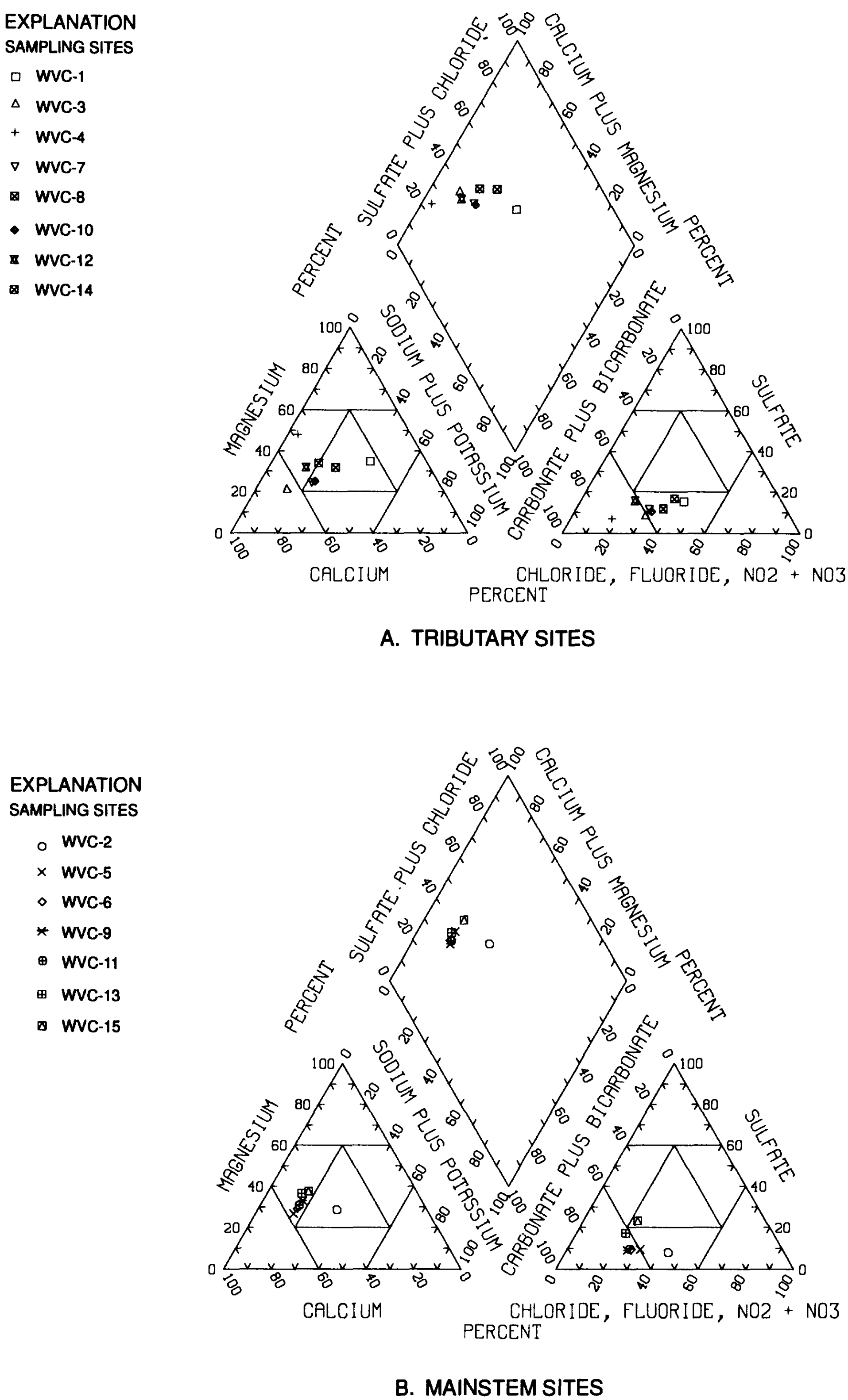


Figure 33. Relative concentrations of major ions in stream samples collected September 5-6, 1990, West Valley Creek Basin, Pennsylvania.

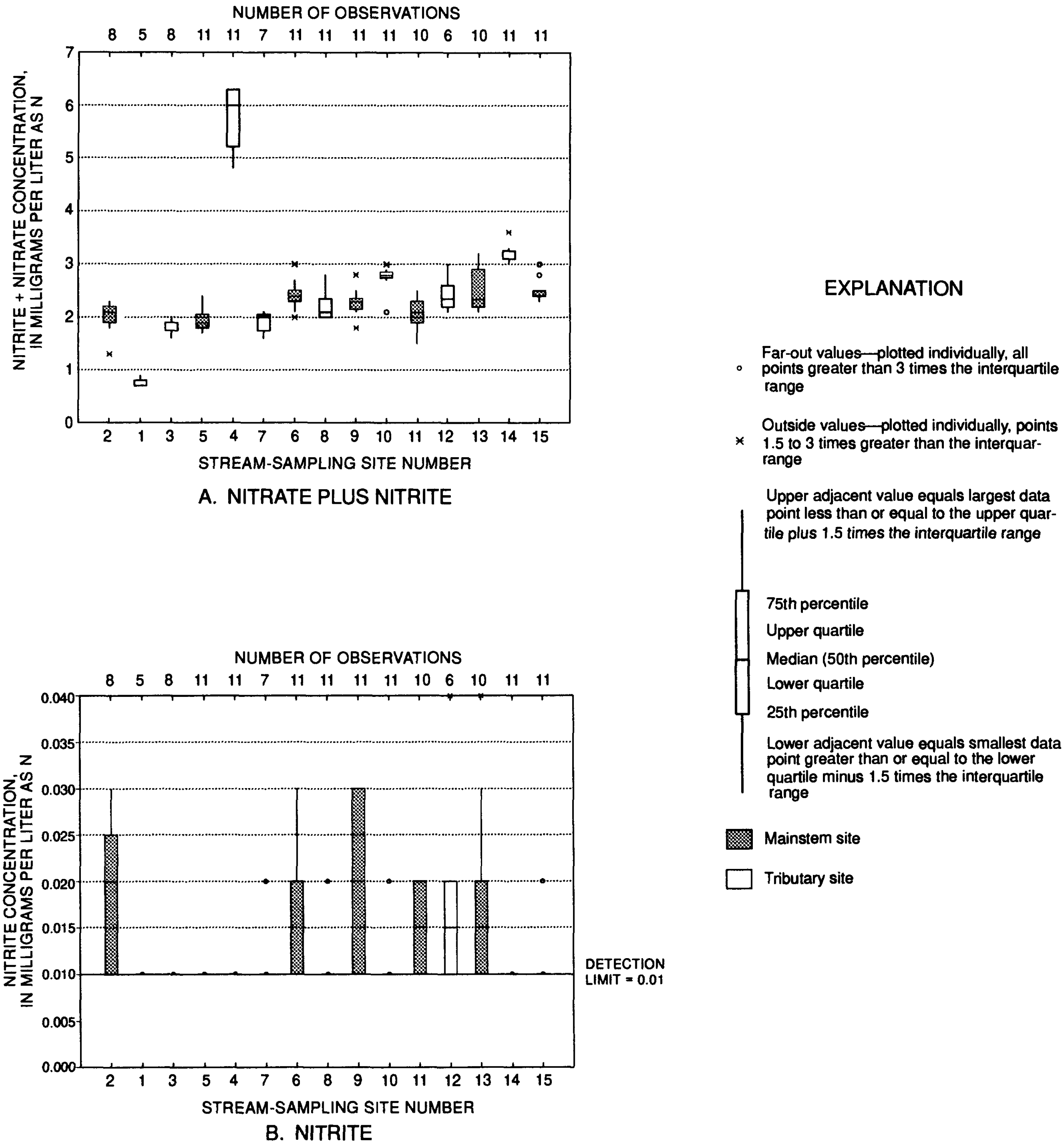
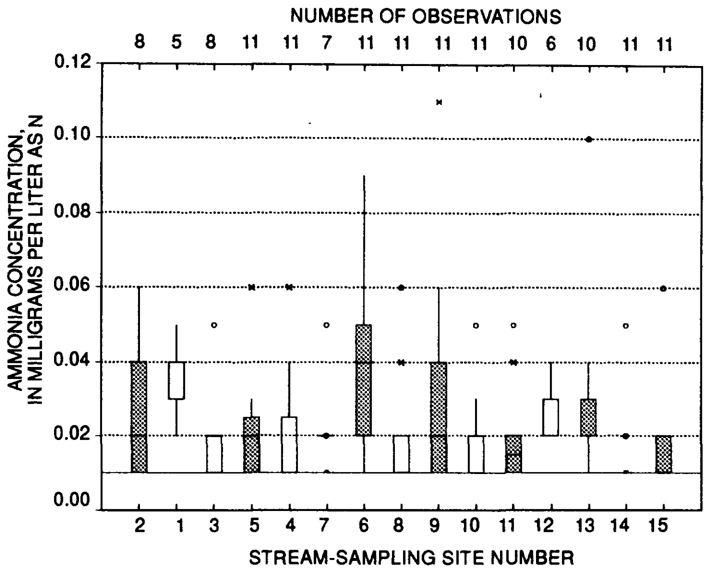
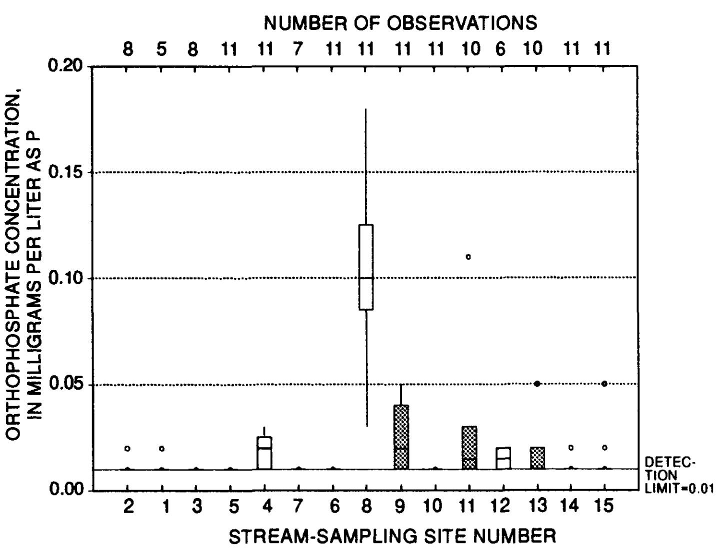


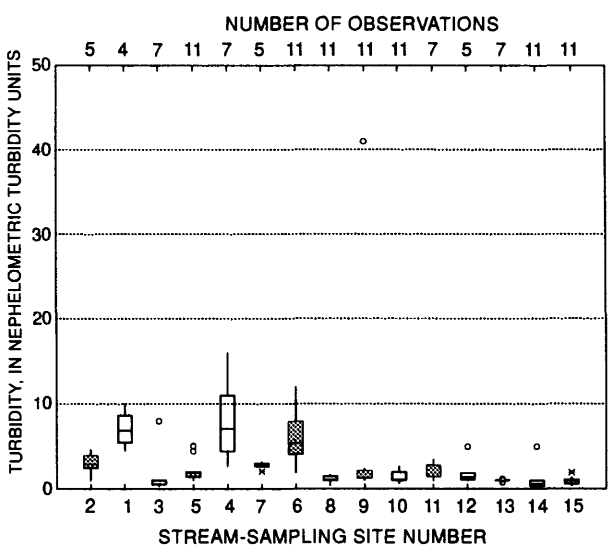
Figure 34. Distribution of dissolved nutrients and turbidity concentrations in monthly base-flow samples from 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.



C. AMMONIA



D. ORTHOPHOSPHATE



E. TURBIDITY

Figure 34. Distribution of dissolved nutrients and turbidity concentrations in monthly base-flow samples from 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991—Continued.

with sufficient oxygen. Concentrations of ammonia generally were less than 0.04 mg/L as N in samples from most sites. Slightly higher ammonia concentrations (median 0.04 mg/L as N) were consistently measured in samples from site WVC-6, although greater ammonia concentrations were measured in two samples from sites WVC-9 and WVC-13 (0.11 and 0.10 mg/L as N, respectively). The concentrations of dissolved oxygen in samples from site WVC-6 are slightly lower than those at other sites (fig. 25), indicating a less oxygen-rich environment. Site WVC-6 is downstream of a pond where biologically mediated reduction reactions could occur. High ammonia concentrations were not detected at sites where high nitrate concentrations were measured, reflecting the difference in chemical environments that affect stability of nitrogen species.

Orthophosphate concentrations were at or near the level of detection of 0.01 mg/L as P for samples from most sites. Elevated concentrations of orthophosphate (up to 0.18 mg/L as P) above background levels were measured in the samples from tributary site WVC-8. A sewage-treatment plant discharges to this tributary and is a likely source of phosphate. Phosphate concentrations were slightly higher in the mainstem downstream of the tributary with the sewage treatment discharge than upstream. Stream samples from sites WVC-4 and WVC-12 also contained detectable concentrations of orthophosphate; these sites may be affected by fertilizers applied in agricultural activities.

Turbidity is a measure of the clarity of water and is affected by suspended clay, silt, organic matter, microscopic organisms, and soluble colored organic compounds (American Public Health Association and others, 1985, p. 133). Turbidity was greatest in samples from sites WVC-1, WVC-4, and WVC-6; median concentrations ranged from 5 to 7 nephelometric turbidity units (NTU). Sites WVC-1 and WVC-4 are on streams draining agricultural parts of the basin, suggesting that the stream turbidity may be related to agricultural land use. Site WVC-6 is on the mainstem, downstream and near the confluence of the tributary with site WVC-4.

Metals and other trace constituents

Concentrations of iron, manganese, lithium, boron, and chromium were determined in samples from selected stream sites throughout the year. The range and median concentrations of iron, manganese, lithium, and boron are shown in figure 35. A suite of 20 metals was analytically determined by inductively coupled plasma in samples collected at 14 of the 15 sites (WVC-12 was dry) in November 1990 (table 35).

Concentrations of iron and manganese in ground water and surface water are affected by the solubility of iron and manganese minerals in the rocks and soil and generally are greater in ground water from noncarbonate rocks than from carbonate rocks. The consistently highest concentrations of iron (median of 48 μg/L) were measured in samples from site WVC-1, although concentrations up to 90 μg/L were measured in samples from sites WVC-3 and WVC-9. Site WVC-1 is on a tributary whose source is a spring in the quartzite. The consistently lowest concentrations of iron (median of 8 μg/L) were measured in samples from site WVC-4 on a tributary whose source is primarily ground water in carbonate rocks. Median concentrations of iron and manganese in samples from sites other than WVC-1 and WVC-4 ranged from 10 to 19 μg/L, were only slightly greater than the median concentration of less than 10 μg/L of ground water in carbonate rocks, and do not significantly differ in the tributaries and mainstem.

In contrast to iron, concentrations of manganese are greater in the mainstem than tributaries. The consistently highest concentrations of manganese (median of 34 μg/L) were measured in water samples from site WVC-6, which also had the highest concentrations of ammonia. At other sites, the median concentrations of manganese ranged from 8 to 23 μg/L. Manganese may be mobilized in the reducing environment indicated by detectable ammonia and nitrite in water at site WVC-6.

Concentrations of lithium of 10 μg/L or less represent natural background concentrations in West Valley Creek. In samples collected at site WVC-2, lithium concentrations up to 4,800 μg/L were measured and were 1 to 3 orders of magnitude greater than lithium concentrations in stream samples at other sites. Site WVC-2 is less than 0.5 mi downstream from the point where the lithium-processing facility near Planebrook (pl. 1) discharged wastewater to the stream. Concentrations of lithium decrease downstream in the mainstem because of dilution by tributary and ground-water inflow that contains low concentrations of lithium. Concentrations of lithium are higher (median of 27 μg/L) in samples from site WVC-10, a tributary that flows by the other lithium-processing facility near Exton than in samples from other tributaries. Although the facility in Exton no longer discharges to the stream, wastewater that may contain lithium apparently is discharged to a septic system on site (Jim Mahlon, West Whiteland Township, oral commun., 1992).

The monthly average lithium loads from the lithium-processing facility near Planebrook reported under the NPDES permit are shown in relation to lithium loads calculated from stream samples at site WVC-2 (fig. 36). Measured loads were calculated by use of measured lithium concentration and discharge at time of sampling. Although these loads are instantaneous values and do not necessarily represent the average load, the measured and reported loads are similar for months with data, except for June 1991; differences between measured and reported loads are probably related to variability in discharge rates during that month. About 1,800 lb (818 kg) of lithium were discharged from the lithium-processing facility to West Valley Creek from August 1990 through July 1991. Concentrations of lithium did not correlate with discharge at sites in West Valley Creek because the loads of lithium discharged to the stream varied throughout the year.

The highest concentrations of boron (up to 80 μg/L) in West Valley Creek Basin were measured in samples from site WVC-2. Downstream of WVC-2, boron concentrations fell to background levels (about 10 to 30 μg/L) in the mainstem (fig. 35). Sloto (1987) found that ground water containing high concentrations of lithium and boron discharged to Valley Creek to the east of the lithium-processing facility near Planebrook; concentrations of lithium up to 800 μg/L and boron up to 130 μg/L were measured in Valley Creek east of the lithium-processing facility. Sloto (1987) reported that concentrations of lithium and boron were directly related and inversely related to discharge, respectively, in Valley Creek. Boron concentrations directly correlated with lithium concentrations and inversely with discharge in samples from site WVC-2 but not at other sites on West Valley Creek.

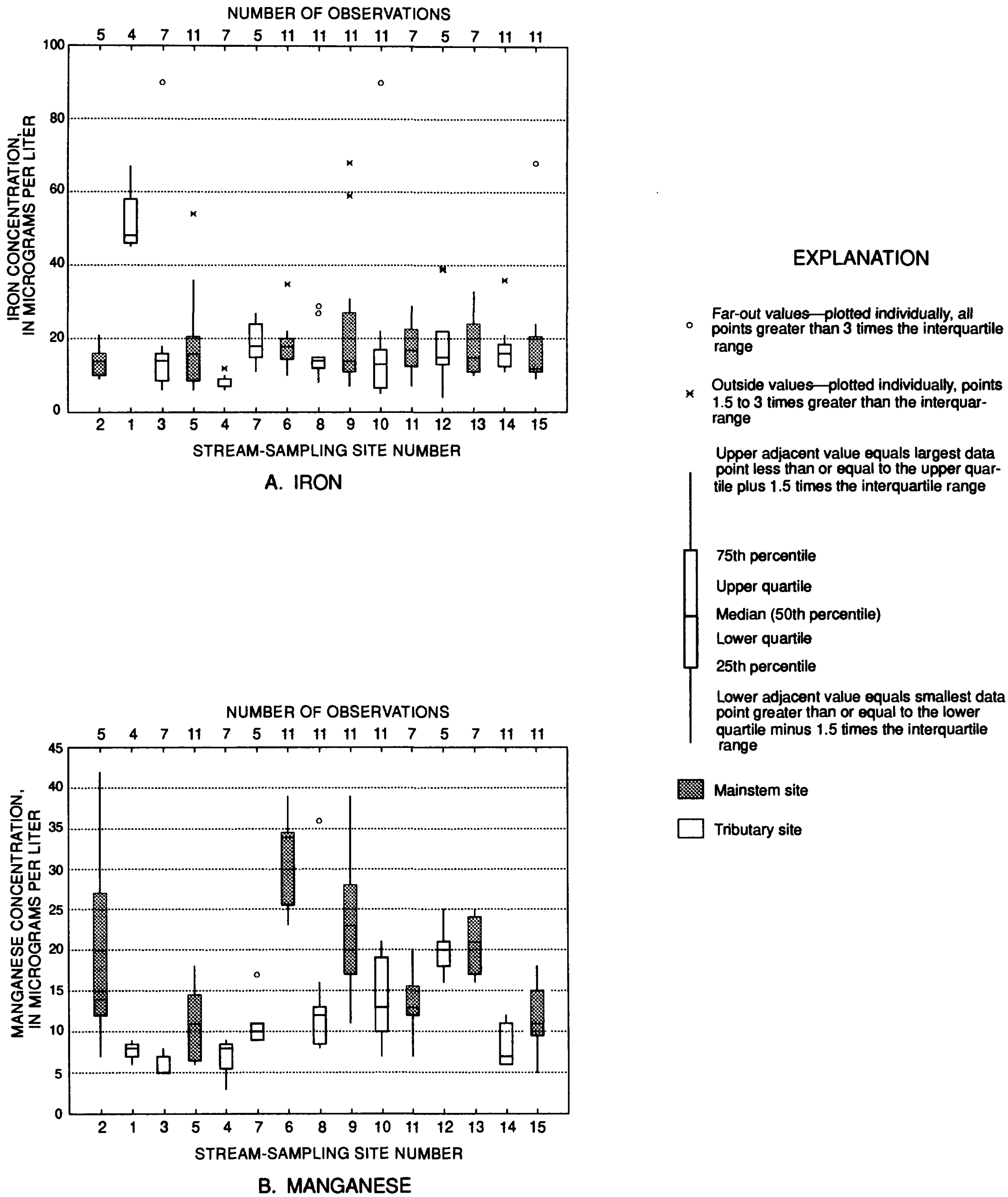
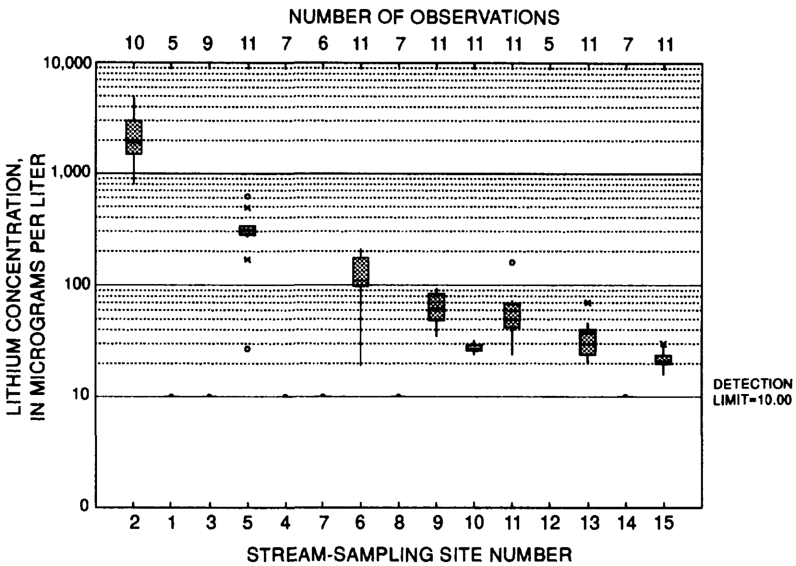
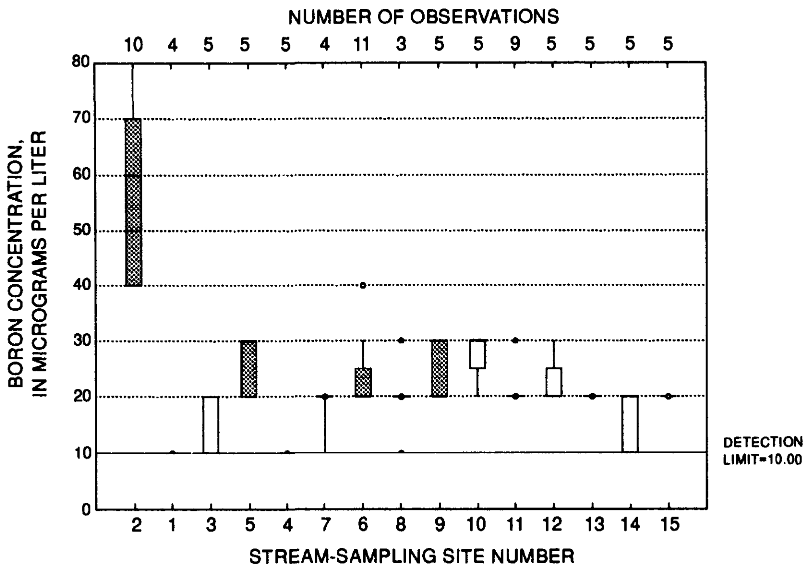


Figure 35. Distribution of dissolved iron, manganese, lithium, and boron concentrations in base-flow samples from 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991.



C. LITHIUM



D. BORON

Figure 35. Distribution of dissolved iron, manganese, lithium, and boron concentrations in base-flow samples from 15 sites on West Valley Creek, Pennsylvania, August 1990 - July 1991—Continued.

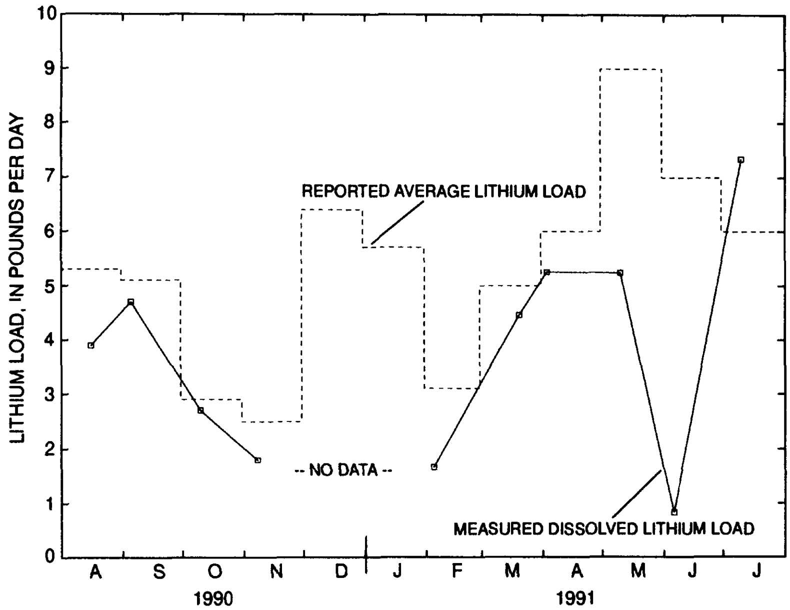


Figure 36. Reported and measured lithium loads at stream site WVC-2, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991.

Chromium was consistently measured in concentrations at or above the reporting level of 1 µg/L in stream samples from sites WVC-2 and WVC-10, both of which are near lithium-processing facilities. The maximum concentration of chromium of 5 µg/L was measured in a sample from site WVC-2. Concentrations of chromium in addition to lithium and boron, are elevated (up to 60 µg/L) in ground water, in the area of the lithium-processing facility near Planebrook (Sloto, 1987). Stream samples from sites WVC-2 and WVC-10 also contained lithium concentrations above background levels. Chromium may be present in or associated with discharges from the two lithium-processing facilities.

Results of analysis for 20 metals in the November 1990 samples are given in table 35. Concentrations were below the level of detection in all samples for arsenic, cadmium, cobalt, copper, lead, molybdenum, nickel, silver, and vanadium. The metals and trace elements that were measured in concentrations greater than detection were aluminum, barium, beryllium, and zinc, as well as iron, manganese, lithium, boron, bromide, and chromium. Concentrations of aluminum, barium, and zinc measured in samples probably represent natural background concentrations.

Aluminum generally is not very soluble in the pH range of the stream samples. Aluminum was measured in concentrations ranging from 20 to 30 µg/L (the detection limit was 10 µg/L) at sites WVC-1, WVC-10, WVC- 11, WVC-14, and WVC-15. Sites WVC-1, WVC-10, and WVC-14 are on tributaries that drain noncarbonate rocks from which aluminum may be released through mineral weathering. The other two sites, WVC-11 and WVC-15, are immediately downstream of the tributaries that contain aluminum in detectable concentrations.

Barium is a trace element that occurs naturally in minerals and was present in concentrations ranging from 12 to 59 µg/L. The highest concentration of barium was in a sample from tributary site WVC-8, which receives effluent from the sewage-treatment plant and drains gneiss, quartzite, and carbonate rocks.

Zinc was measured in concentrations ranging from 3 to 13 µg/L in water samples from 10 sites (table 35). Zinc may occur naturally at trace levels and can be introduced into the environment by some industrial discharges. The highest concentrations of zinc were in samples from sites WVC-9 and WVC-13 (10 and 13 µg/L, respectively), both mainstem sites on reaches underlain primarily by carbonate rocks in industrial and commercial areas of the basin.

Beryllium was measured at the limit of detection, 0.5 µg/L, in water samples from sites WVC-3, WVC-6, WVC-7, and WVC-8. Because the concentration is so close to the detection limit, there is some uncertainty about the actual beryllium concentrations. Beryllium is an uncommon trace element that has low solubility in nonacidic waters. The detection of beryllium in the stream samples indicates anthropogenic sources. WVC-3 drains an area under investigation as a NPL site for solvents and metals; sites WVC-6 and WVC-7 are in commercial and industrial areas, and site WVC-8 is below a sewage-treatment plant.

Streambed Sediment

Many inorganic and organic substances that are toxic (or otherwise damaging) to living organisms are also relatively insoluble, such as lead and polychlorobiphenyls (PCB), and sorb onto sediment. The relatively insoluble constituents can be taken up by benthic invertebrates or other organisms that inhabit stream bottoms. Grain size and organic content are important factors in determining partitioning of insoluble constituents; most metals and organic compounds will be more concentrated in the fine- rather than coarse-grained sediment.

In 1985, sediment samples were collected for pesticide and PCB analysis at 20 biological monitoring sites in Chester County, including site WVC-15 on West Valley Creek. The sediment samples were not sorted by size or adjusted for organic content. The reported concentrations of organic compounds in the grab samples of stream sediment are not necessarily representative of mean sediment concentrations and may underestimate maximum possible concentrations. Several pesticides and PCB's were detected in the sediment sample from West Valley Creek in the following concentrations: DDD, 0.4 µg/kg; chlordane, 4.0 µg/kg; dieldrin, 0.3 µg/kg; and PCB's, 40 µg/kg.

The pesticides, DDT, and its metabolites, DDE and DDD, chlordane, and dieldrin, were detected at similar concentrations in sediments from several other streams in Chester County, including Valley Creek to the east. DDT is the common name for a mixture of compounds in which the main component is 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane. DDT was one of the first of the organochlorine insecticides introduced to agriculture and was widely applied from the 1940's until it was banned in 1971. Most uses of DDT and DDD have been prohibited by the USEPA. Chlordane is used by licensed commercial operators for subsurface termite control and was sold over-the-counter until recently; use of chlordane was cancelled in 1988 (USEPA, 1990). Dieldrin has been used as a contact insecticide to control soil pests, termites, and many other pests. Most uses of dieldrin have been restricted by the USEPA since 1974, and since 1987, has not been manufactured in the United States (USEPA, 1990). PCB's are organic compounds that have a low solubility in water and have been used mainly as a coolant in electrical transformers. The presence of pesticides and PCB's in sediments in the West Valley Creek reflects the agricultural and industrial land uses in the basin. Transport of sediment through the West Valley Creek is an ongoing process. Several ponds on West Valley Creek in the upper reaches above site WVC-6 may act as sediment traps where pesticides and other insoluble compounds may accumulate.

Benthic Invertebrate Indices

The streamwater-quality and biological-monitoring program in Chester County is designed to determine relations between surface-water quality and the diversity of the benthic macroinvertebrate community. The monitoring program involves collection of benthic macroinvertebrate samples from streams during low flow in the autumn. Because many benthic macroinvertebrates live on or under rocks on the stream bottom, samples are collected from riffle areas by selecting 10 rocks of similar size and removing the associated organisms for identification. The organisms are identified in the laboratory to at least the genus level, except for midges (Chironomidae), flatworms (Planariidae), and water mites (Hydracarina), which are identified only to the family level. Methodology of benthic macroinvertebrate collection and analysis is described in detail by Moore (1987). Benthic macroinvertebrates are well suited for water-quality evaluations because of their habitat and low mobility. These bottom-dwelling organisms are in contact with bottom sediment, which may be contaminated with metals, pesticides, or organic compounds. Benthic macroinvertebrates have relatively short life cycles allowing changes in water quality to effect a quick change in community structure, including rapid recovery of the benthic macroinvertebrate community from short-term water-quality degradation. Benthic macroinvertebrate communities are affected by sediment load, climatic variations, hydrologic conditions, presence of toxins, nutrient load, and general water chemistry. The benthic macroinvertebrate community can act, at a specific stream site, as an around-the-clock instream monitoring system that integrates the effects of all conditions.

The stream monitoring program provides data to assess long-term water-quality trends. Biological samples have been collected at site WVC-15 (West Valley Creek at Mullsteins Meadow) since 1973 as part of the streamwater-quality monitoring network in Chester County. For the monitoring program in Chester County, trend analysis of water-chemistry data is limited by incomplete record for certain constituents, and changes in laboratory methodology and detection limits; however, the biological data are complete and consistent over the period of record and can be analyzed for statistical trends.

The benthic macroinvertebrate community can be described by a descriptive statistic called a diversity index. A diversity index is composed of two quantitative properties: (1) the number of different kinds of organisms (taxa); and (2) relative abundances of organisms. Brillouin's diversity index (Brillouin, 1962) was calculated to evaluate all samples collected in the basin. Brillouin's diversity index values generally range from 0 to 4.0. A diversity index indicates the relative stress on a community, but does not identify the specific type of stress. However, Brillouin's index values between 3.0 and 4.0 typically indicate waters free of organic waste, values between 1.0 and 3.0 indicate waters receiving moderate quantities of organic waste, and values below 1.0 indicate waters receiving large quantities of organic waste (Whilm and Doris, 1968; Whilm, 1970).

Diversity indexes at site WVC-15 (fig. 37) show an increase from 1973 to 1980 that is significant at the 95-percent confidence level (Moore, 1987). Low diversity indicates environmental stress on the benthic macroinvertebrate community. Since 1980, the diversity index at site WVC-15 has been steady near 3.0, placing it between an unstressed and an intermediate community (fig. 17). The increase in diversity from 1973 to 1980 may be caused by the banning of certain pesticides such as DDT (which was banned in 1971), increased regulation of point-source discharges, and the elimination of sewage-treatment plants. For example, in the 1970's, the lithium-processing facility operated a sewage-treatment facility that discharged effluent into a tributary to West Valley Creek; in the 1980's, the plant ceased operating, and the sewage-treatment plant was replaced by on-lot disposal. Another factor affecting diversity is change in land use. Diversity indexes tend to increase in areas that are changing from agricultural to residential land use (Sloto, 1987). This may be caused by (1) reduction of pesticides in storm runoff, (2) decreased sediment load, or (3) flushing of contaminated sediment by increased peak flows caused by urbanization (Sloto, 1987). From 1967 to 1987, residential land use increased from 13 to 40 percent and agricultural land use decreased from 30 to 9.3 percent in the West Valley Creek Basin above site WVC-5 (Hardy and others, 1995).

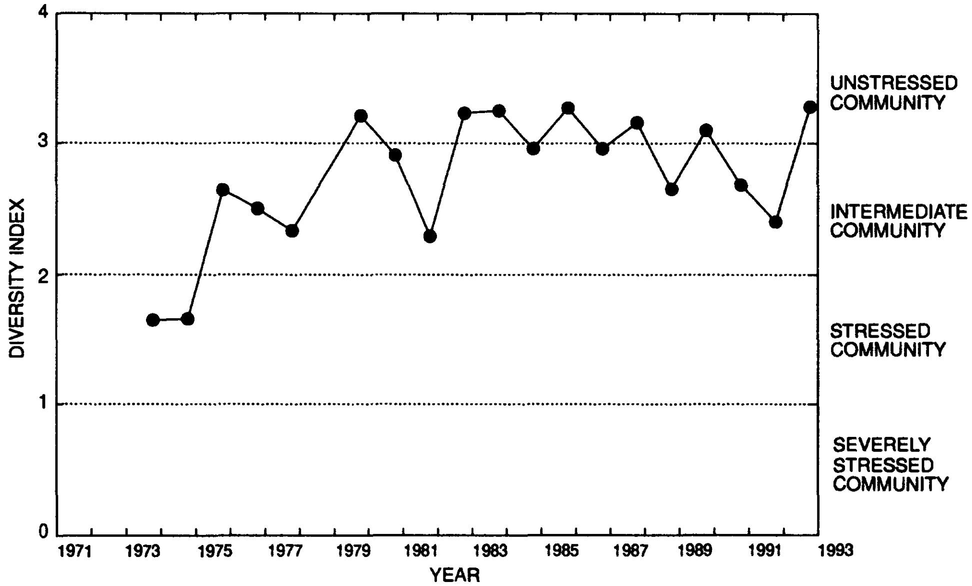


Figure 37. Brillouin's benthic invertebrate diversity indices at biological monitoring site 01480903, [West] Valley Creek at Mullsteins Meadow (WVC-15), Pennsylvania, showing improvement in diversity index values, 1973-92.

An evaluation of community structure is needed to interpret the Brillouin's diversity indexes because the Brillouin's index is not weighted by pollution tolerace of organisms. The relative numbers of pollution-sensitive organisms—such as stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera)—to pollution-tolerant organisms—the true flies (Diptera) and worms (Oligocheata)—can indicate the amount of stress on the invertebrate community. A diverse, pollution-sensitive community is an indication of a low-stress environment. Consistently low numbers of pollution-tolerant organisms is also an indication of a low-stress environment.

The macroinvertebrate community structure and diversity indexes at site WVC-15 indicate an intermediate (light to moderate) stress on the aquatic community. Relative to other streams in Chester County, the diversity index and community structure at site WVC-15 is similar to that in streams in partially urbanized basins. The structure of the macroinvertebrate community at site WVC-15 is dominated by pollution-sensitive organisms. In 1991, the macroinvertebrate sample of 1,492 individual organisms at site WVC-15 was composed of 51 percent pollution-sensitive organisms and 47 percent pollution-tolerant organisms. The pollution-sensitive community comprises few taxa; caddisflies are the dominant group along with smaller populations of mayflies and stoneflies. The population of pollution-tolerant organisms varies with time. Diptera populations since 1980 have ranged from low to moderate, indicating occasional high-stress conditions. One possible cause of stress is nutrient concentrations above natural background levels, a condition indicated by large quantities of algal beds, which are not commonly found in equally large quantities elsewhere in Chester County streams. Downstream of Broad Run, along the stream edge where velocities are slow and the water temperature is warm, these algal beds can grow to be 1 ft thick and 20 ft long. Algal growth can cover stream bottoms, which may degrade habitat and cause increased sedimentation.

The improvement in water quality indicated by benthic diversity indexes from 1973 to 1993 is not reflected in changes in the concentrations of dissolved major ions, nutrients, and turbidity determined in base-flow samples. However, benthic macroinvertebrates are more sensitive to contamination in bottom sediment than dissolved contaminants in the water column. Concentrations of dissolved constituents—except for chloride, which has increased (fig. 31)—determined for base flow in the autumn do not appear to have changed since 1971.

Relation Between Ground-Water and Surface-Water Quality

Because base flow is sustained by ground-water discharge, the chemical composition of streamwater under base-flow conditions is related to the composition of ground water that is largely controlled by mineralogy of geologic materials. A comparison of the Piper diagrams for ground-water (fig. 22) and surface-water samples (fig. 33) shows that the relative concentrations of major ions in surface water is similar to those in the ground water that discharges to the streams. The Conestoga Limestone is predominantly composed of calcium carbonate and contains relatively less enriched in magnesium than the Ledger Dolomite. The mainstem of West Valley Creek is underlain primarily by the Ledger Dolomite, which dominates water quality of the mainstem. Samples at stream sites WVC-3 and WVC-7 are from tributaries that flow from the noncarbonate rocks over the Conestoga Limestone before joining the mainstem and have relatively less magnesium and more calcium. Mixing, chemical reactions (including reactions with stream sediments), and biological processes can change the composition of ground water after it discharges to the stream. Additionally, discharged effluents and surface runoff can affect stream quality.

Seepage investigations identified gaining and losing reaches in West Valley Creek. The potential for cross-contamination between the ground-water and surface-water systems is high because the systems are well connected. In the gaining reaches, ground water contributes to stream quality. In losing reaches, surface water contributes to ground-water quality. The water quality of the stream and tributaries can change as it enters the carbonate valley because of interaction with stream sediments or with the ground-water system. The tributaries drain areas underlain by noncarbonate rocks, but also cross the carbonate valley before joining the mainstem. Losses and gains identified in the seepage investigations in 1990 and 1991 represent net changes and losses and gains were not accounted for in the reaches between measurements.

Regional changes in ground-water quality related to land use are indicated by the concentrations of chloride and nitrate in base flow. Anthropogenic sources of chloride include deicing salt and for nitrate include fertilizers and effluent from septic systems. Chloride concentrations are elevated above natural background concentrations in ground water in carbonate rocks and base flow in streams. The median concentration of 28 mg/L in ground water from carbonate rocks (table 17) is similar to concentrations measured at the downstream sites WVC-13, WVC-14, and WVC-15. The median concentrations of chloride ranged from 32 to 44 mg/L in stream samples from tributaries in the upper part of the basin (sites WVC-3, WVC-7, WVC-8, and WVC-10). The higher chloride concentrations in stream samples from the upper part of the basin may indicate greater chloride loads to ground water near Routes 30 and 100. The relatively elevated concentrations of nitrate (greater than 3 mg/L as N) above background levels in tributaries sampled at sites WVC-4 and WVC-14 indicate nitrate loading to ground water from agriculture and septic systems, respectively. Elevated concentrations of nitrate (median is about 4.0 mg/L as N (up to 13 mg/L as N) above background levels were measured in ground water near site WVC-4. Site WVC-14 is on Broad Run, a tributary that drains an unsewered part of the basin underlain by schist. Ground water in the schist contains relatively higher concentrations of nitrate (median is about 4.0 mg/L as N) (fig. 21) than other geologic units in the basin.

Temporal changes in ground-water and surface-water quality are related to seasonal cycles of recharge and human and biological activities. Sloto (1987) observed concentrations of chloride in water samples from a well drilled in carbonate rock increased as depth to water decreased during late winter when recharge is greatest. Recharge in the winter may transport chloride that has accumulated in the soil zone during other seasons and that may have been applied to roads. The increase in chloride concentrations observed in the stream samples in late winter (table 34) may reflect the increase in chloride concentrations in this recharge period. Small increases in nitrate concentrations in the winter also were observed in stream samples from some sites, which may be caused by a decrease in biological uptake of nitrogen in soils, aquifers, and streams during this period of colder temperatures that coincides with greatest recharge.

Local anthropogenic changes to ground-water and surface-water quality have affected ground-water and surface-water systems because the systems are well connected. Contaminants introduced to the stream can enter the ground-water system and return to the surface-water system where ground water discharges. For example, in the West Valley Creek Basin, lithium-processing wastewater was discharged for several years into a stream reach that periodically loses water to the ground-water system. Thus, lithium, boron, and other constituents from the lithium-processing facility near Planebrook have entered the ground-water system from streamflow. Lithium is a relatively conservative element and is used as a tracer in ground-water and surface-water studies. Downstream from the losing reach, ground water discharges to the stream and samples of ground water, including a sample from a spring (SP-CH-42), contained concentrations of lithium and boron that were above background levels. Ground water with unnaturally high concentrations of lithium and boron discharged to, and thus contributed lithium to, streamwater in Valley Creek east of the lithium-processing facility near Planebrook (Sloto, 1987). The lithium infiltrated to the ground-water system from an unlined quarry that received wastewater. The ground-water divide between the Valley Creek and West Valley Creek Basins is beneath the lithium-processing facility.

The area of ground-water discharge near the confluence of the tributary with site WVC-3 and the mainstem of West Valley Creek is downgradient from both the lithium-processing facility near Planebrook and the AIW Frank NPL Superfund site where VOC's have been detected in ground water. In addition to concentrations of lithium greater than background levels, VOC's were detected in a spring sample (CH-SP-42) downgradient from these sites. Although lithium may reenter the stream in ground-water discharge and persist, VOC's are not likely to remain in the stream because of volatilization. A stream sample from the area of ground-water discharge did not contain concentrations of VOC's above the detection level of 0.2 μg/L.

A comparison of lithium and chloride stream loads (fig. 38) shows the effect of point and nonpoint anthropogenic sources for these soluble contaminants. Most lithium in the basin is derived from point sources (two lithium-processing facilities), and most chloride is derived from nonpoint sources (road salt, fertilizers, and septic systems). Lithium and chloride are relatively conservative ions, although lithium may sorb onto sediments. Loads were determined by multiplying measured discharge and concentration at mainstem sites. Calculated discharges and loads at mainstem sites were estimated by adding discharge and loads in tributaries to those at the nearest upstream mainstem site. Loads are only estimates because of the cumulative error (up to about 15 percent) related to the discharge measurement, chemical analysis, and different times of sampling.

The stream loads of chloride generally increase downstream (fig. 38) because of the regional distribution of these ions in ground water that discharges to the stream. The load of lithium generally decreases in the mainstem downstream of site WVC-2 until site WVC-9 (fig. 38) because lithium is contributed primarily from one point source that is upstream of one or more losing reaches of Valley Creek. Above the upper mainstem sites WVC-5 and WVC-6, some loss of streamflow and mass (chloride and lithium load) to the ground-water system takes place. Thus, lithium moves from the stream to the ground-water system; lithium that is not sorbed onto stream sediments or aquifer materials should eventually return to the surface-water system in ground-water discharge. Downstream from site WVC-9, changes in lithium load are small. Increases in the stream load of lithium between sites WVC-9 and WVC-11 may be caused by addition of lithium in the ground water and a tributary (WVC-10) downgradient from the lithium-processing facility near Exton. Losses in the lithium load between sites WVC-11 and WVC-13 may be caused by quarry withdrawals or stream losses just before the stream leaves the carbonate valley.

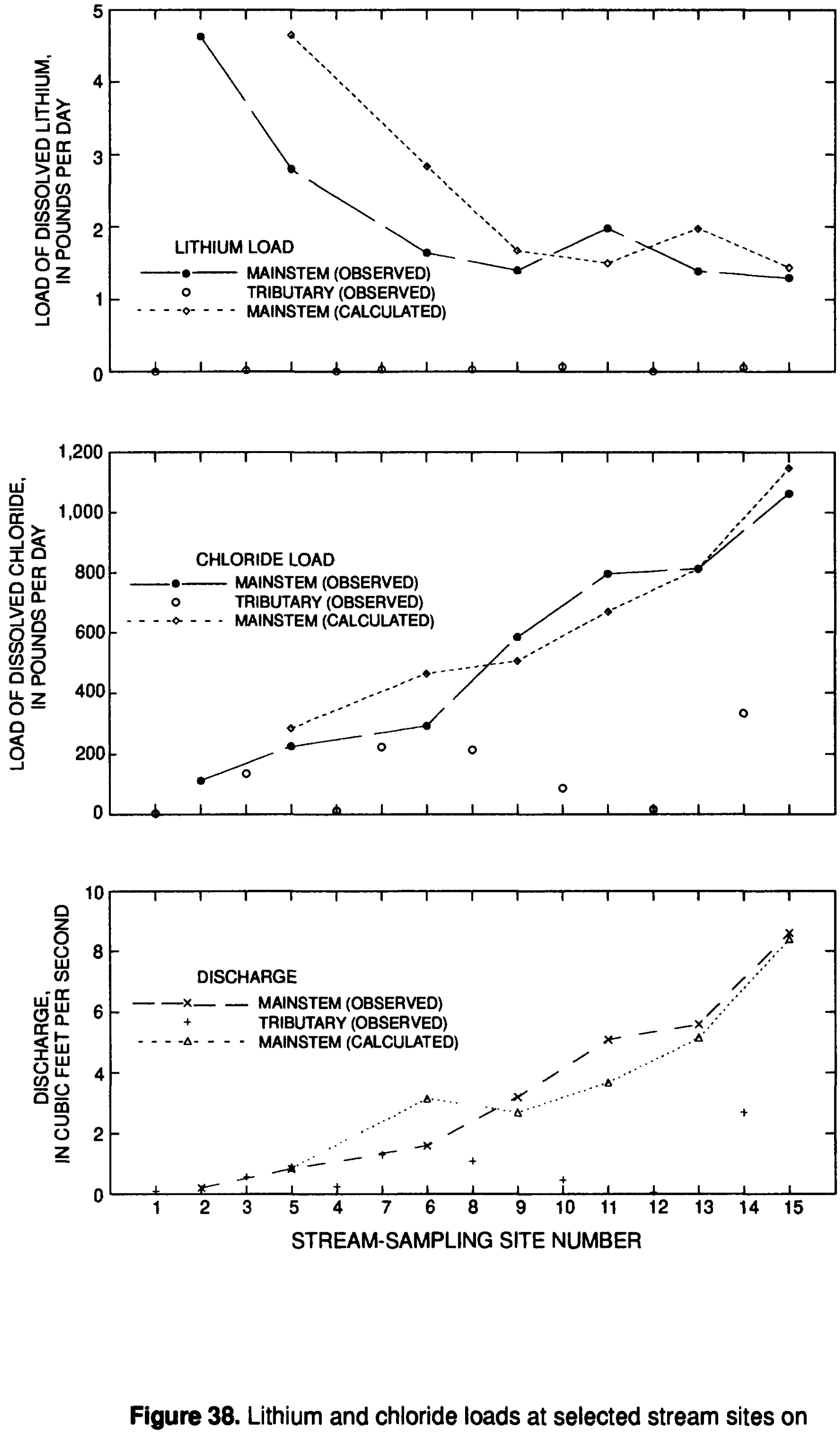


Figure 38. Lithium and chloride loads at selected stream sites on West Valley Creek, Pennsylvania, September 5-6, 1990.

The lithium isotopic signature was used as a tracer to further investigate the relation between ground water and surface water in the West Valley Creek Basin. Lithium is a light alkaline element that with two natural isotopes, lithium-6, (^{6} Li, atomic mass of 6.01697), and lithium-7 (^{7}Li, atomic mass of 7.01822). The natural abundance of these two isotopes determines the atomic mass of lithium, 6.94. Discharge from lithium-processing facilities and sewage contains lithium with isotopic ratios different from natural lithium isotopic ratios in the West Valley Creek Basin. Stream samples collected in July and October 1991, when the lithium-processing facility was still discharging wastewater, a quarry sump sample, and ground-water samples from wells in carbonate rocks were analyzed for the two isotopes of lithium (table 23). Stream samples from sites WVC-1, WVC-3, WVC-18 and WVC-20 and the ground-water sample from well CH-2723 probably represent background concentrations of lithium (less than 10 μg/L) and lithium isotopic ratios (about 12) (table 23).

Table 23. *Lithium isotopic ratios and lithium concentrations in surface water and ground water, West Valley Creek Basin, Pennsylvania. Surface-water sites listed in general downstream order for mainstem and tributaries. Location of sites shown on figure 23.*

[Li, lithium; δ, delta; per mil, parts per thousand; μg/L, micrograms per liter; lbs/day, pounds per day; NA, not applicable; <, less than]

Stream site or well number	Date of sample	Mass ratio ^{7}Li / ^{6}Li	[a] δ^7Li (per mil)	Li concentration (μg/L)	Li load (lbs/day)
Surface water					
Sampling site number					
Mainstem					
WVC-2	7-10-91	15.6603	286	4,800	7.23
WVC-5	7-11-91	15.4229	266	490	1.69
WVC-6	7-11-91	15.4439	268	170	1.10
WVC-9	7-11-91	15.4559	269	90	.97
WVC-11	7-09-91	15.4499	268	160	3.10
WVC-13	7-09-91	15.1987	248	70	.90
WVC-15	7-12-91	14.8690	221	20	.83
Tributaries					
WVC-1	7-10-91	11.9234	-21	<10	<.01
WVC-3	7-10-91	12.2120	3	<10	<.02
WVC-20	10-07-91	11.9508	-19	<10	<.01
WVC-4	7-10-91	14.1617	163	<10	<.01
WVC-7	7-09-91	12.4536	22	<10	<.02
WVC-8	7-09-91	12.7235	45	<10	<.05
WVC-17	10-04-91	12.3417	13	<10	<.02
WVC-16	10-04-91	12.3181	11	<10	<.03
WVC-10	7-11-91	13.9755	147	40	.07
WVC-12	7-09-91	13.1056	76	<10	<.01
WVC-18	10-05-91	12.1261	-4	<10	<.03
WVC-19	10-05-91	13.3443	96	<10	<.09
WVC-14	7-12-91	13.6260	119	<10	<.65
Ground water					
Local well number					
CH-2723	9-11-91	12.1472	-3	7	NA
CH-2725	9-05-91	12.5859	33	5	NA
CH-2730	9-11-91	16.4935	354	37	NA
CH-2742	9-12-91	12.6828	41	5	NA
CH-4129	9-09-91	12.2643	7	7	NA
quarry sump	11-4-91	12.2429	5	6	NA

[a] Delta is the deviation in mass ratio determined relative to a standard mass ratio of 12.18 for ^{7}Li / ^{6}Li; delta expressed in parts per thousand.

Stream samples from the mainstem downstream from the lithium-processing facility near Planebrook were relatively enriched in lithium-7 (Bullen and Senior, 1992). The samples were collected during several days in July, when the concentrations of lithium in the discharges from the lithium-processing facility could have varied. Nevertheless, the isotopic signature remained nearly constant from site WVC-2 downstream to site WVC-11, indicating little or no isotopic fractionation of the lithium in the stream and little dilution from natural lithium in ground-water and surface-water inflow (table 23). The lithium load and the lithium-7/lithium-6 mass ratio in the stream decreased slightly between sites WVC-2 and WVC-5 because of stream losses (losing reach), and between sites WVC-11 and WVC-13 because of quarry withdrawals of streamwater. A sample of the quarry-sump water did not contain concentrations of lithium greater than background and was not enriched in lithium-7, indicating that ground-water pumping for quarry operations does not induce significant recharge from streamflow. Downgradient from the lithium-processing facility near Exton, lithium-7 was enriched relative to background in samples from stream site WVC-10 and in ground-water samples from wells CH-2725 and CH-2730 near site WVC-10 that contained slightly elevated to near background concentrations of lithium. The lithium isotopic signature can be used to trace the path of lithium through the ground-water and surface-water systems even at concentrations of lithium below background levels.

Stream samples collected at sites WVC-4, WVC-8, and WVC-14 also contained relatively more lithium-7 than background and appear to derive their lithium isotopic ratio from anthropogenic sources that could include sewage or industrial effluent. Site WVC-4 is on a tributary that drains an agricultural and residential area and also is downgradient from the losing reach below site WVC-2. Ground water discharges to the tributary between sites WVC-20, where enrichment of lithium-7 is absent, and site WVC-4. The lithium isotopic signature at site WVC-4 may be caused by lithium in discharge from the lithium-processing facility or possibly by a leaking sewer line. Samples from this site contain concentrations of nitrate greater than natural background that are probably related to agricultural activities, but could be related to sewage effluent. Site WVC-8 is on a tributary that receives sewage treatment effluent. Site WVC-14 is on Broad Run, which drains a subbasin partially served by regional sewer lines. Enriched lithium-7 was measured downstream (at site WVC-19) but not upstream (at site WVC-18) from the sewage pumping station. Ground water underlying the Broad Run subbasin was not enriched in lithium-7, suggesting that the sewer line may be leaking into the stream.

SUMMARY

The West Valley Creek Basin drains 20.9 mi^2 in the Piedmont Physiographic Province of southeastern Pennsylvania and is partly underlain by carbonate rocks that are highly productive aquifers. The basin is undergoing rapid urbanization as part of development along U.S. Route 30 and Pennsylvania State Route 100. Ground water is the sole source of supply in the basin, and West Valley Creek, although relatively small, is of recreational value and is designated a cold-water fishery by PaDER.

West Valley Creek flows through a valley underlain by Paleozoic carbonate rocks. The 1.5-mi-wide valley trends east-northeast, parallel to regional geologic structures. The valley is flanked by hills underlain by Paleozoic quartzite and Precambrian gneiss to the north and Paleozoic phyllite and schist to the south. The structure of rocks in the valley is complex and overall is a south-dipping faulted syncline.

Surface-water and ground-water flow from the hills toward the center of the valley. Ground water in the valley flows west-southwest parallel to the course of the stream. Seepage investigations identified losing reaches in the headwaters underlain by carbonate rocks and gaining reaches downstream. Tributaries contribute about 75 percent of streamflow. Springs discharge at the edges of the valley at contacts between different carbonate units. The ground-water and surface-water divides do not coincide in the carbonate valley. The ground-water divide is about 0.5 mi west of the surface water divide at the eastern edge in the carbonate valley. Underflow to the east is about 1.1 in. per year. Quarry dewatering at the western edge may act partly as an artificial basin boundary, preventing underflow to the west.

Water budgets for 1990, a year of normal precipitation (45.8 in.) and 1991, a year of sub-normal precipitation (41.5 in.) were calculated. Streamflow was 14.61 in. in 1990 and 12.08 in. in 1991. Evapotranspiration was estimated to range from 50 to 60 percent of precipitation. Base flow was about 62 percent of streamflow in both years. Sewer systems exported about 3 in. of water from the basin; at times in the dry autumn of 1991, export by sewer systems equaled base flow.

Ground-water quality in the basin reflects differences in lithology and has been affected by human activities. Regional contamination by chloride and nitrate and local contamination by organic compounds and metals is present. Ground water in the carbonate rocks has near neutral pH and contains more dissolved solids than ground water in the noncarbonate rocks, which has a moderately acidic to acidic pH. Ground water in unsewered areas and agricultural areas has the greatest median concentration of nitrate. Ground water in the carbonate rocks of the urbanized valley contains greater concentrations of chloride than ground water in noncarbonate rocks in the residential areas in the hills; road salt is the probable main source of chloride concentrations elevated above natural background levels. Organic solvents, such as TCE, were detected in 30 percent of the well samples in the carbonate valley. Low concentrations (10 μg/L or less) of beryllium, chromium, lead, and mercury were detected in a few ground-water samples from the carbonate aquifer. Two sites in the basin are listed on the USEPA National Priority List (NPL) and are underlain by ground water contaminated by organic solvents and metals. Lithium concentrations up to 37 μg/L were measured in ground-water samples.

Base-flow quality of West Valley Creek was determined monthly at 15 sites from August 1990-July 1991. Temporal changes in concentrations of dissolved oxygen were inversely related to seasonal changes in temperature; concentrations of dissolved oxygen ranged from 5.7 to 17.1 mg/L. The concentrations of most chemical constituents were not consistently related to discharge, although at many sites alkalinity was inversely related to discharge. Chloride concentrations increased slightly in stream samples from most sites during the late winter, possibly because of road-salt applications. Base-flow quality of the mainstem of West Valley Creek was affected by discharge from a lithium-processing facility. Because discharges from anthropogenic sources can change the quality of streamwater, base-flow quality in the mainstem determined during the study when the lithium-processing wastewater was discharged may not be comparable to water quality after the discharge was discontinued.

Differences in stream quality at the 15 sites reflect differences in underlying lithology, land use, and point sources in tributary subbasins and mainstem reaches. Stream chemistry in the mainstem is dominated by ground water from carbonate rocks. Tributaries in the valley that drain quartzite, phyllite,

schist, and gneiss retain some chemical signatures of their origin in these noncarbonate rocks, such as lower pH and higher concentrations of silica than samples from the mainstem in the carbonate valley. Elevated concentrations of nitrate (ranging from 3 to 6 mg/L as N) in base flow were measured in a tributary draining agricultural land and in a tributary draining an unsewered residential area. Elevated phosphorus was measured in a stream that receives treated sewage effluent. Quarry dewatering may cause increases in concentrations of sulfate downstream from the quarry discharge point. Concentrations of chloride at most stream sites (medians ranged from 8 to 89 mg/L) are greater than background concentrations (less than 3 mg/L) contributed by precipitation to the basin, indicating anthropogenic sources of chloride throughout the basin.

The diversity index of the benthic invertebrate community increased from 1973 to 1980 at the long-term biological monitoring site on West Valley Creek, indicating an improvement in streamwater quality. The improvement indicated by the benthic diversity index probably is related to controls on discharges and banning of pesticides, such as DDT, in the 1970's. Concentrations of dissolved constituents, except for chloride, determined for base flow in the autumn do not appear to have changed since 1971. The seasonal Kendall test for trend indicates that concentrations of chloride have increased since 1971; this increase may be related to the increase in urbanization in the basin. The benthic community structure at the West Valley Creek site in 1991 suggests slight nutrient enrichment. West Valley Creek has a slightly stressed biological community, similar to other small, urbanized basins in Chester County.

Lithium was detected in ground water and surface water downgradient from two lithium-processing facilities. Lithium was discharged until 1991 into a losing reach of West Valley Creek, thus introducing lithium into the ground-water system. The potential for cross-contamination between ground- and surface-water systems is indicated by the presence of lithium in the ground water and surface water downgradient and downstream from two lithium-processing facilities. The lithium that was discharged into the stream behaves like a conservative tracer, maintaining a mass balance and characteristic isotopic signature for gaining reaches of West Valley Creek. Lithium-7/lithium-6 ratios were greater than natural background lithium isotopic ratios in streams that are affected by sewage and by discharge of lithium processing wastes and in ground water downgradient from the lithium-processing facilities. The lithium isotopic signature is a tracer of ground-water and surface-water pathways even for low concentrations of lithium.

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Table 24. Record of selected wells and springs, West Valley Creek Basin, Pennsylvania

U.S. Geological Survey (USGS) well or spring number: Springs are designated by the prefix SP; all other numbers refer to wells.

Township or borough: Name refers to township unless noted as Boro for Borough.

Driller license number: 0084, McElhaney and Griffiths; 0154, Leroy Myers; 0188, C.S. Garber and Sons, Inc.; 0208, C.D. Baird; 0248, Thomas G. Keyes; 0249, Ridpath and Potter Company, Inc.; 0308, Petersheim Bros.; 0413, Rulon and Cook; 0503, J.F. Alexander & Co.; 0514, F.L. Bollinger and Sons; 0561, Kohl Bros., Inc.; 0904, Brookover Well Drilling Co.; 0909, Calvin E. Powell; 1083, Kenneth L. Madron; 1290, B.L. Myers; 1308, Robert E. Matteson; 1365, Alfred G. Gurley; 1457, Bonnie J. Myers; 1515, John W. Wilwert; 1609, Edward Powell Well Drilling; 1628, B.L. Myers Bros., Inc.

Use of site: U, unused; W, withdrawal; O, observation.

Use of water: C, commercial; H, domestic; I, irrigation; N, industrial; P, public supply; T, institutional; U, unused.

Topographic setting: F, flat; H, hilltop; S, slope; V, valley.

Hydrogeologic unit codes: 300WSCKA, Octoraro Phyllite; 300WSCKO, Wissahickon Formation; 300PRCK, Peters Creek Schist; 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377VNTG, Vintage Dolomite; 377ANTM, Antietam Quartzite; 377HRPR, Harpers Phyllite; 377CCKS, Chickies Quartzite; 377HRDS, Hardyston Quartzite; 400FCIGA, Felsic and intermediate gneiss, amphibolite facies.

Altitude of land surface is estimated from topographic maps. Datum is sea level.

Water level is in feet below land surface.

[–, no data]

Table 24. *Record of selected wells and springs, West Valley Creek Basin, Pennsylvania*

USGS well or spring number	Location		Township or borough	Owner	Driller license number	Year drilled	Primary		Elevation of land surface	Topo-graphic setting
	Latitude (degrees)	Longitude (degrees)					Use of site	Use of water		
CH-6	400045	0754130	Dowingtown Boro	Englerth, J	--	--	U	H	270	V
81	400124	0753820	W Whiteland Twp	Metropolitan Communications	0904	1981	W	C	300	V
82	395927	0754055	E Bradford Twp	Long, Bill	1628	1985	W	H	465	H
249	400103	0753901	W Whiteland Twp	Uwchlan Twp Mun Auth	0249	1986	W	P	267	S
262	400242	0753806	Uwchlan Twp	Uwchlan Twp Mun Auth	0514	1965	U	U	480	S
263	400116	0754042	E Caln Twp	Uwchlan Twp Mun Auth	0248	1957	W	P	305	S
264	400116	0754043	East Caln Twp	Uwchlan Twp Mun Auth	0248	1959	W	P	310	S
307	400124	0753741	W Whiteland Twp	Foote Mineral Co	0248	1958	U	N	340	V
308	400116	0753743	W Whiteland Twp	Foote Mineral Co	0248	1958	U	N	323	V
341	395920	0753705	West Goshen Twp	Chubbs, James	--	--	W	H	470	S
1093	400225	0753814	W Whiteland Twp	Mattioni, Amberto	1365	--	W	H	450	S
1213	400224	0754055	Uwchlan Twp	Fetteroft, Ken	0248	1971	W	H	615	S
1217	400216	0754056	Uwchlan Twp	Copp, Karen	0248	1972	W	H	555	S
1228	400211	0753827	W Whiteland Twp	Uwchlan Twp Mun Auth	0514	1968	W	P	360	S
1298	400214	0753819	W Whiteland Twp	Uwchlan Twp Mun Auth	0514	1968	W	P	349	S
1315	400205	0753723	W Whiteland Twp	West Whiteland Twp	0248	1952	W	P	340	S
1316	400205	0753721	W Whiteland Twp	West Whiteland Twp	--	1953	W	P	340	S
1449	395956	0753747	W Whiteland Twp	Philadelphia Suburban WC	0248	1966	W	P	368	V
1451	400036	0753601	W Whiteland Twp	Philadelphia Suburban WC	0248	1961	W	P	515	V
1452	400040	0753534	W Whiteland Twp	Philadelphia Suburban WC	0248	1962	W	P	532	S
1716	400019	0753651	W Whiteland Twp	Philadelphia Suburban WC	0248	1973	W	P	440	V
1981	400126	0753419	E Whiteland Twp	Mushroom Cooperative	0904	1967	W	H	570	S
2143	400210	0753509	E Whiteland Twp	Philadelphia Electric Co	0248	1967	W	H	390	V
2161	400118	0753832	W Whiteland Twp	Wick's Lumber and Supply	0904	1968	W	C	289	V
2279	395916	0753819	West Goshen Twp	Comp, Leroy	0904	1973	W	H	305	V
2308	400049	0753249	East Goshen Twp	Kelly, Andrew	0904	1966	W	H	525	S
2315	400239	0753715	W Whiteland Twp	Church Farm School	0308	1968	W	H	435	S
2348	400008	0754010	E Caln Twp	General Crushed Stone	0188	1974	W	C	280	S
2412	400129	0753659	W Whiteland Twp	Tabas Enterprises	--	--	W	N	350	V
2422	400130	0753623	W Whiteland Twp	Cockerham, Gilbert	--	--	W	H	410	H
2436	400313	0753655	W Pikeland Twp	Diest, Robert	--	--	W	H	685	S
2453	395847	0753752	West Goshen Twp	Chelland, Michael	--	--	W	H	455	F
2467	395900	0753810	West Goshen Twp	Ellis	--	--	W	H	430	S
2477	400153	0753615	W Whiteland Twp	Gatlas	--	--	W	H	355	F
2495	400117	0753611	W Whiteland Twp	Council, Peg	--	--	W	H	410	--
2496	400145	0753634	W Whiteland Twp	Entenmanns	0248	1976	U	C	350	F
2497	400136	0753855	W Whiteland Twp	Waterloo Gardens	0561	1959	W	I	320	S
2535	400231	0753449	E Whiteland Twp	Gross, Sally	--	--	O	H	362	F
2669	400142	0753911	W Whiteland	Uwchlan Twp Mun Auth	0413	1979	W	P	338	S
2670	400145	0753912	W Whiteland Twp	Uwchlan Twp Mun Auth	0413	1978	W	P	356	S
2674	400147	0753631	W Whiteland Twp	Sts Phillip & John Church	--	--	W	H	355	--
2716	400022	0754027	E Caln Twp	T's Pub Inc	0904	1966	U	C	355	S
2721	400137	0753902	W Whiteland Twp	Waterloo Gardens	0248	1982	U	I	315	V
2723	400103	0753958	E Caln Twp	Parke, Caroline	--	--	W	H	340	V
2724	400033	0754009	E Caln Twp	General Crushed Stone	0188	1973	W	C	278	V

***Table 24.** Record of selected wells and springs, West Valley Creek Basin, Pennsylvania—Continued*

Hydro-geologic unit	Depth of well (feet)	Casing: Depth (feet)	Casing: Diameter (inches)	Depth of water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Measured yield: Specific capacity [(gal/min)/ft]	Measured yield: Discharge (gal/min)	Measured yield: Pumping period (hours)	USGS well or spring number
377LDGR	21	--	--	--	18.00	08-01-51	--	--	--	--	CH-6
367CNSG	145	22	6	--	56.30	07-07-86	--	--	--	--	81
300WSCKA	--	--	--	--	--	--	--	--	--	--	82
377LDGR	600	--	--	--	--	--	100	--	--	--	249
377CCKS	490	40	8	--	--	--	17	--	--	--	262
377LDGR	200	172	8	--	27.00	01-01-74	--	7.1	400	48.0	263
377LDGR	186	120	8	--	27.00	02-01-74	--	80	400	48.0	264
367CNSG	139	24	6	--	--	--	100	--	--	--	307
367CNSG	253	74	--	--	16.00	01-01-58	--	.05	10	--	308
300WSCKO	135	--	--	100	--	--	20	--	--	--	341
377CCKS	150	43	6	118/126	59.80	06-26-87	--	.33	5	.7	1093
377CCKS	70	40	6	53	29.00	01-01-74	--	.44	15	1.0	1213
377CCKS	120	75	6	50	18.00	02-01-74	--	.14	15	1.0	1217
377LDGR	410	81	14	--	22.00	07-01-71	--	66	1120	--	1228
377LDGR	300	83	12	--	13.00	06-01-73	--	56	725	48.0	1298
377LDGR	107	90	8	--	22.00	11-01-52	--	25	200	48.0	1315
377LDGR	85	74	8	--	22.00	09-01-53	--	15	150	8.0	1316
300WSCKA	360	52	8	--	2.50	06-02-66	--	2.3	191	73.0	1449
300WSCKA	314	61	10	--	4.78	06-24-74	--	.57	85	48.0	1451
300WSCKA	300	62	8	--	14.00	11-19-62	--	2.6	230	48.0	1452
300WSCKO	237	60	8	--	5.00	02-28-73	--	2.2	250	--	1716
300WSCKA	240	20	6	67/227	38.00	12-09-67	--	.07	2	4.0	1981
367CNSG	290	216	8	223	49.50	09-26-83	--	.01	2	40.0	2143
377LDGR	97	37	6	30/ 67/ 88	12.00	11-01-68	--	.07	5	3.0	2161
300PRCK	145	24	7	68/124/134	28.00	02-22-73	--	.08	8	2.0	2279
300WSCKO	128	40	6	66/112	37.00	10-11-66	--	.32	12	3.0	2308
377CCKS	175	154	6	155	35.00	05-20-68	50	--	--	--	2315
377LDGR	100	48	7	--	25.30	06-07-84	--	.50	100	1.0	2348
367CNSG	--	--	--	--	6.73	06-15-84	--	--	--	--	2412
367CNSG	130	--	--	--	40.00	01-01-83	--	--	--	--	2422
377CCKS	--	--	--	--	--	--	--	--	--	--	2436
300WSCKO	--	--	--	--	--	--	--	--	--	--	2453
300WSCKO	--	--	--	--	--	--	--	--	--	--	2467
367CNSG	--	--	--	--	--	--	--	--	--	--	2477
300WSCKA	--	--	--	--	--	--	--	--	--	--	2495
367CNSG	170	40	6	145/150	10.00	05-14-76	--	.38	60	1.0	2496
377LDGR	150	--	--	--	30.00	07-03-84	500	--	--	--	2497
377LDGR	125	--	--	--	54.10	09-22-83	--	--	--	--	2535
377LDGR	600	141	10	--	47.00	03-01-79	--	7.2	203	68	2669
377LDGR	158	128	8	--	61.00	04-05-78	--	24	292	56.0	2670
367CNSG	--	--	--	--	--	--	--	--	--	--	2674
367CNSG	370	48	6	187/321	55.00	06-04-84	--	.01	1	5	2716
377LDGR	197	165	6	190	21.70	06-06-84	--	15	231	48.0	2721
367CNSG	180	--	--	--	29.80	06-06-84	--	--	--	--	2723
377LDGR	100	71	6	--	28.50	06-07-84	--	.33	25	.5	2724

Table 24. _Record of selected wells and springs, West Valley Creek Basin, Pennsylvania—Continued_

USGS well or spring number	Location: Latitude Longitude (degrees)	Township or borough	Owner	Driller license number	Year drilled	Primary: Use of site	Primary: Use of water	Elevation of land surface	Topo-graphic setting
CH- 2725	400058 0753848	E Caln Twp	Magee, James	--	--	W	H	280	V
2730	400108 0753825	W Whiteland Twp	Precision Craft	0904	1979	W	C	298	V
2735	400132 0753735	W Whiteland Twp	Roberts, George	0084	1978	U	H	345	S
2739	400153 0753535	W Whiteland Twp	Church Farm School	--	1919	W	T	410	V
2740	400153 0753535	W Whiteland Twp	Church Farm School	--	1919	W	T	410	V
2742	400227 0753613	W Whiteland Twp	Church Farm School	--	--	W	H	340	--
2743	400224 0753705	W Whiteland Twp	Church Farm School	--	--	W	H	355	V
2745	400158 0753528	W Whiteland Twp	St Paul's Church	0248	--	W	C	410	S
2746	400200 0753650	W Whiteland Twp	Hedberg, Robert	0248	1977	W	H	330	V
2753	400038 0754011	E Caln Twp	General Crushed Stone	0188	1974	W	C	300	F
2846	400151 0753606	W Whiteland Twp	Cassels, John	--	--	W	H	375	F
2847	400320 0753553	Charlestown Twp	Magargee, Steven	0248	--	W	H	648	S
2968	395948 0753911	East Bradford T	Hobson	0248	--	W	H	515	H
2969	395949 0753908	East Bradford T	Hobson	0904	--	W	H	515	H
3085	395927 0754049	E Bradford Twp	Obin, Andrew	1628	1985	W	H	470	H
3087	400325 0753555	Charlestown Twp	Sorgenfrei, Mal	1609	1983	W	H	705	H
3088	400305 0753651	Charlestown Twp	Wallin, Mark	1628	1986	W	H	680	H
3111	400315 0753540	E Whiteland Twp	Wiley, Frank	0904	1982	W	H	570	S
3136	400318 0753526	E Whiteland Twp	Turner, Thomas	0248	--	W	H	465	S
3362	400220 0753647	W Whiteland Twp	Church Farm School	--	--	W	H	350	S
3363	400156 0753629	W Whiteland Twp	Church Farm School	--	--	W	H	335	V
3551	400228 0753544	W Whiteland Twp	Church Farm School	--	--	W	H	381	S
3719	400214 0753912	W Whiteland Twp	Palladino, Bob	--	--	W	H	530	S
3916	400241 0753741	W Whiteland Twp	Waters, Albert	0909	1975	U	U	520	H
3917	400239 0753921	Uwchlan Twp	Bauer, Edwin	--	--	U	U	588	S
3918	395947 0753913	E Bradford Twp	Wallace, Pat	0904	1977	U	U	510	H
3919	400038 0753628	W Whiteland Twp	Devereux School	--	--	U	U	585	H
3920	400032 0753642	W Whiteland Twp	Devereux School	--	--	U	U	542	S
3922	400259 0753531	E Whiteland Twp	Eastman Pharmaceutical	0188	1987	O	U	390	S
3924	400245 0753522	E Whiteland Twp	Eastman Pharmaceutical	0188	1987	O	U	390	S
3926	400233 0753556	W Whiteland Twp	Eastman Pharmaceutical	0188	1987	O	U	350	S
3927	400240 0753600	W Whiteland Twp	Eastman Pharmaceutical	0188	1987	O	U	361	S
3928	400120 0753953	W Whiteland Twp	Mccahon	--	--	U	U	303	V
3930	400205 0753458	E Whiteland Twp	Sheraton	--	--	W	--	425	S
3931	400105 0753958	East Caln Twp	Parke	--	1941	O	U	361	H
4129	400026 0754009	East Caln Twp	HighWay Materials	--	1961	W	H	275	S
4147	400142 0753814	W Whiteland Twp	West Whiteland Township	0180	1990	U	P	293	V
4148	395909 0753847	E Bradford Twp	Johnson, Ralph	0960	--	W	H	265	V
4149	400147 0753857	W Whiteland Twp	Whitford Flowers	--	1929	W	I	340	S
4166	400152 0753608	E Whiteland Twp	AIW/Frank	--	--	U	N	370	V
4292	400106 0753815	W Whiteland Twp	Packaging Accessories Co	--	1985	W	H	315	V
4293	400113 0753827	W Whiteland Twp	Ludwick, Robert	--	--	W	H	290	V
SP-42	400157 0753640	W Whiteland Twp	Carville, John	--	--	W	H	325	V
SP-45	400255 0753619	W Whiteland Twp	Church Farm School	--	--	W	H	416	V
SP- 6	400325 0753525	E Whiteland Twp	Manning-smith, P	--	--	--	--		S

Table 24. *Record of selected wells and springs, West Valley Creek Basin, Pennsylvania—Continued*

Hydro-geologic unit	Depth of well (feet)	Casing Depth (feet)	Casing Diameter (inches)	Depth of water-bearing zone(s) (feet)	Water level (feet)	Date water level measured	Reported yield (gal/min)	Measured yield Specific capacity [(gal/min)/ft]	Measured yield Discharge (gal/min)	Measured yield Pumping period (hours)	USGS well or spring number
367CNSG	40	--	--	--	5.60	06-07-84	--	--	--	--	CH- 2725
377LDGR	43	27	6	33/ 38	7.58	06-08-84	--	6.0	60	4.5	2730
367CNSG	376	22	6	--	23.30	06-11-84	<1	--	--	--	2735
367CNSG	150	--	--	--	17.60	06-12-84	--	--	--	--	2739
367CNSG	150	--	--	--	--	--	--	--	--	--	2740
377LDGR	--	--	--	--	3.60	06-12-84	--	--	--	--	2742
377LDGR	--	--	--	--	18.80	06-12-84	--	--	--	--	2743
367CNSG	--	--	--	--	19.00	06-12-84	1	--	--	--	2745
377LDGR	220	40	6	53/210	18.20	06-12-84	--	.17	30	1	2746
377LDGR	225	47	6	--	25.00	03-19-75	--	--	--	--	2753
367CNSG	--	--	--	--	--	--	--	--	--	--	2846
377CCKS	123	89	6	92/101	60.00	09-05-87	--	.21	15	1	2847
300WSCKA	--	--	--	--	25.20	07-22-87	--	--	--	--	2968
300WSCKA	--	--	--	--	31.40	07-22-87	--	--	--	--	2969
300WSCKA	230	--	--	--	--	--	--	--	--	--	3085
377CCKS	160	21	6	84/ 95/125/143	47.00	08-13-87	--	.13	10	3	3087
377CCKS	280	168	6	180	49.50	07-08-90	2	--	--	--	3088
377CCKS	146	20	6	133	30.30	08-26-87	--	.08	7	4	3111
377HRPR	200	--	--	--	--	--	--	--	--	--	3136
377LDGR	52	42	--	--	--	--	--	--	--	--	3362
377LDGR	--	--	--	--	--	--	--	--	--	--	3363
377CCKS	--	--	--	--	--	--	--	--	--	--	3551
377CCKS	--	--	--	--	--	--	--	--	--	--	3719
377CCKS	305	150	6	--	12.00	12-29-89	--	--	--	--	3916
400FCIGA	24	--	--	--	14.00	01-02-90	--	--	--	--	3917
300WSCKA	207	21	0	128/188	27.50	12-14-89	--	.02	3	4.0	3918
300WSCKA	--	--	--	--	35.80	01-05-90	--	--	--	--	3919
300WSCKA	--	--	--	--	45.90	01-05-90	--	--	--	--	3920
377ANTM	79	59	4	59	55.20	08-07-90	--	--	--	--	3922
377LDGR	85	65	4	65/ 85	63.10	08-07-90	3	--	--	1.0	3924
377LDGR	50	37	0	34/ 37	9.71	05-30-90	--	.20	3	.5	3926
377LDGR	56	43	0	40/ 43	18.90	05-30-90	--	.03	1	.5	3927
377LDGR	34	33	4	--	17.70	01-03-90	--	--	--	--	3928
367CNSG	--	--	--	--	24.50	06-22-90	--	--	--	--	3930
367CNSG	--	--	--	--	19.90	01-02-90	--	--	--	--	3931
367CNSG	54	--	--	--	11.00	09-09-91	--	--	--	--	4129
377LDGR	507	100	8	100/400/490	10.20	09-25-92	--	3.8	275	48	4147
300PRCK	--	--	--	--	--	--	--	--	--	--	4148
377LDGR	136	--	--	--	--	--	--	--	--	--	4149
367CNSG	85	64	6	--	29.4	11-06-92	125	--	--	--	4166
367CNSG	152	--	--	--	27.30	09-28-92	--	--	--	--	4293
377LDGR	--	--	--	--	--	--	--	--	--	--	4293
377LDGR	--	--	--	--	--	--	--	--	--	--	SP-42
377HRPR	--	--	--	--	--	--	--	--	--	3	SP-45
377ANTM	--	--	--	--	--	--	--	--	--	--	SP - 6

Table 25. *Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrologic unit codes: 300PRCK, Peters Creek Schist; 300WSCKA, Octoraro Phyllite; 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377ANTM, Antietam Quartzite; 377CCKS, Chickies Quartzite; 400FCIGA, felsic and intermediate gneiss, amphibolite facies; °C, degrees Celsius: Abbrevations: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; <, less than]

USGS local well or spring number	Hydro-geologic unit	Date	Tempera-ture (°C)	Specific conduc-tance (µS/cm)	Oxygen, dis-solved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint field (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Alkalinity, water whole total incre-mental field (mg/L as $CaCO_3$)
2279	300PRCK	09-08-92	14.5	201	8.7	6.2	--	71	13
4148	300PRCK	10-06-92	13.5	240	2.8	6.7	--	82	37
82	300WSCKA	07-09-86	14.0	55	--	6.3	20	--	--
1451	300WSCKA	06-13-73	--	--	--	7.1	80	80	--
1451	300WSCKA	06-14-83	12.0	340	--	5.9	24	--	--
2453	300WSCKA	06-22-82	14.0	1,030	--	6.3	--	--	--
2495	300WSCKA	06-22-83	11.0	265	--	6.3	40	--	--
3085	300WSCKA	08-06-87	14.0	60	--	5.8	16	--	--
3085	300WSCKA	06-21-88	13.5	60	--	5.8	14	--	--
81	367CNSG	07-07-86	13.5	650	--	7.3	270	--	--
307	367CNSG	06-02-81	12.0	800	--	6.9	--	--	--
307	367CNSG	07-16-91	22.0	670	7.0	6.9	250	300	--
2143	367CNSG	08-17-81	14.0	420	--	7.5	--	--	--
2143	367CNSG	06-01-84	13.5	395	--	7.3	142	--	--
2412	367CNSG	08-26-80	13.0	420	--	8.9	--	--	--
2412	367CNSG	06-24-82	12.0	425	--	7.5	--	--	--
2422	367CNSG	05-26-81	18.0	990	--	6.4	--	--	--
2477	367CNSG	08-03-82	15.0	775	--	7.3	--	--	--
2496	367CNSG	06-22-83	12.0	555	--	7.1	220	--	--
2674	367CNSG	08-06-85	12.5	925	--	6.8	274	360	--
2723	367CNSG	09-11-91	13.5	855	8.4	7.2	240	330	--
2725	367CNSG	09-05-91	14.0	500	4.6	7.5	188	230	--
2740	367CNSG	06-27-88	12.5	440	1.0	7.1	162	--	--
2740	367CNSG	07-12-89	15.5	472	5.6	7.3	162	--	--
2745	367CNSG	07-07-86	14.5	430	--	6.9	204	--	--
2846	367CNSG	09-05-85	21.0	535	--	7.5	224	270	--
4129	367CNSG	09-09-91	15.0	805	3.8	7.0	348	430	--
4293	377LDGR	09-28-92	16.0	498	3.2	7.1	--	260	224
SP-6	377ANTM	04-08-65	1.5	32	--	5.5	5	8	--
262	377CCKS	02-13-73	--	--	--	7.9	126	120	--
1093	377CCKS	06-26-87	13.0	193	8.0	5.6	11	33	--
1213	377CCKS	07-02-87	12.5	203	7.3	5.3	27	61	--
2315	377CCKS	08-08-89	17.5	84	8.7	6.0	3	--	--
2436	377CCKS	06-10-81	12.0	85	--	4.5	--	--	--
2436	377CCKS	08-23-85	13.0	78	--	4.6	2	32	--

Table 25. *Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well or spring number	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
2279	35	5.7	<0.10	9.5	--	6	2
4148	27	16	<.10	13	--	<10	<10
82	2.8	1.2	--	--	--	20	10
1451	23	30	<.10	--	--	<10	<10
1451	--	--	--	--	--	--	--
2453	--	--	--	--	--	44	8,700
2495	--	--	--	--	--	25	3
3085	4.2	5.0	--	--	--	13	320
3085	4.1	4.3	--	--	--	--	--
81	41	66	--	--	--	--	--
307	--	--	--	--	--	10	2
307	52	31	.10	8.8	--	8	3
2143	--	--	--	--	--	<10	2
2143	--	--	--	--	--	--	--
2412	--	--	--	--	--	10	10
2412	--	--	--	--	--	<3	2
2422	--	--	--	--	--	10	30
2477	--	--	--	--	--	4	9
2496	--	--	--	--	--	9	2
2674	110	42	--	--	--	--	--
2723	46	66	.20	11	--	7	1
2725	22	22	.10	7.9	--	<3	2
2740	16	37	--	--	--	--	--
2740	17	37	--	--	--	4	2
2745	14	28	--	--	--	--	--
2846	33	20	--	--	--	--	--
4129	28	62	<.10	15	--	13	2
4293	19	22	.10	8.7	--	5	2
SP-6	4.0	1.4	0	7.6	--	100	0
262	4.0	10	<.10	--	--	180	<10
1093	34	8.3	.10	12	100	16	6
1213	8.7	37	.20	7.0	40	15	79
2315	3.1	<1.0	--	--	--	10	50
2436	--	--	--	--	--	<10	20
2436	4.5	12	--	--	--	--	--

***Table 25.** Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania*—*Continued*

USGS local well or spring number	Nitrogen, ammonia, dis-solved (mg/L as N)	Nitrogen, nitrite, dis-solved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dis-solved (mg/L as N)	Phos-phorus, ortho, dis-solved (mg/L as P)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)
2279	0.020	<0.010	3.50	0.020	17	7.0	4.3	1.0
4148	<.010	<.010	1.90	<.010	21	7.1	8.6	.80
82	.020	<.010	.250	--	--	--	--	--
1451	--	--	--	.030	--	--	--	--
1451	.010	.010	6.20	.010	--	--	--	--
2453	4.20	<.010	7.00	--	--	--	--	--
2495	<.010	<.010	4.40	--	--	--	--	--
3085	--	--	--	--	--	--	--	--
3085	--	--	--	--	--	--	--	--
81	.050	<.010	<.100	--	--	--	--	--
307	.020	<.010	3.20	--	--	--	--	--
307	.020	<.010	3.80	<.010	84	22	22	1.3
2143	.00	.00	1.70	--	--	--	--	--
2143	--	--	--	--	--	--	--	--
2412	.010	.00	2.10	--	--	--	--	--
2412	<.010	<.010	2.30	--	--	--	--	--
2422	.020	.030	6.50	--	--	--	--	--
2477	.020	<.010	4.80	--	--	--	--	--
2496	<.010	<.010	2.50	--	--	--	--	--
2674	--	--	--	--	110	20	52	--
2723	<.010	<.010	3.40	<.010	100	20	29	2.6
2725	--	--	--	--	67	15	11	1.9
2740	--	--	--	--	--	--	--	--
2740	.020	<.010	4.50	--	--	--	--	--
2745	.030	<.010	3.40	--	--	--	--	--
2846	--	--	--	--	75	21	8.3	--
4129	<.010	<.010	4.00	<.010	130	25	14	2.6
4293	.010	<.010	2.00	.020	77	16	15	--
SP-6	--	--	--	--	1.6	1.0	2.5	.50
262	--	--	--	.030	--	--	--	--
1093	--	--	--	--	5.4	4.7	19	3.7
1213	--	--	--	--	8.0	10	2.2	11
2315	.020	<.010	3.30	--	--	--	--	--
2436	.040	.010	.820	--	--	--	--	--
2436	.020	<.010	1.60	--	8.5	2.7	6.4	--

Table 25. *Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well or spring number	Hydro-geologic unit	Date	Tempera-ture (°C)	Specific conduc-tance (µS/cm)	Oxygen, dis-solved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint field (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Alkalinity, water whole total incre-mental field (mg/L as $CaCO_3$)
2436	377CCKS	07-15-86	13.0	75	--	5.3	3	--	--
2847	377CCKS	09-05-87	12.0	49	8.0	4.8	5	11	--
3111	377CCKS	08-26-87	12.0	36	--	4.9	6	7	--
3551	377CCKS	09-05-89	13.0	33	1.2	5.3	14	--	--
SP- 42	377LDGR	08-27-90	15.0	725	3.5	7.0	248	320	--
249	377LDGR	08-25-87	13.0	380	1.0	7.8	134	190	--
263	377LDGR	04-14-71	--	--	--	7.9	126	130	--
264	377LDGR	04-14-71	--	--	--	7.9	129	130	--
1315	377LDGR	08-21-74	19.0	--	--	7.7	157	190	--
1315	377LDGR	06-23-83	12.0	440	--	7.3	170	--	--
1315	377LDGR	09-28-92	13.0	403	7.0	7.4	--	180	163
1316	377LDGR	02-14-73	--	--	--	7.6	170	190	--
1316	377LDGR	09-28-92	13.5	459	9.2	7.6	--	210	156
2161	377LDGR	06-27-88	15.0	510	4.8	7.5	208	--	--
2161	377LDGR	09-05-90	14.5	575	3.5	6.8	212	290	--
2348	377LDGR	06-11-80	13.0	700	--	7.2	--	--	--
2348	377LDGR	05-07-81	12.0	850	--	7.1	--	--	--
2348	377LDGR	06-24-88	14.0	850	1.8	7.3	308	--	--
2497	377LDGR	06-22-83	12.5	650	--	7.9	140	--	--
2724	377LDGR	08-31-90	13.0	1,020	.7	6.5	262	510	--
2730	377LDGR	09-11-91	12.5	500	3.6	7.3	206	240	--
2742	377LDGR	09-12-91	13.5	645	7.0	7.5	219	320	--
2743	377LDGR	07-18-89	15.5	290	2.6	7.9	130	--	--
2746	377LDGR	09-09-86	15.5	650	--	7.2	272	320	--
2746	377LDGR	08-30-90	15.0	765	5.0	7.0	278	330	--
2753	377LDGR	08-15-84	16.0	725	--	7.2	230	--	--
3362	377LDGR	07-17-89	17.0	595	8.0	7.4	208	--	--
3363	377LDGR	07-18-89	12.5	780	4.8	7.2	290	--	--
3926	377LDGR	04-25-91	16.5	530	8.6	7.3	209	280	--
4293	377LDGR	09-28-92	16.0	498	3.2	7.1	--	260	224
260	400FCIGA	06-27-73	--	--	--	7.1	53	76	--
261	400FCIGA	02-13-73	--	--	--	7.1	64	74	--

Table 25. *Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania*—*Continued*

USGS local well or spring number	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, total recoverable (μg/L as Fe)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)
2436	–	–	–	–	–	–	–
2847	7.6	0.90	<0.10	9.7	340	73	17
3111	7.1	4.2	<.10	7.3	480	<3	24
3551	2.7	<1.0	–	–	–	87	4
SP-42	57	31	.50	9.8	–	3	3
249	8.6	28	.20	8.6	130	9	8
263	4.0	4.0	.0	–	–	0	0
264	7.0	5.0	.0	–	–	30	0
1315	13	13	.03	–	–	50	<10
1315	–	–	–	–	–	4	14
1315	17	11	<.10	7.6	–	<10	<10
1316	12	18	<.10	–	–	<10	<10
1316	25	18	<.10	7.5	–	<3	1
2161	12	48	–	–	–	–	–
2161	14	46	.20	8.9	–	6	<1
2348	–	–	–	–	–	860	1,900
2348	–	–	–	–	–	50	100
2348	38	130	–	–	–	–	–
2497	–	–	–	–	–	<3	<1
2724	26	240	<.10	9.7	–	16	8
2730	22	18	<.10	6.7	–	7	<1
2742	30	30	<.10	7.6	–	<3	<1
2743	3.3	13	–	–	–	4	<1
2746	49	28	.10	7.7	70	5	3
2746	48	31	<.10	8.0	–	<3	2
2753	–	–	–	–	–	10	40
3362	15	26	–	–	–	14	4
3363	37	26	–	–	–	9	<1
3926	14	27	<.10	6.4	–	<3	<1
4293	19	22	.10	8.7	–	5	2
260	8.2	28	<.10	–	–	770	30
261	9.7	29	<.10	–	–	1,500	20

Table 25. *Physical and chemical properties, and results of chemical analyses for major ions, nutrients, iron, and manganese in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well or spring number	Nitrogen, ammonia, dis-solved (mg/L as N)	Nitrogen, nitrite, dis-solved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dis-solved (mg/L as N)	Phos-phorus, ortho, dis-solved (mg/L as P)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)
2436	--	--	--	--	--	--	--	--
2847	--	--	--	--	1.5	1.8	4.0	2.4
3111	--	--	--	--	1.0	1.2	4.2	1.3
3551	0.010	<0.010	0.980	--	--	--	--	--
SP-42	<.010	<.010	4.10	--	77	30	29	3.3
249	.050	.290	5.00	<0.010	50	16	4.8	2.1
263	--	--	--	--	--	--	--	--
264	--	--	--	.060	--	--	--	--
1315	--	--	--	.030	--	--	--	--
1315	<.010	<.010	3.30	--	--	--	--	--
1315	.010	<.010	4.50	.040	36	23	8.0	1.1
1316	--	--	--	.020	--	--	--	--
1316	<.010	<.010	5.00	.020	42	26	15	1.2
2161	--	--	--	--	--	--	--	--
2161	<.010	<.010	2.80	--	99	11	3.5	1.6
2348	.040	.009	1.30	--	--	--	--	--
2348	.380	.010	3.00	--	--	--	--	--
2348	--	--	--	--	--	--	--	--
2497	<.010	<.010	3.30	--	--	--	--	--
2724	.280	<.010	1.60	--	120	51	26	3.8
2730	--	--	--	--	73	15	12	1.4
2742	<.010	<.010	13.0	<.010	65	38	15	1.1
2743	.010	<.010	.530	--	--	--	--	--
2746	--	--	--	--	64	38	26	3.1
2746	.030	<.010	4.60	--	67	39	26	3.8
2753	.180	<.010	2.20	--	--	--	--	--
3362	.020	<.010	9.70	--	--	--	--	--
3363	.020	<.010	8.50	--	--	--	--	--
3926	<.010	<.010	11.0	<.010	58	33	4.2	1.4
4293	.010	<.010	2.00	.020	77	16	15	--
260	--	--	--	.410	--	--	--	--
261	--	--	--	.030	--	--	--	--

Table 26. *Results of chemical analyses for selected metals and trace constituents in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 300PRCK, Peters Creek Schist; 300WSCKA, Octoraro Phyllite; 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377CCKS, Chickies Quartzite. Abbreviations: mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; <, less than]

USGS local well or spring number	Hydro-geologic unit	Date	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Beryl-lium, dis-solved (µg/L as Be)	Boron, dis-solved (µg/L as B)	Bromide, dis-solved (mg/L as Br)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Cobalt, dis-solved (µg/L as Co)	Copper, dis-solved (µg/L as Cu)
2279	300PRCK	09-08-92	--	--	--	10	--	--	--	--	--
4148	300PRCK	10-06-92	--	--	--	20	--	--	--	--	--
82	300WSCKA	07-09-86	<1	--	--	--	--	<1.0	<10	--	11
2453	300WSCKA	06-22-82	1	--	--	--	--	<1.0	<1	--	62
2495	300WSCKA	06-22-83	3	--	--	--	--	<1.0	8	--	6
3085	300WSCKA	08-06-87	<1	--	--	--	--	<1.0	3	--	17
81	367CNSG	07-07-86	<1	--	--	--	--	<1.0	<10	--	7
307	367CNSG	06-02-81	2	--	--	--	--	1.0	0	--	--
307	367CNSG	07-16-91	<1	--	--	40	--	<1.0	<1	--	14
2143	367CNSG	08-17-81	1	--	--	--	--	<1.0	<1	--	--
2143	367CNSG	06-01-84	--	--	--	--	--	--	--	--	--
2412	367CNSG	08-26-80	1	--	--	--	--	0	6	--	--
2412	367CNSG	06-24-82	1	--	--	--	--	1.0	<1	--	<1
2422	367CNSG	05-26-81	1	--	--	--	--	1.0	0	--	--
2477	367CNSG	08-03-82	1	--	--	--	--	<1.0	<1	--	12
2496	367CNSG	06-22-83	1	--	--	--	--	<1.0	<1	--	12
2723	367CNSG	09-11-91	<1	--	--	20	--	<1.0	<1	--	4
2725	367CNSG	09-05-91	<1	--	--	10	--	<1.0	2	--	6
2740	367CNSG	07-12-89	<1	--	--	--	--	<1.0	<1	--	8
2745	367CNSG	07-07-86	--	--	--	10	--	--	--	--	--
4129	367CNSG	09-09-91	<1	--	--	50	--	<1.0	<1	--	7
4292	367CNSG	09-28-92	--	--	--	<10	--	--	3	--	--
2436	377CCKS	06-10-81	1	--	--	--	--	3.0	0	--	--
3551	377CCKS	09-05-89	<1	--	--	10	--	<1.0	<1	--	64
SP-42	377LDGR	08-27-90	--	--	--	60	0.090	--	2	--	--
1315	377LDGR	06-23-83	<1	--	--	--	--	<1.0	<1	--	2
2161	377LDGR	09-05-90	--	--	--	10	2.0	--	10	--	--
2348	377LDGR	06-11-80	0	--	--	--	--	0	0	--	--
2348	377LDGR	05-07-81	0	--	--	--	--	<1.0	0	--	--
2497	377LDGR	06-22-83	1	--	--	--	--	<1.0	<1	--	4
2724	377LDGR	08-31-90	--	--	--	30	.16	--	<1	--	--
2730	377LDGR	09-11-91	<1	--	--	20	--	<1.0	<1	--	18
2742	377LDGR	09-12-91	<1	--	--	10	--	<1.0	<1	--	4
2743	377LDGR	07-18-89	<1	--	--	--	--	<1.0	<1	--	43
2746	377LDGR	09-09-86	--	27	--	--	--	--	--	--	--
2746	377LDGR	08-30-90	--	--	--	20	.25	--	<1	--	--
2753	377LDGR	08-15-84	<1	--	--	--	--	<1.0	<1	--	6
3362	377LDGR	07-17-89	<1	--	--	--	--	<1.0	<1	--	9
3363	377LDGR	07-18-89	<1	--	--	--	--	<1.0	<1	--	5
3926	377LDGR	04-25-91	<1	--	--	--	--	<1.0	<1	--	<1
4293	377LDGR	09-28-92	<1	32	0.7	40	.070	<1.0	<5	<3	<10

***Table 26.** Results of chemical analyses for selected metals and trace constituents in ground water, West Valley Creek Basin, Pennsylvania—Continued*

Cyanide, total (mg/L as Cn)	Cyanide, dis-solved (mg/L as Cn)	Lead, dis-solved (µg/L as Pb)	Lithium, dis-solved (µg/L as Li)	Mercury, dis-solved (µg/L as Hg)	Molyb-denum, dis-solved (µg/L as Mo)	Nickel, dis-solved (µg/L as Ni)	Sele-nium, dis-solved (µg/L as Se)	Silver, dis-solved (µg/L as Ag)	Stron-tium, dis-solved (µg/L as Sr)	Vana-dium, dis-solved (µg/L as V)	Zinc, dis-solved (µg/L as Zn)	USGS local well or spring number
--	--	--	<4	--	--	--	--	--	100	--	--	2279
--	--	--	<10	--	--	--	--	--	100	--	--	4148
--	--	<5	--	--	--	3	--	--	--	--	--	82
--	<0.01	2	--	0.1	--	14	<1	--	--	--	18	2453
--	<.01	2	--	<.1	--	2	<1	--	--	--	9	2495
--	--	<5	--	--	--	--	--	--	--	--	31	3085
--	--	<5	--	--	--	5	--	--	--	--	--	81
<0.010	--	0	7	.4	--	0	--	--	--	--	--	307
--	--	<1	<4	<.1	--	--	--	--	--	--	24	307
<.010	--	<1	--	<.1	--	3	--	--	--	--	--	2143
--	--	--	10	--	--	--	--	--	--	--	--	2143
.0	--	0	--	.3	--	0	--	--	--	--	--	2412
--	<.01	<1	--	<.1	--	<1	<1	--	--	--	28	2412
<.010	--	0	--	.1	--	0	--	--	--	--	--	2422
--	<.01	6	--	<.1	--	1	1	--	--	--	9	2477
--	.02	2	--	<.1	--	7	1	--	--	--	22	2496
--	--	10	7	<.1	--	--	--	--	--	--	610	2723
--	--	<1	5	<.1	--	--	--	--	--	--	6	2725
--	--	3	--	<.1	--	--	--	--	--	--	62	2740
--	--	--	<10	--	--	--	--	--	--	--	--	2745
--	--	<1	7	<.1	--	--	--	--	--	--	3	4129
--	--	--	<10	--	--	--	--	--	70	--	--	4292
<.010	--	0	--	.2	--	4	--	--	--	--	--	2436
--	--	1	<4	<.1	--	--	--	--	--	--	120	3551
--	--	--	8	--	--	--	--	--	110	--	--	SP-42
--	<.01	5	--	<.1	--	3	<1	--	--	--	6	1315
--	--	--	9	--	--	--	--	--	300	--	--	2161
0	--	0	--	.6	--	0	--	--	--	--	--	2348
<.010	--	0	--	.3	--	3	--	--	--	--	--	2348
--	<.01	2	--	<.1	--	2	<1	--	--	--	31	2497
--	--	--	12	3.0	--	--	--	--	180	--	--	2724
--	--	<1	37	<.1	--	--	--	--	--	--	4	2730
--	--	<1	5	--	--	--	--	--	--	--	42	2742
--	--	1	--	<.1	--	--	--	--	--	--	97	2743
--	--	--	--	--	--	--	--	--	--	--	--	2746
--	--	--	21	--	--	--	--	--	64	--	--	2746
--	<.01	<1	--	.1	--	2	2	--	--	--	20	2753
--	--	1	--	<.1	--	--	--	--	--	--	350	3362
--	--	1	--	<.1	--	--	--	--	--	--	130	3363
--	--	<1	--	<.1	--	--	--	--	--	--	5	3926
--	--	10	7	--	<10	<10	--	<1.0	180	<6	24	4293

Table 27. *Results of radiochemical analyses for radon-222, radium-226, radium-228, uranium, and gross alpha- and beta-particles in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 300PRCK, Peters Creek Schist; 300WSCKA, Octoraro Phyllite; 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377HRPR, Harpers Phyllite; 377CCKS, Chickies Quartzite; 400FCIGA, felsic and intermediate gneiss, amphibolite facies. Abbreviations: pCi/L, picocuries per liter; µg/L, micrograms per liter; <, less than; --, no data]

USGS local well number	Date	Hydro-geologic unit	Radon-222, total (pCi/L)	Uranium, natural, dissolved (µg/L as U)	Radium-226, dissolved, radon method (pCi/L)	Radium-266, dissolved, planchet count (pCi/L)	Radium-228, dissolved (pCi/L as Ra-228)	Gross alpha, dis-solved (pCi/L as U-nat)	Gross alpha, dis-solved (µg/L as U-nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, dissolved (pCi/L as Sr/Yt-90)
2279	09-08-92	300PRCK	3,900	--	--	--	--	--	--	--	--
4148	10-06-92	300PRCK	5,600	--	--	--	--	--	--	--	--
2969	08-31-92	300WSCKA	--	--	--	--	--	--	--	--	--
307	07-16-91	367CNSG	510	--	--	--	--	--	--	--	--
2723	09-11-91	367CNSG	590	--	--	--	--	--	--	--	--
2725	09-05-91	367CNSG	540	--	--	--	--	--	--	--	--
2740	06-27-88	367CNSG	2,054	0.28	0.10	--	<1.0	--	1.3	1.6	1.1
2740	07-12-89	367CNSG	730	--	--	--	--	--	--	--	--
4129	09-09-91	367CNSG	800	--	--	--	--	--	--	--	--
4292	09-28-92	367CNSG	480	--	--	--	--	--	--	--	--
3136	09-08-87	377HRPR	785	<.05	2.9	--	12	6.1	--	16	--
1093	06-26-87	377CCKS	2,993	<.05	<.10	--	<.50	<2.0	--	5.5	--
1213	07-02-87	377CCKS	1,200	.09	2.1	--	2.9	4.3	--	18	--
1217	06-30-87	377CCKS	1,745	<.05	.93	--	.70	1.4	--	3.9	--
2315	08-08-89	377CCKS	18,000	--	--	--	--	--	--	--	--
2436	08-23-85	377CCKS	--	--	--	4.5	9.0	--	22	15	13
2436	07-15-86	377CCKS	416	--	--	--	--	--	--	--	--
2847	09-05-87	377CCKS	3725	.08	.78	--	2.9	1.7	--	6.9	--
3087	08-13-87	377CCKS	335	<.05	8.7	--	32	23	--	49	--
3088	08-13-87	377CCKS	7,260	<.05	.38	--	<.70	<1.0	--	5.3	--
3111	08-26-87	377CCKS	970	<.05	1.2	--	2.3	2.8	--	4.5	--
3551	09-05-89	377CCKS	1,500	--	--	--	--	--	--	--	--
3719	01-05-90	377CCKS	870	--	--	2.3	--	--	--	--	--
249	08-25-87	377LDGR	5810	97	98	--	20	52	--	58	--
1315	09-28-92	377LDGR	350	--	--	--	--	--	--	--	--
1316	09-28-92	377LDGR	290	--	--	--	--	--	--	--	--
2161	06-27-88	377LDGR	1,120	.56	.42	--	1.1	--	2.6	2.7	2.0
2161	09-05-90	377LDGR	1,900	--	--	--	--	--	--	--	--
2348	06-24-88	377LDGR	622	.80	.35	--	<1.0	--	1.8	5.9	4.2
2724	08-31-90	377LDGR	680	--	--	--	--	--	--	--	--
2730	09-11-91	377LDGR	1,000	--	--	--	--	--	--	--	--
2742	09-12-91	377LDGR	<80	--	--	--	--	--	--	--	--
2743	07-18-89	377LDGR	430	--	--	--	--	--	--	--	--
2746	09-09-86	377LDGR	171	<.40	--	.2	<2.0	--	1.5	2.8	2.0
2746	08-30-90	377LDGR	120	--	--	--	--	--	--	--	--
3362	07-17-89	377LDGR	<80	--	--	--	--	--	--	--	--
3363	07-18-89	377LDGR	260	--	--	--	--	--	--	--	--
3926	04-25-91	377LDGR	190	--	--	--	--	--	--	--	--
4293	09-28-92	377LDGR	1,000	--	--	--	--	--	--	--	--
3135	09-05-87	400FCIGA	3,800	<.05	.38	--	<.70	<1.0	--	3.2	--

Table 28. *Results of chemical analyses for volatile organic compounds in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 300WSCKA, Octoraro Phyllite; 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377CCKS, Chickies Quartzite. Abbreviations: mg/L, micrograms per liter; <, less than; --, no data]

USGS local well or spring number	Date	Hydro-geologic unit	Dichloro-bromo-methane, total (µg/L)	Carbon-tetra-chloride, total (µg/L)	1,2-Dichloro-ethane, total (µg/L)	Bromo-form, total (µg/L)	Chloro-dibromo-methane, total (µg/L)	Chloro-form, total (µg/L)	Phenols, total (µg/L)	Toluene, total (µg/L)
82	07-09-86	300WSCKA	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2495	06-22-83	300WSCKA	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
3085	08-06-87	300WSCKA	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	2	<3.0
81	07-07-86	367CNSG	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	<3.0
307	06-02-81	367CNSG	0	0	0	0	0	0	0	0
307	07-16-91	367CNSG	<.2	<.2	<.2	<.2	<.2	<.2	--	<.2
2143	08-17-81	367CNSG	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
2143	06-01-84	367CNSG	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2412	08-26-80	367CNSG	0	0	0	0	0	0	1	0
2412	06-24-82	367CNSG	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	4	<1.0
2422	05-26-81	367CNSG	0	0	0	0	0	0	0	0
2477	08-03-82	367CNSG	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
2496	06-22-83	367CNSG	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
2723	09-11-91	367CNSG	<.2	<.2	<.2	<.2	<.2	<.2	1	<.2
2725	09-05-91	367CNSG	<.2	<.2	<.2	<.2	<.2	<.2	2	<.2
2740	07-12-89	367CNSG	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	<3.0
2745	07-07-86	367CNSG	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	<3.0
2846	09-05-85	367CNSG	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
4129	09-09-91	367CNSG	<.2	<.2	<.2	<.2	<.2	<.2	--	<.2
2315	08-08-89	377CCKS	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	1	<3.0
2436	06-10-81	377CCKS	0	0	0	0	0	0	4	0
2436	08-23-85	377CCKS	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	<3.0
3551	09-05-89	377CCKS	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	1	<3.0
SP-42	08-27-90	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
249	08-25-87	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	5	<3.0
1315	06-23-83	377LDGR	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
1315	09-28-92	377LDGR	<.2	<.2	<.2	<.2	<.2	.2	--	<.2
2161	06-27-88	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2161	09-05-90	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2348	06-11-80	377LDGR	0	0	0	0	0	0	0	0
2348	05-07-81	377LDGR	0	0	0	0	0	0	0	0
2348	06-24-88	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2497	06-22-83	377LDGR	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1	<1.0
2724	08-31-90	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2730	09-11-91	377LDGR	<.2	.5	<.2	<.2	<.2	<.2	--	<.2
2742	09-12-91	377LDGR	<.2	<.2	<.2	<.2	<.2	<.2	3	<.2
2743	07-18-89	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	1	<3.0
2746	08-30-90	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0
2753	08-15-84	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<1	<3.0
3362	07-17-89	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	1	<3.0
3363	07-18-89	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	4	<3.0
3926	04-25-91	377LDGR	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0

Table 28. *Results of chemical analyses for volatile organic compounds in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well or spring number	Benzene, total (µg/L)	Chloro-benzene, total (µg/L)	Chloro-ethane, total (µg/L)	Ethyl-benzene, total (µg/L	Methyl-bromide, total (µg/L)	Methyl-chlo-ride, total (µg/L)	Methyl-ene chlo-ride, total (µg/L)	Tetra-chloro-ethyl-ene, total (µg/L)	Tri-chloro-fluoro-methane, total (µg/L)
82	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<35	<3.0	<3.0
2495	<1.0	<1.0	--	<1.0	--	--	<1.0	<1.0	--
3085	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
81	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<40	<3.0	<3.0
307	9.0	0.0	0	0	0	--	0	0.0	0
307	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2143	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2143	<3.0	<3.0	--	<3.0	--	--	<3.0	<3.0	<3.0
2412	0	0.0	0	0	0	--	0	0.0	0
2412	4.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2422	0	0.0	0	0	0	--	0	0.0	0
2477	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2496	<1.0	<1.0	--	<1.0	--	--	<1.0	<1.0	--
2723	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2725	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2740	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2745	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<10	<3.0	<3.0
2846	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	<3.0
4129	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2315	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2436	0	0.0	0	0	0	--	0	0.0	0
2436	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	<3.0
3551	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
SP- 42	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
249	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
1315	<1.0	<1.0	--	<1.0	--	--	<1.0	<1.0	--
1315	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2161	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2161	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2348	0	0.0	0	0	0	--	0	0.0	0
2348	0	0.0	0	0	0	--	0	0.0	0
2348	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2497	<1.0	<1.0	--	<1.0	--	--	<1.0	<1.0	--
2724	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2730	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2742	<.2	<.20	<.2	<.2	<.2	<.2	<.2	<.2	<.2
2743	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2746	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2753	<3.0	<3.0	--	<3.0	--	--	<3.0	<3.0	<3.0
3362	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
3363	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
3926	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

Table 28. *Results of chemical analyses for volatile organic compounds in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well or spring number	1,1-Dichloro-ethane, total (µg/L)	1,1-Dichloro-ethylene, total (µg/L)	1,1,1-Trichloro-ethane total (µg/L)	1,1,2-Trichloro-ethane, total (µg/L)	1,1,2,2-Tetra-chloro-ethane, total (µg/L)	1,2-Dichloro-benzene, total (µg/L)	1,2-Dichloro-propane, total (µg/L)	1,2-Transdi-chloro-ethene, total (µg/L)	1,3-Dichloro-propene, total (µg/L)
82	<3.0	<3.0	<3.0	<3.0	<3.0	<0	<3.0	<3.0	<3.0
2495	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
3085	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
81	<3.0	<3.0	<3.0	<3.0	<3.0	<0	<3.0	<3.0	<3.0
307	0	0	0	0	0	--	0	0	0.0
307	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2143	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2143	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	--
2412	0	0	0	0	0	--	0	0	0.0
2412	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2422	0	0	0	0	0	--	0	0	0.0
2477	7.0	63	320	<1.0	<1.0	<1.0	<1.0	16	<1.0
2496	<1.0	<1.0	<1.0	7.0	<1.0	--	<1.0	<1.0	<1.0
2723	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2725	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2740	<3.0.	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2745	<3.0	<3.0	<3.0	<3.0	<3.0	<0	<3.0	<3.0	<3.0
2846	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	<3.0
4129	<.2	<.2	0.7	<.2	<.2	<.2	<.2	<.2	<.20
2315	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2436	0	0	0	0	0	--	0	0	0.0
2436	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	<3.0
3551	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
SP-42	<3.0	5.0	23	<3.0	<3.0	<3.0	<3.0	3.5	<3.0
249	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
1315	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
1315	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2161	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2161	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2348	0	0	60	0	0	--	0	0	0.0
2348	0	0	0	0	0	--	0	0	0.0
2348	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2497	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0	<1.0
2724	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	3.2	<3.0
2730	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2742	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.20
2743	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2746	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2753	<3.0	<3.0	<3.0	<3.0	<3.0	--	<3.0	<3.0	--
3362	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
3363	<3.0	4.1	31	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
3926	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

Table 28. Results of chemical analyses for volatile organic compounds in ground water, West Valley Creek Basin, Pennsylvania—Continued

USGS local well or spring number	1,3-Dichloro-benzene, total (µg/L)	1,4-Dichloro-benzene, total (µg/L)	2-Chloro-ethyl-vinyl-ether, total (µg/L)	Dichloro-difluoro-methane, total (µg/L)	Cis 1,3-Di-chloro-propene, total (µg/L)	1,2-Dibromo ethyl-ene, total (µg/L)	Vinyl chlo-ride, total (µg/L)	Trichloro-ethyl-ene, total (µg/L)	Styrene, total (µg/L)
82	<0	<0	<3.0	<3.0	<0	<0	<3.0	<3.0	<0
2495	--	--	<1.0	--	--	--	--	<1.0	--
3085	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
81	<0	<0	<3.0	<3.0	<0	<0	<3.0	<3.0	<0
307	--	--	0	0	--	--	0	0	--
307	<.2	<.2	<.2	<.2	<.2	--	<.2	<.2	<.2
2143	--	--	<1.0	<1.0	--	--	<1.0	<1.0	--
2143	--	--	--	<3.0	--	--	--	<3.0	--
2412	--	--	0	0	--	--	0	0	--
2412	--	--	<1.0	<1.0	--	--	<1.0	<1.0	--
2422	--	--	0	0	--	--	0	0	--
2477	<1.0	<1.0	<1.0	<1.0	--	--	<1.0	770	--
2496	--	--	<1.0	--	--	--	--	24	--
2723	<.2	<.2	<.2	<.2	<.2	--	<.2	<.2	<.2
2725	<.2	<.2	<.2	<.2	<.2	--	<.2	<.2	<.2
2740	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
2745	<0	<0	<3.0	<3.0	<0	<0	<3.0	<3.0	<0
2846	--	--	<3.0	<3.0	--	--	<3.0	<3.0	--
4129	<.2	<.2	<.2	<.2	<.2	--	<.2	0.2	<.2
2315	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
2436	--	--	0	0	--	--	0	0	--
2436	--	--	<3.0	<3.0	--	--	<3.0	<3.0	--
3551	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
SP-42	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	35	<3.0
249	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
1315	--	--	<1.0	--	--	--	--	<1.0	--
1315	<.2	<.2	<.2	<.2	<.2	--	<.2	<.2	<.2
2161	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2161	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
2348	--	--	0	0	--	--	0	150	--
2348	--	--	0	0	--	--	0	0	--
2348	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
2497	--	--	<1.0	--	--	--	--	<1.0	--
2724	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	14	<3.0
2730	<.2	<.2	<.2	<.2	<.2	--	<.2	.5	<.2
2742	<.2	<.2	<.2	<.2	<.2	--	<.2	<.2	<.2
2743	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
2746	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
2753	--	--	--	<3.0	--	--	--	<3.0	--
3362	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0
3363	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	26	<3.0
3926	<3.0	<3.0	<3.0	<3.0	<3.0	--	<1.0	<3.0	<3.0

Table 29. *Results of chemical analyses for semivolatile organic compounds in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 300WSCKA, Octoraro Phyllite; 367CNSG, Conestoga Limestone. Abbreviations: µg/L, micrograms per liter; <, less than; --, no data]

USGS local well number	Date	Geologic unit	Acenaphthylene, total (µg/L)	Acenaphthene, total (µg/L)	Anthracene, total (µg/L)	Benzo (b) fluoranthene, total (µg/L)	Benzo (k) fluoranthene, total (µg/L)	Benzo (a) pyrene, total (µg/L)
3085	06-21-88	300WSCKA	<5.0	<5.0	<5.0	<10.0	<10.0	<10.0
2477	08-03-82	367CNSG	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Bis (2-chloroethyl) ether, total (µg/L)	Bis (2-chloroethoxy) methane, total (µg/L)	Bis (2-chloroisopropyl) ether, total (µg/L)	N-Butyl benzyl phthalate, total (µg/L)	Chrysene, total (µg/L)	Diethyl phthalate, total (µg/L)	Dimethyl phthalate, total (µg/L)	Fluoranthene, total (µg/L)	Fluorene, total (µg/L)	Hexachlorocyclopentadiene, total (µg/L)
<5.0	<5.0	<5.0	<5.0	<10.0	<5.0	<5.0	<5.0	<5.0	<5.0
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Hexachloroethane, total (µg/L)	Indeno (1,2,3-cd) pyrene, total (µg/L)	Isophorone, total (µg/L)	N-Nitro-sodi-n-propylamine, total (µg/L)	N-Nitrosodiphenylamine, total (µg/L)	N-Nitrosodimethylamine, total (µg/L)	Nitrobenzene, total (µg/L)	Parachlorometa cresol, total (µg/L)	Phenanthrene, total (µg/L)	Pyrene, total (µg/L)
<5.0	<10.0	<5.0	<5.0	<5.0	<5.0	<5.0	<30.0	<5.0	<5.0
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	<1.0

Benzo(g,h,i) perylene, (1,12-benzoperylene), total (µg/L)	Benzo(a) anthracene (1,2-benzanthracene), total (µg/L)	1,2-Di-chlorobenzene, total (µg/L)	1,2,4-Trichlorobenzene, total (µg/L)	1,2,5,6-Dibenzanthracene, total (µg/L)	1,3-Dichlorobenzene, total (µg/L)	1,4-Dichlorobenzene, total (µg/L)	2-Chloronaphthalene, total (µg/L)	2-Nitrophenol, total (µg/L)
<10.0	<5.0	<5.0	<5.0	<10.0	<5.0	<5.0	<5.0	<5.0
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	--

Dinoctyl phthalate, total (µg/L)	2,4-Dichlorophenol, total (µg/L)	2,4-Dichlorophenol, total (µg/L)	2,4-Dimethylphenol, total (µg/L)	2,4-Dinitrotuluene, total (µg/L)	2,4-Dinitrophenol, total (µg/L)	2,4-Dinitrophenol, total (µg/L)	2,4,6-Trichlorophenol, total (µg/L)	2,6-Dinitrotoluene, total (µg/L)	4-Bromophenylphenylether, total (µg/L)
<5.0	<10.0	<5.0	<5.0	<5.0	<20.0	<20.0	<5.0	<5.0	<5.0
--	<1.0	--	--	<1.0	--	--	<1.0	<1.0	<1.0

4-Nitro-phenol, total (µg/L)	4,6-Dinitroorthocresol, total (µg/L)	Phenol (C6H-5OH), total (µg/L)	Naphthalene, total (µg/L)	Pentachlorophenol, total (µg/L)	Bis (2-ethyl-hexyl) phthalate, total (µg/L)	Di-n-butyl phthal-ate, total (µg/L)	Hexachlorobenzene, total (µg/L)	Hexachlorobutadiene, total (µg/L)
<30.0	<30.0	<5.0	<5.0	<30.0	<5.0	<5.0	<5.0	<5.0
--	--	--	<1.0	--	<1.0	<1.0	<1.0	<1.0

Table 30. *Results of chemical analyses for organochlorine insecticides in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite; 377CCKS, Chickies Quartzite. Abbreviations: µg/L, micrograms per liter; <, less than]

USGS local well number	Hydro-geologic unit	Date	Aldrin, total (µg/L)	Chlor-dane, total (µg/L)	DDD, total (µg/L)	DDE, total (µg/L)	DDT, total (µg/L)	Di-eldrin, total (µg/L)	Endo-sulfan, total (µg/L)
307	367CNSG	06-02-81	<0.010	<0.1	<0.010	<0.010	<0.010	<0.010	<0.010
2143	367CNSG	08-17-81	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2143	367CNSG	06-01-84	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2412	367CNSG	08-26-80	.0	0	.0	.0	.0	.0	.0
2412	367CNSG	06-24-82	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2422	367CNSG	05-26-81	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2723	367CNSG	09-11-91	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2740	367CNSG	07-12-89	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2436	377CCKS	06-10-81	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2436	377CCKS	08-23-85	<.010	<.1	<.010	<.010	<.010	<.010	<.010
249	377LDGR	08-25-87	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2348	377LDGR	06-11-80	.0	0	.0	.0	.0	.0	.0
2348	377LDGR	05-07-81	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2497	377LDGR	06-22-83	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2742	377LDGR	09-12-91	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2743	377LDGR	07-18-89	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2746	377LDGR	08-30-90	<.010	<.1	<.010	<.010	<.010	<.010	<.010
2753	377LDGR	08-15-84	<.010	<.1	<.010	<.010	<.010	<.010	<.010
3926	377LDGR	04-25-91	<.010	<.1	<.010	<.010	<.010	<.010	<.010

Table 30. *Results of chemical analyses for organochlorine insecticides in ground water, West Valley Creek Basin, Pennsylvania—Continued*

USGS local well number	Endrin, total (µg/L)	Hepta-chlor, total (µg/L)	Hepta-chlor epoxide, total (µg/L)	Lindane, total (µg/L)	Methoxy-chlor, total (µg/L)	Mirex, total (µg/L)	PCB, total (µg/L)	Perthane, total (µg/L)	Tox-aphene, total (µg/L)
307	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.1	<0.0	<0.1
2143	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.0	<.1
2143	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2412	.0	.0	.0	.0	.0	.0	0	0	0
2412	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2422	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.0	<.1
2723	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2740	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2436	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.0	<.1
2436	<.010	<.010	.010	<.010	<.01	<.01	<.1	<.1	<1
249	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2348	.0	.0	.0	.0	.0	.0	0	0	0
2348	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.0	<.1
2497	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2742	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2743	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2746	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
2753	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1
3926	<.010	<.010	<.010	<.010	<.01	<.01	<.1	<.1	<1

Table 31. *Results of chemical analyses for organophosphorus insecticides in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite. Abbreviations: µg/L, micrograms per liter; <, less than]

USGS local well number	Hydro-geologic unit	Date	Chlor-dyrifos, total, recover-able (µg/L)	Di-azinon, total (µg/L)	Di-syston, total (µg/L)	Ethion, total (µg/L)	Mala-thion, total (µg/L)	Methyl para-thion, total (µg/L)	Para-thion, total (µg/L)	Phorate, total (µg/L)	Total tri-thion (µg/L)	DEF, total (µg/L)
2723	367CNSG	09-11-91	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2742	377LDGR	09-12-91	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
3926	377LDGR	04-25-91	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01

Table 32. *Results of chemical analyses for triazine herbicides in ground water, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 367CNSG, Conestoga Limestone; 377LDGR, Ledger Dolomite. Abbreviations: μg/L, micrograms per liter; --, no data]

USGS local well number	Hydro-geologic unit	Date	Alachlor, total recov-erable (μg/L)	Ametryne, total (μg/L)	Atra-zine, total (μg/L)	Cyan-azine, total (μg/L)	Prome-tone, total (μg/L)	Prome-tryne, total (μg/L)
2740	367CNSG	07-12-89	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
249	377LDGR	08-25-87	<.10	<.10	<.10	<.10	<.10	<.10
2497	377LDGR	06-22-83	--	<.10	<.10	<.10	<.10	<.10
2743	377LDGR	07-18-89	<.10	<.10	<.10	<.10	<.10	<.10
3926	377LDGR	04-25-91	<.20	<.10	.70	<.20	<.20	<.10

USGS local well number	Pro-pazine, total (μg/L)	Sima-zine, total (μg/L)	Sime-tryne, total (μg/L)	Tri-fluralin, total recover-able (μg/L)	Metri-buzin, water whole, total, recover-able (μg/L)	Ver-nolate, water whole, recover-able (μg/L)	Buta-chlor, water whole, recover-able (μg/L)	Butyl-ate, water whole, recover-able (μg/L)
2740	<0.10	<0.10	<0.10	<0.10	<0.10	--	--	--
249	<.10	<.10	<.10	<.10	<.10	--	--	--
2497	<.10	<.10	<.10	--	--	--	--	--
2743	<.10	<.10	<.10	<.10	<.10	--	--	--
3926	<.10	<.10	<.10	<.10	<.10	<0.10	<0.10	<0.10

USGS local well number	Carboxin, water whole, recov-erable (μg/L)	Cycloate, water whole, recov-erable (μg/L)	Diphen-amid, water whole, recov-erable (μg/L)	Hexazi-none, water whole, recov-erable (μg/L)	Propa-chlor, water whole, recov-erable (μg/L)	Ter-bacil, water whole, recov-erable (μg/L)	De-iso-propyl atrazin, water whole, total (μg/L)	Deethyl atrazine, water, whole, total (μg/L)
2740	--	--	--	--	--	--	--	--
249	--	--	--	--	--	--	--	--
2497	--	--	--	--	--	--	--	--
2743	--	--	--	--	--	--	--	--
3926	<0.20	<0.10	<0.10	<0.20	<0.10	<0.20	<0.20	1.1

Table 33. *Results of chemical analyses for gross polychlorinated biphenyls and naphthalenes, West Valley Creek Basin, Pennsylvania*

[Hydrogeologic unit codes: 367CNSG, Conestoga Limestone; 377CCKS, Chickies Quartzite; 377LDGR, Ledger Dolomite. Abbreviations: PCB, polychlorinated biphenyl. μg/L, micrograms per liter; <, less than]

USGS local well number	Geologic unit	Date	Gross PCB, total (μg/L)	Gross naphthalenes, polychlorinated, total (μg/L)
2348	377LDGR	06-11-80	0.0	0.0
2348	377LDGR	05-07-81	<.1	<.1
2753	377LDGR	08-15-84	<.1	<.1
2723	367CNSG	09-11-91	<.1	<.1
2497	377LDGR	06-22-83	<.1	<.1
307	367CNSG	06-02-81	<.1	<.1
249	377LDGR	08-25-87	<.1	<.1
2143	367CNSG	08-17-81	<.1	<.1
2143	367CNSG	06-01-84	<.1	<.1
2422	367CNSG	05-26-81	<.1	<.1
2436	377CCKS	06-10-81	<.1	<.1
2436	377CCKS	08-23-85	<.1	<.1
2742	377LDGR	09-12-91	<.1	<.1
2743	377LDGR	07-18-89	<.1	<.1
2746	377LDGR	08-30-90	<.1	<.1
2412	367CNSG	08-26-80	0	0
2412	367CNSG	06-24-82	<.1	<.1
2740	367CNSG	07-12-89	<.1	<.1
3926	377LDGR	04-25-91	<.1	<.1

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991*

[°C, degrees Celsius; NTU, nephelometric turbidity units; WVC, stream-sampling site number; E, estimated; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ft^3/s, cubic feet per second; <, less than; --, no data]

Date	Temperature, water (°C)	Temperature, air (°C)	Discharge, instantaneous (ft^3/s)	Turbidity (NTU)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-1 Site identification number 400226075360800 Latitude 40°02'26" Longitude 075°36'08" Unnamed tributary to Valley Creek at Swedesford Road near Exton, Pa.								
08-16-90	16.5	27.0	0.10	6.5	78	9.2	6.6	14
09-05-90	15.0	22.0	.10	7.3	68	9.0	7.1	14
10-10-90	17.5	23.0	.10	--	73	8.2	7.7	49
11-08-90	6.0	6.0	.06	10	70	12.4	7.9	40
01-24-91	4.0	2.5	.19	--	70	12.9	6.8	12
02-05-91	4.0	3.0	.17	--	75	12.9	6.6	12
03-20-91	13.5	9.5	.19	--	67	11.4	7.6	110
04-03-91	14.5	11.5	.29	--	65	1.8	6.9	110
05-10-91	15.5	2.0	.27	--	67	1.0	7.4	10
06-06-91	17.0	17.5	.16	--	68	9.5	6.9	10
07-10-91	16.5	21.5	.10	4.5	70	8.8	7.3	12
WVC-2 Site identification number 400212075355000 Latitude 40°02'12" Longitude 075°35'50" Valley Creek at Church Farm School at Private Road near Exton, Pa.								
08-16-90	21.5	29.0	.24	3.9	547	8.6	7.1	133
09-05-90	16.5	22.0	.21	1.0	590	7.4	8.0	168
10-10-90	19.0	22.5	.19	--	590	8.7	6.6	157
11-08-90	5.5	4.5	.15	4.7	590	11.4	7.1	189
01-24-91	3.0	1.5	.40	--	580	14.0	7.6	104
02-05-91	3.0	3.5	.38	--	570	12.5	7.5	112
03-20-91	14.0	1.0	.48	--	595	13.6	7.9	118
04-03-91	16.0	12.0	.64	--	510	13.3	8.0	106
05-10-91	2.0	23.5	.69	--	515	11.0	7.9	109
06-06-91	24.0	19.0	.10	2.5	438	12.0	8.4	88
07-10-91	23.0	23.0	.28	3.0	565	9.3	7.7	142

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temperature, water (°C)	Temperature, air (°C)	Discharge, instantaneous (ft^3/s)	Turbidity (NTU)	Specific conductance (μS/cm)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-3 Site identification number 400155075363800 Latitude 40°01′55″ Longitude 075°36′38″ Unnamed tributary to Valley Creek near Ship Road near Exton, Pa.								
08-16-90	18.0	23.5	0.57	1.1	445	9.4	6.9	135
09-05-90	15.5	22.5	.57	.50	460	9.4	8.1	136
10-10-90	17.5	22.5	.41	8.0	460	8.8	6.6	128
11-07-90	10.0	9.5	.33	.60	439	11.7	7.3	157
12-10-90	7.5	10.0	.36	.30	440	12.9	7.8	142
01-24-91	6.0	2.5	1.2	--	428	11.9	7.2	128
02-04-91	10.5	15.0	.56	--	419	13.0	7.8	132
03-20-91	12.5	14.5	.94	--	420	12.5	7.1	131
04-02-91	10.5	8.5	.86	--	380	12.5	7.2	107
05-08-91	16.5	18.0	1.0	--	397	1.6	7.3	108
06-06-91	17.0	21.0	.38	1.0	420	9.7	6.9	130
07-10-91	16.5	19.5	.37	1.0	440	8.6	7.6	136
WVC-4 Site identification number 400205075370700 Latitude 40°02′05″ Longitude 075°37′07″ Unnamed tributary to Valley Creek at Brookview Street near Exton, Pa.								
08-16-90	14.5	25.5	.33	5.0	350	1.2	7.1	179
09-06-90	12.5	18.5	.25	7.1	310	8.5	8.1	150
10-10-90	15.5	23.5	.12	10	400	9.3	6.9	180
11-08-90	9.5	6.0	.23	16	391	11.1	7.1	174
12-10-90	9.5	10.5	.19	12	389	11.1	7.9	162
01-24-91	7.5	2.5	.78	--	349	11.2	7.7	146
02-04-91	12.0	14.5	.64	--	360	11.4	7.8	145
03-20-91	12.5	10.5	.62	--	344	1.8	7.3	140
04-02-91	11.5	7.5	.70	--	333	11.6	7.4	142
05-10-91	14.5	20.0	.69	--	340	11.5	7.7	144
06-07-91	13.5	19.5	.42	2.7	380	1.6	7.4	142
07-10-91	15.0	25.0	.25	4.0	400	9.8	8.0	164
10-07-91	13.0	13.0	.06	--	387	1.3	7.6	171

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-1 Site identification number 400226075360800 Latitude 40°02'26" Longitude 075°36'08" Unnamed tributary to Valley Creek at Swedesford Road near Exton, Pa.								
08-16-90	0.020	<0.20	<0.20	<0.010	0.800	0.040	0.020	0.010
09-05-90	.030	<.20	.30	<.010	.800	.020	<.010	<.010
10-10-90	.030	.40	.40	<.010	.700	.090	.020	.020
11-08-90	.050	.30	.30	<.010	.700	.050	.020	.010
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-10-91	--	--	--	--	--	--	--	--
06-06-91	--	--	--	--	--	--	--	--
07-10-91	.040	--	--	<.010	.890	--	--	.010
WVC-2 Site identification number 400212075355000 Latitude 40°02'12" Longitude 075°35'50" Valley Creek at Church Farm School at Private Road near Exton, Pa.								
08-16-90	.030	.50	.60	.010	2.10	.040	<.010	<.010
09-05-90	.020	.30	.60	.020	2.20	.020	<.010	<.010
10-10-90	.010	.30	.40	.030	1.80	.010	<.010	<.010
11-08-90	.060	.40	.40	.020	2.30	<.010	<.010	<.010
01-24-91	--	--	--	--	--	--	--	--
02-05-91	<.010	--	--	.010	2.20	--	--	<.010
03-20-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-10-91	.050	--	--	.010	2.00	--	--	<.010
06-06-91	.010	--	--	.020	1.30	--	--	<.010
07-10-91	.020	--	--	.030	2.10	--	--	.020

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-3 Site identification number 400155075363800 Latitude 40°01'55" Longitude 075°36'38" Unnamed tributary to Valley Creek near Ship Road near Exton, Pa.								
08-16-90	0.010	0.30	0.30	<0.010	1.90	0.010	0.030	0.010
09-05-90	.020	.20	.30	<.010	1.90	.010	<.010	<.010
10-10-90	<.010	.40	.40	<.010	1.60	.030	<.010	<.010
11-07-90	.050	.40	.50	<.010	1.60	<.010	<.010	<.010
12-10-90	.020	.20	.40	<.010	1.90	.010	<.010	.010
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-02-91	--	--	--	--	--	--	--	--
05-08-91	.020	--	--	<.010	1.90	--	--	<.010
06-06-91	.010	--	--	.010	2.00	--	--	<.010
07-10-91	.020	--	--	<.010	1.90	--	--	.010
WVC-4 Site identification number 400205075370700 Latitude 40°02'05" Longitude 075°37'07" Unnamed tributary to Valley Creek at Brook-view Street near Exton, Pa.								
08-16-90	.020	.40	.40	<.010	6.10	.040	.030	.030
09-06-90	.030	.40	.60	<.010	5.80	.030	.020	.010
10-10-90	.010	.50	.90	<.010	6.30	.060	.040	<.010
11-08-90	.060	.40	.70	.010	6.30	.070	.030	.030
12-10-90	.040	.70	.60	<.010	6.30	.090	.030	.030
01-24-91	--	--	--	--	--	--	--	--
02-04-91	<.010	--	--	<.010	5.20	--	--	.010
03-20-91	<.010	--	--	<.010	4.90	--	--	.020
04-02-91	<.010	--	--	<.010	4.80	--	--	.010
05-10-91	.020	--	--	<.010	5.20	--	--	.020
06-07-91	.010	--	--	.010	6.30	--	--	<.010
07-10-91	<.010	--	--	<.010	6.00	--	--	.020
10-07-91	.030	<.20	--	.010	6.00	--	--	.040

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
WVC-1 Site identification number 400226075360800 Latitude 40°02'26" Longitude 075°36'08" Unnamed tributary to Valley Creek at Swedesford Road near Exton, Pa.								
08-16-90	3.3	2.8	4.5	1.6	9.3	4.6	<0.10	8.7
09-05-90	2.7	2.4	4.5	1.5	8.3	5.0	<.10	8.8
10-10-90	--	--	--	--	--	--	--	--
11-08-90	2.7	2.5	4.6	2.7	6.0	3.0	<.10	8.1
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-10-91	--	--	--	--	--	--	--	--
06-06-91	--	--	--	--	--	--	--	--
07-10-91	2.5	2.8	4.5	1.5	7.7	4.4	--	7.9
WVC-2 Site identification number 400212075355000 Latitude 40°02'12" Longitude 075°35'50" Valley Creek at Church Farm School at Private Road near Exton, Pa.								
08-16-90	47	18	27	2.2	70	20	.30	6.6
09-05-90	48	22	47	2.0	100	26	.10	5.2
10-10-90	--	--	--	--	--	--	--	--
11-08-90	47	23	31	2.4	71	26	.30	4.9
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	95	28	<.10	--
03-20-91	--	--	--	--	110	21	.10	--
04-03-91	--	--	--	--	89	27	.10	--
05-10-91	--	--	--	--	82	20	<.10	--
06-06-91	30	16	33	1.2	80	22	<.10	7.0
07-10-91	41	22	28	2.1	75	23	--	7.3

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
WVC-3 Site identification number 400155075363800 Latitude 40°01′55″ Longitude 075°36′38″ Unnamed tributary to Valley Creek near Ship Road near Exton, Pa.								
08-16-90	57	12	13	1.5	43	19	0.30	9.6
09-05-90	61	12	13	1.3	44	19	<.10	9.1
10-10-90	63	11	12	1.7	47	21	<.10	9.7
11-07-90	63	10	11	1.6	46	19	<.10	9.7
12-10-90	61	11	12	1.4	46	22	.10	8.5
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	48	22	<.10	--
03-20-91	--	--	--	--	51	--	--	--
04-02-91	--	--	--	--	42	--	--	--
05-08-91	--	--	--	--	40	--	--	--
06-06-91	55	11	14	1.2	43	18	<.10	9.6
07-10-91	60	11	12	1.1	43	18	--	9.9
WVC-4 Site identification number 400205075370700 Latitude 40°02′05″ Longitude 075°37′07″ Unnamed tributary to Valley Creek at Brookview Street near Exton, Pa.								
08-16-90	41	25	3.2	1.6	9.0	15	.30	8.0
09-06-90	41	25	3.3	1.6	9.5	14	<.10	8.3
10-10-90	40	24	3.2	1.8	9.6	18	<.10	8.2
11-08-90	40	25	3.3	2.1	8.2	13	.20	8.3
12-10-90	41	25	3.3	1.7	9.5	18	<.10	7.9
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	8.9	--	--	--
04-02-91	--	--	--	--	--	--	--	--
05-10-91	--	--	--	--	--	--	--	--
06-07-91	40	23	2.8	1.5	9.0	17	<.10	7.9
07-10-91	40	26	3.4	1.7	9.9	16	--	8.1
10-07-91	41	25	3.9	2.5	10	16	.20	8.5

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (μg/L as Sr)	Lithium, dissolved (μg/L as Li)	Boron, dissolved (μg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Chromium, dissolved (μg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-1 Site identification number 400226075360800 Latitude 40°02'26" Longitude 075°36'08" Unnamed tributary to Valley Creek at Swedesford Road near Exton, Pa.								
08-16-90	17	9	<10	0.020	49	9	<1	46
09-05-90	22	<4	<10	.030	47	8	<1	42
10-10-90	--	<10	<10	--	--	--	1	--
11-08-90	17	<4	<10	--	67	6	<1	35
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-10-91	--	--	--	--	--	--	--	--
06-06-91	--	--	--	--	--	--	--	--
07-10-91	10	<10	--	.020	45	8	--	--
WVC-2 Site identification number 400212075355000 Latitude 40°02'12" Longitude 075°35'50" Valley Creek at Church Farm School at Private Road near Exton, Pa.								
08-16-90	160	3,000	80	1.8	10	27	2	315
09-05-90	120	4,100	80	2.0	16	7	4	419
10-10-90	--	2,600	70	--	--	--	3	--
11-08-90	110	2,200	70	--	9	14	5	312
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	800	40	--	--	--	--	--
03-20-91	--	1,700	40	.71	--	--	--	--
04-03-91	--	1,500	50	--	--	--	1	--
05-10-91	--	1,400	40	--	--	--	1	--
06-06-91	--	1,500	40	--	14	12	<1	251
07-10-91	80	4,800	70	1.5	21	42	1	--

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (μg/L as Sr)	Lithium, dissolved (μg/L as Li)	Boron, dissolved (μg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Chromium, dissolved (μg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-3 Site identification number 400155075363800 Latitude 40°01′55″ Longitude 075°36′38″ Unnamed tributary to Valley Creek near Ship Road near Exton, Pa.								
08-16-90	160	6	10	0.070	9	5	<1	264
09-05-90	170	6	20	.080	90	5	<1	280
10-10-90	180	10	20	.060	14	8	<1	263
11-07-90	180	7	10	--	14	8	<1	244
12-10-90	--	4	<10	--	6	5	<1	257
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-02-91	--	<10	--	--	--	--	--	--
05-08-91	--	<10	--	--	--	--	--	--
06-06-91	--	5	--	--	18	6	--	249
07-10-91	160	<10	--	.080	8	5	--	--
WVC-4 Site identification number 400205075370700 Latitude 40°02′05″ Longitude 075°37′07″ Unnamed tributary to Valley Creek at Brookview Street near Exton, Pa.								
08-16-90	24	<4	<10	.020	6	5	<1	215
09-06-90	21	4	10	.030	7	6	<1	235
10-10-90	22	5	<10	.020	12	9	<1	182
11-08-90	21	6	<10	--	10	9	<1	239
12-10-90	--	4	<10	--	8	8	<1	216
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-02-91	--	--	--	--	--	--	--	--
05-10-91	--	--	--	--	--	--	--	--
06-07-91	--	<4	--	--	7	3	--	221
07-10-91	20	<10	--	.030	7	8	--	--
10-07-91	20	<10	--	--	10	4	--	--

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temper-ature, water (°C)	Temper-ature, air (°C)	Dis-charge, inst. (ft^3/s)	Turbidity (NTU)	Specific conduc-tance (μS/cm)	Oxy-gen, dis-solved (mg/L)	pH, water whole field (stand-ard units)	Alka-linity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-5 Site identification number 400157075370100 Latitude 40°01'57" Longitude 075°37'01" Valley Creek at Lakeside Street near Exton, Pa.								
08-16-90	19.5	26.5	0.85	2.0	422	9.0	6.7	126
09-06-90	17.0	21.5	.84	1.0	490	8.6	7.9	150
10-10-90	19.0	24.0	.33	4.5	498	9.1	6.6	151
11-08-90	8.5	6.5	.37	1.9	484	1.9	7.1	147
12-10-90	7.5	11.5	.57	1.0	510	11.7	7.7	170
01-24-91	5.0	4.0	2.1	--	392	13.5	7.2	130
02-04-91	8.0	17.0	1.6	1.0	499	14.6	7.7	129
03-20-91	10.0	9.5	1.9	2.0	464	13.0	7.1	122
04-02-91	9.5	7.5	2.2	5.1	444	13.3	7.3	118
05-10-91	16.0	21.0	1.7	2.1	436	11.0	7.4	124
06-07-91	16.5	22.5	.85	2.0	460	9.6	7.4	151
07-11-91	22.0	3.5	.64	2.0	480	8.9	7.4	164
WVC-6 Site identification number 400152075371600 Latitude 40°01'52" Longitude 075°37'16" Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	19.0	26.5	2.3	7.3	403	9.6	6.9	136
09-05-90	18.0	19.0	1.6	6.4	400	8.6	8.1	134
10-10-90	20.0	22.5	.85	10	364	8.0	6.9	147
11-06-90	12.0	15.5	.94	5.5	416	1.0	7.2	168
12-11-90	4.5	3.0	1.2	1.9	425	13.4	7.2	150
01-23-91	3.5	.5	4.6	--	419	13.5	7.2	115
02-05-91	5.0	8.0	3.6	3.0	405	12.6	7.6	134
03-20-91	8.0	9.5	4.4	4.0	411	12.6	7.1	118
04-02-91	7.5	5.5	4.9	4.7	354	12.5	7.4	124
05-08-91	15.0	16.5	4.5	4.3	352	1.9	7.6	112
06-05-91	17.5	16.0	1.9	8.5	369	9.0	7.0	135
07-11-91	20.5	27.5	1.2	12	400	8.4	7.7	130

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temper-ature, water (°C)	Temper-ature, air (°C)	Dis-charge, inst. (ft^3/s)	Turbidity (NTU)	Specific conduc-tance (μS/cm)	Oxy-gen, dis-solved (mg/L)	pH, water whole field (stand-ard units)	Alka-linity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-7 Site identification number 400151075371500 Latitude 40°01'51" Longitude 075°37'15" Unnamed tributary to Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	18.5	26.5	0.77	2.7	370	9.2	7.2	100
09-05-90	15.5	19.0	1.3	2.1	295	9.7	8.2	98
10-10-90	19.5	25.0	.39	--	362	8.5	7.1	117
11-06-90	11.5	13.5	.35	2.8	358	1.5	6.8	120
01-23-91	3.0	0	1.6	--	339	13.7	7.2	90
02-05-91	5.5	11.5	.94	--	340	13.8	7.4	92
03-20-91	7.5	8.5	1.4	--	340	12.9	7.2	104
04-02-91	7.0	5.5	1.7	--	312	12.9	7.1	88
05-08-91	14.5	16.0	1.4	--	318	1.5	7.4	95
06-05-91	16.0	18.5	.64	3.0	330	1.0	7.6	92
07-11-91	19.5	28.5	.34	3.2	346	8.3	7.5	111
WVC-8 Site identification number 400159075380800 Latitude 40°01'59" Longitude 075°38'08" Unnamed tributary to Valley Creek at Waterloo Boulevard near Exton, Pa.								
08-16-90	22.5	27.0	1.2	.80	330	9.3	7.2	93
09-05-90	18.0	23.5	1.1	1.1	340	1.3	8.9	82
10-11-90	18.0	21.5	.74	1.0	361	8.5	6.4	116
11-06-90	12.5	1.5	1.1	.40	340	12.2	7.3	131
12-10-90	6.5	8.0	1.6	1.5	356	12.7	7.8	106
01-23-91	2.0	2.5	2.4	--	337	15.0	7.2	78
02-05-91	11.0	19.0	1.9	1.5	315	15.6	8.5	76
03-21-91	10.5	1.5	2.3	1.0	328	11.5	7.3	90
04-02-91	11.0	8.5	2.6	1.5	316	13.9	8.2	75
05-10-91	16.0	2.5	2.0	1.7	314	11.9	8.3	80
06-05-91	19.0	2.0	1.2	1.0	330	1.2	7.3	92
07-09-91	24.5	25.5	.85	1.5	338	9.1	8.1	90

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-5 Site identification number 400157075370100 Latitude 40°01'57" Longitude 075°37'01" Valley Creek at Lakeside Street near Exton, Pa.								
08-16-90	0.010	0.20	0.40	<0.010	1.80	0.020	0.030	0.010
09-06-90	.030	.30	.30	<.010	1.90	.010	.010	<.010
10-10-90	.020	.40	.30	<.010	1.70	.070	<.010	<.010
11-08-90	.060	.20	.40	<.010	1.80	.010	.010	.01
12-10-90	.020	.30	.30	<.010	2.30	.020	<.010	<.010
01-24-91	--	--	--	--	--	--	--	--
02-04-91	<.010	--	--	<.010	2.40	--	--	<.010
03-20-91	<.010	--	--	.010	1.80	--	--	<.010
04-02-91	<.010	--	--	.010	2.00	--	--	<.010
05-10-91	.030	--	--	.010	2.00	--	--	<.010
06-07-91	.020	--	--	.010	2.10	--	--	<.010
07-11-91	<.010	--	--	<.010	1.70	--	--	<.010
WVC-6 Site identification number 400152075371600 Latitude 40°01'52" Longitude 075°37'16" Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	.030	.50	.50	.020	2.30	.050	.020	<.010
09-05-90	.050	.50	.30	.020	2.50	.010	<.010	<.010
10-10-90	.040	.40	.50	.030	2.00	.040	<.010	<.010
11-06-90	.090	.60	.60	.030	2.10	.060	.020	.010
12-11-90	.020	.40	.50	.010	2.70	.030	<.010	<.010
01-23-91	--	--	--	--	--	--	--	--
02-05-91	.010	--	--	<.010	3.00	--	--	<.010
03-20-91	.010	--	--	.010	2.40	--	--	<.010
04-02-91	.020	--	--	<.010	2.50	--	--	<.010
05-08-91	.040	--	--	.010	2.30	--	--	<.010
06-05-91	.080	--	--	.020	2.30	--	--	<.010
07-11-91	.050	--	--	.020	2.40	--	--	.010

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-7 Site identification number 400151075371500 Latitude 40°01'51" Longitude 075°37'15" Unnamed tributary to Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	0.020	0.30	<0.20	<0.010	2.10	0.020	0.020	0.010
09-05-90	.020	<.20	.40	<.010	2.00	<.010	<.010	<.010
10-10-90	.010	.20	.30	<.010	1.60	.020	<.010	<.010
11-06-90	.050	.30	.30	.020	1.60	.020	<.010	<.010
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-02-91	--	--	--	--	--	--	--	--
05-08-91	.020	--	--	<.010	2.10	--	--	<.010
06-05-91	.020	--	--	.010	2.00	--	--	<.010
07-11-91	.020	--	--	<.010	1.90	--	--	.010
WVC-8 Site identification number 400159075380800 Latitude 40°01'59" Longitude 075°38'08" Unnamed tributary to Valley Creek at Waterloo Boulevard near Exton, Pa.								
08-16-90	<.010	.40	.20	<.010	2.70	.220	.200	.170
09-05-90	<.010	.50	.40	<.010	2.00	.140	.120	.120
10-11-90	<.010	.30	.30	.010	2.00	.110	.100	.110
11-06-90	.060	.30	.70	.020	2.40	.170	.190	.180
12-10-90	.020	.40	.50	<.010	2.80	.170	.090	.100
01-23-91	--	--	--	--	--	--	--	--
02-05-91	<.010	--	--	<.010	2.00	--	--	.030
03-21-91	<.010	--	--	.010	2.00	--	--	.050
04-02-91	<.010	--	--	<.010	2.30	--	--	.090
05-10-91	.040	--	--	.020	2.30	--	--	.080
06-05-91	<.010	--	--	.010	2.10	--	--	.090
07-09-91	.020	--	--	.010	2.00	--	--	.130

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
WVC-5 Site identification number 400157075370100 Latitude 40°01'57" Longitude 075°37'01" Valley Creek at Lakeside Street near Exton, Pa.								
08-16-90	49	14	16	2.1	38	17	0.30	7.4
09-06-90	56	16	17	1.6	50	21	<.10	6.9
10-10-90	62	16	16	2.1	55	25	<.10	8.4
11-08-90	60	16	15	2.0	51	23	.30	8.0
12-10-90	64	16	15	1.6	48	24	.10	8.5
01-24-91	--	--	--	--	--	--	--	--
02-04-91	50	16	26	1.8	55	19	<.10	5.8
03-20-91	44	14	29	2.1	66	19	<.10	4.9
04-02-91	43	15	23	1.9	52	21	<.10	5.5
05-10-91	44	14	18	1.7	47	17	<.10	5.8
06-07-91	55	16	16	1.6	49	25	<.10	8.5
07-11-91	55	16	17	1.5	48	19	--	8.3
WVC-6 Site identification number 400152075371600 Latitude 40°01'52" Longitude 075°37'16" Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	44	16	14	1.9	28	17	.30	6.7
09-05-90	46	15	15	1.5	34	19	<.10	6.6
10-10-90	44	14	15	2.4	35	20	<.10	7.4
11-06-90	48	14	14	2.3	35	22	<.10	7.6
12-11-90	52	16	15	1.6	34	24	.10	7.5
01-23-91	--	--	--	--	--	--	--	--
02-05-91	44	16	18	1.5	39	22	.40	6.3
03-20-91	42	15	22	1.8	45	19	<.10	5.7
04-02-91	39	15	17	1.6	35	19	<.10	6.2
05-08-91	37	13	16	1.6	28	15	<.10	6.0
06-05-91	39	14	15	1.5	32	17	<.10	7.1
07-11-91	43	16	14	1.3	40	22	--	6.1

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
WVC-7 Site identification number 400151075371500 Latitude 40°01′51″ Longitude 075°37′15″ Unnamed tributary to Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	37	11	17	1.4	32	21	<0.10	8.2
09-05-90	40	11	18	1.5	32	19	<.10	8.3
10-10-90	--	--	--	--	--	--	--	--
11-06-90	40	11	17	2.3	32	19	<.10	7.7
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	32	23	<.10	--
03-20-91	--	--	--	--	33	--	--	--
04-02-91	--	--	--	--	30	--	--	--
05-08-91	--	--	--	--	29	--	--	--
06-05-91	35	9.9	16	1.2	32	21	<.10	7.7
07-11-91	37	11	17	1.1	30	18	--	7.9
WVC-8 Site identification number 400159075380800 Latitude 40°01′59″ Longitude 075°38′08″ Unnamed tributary to Valley Creek at Waterloo Boulevard near Exton, Pa.								
08-16-90	30	13	13	2.9	35	15	<.10	13
09-05-90	32	14	15	2.6	36	18	<.10	10
10-11-90	34	14	14	3.3	35	20	<.10	10
11-06-90	32	13	12	3.6	28	19	<.10	9.8
12-10-90	34	14	13	2.4	34	22	<.10	12
01-23-91	--	--	--	--	--	--	--	--
02-05-91	30	13	15	2.3	39	22	<.10	8.5
03-21-91	30	13	16	2.6	37	20	<.10	7.2
04-02-91	29	12	14	2.5	32	19	<.10	5.5
05-10-91	31	14	14	3.0	33	18	<.10	7.8
06-05-91	31	13	14	2.3	38	19	<.10	13
07-09-91	31	13	13	2.8	35	20	--	10

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (µg/L as Sr)	Lithium, dissolved (µg/L as Li)	Boron, dissolved (µg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Chromium, dissolved (µg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-5 Site identification number 400157075370100 Latitude 40°01'57" Longitude 075°37'01" Valley Creek at Lakeside Street near Exton, Pa.								
08-16-90	130	270	30	0.15	36	6	<1	249
09-06-90	150	620	30	.34	6	6	<1	292
10-10-90	160	310	20	.17	9	11	<1	287
11-08-90	160	340	30	--	12	6	<1	275
12-10-90	--	27	20	--	6	7	<1	287
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	170	--	--	54	12	--	276
03-20-91	--	290	--	--	22	15	--	248
04-02-91	--	300	--	--	19	18	--	239
05-10-91	--	330	--	--	16	14	--	239
06-07-91	--	330	--	--	17	17	--	262
07-11-91	140	490	--	.24	8	7	--	--
WVC-6 Site identification number 400152075371600 Latitude 40°01'52" Longitude 075°37'16" Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	100	110	20	.090	19	36	<1	263
09-05-90	100	190	20	.14	14	35	<1	250
10-10-90	100	210	20	.10	22	34	<1	226
11-06-90	110	110	20	--	35	39	<1	230
12-11-90	--	19	20	--	10	23	<1	234
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	69	30	--	13	23	--	229
03-20-91	--	100	40	--	18	33	--	232
04-02-91	--	140	30	--	16	28	--	213
05-08-91	--	96	20	--	20	23	<1	215
06-05-91	--	180	20	--	20	34	<1	205
07-11-91	100	170	20	.10	15	34	--	--

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (µg/L as Sr)	Lithium, dissolved (µg/L as Li)	Boron, dissolved (µg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Chromium, dissolved (µg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-7 Site identification number 400151075371500 Latitude 40°01'51" Longitude 075°37'15" Unnamed tributary to Valley Creek at Chester County Library near Exton, Pa.								
08-16-90	97	4	20	0.050	15	9	<10	186
09-05-90	110	5	20	.060	24	9	<1	191
10-10-90	--	<10	20	--	--	--	<1	--
11-06-90	100	<4	20	--	27	17	<1	192
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	--	--	--	--
03-20-91	--	--	--	--	--	--	--	--
04-02-91	--	--	--	--	--	--	--	--
05-08-91	--	--	--	--	--	--	--	--
06-05-91	--	<4	--	--	18	10	--	176
07-11-91	110	<10	--	.050	11	11	--	--
WVC-8 Site identification number 400159075380800 Latitude 40°01'59" Longitude 075°38'08" Unnamed tributary to Valley Creek at Waterloo Boulevard near Exton, Pa.								
08-16-90	140	6	20	.040	12	14	5	189
09-05-90	160	5	20	.050	15	36	<1	193
10-11-90	150	<4	20	.030	13	8	<1	208
11-06-90	140	<4	30	--	29	8	<1	176
12-10-90	--	<4	<10	--	14	10	<1	196
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	8	9	--	176
03-21-91	--	--	--	--	15	16	--	184
04-02-91	--	--	--	--	10	12	--	174
05-10-91	--	--	--	--	27	12	--	181
06-05-91	--	<4	--	--	15	12	--	190
07-09-91	140	<10	--	.040	12	8	--	--

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temperature, water (°C)	Temperature, air (°C)	Discharge, instantaneous (ft^3/s)	Turbidity (NTU)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-9 Site identification number 400116075383800 Latitude 40°01'16" Longitude 075°38'38" Valley Creek near Clover Mill and Whitford Roads near Exton, Pa.								
08-17-90	20.0	34.0	3.6	41	419	1.0	7.0	135
09-05-90	18.0	21.5	3.2	1.0	430	11.1	8.4	144
10-11-90	18.5	23.0	2.0	1.4	428	7.0	6.4	135
11-06-90	12.5	11.0	3.4	2.0	381	9.6	6.8	151
12-10-90	4.5	8.0	3.4	1.0	419	12.1	7.6	138
01-23-91	1.0	-1.5	8.2	--	442	14.8	7.2	137
02-04-91	5.5	15.5	6.6	1.2	418	17.1	8.4	130
03-21-91	8.0	9.5	8.0	2.4	422	14.1	7.2	144
04-03-91	6.5	6.0	8.6	1.5	415	15.2	7.4	132
05-10-91	13.5	19.5	7.5	1.4	400	9.8	7.4	120
06-05-91	16.5	15.5	3.4	2.3	399	9.2	7.5	135
07-11-91	19.5	26.0	2.0	1.4	405	8.7	7.4	148
WVC-10 Site identification number 400114075383100 Latitude 40°01'14" Longitude 075°38'31" Unnamed tributary to Valley Creek at Whitford Road near Exton, Pa.								
08-16-90	19.5	27.0	.60	2.0	370	8.8	6.9	96
09-05-90	17.0	23.0	.48	1.1	370	9.4	8.2	102
10-12-90	19.5	24.5	.29	.90	410	8.4	7.0	143
11-06-90	11.0	7.5	.55	1.0	380	1.1	6.7	118
12-10-90	4.5	7.5	.62	.60	319	13.2	7.5	107
01-23-91	1.0	0.0	1.7	--	397	15.4	7.0	96
02-05-91	8.0	19.0	1.2	1.0	385	14.4	8.1	95
03-21-91	8.0	10.0	1.4	1.8	360	13.1	6.8	99
04-03-91	7.5	5.5	1.4	1.1	353	12.5	7.2	96
05-10-91	13.5	20.0	1.2	2.7	350	1.3	7.3	100
06-05-91	15.5	17.5	.62	2.6	368	9.7	7.4	104
07-11-91	18.5	26.0	.32	2.0	373	9.0	7.5	120
10-04-91	19.0	27.0	.28	--	383	1.1	7.5	103

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temperature, water (°C)	Temperature, air (°C)	Discharge, instantaneous (ft^3/s)	Turbidity (NTU)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-11 Site identification number 400043075392000 Latitude 40°00'43" Longitude 075°39'20" Valley Creek near Clover Mill near Exton, Pa.								
08-17-90	19.0	29.5	6.4	3.5	399	9.5	6.9	131
09-06-90	17.5	21.0	5.1	1.0	415	9.3	8.1	118
10-11-90	19.5	22.5	3.8	2.6	406	8.6	7.1	140
11-07-90	9.5	15.5	3.1	3.0	407	15.0	7.4	134
12-07-90	4.5	6.5	6.2	1.5	417	13.2	7.4	130
01-24-91	3.5	6.0	12	--	415	15.4	7.8	128
02-04-91	4.5	13.5	10	--	396	15.2	7.8	138
03-21-91	10.0	13.5	11	--	381	16.0	7.9	116
04-03-91	11.0	13.0	12	--	360	16.7	8.1	123
05-08-91	13.0	20.0	12	--	361	1.5	7.4	116
06-06-91	16.0	21.5	4.7	1.5	375	9.3	7.3	126
07-09-91	20.5	27.0	3.6	1.5	385	8.3	7.6	122
WVC-12 Site identification number 400043075392300 Latitude 40°00'43" Longitude 075°39'23" Unnamed tributary to Valley Creek near Clover Mill Road near Exton, Pa.								
08-17-90	23.0	29.5	.08	1.1	725	8.2	7.2	251
09-06-90	16.0	21.0	.06	1.4	710	7.2	8.0	224
12-07-90	5.5	9.5	.13	1.0	480	11.8	7.4	166
01-24-91	2.0	6.0	.82	--	386	14.1	7.0	116
02-04-91	2.5	12.0	.44	--	397	13.6	7.4	112
03-21-91	9.5	14.5	.62	--	374	14.1	7.3	116
04-03-91	11.0	13.5	.77	--	355	14.0	7.4	99
05-08-91	11.5	20.5	.75	--	401	1.4	7.2	112
06-06-91	14.0	20.0	.03	1.9	590	8.1	7.1	216
07-09-91	19.0	25.0	.06	5.0	660	5.7	7.8	248

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-9 Site identification number 400116075383800 Latitude 40°01'16" Longitude 075°38'38" Valley Creek near Clover Mill and Whitford Roads near Exton, Pa.								
08-17-90	0.020	0.30	0.30	0.010	2.30	0.040	0.040	0.030
09-05-90	.020	.50	.40	.010	2.30	.030	.020	.010
10-11-90	.010	.30	.30	.030	1.80	.060	.030	.040
11-06-90	.110	.60	.60	.030	2.20	.060	.040	.050
12-10-90	.020	.40	.30	<.010	2.80	.050	.050	.040
01-23-91	--	--	--	--	--	--	--	--
02-04-91	<.010	--	--	<.010	2.50	--	--	<.010
03-21-91	<.010	--	--	.010	2.10	--	--	.010
04-03-91	.010	--	--	<.010	2.30	--	--	<.010
05-10-91	.060	--	--	.030	2.40	--	--	.020
06-05-91	.040	--	--	.030	2.10	--	--	<.010
07-11-91	.040	--	--	.020	2.30	--	--	.040
WVC-10 Site identification number 400114075383100 Latitude 40°01'14" Longitude 075°38'31" Unnamed tributary to Valley Creek at Whitford Road near Exton, Pa.								
08-16-90	<.010	.40	.60	<.010	2.80	.020	.010	<.010
09-05-90	<.010	.60	.60	<.010	3.00	.160	.020	<.010
10-12-90	<.010	.40	<.20	.010	2.10	.010	<.010	<.010
11-06-90	.050	.30	1.4	<.010	2.80	<.010	<.010	<.010
12-10-90	.020	.30	.50	<.010	2.90	.010	<.010	<.010
01-23-91	--	--	--	--	--	--	--	--
02-05-91	<.010	--	--	<.010	3.00	--	--	<.010
03-21-91	<.010	--	--	.010	2.70	--	--	<.010
04-03-91	<.010	--	--	<.010	2.70	--	--	<.010
05-10-91	.030	--	--	.010	2.80	--	--	.010
06-05-91	.020	--	--	.020	2.80	--	--	<.010
07-11-91	.020	--	--	<.010	2.80	--	--	.010
10-04-91	.040	<.20	--	<.010	2.40	--	--	<.010

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-11 Site identification number 400043075392000 Latitude 40°00'43" Longitude 075°39'20" Valley Creek near Clover Mill near Exton, Pa.								
08-17-90	<0.010	0.30	0.40	<0.010	2.30	0.040	0.030	0.030
09-06-90	.020	.20	.30	<.010	2.10	.030	<.010	<.010
10-11-90	<.010	.50	.40	.020	1.50	.070	.030	.030
11-07-90	.050	.40	.40	.010	1.90	.100	.100	.110
12-07-90	.020	<.20	.40	<.010	2.40	.030	.020	.020
01-24-91	--	--	--	--	--	--	--	--
02-04-91	<.010	--	--	<.010	2.50	--	--	<.010
03-21-91	<.010	--	--	.020	2.00	--	--	<.010
04-03-91	--	--	--	--	--	--	--	--
05-08-91	.040	--	--	.020	2.10	--	--	.010
06-06-91	.020	--	--	.020	2.20	--	--	<.010
07-09-91	.010	--	--	.010	1.90	--	--	.030
WVC-12 Site identification number 400043075392300 Latitude 40°00'43" Longitude 075°39'23" Unnamed tributary to Valley Creek near Clover Mill Road near Exton, Pa.								
08-17-90	.030	.30	.30	.010	3.00	.020	.020	.020
09-06-90	.020	.30	.40	.010	2.60	.020	.020	.020
12-07-90	.020	.50	.70	<.010	2.20	.020	.010	.010
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-21-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-08-91	.030	--	--	.020	2.20	--	--	<.010
06-06-91	.040	--	--	.040	2.50	--	--	.010
07-09-91	.030	--	--	.020	2.10	--	--	.020

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)
WVC-9 Site identification number 400116075383800 Latitude 40°01'16" Longitude 075°38'38" Valley Creek near Clover Mill and Whitford Roads near Exton, Pa.								
08-17-90	43	16	14	2.0	30	18	<0.10	8.2
09-05-90	45	18	16	1.9	34	19	<.10	5.3
10-11-90	45	18	15	2.8	35	22	<.10	7.0
11-06-90	40	15	13	3.2	29	21	<.10	5.7
12-10-90	48	18	14	2.1	34	24	.10	8.2
01-23-91	--	--	--	--	--	--	--	--
02-04-91	44	16	17	1.8	45	20	<.10	5.6
03-21-91	43	16	17	1.8	39	21	<.10	4.7
04-03-91	43	16	16	1.8	34	21	<.10	4.9
05-10-91	42	16	14	1.9	32	17	<.10	6.2
06-05-91	41	16	14	1.7	36	20	<.10	8.3
07-11-91	43	18	14	1.8	40	22	--	5.8
WVC-10 Site identification number 400114075383100 Latitude 40°01'14" Longitude 075°38'31" Unnamed tributary to Valley Creek at Whitford Road near Exton, Pa.								
08-16-90	36	11	18	1.7	36	21	<.10	7.5
09-05-90	41	12	20	1.5	33	18	<.10	7.5
10-12-90	43	12	18	2.1	34	21	<.10	7.9
11-06-90	38	12	20	2.6	37	23	.30	6.3
12-10-90	41	12	17	1.5	34	23	.10	6.0
01-23-91	--	--	--	--	--	--	--	--
02-05-91	37	11	22	1.4	44	24	<.10	5.1
03-21-91	37	11	21	1.3	40	21	.10	5.7
04-03-91	36	11	19	1.3	36	21	<.10	5.2
05-10-91	35	11	18	1.4	34	18	<.10	6.7
06-05-91	37	11	18	1.4	39	21	<.10	7.8
07-11-91	40	12	18	1.6	34	18	--	7.7
10-04-91	43	12	18	1.7	32	21	.10	6.8

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
WVC-11 Site identification number 400043075392000 Latitude 40°00'43" Longitude 075°39'20" Valley Creek near Clover Mill near Exton, Pa.								
08-17-90	43	16	14	1.9	29	16	<0.10	7.9
09-06-90	45	16	15	1.8	29	17	<.10	5.8
10-11-90	44	16	14	2.7	34	22	<.10	6.4
11-07-90	44	16	13	2.2	33	21	<.10	5.9
12-07-90	47	16	15	2.0	31	25	.10	7.5
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	36	23	<.10	--
03-21-91	--	--	--	--	37	20	.30	--
04-03-91	--	--	--	--	33	24	.20	--
05-08-91	--	--	--	--	29	17	<.10	--
06-06-91	39	14	15	1.7	35	22	<.10	8.0
07-09-91	40	15	14	2.1	32	20	--	6.7
WVC-12 Site identification number 400043075392300 Latitude 40°00'43" Longitude 075°39'23" Unnamed tributary to Valley Creek near Clover Mill Road near Exton, Pa.								
08-17-90	78	28	24	3.4	51	53	.10	7.5
09-06-90	81	30	26	3.5	52	54	<.10	7.2
12-07-90	53	19	17	3.3	37	39	.10	9.0
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	28	32	<.10	--
03-21-91	--	--	--	--	30	29	.20	--
04-03-91	--	--	--	--	26	37	.10	--
05-08-91	--	--	--	--	33	28	<.10	--
06-06-91	68	25	18	2.9	40	48	<.10	8.0
07-09-91	80	31	20	3.7	43	52	--	7.5

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (μg/L as Sr)	Lithium, dissolved (μg/L as Li)	Boron, dissolved (μg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Chromium, dissolved (μg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-9 Site identification number 400116075383800 Latitude 40°01'16" Longitude 075°38'38" Valley Creek near Clover Mill and Whitford Roads near Exton, Pa.								
08-17-90	100	60	20	0.070	10	13	<1	256
09-05-90	120	83	20	.090	12	11	<1	265
10-11-90	110	85	30	.050	31	23	<1	238
11-06-90	120	35	30	--	59	24	<1	205
12-10-90	--	37	20	--	15	22	<1	239
01-23-91	--	--	--	--	--	--	--	--
02-04-91	--	38	--	--	7	21	--	246
03-21-91	--	63	--	--	68	39	--	236
04-03-91	--	62	--	--	10	33	--	225
05-10-91	--	73	--	--	14	31	--	227
06-05-91	--	93	--	--	23	25	--	215
07-11-91	110	90	--	.070	14	12	--	--
WVC-10 Site identification number 400114075383100 Latitude 40°01'14" Longitude 075°38'31" Unnamed tributary to Valley Creek at Whitford Road near Exton, Pa.								
08-16-90	96	26	30	.080	7	9	2	192
09-05-90	110	28	30	.090	5	10	2	231
10-12-90	110	32	20	.060	15	11	2	230
11-06-90	100	26	30	--	90	18	1	212
12-10-90	--	31	20	--	17	17	2	201
01-23-91	--	--	--	--	--	--	--	--
02-05-91	--	27	30	--	13	13	--	166
03-21-91	--	25	30	--	22	20	--	205
04-03-91	--	27	30	--	17	21	<1	182
05-10-91	--	24	30	--	12	20	1	198
06-05-91	--	27	30	--	6	10	<1	196
07-11-91	100	30	20	.080	5	7	2	--
10-04-91	110	40	--	--	11	7	--	--

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (μg/L as Sr)	Lithium, dissolved (μg/L as Li)	Boron, dissolved (μg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Chromium, dissolved (μg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-11 Site identification number 400043075392000 Latitude 40°00'43" Longitude 075°39'20" Valley Creek near Clover Mill near Exton, Pa.								
08-17-90	100	42	20	0.070	7	12	<1	214
09-06-90	110	72	30	.080	10	7	<1	233
10-11-90	100	68	30	.050	24	13	<1	221
11-07-90	110	42	20	--	29	12	<1	227
12-07-90	--	24	20	--	21	20	<1	<223
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	40	20	--	--	--	--	--
03-21-91	--	50	--	--	--	--	--	--
04-03-91	--	50	--	--	--	--	--	--
05-08-91	--	50	20	--	--	--	<1	--
06-06-91	--	69	20	--	17	18	<1	210
07-09-91	100	160	20	.11	15	13	--	--
WVC-12 Site identification number 400043075392300 Latitude 40°00'43" Longitude 075°39'23" Unnamed tributary to Valley Creek near Clover Mill Road near Exton, Pa.								
08-17-90	130	7	20	.060	4	16	<1	464
09-06-90	130	8	20	.050	15	20	<1	479
12-07-90	--	8	30	--	22	21	<1	266
01-24-91	--	--	--	--	--	--	--	--
02-04-91	--	--	--	--	--	--	--	--
03-21-91	--	--	--	--	--	--	--	--
04-03-91	--	--	--	--	--	--	--	--
05-08-91	--	--	--	--	--	--	--	--
06-06-91	--	<4	--	--	39	25	--	344
07-09-91	120	<10	--	.050	13	18	--	--

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temper-ature, water (°C)	Temper-ature, air (°C)	Dis-charge, inst. (ft^3/s)	Turbidity (NTU)	Specific conduc-tance (µS/cm)	Oxy-gen, dis-solved (mg/L)	pH, water whole field (stand-ard units)	Alka-linity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-13 Site identification number 01480887 Latitude 39°59'55" Longitude 075°39'52" Valley Creek at Ravine Road near Downingtown, Pa.								
08-17-90	20.0	25.0	6.6	1.2	425	8.4	7.0	120
09-06-90	18.0	27.0	5.6	1.0	410	1.0	8.2	138
10-11-90	19.0	22.0	3.7	1.0	465	8.0	6.8	140
11-07-90	9.5	9.5	3.7	1.0	480	12.3	7.1	146
12-11-90	4.5	1.0	7.2	1.0	460	12.3	7.4	134
01-24-91	3.0	7.5	16	--	435	12.9	7.1	123
02-05-91	7.0	18.5	9.7	--	440	17.3	8.2	123
03-21-91	9.5	12.5	15	--	425	16.1	7.7	138
04-03-91	10.0	1.5	13	--	359	15.8	7.5	112
05-09-91	13.5	14.0	11	--	338	1.5	7.4	113
06-10-91	20.0	28.0	4.2	.80	390	1.2	7.6	130
07-09-91	21.0	21.0	2.4	1.1	360	7.7	7.5	102
WVC-14 Site identification number 3958540753946 Latitude 39°58'54" Longitude 075°39'46" Broad Run at Valley Creek near Downingtown, Pa.								
08-17-90	18.0	25.5	2.7	5.0	321	9.6	6.7	56
09-06-90	18.0	28.5	2.7	.30	250	9.6	8.0	50
10-11-90	17.5	21.5	2.1	.80	265	8.7	6.6	59
11-07-90	7.0	7.0	2.0	.30	260	12.8	6.8	71
12-11-90	4.5	2.0	2.5	1.0	250	13.6	7.3	122
01-24-91	3.5	1.5	6.6	--	261	13.0	6.9	40
02-11-91	4.0	2.5	4.8	.30	250	14.0	6.8	49
03-21-91	9.0	15.0	5.4	1.0	249	9.9	7.0	53
04-03-91	10.5	13.5	6.7	1.0	239	12.1	7.0	48
05-09-91	12.5	15.0	5.6	.60	239	11.1	7.1	46
06-10-91	17.5	3.0	2.6	.40	252	1.0	7.4	58
07-12-91	17.0	17.5	2.3	.40	258	9.1	7.3	56
10-05-91	17.0	26.5	2.8	--	270	1.3	7.3	75

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Temperature, water (°C)	Temperature, air (°C)	Discharge, inst. (ft^3/s)	Turbidity (NTU)	Specific conductance (μS/cm)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Alkalinity, water whole total fixed endpoint (mg/L as $CaCO_3$)
WVC-15 Site identification number 01480903 Latitude 39°58'31" Longitude 075°39'48" Valley Creek at Mullsteins Meadow near Downingtown, Pa.								
08-17-90	19.0	24.0	12	0.40	369	1.2	6.9	99
09-06-90	20.5	27.5	8.6	1.0	350	14.8	9.1	96
10-11-90	19.0	23.0	6.1	.50	390	1.2	6.9	114
10-11-90	--	--	--	--	--	--	--	--
11-07-90	7.5	4.5	9.0	.70	398	12.4	6.6	115
12-11-90	4.0	.5	10	1.0	390	14.2	7.8	114
01-24-91	2.5	2.5	28	--	354	14.1	7.2	116
02-11-91	4.5	2.5	19	.40	320	16.1	6.8	95
03-21-91	8.5	11.5	24	1.4	353	14.2	7.1	98
04-03-91	8.5	1.5	23	2.0	323	14.2	7.4	93
05-09-91	14.0	14.0	21	1.1	295	11.3	7.4	88
06-07-91	18.5	19.5	9.2	.70	325	13.7	8.0	90
07-12-91	19.0	22.0	7.7	1.1	377	9.9	7.6	104
WVC-16 Site identification number 400106075372400 Latitude 40°01'06" Longitude 075°37'42" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 20)								
10-03-91	18.0	23.0	.47	--	352	8.8	7.3	85
WVC-17 Site identification number 4001150753746 Latitude 40°01'15" Longitude 075°37'46" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 33)								
10-04-91	17.0	23.0	.29	--	336	8.8	7.3	100
WVC-18 Site identification number 395940075375800 Latitude 39°59'40" Longitude 075°37'58" Broad Run at Grove Road near Exton, Pa. (seepage site no. 35)								
10-05-91	19.0	24.5	.49	--	269	10.0	7.2	66
WVC-19 Site identification number 395908075384700 Latitude 39°59'08" Longitude 075°38'47" Broad Run at Copeland School Road near Exton, Pa. (seepage site no. 35)								
10-05-91	19.0	24.0	1.7	--	290	11.0	7.3	79
WVC-20 Site identification number 400217075365700 Latitude 40°02'17" Longitude 075°36'57" Unnamed tributary to West Valley Creek at Swedesford Road near Exton, Pa. (seepage site no. 36)								
10-07-91	12.5	--	.08	--	385	10.5	7.6	199

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-13 Site identification number 01480887 Latitude 39°59'55" Longitude 075°39'52" Valley Creek at Ravine Road near Downingtown, Pa.								
08-17-90	0.020	0.50	0.60	0.010	2.40	0.030	0.020	0.020
09-06-90	.020	.30	.30	<.010	2.20	.020	<.010	<.010
10-11-90	.010	.40	.60	.020	2.30	<.010	<.010	.010
11-07-90	.100	.70	.70	.040	3.20	.050	.060	.050
12-11-90	.030	.50	.30	.010	3.00	.020	.010	<.010
01-24-91	--	--	--	--	--	--	--	--
02-05-91	.020	--	--	.020	2.90	--	--	<.010
03-21-91	<.010	--	--	.020	2.40	--	--	<.010
04-03-91	--	--	--	--	--	--	--	--
05-09-91	.040	--	--	.030	2.10	--	--	.020
06-10-91	.020	--	--	.010	2.10	--	--	<.010
07-09-91	.020	--	--	.020	2.20	--	--	.020
WVC-14 Site identification number 3958540753946 Latitude 39°58'54" Longitude 075°39'46" Broad Run at Valley Creek near Downingtown, Pa.								
08-17-90	<.010	.20	.30	<.010	3.10	.030	.020	.010
09-06-90	.010	.60	.30	<.010	3.10	.020	<.010	<.010
10-11-90	<.010	.20	.30	<.010	3.00	.030	<.010	<.010
11-07-90	.050	.60	.70	<.010	3.10	<.010	.020	<.010
12-11-90	.020	.50	.60	<.010	3.60	.020	.010	.010
01-24-91	--	--	--	--	--	--	--	--
02-11-91	.010	--	--	<.010	3.60	--	--	<.010
03-21-91	<.010	--	--	<.010	3.20	--	--	.010
04-03-91	<.010	--	--	<.010	3.30	--	--	<.010
05-09-91	<.010	--	--	<.010	3.10	--	--	<.010
06-10-91	<.010	--	--	.010	3.20	--	--	<.010
07-12-91	<.010	--	--	<.010	3.10	--	--	.020
10-05-91	.070	<.20	--	<.010	3.30	--	--	.010

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)
WVC-15 Site identification number 01480903 Latitude 39°58'31" Longitude 075°39'48" Valley Creek at Mullsteins Meadow near Downingtown, Pa.								
08-17-90	<0.010	0.40	0.30	<0.010	2.50	0.030	0.020	0.020
09-06-90	.020	.40	.50	<.010	2.30	.020	.020	<.010
10-11-90	<.020	.20	.50	<.010	2.40	.020	<.010	<.010
10-11-90	--	--	--	--	--	--	--	--
11-07-90	.060	.40	.40	.020	2.80	.060	.040	.050
12-11-90	.010	.20	.50	.010	3.00	.010	.010	<.010
01-24-91	--	--	--	--	--	--	--	--
02-11-91	<.010	--	--	<.010	2.50	--	--	<.010
03-21-91	<.010	--	--	.010	2.50	--	--	<.010
04-03-91	<.010	--	--	.010	2.50	--	--	<.010
05-09-91	.020	--	--	.020	2.40	--	--	.010
06-07-91	<.010	--	--	.010	2.40	--	--	<.010
07-12-91	.020	--	--	<.010	2.50	--	--	.010
WVC-16 Site identification number 400106075372400 Latitude 40°01'06" Longitude 075°37'42" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 20)								
10-03-91	.030	<.20	--	<.010	4.30	--	--	.020
WVC-17 Site identification number 4001150753746 Latitude 40°01'15" Longitude 075°37'46" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 33)								
10-04-91	.040	<.20	--	<.010	3.70	--	--	>.010
WVC-18 Site identification number 395940075375800 Latitude 39°59'40" Longitude 075°37'58" Broad Run at Grove Road near Exton, Pa. (seepage site no. 35)								
10-05-91	.030	<.20	--	<.010	3.10	--	--	<.010
WVC-19 Site identification number 395908075384700 Latitude 39°59'08" Longitude 075°38'47" Broad Run at Copeland School Road near Exton, Pa. (seepage site no. 35)								
10-05-91	.040	<.20	--	<.010	3.70	--	--	.010
WVC-20 Site identification number 400217075365700 Latitude 40°02'17" Longitude 075°36'57" Unnamed tributary to West Valley Creek at Swedesford Road near Exton, Pa. (seepage site no. 36)								
10-07-91	.060	<.20	--	<.010	6.00	--	--	.030

***Table* 34.** *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dis- solved (mg/L as Ca)	Magne- sium, dis- solved (mg/L as Mg)	Sodium, dis- solved (mg/L as Na)	Potas- sium, dis- solved (mg/L as K)	Chlo- ride, dis- solved (mg/L as Cl)	Sulfate, dis- solved (mg/L as SO_4)	Fluo- ride, dis- solved (mg/L as F)	Silica, dis- solved (mg/L as SiO_2)
WVC-13 Site identification number 01480887 Latitude 39°59′55″ Longitude 075°39′52″ Valley Creek at Ravine Road near Downingtown, Pa.								
08-17-90	40	23	13	3.1	26	48	<0.10	6.1
09-06-90	42	19	13	2.4	27	37	<.10	4.9
10-11-90	39	28	13	4.5	28	66	<.10	4.2
11-07-90	44	27	12	4.5	27	62	<.10	4.0
12-11-90	49	22	13	2.7	28	48	<.10	5.8
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	--	--	--	32	46	<.10	--
03-21-91	--	--	--	--	35	42	<.10	--
04-03-91	--	--	--	--	33	26	.10	--
05-09-91	--	--	--	--	28	20	<.10	--
06-10-91	41	15	11	1.5	30	26	.20	6.8
07-09-91	39	23	12	3.3	30	68	--	5.9
WVC-14 Site identification number 3958540753946 Latitude 39°58′54″ Longitude 075°39′46″ Broad Run at Valley Creek near Downingtown, Pa.								
08-17-90	17	8.3	12	1.3	25	15	<.10	9.7
09-06-90	17	8.2	13	1.3	23	18	<.10	9.1
10-11-90	23	8.0	12	1.6	25	20	.10	9.2
11-07-90	23	8.4	12	1.6	26	20	<.10	8.6
12-11-90	23	8.3	12	1.4	25	18	.10	8.9
01-24-91	--	--	--	--	--	--	--	--
02-11-91	22	8.0	13	1.3	29	22	<.10	8.0
03-21-91	21	7.8	13	1.3	28	20	<.10	8.2
04-03-91	21	7.6	13	1.3	26	21	<.10	8.4
05-09-91	22	8.5	13	1.3	25	17	<.10	8.1
06-10-91	22	8.0	12	1.1	24	24	<.10	9.4
07-12-91	22	8.5	12	1.3	24	20	--	9.0
10-05-91	23	8.9	14	1.5	25	21	.10	8.7

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
WVC-15 Site identification number 01480903 Latitude 39°58'31" Longitude 075°39'48" Valley Creek at Mullsteins Meadow near Downingtown, Pa.								
08-17-90	33	17	12	2.7	26	40	<0.10	7.0
09-06-90	34	17	13	2.5	23	40	<.10	4.6
10-11-90	32	20	12	3.1	24	43	<.10	5.8
10-11-90	--	--	--	--	--	--	--	--
11-07-90	37	19	12	3.0	26	39	<.10	4.4
12-11-90	39	17	13	2.4	26	38	.10	6.1
01-24-91	--	--	--	--	--	--	--	--
02-11-91	35	12	14	1.5	27	21	<.10	4.9
03-21-91	35	14	15	1.9	31	33	<.10	4.2
04-03-91	32	13	12	1.7	26	28	<.10	5.4
05-09-91	31	14	12	1.8	24	30	<.10	5.5
06-07-91	29	15	11	1.7	26	39	<.10	6.0
07-12-91	33	19	12	2.6	26	50	--	5.3
WVC-16 Site identification number 400106075372400 Latitude 40°01'06" Longitude 075°37'42" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 20)								
10-03-91	27	13	24	1.8	39	19	.10	6.5
WVC-17 Site identification number 4001150753746 Latitude 40°01'15" Longitude 075°37'46" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 33)								
10-04-91	28	12	22	1.9	37	18	.10	6.7
WVC-18 Site identification number 395940075375800 Latitude 39°59'40" Longitude 075°37'58" Broad Run at Grove Road near Exton, Pa. (seepage site no. 35)								
10-05-91	26	10	12	1.2	28	17	.20	7.6
WVC-19 Site identification number 395908075384700 Latitude 39°59'08" Longitude 075°38'47" Broad Run at Copeland School Road near Exton, Pa. (seepage site no. 35)								
10-05-91	27	9.8	16	1.4	28	22	.10	8.6
WVC-20 Site identification number 400217075365700 Latitude 40°02'17" Longitude 075°36'57" Unnamed tributary to West Valley Creek at Swedesford Road near Exton, Pa. (seepage site no. 36)								
10-07-91	41	27	4.1	2.2	9.7	15	.10	8.6

***Table 34.** Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (μg/L as Sr)	Lithium, dissolved (μg/L as Li)	Boron, dissolved (μg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Chromium, dissolved (μg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-13 Site identification number 01480887 Latitude 39°59′55″ Longitude 075°39′52″ Valley Creek at Ravine Road near Downingtown, Pa.								
08-17-90	92	27	20	0.050	11	17	3	231
09-06-90	98	46	20	.070	10	16	<1	272
10-11-90	87	33	20	.040	26	25	<1	269
11-07-90	99	21	20	--	33	21	<1	265
12-11-90	--	20	20	--	11	17	<1	264
01-24-91	--	--	--	--	--	--	--	--
02-05-91	--	20	--	--	--	--	--	--
03-21-91	--	40	--	--	--	--	--	--
04-03-91	--	40	--	--	--	--	--	--
05-09-91	--	40	--	--	--	--	--	--
06-10-91	--	37	--	--	22	24	--	206
07-09-91	100	70	--	.060	15	24	--	--
WVC-14 Site identification number 3958540753946 Latitude 39°58′54″ Longitude 075°39′46″ Broad Run at Valley Creek near Downingtown, Pa.								
08-17-90	110	<4	10	.050	11	6	1	131
09-06-90	100	4	20	.050	14	6	<1	157
10-11-90	110	6	20	.040	19	7	<1	152
11-07-90	110	5	20	--	36	7	<1	139
12-11-90	--	<4	<10	--	21	10	<1	141
01-24-91	--	--	--	--	--	--	--	--
02-11-91	--	--	--	--	17	12	--	199
03-21-91	--	--	--	--	18	11	--	138
04-03-91	--	--	--	--	15	11	--	141
05-09-91	--	--	--	--	16	12	--	142
06-10-91	--	<4	--	--	11	6	--	138
07-12-91	100	<10	--	.060	11	6	--	--
10-05-91	130	<10	--	--	12	5	--	--

Table 34. *Discharge, physical and chemical properties, and results of chemical analyses for nutrients, major ions, and selected trace constituents in surface water, West Valley Creek Basin, Pennsylvania, August 1990 - July 1991, and October 1991—Continued*

Date	Strontium, dissolved (µg/L as Sr)	Lithium, dissolved (µg/L as Li)	Boron, dissolved (µg/L as B)	Bromide, dissolved (mg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Chromium, dissolved (µg/L as Cr)	Solids, residue at 180°C, dissolved (mg/L)
WVC-15 Site identification number 01480903 Latitude 39°58'31" Longitude 075°39'48" Valley Creek at Mullsteins Meadow near Downingtown, Pa.								
08-17-90	88	21	20	0.050	9	10	<1	195
09-06-90	97	28	20	.050	20	5	<1	248
10-11-90	92	20	20	.030	24	17	<1	220
10-11-90	--	--	--	--	--	--	--	--
11-07-90	100	19	20	--	21	9	<1	213
12-11-90	--	16	20	--	12	9	<1	219
01-24-91	--	--	--	--	--	--	--	--
02-11-91	--	24	--	--	68	13	--	183
03-21-91	--	21	--	--	11	18	--	222
04-03-91	--	23	--	--	10	16	--	168
05-09-91	--	21	--	--	15	14	--	202
06-07-91	--	30	--	--	11	11	--	178
07-12-91	90	20	--	.050	12	11	--	--
WVC-16 Site identification number 400106075372400 Latitude 40°01'06" Longitude 075°37'42" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 20)								
10-03-91	70	<10	--	--	21	3	--	--
WVC-17 Site identification number 4001150753746 Latitude 40°01'15" Longitude 075°37'46" Unnamed tributary to Valley Creek at Route 100 near Exton, Pa. (seepage site no. 33)								
10-04-91	100	<10	--	--	9	5	--	--
WVC-18 Site identification number 395940075375800 Latitude 39°59'40" Longitude 075°37'58" Broad Run at Grove Road near Exton, Pa. (seepage site no. 35)								
10-05-91	100	<10	--	--	37	18	--	--
WVC-19 Site identification number 395908075384700 Latitude 39°59'08" Longitude 075°38'47" Broad Run at Copeland School Road near Exton, Pa. (seepage site no. 35)								
10-05-91	120	<10	--	--	15	8	--	--
WVC-20 Site identification number 400217075365700 Latitude 40°02'17" Longitude 075°36'57" Unnamed tributary to West Valley Creek at Swedesford Road near Exton, Pa. (seepage site no. 36)								
10-07-91	30	<10	--	--	7	12	--	--

Table 35. *Results of chemical analyses for selected metals and trace constituents in surface water, West Valley Creek Basin, Pennsylvania, November 1990*

[µg/L, micrograms per liter; <, less than]

Local identifier	Date	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)
WVC-1	11-08-90	20	<1	22	<0.5	<10	<1.0	<1	<3
WVC-2	11-08-90	<10	<1	23	<.5	70	<1.0	5	<3
WVC-3	11-07-90	<10	<1	29	.5	10	<1.0	<1	<3
WVC-4	11-08-90	<10	<1	18	<.5	<10	<1.0	<1	<3
WVC-5	11-08-90	<10	<1	31	<.5	30	<1.0	<1	<3
WVC-6	11-06-90	<10	<1	22	.5	20	<1.0	<1	<3
WVC-7	11-06-90	<10	<1	21	.5	20	<1.0	<1	<3
WVC-8	11-06-90	<10	<1	59	.5	30	<1.0	<1	<3
WVC-9	11-06-90	<10	<1	37	<.5	30	<1.0	<1	<3
WVC-10	11-06-90	30	<1	20	<.5	30	<1.0	1	<3
WVC-11	11-07-90	20	<1	26	<.5	20	<1.0	<1	<3
WVC-13	11-07-90	<10	<1	23	<.5	20	<1.0	<1	<3
WVC-14	11-07-90	20	<1	12	<.5	20	<1.0	<1	<3
WVC-15	11-07-90	10	<1	21	<.5	20	<1.0	<1	<3

Local identifier	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
WVC-1	<10	67	<10	6	<10	<10	<1.0	17	<6	3
WVC-2	<10	9	<10	14	<10	<10	<1.0	110	<6	7
WVC-3	<10	14	<10	8	<10	<10	<1.0	180	<6	<3
WVC-4	<10	10	<10	9	<10	<10	<1.0	21	<6	6
WVC-5	<10	12	<10	6	<10	<10	<1.0	160	<6	3
WVC-6	<10	35	<10	39	<10	<10	<1.0	110	<6	<3
WVC-7	<10	27	<10	17	<10	<10	<1.0	100	<6	<3
WVC-8	<10	29	<10	8	<10	<10	<1.0	140	<6	4
WVC-9	<10	59	<10	24	<10	<10	<1.0	120	<6	10
WVC-10	<10	90	<10	18	<10	<10	<1.0	100	<6	8
WVC-11	<10	29	<10	12	<10	<10	<1.0	110	<6	4
WVC-13	<10	33	<10	21	<10	<10	<1.0	99	<6	13
WVC-14	<10	36	<10	7	<10	<10	<1.0	110	<6	<3
WVC-15	<10	21	<10	9	<10	<10	<1.0	100	<6	6

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