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Notice

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

Nutrient inputs from human activities have resulted in the "cultural eutrophication" of lakes and coastal waters. This publication documents a study of the role of the shallow subsurface stratigraphy in determining the potential for nutrient impacts from nitrogen species on water quality in streams as a result of ground-water discharges to the streams. The study focused on two adjacent watersheds in Kent County, Maryland, that had similar topography, land use and soils. Although the watersheds were similar in landscape features and land use, it was found that the hydrostratigraphy of the aquifer underlying the watershed had a dominant role in producing the observed differences in nitrogen yields from the two watersheds. The study illustrates the importance of understanding hydrogeology for management of nitrogen yields from watersheds to coastal waters.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

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Abstract

Hydrostratigraphic and geochemical data collected in two adjacent watersheds on the Delmarva Peninsula, in Kent County, Maryland, indicate that shallow subsurface stratigraphy is an important factor that affects the concentrations of nitrogen in ground water discharging as stream base flow. The flux of nitrogen from shallow aquifers can contribute substantially to the eutrophication of streams and estuaries, degrading water quality and aquatic habitats. The information presented in this report includes a hydrostratigraphic framework for the Locust Grove study area, analyses and interpretation of ground-water chemistry, and an analysis of nutrient yields from stream base flow. An understanding of the processes by which ground-water nitrogen discharges to streams is important for optimal management of nutrients in watersheds in which ground-water discharge is an appreciable percentage of total streamflow. The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency (USEPA), collected and analyzed hydrostratigraphic and geochemical data in support of ground-water flow modeling by the USEPA.

The adjacent watersheds of Morgan Creek and Chesterville Branch have similar topography and land use; however, reported nitrogen concentrations are generally 6 to 10 milligrams per liter in Chesterville Branch but only 2 to 4 milligrams per liter in Morgan Creek. Ground water in the surficial aquifer in the recharge areas of both streams has high concentrations of nitrate (greater than 10 milligrams per liter as N) and dissolved oxygen. One component of the ground water discharging to Morgan Creek typically is anoxic and contains virtually no dissolved nitrate; most of the ground water discharging to Chesterville Branch is oxygenated and contains moderately high concentrations of nitrate.

The surficial aquifer in the study area is composed of the deeply weathered sands and gravels of the Pensauken Formation (the Columbia aquifer) and the underlying glauconitic sands of the upper Aquia Formation (the Aquia aquifer). The lower 6 to 9 meters of the Aquia Formation is a low-permeability silt-clay with abundant glauconite. The Aquia confining layer underlies the Columbia-Aquia surficial aquifer throughout the study area. The sediment redox transition, identified in cores, that occurs in the upper 0.5 to 1 meter of the Aquia confining layer is thought to be a site for subsurface denitrification of ground water. The first confined aquifer is composed of the glauconitic sands in the upper 9 to 11 meters of the Hornerstown Formation. The Hornerstown aquifer is underlain by 10 to 15 meters of glauconitic silt-clay at the base of the Hornerstown Formation (the Hornerstown confining layer), and 5 meters of low-permeability clay in the underlying Severn Formation.

The Aquia and Hornerstown Formations dip and thicken to the southeast, and the Aquia confining layer subcrops shallowly (within 5 meters of the land surface) in a band that strikes southwest to northeast across the northern edge of the study area. The surficial aquifer is very thin (generally less than 5 meters) north of Morgan Creek, and the alluvial valley of Morgan Creek has incised into the top of the Aquia confining layer. In contrast, the Aquia confining layer lies 22 meters below Chesterville Branch, and the surficial aquifer approaches 30 meters in thickness (away from the creek).

Chemically reduced iron sulfides and glauconite in the Aquia confining layer are likely substrates for denitrification of nitrate in ground water. Evidence from the dissolved concentrations of nitrate, sulfate, iron, argon, and nitrogen gas, and stable nitrogen isotopes support the interpretation that ground water flowing near the top of the Aquia confining layer, or through the confined Hornerstown aquifer, has undergone denitrification. This process appears to have the greatest effect on ground-water chemistry north of Morgan Creek, where the surficial aquifer is thin and a greater percentage of the ground water contacts the Aquia confining layer.

The base-flow discharges of total nitrogen from the two watersheds are of similar magnitude, although Chesterville Branch has somewhat higher loads (29,000 kilograms of nitrogen per year) than Morgan Creek (20,000 kilograms of nitrogen per year), although Morgan Creek has a larger drainage area and a greater discharge of water. The base-flow yield of nitrogen (load per unit area) in Chesterville Branch (median of 0.058 grams per second per square kilometer at the outlet) is more than twice that of Morgan Creek (median of 0.022 grams per second per square kilometer at the outlet), reflecting the higher concentration of nitrate in ground water discharging to Chesterville Branch. Total nitrogen concentrations tend to decrease downstream in Chesterville Branch and increase downstream in Morgan Creek. The downstream trend in Chesterville Branch may be affected by instream nitrogen uptake and denitrification, and an increasing proportion of older, denitrified ground water in downstream discharge. The downstream trends in Morgan Creek may be affected by inflow from tributaries, downstream changes in the source of discharge water, and downstream changes in the riparian zone, which could affect the processes and degree of denitrification.

Although these two watersheds appear to have landscape features (such as topography, land use, and soils) that would produce similar nitrogen discharges, a more detailed examination of landscape features indicates that Chesterville Branch has soils that are slightly better drained, tributary stream outlets at higher altitudes, and a slightly higher percentage of agricultural land. All of these factors have been related to higher nitrogen yields. Nonetheless, most of the data support the interpretation that hydrostratigraphy has the greatest effect in producing the difference in nitrogen yields between the two watersheds.

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SI Conversion Factors

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic feet (ft^3)	28.32	liters
pounds (lb)	0.4536	kilograms

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

$$°F = 1.8 (°C) + 32$$

Measurements in the interpretive sections of this report are given in metric units (modified SI system) to conform with U.S. Government policy and generally accepted scientific practice. However, many of the field measurements were made using U.S. Customary ("foot-pound") units, and are so reported in the appendices. The conversion tables above will aid the reader in converting from one system of measurement to the other.

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 the Sea Level Datum of 1929.

Chemical concentration is given in milligrams per liter (mg/L), which expresses the dissolved concentration of a constituent as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Concentrations of nitrogen compounds, such as nitrate (NO_3^-), are given in units of milligrams per liter as nitrogen (N).

Stable isotopic composition of nitrogen compounds, such as nitrate, are reported in standard delta notation ($\delta^{15}N$), which relates the ratio of ^{15}N to ^{14}N in the sample to the ratio in a reference standard; values are reported in units of per mil (‰, or parts per thousand).

Acknowledgments

Introduction

Eutrophication of lakes and coastal waters has long been recognized as a major environmental problem in many parts of the world. Increased inputs of mineral nutrients to lakes and coastal waters has led to increased biomass and organic carbon, which degrade the aquatic environment. Although some eutrophication is due to natural causes, in the context of environmental management this term usually represents the effects of "cultural eutrophication," caused by inputs of nutrients from human activities (Richardson and Jørgensen, 1996).

Eutrophication may be controlled by the availability of mineral nutrients, such as nitrogen, phosphorus, or silica, or it may be affected by the availability of organic matter. For many years, research on the problem was focused on the input of nutrients from surface-water discharge, especially nutrients associated with suspended sediment. This focus on runoff is reasonable for water bodies where primary production is controlled by the availability of phosphorus ("phosphorus limited"), because phosphorus is insoluble in oxidized environments, adsorbs strongly to sediment particles, and is transported with suspended sediment in surface-water discharge. In many other ecosystems, however, primary productivity generally is nitrogen limited (Fisher and Butt, 1994; Borum, 1996). The discharge of nitrogen compounds dissolved in ground water is likely to play a major role in the nutrient dynamics of coastal waters in temperate regions because of the following factors: (1) nitrogen, in the form of nitrate, is much more soluble than phosphorus in oxygenated environments; (2) nitrogen concentrations elevated above background levels have been documented in shallow aquifers in many coastal areas (Bachman, 1984a; 1984b; Hamilton and others, 1993; Mueller and others, 1995; and Mueller and Helsel, 1996); and (3) ground-water discharge comprises an appreciable percentage of total streamflow in many temperate areas. These factors have implications for environmental management, because the beneficial effects of nutrient control may not be apparent immediately after the control practices have been implemented. Ground-water traveltimes are much longer than surface-water traveltimes, on the order of years or decades rather than days or weeks, respectively. Consequently, the effects of reducing the recharge of nutrients to an aquifer may be delayed for many years after the implementation of nutrient-control practices (Focazio and others, 1998).

The management of nutrient inputs to control eutrophication is relatively advanced in the Chesapeake Bay watershed. The Chesapeake Bay is the Nation's largest and most productive estuary, but the presence of toxic dinoflagellates and anoxic zones in its deeper waters stress the estuarine ecosystem. Both of these stresses have been linked to nutrient enrichment (Fisher and Butt, 1994; Lewitus and others, 1995). Stream base-flow surveys indicate that ground-water nitrogen accounts for approximately 40 to 50 percent of the total nitrogen discharge to the bay from nontidal rivers and streams (Bachman and Phillips, 1996; Bachman and others, 1998). Other investigations have provided estimates of ground-water flow rates from shallow aquifers (Simmons and others, 1990; McFarland, 1995), descriptions of the relation between ground-water traveltimes and nitrogen concentrations (Dunkle and others, 1993; Böhlke and Denver, 1995; and Speiran, 1996), and the relation between landscape features and water quality (Bachman and Phillips, 1996; Phillips and Bachman, 1996).

Many aspects of the relation between the details of ground-water flow and geochemical processes that influence nitrogen discharge from shallow aquifers have not been resolved. The results presented in this report further document the processes associated with the flux of nitrogen to Chesapeake Bay by ground-water discharge. In particular, it has been suggested that geochemical reactions, such as denitrification, may have the capacity to substantially reduce nitrogen loads in a watershed (Böhlke and Denver, 1995). Denitrification is a process by which bacteria obtain energy by the chemical reduction of nitrate and the oxidation of organic matter or other reduced compounds in the absence of oxygen. If carried to completion, denitrification transforms dissolved nitrate to nitrogen gas. When denitrification occurs in a ground-water system, the nitrogen gas remains dissolved in the ground water until it can escape to the atmosphere when the ground water discharges to a surface-water body.

The objectives of this project were to extend the results of the previous investigation by Böhlke and Denver (1995) that documented the occurrence of denitrification in deep parts of the surficial aquifer, to relate the occurrence of denitrification to shallow subsurface geologic formations, and to assess the effect of the discharge of denitrified water on the chemical composition of stream base flow. This project focused on the relation between the hydrogeologic framework and nitrogen discharge from a shallow Coastal Plain aquifer system.

This report contains a summary of the results of activities conducted by the U.S. Geological Survey (USGS) from 1997 through 2000 in support of a collaborative research effort between the USGS and the National Risk Management Research Laboratory

(NRMRL) of the U.S. Environmental Protection Agency (USEPA). The research project, "Geohydrologic Foundations for Ecosystem Restoration," is an examination of the movement and fate of nutrients, particularly nitrogen, in the subsurface at the Locust Grove research site in the Chester River watershed on the Delmarva Peninsula (Figures 1a and 1b). Field data-collection efforts by the USGS were based on an extensive network of stream-gaging stations, wells, surface-water-sampling sites, and coreholes (Figure 2).

USEPA activities, as described by Hantush and Cruz (1999), included geological modeling, development of analytical and numerical models of ground-water flow and nitrate transport, assessment of the watershed capacity for nitrogen reduction, and management of a site database, which has been shared among project collaborators and is available for other investigators. The major objective of the USGS activities were: (1) to describe the geometry of the shallow subsurface sediments and provide stratigraphic interpretations for hydrogeologic models; (2) to describe the configuration of the water table and ground-water flow paths in the surficial aquifer and the uppermost confined aquifer; (3) to provide evidence of hydrogeochemical processes that affect nitrogen discharge to streams from ground water; and (4) to provide information needed to estimate the volume of ground-water discharge and ground-water nitrogen loads.

Description of the Study Area

The Locust Grove study area is located in central Kent County, Maryland, (Figure 1), between the tidal Chester and Sassafras Rivers, about 30 km south of Elkton, Maryland, and about 15 km northeast of Chestertown, Maryland. The study area consists of the Morgan Creek and Chesterville Branch watersheds (Figure 2) above their respective stream-gaging stations. Although topographic maps show no impoundments in these two streams, field technicians observed a small pond in the main channel of Chesterville Branch downstream of site 01493110, and other field technicians have reported beaver dams and other obstructions to streamflow on sections of both Chesterville Branch and Morgan Creek.

The gaging station at Morgan Creek near Kennedyville (site 01493500) is part of the USGS basic-data network for Maryland, and discharge has been measured continuously at this site since 1951. The gaging station at Chesterville Branch near Crumpton (site 01493112) was established in 1996, and is maintained as part of an ongoing USGS project to estimate river input of nutrients to Chesapeake Bay. The combined area of both drainage basins is about 47 km^2. Morgan Creek is a larger watershed (31 km^2) than Chesterville Branch (16 km^2) (Figure 3; Table 1).

The soils in the two watersheds are generally well drained, with over half the land area in both watersheds classified as soil hydrologic classes of "well-drained" (class A) and "moderately well-drained" (class B) (Maryland Department of State Planning, 1973). However, the Morgan Creek watershed does have a somewhat higher percentage of areas with "moderately poorly drained" (class C) and "poorly drained" (class D) soils (Table 1).

Because of the fertile, well-drained soils, agriculture is the dominant land use in the study area, accounting for about 90 percent of the watershed area (Figure 3; Table 1); Most of the cropland is in a rotation of corn, soybeans, and small grains. A significant part of the Chesterville Branch watershed is under cultivation for nursery stock. Fields near the headwaters of Morgan Creek and along some tributaries west and northwest of Morgan Creek near Kennedyville, Maryland (Figure 3), are used as pasture for dairy operations. A few confined animal-feeding operations and poultry houses are scattered throughout the study area, but there are fewer in this area than farther south on the Delmarva Peninsula. The primary area classified as urban is the village of Kennedyville, located along the northwest edge of the Morgan Creek watershed (Figure 3). Some other areas shown as urban by the remote-sensing land-cover classification system of Bara (1994) are commercial establishments or farm buildings. Woodlands and wetlands are located almost exclusively in the riparian areas along Morgan Creek and Chesterville Branch.

The hydrologic setting of the study area has the potential to discharge large volumes of ground water to the streams. The study area is located in the Atlantic Coastal Plain Physiographic Province, and is underlain by unconsolidated clastic sediments that can store and transmit large volumes of ground water. The climate is humid temperate, with an excess of precipitation over evapotranspiration. The average rainfall is about 110 centimeters (42 inches) per year, and the average temperature is 13°C or 55°F (Vokes and Edwards, 1974). Although rainfall is distributed relatively evenly throughout the year, evapotranspiration is substantially lower in the winter because of the lower temperatures and dormant vegetation.

Previous Investigations

The geologic framework of Kent County, Maryland, was first mapped by Clark (1915). The stratigraphic nomenclature underwent various revisions over the years, culminating in work by Owens and Denny (1979), Owens and Minard (1979), and Hansen (1992). Regional descriptions of the configuration of aquifers and confining layers in central Kent County are provided by Overbeck and Slaughter (1958), Cushing and others (1973), Bachman (1984b), and Drummond (1998). Local-scale work at the Locust Grove site began in 1988 as part of the Delmarva pilot project of the USGS National Water-Quality Assessment (NAWQA) program (Shedlock and others, 1999). A general description of the hydrogeologic and water-quality conditions in the area was presented by Hamilton and others (1993). Dunkle and others (1993) and Reilly and others (1994) applied age-dating tracers to describe ground-water flow in parts of the Chesterville Branch watershed. Böhlke and Denver (1995) used the estimated recharge dates and a variety of geochemical data to describe the history of nitrogen recharge to the surficial aquifer, and discuss possible mechanisms for the transport and fate of nitrogen in the Chesterville Branch and Morgan Creek watersheds.
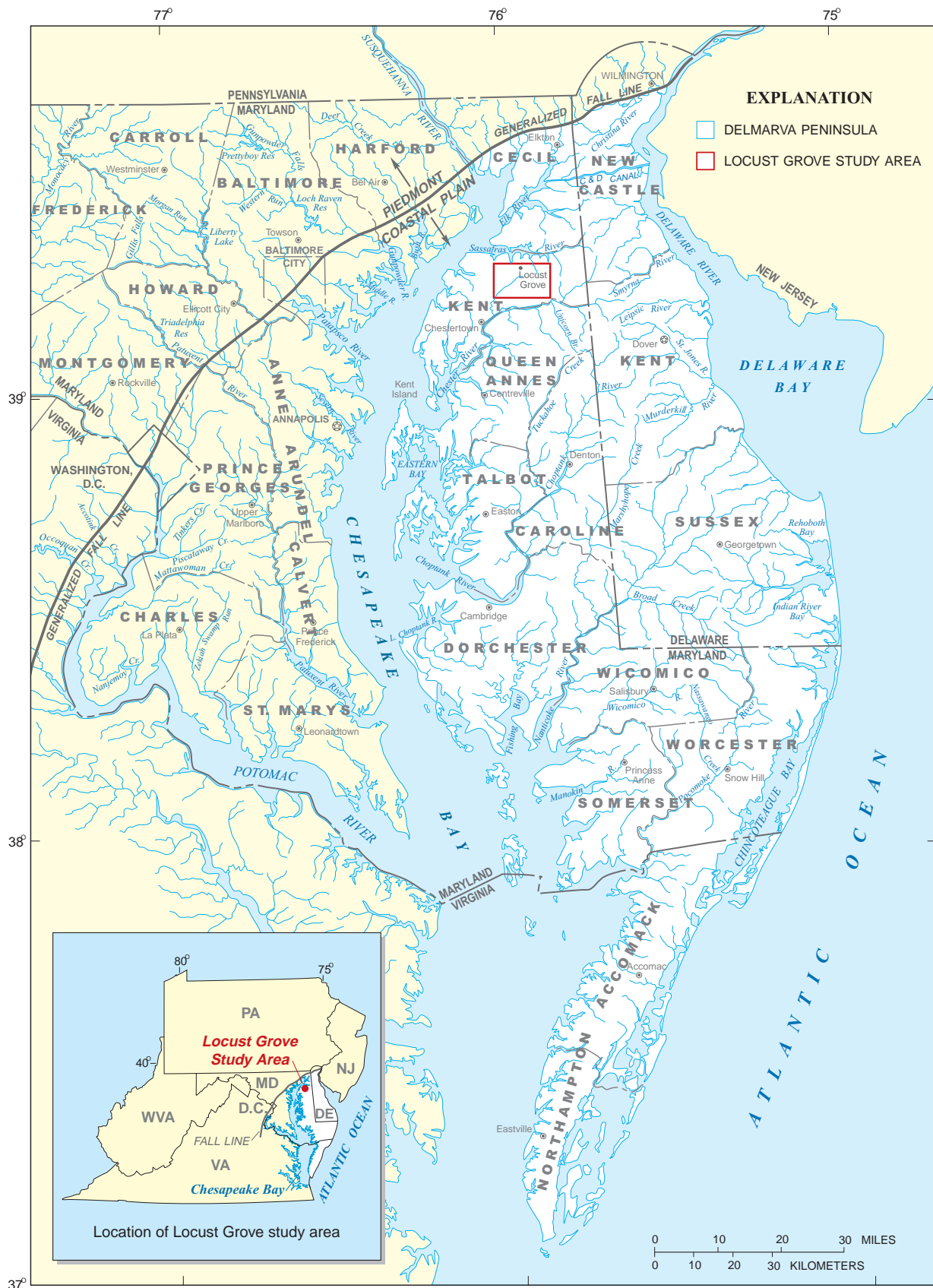
Figure 1a. Location of Chesapeake Bay, Delmarva Peninsula, and the Locust Grove study area in Kent County, Maryland.
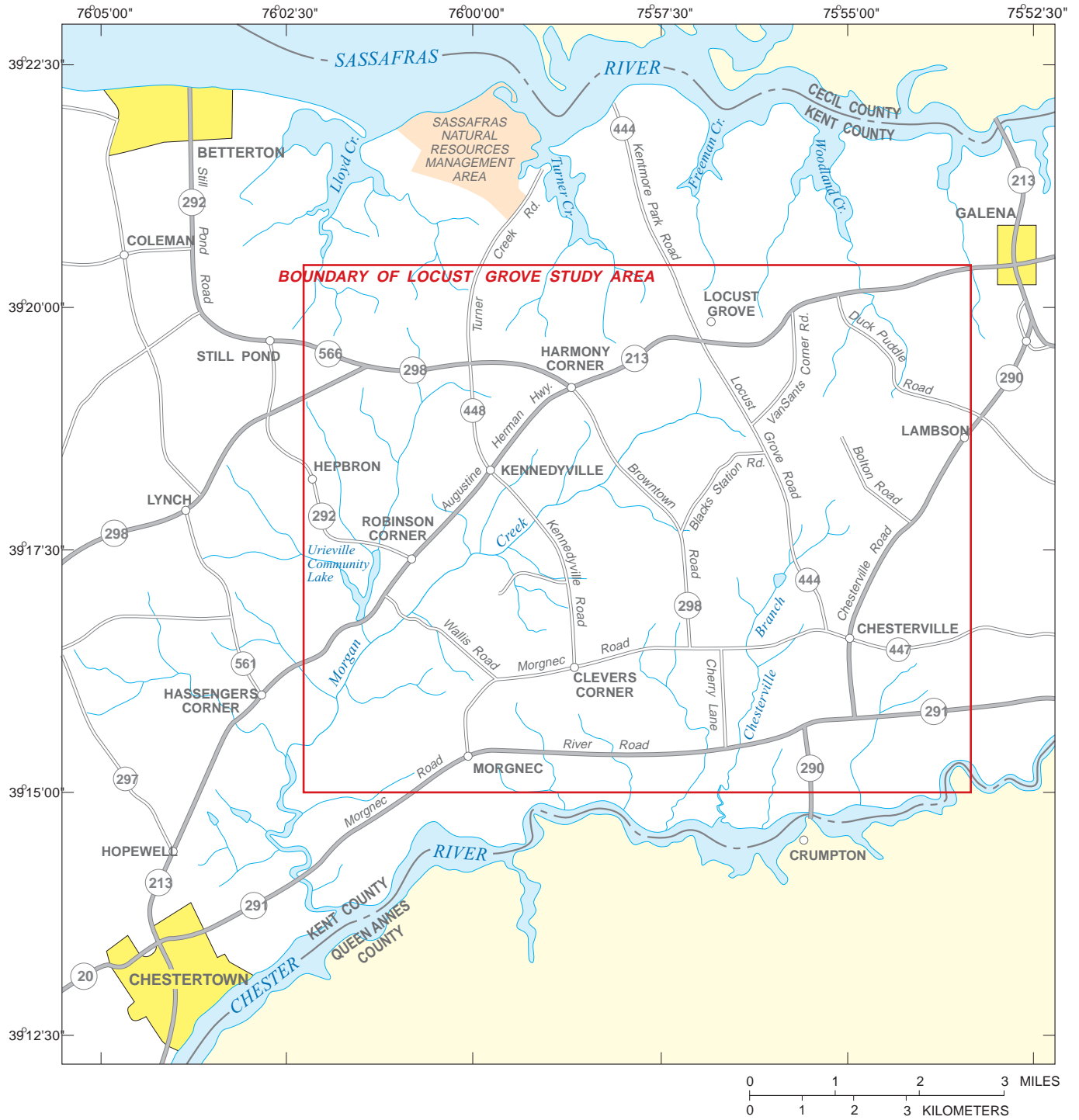
Figure 1b. Location of the Locust Grove study area in Kent County, Maryland.

Figure 2. The Locust Grove study area, Kent County, Maryland, showing the locations of stream-gaging stations, surface-water sampling sites, wells, coreholes, and transects of the hydrostratigraphic sections.

Figure 3. Land use in 1994 for the Morgan Creek and Chesterville Branch watersheds, Kent County, Maryland.

Table 1. Physical Characteristics of the Two Watersheds in the Locust Grove Study Area, Kent County, Maryland

		Chesterville Branch	Morgan Creek
	Drainage area, in km^2	15.9	31.1
	Stream length, in km	5.8	8.6
Hydrologic soil class, percentage of watershed	Class A, well-drained	32	15
	Class B, moderately well-drained	49	59
	Class C, moderately poorly drained	8	15
	Class D, poorly drained	1	4
Land use, percentage of watershed	Agricultural	93	88
	Forested	6	8

[Values are for the watershed areas above gaging station 01493112 on Chesterville Branch and station 01493500 on Morgan Creek; locations of gaging stations shown in Figure 2. Compiled from data of Maryland Department of State Planning (1973). More complete data for these watersheds and selected subwatersheds are presented in Appendix F. km, kilometers; km², square kilometers.]

Data-Collection Methods

Much of the geochemical interpretation presented in this report is based on numerous chemical analyses of water samples from the Delmarva NAWQA and related projects; these data have been reported previously by Hamilton and others (1993) and Böhlke and Denver (1995). New and refined hydrostratigraphic interpretations are based on drillers' and gamma logs from 23 wells originally described in previous studies, 10 private monitoring wells, and 33 new wells and 4 new coreholes drilled for this project. A corehole is a drilled hole from which a sediment core has been recovered; a borehole is a more generic term for a drilled hole that may include a well (a drilled hole with casing) or a rotary-drilled hole that was used only to collect cuttings and/or a geophysical log. Monthly water-level measurements were made on all of the 63 wells in the network during the project. Additional ground-water samples were collected from 11 of the newly drilled wells for chemical analyses. Seventy-nine base-flow samples were collected from 14 stream-sampling sites.

Compilation of Existing Data

Five categories of data were compiled from published and unpublished sources, and from data collected as part of this project. These categories include: (1) geologic or geophysical logs from drill holes in the area, which provide information on the hydrogeologic framework of the area; (2) measurements of ground-water levels and stream discharge, which provide information on flow directions and flow quantities; (3) chemical analyses of water samples from wells, which provide information on the geochemical processes controlling ground-water quality; (4) chemical analyses of stream base flow, which provide information about surface- and ground-water geochemistry and nutrient yields from base flow; and (5) digital geographic data used for relating base-flow nitrogen loads to landscape features. All existing data compiled for this project have been previously published (except for some of the digital geographic data), although some original field records of published data also were examined. The data include material originally reported by Overbeck and Slaughter (1958), Hansen (1992), Hamilton and others (1993), Tompkins and others (1994), and Böhlke and Denver (1995).

The digital geographic data were compiled, stored, and analyzed using the ARC/INFO and ArcView geographic information systems (GIS). Basin boundaries for all surface-water sampling sites were hand-digitized from paper copies of the USGS Betterton and Galena 7 ½-minute topographic quadrangle maps, produced at a scale of 1:24,000. Land use was derived from the Multi-Resolution Land Characteristics (MRLC) data set, which is based on land cover at 30-m resolution compiled in the early 1990s (Bara, 1994). Soil characteristics were compiled from U.S. Department of Agriculture sources by Dr. Margaret Mayers-Norton, formerly of the University of Maryland Horn Point Environmental Laboratory.

Corehole Drilling

Four coreholes drilled at the beginning of the project in October and November 1997, provide ground truth for interpreting geophysical logs from other boreholes in the area, and details of the lithology relevant to ground-water-flow modeling and ground-water geochemistry. The four coreholes varied in depth from 25.9 to 39.6 m below land surface (Table 2), and all penetrated the confining layer at the base of the surficial aquifer. Coreholes KE Be 185 (Locust Grove) and KE Be 186 (Chesterville Branch North) align with the existing corehole KE Bf 180 (Hansen, 1992) along a transect that runs north-northwest to south-southeast, and is very close to the regional dip of the subsurface formations (Figure 2). Coreholes KE Be 183 (Morgan Creek North) and KE Be 184 (Morgan Creek South) are located on the upland approximately 0.3 km north and south, respectively, of Morgan Creek. These two coreholes provide control along strike and away from the primary hydrostratigraphic transect along Maryland Road 444, and detailed stratigraphy for the wells near Morgan Creek valley (Figure 2).

The four coreholes were drilled with a truck-mounted drill rig using mud-rotary methods and a 9-cm (centimeter)-diameter core barrel with a hollow cutting head. A wire-line retrieval system was used to recover a 3-m (10-foot) inner core barrel that protects a nominal 5-cm (2-inch)-diameter core. The core was removed from the inner core barrel in 0.6-m (2-foot) lengths, washed with a fine spray of water to remove the drilling mud from the exterior, and placed in a partitioned storage box. The on-site geologist measured, labeled, photographed, and described each section of the core while it was fresh. The hand-written notes from the drilling operation and core descriptions, and the photographs of the cores are on file in the USGS Water Resources Division Maryland-Delaware-D.C. District Office, in Baltimore, Maryland.

After each corehole was drilled to the maximum depth and the last section of core retrieved, the hole was filled with drilling mud and the outer core barrel was removed. Natural-gamma and spontaneous-potential and electrical-resistivity logs were run in the mudded hole. These logs are archived in the Maryland-Delaware-D.C. District geophysical-log repository in Baltimore, Maryland.

Table 2.   Summary Information for the Coreholes Drilled in the Locust Grove Study Area, Kent County, Maryland

Well ID	Corehole Name	Latitude	Longitude	Altitude (m)	Total Depth (m)
KE Be 183	Morgan Creek North	39° 18' 30"	75° 58' 11"	21	25.9
KE Be 184	Morgan Creek South	39° 18' 14"	75° 57' 54"	20.3	27.9
KE Be 185	Locust Grove	39° 19' 40"	75° 57' 01"	23.2	28.9
KE Be 186	Chesterville Branch North	39° 18' 09"	75° 55' 53"	22.7	39.6

[Corehole sites are shown in Figure 2.   m, meters; °, degrees; ', minutes; ", seconds.]

Well Network and Water-Level Measurement

A network of 66 wells was used for the project. This network includes 23 existing wells from previous USGS NAWQA projects, 33 new wells installed in April 1998, and 10 private monitoring wells on the property of Angelica Nurseries (Figure 2). Information on the characteristics of the existing wells is summarized in Appendix A, and information on the characteristics of the newly drilled wells is summarized in Appendix B. During the course of the project, water levels in all of these wells were measured monthly, from May 1998 through October 1999. A subset of the new wells was sampled for chemical analyses as described below.

The new wells installed for this project supplemented the existing wells in order to:

(1) Improve the spatial distribution of wells to better represent the water table and ground-water flow system across the entire study area.

(2) Sample more points immediately below the water table (within 3 m of the seasonal water-table low) to document the spatial distribution of nitrate-input concentrations and ground-water recharge rates.

(3) Sample ground water from the confined aquifer (Hornerstown Formation), which was not sampled previously, to characterize its geochemistry.

(4) Sample discrete horizons near the base of the surficial aquifer above, at, and below the transition zone between reduced and oxidized sediments that has been postulated as a source of electron donors for denitrification of ground water (Böhlke and Denver, 1995).

The new wells were installed using hollow-stem auger methods according to the recommended procedures for the USGS NAWQA Program (Koterba and others, 1996). The only deviation from these procedures was that the casing was not steam-cleaned prior to installation, because the wells were not used to sample pesticides or volatile organic compounds. Only freshwater was used to flush the hole. No bentonite drilling mud was circulated during drilling, which can fill pore spaces in the aquifer materials adjacent to the well.

Wells were placed singly or in clusters of two or more to allow sampling of shallow and deep parts of the surficial aquifer. The hole for the deeper well in a cluster was drilled first, then a gamma log was run through the auger flights before the well casing was put in place to obtain lithostratigraphic information, and optimize the placement of the screen on the shallow well(s), and to avoid clay lenses. In most cases, split-spoon samples were taken 0.5 m above and below the proposed depth for the screen. Because the upper part of the surficial aquifer generally is very permeable throughout the study area, some of the shallow wells that are 9 m (30 ft) deep or less were installed directly without running a gamma log first. Any wells that were not logged during installation had gamma logs run the following week.

All wells were constructed with 5-cm-diameter PVC casing with internal threads. Screens have approximately 0.25-mm slots; most screens installed were 0.45 or 0.6 m in length. In some cases, 0.3-m screens were installed to sample ground water from a very narrow interval; for example, near the sediment redox transition at the base of the surficial aquifer associated with the first confining layer.

The annular space between the casing and the walls of the 15-cm hole drilled with the auger was backfilled using materials dug from the hole. The upper part of each hole was sealed with at least 0.6 m of bentonite at 1.5 m below land surface. Because most of the wells were placed along the right-of-way of State or County roads, or along the edges of fields or service roads on private property, all casings were cut off below land surface and a metal well cover was mounted flush with the land surface to avoid damage to the wells by mowers and other equipment, and to avoid damage to the mowers and equipment from the wells.

All wells were surveyed for elevation of the measuring point of the well casing and the adjacent land surface using a Zeiss optical surveying instrument. Survey transects were referenced to USGS benchmarks, or to a previously surveyed well if no benchmark

was near. Survey transects were closed by backsighting to temporary benchmarks; all elevations are accurate to 0.3 cm and are reported relative to sea level.

Latitude and longitude positions for all new USGS wells and private wells used during the project were measured with a Trimble Pathfinder differential global positioning system (GPS) receiver. Coordinates of discrete reference locations were measured repeatedly on different days; reproducibility was 0.1 second or better (approximately 3 m). All new wells were marked with the well identification number on the cap and with an attached aluminum permit tag.

The new wells were developed by purging either manually with a bailer or with a downhole pump until the water was clear of suspended solids. Some wells with high-turbidity water were revisited over a 2-week period for additional purging.

Two multiport ground-water samplers were installed to obtain water samples near the sediment redox transition at closely spaced vertical intervals. The locations of these samplers are shown in Figure 2. They were installed at sites in which clusters of wells with single, short (1- to 1.5-ft) screened intervals were completed at depths bracketing the redox transition zone. Split-spoon sediment samples were collected during the installation of both multiport ground-water samplers to confirm the depth of the sediment redox transition and to position the ports accordingly.

The multiport ground-water samplers were constructed with 5-cm-diameter schedule-80 PVC threaded casing. Each sampling port is constructed of 1-cm-diameter Teflon tubing, which runs down the inside of the casing. The downhole end of each tube exits the casing through a hole (port) drilled through the side of the casing. The end of the tube is cut diagonally, covered with a fine nylon mesh, and secured to the casing with nylon pull-ties. Ports are spaced 30 cm (1 ft) apart on alternating sides in the lower 3 m (10 ft) of the casing in both wells. In sampler KE Be 209, ports in an additional 3-m section from the bottom of the well are spaced 0.9 m (3 ft) apart.

To finish the well, the annular space between the casing of the multiport well and the wall of the augered hole was filled with the native material drilled from the hole. The top of each tube was covered with a tight-fitting removable cap, and the bundle of tubing was coiled inside a plastic bag and secured in an alcove beneath the flush-mounted well cover. The tubes were color-coded and cut to different lengths to identify the sampling depth.

The static water level in observation wells was measured by an electrical water-level depth sensor from a marked measurement point on the well casing, and recorded to the nearest 0.01 ft. This follows the procedure described in the National Handbook of Recommended Methods for Water-Data Acquisition (U.S. Geological Survey, 1977) and by Hardy and others (1989). Depth below land surface and altitude relative to sea level are reported in feet (the units of the field measurement) and meters. All wells in the network were measured monthly from May 1998 through October 1999; existing wells from the previous NAWQA project also were measured in October 1997 and March 1998. The water-level measurements are listed in Appendix C.

Well Sampling

Water samples for chemical analysis were collected from 11 wells during July 1998, and from the multiport sampler KE Be 190 (Figure 2) in March 2000. Three wells were selected to examine the confined Hornerstown aquifer, two wells were selected to obtain data from a previously unsampled recharge area in the surficial aquifer south of Morgan Creek, and the rest of the wells and the multiport samplers were selected to obtain samples from the redox-transition zone. No ground-water samples were collected below the redox transition from multiport sampler KE Be 209 because no water could be pumped from the low-permeability sediments of the Aquia confining layer. Results of the chemical analyses are in Appendix D.

Water samples for analyses of major ions, nutrients, dissolved gases, and stable isotopes were collected from wells with a positive-displacement, battery-operated submersible pump with a Teflon discharge tube. Samples for analyses of major ions, nutrients, and dissolved gases were collected from the multiport sampler using a peristaltic pump and a silicone discharge tube.

Water samples were collected for the chlorofluorocarbon (CFC) age-dating tracers (Busenberg and Plummer, 1992) with a peristaltic pump and a copper discharge tube. The date of ground-water recharge (and thereby the age of the water) was calculated by relating historical atmospheric concentrations of CFC-11, CFC-12, and CFC-113 to concentrations measured in the ground water. The ages were estimated by modeling expected recharge concentrations of the three CFC compounds based on Henry's Law (Busenberg and Plummer, 1992). Three replicate samples from each well were analyzed, and the reported ground-water age represents the average of the three replicates (Table 3). Because age estimates from the different CFC compounds varied, the final ground-water age reported in Appendix D is the average of the ages determined by each individual CFC compound.

Base-Flow Sampling

The seasonal and spatial variability of nitrogen discharge from stream base flow in the Morgan Creek and Chesterville Branch watersheds were measured in three synoptic surveys from a network of 14 sites (Figure 2). Of these sites, eight are at outlets of first-order drainage basins; the other six sites are on the mainstems of Morgan Creek and Chesterville Branch. The two sites farthest downstream (sites 01493500 and 01493112) are located close to the transition between nontidal and tidal conditions. The base-flow sampling network was designed to describe the areal distribution of base-flow nitrogen and how nitrogen discharge varies downstream within the watersheds. Samples collected at the two outlets were used to estimate the total discharge of nitrogen from

Table 3.   Chlorofluorocarbon (CFC) Recharge Dates and Ground-water Ages from Wells Sampled in 1998

Well Number	Sampling Date	CFC Recharge Dates			CFC Recharge Ages			Average Recharge Age (years) And Date
		CFC-11	CFC-12	CFC-113	Average CFC-11	Average CFC-12	Average CFC-113	
KE Be 50	07/24/98	1989.5	Modern	1990.5	9.6	7.1	9.1	8.6
		1989.5	Contaminated	Modern				1990
		1988.0	1991.5	1988.5				
KE Be 158	07/21/98	1985.5	1986.5	1988.0	12.2	8.7	9.6	10.2
		1987.0	1991.5	1990.0				1988.5
		1986.5	1991.5	1993.0/1995.0				
KE Be 189 *Hornerstown aquifer*	07/21/98	1949.0	1954.0	<1955	~50	45.9	>43	>45
		1948.5	1951.5	<1955				<1953
		<1945	1952.5	<1955				
KE Be 192	07/21/98	Modern	1997.0	Contaminated	n/d	1.9	n/d	1.9
		1993.5/1995.5	1996.0	Modern				1996.5
		Modern	1997.0	Modern				
KE Be 193	07/24/98	Contaminated	Contaminated	Contaminated	n/d	n/d	n/d	n/d
		Contaminated	Modern	Contaminated				
		Contaminated	Contaminated	Contaminated				
KE Be 194	07/20/98	1985.5	1987.5	1986.5	13.1	10.9	11.6	11.8
		1985.5	1988.0	1991.5/1998.0				1987
		1985.5	1987.5	1987.5				
KE Be 195 *deep in Aquia aquifer*	07/20/98	1977.5	1976.5	1978.0	21.1	22.4	19.4	20.9
		1977.5	1976.0	1980.5				1978
		1977.5	1976.0	1979.0				
KE Be 199 *deep in Aquia aquifer*	07/22/98	1978.0	1976.5	1976.5	21.1	21.9	22.2	21.7
		1978.0	1978.0	1976.5				1977
		1976.5	1975.5	1976.0				
KE Be 200 *Hornerstown aquifer*	07/22/98	1954.5	1955.0	1965.5	44.2	42.2	40.0	42.1
		1955.0	1964.5	<1955				1956
		1953.5	1949.5	<1955				
KE Be 206	07/22/98	1982.0	1982.0	1981.5	16.9	16.4	17.9	17.1
		1981.5	1982.0	1980.5				1981.5
		1981.5	1982.5	1980.0				
KE Be 207 *deep in Aquia aquifer*	07/23/98	1978.0	1978.0	1980.5	20.9	20.6	19.6	20.3
		1977.5	1978.0	1979.5				1978.5
		1977.5	1978.0	1977.0				
KE Be 207 *deep in Aquia aquifer*	12/10/98	1977.0	1978.0	1979.5	21.8	21.1	19.3	20.7
		1977.5	1978.0	1980.0				1978
		1977.0	1977.5	1979.5				
KE Be 208 *deep in Aquia aquifer*	07/23/98	1967.0	1967.0	1967.5	31.6	31.4	31.6	31.5
		1967.0	1967.0	1967.0				1967
		1967.0	1967.5	1966.5				
KE Be 208 *deep in Aquia aquifer*	12/10/98	1968.0	1968.5	1968.0	30.9	30.4	31.9	31.1
		1968.0	1968.5	1966.0				1967.5
		1968.0	1968.5	1967.0				
KE Be 210 *Hornerstown aquifer*	07/22/98	1954.5	1959.5	<1955	48.8	46.1	>43	46
		1949.0	1949.0	<1955				<1952
		<1945	1949.0	<1955				
KE Be 211 *Hornerstown aquifer*	12/11/98	<1945	<1940	<1955	>50	>55	>44	>50
		<1945	<1940	<1955				<1950
KE Be 212	07/23/98	1986.5	1991.5	1991.0	11.9	6.4	8.6	8.9
		1987.0	1992.5	1989.0				1989.5
		1986.5	1992.5	Modern				
KE Be 216	07/24/98	1987.0	1993.0	1990.0	11.4	5.7	8.9	8.7
		1987.5	1994.0	1988.5				1989.5
		1987.0	1991.5	1990.5				

["CFC Recharge Dates" are the calculated years in which each sampled parcel of ground water recharged the water table, based on historical atmospheric CFC concentrations; "Modern" indicates a CFC concentration similar to that expected for water in equilibrium with 1998-99 atmospheric concentration; "Contaminated" indicates a CFC concentration higher than that expected from equilibrium with current or historical atmospheric concentrations; n/d = not determined; ~, approximately; <, less than; >, greater than.]

the two watersheds during the study period. Samples were analyzed for nitrite-plus-nitrate nitrogen and ammonia-plus-organic (Kjeldahl) nitrogen. These two analytes were added to obtain the total dissolved nitrogen concentration. The instantaneous nitrogen load was calculated by multiplying the measured stream discharge (in units of volume per time) by the total dissolved nitrogen concentration (in units of mass per volume) and adjusting the units to obtain values in $gm\ sec^{-1}$ (units of mass per time). Instantaneous yields were calculated by dividing the load by the drainage area to obtain units of $gm\ sec^{-1}\ km^{-2}$.

Stream base-flow samples were collected from the entire network during synoptic surveys in April 1998, September 1998, and February 2000. Samples were collected during both winter base flow and summer base flow to evaluate the effect of seasonal differences in base-flow discharge and biological activity in the stream. Bachman and Phillips (1996) noted that base-flow discharge of water in the central upland of the Delmarva Peninsula was approximately an order of magnitude lower in summer than in winter, when evapotranspiration is minimal. They also noted that over the entire Delmarva Peninsula, base-flow nitrogen loads and yields tended to be higher in winter. Base-flow samples also were collected monthly at the two downstream gaging stations from April 1998 through March 1999. These monthly samples were supplemented by additional base-flow samples collected at Chesterville Branch (site 01493112) before and after this period for other USGS projects. All base-flow samples were accompanied by stream-discharge measurements made by use of standard USGS methods (U.S. Geological Survey, 1977). Results of the chemical analyses of the base-flow samples are listed in Appendix E.

Chemical Analysis of Water Samples

Chemical analyses were made on samples filtered through a membrane filter with a 0.45-μm pore diameter to provide an approximation of the "dissolved" concentration of solutes. In addition, unfiltered base-flow samples were analyzed for nitrogen species and phosphate to determine the "total" (suspended and dissolved) concentrations of these constituents. Water samples collected for CFC age-dating tracers and other dissolved gases were not filtered.

Many physical and chemical properties are unstable, and, therefore, were measured in the field. These include pH, temperature, specific conductance, dissolved oxygen (measured on unfiltered samples), and carbonate alkalinity (measured on filtered samples). The analysis methods follow those recommended by Wilde and Radtke (1998).

Samples for the analysis of major ions, silica, iron, nutrients, and total organic carbon were sent to the USGS NWQL in Arvada, Colorado. Samples for stable isotopes, dissolved gases, and chlorofluorocarbon age-dating tracers, and a subset of samples for major ions and nutrients were analyzed at the laboratories of the USGS National Research Program in Reston, Virginia.

Cations and silica were analyzed by plasma emission spectroscopy, sulfate and chloride by ion chromatography, and nitrogen species and phosphate by various standard colorimetric methods (Fishman and Friedman, 1985). Quality-assurance methods used at NWQL are described by Pritt and Raese (1995). In addition, field replicates were collected and analyzed. From these replicates, variation (using the standard deviation of replicates as described by Taylor, 1988) of dissolved nitrogen concentrations due to sampling and analytical methods is estimated to be 0.09 mg/L; variation of calcium, magnesium, and silica concentrations are less than the precision of the analysis as described by Fishman and Friedman (1985).

Data Analysis

Processes affecting ground-water and surface-water geochemistry were evaluated by examining the relations between selected constituents and their location in the watershed or along a ground-water flow path. Previous studies indicated that, in general, the surficial aquifer has multiple ground-water flow paths with traveltimes (from recharge to discharge) that range from a year to decades (Dunkle and others, 1993; Böhlke and Denver, 1995). The older ground water (from flow paths with long traveltimes) tends to have lower nitrate concentrations than younger ground water (from flow paths with short traveltimes). The relative proportion of old and young ground water discharging to a stream upstream of a sampling point will affect the concentration of solutes in base flow at that sampling point. In a detailed investigation, Modica and others (1998) evaluated the flow systems, ground-water traveltimes, and nitrate concentrations in a similar watershed in the Coastal Plain of New Jersey. Their model simulation showed that ground-water discharge in the headwaters of a stream is dominated by relatively young water, whereas farther downstream, ground-water discharge contains an appreciable component of older water mixed with the young water (Figure 4). In order to evaluate this process in the Locust Grove study area, concentrations of nitrogen and other constituents that are geochemical markers for old and young ground water were examined at seven sites along the mainstems of Morgan Creek and Chesterville Branch. Observed trends in concentrations were compared to trends expected from various mixtures of old and young ground water.

Although samples were analyzed for both nitrogen and phosphorus, this report focuses on the nitrogen data. Because phosphorus adsorbs to soil particles under oxic conditions, it is likely that little phosphorus enters the oxygenated environment of the surficial aquifer with recharging ground water. Further, the near-surface sediments in this area are not rich in phosphate, and even if there were chemically reducing environments in the surficial aquifer, there is little potential for the mobilization of phosphorus. There is some question as to whether the ground-water sampling methods used in this project actually measure dissolved phosphorus in the aquifer, or colloidal particulate phosphorus that was stirred up by the sampling pumps and passed through the 0.45-μm filters used to separate the "dissolved" from "particulate" fractions (M. T. Koterba, U.S. Geological Survey, oral commun., 1999).
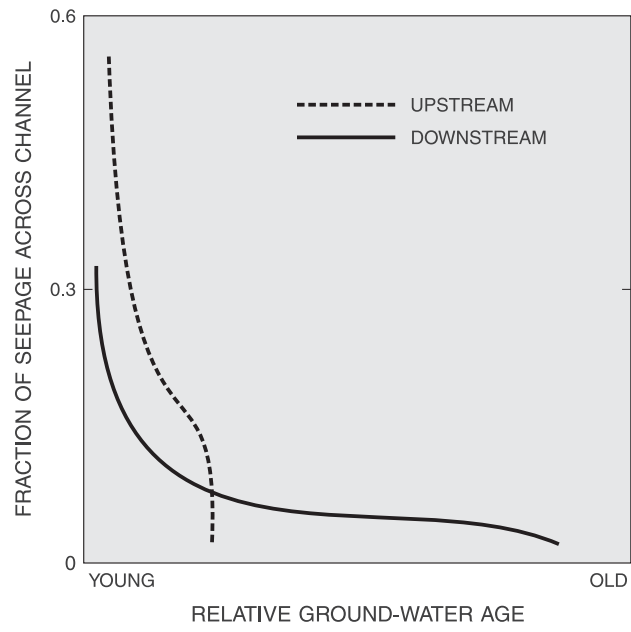
Figure 4.   Relative distribution of the age of discharging ground water in stream headwaters and downstream (adapted from Modica and others, 1998).

Hydrogeologic Framework

The study area is located in the updip region of the Delmarva Peninsula, approximately 30 km from the Fall Line (Figure 1a). A broad band of lower Tertiary and upper Cretaceous marine sedimentary sequences crops out or subcrops shallowly between the Sassafras and Chester Rivers (Owens, 1967; Drummond, 1998). These Cretaceous and lower Tertiary units dip and thicken to the southeast with the regional dip of crystalline rocks beneath the Coastal Plain.

Formations exposed above sea level in the area near Locust Grove (Figure 5) include the upper Cretaceous Mt. Laurel and Severn Formations of the Monmouth Group, the lower Paleocene Hornerstown Formation, and the upper Paleocene Aquia Formation (Minard, 1974; Hansen, 1992; Drummond, 1998). In the southeast corner of Kent County, including the southeast part of the study area, younger marine sediments of the upper Oligocene Old Church (?) Formation and the Miocene Calvert Formation may overlie the Aquia Formation (Hansen, 1992; Drummond, 1998). However, the Oligocene and Miocene sediments generally are very thin (less than 1-2 m thick) north of the Chester River, and probably are not important as hydrostratigraphic units.
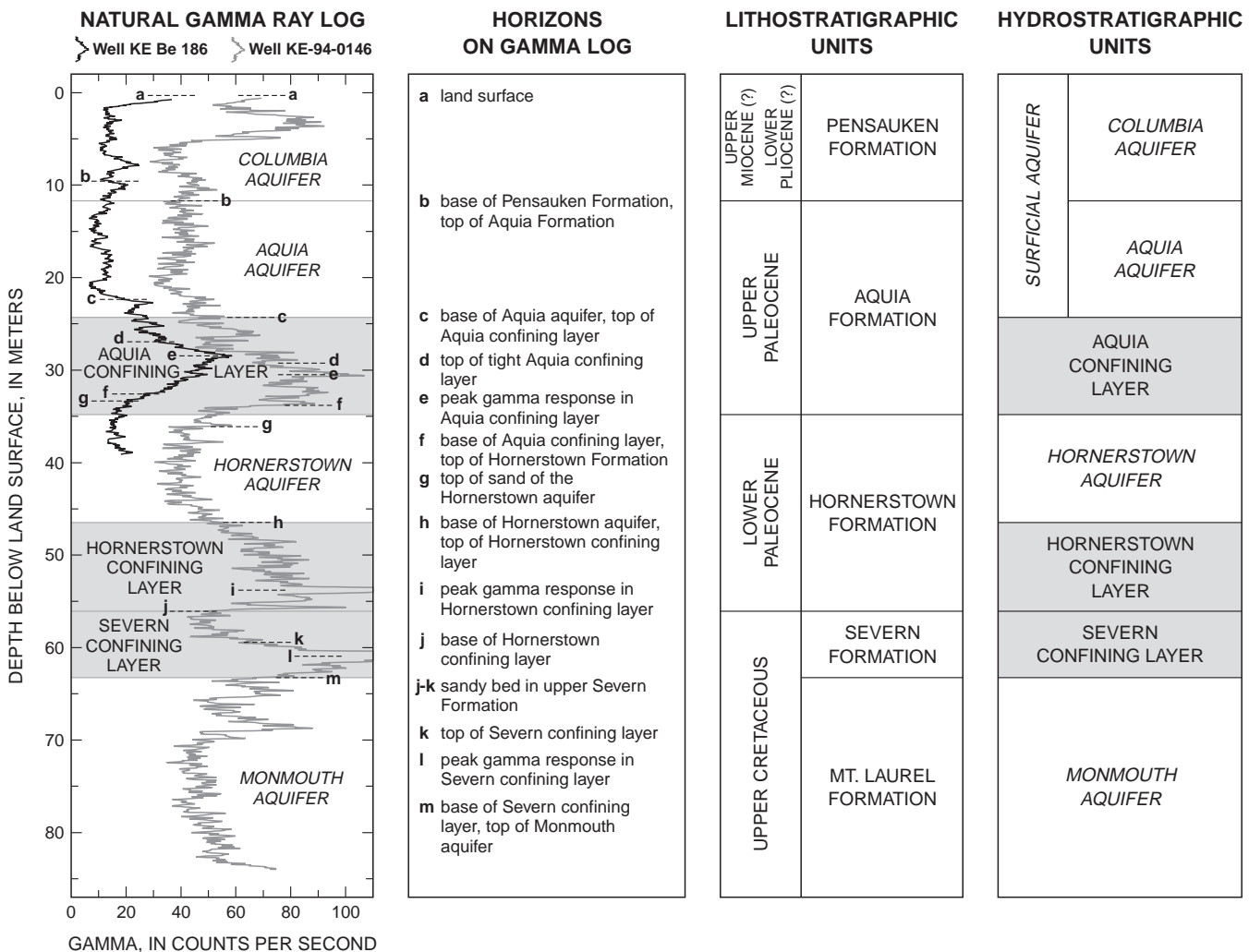
Figure 5.   Composite hydrostratigraphic sequence of the Locust Grove study area, Kent County, Maryland.

The upland in central and eastern Kent County above an altitude of approximately 15 m (50 ft) is capped by a gravelly coarse sand. This unit has been mapped as the Pensauken Formation on the northern and central Delmarva Peninsula by correlation with similar deposits along the flanks of the Delaware River valley in New Jersey (Owens and Denny, 1979; Owens and Minard, 1979). The age of the Pensauken Formation has been estimated as latest Miocene to early Pliocene based on its stratigraphic position relative to other dated units in New Jersey. Lithologically similar deposits that cover two-thirds of Delaware have been mapped as the Columbia Formation (Jordan, 1962; 1964). Age estimates for the Columbia Formation are early to middle Pleistocene based on pollen assemblages (Groot and Jordan, 1999). It is not clear whether the sediments mapped as the Pensauken Formation in Maryland and the Columbia Formation in Delaware were deposited during the same period, or whether they represent two or more depositional episodes with similar sediment provenance and depositional environment.

Middle to upper Quaternary deposits in Kent County include Pleistocene estuarine-terrace deposits and Holocene alluvial sediments. Pleistocene terraces are restricted to the margins of the Sassafras and Chester Rivers, the mouths of the larger tributary creeks, and the Chesapeake Bay shoreline in western Kent County. The highest terraces are at altitudes of approximately 15 m above sea level. Although the lower reaches of Morgan Creek and Chesterville Branch cut across the Pleistocene terraces along the Chester River, no Pleistocene estuarine deposits are within the immediate study area. However, the incised valleys of Morgan Creek and Chesterville Branch are filled with Holocene alluvial sediments derived from the erosion of the adjacent upland.

Most of the upland in the study area away from the stream valleys is covered with a surficial deposit of loess (wind-blown silt) that may be 0.3 to 1 m thick. Previous studies of soils in the northern Delmarva Peninsula have attributed the source of the loess to estuarine silts that were deposited in the Delaware River estuary and subsequently exposed during late Quaternary lowstands of sea level to be eroded and transported by winds (Carey and others, 1976).

Lithostratigraphic Units

Four primary lithostratigraphic units compose the upper 30 m of the sedimentary column in the Locust Grove study area. These units are:

   (1) the Holocene alluvial sediments that fill the incised valleys of Morgan Creek and Chesterville Branch;

   (2) the coarse fluvial sands and gravels of the Pensauken Formation that cap the upland;

   (3) the Aquia Formation, which immediately underlies the Pensauken Formation throughout most of the study area; and

   (4) the Hornerstown Formation, which underlies the Aquia Formation.

In this report, the Severn confining layer (Figure 5) is considered as the base of the active hydrogeologic system that interacts with the streams in the study area, and, therefore, descriptions of underlying stratigraphic units are omitted.

Developing the hydrostratigraphic framework for the Locust Grove study area was an iterative process of interpreting cores and geophysical logs, correlating lithostratigraphic units across the study area, and defining hydrostratigraphic units. The first step was the description and interpretation of the lithology of the four new cores drilled for the project (Table 2). These cores were not studied in the same detail as core KE Bf 180 (Hansen, 1992), and inference of physical properties and other characteristics is based on correlation with core KE Bf 180. The new cores were described in sufficient detail to identify changes in grain size that relate to permeability, and mineral composition and degree of weathering that relate to redox chemistry. The lithologic changes were matched with excursions in the geophysical logs (natural gamma, electrical resistivity, and spontaneous potential) from the coreholes. These features in the logs were used to define a set of specific horizons in the geophysical logs with consistent and characteristic responses that could then be used to correlate lithostratigraphic horizons among the geophysical logs from all wells in the study area.

An initial stratigraphic framework was developed by correlating the geophysical logs of the deepest wells and coreholes to determine the general geometry and distribution of units. This correlation also was used to assemble a composite stratigraphic sequence and define hydrostratigraphic units for the study area (Figure 5). Specific surfaces, such as the top of the clay-rich section in the lower Aquia Formation, were mapped throughout the study area. This preliminary framework was refined subsequently by checking the consistency of picks in cases where the interpretation of the geophysical log was uncertain, and by inferring the depths to specific horizons in shallow wells.

Holocene Alluvial Sediments

The valleys of Morgan Creek and Chesterville Branch are filled with 4 to 6 m of alluvium in the axis of the valleys, although this thickness is inferred from relatively few holes. These sediments are dominantly coarse sands with gravels that were eroded from the upland, and overlain by silty overbank deposits. The sands in the lower part of the alluvium may have interbedded lenses of silt, poorly sorted silty sand, and peats; some beds also contain trace amounts of glauconite reworked from the Aquia Formation. The silt overbank deposits that form the modern floodplain typically are 0.5 to 1 m thick and contain organic material accumulated from the riparian forest. Bedding within the alluvial sediments represents transport and deposition during episodic storm events. The alluvial valley of Chesterville Branch at Road 444 is 50 to 70 m wide; the valley of Morgan Creek at Road 298 is 80 to 100 m wide.

Pensauken Formation, Upper Miocene (?) / Lower Pliocene (?)

The Pensauken Formation in Kent County is a thick sequence of medium to coarse sands and gravels, with common cobbles and less common boulders. Sandy beds typically are poorly sorted and may have interbedded lenses of silt or clay. In exposures, this unit contains cross-bedded sets in cut-and-fill channels 2 to 5 m deep. The sand grains generally are subrounded to subangular, and are predominantly quartz with some feldspar. The fine-sand fraction may contain abundant heavy minerals; Hansen (1992) reported the mineralogy of the heavy mineral sands. X-ray diffraction analyses of samples from core KE Bf 180 showed kaolinite, illite, and smectite in the clay fraction (Hansen, 1992). Pebbles are rounded and dominantly vein quartz, quartzite, and chert, with uncommon lithic clasts. The sediments of the Pensauken Formation typically are deeply weathered; the dominant colors are yellowish-oranges, light to very light browns (tan), and light grays. Much of the feldspar and labile heavy mineral suite has been leached and hydrated to form clays.

The sediments of the Pensauken Formation were deposited by a very large braided-river system that covered most of the central Delmarva Peninsula (Owens and Denny, 1979). Fluvial erosion during the deposition of the Pensauken Formation truncated the older Tertiary and Cretaceous sediments to create a regional angular unconformity. The base of the Pensauken Formation underlying the Locust Grove study area generally is between 12 and 15 m asl, but is very irregular because of channelization and scouring. The unit typically is 6 to 15 m thick, but Minard (1974) reported a maximum observed thickness of 44 m (145 ft) in a paleochannel. Determining the base of the Pensauken Formation in the Locust Grove study area from geophysical logs without lithologic control was difficult because the gamma response of the lower part of the Pensauken is very similar to that of the sand facies in the upper Aquia Formation.

Old Church (?) Formation, Upper Oligocene, and Calvert Formation, Lower to Middle Miocene

Hansen (1992) reported 1.5 m (5 ft) of a glauconitic fine to medium sand with a late Oligocene foraminiferal assemblage in core KE Bf 180. This unit was tentatively assigned to the Old Church Formation. Drummond (1998) showed the updip limit of the Calvert Formation just to the north of the Chester River; the Calvert may extend into the southeast corner of the Locust Grove study area, although it was not identified in core KE Bf 180. The Calvert Formation typically is a compacted marine silt with low permeability, and is a regional confining or semi-confining layer south of the Chester River. Neither Old Church nor Calvert sediments were confirmed in cores or geophysical logs collected for this project. However, a thin bed of silty fine sand similar to the description of the Old Church (?) Formation was observed when augering the hole for well KE Be 216, which is approximately 700 m northwest (updip) from corehole KE Bf 180.

Aquia Formation, Upper Paleocene

The upper Paleocene Aquia Formation underlies the Pensauken Formation throughout the study area except where the Pensauken has been removed by erosion. The Aquia Formation is a coarsening-upward marine sequence with two distinct facies. The lower section of the Aquia is a fine to medium sand with abundant (30 to 50 percent) glauconite grains and a sticky silt-clay matrix. When seen in fresh cores, the sediments of this facies are dark greenish-gray to dusky blue-green, and show no evidence of leaching or oxidation except at the upper and lower boundaries. Hansen (1992) and Minard (1974) give detailed descriptions of the lithology of this facies, including the characteristics of the glauconite grains. Mollusk and brachiopod shells are preserved in this section of the Aquia in coreholes KE Bf 180 (Hansen, 1992) and KE Be 186. The upper section of the Aquia Formation is a medium quartz sand with a minor component of coarse sand grains and 5 to 15 percent glauconite. This section is weathered throughout its vertical extent, and there is little silt-clay matrix between the sand grains. The sediments of the upper Aquia are light olive to light olive-brown with dark reddish-brown to dark gray flecks of glauconite, giving a "salt and pepper" appearance. Individual glauconite grains in the upper section commonly have oxidized rinds or are worn and polished.

The transition between the upper sandy facies and the lower facies with the silt-clay matrix, referred to as the "redox transition zone," occurs in a 0.5 to 1 m interval at the base of the sandy facies. This textural change coincides with a transition from leached and oxidized sediments above to relatively unaltered sediments with reduced mineral phases below. Iron oxides were observed near this boundary in the cores. Joints and fractures that extend below this textural and sediment-redox transition have brown or reddish-brown oxidized zones 1 to 5 mm wide, indicating localized flow of oxygenated ground water into this layer. A second sediment-redox transition was observed at the base of the Aquia silt-clay facies, with oxidation proceeding upward from the underlying sandy facies of the Hornerstown Formation. This lower redox transition was most prominent in corehole KE Be 183, but was observed in all four cores collected in this project.

The updip limit of the Aquia Formation appears to be in a zone trending west-southwest to east-northeast immediately north of Route 213 (Figure 2) at the northern boundary of the study area, but its exact location is poorly delineated by the available data. The updip limit of the Aquia aquifer shown in a subcrop map for Kent County published by Drummond (1998) includes the Hornerstown Formation as part of the Aquia aquifer, and does not specifically represent the areal extent of the Aquia Formation. The silt-clay facies at the base of the Aquia Formation is within 14 m of the land surface in the three northernmost wells (KE Be 187, KE Be 197, and KE Ae 29), and corehole KE Be 185 (Locust Grove) (Figure 2). The base of the Aquia Formation drops from 10 m asl in corehole KE Be 185 (Locust Grove) at the northern boundary of the study area, to 21 m below sea level in KE Bf 180 at the southern boundary. The Aquia thickens from 5 m to 28 m in the 6 km between the two coreholes. The

stratigraphic boundary between the upper and lower facies of the Aquia Formation appears clearly in gamma logs (Figure 5) and was used as a marker horizon for correlation throughout the study area. Where the entire sequence of the Aquia Formation is preserved downdip, the upper and lower facies are 19 and 9 m thick, respectively.

Hornerstown Formation, Lower Paleocene

The lower Paleocene Hornerstown Formation is lithologically very similar to the overlying upper Paleocene Aquia Formation. The Hornerstown Formation also is a coarsening-upward sequence of marine glauconitic sands. In the study area, only corehole KE Bf 180 and wells KE-94-0146 and KE Be 171 penetrate the entire thickness of the Hornerstown Formation. The coreholes and the deeper wells drilled for this project were completed in the upper section of the Hornerstown Formation. The lower 15 to 16 m of the Hornerstown Formation has a substantial clay content based on the gamma logs; a prominent gamma excursion in the lower 2 m of the unit probably is a relatively low-permeability clay bed. A larger gamma excursion in the underlying Severn Formation indicates a clay bed that is a regional confining layer and an excellent marker horizon (Figure 5). The upper 10 to 13 m of the Hornerstown Formation is predominantly sand. However, the uppermost 2 to 4 m of the Hornerstown, immediately below the silt-clay-rich facies of the Aquia Formation, commonly has a substantial clay content, although not as much as in the lower section of the Hornerstown.

The contacts between the Aquia and Hornerstown Formations in the four cores collected in this project were not as distinct as the one described in core KE Bf 180 (Hansen, 1992). In this project, the base of the Aquia Formation was interpreted consistently as the transition between the bottom of the silt-clay-rich facies of the Aquia and the top of the sandy facies of the Hornerstown; this boundary can be identified readily in most of the geophysical logs. The actual stratigraphic unconformity between the two formations could be verified only by detailed biostratigraphy across this interval.

Composite Hydrostratigraphic Sequence

Hydrostratigraphic units in the Locust Grove study area were defined from the permeabilities inferred from the sediment textures in the cores and the character of the geophysical logs. Five hydrostratigraphic units were identified in the surficial and first confined aquifer systems: the Columbia aquifer and the Aquia aquifer, which together make up the surficial aquifer, the Aquia confining layer, the Hornerstown aquifer, and the Hornerstown confining layer. A very low-permeability clay bed in the Severn Formation lies immediately below the Hornerstown confining layer throughout most of the study area to form a regional confining layer.

Surficial Aquifer (Columbia and Aquia Aquifers)

By regional usage for the Delmarva Peninsula, the term "Columbia aquifer" includes the Pensauken Formation in Maryland and the Columbia Formation in Delaware (Bachman 1984b). Drummond (1998) also included the Pleistocene terrace deposits in his definition of the Columbia aquifer in Kent County, Maryland. Because no Pleistocene terrace deposits occur within the study area, the Columbia aquifer as used in this project is restricted to the sands and gravels of the Pensauken Formation. In the Locust Grove study area, the Columbia aquifer is less than 2.5 m thick updip in well KE Be 187, and greater than 10 m thick downdip. The base of the Columbia aquifer cannot be readily identified in geophysical logs without lithologic control.

The upper sandy facies of the Aquia Formation is designated the "Aquia aquifer." In previous usage by other investigators, the Aquia aquifer in Kent County, Maryland, includes the glauconitic sands of the Aquia and Hornerstown Formations (Overbeck and Slaughter, 1958; Otton and Mandle, 1984; Hansen, 1992; Drummond, 1998). However, the cores obtained as part of this project indicate that the silt-clay layer at the base of the Aquia Formation is very impermeable (see "Aquia confining layer," below), and there is much less hydraulic connection between the Aquia and Hornerstown Formations than between the Aquia and overlying Pensauken Formation. Thus, the "surficial aquifer" is defined here as the combined Pensauken Formation and upper sandy facies of the Aquia Formation, and referred to as the Columbia-Aquia aquifer. As the sandy facies of the Aquia Formation pinches out updip, toward the north of the study area, the surficial aquifer is composed solely of the Pensauken Formation, or Columbia aquifer.

Aquia Confining Layer

The silt-clay at the base of the Aquia Formation was recognized in previous studies, but was considered permeable or at least semi-permeable, and therefore the Aquia and Hornerstown Formations were interpreted as hydraulically connected. The silt-clay facies at the base of the Aquia Formation typically is from 6 to 9 m thick and can be identified in geophysical logs throughout the study area. A very low-permeability clay-rich bed from 2 to 3 m thick occurs in the lower third of the unit and is associated with a peak in the gamma logs. Fresh core material from this clay-rich bed, although plastic, was nearly dry in appearance. Geochemical and age-dating evidence, discussed in the Ground-Water Geochemistry section, show substantial differences in the properties of ground water above and below the silt-clay layer at the base of the Aquia Formation. These lines of evidence suggest that the lower Aquia Formation is an effective confining layer. The possible exceptions to this are in areas of enhanced vertical hydraulic gradients, such as discharge areas beneath streams and near production wells pumping from the sands in the upper part of the Hornerstown Formation.

Hornerstown Aquifer and Hornerstown Confining Layer

The Hornerstown Formation, similar to the Aquia Formation, has an upper sandy facies and a lower silt-clay-rich facies that are designated the "Hornerstown aquifer" and the "Hornerstown confining layer," respectively (Figure 5). The thickness and clay content inferred from gamma logs of these two Hornerstown units are more variable than those of the Aquia Formation in the Locust Grove study area and across Kent County (see the hydrogeologic sections of Drummond, 1998). In the study area, the Hornerstown aquifer is from 9 to 11 m thick, and the Hornerstown confining layer is from 10 to 15 m thick. The Hornerstown confining layer is underlain by the Severn Formation, which includes at its base approximately 5 m of low-permeability clay; the two units together form a regional confining layer that separates the Aquia/Hornerstown aquifer system from the Monmouth aquifer. The subcrop area of the Hornerstown aquifer is to the north and northwest of Route 213 (Figure 1b). Part of this area is deeply incised by tributaries extending south from the Sassafras River. The most likely recharge area for the Hornerstown aquifer is the upland plain north of Kennedyville, Maryland, and northwest of the intersection of Routes 213 and 298.

Geometry of the Hydrostratigraphic Units

The five hydrostratigraphic sections presented in Figures 6 through 10 show the geometry of the primary hydrostratigraphic units, coreholes, and wells in the Locust Grove study area. These sections were prepared by correlating lithostratigraphic and hydrostratigraphic units away from the five coreholes using the geophysical logs from the deeper wells at each site. Sections A-A' (Figure 6) and B-B' (Figure 7) run mostly southwest to northeast, close to the regional strike of the Cretaceous and Tertiary units. Sections C-C" (Figure 8), D-D' (Figure 9), and E-E' (Figure 10) run mostly north to south, close to the regional dip. Section D-D' was the primary transect for the previous NAWQA project (Hamilton and others, 1993) and ground-water dating and flow-path modeling studies (Dunkle and others, 1993; Reilly and others, 1994).

Hydrostratigraphic section A-A' (Figure 6) runs west-southwest to east-northeast along Route 213 at the northern boundary of the study area. This transect runs along the southern edge of the subcrop zone of the Aquia confining layer (Aquia CL). The surficial aquifer is very thin, less than 3 m thick in places, because the sandy facies of the Aquia Formation (the Aquia aquifer, or Aquia AQ) was removed by erosion prior to or during the deposition of the Pensauken Formation. The sands of the Pensauken Formation (the Columbia aquifer) also thin across a subsurface high that probably was created because the silt-clay facies in the lower Aquia Formation (the Aquia CL) is more resistant to erosion than the sands in the upper Aquia Formation. The updip limit of the subcropping Aquia CL and the Hornerstown aquifer (Hornerstown AQ) are not known precisely because of a lack of boreholes for control.

Section A-A' straddles the surface-water drainage divide between the tributaries of the Sassafras River to the north and Morgan Creek to the south. The saturated zone in the surficial aquifer overlying the Aquia CL is very thin. Wells KE Be 187 and KE Be 197 are screened at the base of the surficial aquifer. For well KE Be 187, the maximum thickness of the saturated zone was 1.5 m in May 1998 and the minimum was 0.1 m in May 1999; for well KE Be 197, the maximum was 0.8 m in May 1998, and the well was dry from November 1998 through August 1999, during a prolonged drought. It is inferred that ground water drains quickly off the subsurface high of the subcropping Aquia CL through the coarse sands and gravels of the Pensauken Formation.

Hydrostratigraphic section B-B' (Figure 7) runs diagonally across the study area, including part of the high ground along Blacks Station Road that is the drainage divide between Morgan Creek and Chesterville Branch. The transect is oblique to the regional strike, so it has a dip component. Only one well on the transect (KE Be 210) penetrates the Aquia CL; consequently, hydrostratigraphic units could not be identified for most of this section.

Hydrostratigraphic section C-C" (Figure 8) runs north-south on the western border of the study area along Road 298 and crosses Morgan Creek. The transect extends from the northern drainage divide for Morgan Creek (at well KE Be 187) to just south of the southern drainage divide (at the well KE Be 195 cluster). Two coreholes, KE Be 183 (Morgan Creek North) and KE Be 184 (Morgan Creek South), provide lithologic control for the updip part of the section. The Aquia CL subcrops shallowly at the north (updip) end of the section, beneath wells KE Be 187 and 188. These two wells are screened in the surficial (Columbia) aquifer at the top of the confining layer. The holes for these two wells were not drilled through the Aquia CL, so the thickness of the confining layer at these sites is not known. The most complete hydrostratigraphic sequence for the updip part of the section is provided by the gamma log of the Nau Farm well. This sequence is projected along strike approximately 1.2 km due southwest onto section C-C".

The surficial aquifer thins appreciably north of Morgan Creek as the top of the Aquia CL rises in altitude. The Pensauken Formation typically is from 7 to 10 m thick south of Morgan Creek and the Aquia AQ thickens appreciably downdip, although the actual geometry cannot be represented because of a lack of deep holes south of the KE Be 184 corehole. In Morgan Creek valley, both the Pensauken Formation and the sandy facies of the Aquia Formation (the Aquia AQ) have been removed by stream incision. The alluvial sediments filling the incised valley are 3.5 to 4 m thick in the center of the valley and sit directly on the Aquia CL. The upper 2 or 3 meters of the Aquia CL also may have been eroded in the deepest part of the valley.

One notable feature of the C-C" section is the abrupt offset of the base of the Aquia CL between well KE Be 189 in Morgan Creek valley and corehole KE Be 183 approximately 350 m to the north. This offset might be related to a fault, although this is a tentative interpretation. Supporting evidence for a fault is based on the correlation of the base of the Aquia CL and the gamma log peak in the Aquia CL in three deep holes (coreholes KE Be 183 and 184, and well KE Be 189) near Morgan Creek valley. The updip part

HYDROSTRATIGRAPHIC SECTION A-A'
(along Route 213)
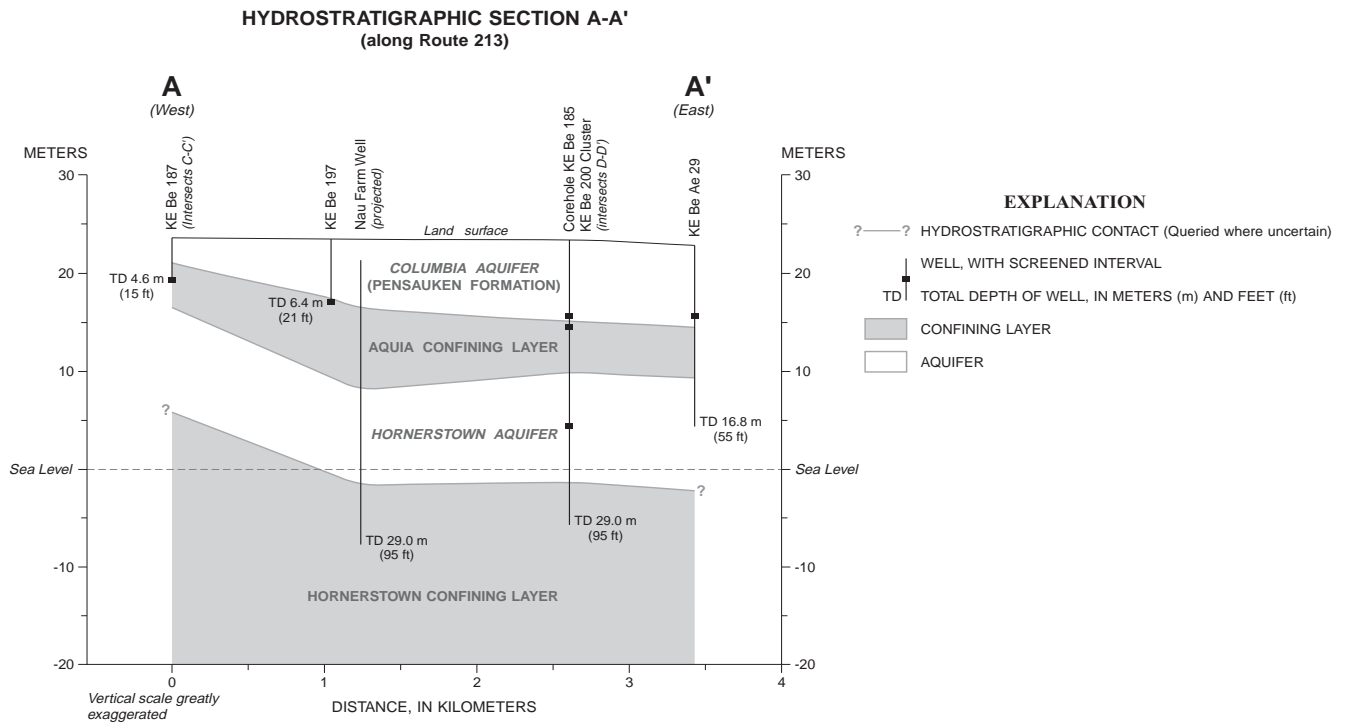
Figure 6. Hydrostratigraphic section A-A' along Route 213 at the northern boundary of the Locust Grove study area, Kent County, Maryland.

HYDROSTRATIGRAPHIC SECTION B-B'
(along Blacks Station Road and VanSants Corner Road)
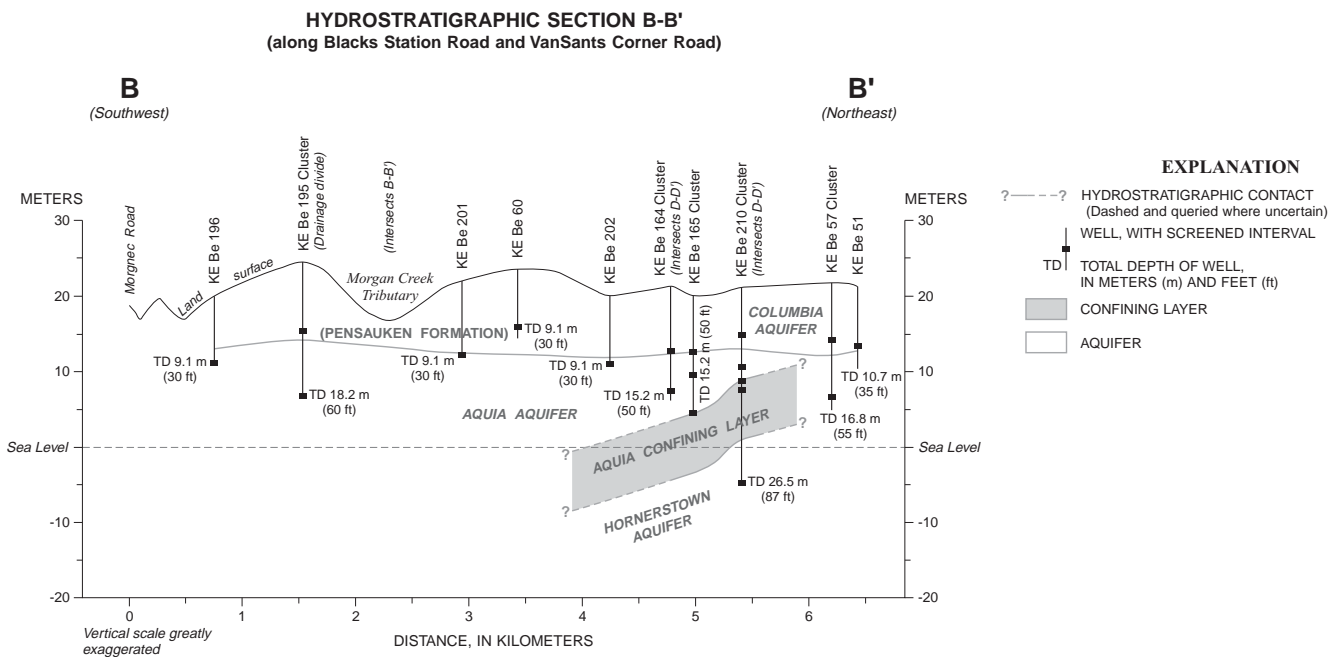
Figure 7. Hydrostratigraphic section B-B' along Blacks Station Road and VanSants Corner Road through the middle of the Locust Grove study area, Kent County, Maryland.
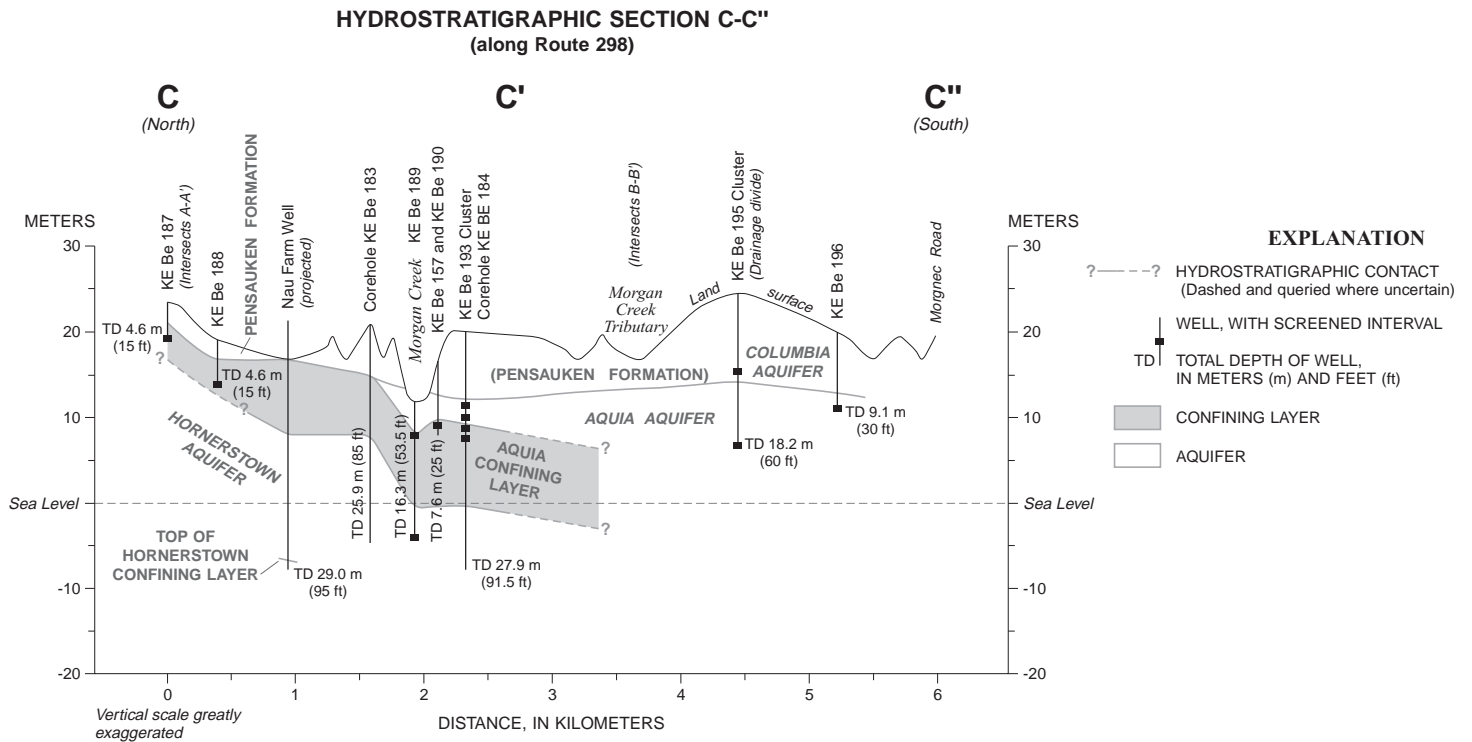
Figure 8. Hydrostratigraphic section C-C" along Harmony Woods Road (State Highway 298), the western boundary of the Locust Grove study area, Kent County, Maryland.
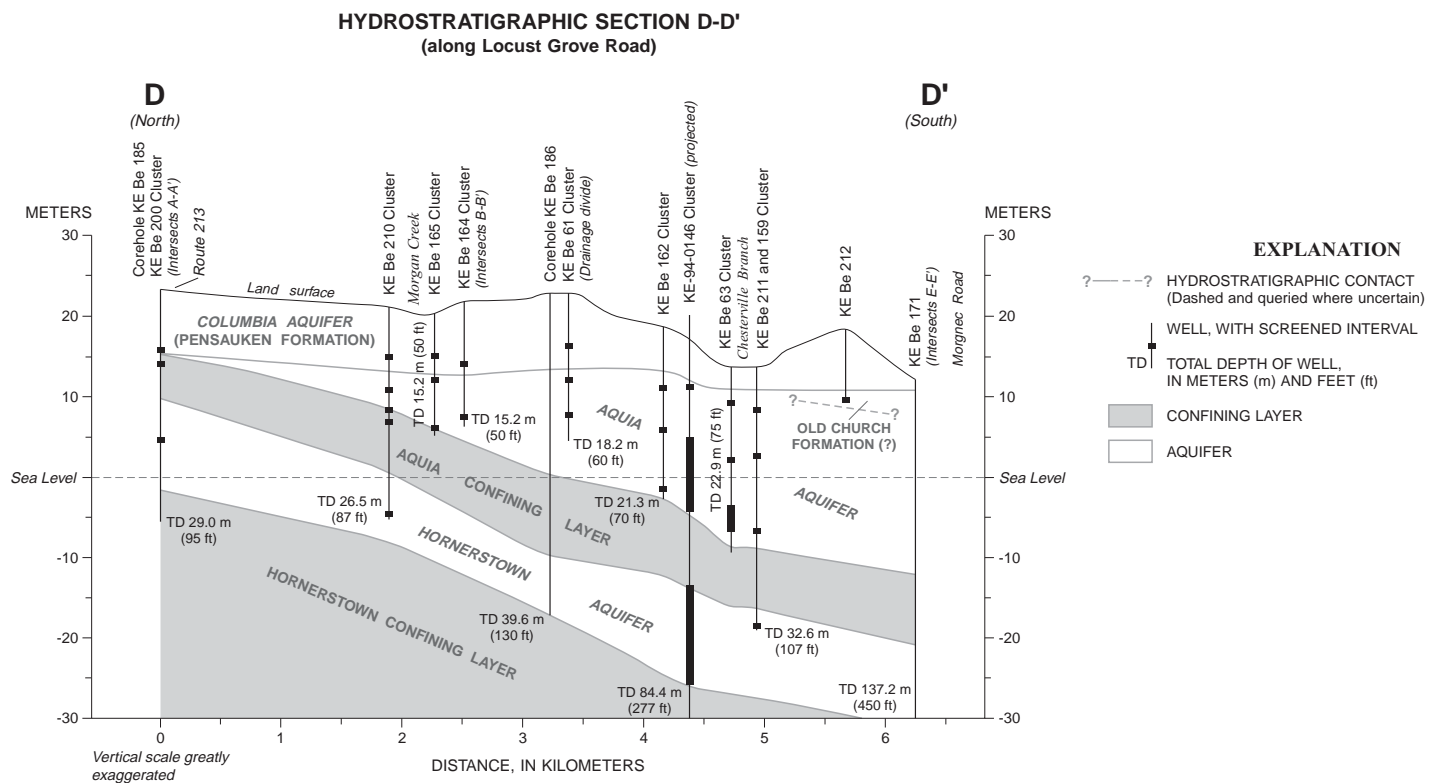
Figure 9. Hydrostratigraphic section D-D', the primary transect along Locust Grove Road from Locust Grove to Chesterville, in the Locust Grove study area, Kent County, Maryland.

HYDROSTRATIGRAPHIC SECTION E-E'
(along Bolton Road and through Angelica Nurseries)
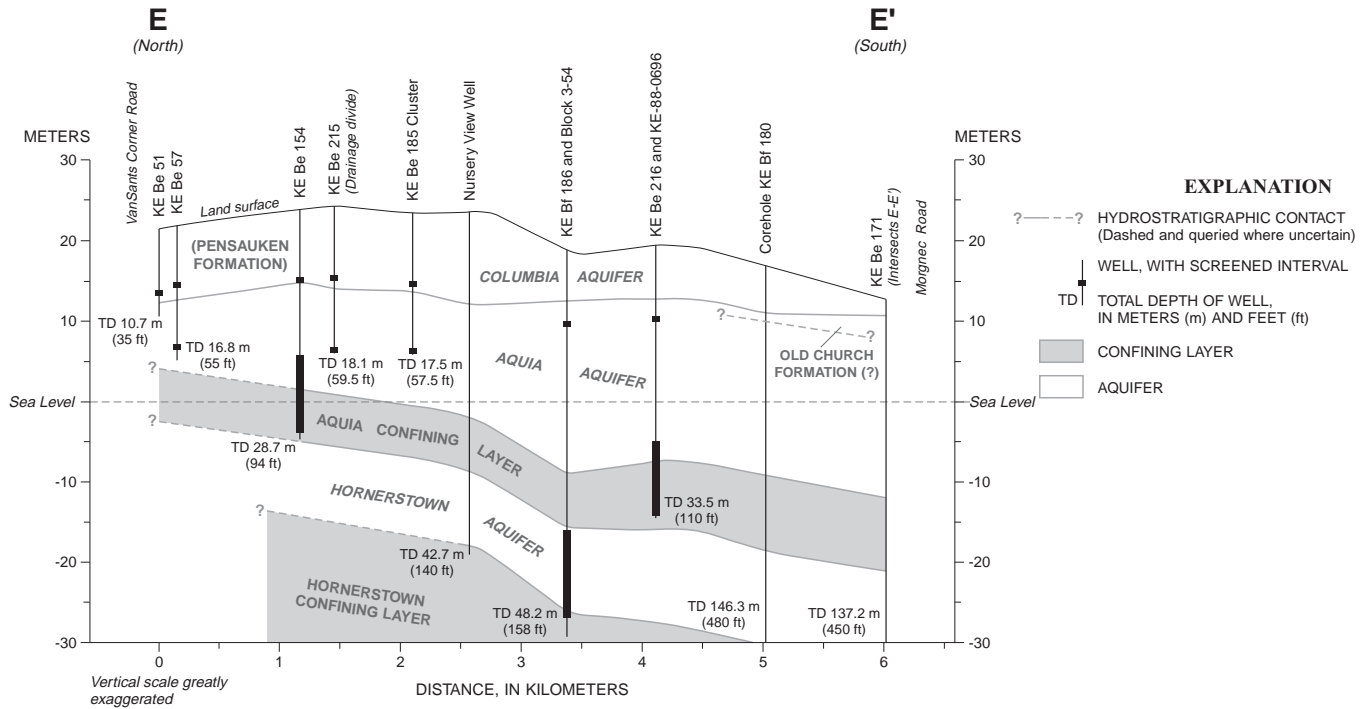
Figure 10. Hydrostratigraphic section E-E', the eastern boundary of the Locust Grove study area through Angelica Nurseries, Kent County, Maryland.

of section C-C" (Figure 8) shows a reversal of the regional dip to the southeast between corehole KE Be 184 (south) and well KE Be 189 in Morgan Creek valley, and a steep rise between KE Be 189 and corehole KE Be 183 (north). The gamma peak in the Aquia CL and the bottom of the Aquia CL drop in altitude by 2.0 and 0.8 m, respectively, from KE Be 184 to 189, and then rise by 6.75 and 8.0 m between KE Be 189 and KE Be 183. The regional dip estimated from section D-D', which is roughly parallel to section C-C", is from 5.3 to 5.5 m/km (meters per kilometer). The steep dip between corehole KE Be 183 and well KE Be 189 is between 20 and 23 m/km; even when using the more conservative correlation between coreholes KE Be 183 (north) and 184 (south), the dip is between 7.0 and 10.5 m/km. If this interpretation is correct, the downdropped side of the fault lies directly below Morgan Creek, and the upthrown side is immediately to the north of the creek. The displacement across the possible fault is on the order of 5 m. With only one transect crossing the potential fault, it is not possible to estimate the strike of the fault, although the southwest-northeast trend of Morgan Creek may be a geomorphic expression.

If a fault is present beneath Morgan Creek, it may have a large effect on ground-water flow from the Hornerstown aquifer. The entire confining layer in this area is 9-10 m thick, and the lowest-permeability part of the confining layer is 2-3 m thick. A 5-m offset caused by a fault could breach the low-permeability part of the confining layer to create a lateral conduit that would allow discharge of Hornerstown water directly to Morgan Creek.

Hydrostratigraphic section D-D' (Figure 9) is the primary transect running north-south through the study area from Locust Grove to Chesterville, Maryland. This transect is very close to the regional dip, contains two coreholes (KE Be 185 and 186), and five deep wells that penetrate the Aquia CL and part or all of the Hornerstown Formation. All of the hydrostratigraphic units of the surficial and first confined aquifer systems are shown in this section. The updip pinchout of the Aquia AQ is apparent, although the Pensauken Formation (Columbia aquifer) is not as thin in the Locust Grove corehole (KE Be 185) as at the site of well KE Be 187 (Figure 9). Downdip, the Old Church (?) Formation overlies the Aquia AQ; farther downdip, south of the Chester River, the silty Calvert Formation overlies the Aquia and it becomes a confined aquifer. The base of the Pensauken Formation drops 5 m in altitude from the updip to the downdip end of the section.

Hydrostratigraphic section E-E' (Figure 10) runs sub-parallel to section D-D' and intersects D-D' at the southern end. Section E-E' runs through Angelica Nurseries and is the eastern boundary of the study area. Because of the regional southwest-to-northeast strike, the Aquia AQ is thicker in section E-E' than in D-D'. Five deep holes provide excellent control for the position of the Aquia CL. The transect crosses the three-way drainage divide between Morgan Creek, Chesterville Branch, and Woodland Creek (to the northeast) near the site of wells KE Be 154 and KE Be 213. The Pensauken Formation thins considerably to the south because of the headward erosion of the Chesterville Branch drainage.

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The extent of the shallow subcropping of the Aquia CL (Figure 11) was mapped using the coreholes and geophysical logs from this project, and the more regional map presented by Drummond (1998). The subcropping zone was developed from the hydrostratigraphic sections (Figures 6-10), and projected or inferred where core control is lacking. The trend of the subcropping zone roughly parallels Morgan Creek to the north of the creek, and underlies the northern drainage divide for the Morgan Creek watershed. The tributaries north of Morgan Creek all drain basins where the sedimentary redox zone at the top of the Aquia CL is within 10 or 15 m of the land surface.

Ground-Water Flow Paths and Traveltimes

The water-level measurements of wells screened in the Columbia-Aquia surficial aquifer indicate that ground-water flow patterns are similar to those reported by Hamilton and others (1993). Ground-water levels from May 1998 (Appendix C), when the water table was at its maximum height during the project, were used to create a water-table map (Figure 12) and to represent flow paths in vertical sections (Figures 13a and 13b). The basic flow patterns were similar throughout the 1997-99 period of record, including a period of extreme drought during the summer of 1999.

In general, water is recharged in the uplands, flows through the surficial aquifer, and discharges to the perennial streams (Figures 12 and 13). There is some evidence, particularly on the northern boundary of the Chesterville Branch watershed (Figure 12), that ground-water divides do not coincide with surface-water divides; however, the relatively poor resolution of topographic mapping in the study area makes precise delineation of surface-water divides difficult. A water-table high in the northeastern part of the Morgan Creek watershed is inferred from data presented by Hamilton and others (1993). However, the wells that showed this mound subsequently were destroyed, and were not available for this investigation.

The recharge areas and flow patterns of ground water in the Hornerstown aquifer are difficult to interpret from the limited number of available wells. Downdip flow is indicated from well KE Be 210 to KE Be 211 (at Chesterville Branch) (Figure 13), but there is also the possibility of flow to the north (updip) from a divide south of well KE Be 200 toward the Sassafras River watershed. It is unclear whether most of the recharge to the Hornerstown aquifer comes from the outcrop/subcrop zone north of the study area, or whether an appreciable proportion of the recharge is through the Aquia confining layer.

Ground-water traveltimes, as determined from CFC ages (Appendix D; E. Busenberg, U.S. Geological Survey, written commun., 1998) are similar to those reported in earlier work (Dunkle and others, 1993; Reilly and others, 1994; Böhlke and Denver, 1995),
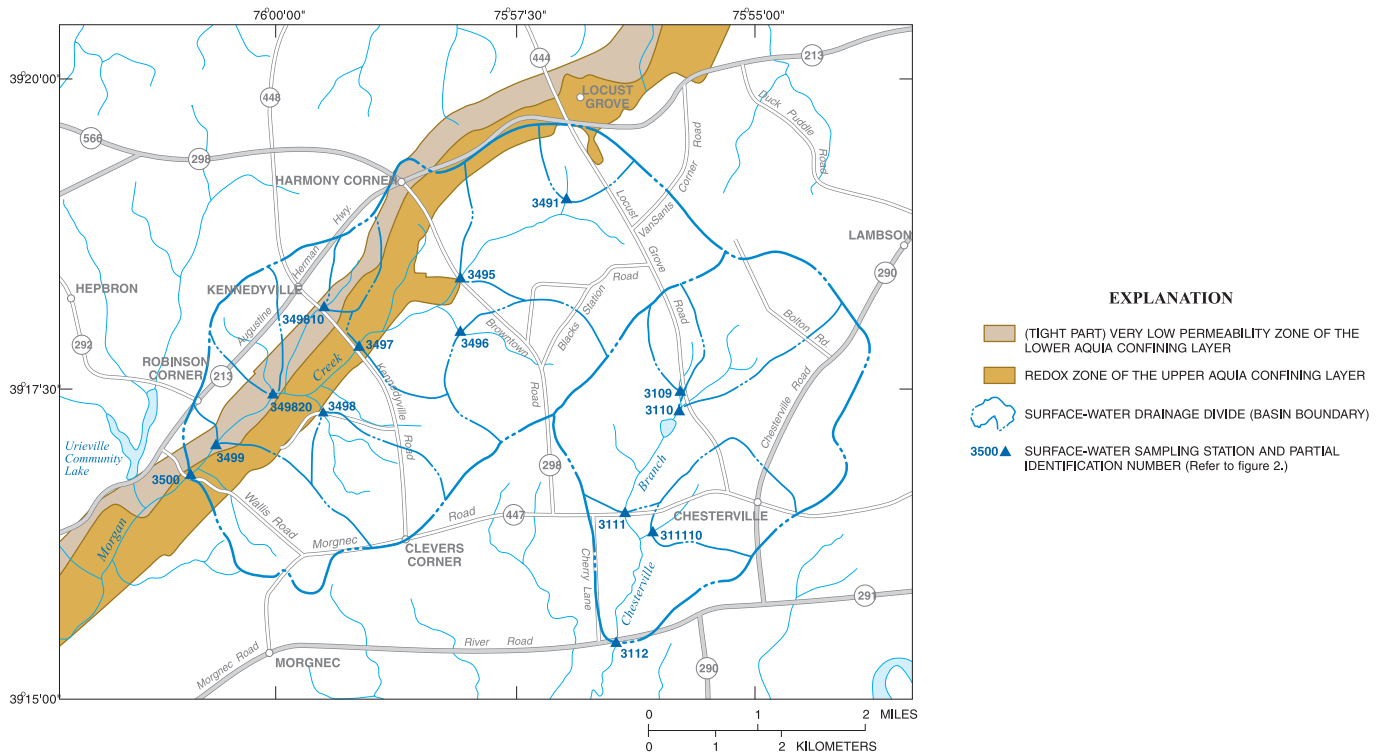
Figure 11. The extent of the subcropping Aquia confining layer and redox zone in the Locust Grove study area, Kent County, Maryland, with subbasins for surface-water sampling sites.

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and generally confirm the relation between traveltimes and parts of the ground-water flow system. The youngest ground water is less than 10 years old and is found in shallow wells in recharge areas (for example, wells KE Be 192 and 194; Appendix D). Ground water collected deeper in the surficial aquifer, such as from well KE Be 195, is on the order of 20 to 30 years old. Ground water from the Hornerstown aquifer in the study area had not been sampled for geochemistry or age dating prior to this project. Hornerstown water is consistently greater than 40 years old in all four wells sampled (Table 3), with progressively older CFC ages downdip, from 42 years in well KE Be 200 to greater than 50 years in well KE Be 210. In addition, local trends in the concentrations of ^{4}He (helium-4) indicate that the downdip Hornerstown water may be 75 years old or older (E. Busenberg, U.S. Geological Survey, written commun., 2000).

The ground water in the surficial aquifer that discharges to Morgan Creek follows flow paths very different from ground water that discharges to Chesterville Branch because of the aquifer geometry. This geometry also results in generally longer ground-water traveltimes for the Chesterville Branch watershed. Ground water discharging to Chesterville Branch behaves as if in a simple, moderately deep, unconfined aquifer with an impermeable horizontal base. The details of flow may be slightly different from the idealized conceptualization because of the southward dip (approximately 5 m/km) of the base of the Aquia aquifer. In general, the flow paths that contact the reducing sediments at the base of the aquifer represent a relatively small fraction of the total discharge to Chesterville Branch. Discharge to Morgan Creek is more complex. The Columbia-Aquia surficial aquifer is relatively thick only southeast of Morgan Creek. The incised valley of Morgan Creek has cut down to, and probably into, the reduced sediments of the Aquia confining layer (Figure 13b). Much of the ground water moving to Morgan Creek probably flows updip and contacts the reducing sediments. This process was evaluated by Hantush and Cruz (1999) using numerical simulations based on the data presented here. They found that the data were consistent with the concept that a large percentage of discharge to Morgan Creek flows through the reducing layer at the base of the aquifer.

In addition to ground-water discharge from the lower part of the Aquia aquifer, Morgan Creek also may receive considerable discharge from the Hornerstown aquifer. If a fault is present beneath Morgan Creek, it may allow appreciable ground-water flow from the Hornerstown aquifer through a breached Aquia confining layer. The entire confining layer in this area is 9 to 10 m thick and the lowest-permeability part of the confining layer is 2 to 3 m thick. A 5-m offset caused by a fault could breach the low-permeability part of the confining layer to create a lateral conduit that would allow discharge of Hornerstown water directly to Morgan Creek. However, further study is needed to verify the presence of the fault, and to document ground-water flow through the confining layer.
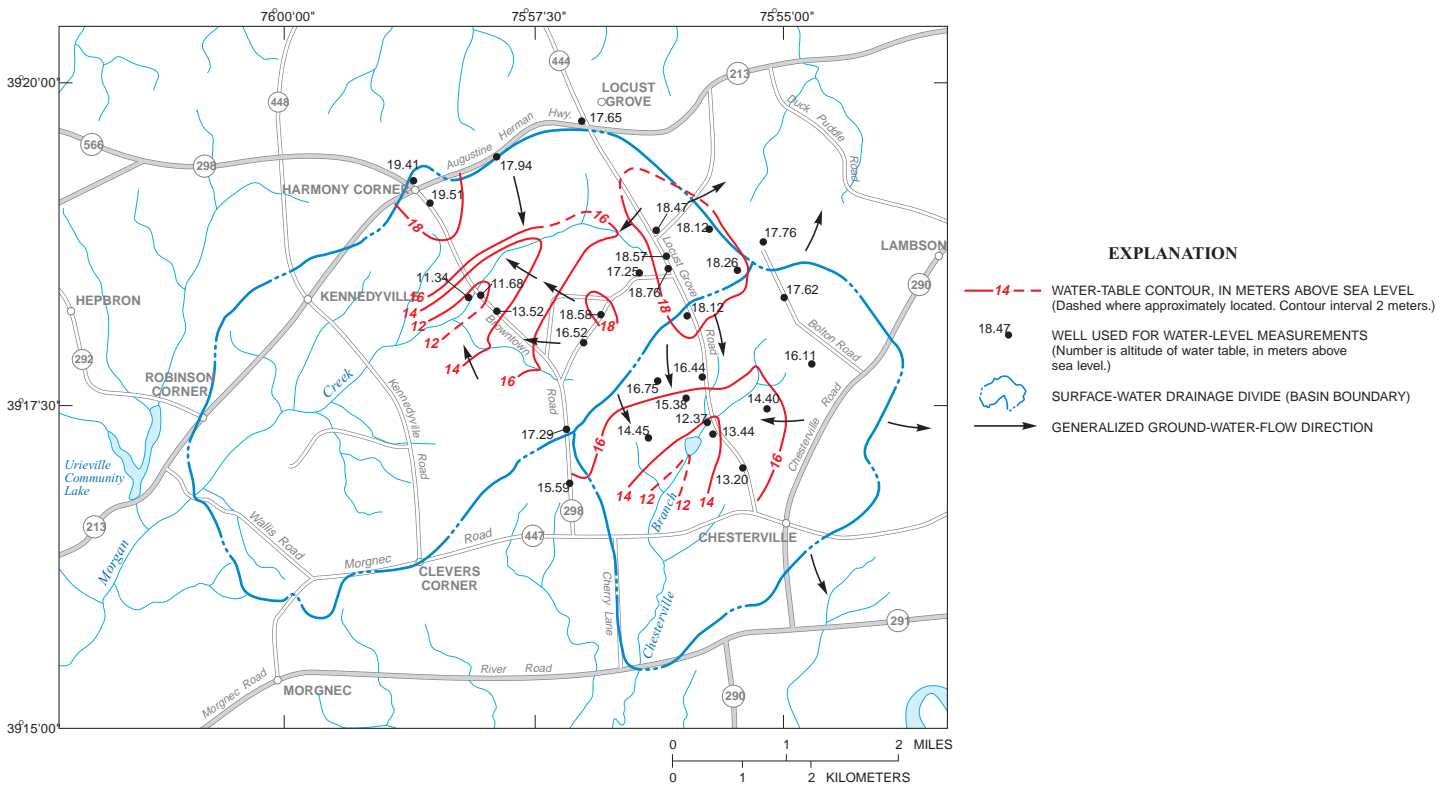
Figure 12. Configuration of the water table and generalized ground-water flow, Locust Grove study area, Kent County, Maryland, May 1998.

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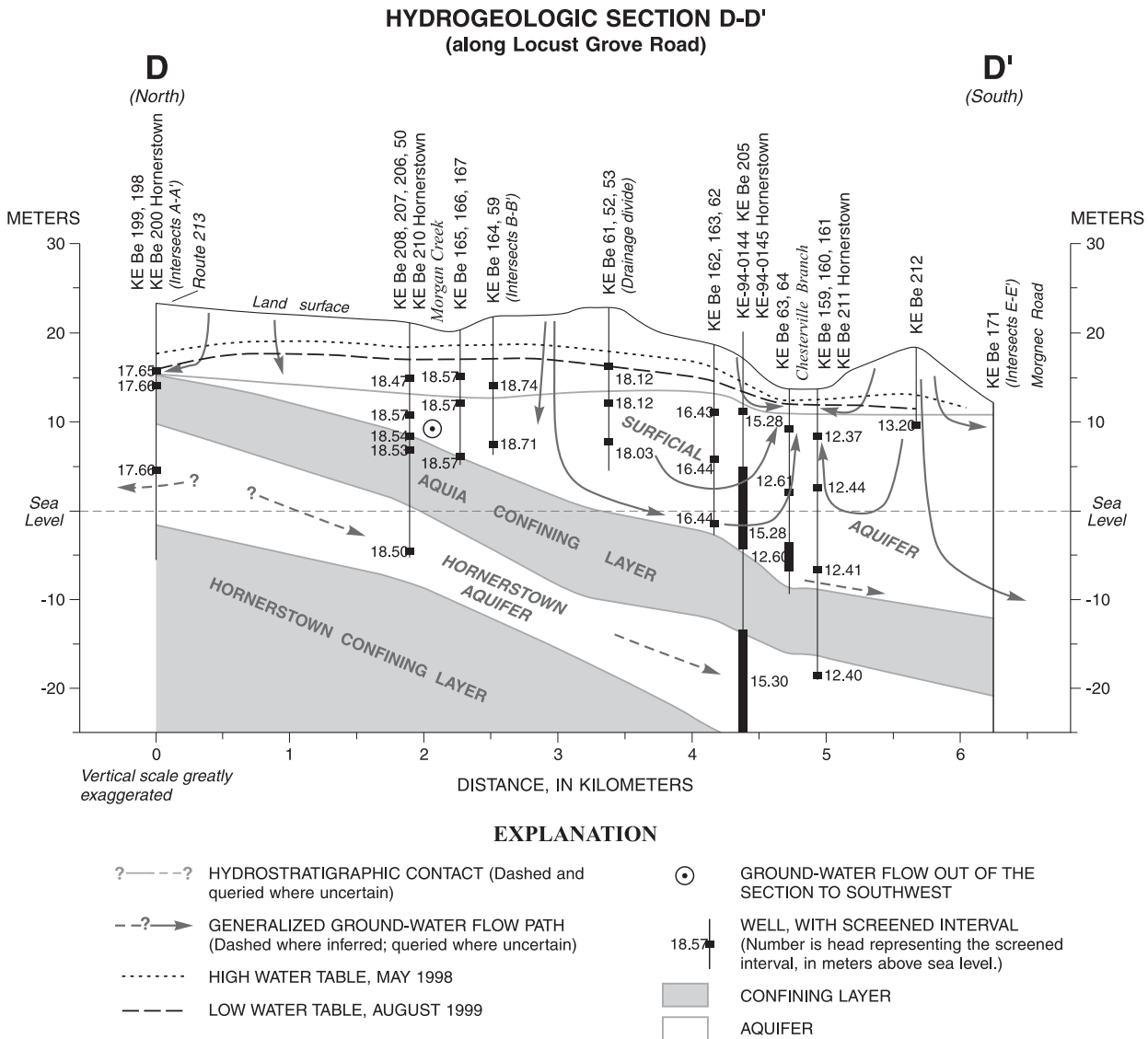
Figure 13a. Hydrogeologic section D-D' (along Locust Grove Road) showing ground-water flow paths in the shallow aquifer system, May 1998, Locust Grove study area, Kent County, Maryland.
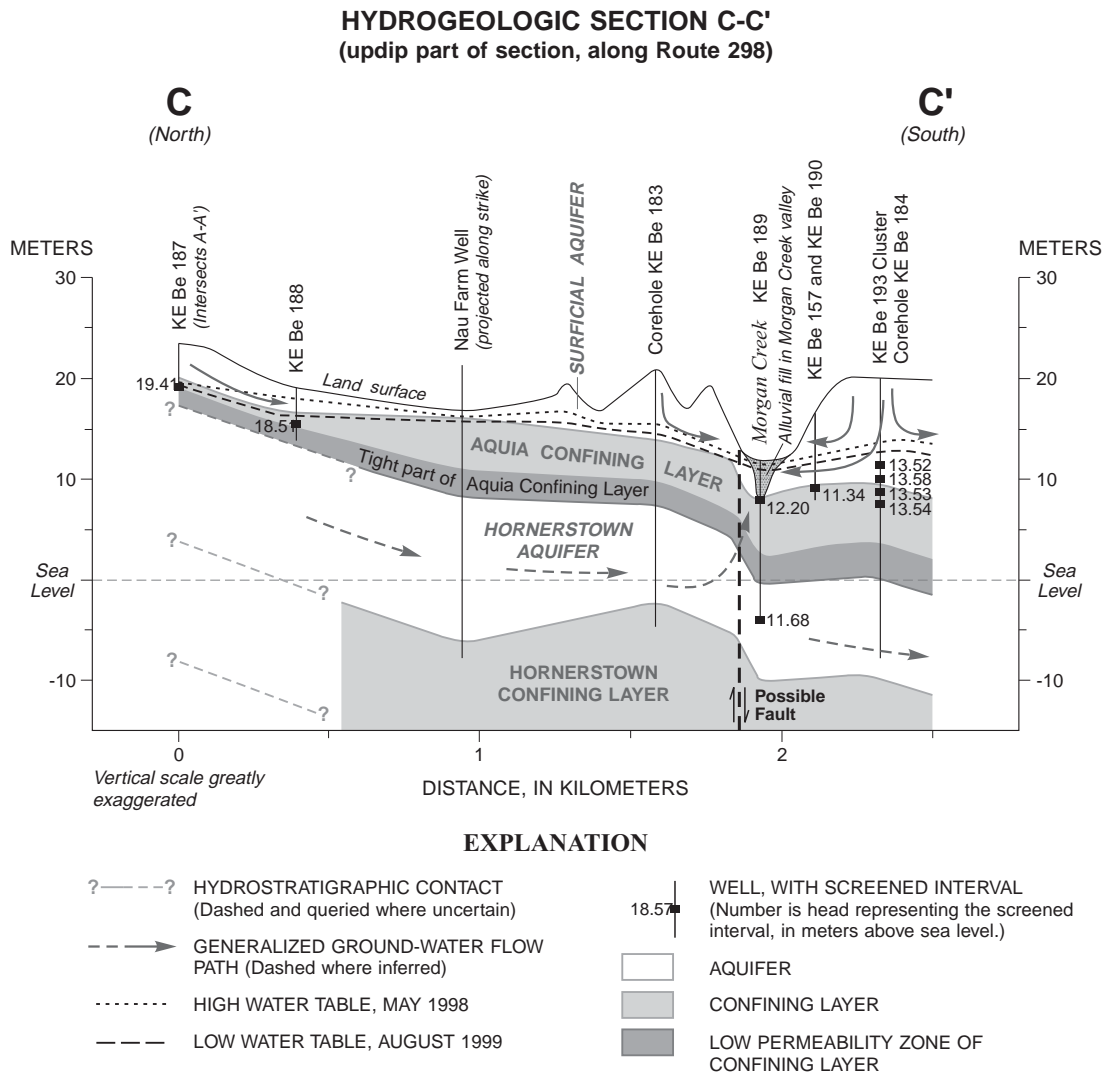
Figure 13b. Hydrogeologic section C-C' (along Harmony Woods Road, State Highway 298) showing ground-water flow paths in the shallow aquifer system, May 1998, Locust Grove study area, Kent County, Maryland.

Ground-Water Geochemistry

The ground-water geochemistry of the study area has been described in some detail by Hamilton and others (1993) and Böhlke and Denver (1995). The shallow aquifers contain three major water types: "young" (post-1970 recharge) agricultural ground water; "old" (pre-1970 recharge) agricultural ground water; and "old" calcareous water. The "agricultural" ground water has concentrations of dissolved nitrate that are considerably elevated above natural background levels; "old" agricultural water has nitrate concentrations of 2-3 mg/L as N and "young" agricultural water has nitrate concentrations greater than 3 mg/L as N. Nitrate concentrations in young water can exceed 20 mg/L as N. Nitrate concentrations in the "calcareous" waters are near or below the analytical detection limit (0.05 mg/L). Böhlke and Denver (1995) also reported that the relative concentrations of magnesium generally covary with nitrate concentrations in ground water. This covariance results from the application of dolomitic limestone (calcium-magnesium carbonate) as a soil amendment, which is apparently applied in proportion to the amount of nitrogen fertilizer used.

Agricultural waters have dissolved oxygen concentrations exceeding 5 mg/L, whereas the "calcareous" waters have dissolved oxygen concentrations close to zero mg/L. Low, but measurable, concentrations of dissolved oxygen were reported in a number of wells sampled in the study area. These low concentrations were interpreted by Böhlke and Denver (1995) as representing mixtures of oxygenated agricultural water and anoxic calcareous water. For the hydrogeochemical interpretations, these mixtures were classified with the anoxic waters as "suboxic" (Böhlke and Denver, 1995).

Young agricultural waters were a calcium-magnesium nitrate-chloride type (Figure 14), reflecting the application of nitrogen and potash (KCl) fertilizers and of dolomitic limestone for pH adjustment of soil (Hamilton and others, 1993). The older agricultural
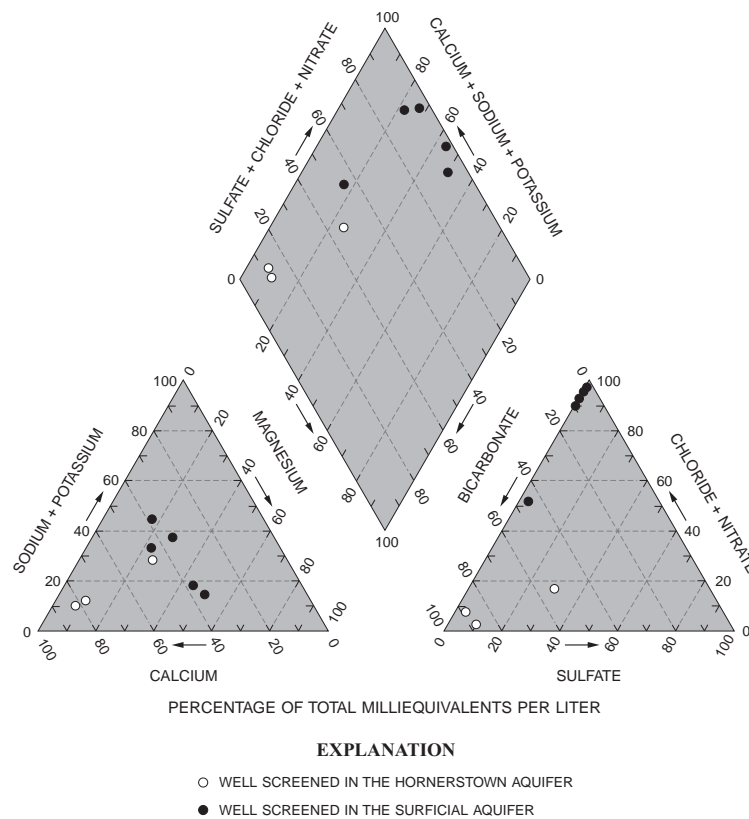
Figure 14. Chemistry of water from ground-water samples collected in July 1998 at the Locust Grove study area, Kent County, Maryland.

water was relatively enriched in sodium (Figure 14), probably because of water-rock interactions (Böhlke and Denver, 1995). The calcareous water was found previously in discharge areas at various depths above the confining layer. The water is of a reduced (suboxic) calcium-bicarbonate type (Figure 14), with bicarbonate concentrations roughly an order of magnitude higher than those in the oxic agricultural waters because of calcium carbonate dissolution.

Ground-water sampling conducted during this project generally confirmed the conclusions of Böhlke and Denver (1995), including the relations between recharge dates and nitrate concentrations (Appendix D). In addition, samples were collected from four new wells in the Hornerstown aquifer, and a series of samples were collected from a multiport well near the bottom of the Aquia Formation in the sediment redox transition. Ground water sampled from the multiport well had relatively low pH values, with relatively low concentrations of dissolved oxygen, and relatively high concentrations of nitrate and sulfate (Appendix D). Dissolved-gas analyses indicate that the multiport samples did not have substantial amounts of excess nitrogen gas from denitrification (Figure 15). Thus, the multiport samples appear to represent a water type with agricultural contaminants and is partly reduced, but has not been denitrified and has not encountered calcium carbonate. Waters from the confined Hornerstown aquifer were an anoxic, calcium-bicarbonate type similar to the old calcareous waters identified previously above the confining layer in discharge areas in stream valleys. The Hornerstown waters were relatively old (some more than 50 years old) and had relatively high silica and sulfate concentrations and minor amounts of excess nitrogen gas, as did the discharging waters.

Dissolved Nitrate and Denitrification

In general, the highest concentrations of dissolved nitrate were found in the recharge areas of the surficial aquifer, whereas waters with low concentrations of nitrate were found in discharge areas and commonly exhibited evidence of denitrification (Böhlke and Denver, 1995). Stream base flow, which is composed primarily of ground-water discharge, had nitrate concentrations in Morgan Creek (2.3 - 4.1 mg/L as N) that were appreciably lower than concentrations in Chesterville Branch (4.0 - 8.4 mg/L as N). Morgan Creek appears to receive a greater proportion of denitrified ground water than Chesterville Branch.

All water samples from the Hornerstown aquifer contained excess dissolved nitrogen gas above saturated equilibrium, as normalized to argon concentrations (Figure 15). The presence of excess nitrogen indicates that the water that recharged the Hornerstown aquifer contained measurable dissolved nitrate, probably on the order of 1-2 mg/L as N, which had been denitrified and transformed to dissolved nitrogen gas. Isotopic analyses of the nitrogen gas indicate that the Hornerstown waters may have had nitrate with nitrogen isotope $d^{15}N$ values between 2 and 5 ‰ (per mil, or parts per thousand), similar to the values obtained by Böhlke and Denver (1995) for ground water discharging in the stream valleys. The amount of excess nitrogen was slightly less in the southernmost and deepest Hornerstown well (KE Be 211, farthest downgradient) than in the three shallower, upgradient Hornerstown wells (KE Be 189, 200, and 210). All of the Hornerstown samples had low concentrations of CFCs and tritium,
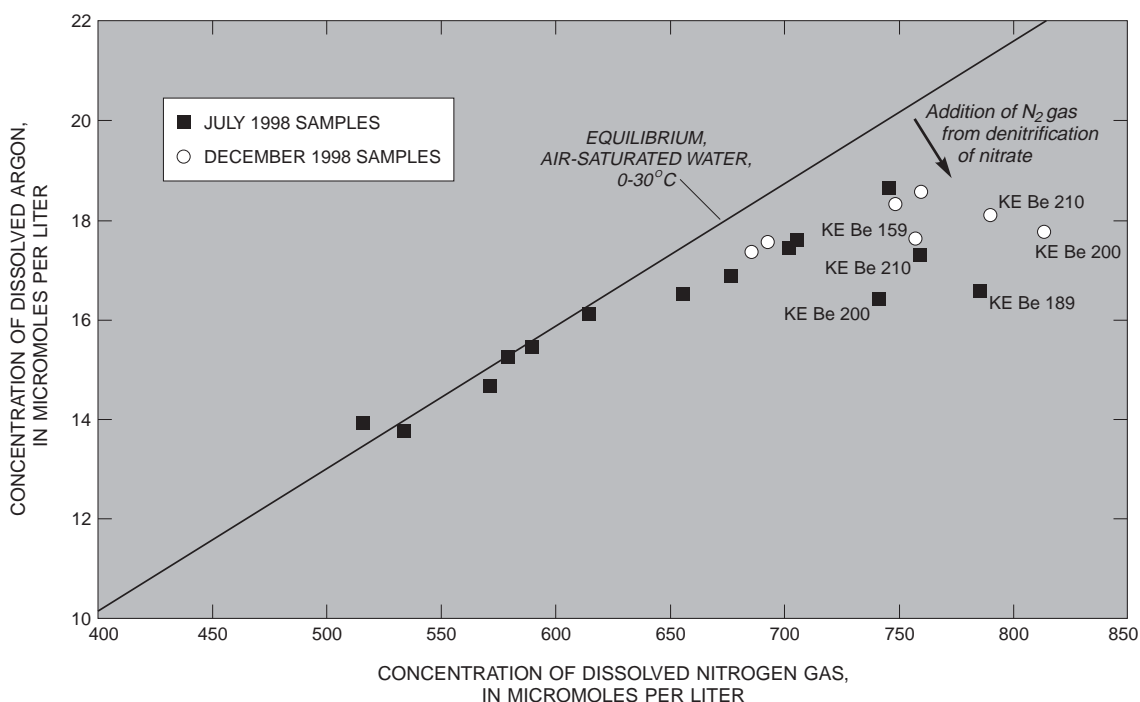
Figure 15. Distribution of dissolved argon and dissolved nitrogen gas with relation to solubility in air and enrichment of nitrogen by denitrification, Locust Grove study area, Kent County, Maryland.

indicating that they were recharged before the mid-1900s. According to E. Busenberg (U.S. Geological Survey, written commun., 2000), the ground water in well KE Be 211 had a higher concentration of radiogenic helium than the other samples, indicating that well KE Be 211 probably contained the oldest ground water sampled, with an apparent age of about 75 years (although the uncertainty of this age estimate is not well known). These data indicate that the ground water in the Hornerstown aquifer was recharged within the last 100 years, and that the recharge area probably is in the northern part of the study area. Although the recharge areas are not the same for all samples represented, the overall pattern of increasing nitrate concentrations over the last 75 years, with the most rapid increase between about 1960 and 1980, appears to be a general trend for the region.

Böhlke and Denver (1995) suggested three possible sources of electron acceptors for denitrification of ground water in the study area:

- Oxidation of glauconite;

- Oxidation of iron-sulfide minerals; and/or

- Oxidation of organic matter.

The cores collected for this project show that the sediments in the upper sandy section of the Aquia Formation are extensively oxidized, but there is an abrupt transition to sediments with predominately reduced mineral phases at the top of the Aquia confining layer. Silica concentrations on the order of 20 mg/L in suboxic Aquia waters and 30 mg/L in Hornerstown waters are elevated relative to concentrations of 10 mg/L that are typical of oxic Columbia-Aquia waters. The higher silica concentrations in the deeper units are consistent with longer residence times and the dissolution of glauconite to release silica. Sulfate concentrations of oxic Columbia-Aquia waters generally are below reporting levels (0.10 mg/L), whereas concentrations in suboxic Aquia and Hornerstown waters generally range from 5 to 20 mg/L. Sulfate is a common product of the dissolution and oxidation of iron-sulfide minerals, such as pyrite or marcasite. The data presented here provide no new insights into the relative importance of organic matter oxidation. From mass-balance modeling and carbon stable-isotope data, Böhlke and Denver (1995) inferred that the oxidation of organic matter was not the major mechanism for denitrification of the discharging ground water.

The samples collected from the multiport well (KE Be 190) and the nearby wells that are screened above and within the Aquia redox transition zone provided inconclusive evidence on the relative importance of glauconite or iron-sulfide oxidation. Concentrations of dissolved oxygen decreased in the ports located within the redox transition zone, but none were lower than 2 mg/L, indicating oxic conditions or mixtures of oxic and anoxic water; this result also was true of the data from the cluster of individual wells. These samples also contained nitrate concentrations of 5 to 6 mg/L as N from the sampling ports of well KE Be 190 and concentrations of 11 to 12 mg/L as N in the well cluster. Sulfate concentrations from the ports of well KE Be 190 ranged from 15 to 23 mg/L, similar to those of old anoxic water. The geochemical data for ground water from the lower Aquia aquifer could indicate that sulfate was produced by iron-sulfide oxidation coupled with reduction of dissolved oxygen, which would not consume nitrate (because the thermodynamic sequence of electron-accepting processes generally consumes dissolved oxygen before nitrate). If iron-sulfide oxidation were driven mainly by dissolved oxygen, then the lower nitrate concentrations could represent older, pre-1970 recharge, when nitrate concentrations were lower than in waters currently recharging at the water table.

Oxidation of pyrite by reduction of dissolved oxygen can be represented by:

$$4FeS_2 + 15O_2 + 10H_2O \ll 8SO_4^{-2} + 4FeOOH + 16H^+ \tag{1}$$

This reaction requires about 1.9 moles of oxygen to yield 1 mole of sulfate. In contrast, oxidation of pyrite by denitrification can be represented by:

$$2FeS_2 + 6NO_3^- + 2H_2O \ll 4SO_4^{-2} + 2FeOOH + 3N_2 + 2H^+ \tag{2}$$
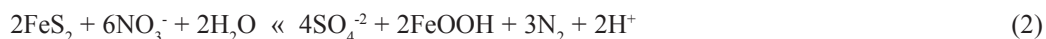
In equation 2, 1.5 moles of nitrate are required to yield an additional mole of sulfate. Water recharging the surficial aquifer contains on the order of 10 mg/L (~0.3 mmol/L, or millimoles per liter) dissolved oxygen, but variable concentrations of nitrate, ranging from 2 mg/L (0.15 mmol/L) as N to over 10 mg/L (0.71 mmol/L) as N. In a ground-water chemical system not limited by the supply of iron sulfide, consumption of dissolved oxygen should result in a sulfate concentration of 15 mg/L (0.16 mmol/L). Denitrification of ground water with a nitrate concentration of 2 mg/L as N would result in an additional 9.6 mg/L (0.1 mmol/L) of sulfate. Denitrification of ground water with a nitrate concentration of 10 mg/L as N would result in an additional sulfate concentration of 45 mg/L (0.47 mmol/L). Thus, sulfate concentrations above 15 mg/L could be interpreted as evidence that denitrification has occurred, or that the ground water contained some sulfate when recharged. The latter appears to be the case for the multiport samples, which did not contain excess nitrogen gas.

In summary, these results indicate that the samples collected from the multiport well did not contain denitrified ground water, although several ports were deep enough to be within what appeared to be reduced glauconitic sediments in nearby cores. If the samples from these sites did indeed represent ground water from within the reduced zone at the top of the confining layer, then these observations could indicate that denitrification did not have a large effect on ground-water chemistry in the Aquia aquifer flow system. It is possible that suboxic ground waters carrying nitrate moved along the redox boundary toward discharge sites without losing measurable amounts of nitrate. Alternatively, reduced ground waters may be present but could not be sampled because the construction of the multiport wells and piezometers permitted overlying oxic water to enter the screens (by downward flow in the

annular space around the well casing). This flow might have occurred because hydraulic conductivities within and below the sediment redox transition at the top of the Aquia confining unit are much lower than that of the overlying sand of the Aquia aquifer. Whether or not the persistence of nitrate in the multiport samples is an artifact of the well design, these results do not provide strong support for appreciable denitrification above the confining layer.

Many of the chemical and chronological characteristics of the Hornerstown waters appear to match those of ground waters discharging beneath the streams. Ground water from the four new wells screened in the Hornerstown confined aquifer was reduced, alkaline, and nitrate-free. Ground water from all four contained minor amounts of excess nitrogen gas with an isotopic composition ($d^{15}N$ [of excess N_2] = 2-5 ‰; J. Böhlke, U.S. Geological Survey, written commun., 2000) slightly different from that of atmospheric nitrogen, which indicates that the Hornerstown waters were recharged with minor amounts of nitrate that was denitrified subsequently. Böhlke and Denver (1995) identified tritium-poor ground water discharging to both streams, and Hornerstown waters all appear to be older than mid-1900s. The isotopic composition of the Hornerstown N_2 gas is consistent with denitrification of nitrate similar to that of older ground water above the confining layer (data presented by Böhlke and Denver [1995] in their figures 12 and 13); further, the apparent initial nitrate concentrations of the Hornerstown ground waters are consistent with those of the discharging ground waters. The high alkalinities, moderate sulfate concentrations, and other chemical characteristics of the Hornerstown waters match those of ground waters discharging at stream-sampling sites KE Be 172, 173, and 178. Water of this type has not yet been identified within the surficial aquifer, except near discharge zones (for example, well KE Be 159 in the Chesterville Branch valley) with upward flow from deep in the surficial aquifer. These observations could be readily explained if the Hornerstown ground-water flow system were connected with the overlying Columbia-Aquia aquifer, as suggested by Böhlke and Denver (1995), but they are difficult to explain if the two flow systems are separated completely.

The similarity of nitrate concentrations, dissolved nitrogen and argon gases, ground-water age-dating estimates, and other chemical signatures such as alkalinity and silica concentrations between discharging ground water in Morgan Creek as reported by Böhlke and Denver (1995) and the Hornerstown ground water reported here, could indicate that discharge from the Hornerstown aquifer may influence much of the chemical composition of ground-water discharge to Morgan Creek.

Nutrient Yields from Stream Base Flow

The chemistry of stream base flow relates closely to the chemistry of ground water discharging to the stream. The spatial patterns of base-flow chemistry within each watershed provide insight into the chemical environment of the surficial aquifer, allowing for instream processes. The current project included three synoptic surveys of stream base flow at 14 sites in the Morgan Creek and Chesterville Branch watersheds. These synoptic surveys sampled conditions during periods of low water table (September 1998) and high water table (April 1998 and February 2000). The synoptic surveys were supplemented by monthly base-flow samples at the Morgan Creek and Chesterville Branch gaging stations to provide a record of seasonal variability. These data were evaluated to relate the loads and yields of nutrients from the two watersheds to landscape factors and geologic setting.

Sampling at Fixed Sites

Time-series plots of samples collected from the fixed sites (Figure 16) show seasonal variations in dissolved nitrogen concentrations. Concentrations tend to be lowest during the summer months. Low stream discharge in the summer is common in this area because evapotranspiration removes water that would otherwise recharge the aquifer. The lower nitrogen concentrations are likely due to uptake by stream phytoplankton, macrophytes, and submerged aquatic vegetation during the warmer growing season. The data also show that Morgan Creek has lower nitrogen concentrations than Chesterville Branch in the upstream parts of the watershed, as previously reported by Böhlke and Denver (1995).
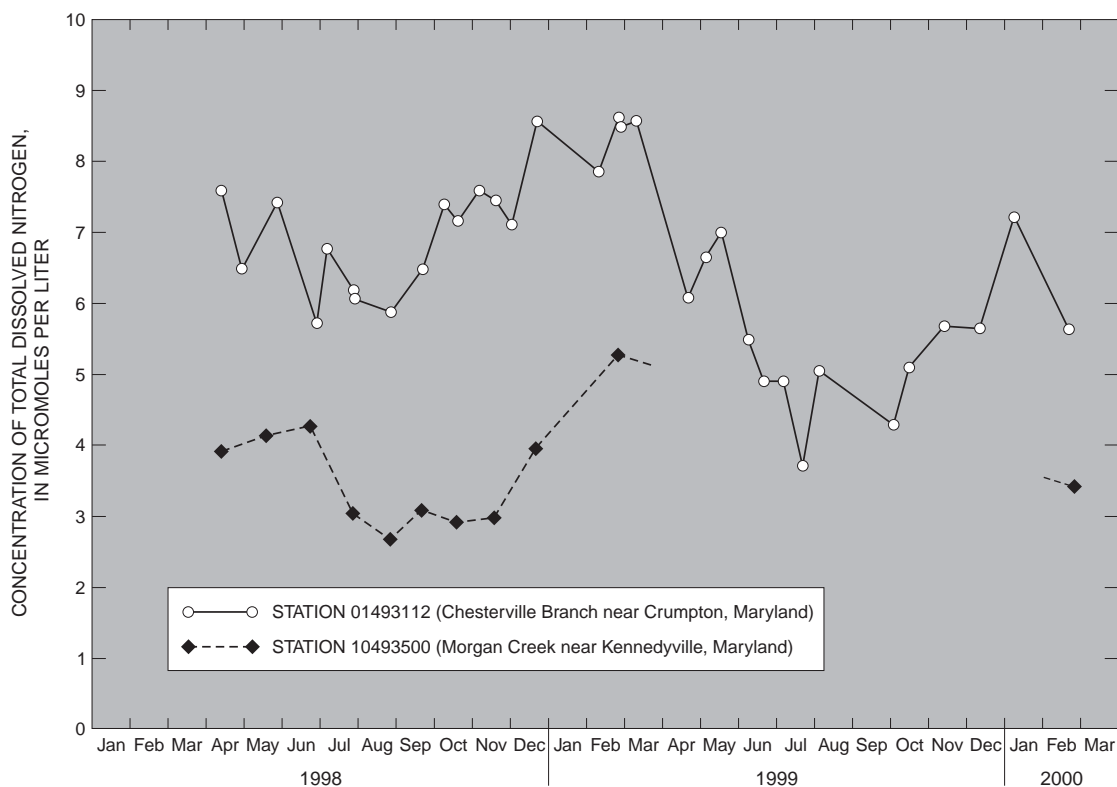
Figure 16. Time-series plots of total dissolved nitrogen concentrations at the two fixed stream-sampling sites (station numbers 01493112 and 01493500) in the Locust Grove study area, Kent County, Maryland.

Although there is some overlap in the range of values, the nitrogen loads (mass per year) from Chesterville Branch generally are higher than those from Morgan Creek (Table 4). Nitrogen yields (load per unit watershed area) are higher from Chesterville Branch than from Morgan Creek. Chesterville Branch yields of 0.04-0.08 gm sec^{-1} km^{-2} are higher than those reported by Bachman and Phillips (1996) for well-drained landscapes on the Delmarva Peninsula, which ranged from 0.02 to 0.04 gm sec^{-1} km^{-2}. Morgan Creek yields (0.01-0.03 gm sec^{-1} km^{-2}) overlapped those of Chesterville Branch, and were slightly higher than yields reported for poorly drained landscapes on the Delmarva Peninsula (0.007-0.02 gm sec^{-1} km^{-2}) (Bachman and Phillips, 1996). Both of these watersheds were considered to be in the well-drained landscape in the analysis by Bachman and Phillips (1996); the results presented here further underscore the extent of variation in nitrogen yields within a given landscape class reported in that study.

Base-Flow Synoptic Surveys

The data from the base-flow synoptic surveys also confirm observations by Böhlke and Denver (1995) that total nitrogen concentrations in Morgan Creek generally are lower than those in Chesterville Branch (Figure 17). The synoptic surveys revealed some fundamental differences in the patterns of occurrence of nitrogen and related chemical constituents between the two watersheds. In particular, total nitrogen concentrations tended to decrease downstream in Chesterville Branch, whereas they increased downstream in Morgan Creek (Figure 18). In both watersheds, stream discharge (of water) and nitrogen loads increase monotonically downstream. The increasing trend of stream discharge indicates that both streams are gaining flow from ground-water discharge. Although loads in the two streams appear similar in the upstream reaches, they are consistently higher in Chesterville Branch than in Morgan Creek at the downstream gage (Figure 18), even though Morgan Creek has consistently higher discharge than Chesterville Branch for any given season (Figure 18).

The higher stream discharge in Morgan Creek may be due to the larger watershed area of Morgan Creek (31 km^2) as compared to Chesterville Branch (16 km^2). The specific discharge (discharge per unit area of the watershed) for any given season is greater in Chesterville Branch than in Morgan Creek (Figure 18). This pattern also occurs in the downstream trends of nitrogen yields (Figure 18). Yields in Morgan Creek increase downstream, similar to nitrogen concentrations (Figure 18), whereas Chesterville Branch displays a more variable trend similar to that of specific discharge. The higher yields in Chesterville Branch also appear to be related to the nitrogen concentrations.

Böhlke and Denver (1995) presented evidence that the lower concentrations of nitrate in Morgan Creek were due to denitrification in the discharge areas where the Aquia confining layer is shallow. However, it also is possible that the lower concentrations could be due to the mixing of higher proportions of older ground water with low nitrate concentrations in base flow. These two

Table 4. Summary of Base-flow Nitrogen Loads from the Locust Grove Study Area, Kent County, Maryland

		Chesterville Branch near Crumpton, Md. (station 01493112)	Morgan Creek near Kennedyville, Md. (station 01493500)
Instantaneous load, in gm N sec^{-1}	minimum	0.27	0.36
	25th percentile	0.71	0.47
	median	0.92	0.62
	75th percentile	1.2	1.0
	maximum	2.3	1.2
	number of samples	33	11
Instantaneous yield, in gm N sec^{-1} km^{-2}	25th percentile	0.045	0.015
	median	0.058	0.022
	75th percentile	0.076	0.032
Annualized load, in kg N year^{-1}	25th percentile	22,000	15,000
	median	29,000	20,000
	75th percentile	39,000	32,000

[Estimates are based on monthly samples collected from April 1998 to March 1999 and one sample collected in February 2000. gm N sec^{-1}, grams of nitrogen per second; gm N sec^{-1}km^{-2}, grams of nitrogen per second per square kilometer; kg N year^{-1}, kilograms of nitrogen per year.]
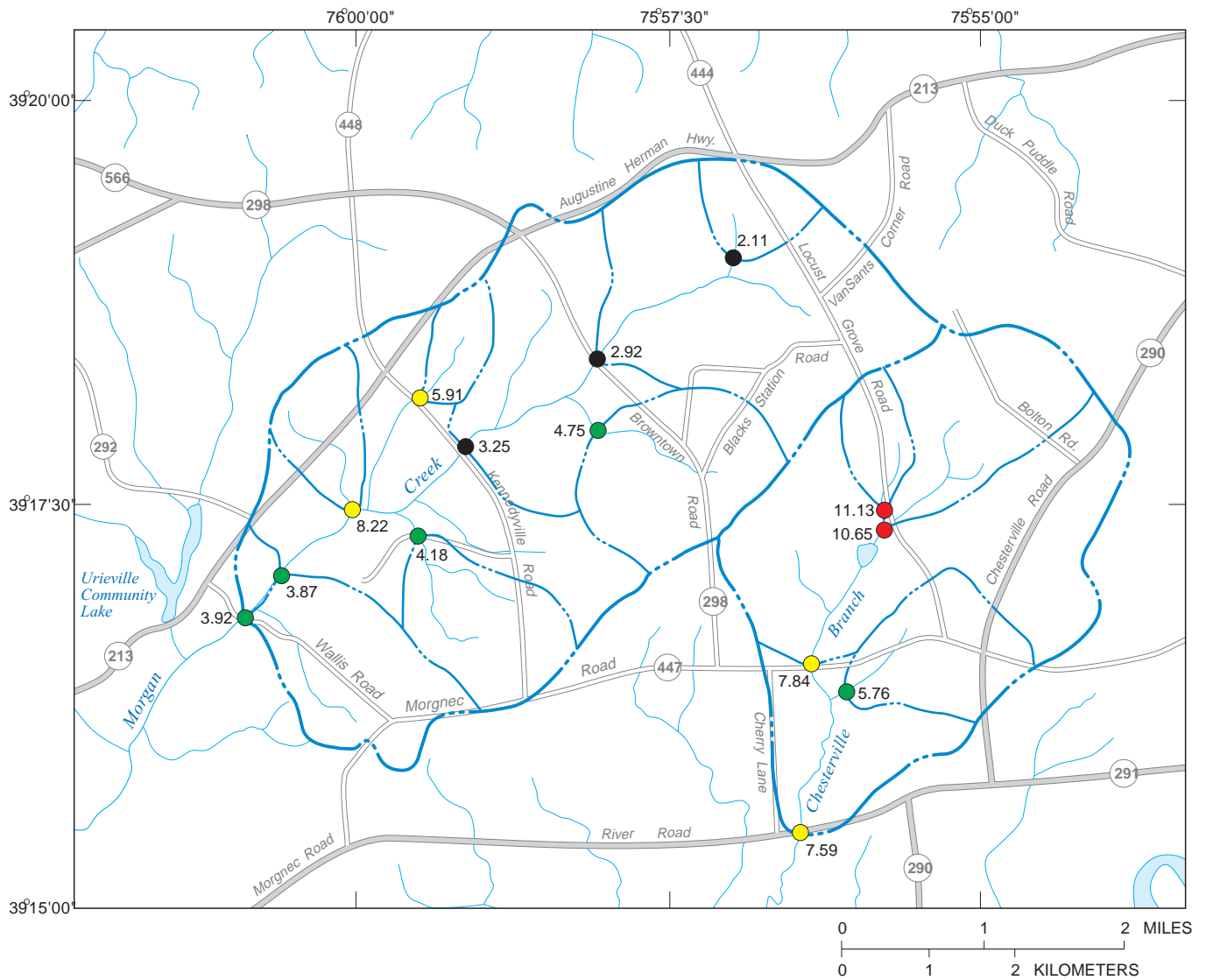
Figure 17. Areal distribution of total dissolved nitrogen concentrations in stream base flow for the Locust Grove study area, Kent County, Maryland, April 1998 synoptic survey.
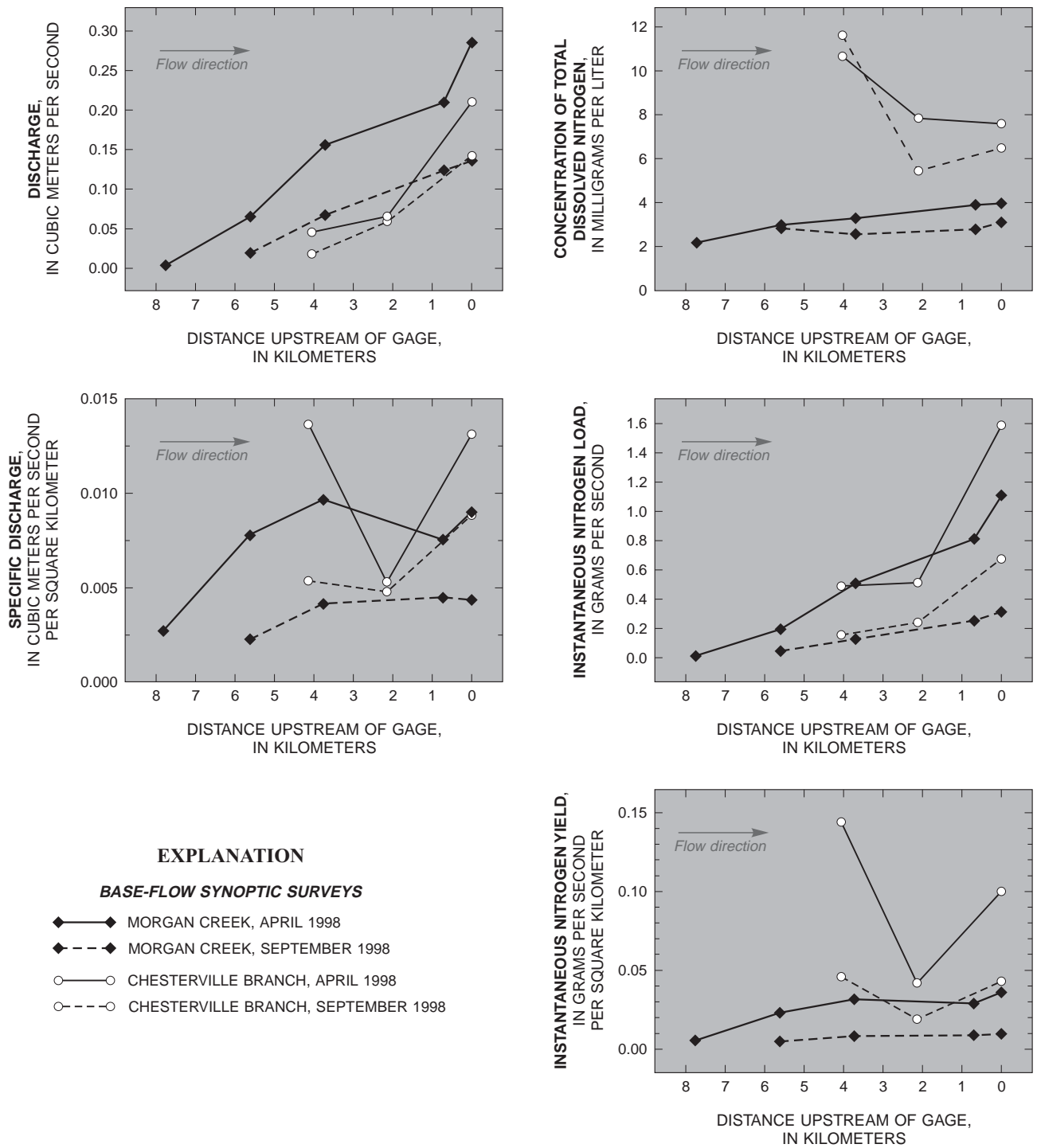
Figure 18. Observed downstream trends of stream discharge, specific discharge, total dissolved nitrogen concentration, instantaneous nitrogen load, and instantaneous nitrogen yield from base-flow synoptic surveys in April and September 1998, Locust Grove study area, Kent County, Maryland.

hypotheses can be evaluated from the distribution of selected geochemical constituents in base flow from the two basins. As described above, ground water recharged before 1970 has lower nitrate concentrations than water recharged more recently. In addition, old agricultural and old calcareous waters have had more contact time with the aquifer materials, and may be more chemically evolved with higher concentrations of dissolved bicarbonate and silica than the young agricultural water. Further, the work of Modica and others (1998) suggests that the proportion of older ground water discharging to a stream increases downstream (Figure 4). In addition to lowering nitrogen concentrations, a larger proportion of older ground water in discharge to base flow also would have the cumulative effect of an increasing downstream trend of bicarbonate and silica, and a decreasing trend of magnesium (Figure 19).

The observed trends of bicarbonate, silica, and magnesium in Morgan Creek and Chesterville Branch were compared to the trends expected from a systematically increasing proportion of discharge from old ground water (Figure 20). The observed data are consistent with the expected trend for magnesium in all cases, and for bicarbonate in Chesterville Branch. However, bicarbonate shows a decreasing trend in Morgan Creek (especially for the April 1998 samples), and both watersheds have decreasing downstream trends in silica concentrations. Decreasing silica concentrations would be expected in Chesterville Branch, because discharge of high-silica water from the Hornerstown aquifer is less likely than in the upstream reaches of Morgan Creek. The top of the Hornerstown Formation dips to the south, and Chesterville Branch has not incised a stream channel through the Aquia confining layer. This may not be the case in Morgan Creek, however, where the channel appears to follow the outcrop zone of the Aquia confining layer (Figure 11), and there is some evidence of ground-water discharge from the Hornerstown aquifer (Böhlke and Denver, 1995).

Iron-sulfide oxidation to produce sulfate is one possible redox process associated with denitrification. If denitrification were related to iron-sulfide oxidation, then denitrified water would have sulfate concentrations elevated above background. However, the trends of sulfate concentration shown in Figure 20 indicate that downstream water, which is hypothesized to have a greater proportion of denitrified ground-water discharge, has lower concentrations of sulfate than upstream water.

The concentrations of dissolved constituents in base flow are not merely the aggregation of the concentrations of ground-water discharge to the mainstem channel of the stream. Concentrations in base flow also are affected by the loads of constituents entering from tributaries and processes occurring in the stream channel or alluvial sediments that may be sinks and sources for the dissolved substances. Although a thorough discussion of riparian and instream processes is beyond the scope of this report, an analysis of the effects of the mixing of water from tributaries provides some evidence that processes other than ground-water discharge are affecting base-flow concentrations.

In a typical stream, the flow from two tributaries mixes in a downstream channel (Figure 21). Without the physical or geochemical removal of a constituent, the downstream load, C_3Q_3, is equal to the sum of the loads of the two upstream tributaries (C_1Q_1 and C_2Q_2) plus the load derived from ground-water discharge $C_{GW}Q_{GW}$:

$$C_1Q_1 + C_2Q_2 + C_{GW}Q_{GW} = C_3Q_3 \qquad (3)$$

where C is concentration (mass per volume), Q is discharge (volume per time), and $_{GW}$ refers to ground water.
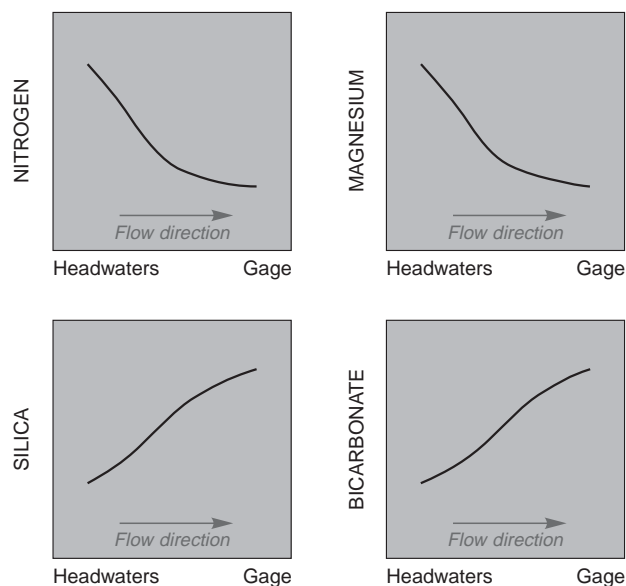
Figure 19. Expected downstream trends of nitrogen and related geochemical constituents from a downstream increase in the discharge of old ground water.

Figure 20. Observed downstream trends of sulfate, magnesium, bicarbonate, and silica concentrations from base-flow synoptic surveys in April and September 1998, Locust Grove study area, Kent County, Maryland.

Figure 21. Relations among discharge and concentrations of dissolved constituents in tributaries and downstream sites under non-reactive mixing.

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An estimate of ground-water inflow can be made by subtracting the upstream discharges (Q_1 and Q_2) from the downstream discharge (Q_3):

$$Q_{GW} = Q_3 - (Q_1 + Q_2) \qquad (4)$$

The expected average concentration of ground-water discharge between the tributaries and the downstream site can be estimated by dividing equation (3) by the estimate of ground-water inflow and rearranging the terms:

$$C_{GW} = C_3(Q_3/Q_{GW}) - C_1(Q_1/Q_{GW}) - C_2(Q_2/Q_{GW}) \qquad (5)$$

A negative value of C_{GW} for cases in which Q_3 is greater than the sum Q_1+Q_2 (for example, an effluent stream system with C_3 considerably less than C_1 or C_2) is evidence of a physical or geochemical sink for the constituent. In such cases, the concentration of ground-water inflow cannot be estimated. In other cases, further evidence is needed to determine whether instream or alluvial-channel processes are acting as a geochemical source or sink for the constituent.

An estimate of the downstream concentration C'_3 can be made on the basis of any hypothesized average concentration of ground-water discharge, and this estimate can be compared to the actual measured downstream concentration. Rearranging equation 5 results in:

$$C'_3 = C_1(Q_1/Q_3) + C_2(Q_2/Q_3) + C_{GW}(Q_{GW}/Q_3) \qquad (6)$$

If the estimated value for C'_3 is close to the measured value, it is likely that ground-water discharge with non-reactive mixing accounts for most of the observed concentrations of dissolved constituents in base flow.

In the study area, these relations can be calculated at four reaches that have sites with upstream measurements, downstream measurements, and measurements at tributaries:

	Upstream site	*Downstream site*	*Tributary site(s)*
Chesterville Branch			
Reach C1:	01493110	01493111	01493109
Reach C2:	01493111	01493112	0149311110
Morgan Creek:			
Reach M1:	01493495	01493497	01493496
Reach M2:	01493497	01493499	01493498,
			0149349810,
			0149349820

The locations of these sites and the stream reaches C1, C2, M1, and M2 are shown in Figure 22.

Figure 22. Location of surface-water sampling stations and stream reaches on Morgan Creek and Chesterville Branch in the Locust Grove study area, Kent County, Maryland.

Estimates from equations (5) and (6) of ground-water discharge, concentrations of selected constituents in ground water, and the downstream concentration in the reach under the bounding condition of ground-water concentrations equal to zero are presented in Tables 5a through 5d. A comparison of the estimated and observed constituents shows that they only are partially consistent with the hypothesis of increased downstream contribution of older ground water. However, a number of interesting trends are evident that could justify further evaluation of the data and additional study of the processes of ground-water discharge to streams in the study area.

The most striking observation in Table 5a is that the decrease in nitrate (from greater than 10 mg/L down to 7.84 mg/L) observed in Chesterville Branch reach C1 cannot be accounted for by inflow of lower-nitrate ground water. Even where the ground-water discharge is nitrogen-free (the case in which C_{GW} in equation 6 equals 0), the estimated downstream total-nitrogen concentration is 8.9 mg/L, higher than what is observed. Reach C1 of Chesterville Branch has a manmade pond that is approximately 10,000 m^2 (about 2.5 acres). It is possible that this pond provides a geochemical environment that facilitates denitrification; alternatively, the dissolved nitrogen may be taken up by plants.

The data in Table 5b provide evidence that inflow of low-nitrogen ground water contributes to the downstream decrease of nitrogen concentrations in Chesterville Branch. In reach C2, the observed decline in total nitrogen concentrations (from 7.8 to 7.6 mg/L) can be explained by the dilution of ground-water inflow with an average concentration of 8.1 mg/L (which can be obtained from a mixture of old and young ground water) and by inflow from the tributary (site 0149311110) with a lower nitrate concentration (5.8 mg/L). Bicarbonate concentrations in both reaches increase to a degree that can be explained by the input of high (greater than 0.5 meq/L) bicarbonate water typical of old calcareous ground water.

In Morgan Creek, the higher total nitrogen concentrations in the tributaries may explain in part why concentrations increase downstream. In reach M1 (Figure 22), the average ground-water nitrogen concentration was calculated as 2.8 mg/L (Table 5c), this mixture would have a considerable proportion of old calcareous water mixed with the young, high-nitrogen water. Discharge of nitrogen-free ground water would result in a downstream concentration of 2.2 mg/L, below the observed value of 3.25 mg/L. In addition, one tributary (site 01493496) with a higher nitrogen concentration (4.75 mg/L) may contribute to the observed downstream increase in nitrogen concentration; this tributary watershed is underlain by a thicker sequence of the Columbia-Aquia surficial aquifer rather than the shallow Aquia confining layer. Estimated ground-water bicarbonate inputs are consistent with a source of old calcareous water, but estimated silica concentrations appear to be lower than those observed in ground water. Estimated sulfate concentrations appear to be more typical of those observed in the Aquia redox transition zone than in the Hornerstown aquifer.

In Morgan Creek reach M2 (Figure 22), the calculated ground-water nitrogen input is 6.3 mg/L (Table 5d); apparently the discharge of the high-nitrogen tributaries (sites 01493498, 0149349810, and 0149349820) is not sufficient to account for the observed increase in nitrogen concentration (from 3.3 to 3.9 mg/L) in this reach. The bicarbonate decrease observed in this reach may indicate that the ground water being discharged is young, low-bicarbonate, high-nitrate water; however, the calculated ground-water concentration is negative, indicating that riparian or instream processes may be removing bicarbonate. Silica displays a pattern similar to bicarbonate. The calculated sulfate concentration is not consistent with the calculated nitrogen concentration, because it is more typical of Hornerstown water than water from the surficial aquifer.

The patterns observed in the base-flow synoptic surveys can be related to the hydrogeologic framework of the two watersheds. Chesterville Branch reaches C1 and C2 are underlain by the thick Columbia-Aquia surficial aquifer. It is likely that only a small percentage of the ground water discharging to Chesterville Branch flowed through the redox zone at the base of the Aquia aquifer or from the Hornerstown aquifer. This watershed functions in a manner similar to those described by Modica and others (1998), with a greater proportion of older ground water contributing to flow in the downstream reach. In addition, impoundments, both natural (such as beaver dams) and artificial, may be sinks for nitrogen.

Morgan Creek reach M1 is underlain by a thin cover of the Columbia-Aquia aquifer, which makes it more likely that a greater proportion of ground-water discharge flowed through the Aquia redox zone and was denitrified. At the downstream end, the stream channel overlies the subcrop of the Aquia redox zone. The Aquia confining layer may be breached locally, either by faulting or stream incision, and water from the Hornerstown aquifer may discharge through the alluvial fill. Alternatively, the tributary in reach M1 is underlain by a thicker section of the Columbia-Aquia surficial aquifer, and higher-nitrate ground water may discharge as base flow.

In Morgan Creek reach M2, the streambed and alluvial channel are underlain along the entire length of the reach by the Aquia confining layer and the sedimentary redox zone. Nitrogen concentrations increase downstream, which could be explained by an increased discharge of relatively high-nitrogen (~6 mg/L) ground water. These observations indicate that either the incised valley in this reach does not penetrate the Aquia confining layer, or the alluvial fill is more fine-grained and Hornerstown water cannot easily discharge to the stream. In addition, riparian and instream processes may be acting as sinks for bicarbonate and silica, or sources for sulfate and other constituents.

Table 5A-5D. Estimated Concentrations of Dissolved Constituents in Ground Water Discharge Calculated from Measured Stream Flow and Concentrations of Constituents at Upstream, Downstream, and Tributary Sampling Sites

Table 5A. Estimated Concentrations of Dissolved Constituents in Ground-water Discharge Calculated from Measured Streamflow and Concentrations of Constituents at Upstream, Downstream, and Tributary Sampling Sites on the Chesterville Branch, Reach C1 in the Locust Grove Study Area, Kent County, Maryland

Station number	Position of sampling site	Discharge (m^3/s)	Nitrogen, total (mg/L as N)	Silica, dissolved (μmol/L as SiO_2)	Bicarbonate, dissolved (meq/L as HCO_3)	Magnesium, dissolved (meq/L as Mg)	Sulfate, dissolved (meq/L as SO_4)
			CHESTERVILLE BRANCH REACH C1				
			OBSERVED				
01493109	Tributary	0.01	11.13	0.14	0.25	0.91	0.35
01493110	Upstream	0.05	10.65	0.16	0.28	0.54	0.20
01493111	Downstream	0.07	7.84	0.15	0.43	0.42	0.12
			ESTIMATED FOR STREAM REACH				
Total streamflow (measured)	–	0.07					
Ground-water discharge (14 percent of total streamflow)	–	0.01					
Concentration in ground water	–	–	[A] -6.35	0.14	1.18	[A] -0.45	[A] -0.42
[B] **Downstream concentration with C_{gw} = 0**	–	–	8.90	0.13	0.23	0.50	0.19

[A] A negative value for estimated concentration implies uptake or consumption of the constituent in the stream reach.

[B] Estimated downstream concentration assuming that the dissolved concentration of the constituent in ground water is zero (C_{gw} = 0).

[See Figure 22 for location of Reach C1; m^3/s, cubic meters per second; mg/L, milligrams per liter; meq/L, milliequivalents per liter; μmol/L, micromoles per liter; –, no data available.]

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Table 5B. Estimated Concentrations of Dissolved Constituents in Ground-water Discharge Calculated from Measured Streamflow and Concentrations of Constituents at Upstream, Downstream, and Tributary Sampling Sites on Chesterville Branch, Reach C2 in the Locust Grove Study Area, Kent County, Maryland

[See Figure 22 for location of Reach C2; m³/s, cubic meters per second; mg/L, milligrams per liter; µmol/L, micromoles per liter; meq/L, milliequivalents per liter; –, no data available.]

Station number	Position of sampling site	Discharge (m³/s)	Nitrogen, total (mg/L as N)	Silica, dissolved (µmol/L as SiO_2)	Bicarbonate, dissolved (meq/L as HCO_3)	Magnesium, dissolved (meq/L as Mg)	Sulfate, dissolved (meq/L as SO_4)
CHESTERVILLE BRANCH REACH C2							
OBSERVED							
01493111	Upstream	0.07	7.84	0.15	0.43	0.42	0.11
0149311110	Tributary	0.04	5.76	0.13	0.34	0.39	0.08
01493112	Downstream	0.21	7.59	0.13	0.44	0.42	0.11
ESTIMATED FOR STREAM REACH							
Total streamflow (measured)		0.21					
Ground-water discharge (48 percent of total streamflow)	–	0.10					
Concentration in ground water	–	–	8.18	0.12	[A] -0.48	0.43	0.13
[B] Downstream concentration with $C_{gw} = 0$	–	–	3.56	0.07	0.21	0.21	0.05

[A] A negative value for estimated concentration implies uptake or consumption of the constituent in the stream reach.

[B] Estimated downstream concentration assuming that the dissolved concentration of the constituent in ground water is zero ($C_{gw} = 0$).

Table 5C. Estimated Concentrations of Dissolved Constituents in Ground-water Discharge Calculated from Measured Streamflow and Concentrations of Constituents at Upstream, Downstream, and Tributary Sampling Sites on Morgan Creek, Reach M1 in the Locust Grove Study Area, Kent County, Maryland

Station number	Position of sampling site	Discharge (m³/s)	Nitrogen, total (mg/L as N)	Silica, dissolved (μmol/L as SiO₂)	Bicarbonate, dissolved (meq/L as HCO₃)	Magnesium, dissolved (meq/L as Mg)	Sulfate, dissolved (meq/L as SO₄)
				MORGAN CREEK REACH M1			
				OBSERVED			
01493495	Upstream	0.07	292	0.11	0.64	0.48	0.17
01493496	Tributary	0.03	4.75	0.05	0.86	0.48	0.16
01493497	Downstream	0.16	3.25	0.10	0.78	0.44	0.13
				ESTIMATED FOR STREAM REACH			
Total streamflow (measured)		0.16					
Ground-water discharge (38 percent of total streamflow)	–	0.06	–	–	–	–	–
Concentration in ground water	–	–	2.83	0.13	0.89	0.39	0.07
[B] Downstream concentration with C$_{gw}$ = 0	–	–	2.16	0.05	0.44	0.29	0.10

[B] Estimated downstream concentration assuming that the dissolved concentration of the constituent in ground water is zero (C$_{gw}$ = 0).

[See Figure 22 for location of Reach M1; m³/s, cubic meters per second; mg/L, milligrams per liter; μmol/L, micromoles per liter; meq/L; milliequivalents per liter; –, no data available.]

Table 5D. Estimated Concentrations of Dissolved Constituents in Ground-water Discharge Calculated from Measured Streamflow and Concentrations of Constituents at Upstream, Downstream, and Tributary Sampling Sites on Morgan Creek, Reach M2 in the Locust Grove Study Area, Kent County, Maryland

[See Figure 22 for location of Reach M2; m^3/s, cubic meters per second; mg/L, milligrams per liter; µmol/L, micromoles per liter; meq/L, milliequivalents per liter; −, no data available.]

Station number	Position of sampling site	Discharge (m^3/s)	Nitrogen, total (mg/L as N)	Silica, dissolved (µmol/L as SiO_2)	Bicarbonate, dissolved (meq/L as HCO_3)	Magnesium, dissolved (meq/L as Mg)	Sulfate, dissolved (meq/L as SO_4)
			MORGAN CREEK REACH M2				
			OBSERVED				
01493497	Upstream	0.16	3.25	0.10	0.78	0.44	0.13
01493498	Tributary	0.02	4.18	0.17	0.74	0.39	0.17
0149349810	Tributary	<0.01	5.91	0.09	0.96	0.56	0.21
0149349820	Upstream	<0.01	8.22	0.15	0.48	0.71	0.23
01493499	Downstream	0.21	3.87	0.10	0.60	0.44	0.14
			ESTIMATED FOR STREAM REACH				
Total streamflow (measured)		0.21					
Ground-water discharge (14 percent of total streamflow)	−	0.03					
Concentration in ground water	−	−	6.34	0.00	[A] -0.49	0.38	0.15
[B] **Downstream concentration with $C_{gw} = 0$**	−	−	2.95	0.01	0.67	0.38	0.12

[A] A negative value for estimated concentration implies uptake or consumption of the constituent in the stream reach.

[B] Estimated downstream concentration assuming that the dissolved concentration of the constituent in ground water is zero, ($C_{gw} = 0$).

The relative importance of ground-water discharge to these two streams compared to the effects of riparian and instream processes is not well understood. Additional investigations, including coring the alluvial fill, sampling ground water in the riparian zone, and conducting more intensive biological and hydrochemical sampling in the streams, are needed to improve the understanding of base-flow nitrogen discharge in this area.

Relation Between Nutrients and Landscape Factors

Bachman (1984b), Hamilton and others (1993), Bachman and Phillips (1996), and Phillips and Bachman (1996) described the variability in the landscape features on the Delmarva Peninsula and how this variability was related to the quality of ground water and base flow. Hamilton and others (1993) developed the "hydrogeomorphic region" approach, whereby landscapes were defined on the basis of the overall occurrence of certain mappable features, most notably the degree of stream incision, the drainage characteristics of the soil, and the presence of shallow confining layers within the surficial aquifers. These features appear to be related to the arrangement of ground-water flow paths and the presence of geochemical processes that can affect the chemical composition of ground water (Bachman and Katz, 1986; Hamilton and others, 1993; and Bachman, 1994). Hydrogeomorphic regions are independent of stream basins; thus the discharge from a basin could be a combination of several hydrogeomorphic regions. Phillips and Bachman (1996) and Bachman and Phillips (1996) developed a "basin index" to characterize landscapes within a drainage basin. The index is essentially the principal-components score using three basin characteristics (stream slope, percentage of poorly drained soils, and forest cover in the basin) that appear to be related to the hydrogeomorphic regions.

The Locust Grove study area is in the well-drained upland hydrogeomorphic region defined by Hamilton and others (1993). This area is characterized by a relatively thick (15-30 m) surficial aquifer, deeply incised stream valleys, and well-drained soils. Ground-water flow paths may extend from drainage divides to discharge in streams and penetrate to the base of the surficial aquifer. The land use in the study area is mostly agricultural, and there is little interspersion of agricultural and wooded areas. The uplands are farmed, and the woodlands and wetlands are restricted almost exclusively to the riparian areas (forest land use in Figure 3). The well-drained upland was reported to have ground water with high concentrations of nitrogen (Hamilton and others, 1993).

Although the study area is entirely within the well-drained upland, the dissolved nitrogen concentrations vary considerably between Chesterville Branch and Morgan Creek (Böhlke and Denver, 1995). A local-scale landscape analysis was conducted to aid modelers in locating subregions within the study area that have similar hydrologic conditions. The analysis was based on the "basin index" approach of Phillips and Bachman (1996), and tested by relating the basin index to constituent concentrations of water samples collected during the base-flow synoptic surveys.

The original basin index was developed from landscape data for basins located throughout the Delmarva Peninsula. The well-drained upland in the Locust Grove study area represents one end-member of the landscapes used to classify the Delmarva Peninsula; consequently, alternative classification variables were examined to determine whether they could provide better correlation with water quality at the local scale. The following basin characteristics were examined:

(1) Topography

    (1a) Stream slope and the variables used to calculate stream slope;

    (1b) Stream-reach length;

    (1c) Altitude of stream at the basin outlet; and

    (1d) Stream-reach relief (difference in altitude between stream outlet and highest altitude of stream reach).

(2) Soil type

    (2a) Percentage of well-drained (type A) soils in basin;

    (2b) Percentage of moderately well-drained (type B) soils in basin;

    (2c) Percentage of moderately poorly drained (type C) soils in basin; and

    (2d) Percentage of poorly drained (type D) soils in basin.

(3) Land use

    (3a) Percentage of agricultural land in basin;

    (3b) Percentage of land in Animal Feeding Operations in basin;

    (3c) Percentage of nursery operations in basin;

    (3d) Percentage of urban land in basin; and

    (3e) Percentage of forests and wetlands in basin.

Fourteen basins in the Chesterville Branch and Morgan Creek watersheds were delineated and used for the local-scale landscape analysis (Figures 3 and 11). Nine of the basins are first-order, headwater watersheds; the others were included to examine

systematic changes in landscape and nutrient concentrations within a watershed. Basin characteristics for the sites sampled in the base-flow synoptic surveys are listed in Appendix F.

The correlation pattern among the basin characteristics is shown in Table 6. In contrast to the findings of Phillips and Bachman (1996), stream slope, the percentage of type D soils, and the percentage of forested land show no statistically significant correlation. This result is not entirely unexpected, because the Locust Grove area represents one extreme of the landscapes in the Delmarva Peninsula, and even the best correlations reported by Phillips and Bachman (1996) accounted for less than 40 percent of the total variation. Despite this lack of correlation, the coefficients in Table 6 show some correlation among basin characteristics related to topography, soil type, and land use. It appears that the strongest correlations are among the outlet altitude, percentage of type C soils, and percentage of the basin in agriculture (Figure 23). Principal-components analysis was used on these three variables to generate a principal-components score, which is essentially a new, synthetic variable that is based on the shared variance among the original variables (Phillips and Bachman, 1996). The analysis was done on the rank-scores of the basin characteristics, which results in a non-parametric test that requires no assumptions about the frequency distributions of the variables (Conover, 1980). The analysis (Table 7) indicates that 77 percent of the variation was accounted for by the first eigenvalue of the correlation matrix (the first principal component). All three variables are heavily loaded on the first component, and the communalities (the percent of total variance of each variable accounted for by the first component) range from 71 to 86 percent. The resulting principal-components score is called the "local basin index" in this report to distinguish it from the "regional basin index" of Phillips and Bachman (1996). The local basin index is computed from the altitude of the basin outlet, the percentage of type C soils, and agricultural land use; the regional basin index is computed from the stream slope, the percentage of type D soils, and forested land use.

The areal distribution of the local basin index (Figure 24) displays a systematic decrease from the headwaters of each basin to the gaging station. This result is not unexpected because the outlet altitude also systematically decreases from the headwaters to the gaging stations (which have the lowest outlet altitudes), and the other variables are correlated with the outlet altitude. This trend is true for both the first-order headwater basins as well as the nested mainstem basins. The pattern is found in both Morgan Creek and Chesterville Branch; however, the values of the basin index in the downstream basins of Morgan Creek are much more negative than those in the downstream part of Chesterville Branch.

Although the variables of the regional basin index do not show significant correlations at the local scale, there are some indirect relations (Table 6). The altitude of the basin outlet is significantly correlated with the length of the stream reach which, in turn, is correlated with stream slope and the percent forested land in the basin. The outlet altitude also is significantly correlated with the percentage of type D soils in the basin. The percentages of type D soils and forested land have a significant inverse correlation with percentage of agricultural land within a basin.

The relations among basin index, nitrogen concentration, and location of sites within the stream network (Figure 24) show patterns that could indicate that denitrification at the top of the Aquia confining layer is an important mechanism to explain the differences between nitrogen concentrations in Morgan Creek and Chesterville Branch. This relation for the April 1998 synoptic data is shown in Figure 24. The September 1998 synoptic data show a similar pattern, although the nitrogen concentrations generally are lower. Most of the first-order basins, and many of the nested mainstem basins, show a rough correlation of increasing nitrogen with increasing value of the local basin index. The nested mainstem basins display downstream patterns (increasing concentrations for Morgan Creek and decreasing concentrations for Chesterville Branch) similar to the actual downstream plots of concentrations by distance from the gage (Figures 17 and 24). The three samples that depart significantly from the correlation (sites 01493491, 01493495, and 01493496) are from the headwaters of Morgan Creek, in the area where the Aquia confining layer subcrops shallowly, and allows a larger percentage of flow paths in the surficial aquifer to flow through the redox transition zone. The nitrogen concentration at site 01493496 also may be explained in that the tributary sampled there was dammed into a small farm pond until shortly before sampling, when the dam was breached. Base flow from site 01493496 could represent a certain amount of ground-water discharge that has passed through former pond-bottom sediments that may still be under reducing conditions.

Table 6. Correlation Coefficients for Landscape Variables Used in the Analysis of the Morgan Creek and Chesterville Branch Watersheds, Locust Grove Study Area, Kent County, Maryland

*Spearman's **ρ** Correlation Coefficient*

	Stream length	Lowest altitude	Altitude change	Stream slope	% type A soils	% type B soils	% type C soils	% type D soils	% agri-culture	% AFO	% nursery	% urban	% forest
Stream length	1.00												
Lowest altitude	**-0.62**	1.00											
Altitude change	**0.61**	**-0.97**	1.00										
Stream slope	**-0.68**	-0.04	0.03	1.00									
% type A soils	0.17	-0.38	0.37	0.33	1.00								
% type B soils	-0.15	0.43	-0.34	-0.34	**-0.69**	1.00							
% type C soils	0.20	**-0.54**	**0.46**	0.13	-0.09	-0.48	1.00						
% type D soils	0.19	**-0.50**	0.38	-0.13	-0.24	-0.26	**0.84**	1.00					
% agriculture	-0.47	**0.73**	**-0.74**	0.11	-0.05	0.26	**0.69**	**-0.63**	1.00				
% AFO	0.31	**-0.67**	**0.67**	0.01	0.10	-0.16	0.37	0.32	**-0.57**	1.00			
% nursery	**0.66**	-0.19	0.16	**-0.52**	0.43	-0.20	-0.25	-0.05	-0.19	0.05	1.00		
% urban	0.38	-0.32	0.30	-0.17	-0.24	0.02	0.38	0.35	-0.11	0.07	-0.22	1.00	
% forest	**0.64**	**-0.66**	**0.68**	-0.30	0.12	-0.07	0.32	0.33	**-0.81**	0.33	0.49	0.09	1.00

[Bold numbers are significant at á = 0.05; 16 pairs of variables; AFO = animal feeding operation; %, percent; soil types: A, well-drained; B, moderately well-drained; C, moderately poorly drained; D, poorly drained]
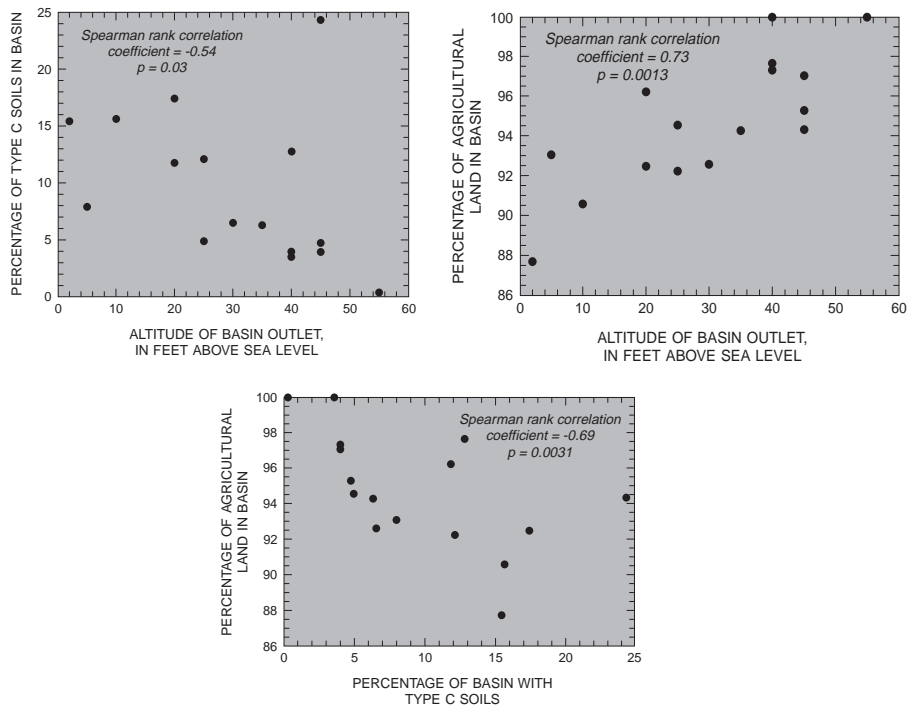
Figure 23. Relations among stream-outlet altitude, percentage of type C (moderately poorly drained) soils, and percentage of agriculture in the Morgan Creek and Chesterville Branch basins, Locust Grove study area, Kent County, Maryland.

Table 7. Results of Principal-components Analysis of Landscape Variables for the Morgan Creek and Chesterville Branch Watersheds, Locust Grove Study Area, Kent County, Maryland

Number of samples = 16

Three variables:
ALT_MIN – altitude of the basin outlet
PCT_C – percentage of the basin with Type C (moderately poorly drained) soil
PCT_AG – percentage of the basin under agriculture

Values of all variables were converted to rank scores and normalized
  (means = 0; standard deviation and variance = 1)

Total variance of all three variables = 3

Eigenvalues of the correlation matrix:

Component	1	2	3
Eigenvalue	2.31	0.46	0.23
Proportion of total variance	0.77	0.15	0.08

Component # 1 is the only one retained; 77 percent of the total variance is explained by this component.

Component loadings for each variable:

ALT_MIN: 0.86
PCT_C: -0.84
PCT_AG: 0.92

Final communality estimates: Total = 2.31 (0.77)

ALT_MIN: 0.75   PCT_C: 0.71   PCT_AG: 0.86
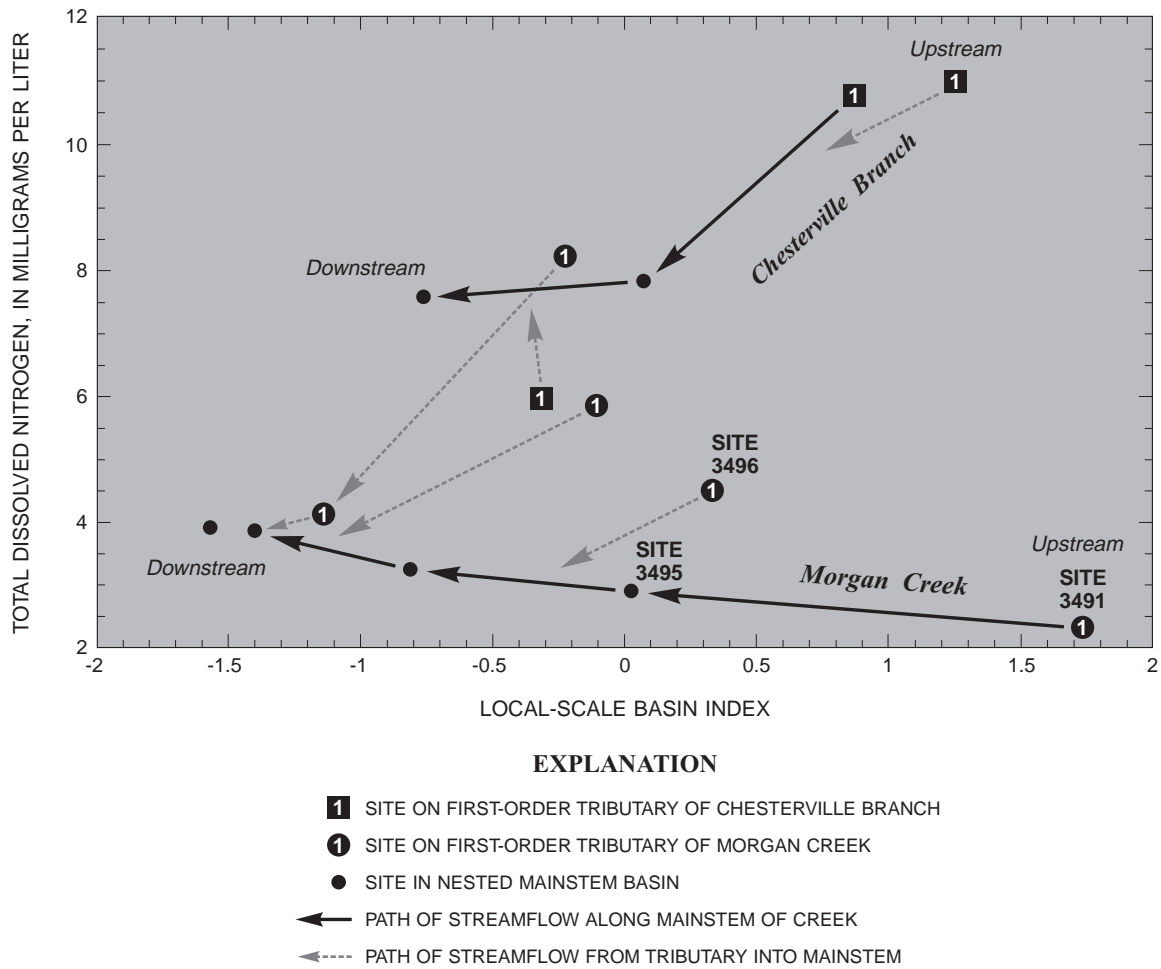
Figure 24. Relations among basin index, dissolved nitrogen concentration, and location within the stream network, Locust Grove study area, Kent County, Maryland.
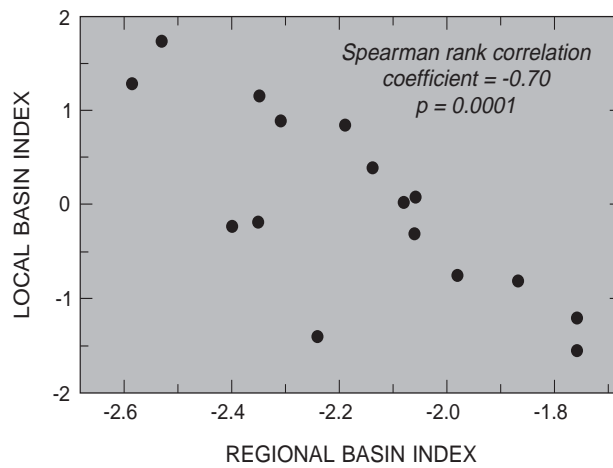
Figure 25. Correlation between regional and local basin index scores for sites in the Locust Grove study area, Kent County, Maryland.

Summary and Conclusions

This report presents the results of data collection and analysis by the U.S. Geological Survey in support of ground-water flow modeling by the U.S. Environmental Protection Agency for the Locust Grove study area, Kent County, Maryland. This effort has provided evidence that subsurface hydrostratigraphic units substantially affect the transport and fate of dissolved nitrogen through the surficial aquifer to discharge as stream base flow. The highly permeable surficial aquifer in the study area is underlain by a low-permeability confining layer, which dips to the south. Continuous cores and geophysical logs indicate that the confining layer approaches the surface near the riparian zone of Morgan Creek, but is deeper than 20 to 30 meters below the surface near Chesterville Branch. The Chesterville Branch watershed is completely underlain by a thick, permeable surficial aquifer that yields considerable base flow, whereas much of the Morgan Creek watershed is underlain shallowly by low-permeability sediments.

In addition to affecting ground-water flow paths and discharge to streams, the confining layer also has a geochemical environment that may be conducive to denitrification of dissolved nitrate in the ground water. Reduced-iron minerals are abundant in the confining layer but generally have been removed by weathering from the overlying aquifer. Chemical analyses indicate that ground water in the surficial aquifer evolves from a high-nitrate water dominated by calcium to a low-nitrate, bicarbonate water with more sodium. The concentrations of dissolved nitrogen and argon gases; dissolved oxygen, iron, and sulfate; and nitrogen and carbon isotopes as tracers, all provide evidence that the low-nitrogen water discharging to the streams originally contained considerable amounts of nitrate that was subsequently denitrified. Ground water that discharges to Morgan Creek is more likely to interact with the sedimentary redox zone at the top of the Aquia confining layer, and appears to have a higher proportion of denitrified water than ground water that discharges to Chesterville Branch. The geochemical data also confirm that denitrification was not active in ground waters in the surficial aquifer above the sediment redox transition. Nitrate in the ground water has remained stable for at least 40 to 50 years where it flowed through the deeply weathered sediments and oxic conditions of the Columbia-Aquia surficial aquifer.

Base-flow nitrogen yields are about twice as high from Chesterville Branch (median of 0.058 grams per second per square kilometer) than from Morgan Creek (0.022 grams per second per square kilometer), although annual loads are only 45 percent higher in Chesterville Branch (median of 29,000 kilograms per year) than in Morgan Creek (20,000 kilograms per year). Although the two watersheds were identified as having similar hydrologic landscape characteristics in previous studies, a more detailed analysis indicates that the Morgan Creek basin contains soils that are somewhat more poorly drained. Soil drainage, altitude of the watershed or sub-watershed outlet, and the percentage of agricultural land use are related to each other and to total dissolved nitrogen concentrations in stream base flow.

The base-flow synoptic data show that nitrate concentrations tend to increase downstream in Morgan Creek and decrease downstream in Chesterville Branch. The downstream increase of nitrate concentrations in Morgan Creek may be due to flow from tributaries in which ground-water discharge is less likely to be denitrified, or from a downstream decrease in denitrification of discharging ground water. The downstream decrease of nitrate concentrations in Chesterville Branch may be due to a downstream increase of instream denitrification and uptake by biota, or by an increase in the relative proportion of older ground-water discharge; this older ground water may have relatively low nitrate concentrations either because of lower historic inputs of nitrogen or because of denitrification. There also is some evidence that the shallow Aquia confining layer may be breached, possibly by a fault, under the riparian zone of Morgan Creek near site 01493495, and low-nitrate water from the underlying confined Hornerstown aquifer may be contributing to base flow.

Further study would help to better define the processes affecting ground-water discharge to streams. In particular, an extended hydrostratigraphic framework and ground-water geochemistry from wells in downstream sections of the watersheds, below sites 01493495 and 01493110, would contribute to an improved understanding of the lower reaches of the two streams. More detailed data on the shallow subsurface geology of the riparian zone would help determine whether Hornerstown water is discharging to Morgan Creek, and provide further evidence to evaluate the role of organic-carbon oxidation as a mechanism for denitrification in both watersheds. Additional wells in the Hornerstown aquifer, particularly to the north of the study area, would provide data on the source of ground-water recharge and the geochemical evolution of water in the Hornerstown aquifer. Finally, additional chemical and biological sampling of streamwater would be helpful in characterizing instream processes that may be sources and sinks for nitrogen and other dissolved constituents.

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Appendix A

Appendix A. Wells from Previous Projects that Were Used for Water-level Measurements, Chemical Sampling of Ground Water, and the Hydrogeologic Framework for the Locust Grove Study Area, Kent County, Maryland

Aquifer codes:
112PCPC – Pensauken Formation
125AQUI – Aquia Formation
125 HRRS – Hornerstown Formation
211MMMT – Monmouth Formation

Types of logs:
D- Drillers
G- Geologist
J – Gamma
E - Electric

Method of determining altitude:
L – Level (surveyed)
M – from topographic map

Local well number	Site ID number	Latitude ddmmss	Longitude ddmmss	Altitude, (feet above sea level)	Depth below land surface			Depth relative to sea level			Aquifer code	Type of logs	Total depth of log (feet)	Method of determining altitude	Altitude accuracy (feet)
					Bottom of hole (feet)	Top of screen (feet)	Bottom of well (feet)	Bottom of hole (feet)	Top of screen (feet)	Bottom of well (feet)					
KE Be 46	39183207556 0801	391832	755608	64	55	40	50	9	24	14	125AQUI	D	55	M	10
KE Be 50	39185107556 1801	391851	755618	70.17	35	20	22	35.17	50.17	48.17	112PCPC	D, J	31.5	L	0.01
KE Be 51	39185107555 4401	391851	755544	70.01	35	24	27	35.01	46.01	43.01	112PCPC	D, J	31	L	0.01
KE Be 52	39181007555 5801	391810	755558	74.72	50	33	36	24.72	41.72	38.72	112PCPC	D, J	46.5	L	0.01
KE Be 53	39181007555 5802	391810	755558	74.61	25	20	22	49.61	54.61	52.61	112PCPC	D	25	L	0.01
KE Be 59	39183207556 0803	391832	755608	71.36	30	23.5	26.5	41.36	47.86	44.86	125AQUI	D	30	L	0.01
KE Be 60	39181107556 4901	391811	755649	78.12	30	24.5	26.5	48.12	53.62	51.62	125AQUI	D	30	L	0.01
KE Be 61	39181007555 5803	391803	755552	74.58	60	47.5	50.5	14.58	27.08	24.08	125AQUI	D, J	46.5	L	0.01
KE Be 62	39174207555 4801	391742	755548	60.7	30	22.5	25.5	30.7	38.2	35.2	125AQUI	D	30	L	0.01
KE Be 63	39172107555 4501	391721	755545	45.09	40	36.5	39.5	5.09	8.59	5.59	125AQUI	D	40	L	0.01
KE Be 64	39172107555 4502	391721	755545	45.11	20	13	16	25.11	32.11	29.11	125AQUI	D	20	L	0.01
KE Be 65	39160807559 4301	391608	755943	49	25	19	22	24	30	27	125AQUI	D	25	M	1
KE Be 156	39181907558 0901	391819	755809	38	20	11	14	18	27	24	125AQUI	D, U	20	M	10
KE Be 157	39181807556 0901	391818	755802	43	25	15	18	18	28	25	125AQUI	D, U	25	M	10
KE Be 158	39181407557 5501	391814	755755	65	40	31	34	25	34	31	125AQUI	D, U	40	M	10
KE Be 159	39172007555 4601	391720	755546	45.27	70	65.5	68.5	-24.73	-20.23	-23.23	125AQUI	D, U	70	M	10
KE Be 160	39172007555 4602	391720	755546	45.23	45	35	38	0.23	10.23	7.23	125AQUI	D	45	M	10
KE Be 161	39172007555 4603	391720	755546	45.18	25	16	19	20.18	29.18	26.18	125AQUI	D	25	M	10

[ddmmss are the digits for degrees, minutes, and seconds; –, information not available.]

Appendix A. Wells from Previous Projects that Were Used for Water-level Measurements, Chemical Sampling of Ground Water, and the Hydrogeologic Framework — continued

Local well number	Site ID number	Latitude ddmmss	Longitude ddmmss	Altitude, (feet above sea level)	Depth below land surface			Depth relative to sea level			Aquifer code	Type of logs	Total depth of log (feet)	Method of determining altitude	Altitude accuracy (feet)
					Bottom of hole (feet)	Top of screen (feet)	Bottom of well (feet)	Bottom of hole (feet)	Top of screen (feet)	Bottom of well (feet)					
KE Be 162	3917420755554802	391742	755548	61.02	70	64	67	-8.98	-2.98	-5.98	125AQUI	D	70	M	2
KE Be 163	3917420755554803	391742	755548	60.84	45	40	43	15.84	20.84	17.84	125AQUI	D	45	M	2
KE Be 164	3918320755560804	391832	755608	71.4	50	45	48	21.4	26.4	23.4	125AQUI	D	50	M	1
KE Be 165	3918380755560901	391838	755609	65.65	50	45	48	15.65	20.65	17.65	125AQUI	D	50	M	5
KE Be 166	3918380755560902	391838	755609	65.81	35	25	28	30.81	40.81	37.81	125AQUI	D	35	M	5
KE Be 167	3918380755560903	391838	755609	65.92	25	15	18	40.92	50.92	47.92	125AQUI	D	25	M	5
KE Be 169	–	391719	755547	38.71	5.5	2.5	5.5	33.21	36.21	33.21	112PCPC	–	–	L	1
KE Be 170	3917200755554701	391720	755547	40.3	6.9	3.9	6.9	33.4	36.4	33.4	112PCPC	–	–	L	1
KE Be 205	–	391732	755558	65.40	35.4	36.9	35.9	30.0	28.5	29.5	125AQUI	–	–	–	–
KE Bf 186	–	391748	755442	62.15	32.2	33.7	32.2	30.0	28.5	30.0	125AQUI	–	–	–	–
KE Be 216	–	391727	755509	63.55	33.6	35.1	33.6	30.0	28.5	30.0	125AQUI	–	–	–	–
Block 3-54	–	391748	755442	62	158	115	150	-96	-53	-88	125HRRS	G,E	158	M	1
Block 6-12	–	391803	755532	62	84	60	80	-22	2	-18	125AQUI	G,E	84	M	5
KE-88-0695	–	391727	755535	45	75	55	75	-30	-10	-30	125AQUI	G,E	75	M	5
KE-88-0696	–	391727	755509	63.55	110	80	110	-46.45	-16.45	-46.45	125AQUI	G,E	110	L	0.01
KE-94-0144	–	391732	755558	66.02	87	50	80	-20.98	16.02	-13.98	125AQUI	–	–	L	0.01
KE-94-0145	–	391732	755558	66.01	150	110	150	-83.99	-43.99	-83.99	125HRRS	G,E	149	L	0.01
KE-94-0146	–	391732	755558	65.94	277	205	275	-211.1	-139.1	-209.1	211MNMT	G,E	275	L	0.01

Appendix B

Appendix B. Wells Installed in April 1998 that Were Used for Water-level Measurements, Chemical Sampling of Ground Water, and the Hydrogeologic Framework for the Locust Grove Study Area, Kent County, Maryland

Aquifer codes: CLMB – Pensauken Fm; AQUI – Aquia Fm; CLVR - Calvert Fm; HRRS – Hornerstown Fm; "multiport" well has numerous very narrow screened intervals.

Maryland permit number	Local well number	Date installed	Latitude ddmmss	Longitude ddmmss	Aquifer code	Altitude of land surface (feet MSL)	Well depth (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Depth logged (gamma, feet)	Altitude of bottom of well (feet MSL)	Altitude of top of screen (feet MSL)	Altitude of bottom of screen (feet MSL)
KE-94-0246	KE Be 187	04/21/98	391914	755842	CLMB	77.50	15.0	13.5	14.5	14.5	62.5	64.0	63.0
KE-94-0247	KE Be 188	04/21/98	391904	755832	AQUI	64.13	15.0	13.5	14.5	14.5	49.1	50.6	49.6
KE-94-0248	KE Be 189	04/19/98	391820	755802	HRRS	38.85	53.5	50.5	53.0	53.0	-14.7	-11.7	-14.2
KE-94-0250	KE Be 190	04/15/98	391818	755758	AQUI	49.49	21.0	multiport	multiport	—	28.5	multiport	multiport
KE-94-0180	KE Be 191	04/15/98	391813	755752	AQUI	66.60	29.5	27.8	29.5	—	37.1	38.8	37.1
KE-94-0251	KE Be 192	04/15/98	391813	755752	AQUI	66.76	38.5	36.8	38.5	—	28.3	30.0	28.3
KE-94-0252	KE Be 193	04/15/98	391813	755752	AQUI	66.81	42.0	40.5	41.5	—	24.8	26.3	25.3
KE-94-0254	KE Be 194	04/16/98	391717	755710	CLMB	81.02	31.0	29.2	31.0	—	50.0	51.8	50.0
KE-94-0253	KE Be 195	04/16/98	391717	755710	AQUI	81.02	60.0	57.0	59.8	59.0	21.0	24.0	21.2
KE-94-0280	KE Be 196	04/16/98	391652	755707	CLVR	65.81	30.0	28.2	30.0	29.5	35.8	37.6	35.8
KE-94-0255	KE Be 197	04/21/98	391925	755752	CLMB	76.79	21.0	19.5	20.5	20.2	55.8	57.3	56.3
KE-94-0257	KE Be 198	04/14/98	391941	755701	CLMB	76.22	25.5	24.0	25.0	—	50.7	52.2	51.2
KE-94-0256	KE Be 199	04/14/98	391941	755701	AQUI	76.28	31.0	29.5	30.5	—	45.3	46.8	45.8
KE-94-0178	KE Be 200	04/14/98	391941	755701	HRRS	76.25	63.0	60.0	62.5	63.3	13.3	16.3	13.8
KE-94-0258	KE Be 201	04/23/98	391758	755659	CLMB	69.85	30.0	28.5	29.5	29.5	39.9	41.4	40.4
KE-94-0259	KE Be 202	04/23/98	391830	755626	CLMB	66.12	30.0	28.5	29.5	29.5	36.1	37.6	36.6
KE-94-0260	KE Be 203	04/22/98	391713	755621	AQUI	60.99	30.0	29.0	30.0	28.0	31.0	32.0	31.0
KE-94-0261	KE Be 204	04/23/98	391740	755615	AQUI	70.07	30.0	28.5	29.5	29.5	40.1	41.6	40.6
KE-94-0262	KE Be 205	04/23/98	391732	755558	AQUI	65.40	30.0	28.5	29.5	—	35.4	36.9	35.9
KE-94-0268	KE Be 206	04/18/98	391851	755617	AQUI	70.68	36.0	34.3	36.0	—	34.7	36.4	34.7
KE-94-0267	KE Be 207	04/18/98	391849	755616	AQUI	70.03	43.5	42.0	43.0	—	26.5	28.0	27.0
KE-94-0266	KE Be 208	04/18/98	391849	755616	AQUI	69.91	48.5	47.0	48.0	46.6	21.4	22.9	21.9
KE-94-0265	KE Be 209	04/21/98	391849	755616	AQUI	69.57	44.2	multiport	multiport	—	25.4	multiport	multiport
KE-94-0264	KE Be 210	04/17/98	391851	755617	HRRS	70.47	87.0	84.0	87.0	97.0	-16.5	-13.5	-16.5
KE-94-0279	KE Be 211	04/22/98	391715	755542	HRRS	44.34	107.0	104.0	106.5	103.2	-62.7	-59.7	-62.2
KE-94-0269	KE Be 212	04/23/98	391659	755524	AQUI	61.05	30.0	28.5	29.5	29.0	31.1	32.6	31.6
KE-94-0281	KE Be 213	04/20/98	391845	755511	AQUI	78.43	30.0	27.0	30.0	—	48.4	51.4	48.4
KE-94-0271	KE Be 214	04/19/98	391832	755527	CLMB	79.32	29.5	28.0	29.0	—	49.8	51.3	50.3
KE-94-0270	KE Be 215	04/19/98	391832	755527	AQUI	79.32	59.5	58.0	59.0	58.5	19.8	21.3	20.3
KE-94-0272	KE Bf 184	04/20/98	391819	755458	CLMB	76.85	29.5	27.5	29.0	—	47.4	49.4	47.9
KE-94-0273	KE Bf 185	04/20/98	391819	755458	AQUI	76.85	57.5	55.5	57.0	56.5	19.4	21.4	19.9
KE-94-0275	KE Bf 186	04/20/98	391748	755442	AQUI	62.15	30.0	28.5	30.0	—	32.2	33.7	32.2
KE-94-0277	KE Be 216	04/20/98	391727	755509	AQUI	63.55	30.0	28.5	30.0	—	33.6	35.1	33.6

[ddmmss, digits of degrees, minutes, and seconds; MSL, mean sea level; –, not collected; n/a, not applicable.]

Appendix C

Appendix C. Water Levels in Observation Wells in the Locust Grove Study Area, Kent County, Maryland

Well number	10/08/97	03/12/98	05/06/98	06/23/98	07/30/98	09/03/98	10/30/98	11/30/98	12/22/98	01/27/99	03/05/99	04/08/99	05/13/99	07/16/99	08/25/99	09/23/99	09/30/99	10/22/99
KE Bf 154	–	32.02	32.26	31.89	21.26	30.19	6.70	29.19	28.64	29.46	29.59	30.20	29.54	28.68	12.90	29.43	29.72	29.74
KE Bf 155	–	32.64	32.84	31.45	21.71	30.78	11.11	29.74	29.21	30.02	30.13	30.79	30.11	29.24	13.24	30.00	30.26	30.31
KE-88-0696	–	46.70	47.28	46.69	45.87	45.10	44.37	44.03	43.90	43.99	44.34	44.98	44.79	43.56	42.73	43.65	44.06	44.53
KE Be 216	–	–	47.26	46.69	45.86	45.09	44.37	44.01	43.91	43.98	44.34	44.97	44.77	43.55	42.75	43.65	44.05	44.52
KE Bf 186	–	–	52.87	51.97	43.66	48.67	48.52	46.60	48.07	48.41	48.83	49.62	38.04	46.05	44.85	46.72	47.33	48.16
Block 3-54	–	51.39	51.69	50.79	40.40	47.53	47.39	45.11	46.89	47.27	47.66	48.45	3.10	44.98	43.80	45.63	46.25	46.92
KE Bf 184	–	–	57.81	57.39	56.43	55.47	54.09	53.63	53.68	53.57	53.68	54.02	52.82	51.92	50.21	51.67	52.31	52.80
KE Bf 185	–	–	57.83	57.41	56.42	55.45	54.04	53.68	53.66	53.60	53.71	54.06	52.82	51.91	50.27	51.77	52.34	52.79
KE Be 154	–	56.60	58.27	57.32	49.53	55.91	51.54	55.08	54.81	54.41	53.99	53.99	49.74	44.44	43.79	51.94	52.19	52.58
KE Be 213	–	–	58.29	57.19	54.34	55.84	50.57	55.06	54.83	54.53	54.02	54.00	51.50	50.07	49.96	51.98	52.17	52.59
KE Be 214	–	–	59.91	59.69	59.06	58.25	56.96	56.21	55.94	55.64	55.61	55.87	55.59	54.39	53.54	53.65	54.00	54.45
KE Be 215	–	–	59.92	59.68	59.04	58.24	56.93	56.19	55.97	55.63	55.60	55.87	55.60	54.38	53.53	53.67	54.02	54.43
Block 6-12	–	51.78	52.36	51.84	50.85	50.10	49.06	48.15	48.37	48.58	48.98	49.45	48.98	47.65	46.57	48.14	48.41	48.51
KE-88-0695	–	43.00	42.56	42.39	38.18	41.60	40.15	41.58	41.70	41.98	41.99	42.20	41.43	36.15	40.68	41.92	42.00	42.09
KE Be 212	–	–	43.32	42.27	41.11	40.16	39.52	39.29	38.25	39.46	39.79	40.55	40.50	38.81	37.68	38.87	39.40	40.25
KE Be 211	–	–	44.11	44.11	43.11	42.82	42.50	42.31	42.23	42.38	42.51	43.01	42.75	42.01	41.55	42.42	42.65	42.76
KE Be 159	40.25	41.09	40.70	40.48	40.41	40.45	40.37	40.41	40.21	40.28	40.39	40.26	40.60	40.00	39.89	40.59	40.82	40.62
KE Be 160	40.23	41.03	40.82	40.62	40.34	40.43	40.12	40.17	40.17	40.18	40.29	40.38	40.61	40.03	39.90	40.63	40.80	40.77
KE Be 161	40.08	40.74	40.60	40.44	40.17	40.74	39.98	40.00	40.01	40.11	40.17	40.15	40.50	39.84	39.82	40.47	40.71	40.66
KE Be 63	40.73	41.62	41.35	41.31	40.93	40.94	40.71	40.75	40.71	40.84	40.85	40.83	40.97	40.53	40.35	41.12	41.23	41.61

[Altitude in feet above mean sea level; –, not measured.]

Appendix C. Water Levels in Observation Wells in the Locust Grove Study Area, Kent County, Maryland — continued

Date of measurement

Well number:	10/08/97	03/12/98	05/06/98	06/23/98	07/30/98	09/03/98	10/30/98	11/30/98	12/22/98	01/27/99	03/05/99	04/08/99	05/13/99	07/16/99	08/25/99	09/23/99	09/30/99	10/22/99
KE Be 64	40.74	41.66	41.36	41.22	40.90	41.03	40.70	40.71	40.38	40.97	40.99	40.94	41.03	40.42	40.37	41.13	41.25	41.65
KE-94-0144	—	50.13	50.45	49.92	49.28	48.55	34.91	47.61	45.84	47.38	47.43	40.43	37.85	39.32	45.92	46.57	46.89	47.11
KE-94-0145	—	49.90	50.20	49.69	49.04	48.40	35.38	47.44	45.76	47.33	47.29	37.27	35.84	38.39	45.82	46.51	46.78	46.99
KE-94-0146	—	49.60	50.14	50.16	49.15	48.50	58.14	47.54	44.96	47.46	47.26	n/d	60.94	n/d	45.98	46.53	46.81	47.44
KE Be 205	—	—	50.24	49.70	49.06	48.15	46.59	47.47	45.01	47.27	47.25	46.84	46.64	45.55	45.71	46.36	46.76	46.85
KE Be 203	—	—	47.40	46.87	45.10	45.42	44.93	44.73	44.41	44.20	44.13	44.34	44.06	43.50	42.72	43.61	n/d	43.67
KE Be 204	—	—	54.96	54.67	54.01	53.18	52.00	51.67	51.07	50.69	50.38	50.57	50.66	50.05	49.56	49.50	49.65	49.88
KE Be 62	51.56	53.78	53.89	53.34	52.55	52.01	51.26	50.81	50.74	50.95	50.91	51.30	50.86	49.85	48.66	49.99	50.23	50.40
KE Be 162	51.52	53.75	53.93	53.32	52.52	52.02	51.28	50.81	50.75	50.94	50.92	51.28	50.86	49.85	48.84	49.97	50.23	50.60
KE Be 163	51.59	53.82	53.94	53.35	52.55	52.03	51.29	50.83	50.77	50.94	50.93	51.31	50.87	49.89	48.87	50.00	50.25	50.54
KE Be 61	55.18	57.87	59.16	58.55	57.95	57.16	55.80	55.13	54.88	54.49	54.68	55.04	55.01	53.88	53.12	53.41	53.81	54.47
KE Be 53	55.01	58.12	59.46	58.87	58.25	57.44	56.15	55.42	55.17	54.88	54.95	55.35	55.33	54.24	Dry	Dry	54.16	54.73
KE Be 52	56.73	58.13	59.45	58.84	58.22	57.42	56.11	55.40	55.17	54.89	54.95	55.34	55.30	54.16	53.41	53.68	54.09	54.20
KE Be 59	59.39	61.64	61.48	61.52	60.52	59.84	58.75	58.13	57.79	57.70	57.61	58.16	57.80	56.96	56.25	57.37	57.65	57.46
KE Be 164	59.12	61.58	61.40	61.47	60.55	59.78	58.70	58.06	57.70	57.65	57.53	58.12	57.71	56.88	56.13	57.29	57.55	57.39
KE Be 165	59.00	61.54	60.92	61.03	59.99	59.62	58.59	58.09	57.75	57.95	57.64	57.70	57.63	56.94	56.20	57.86	57.64	57.50
KE Be 166	59.03	61.58	60.94	61.06	60.04	59.61	58.59	58.10	57.75	58.09	57.70	58.20	57.67	56.94	56.21	57.87	57.67	57.53
KE Be 167	59.06	61.74	60.94	61.09	60.05	59.64	58.60	58.10	57.76	58.05	57.70	58.12	57.68	56.97	56.20	57.88	57.69	57.55
KE Be 51	57.88	58.18	59.44	59.38	58.89	58.19	56.96	56.26	55.81	55.33	54.79	55.06	54.86	54.41	53.96	54.56	54.65	54.42
KE Be 207	—	—	60.84	60.96	59.87	59.29	58.63	58.21	57.78	57.78	57.64	58.41	57.73	56.90	56.09	57.00	57.28	57.20

Appendix C. Water Levels in Observation Wells in the Locust Grove Study Area, Kent County, Maryland — continued

Date of measurement

Well number:	10/08/97	03/12/98	05/06/98	06/23/98	07/30/98	09/03/98	10/30/98	11/30/98	12/22/98	01/27/99	03/05/99	04/08/99	05/13/99	07/16/99	08/25/99	09/23/99	09/30/99	10/22/99
KE Be 208	–	–	60.80	60.95	59.82	59.29	58.45	57.96	57.71	57.84	57.64	58.38	57.68	56.86	56.07	57.09	57.16	57.15
KE Be 50	58.53	62.86	60.60	60.72	59.62	59.04	58.19	57.72	57.50	57.48	57.38	58.21	57.46	56.60	55.80	56.82	56.92	56.92
KE Be 210	–	–	60.69	61.02	59.85	59.26	58.71	58.30	57.68	57.79	57.68	58.33	57.36	56.51	55.98	56.90	56.98	57.01
KE Be 206	–	–	60.94	61.03	59.92	59.32	58.45	57.97	57.72	57.76	57.74	58.42	57.65	56.77	56.00	56.89	57.03	57.07
KE Be 198	–	–	57.91	58.01	57.67	57.20	56.37	55.72	55.31	54.89	54.01	54.09	53.82	53.42	53.07	52.86	52.97	53.08
KE Be 199	–	–	57.93	58.04	57.69	57.23	56.46	56.30	55.34	55.24	54.80	54.86	53.79	53.44	53.16	52.88	52.83	52.89
KE Be 200	–	–	57.93	58.04	57.72	58.25	54.41	55.95	55.39	54.84	54.10	54.12	53.88	53.46	53.11	53.00	52.96	52.97
KE Be 197	–	–	58.85	58.70	58.28	57.61	56.36	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	56.37	56.50	56.34
KE Be 187	–	–	63.67	66.61	64.96	67.24	63.10	65.03	64.84	67.23	67.40	66.15	62.79	63.25	63.63	67.82	66.04	66.54
KE Be 188	–	–	60.72	61.12	59.98	59.75	58.28	57.68	57.11	57.51	56.50	56.57	55.82	55.13	54.57	56.31	56.11	56.05
KE Be 189	–	–	38.32	38.22	37.84	37.87	38.13	37.68	37.61	37.58	37.53	37.88	37.41	37.25	37.15	37.76	37.56	37.57
KE Be 156	–	37.39	37.20	37.01	36.77	36.92	36.75	36.80	36.60	36.67	36.62	36.68	36.45	35.85	36.23	36.78	36.55	36.61
KE Be 157	39.41	39.92	40.03	39.78	39.47	39.39	39.04	38.92	38.94	38.99	38.80	38.99	38.79	38.58	38.37	39.09	38.90	38.79
KE Be 158	–	43.76	44.55	44.14	43.87	43.51	42.97	42.72	42.51	42.40	42.44	42.48	42.46	42.18	42.02	42.21	42.18	42.16
KE Be 191	–	–	44.36	43.97	43.69	43.36	42.80	42.54	42.36	42.21	42.14	42.33	42.29	42.04	41.85	42.01	42.01	42.00
KE Be 192	–	–	44.38	44.00	43.70	42.94	42.83	42.56	42.38	42.23	42.19	42.35	42.32	42.04	41.87	42.02	41.95	41.96
KE Be 193	–	–	44.42	44.04	43.74	43.41	42.85	42.64	42.40	42.26	42.22	42.41	42.36	42.09	41.90	41.96	42.01	42.02
KE Be 201	–	–	54.20	54.08	53.49	52.50	51.53	50.84	50.23	49.92	49.43	50.03	49.97	49.48	49.07	49.00	49.14	49.17
KE Be 60	59.23	59.22	60.97	60.51	60.17	60.37	58.07	57.35	57.58	56.27	55.87	56.28	56.67	56.10	56.77	–	–	53.47
KE Be 202	–	–	56.59	56.60	55.61	55.03	54.19	53.60	53.13	53.08	53.03	53.44	53.23	52.68	52.06	53.21	53.56	53.47
KE Be 195	–	–	56.74	56.42	56.11	55.53	54.71	54.25	53.89	53.33	52.97	52.70	52.73	52.30	51.73	51.75	51.75	51.90
KE Be 194	–	–	56.74	56.45	56.11	55.54	54.73	54.24	53.90	53.41	52.87	52.70	52.75	52.30	51.74	51.54	51.68	51.95
KE Be 196	–	–	51.14	50.94	50.64	50.28	49.58	49.13	48.80	48.38	47.93	47.73	47.40	47.08	46.87	46.82	46.72	46.53

Appendix D

Appendix D. Chemical Analyses of Ground-water Samples Collected from Observation Wells in the Locust Grove Study Area, Kent County, Maryland

Station ID number	Local well number	Date sample collected	Time sample collected	Altitude of land surface, feet above sea level	Static water level, feet below land surface	Depth of well, feet below land surface	Water temperature, in degrees Celsius	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Dissolved oxygen, in milligrams per liter	pH, in standard units
391717075571001	KE Be 194	07/20/98	1150	81	24.2	31	20.5	346	6.8	4.5
391717075571002	KE Be 195	07/20/98	1530	81	24.0	60	19.2	200	7.3	6.6
391820075580201	KE Be 189	07/21/98	1100	38.8	0.8	53	14.5	172	0	7
391813075575202	KE Be 192	07/21/98	1330	66.8	22.65	38.5	14.6	167	8.5	5
391941075570102	KE Be 199	07/22/98	1100	76.3	18.11	31	17.6	152	6.9	5.3
391941075570103	KE Be 200	07/22/98	0920	76.3	17.85	63	15.1	153	0	6.3
391851075561702	KE Be 206	07/22/98	1500	70.7	10.17	36	14.4	153	7.5	5.4
391851075561701	KE Be 210	07/22/98	1400	70.5	10.2	87	16.1	283	0.1	7.1
391659075552401	KE Be 212	07/23/98	1300	61	19.4	30	16.1	426	8.3	5
391849075561601	KE Be 207	07/23/98	1030	70	9.65	43	14.3	152	9	5.6
391849075561602	KE Be 208	07/23/98	0900	69.9	9.43	48	13.9	89	9.5	5.9
Multiport sampler:						**Port depth:**				
391818075575801	KE Be 190-3	03/06/00	—	49.49	—	12.8	—	411	6.0	4.71
	KE Be 190-4	03/06/00	—	49.49	—	13.8	—	506	5.4	4.81
	KE Be 190-5	03/06/00	—	49.49	—	14.8	—	426	4.3	4.60
	KE Be 190-6	03/06/00	—	49.49	—	15.8	—	270	2.7	4.77
	KE Be 190-7	03/06/00	—	49.49	—	16.8	—	179	2.0	4.83
	KE Be 190-8	03/06/00	—	49.49	—	17.8	—	202	2.5	4.98
	KE Be 190-9	03/06/00	—	49.49	—	18.8	—	150	3.7	5.00

Local well number	Date sample collected	Calcium, in milligrams per liter	Magnesium, in milligrams per liter	Sodium, in milligrams per liter	Potassium, in milligrams per liter	Silica, in milligrams per liter as Si	Iron, in micrograms per liter	Manganese, in micrograms per liter
KE Be 194	07/20/98	20	17	7.4	2.7	13	130	77
KE Be 195	07/20/98	15	4	19	1.9	11	<10	<4
KE Be 189	07/21/98	25	2.1	3	2.4	24	4100	14
KE Be 192	07/21/98	9.6	6.9	2.8	4.3	7.7	<10	181
KE Be 199	07/22/98	8.6	4.1	9.1	2.3	20	36	11
KE Be 200	07/22/98	8.1	2.7	3.7	3.4	28	16000	91
KE Be 206	07/22/98	11	3.4	8.2	1.9	17	<10	39
KE Be 210	07/22/98	43	2.6	3.5	4.4	38	1900	151
KE Be 212	07/23/98	—	—	—	—	—	—	—
KE Be 207	07/23/98	—	—	—	—	—	—	—
KE Be 208	07/23/98	—	—	—	—	—	—	—

[–, no sample collected; <, less than.]

Appendix D. Chemical Analyses of Ground-water Samples Collected from Observation Wells — continued

Local well number	Date sample collected	Alkalinity, in milligrams per liter as calcium carbonate	Bicarbonate, in milligrams per liter	Sulfate, in milligrams per liter	Chloride, in milligrams per liter	Fluoride, in milligrams per liter	Ammonia plus organic nitrogen, in milligrams per liter as N	Nitrite plus nitrate nitrogen, in milligrams per liter as N	Ortho-phosphate, in milligrams per liter as P	Ground-water age, in years	Nitrogen-15 of nitrate, in $\delta^{15}N$ per mil	Nitrogen gas, dissolved, milligrams per liter	Argon gas, dissolved, milligrams per liter
KE Be 194	07/20/98	10	12	0.12	84	<0.10	<0.10	3.58	0.011	11.8	3.7	14.45	0.56
KE Be 195	07/20/98	41	50	2.9	11	<0.10	<0.10	8.86	0.012	20.9	3.5	14.95	0.55
KE Be 189	07/21/98	69	84	3.2	3.7	0.47	<0.10	0.055	<0.01	>40	–	22.01	0.08
KE Be 192	07/21/98	2	2	0.49	15	<010	<0.10	11.8	<0.01	1.9	3.4	16.23	0.62
KE Be 199	07/22/98	3	3	0.12	17	<0.10	<0.10	9.8	0.023	21.7	3.7	16.02	0.59
KE Be 200	07/22/98	34	41	18	7.3	0.28	<0.10	0.025	0.34	39.8	–	20.77	0.66
KE Be 206	07/22/98	7	8	<0.10	12	<0.10	<0.10	11.9	0.025	17.1	2.2	19.68	0.70
KE Be 210	07/22/98	156	190	18	2.1	0.61	<0.10	0.073	0.216	>40	–	21.28	0.69
KE Be 212	07/23/98	2	2	–	–	–	<0.10	43	0.01	8.9	2.6	19.29	0.69
KE Be 207	07/23/98	8	10	–	–	–	<0.10	9.04	0.202	20.3	3.6	18.96	0.68
KE Be 208	07/23/98	6	7	–	–	–	<0.10	5.18	1.04	31.5	3.1	19.78	0.70
Multiport sampler:								Nitrate,[1] in milligrams per liter as N					
KE Be 190-3	03/06/00	1.3		15	92	–	–	4.97	–	–	–	–	–
KE Be 190-4	03/06/00	1.5		17	119	–	–	5.15	–	–	–	–	–
KE Be 190-5	03/06/00	0.6		22	86	–	–	5.31	–	–	–	–	–
KE Be 190-6	03/06/00	0.5		23	48	–	–	6.16	–	–	–	–	–
KE Be 190-7	03/06/00	1.0		21	18	–	–	6.21	–	–	–	–	–
KE Be 190-8	03/06/00	2.5		19	14	–	–	5.89	–	–	–	–	–
KE Be 190-9	03/06/00	3.0		18	12	–	–	5.71	–	–	–	–	–

[1] Analysis from 3/6/2000 samples from multiport was for nitrate-nitrogen only.

Appendix E

Appendix E. Chemical Analyses of Base-flow Samples from the Locust Grove Study Area, Kent County, Maryland

Station ID number	Station name	Sample date	Sample time (Eastern Standard Time)	Discharge, in cubic meters per second	Discharge, in cubic feet per second	Temperature, in degrees Celsius	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Dissolved oxygen, in milligrams per liter	pH, in standard units	Alkalinity, in milligrams per liter as calcium carbonate
01493109	COW C NR CHESTERVILLE, MD	04/14/1998	0915	0.009	0.33	12.8	238	9.6	6.6	12
01493109	COW C NR CHESTERVILLE, MD	09/21/1998	1030	0.003	0.12	19.4	219	6.6	5.6	14
01493109	COW C NR CHESTERVILLE, MD	03/02/2000	1030	0.008	0.28	9.5	181	11.9	6.2	16
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	04/14/1998	1030	0.045	1.6	11.9	183	9.4	6.3	14
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	09/21/1998	0915	0.018	0.63	18.8	213	7.2	6.2	22
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	10/13/1999	0900	0.015	0.53	14	187	7.5	5.8	20
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	02/24/2000	1200	0.022	0.78	9.2	187	11.0	6.5	17
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	04/14/1998	1145	0.065	2.3	16.6	168	2.4	6.0	22
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	09/21/1998	1200	0.059	2.1	20.5	162	6.3	6.2	32
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	04/14/1998	1315	0.042	1.5	18.6	141	6.2	6.5	20
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	09/21/1998	1315	0.008	0.3	21.2	150	8.2	6.2	25
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/14/1998	1430	0.193	6.8	16.5	165	9.9	6.5	22
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/30/1998	0945	0.221	7.8	14.5	164	7.8	6.8	25
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/28/1998	0900	0.218	7.7	17.3	169	8.3	6.4	25
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/29/1998	0900	0.193	6.8	20.3	166	6.8	6.5	27
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/07/1998	1000	0.178	6.3	20	163	7.3	6.8	25
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/28/1998	1200	0.142	5	23.5	171	7.2	5.6	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/29/1998	0830	0.139	4.9	21.3	166	7.0	6.2	30
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/27/1998	1100	0.142	5	22.4	172	7.8	6.2	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/15/1998	0800	0.113	4	20	161	7.5	6.2	30
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/21/1998	1445	0.142	5	20.7	164	7.8	6.5	31
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/08/1998	0830	0.133	4.7	16.5	171	7.6	6.8	28
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/19/1998	1200	0.122	4.3	–	–	10.6	5.3	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/05/1998	0900	0.116	4.1	8	171	9.4	7.1	24
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/18/1998	1400	0.122	4.3	9	178	10.0	5.1	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/01/1998	1100	0.091	3.2	11.5	173	8.7	6.9	–

[–, sample not collected; <, less than.]

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Sample time (Eastern Standard Time)	Discharge, in cubic meters per second	Discharge, in cubic feet per second	Temperature, in degrees Celsius	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Dissolved oxygen, in milligrams per liter	pH, in standard units	Alkalinity, in milligrams per liter as calcium carbonate
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/21/1998	1130	0.272	9.6	9.5	121	5	5.7	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/08/1999	1330	0.153	5.4	6.8	174	10.8	6.5	24
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/24/1999	1130	0.122	4.3	4	179	–	7.1	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/26/1999	1145	0.133	4.7	6	–	11.2	6.5	23
01493112	CHESTERVILLE B NR CRUMPTON, MD	03/10/1999	1200	0.139	4.9	4	179	12.3	6.5	18
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/06/1999	1000	0.133	4.7	13	170	8.5	6.4	28
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/21/1999	1000	0.130	4.6	10	124	10.2	6.8	27
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/05/1999	1100	0.139	4.9	15	172	9.6	5.9	30
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/17/1999	1030	0.130	4.6	16	172	9.7	5.9	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/08/1999	1000	0.102	3.6	22.5	165	7	6.1	36
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/20/1999	1700	0.193	6.8	–	165	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/06/1999	1000	0.105	3.7	21	157	4.2	6.6	33
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/21/1999	915	0.074	2.6	24	167	6.8	5.7	36
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/03/1999	1000	0.071	2.5	21.7	174	7.3	7.2	35
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/16/1999	1000	23.307	823	19	40	–	6	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/01/1999	1030	0.159	5.6	16.6	153	7	6.4	28
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/13/1999	1230	0.122	4.3	15.3	155	9.1	6.4	30
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/10/1999	1200	0.125	4.4	10.7	163	8.7	6.2	32
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/08/1999	1200	0.122	4.3	7.5	173	–	8	32
01493112	CHESTERVILLE B NR CRUMPTON, MD	01/04/2000	1010	0.156	5.5	11.6	153	9.2	7.3	27
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/17/2000	1230	0.178	6.3	5.2	143	11.3	6.3	26
01493491	MORGAN C TR NR GALENA, MD	04/15/1998	1500	0.003	0.11	24.1	169	9.9	6.3	32
01493491	MORGAN C TR NR GALENA, MD	02/23/2000	1445	0.001	0.03	10.1	234	11.5	7.3	30
01493495	MORGAN C NR LOCUST GROVE, MD	04/14/1998	1130	0.065	2.3	13.6	168	7.9	5.1	32
01493495	MORGAN C NR LOCUST GROVE, MD	09/21/1998	1630	0.019	0.67	24.5	176	6.6	6.5	46

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Sample time (Eastern Standard Time)	Discharge, in cubic meters per second	Discharge, in cubic feet per second	Temperature, in degrees Celsius	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Dissolved oxygen, in milligrams per liter	pH, in standard units	Alkalinity, in milligrams per liter as calcium carbonate
01493495	MORGAN C NR LOCUST GROVE, MD	02/22/2000	1300	0.042	1.5	7.2	202	10.5	7.1	25
01493496	MORGAN C TR NR KENNEDYVILLE, MD	04/14/1998	1000	0.031	1.1	17	215	10.2	5.3	43
01493496	MORGAN C TR NR KENNEDYVILLE, MD	09/21/1998	1630	0.012	0.43	24	261	1	6.1	85
01493496	MORGAN C TR NR KENNEDYVILLE, MD	02/22/2000	1430	0.031	1.1	15.2	211	12.7	7.2	35
01493497	MORGAN C AT KENNEDYVILLE, MD	04/15/1998	1000	0.156	5.5	15.6	173	8.5	6.3	39
01493497	MORGAN C AT KENNEDYVILLE, MD	09/21/1998	1340	0.068	2.4	23.5	177	5.5	6.1	50
01493497	MORGAN C AT KENNEDYVILLE, MD	02/23/2000	1030	0.136	4.8	5	184	10.3	6.7	35
01493498	MORGAN C TR AT KENNEDYVILLE, MD	04/15/1998	1100	0.019	0.66	15.3	171	8.3	5.5	37
01493498	MORGAN C TR AT KENNEDYVILLE, MD	09/21/1998	1730	0.023	0.82	23.5	195	3.6	6.1	67
0149349810	MORGAN C TR NR MORGNEC, MD	04/14/1998	1300	0.003	0.09	21	240	7.3	5.5	48
0149349810	MORGAN C TR NR MORGNEC, MD	09/21/1998	1245	0.000	0.01	22	215	1.7	5.5	32
0149349810	MORGAN C TR NR MORGNEC, MD	02/23/2000	1330	0.003	0.11	12	187	2.3	6.6	24
0149349820	MORGAN C TR NR LYNCH, MD	04/15/1998	1330	0.003	0.12	18.7	252	8.6	5.8	24
0149349820	MORGAN C TR NR LYNCH, MD	02/25/2000	1330	0.003	0.09	11.8	279	12.8	7.1	29
01493499	MORGAN C NR WORTON, MD	04/14/1998	1630	0.210	7.4	18.6	173	10.1	6.3	30
01493499	MORGAN C NR WORTON, MD	09/21/1998	1045	0.125	4.4	21	184	6.5	5.8	48
01493499	MORGAN C NR WORTON, MD	02/25/2000	1100	0.181	6.4	9.3	178	9.6	7.1	32
01493500	MORGAN C NR KENNEDYVILLE, MD	04/14/1998	1500	0.280	9.9	17.4	170	11.4	6.7	30
01493500	MORGAN C NR KENNEDYVILLE, MD	05/20/1998	1030	0.227	8.0	21	176	5.2	5.9	–
01493500	MORGAN C NR KENNEDYVILLE, MD	06/24/1998	1030	0.246	8.7	24.2	179	4.9	5.4	–
01493500	MORGAN C NR KENNEDYVILLE, MD	07/28/1998	1100	0.167	5.9	23	179	6.4	5.4	–
01493500	MORGAN C NR KENNEDYVILLE, MD	08/27/1998	1000	0.136	4.8	24	184	7.2	6.5	–
01493500	MORGAN C NR KENNEDYVILLE, MD	09/21/1998	930	0.136	4.8	20.5	184	8.3	5.5	46
01493500	MORGAN C NR KENNEDYVILLE, MD	10/19/1998	1030	0.187	6.6	15.7	173	7.5	5.4	–
01493500	MORGAN C NR KENNEDYVILLE, MD	11/18/1998	1100	0.144	5.1	7.5	187	8.6	5.4	–
01493500	MORGAN C NR KENNEDYVILLE, MD	12/21/1998	1000	0.156	5.5	7	184	8.9	5.4	–
01493500	MORGAN C NR KENNEDYVILLE, MD	02/24/1999	1000	0.187	6.6	0.5	209	–	6.5	–
01493500	MORGAN C NR KENNEDYVILLE, MD	02/22/2000	1000	0.340	12	3.4	226	11.2	7.1	30

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Calcium, dissolved, in milligrams per liter	Magnesium, dissolved, in milligrams per liter	Sodium, dissolved, in milligrams per liter	Potassium, dissolved, in milligrams per liter	Silica, dissolved, in milligrams per liter as Si	Iron, dissolved, in micrograms per liter	Manganese, dissolved, in milligrams per liter
01493109	COW C NR CHESTERVILLE, MD	04/14/1998	15	11	5.7	3.7	8.3	21	189
01493109	COW C NR CHESTERVILLE, MD	09/21/1998	15	7.9	6.3	6.7	9.8	11	61
01493109	COW C NR CHESTERVILLE, MD	03/02/2000	14	6.8	5	3.2	8.8	13	50
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	04/14/1998	15	6.5	4.2	2.9	9.4	14	61
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	09/21/1998	18	6.4	4.4	8.8	12	19	26
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	10/13/1999	17	6.8	4.5	4.2	11	18	74
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	02/24/2000	16	6.6	4.7	3	9.5	10	37
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	04/14/1998	15	5.1	4.6	2.8	9	52	147
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	09/21/1998	15	5	4.9	3.8	6.2	23	113
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	04/14/1998	11	4.7	5.3	3.3	7.6	260	264
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	09/21/1998	13	4.5	5.5	3.8	11	27	211
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/14/1998	15	5.1	5	3	7.8	110	148
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/30/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/28/1998	15	4.9	5.3	3.5	7.3	78	172
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/29/1998	15	4.7	4.9	4.8	9.5	90	187
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/07/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/28/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/29/1998	16	4.7	5.4	3.8	8.8	50	116
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/27/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/15/1998	15	4.3	4.9	4.1	9	250	110
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/21/1998	15	4.6	5.4	3.7	8.4	30	93
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/08/1998	15	4.6	5.1	3.7	9	52	100
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/19/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/05/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/18/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/01/1998	16	4.4	5.6	3.6	9.8	92	150
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/21/1998	—	—	—	—	—	—	—
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/08/1999	15	4.4	5.4	3.3	10	110	237

Appendix E.   Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Calcium, dissolved, in milligrams per liter	Magnesium, dissolved, in milligrams per liter	Sodium, dissolved, in milligrams per liter	Potassium, dissolved, in milligrams per liter	Silica, dissolved, in milligrams per liter as Si	Iron, dissolved, in micrograms per liter	Manganese, dissolved, in milligrams per liter
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/24/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/26/1999	16	4.5	5.3	3.6	9.9	80	230
01493112	CHESTERVILLE B NR CRUMPTON, MD	03/10/1999	15	4.5	5.2	3.2	9.3	110	186
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/06/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/21/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/05/1999	14	4.4	5.3	3	6.2	82	120
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/17/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/08/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/20/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/06/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/21/1999	–	–	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/03/1999	17	4.3	5.5	3	8.1	18	78
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/16/1999	–	–	–	–	1.5	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/01/1999	13	4.2	4.7	5.1	8.6	77	89
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/13/1999	14	4.6	5.1	4.5	6.8	44	89
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/10/1999	–	–	–	–	8.6	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/08/1999	–	–	–	–	10	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	01/04/2000	17	4.7	5.1	3.2	10	95	132
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/17/2000	13	4.2	5.9	3.3	8	78	157
01493491	MORGAN C TR NR GALENA, MD	04/15/1998	11	6.2	8.2	6.3	4.8	720	157
01493491	MORGAN C TR NR GALENA, MD	02/23/2000	10.1	8.2	20	9.3	9.3	480	233
01493495	MORGAN C NR LOCUST GROVE, MD	04/14/1998	14	5.8	5.6	4.3	6.4	340	176
01493495	MORGAN C NR LOCUST GROVE, MD	09/21/1998	16	5.5	6.4	4.1	14	37	262
01493495	MORGAN C NR LOCUST GROVE, MD	02/22/2000	10	4.2	11	5.1	7.7	200	184
01493496	MORGAN C TR NR KENNEDYVILLE, MD	04/14/1998	19	5.8	7.3	4.4	2.9	450	280
01493496	MORGAN C TR NR KENNEDYVILLE, MD	09/21/1998	23	6.7	7.1	8.4	12	1600	1570
01493496	MORGAN C TR NR KENNEDYVILLE, MD	02/22/2000	9	3.2	13	8.5	4.5	25	122
01493497	MORGAN C AT KENNEDYVILLE, MD	04/15/1998	15	5.4	6.6	3.8	6.2	500	341

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station Name	Sample date	Calcium, dissolved, in milligrams per liter	Magnesium, dissolved, in milligrams per liter	Sodium, dissolved, in milligrams per liter	Potassium, dissolved, in milligrams per liter	Silica, dissolved, in milligrams per liter as Si	Iron, dissolved, in micrograms per liter	Manganese, dissolved, in milligrams per liter
01493497	MORGAN C AT KENNEDYVILLE, MD	09/21/1998	15	4.8	6.8	5.3	13	190	145
01493497	MORGAN C AT KENNEDYVILLE, MD	02/23/2000	11	4.1	11	5.7	7.7	220	332
01493498	MORGAN C TR AT KENNEDYVILLE, MD	04/15/1998	18	4.7	4.8	2.7	10	260	289
01493498	MORGAN C TR AT KENNEDYVILLE, MD	09/21/1998	21	4.6	5.2	3.9	14	120	414
0149349810	MORGAN C TR NR MORGNEC, MD	04/14/1998	22	6.8	7.4	5.8	5.3	700	579
0149349810	MORGAN C TR NR MORGNEC, MD	09/21/1998	14	5.7	8.6	4.6	11	55	380
0149349810	MORGAN C TR NR MORGNEC, MD	02/23/2000	11	4.4	9.8	9.7	3.2	62	152
0149349820	MORGAN C TR NR LYNCH, MD	04/15/1998	17	8.6	11	5.1	9.2	120	383
0149349820	MORGAN C TR NR LYNCH, MD	02/25/2000	18	8.5	12	5.6	10	250	426
01493499	MORGAN C NR WORTON, MD	04/14/1998	14	5.3	6.6	3.8	5.7	330	157
01493499	MORGAN C NR WORTON, MD	09/21/1998	15	5.3	6.8	4.9	13	62	140
01493499	MORGAN C NR WORTON, MD	02/25/2000	13	5.1	8.9	5.4	8.4	190	164
01493500	MORGAN C NR KENNEDYVILLE, MD	04/14/1998	14	5.3	6.3	3.6	6.1	250	184
01493500	MORGAN C NR KENNEDYVILLE, MD	05/20/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	06/24/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	07/28/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	08/27/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	09/21/1998	15	5.2	7.1	4.7	13	89	149
01493500	MORGAN C NR KENNEDYVILLE, MD	10/19/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	11/18/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	12/21/1998	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	02/24/1999	–	–	–	–	–	–	–
01493500	MORGAN C NR KENNEDYVILLE, MD	02/22/2000	11	4.4	12	5.8	7.5	150	183

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Bicarbonate, dissolved, in milligrams per liter	Sulfate, dissolved, in milligrams per liter	Chloride, dissolved, in milligrams per liter	Ammonia plus organic nitrogen, in milligrams per liter	Nitrite plus nitrate nitrogen, in milligrams per liter	Total nitrogen, dissolved, in milligrams per liter	Total Phosphorus, in milligrams per liter	Orthophosphate, in milligrams per liter as P
01493109	COW C NR CHESTERVILLE, MD	04/14/1998	15	17	23	0.23	10.9	11.13	0.031	0.019
01493109	COW C NR CHESTERVILLE, MD	09/21/1998	17	11	18	0.43	12.3	12.73	0.093	0.027
01493109	COW C NR CHESTERVILLE, MD	03/02/2000	20	8.9	13	0.10	9.64	9.74	0.019	<.010
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	04/14/1998	17	9.3	11	<.10	10.6	10.6	0.015	0.014
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	09/21/1998	27	9.1	15	0.44	11.2	11.64	0.431	0.111
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	10/13/1999	24	11	12	0.19	9.58	9.77	0.03	<.010
01493110	CHESTERVILLE B NR CHESTERVILLE, MD	02/24/2000	21	9.6	12	0.10	10.4	10.4	0.01	<.010
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	04/14/1998	27	5.4	12	0.2	7.64	7.84	0.039	0.022
01493111	CHESTERVILLE B AT CHESTERVILLE, MD	09/21/1998	39	4.5	12	0.37	5.05	5.42	0.045	0.016
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	04/14/1998	24	3.9	11	0.34	5.42	5.76	0.091	0.023
0149311110	CHESTERVILLE B TR NR CHESTERVILLE, MD	09/21/1998	30	1.8	11	0.31	6.3	6.61	0.108	0.017
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/14/1998	27	5.4	12	0.22	7.37	7.59	0.064	0.018
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/30/1998	30	–	–	0.23	6.26	6.49	0.024	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/28/1998	30	4.3	13	0.28	7.14	7.42	0.069	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/29/1998	33	5	12	0.21	5.51	5.72	0.13	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/07/1998	30	–	–	0.19	6.58	6.77	0.044	0.011
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/28/1998	–	–	–	0.43	5.76	6.19	–	0.013
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/29/1998	37	3.4	12	0.23	5.84	6.07	0.011	0.01
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/27/1998	0	–	–	0.36	5.52	5.88	0.028	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/15/1998	37	3.1	12	–	–	–	–	–
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/21/1998	38	3.1	12	0.18	6.3	6.48	0.044	0.014
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/08/1998	34	3.3	13	0.21	7.18	7.39	<.050	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/19/1998	–	–	–	0.22	6.94	7.16	<.050	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/05/1998	29	–	–	0.16	7.43	7.59	<.050	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/18/1998	–	–	–	0.28	7.17	7.45	0.037	0.01
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/01/1998	–	2.8	13	0.19	6.92	7.11	<.050	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/21/1998	–	–	–	0.2	8.36	8.56	0.032	0.016
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/08/1999	29	4.6	12	0.32	7.53	7.85	0.044	<.010

Station ID number	Station name	Sample date	Bicarbonate, dissolved, in milligrams per liter	Sulfate, dissolved, in milligrams per liter	Chloride, dissolved, in milligrams per liter	Ammonia plus organic nitrogen, in milligrams per liter	Nitrite plus nitrate nitrogen, in milligrams per liter	Total nitrogen, dissolved, in milligrams per liter	Total Phosphorus, in milligrams per liter	Orthophosphate, in milligrams per liter as P
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/24/1999	—	—	—	0.55	8.07	8.62	0.132	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/26/1999	28	4.6	13	0.51	7.97	8.48	0.105	0.003
01493112	CHESTERVILLE B NR CRUMPTON, MD	03/10/1999	22	4.2	17	0.31	8.26	8.57	0.048	0.02
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/06/1999	34	—	—	<.10	—	—	0.042	0.044
01493112	CHESTERVILLE B NR CRUMPTON, MD	04/21/1999	33	—	—	0.28	5.8	6.08	0.041	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/05/1999	37	3.7	13	0.24	6.41	6.65	0.038	0.003
01493112	CHESTERVILLE B NR CRUMPTON, MD	05/17/1999	—	—	—	0.22	6.78	7	0.039	0.003
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/08/1999	44	—	—	0.32	5.17	5.49	0.079	0.005
01493112	CHESTERVILLE B NR CRUMPTON, MD	06/20/1999	—	—	—	0.32	4.58	4.9	0.06	0.002
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/06/1999	40	—	—	0.35	4.56	4.91	0.075	0.011
01493112	CHESTERVILLE B NR CRUMPTON, MD	07/21/1999	44	—	—	0.42	3.29	3.71	0.044	0.014
01493112	CHESTERVILLE B NR CRUMPTON, MD	08/03/1999	43	2.8	12	0.15	4.9	5.05	0.03	0.011
01493112	CHESTERVILLE B NR CRUMPTON, MD	09/16/1999	—	—	—	0.49	0.609	1.099	1.13	0.094
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/01/1999	34	4.8	13	0.28	4.01	4.29	0.06	0.027
01493112	CHESTERVILLE B NR CRUMPTON, MD	10/13/1999	37	5.6	13	0.23	4.87	5.1	0.033	<.010
01493112	CHESTERVILLE B NR CRUMPTON, MD	11/10/1999	39	—	—	0.19	5.49	5.68	0.019	0.001
01493112	CHESTERVILLE B NR CRUMPTON, MD	12/08/1999	39	—	—	0.18	5.47	5.65	0.034	0.001
01493112	CHESTERVILLE B NR CRUMPTON, MD	01/04/2000	33	4	13	0.17	7.04	7.21	0.024	0.001
01493112	CHESTERVILLE B NR CRUMPTON, MD	02/17/2000	32	5.7	13	0.26	5.37	5.63	0.065	<.010
01493491	MORGAN C TR NR GALENA, MD	04/15/1998	39	12	15	1.1	1.01	2.11	0.343	0.072
01493491	MORGAN C TR NR GALENA, MD	02/23/2000	37	11	31	1.2	1.45	2.65	0.204	0.034
01493495	MORGAN C NR LOCUST GROVE, MD	04/14/1998	39	8.3	13	0.44	2.48	2.92	0.115	0.021
01493495	MORGAN C NR LOCUST GROVE, MD	09/21/1998	56	3.6	14	0.49	2.35	2.84	0.088	0.018
01493495	MORGAN C NR LOCUST GROVE, MD	02/22/2000	30	6.7	24	0.59	2.49	3.08	0.169	0.011
01493496	MORGAN C TR NR KENNEDYVILLE, MD	04/14/1998	52	7.6	18	1.7	3.05	4.75	0.174	0.026
01493496	MORGAN C TR NR KENNEDYVILLE, MD	09/21/1998	104	2.3	19	1.1	0.098	1.198	0.512	0.015
01493496	MORGAN C TR NR KENNEDYVILLE, MD	02/22/2000	43	5.7	26	2.8	1.16	3.96	0.463	0.027
01493497	MORGAN C AT KENNEDYVILLE, MD	04/15/1998	48	6.3	14	0.67	2.58	3.25	0.139	0.023

Appendix E. Chemical Analyses of Base-flow Samples — continued

Station ID number	Station name	Sample date	Bicarbonate, dissolved, in milligrams per liter	Sulfate, dissolved, in milligrams per liter	Chloride, dissolved, in milligrams per liter	Ammonia plus organic nitrogen, in milligrams per liter	Nitrite plus nitrate nitrogen, in milligrams per liter	Total nitrogen, dissolved, in milligrams per liter	Total Phosphorus, in milligrams per liter	Orthophosphate, in milligrams per liter as P
01493497	MORGAN C AT KENNEDYVILLE, MD	09/21/1998	61	2.6	15	0.88	1.63	2.51	0.25	0.022
01493497	MORGAN C AT KENNEDYVILLE, MD	02/23/2000	43	6.1	22	1.4	2.36	3.76	0.267	0.016
01493498	MORGAN C TR AT KENNEDYVILLE, MD	04/15/1998	45	8.1	10	0.54	3.64	4.18	0.131	0.015
01493498	MORGAN C TR AT KENNEDYVILLE, MD	09/21/1998	82	3.3	11	0.48	0.263	0.743	0.201	0.016
0149349810	MORGAN C TR NR MORGNEC, MD	04/14/1998	59	10	20	1.5	4.41	5.91	0.211	0.036
0149349810	MORGAN C TR NR MORGNEC, MD	09/21/1998	39	1.1	21	1.7	8.32	10.02	0.066	0.016
0149349810	MORGAN C TR NR MORGNEC, MD	02/23/2000	29	8.5	22	0.89	4.07	4.96	0.515	<.010
0149349820	MORGAN C TR NR LYNCH, MD	04/15/1998	29	11	34	1.8	6.42	8.22	0.146	0.018
0149349820	MORGAN C TR NR LYNCH, MD	02/25/2000	35	16	37	0.48	5.04	5.52	0.078	<.010
01493499	MORGAN C NR WORTON, MD	04/14/1998	37	6.7	16	0.38	3.49	3.87	0.125	0.019
01493499	MORGAN C NR WORTON, MD	09/21/1998	59	3	17	0.4	2.33	2.73	0.091	0.028
01493499	MORGAN C NR WORTON, MD	02/25/2000	39	7.5	21	0.57	3.36	3.93	0.1	0.011
01493500	MORGAN C NR KENNEDYVILLE, MD	04/14/1998	37	6.7	15	0.41	3.51	3.92	0.104	0.019
01493500	MORGAN C NR KENNEDYVILLE, MD	05/20/1998	—	—	—	0.59	3.54	4.13	0.015	<.010
01493500	MORGAN C NR KENNEDYVILLE, MD	06/24/1998	—	—	—	0.73	3.54	4.27	0.136	0.026
01493500	MORGAN C NR KENNEDYVILLE, MD	07/28/1998	—	—	—	0.43	2.61	3.04	–	0.019
01493500	MORGAN C NR KENNEDYVILLE, MD	08/27/1998	—	—	—	0.42	2.26	2.68	0.111	0.011
01493500	MORGAN C NR KENNEDYVILLE, MD	09/21/1998	56	3.1	16	0.39	2.69	3.08	0.094	0.019
01493500	MORGAN C NR KENNEDYVILLE, MD	10/19/1998	—	—	—	0.26	2.66	2.92	0.057	0.017
01493500	MORGAN C NR KENNEDYVILLE, MD	11/18/1998	—	—	—	0.36	2.62	2.98	0.057	0.011
01493500	MORGAN C NR KENNEDYVILLE, MD	12/21/1998	—	—	—	0.42	3.53	3.95	0.055	0.015
01493500	MORGAN C NR KENNEDYVILLE, MD	02/24/1999	—	—	—	1.2	4.07	5.27	0.138	0.013
01493500	MORGAN C NR KENNEDYVILLE, MD	02/22/2000	37	7.8	25	0.66	2.76	3.42	0.151	0.012

Appendix F

Appendix F. Basin Characteristics of Sites from the Base-flow Synoptic Surveys Used in the Landscape Analysis for the Locust Grove Study Area, Kent County, Maryland

Site ID number	Station name	Drainage area (square miles)	Regional basin index	Local basin index	Stream length (miles)	Minimum altitude of stream (feet above sea level)	Stream slope
01493 491	MORGAN CREEK TR NR GALENA MD	0.45	-2.53	1.75	0.35	55.00	14.41
01493 495	MORGAN C NR LOCUST GROVE MD	3.18	-2.08	0.03	1.94	35.00	12.89
01493 496	MORGAN C TR NR KENNEDYVILLE MD	1.33	-2.14	0.39	1.03	40.00	14.59
01493 497	MORGAN C AT KENNEDYVILLE MD	6.16	-1.87	-0.81	3.10	25.00	11.31
01493 498	MORGAN C TR AT KENNEDYVILLE MD	0.99	-1.76	-1.19	0.95	20.00	36.73
01493 49810	MORGAN C TR NR MORGNEC MD	0.32	-2.35	-0.18	0.51	45.00	19.46
01493 49820	MORGAN C TR NR LYNCH MD	0.54	-2.40	-0.22	1.04	20.00	38.65
01493 499	MORGAN C NR WORTON MD	10.62	-2.13	-1.40	3.75	10.00	12.00
01493 500	**MORGAN C NR KENNEDYVILLE MD**	**11.99**	**-1.76**	**-1.57**	**5.38**	**2.00**	**10.77**
01493 109	COW C NR CHESTERVILLE MD	0.35	-2.59	1.28	0.53	40.00	38.02
01493 110	CHESTERVILLE B NR CHESTERVILLE MD	1.29	-2.31	0.92	1.06	40.00	14.11
01493 111	CHESTERVILLE B AT CHESTERVILLE MD	4.74	-2.06	0.07	2.19	25.00	13.71
01493 11110	CHESTERVILLE B TR NR CHESTERVILLE MD	0.93	-2.06	-0.30	0.73	30.00	41.15
01493 112	**CHESTERVILLE B NR CRUMPTON MD**	**6.12**	**-1.98**	**-0.76**	**3.64**	**5.00**	**13.73**

Site ID number	Station name	Percentage of type A (well-drained) soils in watershed	Percentage of type B (moderately well-drained) soils in watershed	Percentage of type C (moderately poorly drained) soils in watershed	Percentage of type D (poorly drained) soils in watershed	Percentage of agricultural land in watershed	Percentage of confined animal feeding operations in watershed	Percentage of nursery in watershed	Percentage of urban land in watershed	Percent of forest in watershed
01493 491	MORGAN CREEK TR NR GALENA MD	11.43	86.45	0.18	0.00	100.00	0.00	0.00	0.00	0.00
01493 495	MORGAN C NR LOCUST GROVE MD	13.52	74.11	6.31	0.86	94.27	0.00	4.49	0.00	5.41
01493 496	MORGAN C TR NR KENNEDYVILLE MD	6.45	72.86	12.76	3.28	97.66	0.00	0.00	1.74	2.34
01493 497	MORGAN C AT KENNEDYVILLE MD	12.78	65.69	12.10	2.93	92.23	0.00	2.24	0.77	6.85
01493 498	MORGAN C TR AT KENNEDYVILLE MD	19.18	49.86	17.39	5.77	92.49	0.00	0.00	0.00	7.51
01493 49810	MORGAN C TR NR MORGNEC MD	13.81	41.77	24.32	3.14	94.32	0.00	0.00	0.00	0.00
01493 49820	MORGAN C TR NR LYNCH MD	42.27	42.74	11.81	0.00	96.22	0.00	0.00	1.31	2.46
01493 499	MORGAN C NR WORTON MD	25.53	56.38	15.63	1.56	90.60	12.51	0.00	0.00	3.81
01493 500	**MORGAN C NR KENNEDYVILLE MD**	**14.67**	**58.77**	**15.42**	**3.51**	**87.74**	**0.45**	**1.19**	**1.32**	**8.21**
01493 109	COW C NR CHESTERVILLE MD	33.88	59.50	3.55	0.00	100.00	0.00	0.00	0.00	0.00
01493 110	CHESTERVILLE B NR CHESTERVILLE MD	42.66	48.59	3.98	0.09	97.32	0.00	29.95	0.00	2.68
01493 111	CHESTERVILLE B AT CHESTERVILLE MD	32.40	51.18	4.93	1.46	94.56	0.00	26.49	0.00	5.10
01493 11110	CHESTERVILLE B TR NR CHESTERVILLE MD	36.17	49.78	6.53	0.42	92.60	0.00	18.20	0.00	7.74
01493 112	**CHESTERVILLE B NR CRUMPTON MD**	**32.36**	**48.64**	**7.93**	**1.40**	**93.07**	**0.72**	**21.17**	**0.00**	**6.70**

[Stations 01493 500 and 01493 112, in bold, are gaging stations; the regional and local basin indexes are explained in the Nutrient Yields from Base Flow section of the report.]

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