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Influence of Septic Systems on Stream Base Flow in the Apalachicola–Chattahoochee–Flint River Basin Near Metropolitan Atlanta, Georgia, 2012

Scientific Investigations Report 2014–5144

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

Cover. Suburban area of Metropolitan Atlanta, Georgia (photograph by Daniel J. Hippe, USGS).

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John S. Clarke and Jaime A. Painter

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Contents

Abstract....1
Introduction....2
Purpose and Scope....2
Previous Studies....2
Methods of Analysis and Sources of Data....3
Description of Study Area....10
Physiography....10
Geology....10
Climate....10
Surface-Water Hydrology....15
Groundwater Hydrology....15
Land Use....17
Water Use....19
Influence of Septic Systems on Stream Base Flow....20
Distribution of Septic Systems....21
Site Characteristics of Study Area Basins....21
Base Flow in September 2012....25
Influence of Septic System Density....28
Influence of Basin Characteristics....31
Influence of Geologic Area....33
Influence of Subareas....36
Influence of Septic System Density in the Riparian Zone....40
Base-Flow Analysis of Continuous Streamflow Data....42
Influence of Septic System Percolation on Base Flow....48
Level Creek Basin....49
Woodall Creek Basin....49
Maximum Potential Septic System Percolation Rate....49
Limitations of Analysis....52
Summary and Conclusions....52
Selected References....54
Appendixes....57

Figures

1. Maps showing location of Metropolitan Atlanta, Georgia, study area and data-collection sites....4
2. Flowchart showing procedure for evaluating basins with high and low density of septic systems....9
3. Map showing physiographic provinces and districts of the Apalachicola–Chattahoochee–Flint River Basin....11
4. Map showing elevation in the study area....12
5. Map showing percent slope in the study area....13
6. Map showing geologic areas of northern Georgia....14
7. Graphs showing stream discharge at USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA, September 3–14, 2012....16
8. Pie chart showing land use in the study area, 2009....17
9. Map showing percentage of impervious area in the study area, 2006....18
10. Graph showing average annual surface-water withdrawals and return flows within the upper and middle Chattahoochee, upper Flint, and Apalachicola–Chattahoochee–Flint River Basins in the study area, 2010....19
11. Conceptual diagram of groundwater flow in the vicinity of septic systems, groundwater divides, and streams during dry hydrologic conditions....20
12. Map showing septic system density in study area, 2012....22
13. Graph showing land-use characteristics for basins with high and low density of septic systems in the study area, 2009....23
14. Boxplots showing drainage area, impervious area, and topographic and soil characteristics of basins with high and low density of septic systems in the study area....24
15. Graphs showing base-flow yield and selected water-quality parameters in the study area, September 10–13, 2012....25
16. Map showing intensity of drought in Georgia, September 11, 2012....26
17. Graphs showing daily total rainfall, potential evapotranspiration, and net precipitation at Georgia Environmental Monitoring Network sites at Gainesville, Atlanta, and Roopville, September 2–14, 2012....27
18. Boxplots showing base-flow yield and selected water-quality parameters of basins with high and low density of septic systems in the study area, September 10–13, 2012....28
19. Graph showing base-flow yield and septic system density for basins with high and low density of septic systems in the study area, September 10–13, 2012....29
20. Graph showing specific conductance and septic system density for basins with high and low density of septic systems in the study area, September 10–13, 2012....29

21. Graphs showing predicted and observed base-flow yield and residuals for multiple linear regression model....32
22. Graph showing base-flow yield by geologic area, September 10–13, 2012....33
23. Boxplots showing base-flow yield, drainage area, impervious area, and topographic and soil characteristics of basins by geologic area....34
24. Boxplots showing base-flow yield and specific conductance by geologic area and septic system density....35
25. Graph showing base-flow yield by subarea, September 10–13, 2012....36
26. Boxplots showing base-flow yield, drainage area, impervious area, and topographic and soil characteristics of basins by subarea....37
27. Boxplots showing base-flow yield and specific conductance by subarea and septic system density....38
28. Boxplots showing drainage area, impervious area, and topographic and soil characteristics within the 45-meter buffer by septic system density....40
29. Boxplots showing base-flow yield and specific conductance within the 45-meter buffer zone by septic system density....41
30. Graphs showing base-flow yield and basin characteristics of USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA....43
31. Map showing drainage area and location of USGS site 02334578, Level Creek at Suwanee Dam Road near Suwanee, GA....44
32. Map showing drainage area and location of USGS site 02336313, Woodall Creek at Defoors Ferry Road, at Atlanta, GA....45
33. Graphs showing base-flow separation using the local-minimum method for daily streamflow during January 2011 through September 2012 at USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA....46
34. Graphs showing percentage contribution of base flow to streamflow during January 2011 through September 2012 at USGS sites 02334578 and 02336313....47
35. Graph showing base flow contributed by maximum potential septic system percolation and other contributors, USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, January 2011–September 2012....48
36. Graph showing base flow contributed by maximum potential septic system percolation and other contributors, USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA, January 2011–September 2012....48
37. Map showing maximum estimated potential septic system percolation rate in the study area....50
38. Graphs showing daily mean streamflow at USGS site 02338000 Chattahoochee River near Whitesburg, GA, and USGS site 02344350 Flint River near Lovejoy, GA, and maximum potential contribution from septic system percolation, January 2011–September 2012....51

Tables

1. Sources of basin characteristic and population data 6
2. Sources of information and procedures used to estimate septic system locations 7
3. Statistical summary of base-flow yield, and selected water-quality parameters, September 10–13, 2012 30
4. Statistics for multiple linear regression model comparing base-flow yield to selected basin characteristics, September 10–13, 2012 31
5. Statistical summary of base-flow yield and specific conductance by geologic area, September 10–13, 2012 35
6. Statistical summary of base-flow yield and specific conductance by subarea, September 10–13, 2012 39
7. Statistical summary of base-flow yield within 45-meter buffer zone for areas with high and low density of septic systems, September 10–13, 2012 41
8. Summary of streamflow, estimated base flow, and base-flow yield during January 2011 through September 2012 at sites 02334578 and 02336313 47
9. Average daily single family residential water use, 2009 51

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Potential evapotranspiration	
inch per day (in/d)	25.4	millimeter per day (mm/d)

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

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

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

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

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

ACF	Apalachicola–Chattahoochee–Flint
GIS	geographic information system
HDS	high density of septic systems
LDS	low density of septic systems
NED	National Elevation Dataset
NLCD	National Land Cover Database
PET	potential evapotranspiration
STATSGO	State Soil Geographic dataset
USGS	U.S. Geological Survey

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Influence of Septic Systems on Stream Base Flow in the Apalachicola–Chattahoochee–Flint River Basin Near Metropolitan Atlanta, Georgia, 2012

John S. Clarke and Jaime A. Painter

Abstract

Septic systems were identified at 241,733 locations in a 2,539-square-mile (mi^2) study area that includes all or parts of 12 counties in the Metropolitan Atlanta, Georgia, area. Septic system percolation may locally be an important component of streamflow in small drainage basins where it augments natural groundwater recharge, especially during extreme low-flow conditions. The amount of groundwater reaching streams depends on how much is intercepted by plants or infiltrates to deeper parts of the groundwater system that flows beyond a basin divide and does not discharge into streams within a basin.

The potential maximum percolation from septic systems in the study area is 62 cubic feet per second (ft^3/s), of which 52 ft^3/s is in the Chattahoochee River Basin and 10 ft^3/s is in the Flint River Basin. These maximum percolation rates represent 0.4 to 5.7 percent of daily mean streamflow during the 2011–12 period at the farthest downstream gaging site (station 02338000) on the Chattahoochee River, and 0.5 to 179 percent of daily mean streamflow at the farthest downstream gaging site on the Flint River (02344350).

To determine the difference in base flow between basins having different septic system densities, hydrograph separation analysis was completed using daily mean streamflow data at streamgaging stations at Level Creek (site 02334578), with a drainage basin having relatively high septic system density of 101 systems per square mile, and Woodall Creek (site 02336313), with a drainage basin having relatively low septic system density of 18 systems per square mile. Results indicated that base-flow yield during 2011–12 was higher at the Level Creek site, with a median of 0.47 cubic feet per second per square mile ($[ft^3/s]/mi^2$), compared to a median of 0.16 $(ft^3/s)/mi^2$, at the Woodall Creek site. At the less urbanized Level Creek site, there are 515 septic systems with a daily maximum percolation rate of 0.14 ft^3/s, accounting for 11 percent of the base flow in September 2012. At the more urban Woodall Creek site, there are 50 septic systems with an average daily maximum percolation rate of 0.0097 ft^3/s, accounting for 5 percent of base flow in September 2012.

Streamflow measurements at 133 small drainage basins (less than 5 mi^2 in area) during September 2012 indicated no statistically significant difference in streamflow or specific conductance between basins having high and low density of septic systems (HDS and LDS, respectively). The median base-flow yield was 0.04 $(ft^3/s)/mi^2$ for HDS sites, ranging from 0 to 0.52 $(ft^3/s)/mi^2$, and 0.10 $(ft^3/s)/mi^2$ for LDS sites, ranging from 0 to 0.49 $(ft^3/s)/mi^2$. A Wilcoxon rank-sum test indicated the median base-flow yields for HDS and LDS sites were not statistically different, with a p-value of 0.345.

Because of the large size of the study area and associated variations in basin characteristics, data collected in September 2012 were also evaluated on the basis of the basins physical characteristics in an attempt to reduce or eliminate other basin characteristics that might affect base flow. Basins were evaluated based on geologic area, four geographic subareas, and 45-meter (147.6 ft) buffer zone; there were no statistically significant differences between median base-flow yield for HDS and LDS basins. It is probable that detection of the contribution from septic system percolation in base flow at many of the sites visited in September 2012 was obscured by a combination of the limitations of measurement accuracy and evapotranspiration. Detection of septic system percolation may also have been complicated by leaky water and sewer mains, which may have resulted in higher streamflows in LDS basins relative to HDS basins.

Introduction

In 2010, the U.S. Geological Survey (USGS) launched the National Water Census as authorized by sec. 9508 of the Omnibus Public Land Management Act of 2009 (42 USC 10368), which calls for the establishment of a "national water availability and use assessment program." As part of the National Water Census, the USGS is studying water availability and use in various focus areas across the country, including the Apalachicola–Chattahoochee–Flint (ACF) River Basin in Alabama, Florida, and Georgia (fig. 1). Knowing how much water is withdrawn, consumed, lost, transferred, and disposed of within a river basin is necessary for effective resource management (Fanning, 2007).

Assessment of water budgets that account for inputs to, outputs from, and changes in the amount of water within a river basin are an important part of the USGS focus-area studies completed for the National Water Census. This study focuses on water budgets for surface water in the ACF River Basin. The basic components of the water budget are precipitation, evapotranspiration, surface-water and groundwater flow into and out of the basin, changes in surface-water and groundwater storage, water withdrawals, and interbasin transfer.

The USGS defines consumptive water use as water that is evaporated, transpired, incorporated into a product or a crop, consumed by humans or animals, or otherwise removed from the immediate environment and is therefore not immediately available for reuse (Hutson and others, 2004). Net water use represents the difference between all water withdrawn from a river basin and all water returned to the basin (discharge) within a given water-use timeframe, and is thus the net effect of all consumptive use, withdrawals, and discharges (Fanning, 2007). The net-use calculation includes interbasin transfers; groundwater discharged from supply systems to streams (for example, withdrawn from a well and discharged into a stream); and groundwater discharged to streams from groundwater storage, which includes natural recharge, pipe leakage, and septic system percolation. The contribution to stream base flow by septic systems has become an important water-management issue in Metropolitan Atlanta, Georgia, because of growing demands for limited water resources (Georgia Environmental Protection Division, 2008). In particular, knowing the amount of water percolating from septic systems that returns to streams within a river basin will enable a more accurate accounting of water resources.

Landers and Ankcorn (2008) reported an estimated 26 percent of the single-family housing units in Metropolitan Atlanta were served by septic systems in 2004 (U.S. Department of Housing and Urban Development and U.S. Census Bureau, 2005); a similar evaluation of data for 2010 indicated the percentage was about 27 percent (U.S. Department of Housing and Urban Development and U.S. Census Bureau, 2010). Water percolating from septic systems into groundwater and ultimately discharged into streams may be an important component of the water budget in small watersheds, which predominate much of the Metropolitan Atlanta study area. To quantify the effect of septic systems on stream base flow, the USGS completed a study in a 12-county area within the upper part of the ACF River Basin during 2012.

Purpose and Scope

The purpose of this report is to quantify the effect of septic systems on stream base flow in a 12-county area within the upper part of the ACF River Basin during 2012. To fulfill this objective, the following information is presented herein:

- Synoptic streamflow measurements at 133 ungaged sites and field water-quality measurements at 94 sites during the low-flow period September 10–13, 2012;
- Compiled locations of septic systems, and land use, geologic, soil, and topographic characteristics in the study area;
- Statistical evaluations of differences in streamflow in basins having high and low density of septic systems;
- Analyses of water budgets in two small watersheds—one with a relatively high density of septic systems and one with a low density of septic systems—including analysis of existing continuous streamflow records using hydrograph separation techniques;
- Estimates of maximum potential septic system percolation rates for the study area; and
- Analysis of the potential contribution of septic system percolation to daily mean streamflow at sites representing the most downstream streamgage locations in the Chattahoochee and Flint River Basins in the study area.

Previous Studies

Landers and Ankcorn (2008) completed a reconnaissance-level investigation during October 2007 comparing base flow in 24 basins having low and high densities of septic systems in southeastern Gwinnett County, Ga., about 5 to 10 miles southeast of the ACF River Basin. An arbitrary threshold of less than 100 systems per square mile (systems/mi^2) was set for low density (LDS) watersheds and greater than 200 systems/mi^2 for high density (HDS) watersheds. Spatial data were analyzed to characterize a variety of basin characteristics, including drainage area, slope,

impervious area, and septic system density. The study area was selected to ensure that geologic setting was consistent among all basins. The Landers and Ankcorn (2008) study indicated that mean base-flow yield, normalized for drainage area, was 90 percent greater in HDS watersheds than in LDS watersheds. Specific conductance of base flow was generally higher in the HDS watersheds than in the LDS watersheds.

Several earlier studies documented the relation between stream base flow and septic systems. On Long Island, New York, Simmons and Reynolds (1982) analyzed long-term streamflow records in two urban watersheds that indicated a 60-percent decrease in annual base flow coincident with increased imperviousness and a transition from septic systems to centralized sanitary sewer systems. Most of this decrease was attributed to the elimination of septic systems, because the base-flow decline in two nearby watersheds that were increasingly urbanized but unsewered was only 10 percent during the same period. Also in New York, Burns and others (2005) reported increased base flow associated with higher residential density in three small basins. Elevated nitrate and sulfate concentrations in the three basins indicated that the increase was attributable to septic system discharges, and the increased base flow was equivalent to the estimated flow into septic systems.

The Metropolitan North Georgia Water Planning District (2006) provided an overview of septic system management practices and usage that included a survey of county environmental health officers responsible for septic management in each of the 16 counties of the district. The survey yielded information about the current usage of septic systems, their ages, and failure rates and causes by county.

LaFontaine (2009) described differences in streamflow characteristics between rural, suburban, and urban basins based on data collected at 12 streamgaging sites in the ACF River Basin near Atlanta from October 2003 through September 2006. The study included the development of a base-flow index based on hydrograph separation. The base-flow index (Wahl and Wahl, 1995) is the total volume of base flow divided by the total volume of runoff during a specified period, providing an indication of the percentage of streamflow provided by base flow. The study found that the base-flow index was highest in rural basins, followed by suburban and urban basins. Higher percentages of impervious area in suburban and urban settings likely inhibits the infiltration of precipitation into groundwater and accounts for the lower base-flow indices in those areas.

Methods of Analysis and Sources of Data

To quantify base flow in the northern ACF River Basin, small watersheds were selected for evaluation on the basis of basin size (less than 5 square mile [mi^2] drainage area) and accessibility for streamflow measurements. Once sites having suitable drainage area and accessibility were identified, a subset of 133 sites were selected to ensure a uniform distribution throughout the study area. A geographic information system (GIS) was used to delineate a drainage basin for each measurement point location and the following characteristics were determined: drainage area, minimum, maximum and mean basin elevation, mean percent basin slope, land use type, percentage of basin imperviousness, water-table and bedrock depth, soil permeability, number of septic systems, population size, and estimated average water use per household. Sources of basin characteristic and population data are listed in table 1.

Locations of septic systems were acquired from the GIS, planning, or water departments of individual counties or municipal governments and were assimilated into a consistent format in the project database (table 2). Some of the data were provided as point locations in geospatial datasets and required no modifications for incorporation into the study database. One county provided septic systems as locations in the form of a street address. This address was georeferenced and converted to a point spatial dataset. In some areas that lacked specific information about the existence of septic systems, land-parcel data attributes were used to delineate septic system locations. If a parcel had at least one bathroom that was more than 100 feet (ft) away from a sewer line, then it was considered served by a septic system.

The majority of septic system locations were derived from billing records. Billing addresses served by water but not sewer were considered served by septic systems. These addresses were geo-referenced and linked to the corresponding parcel polygon data. The centroid of the parcel polygon that shared the address of a septic system user was designated as the location of the septic system.

In some counties, multiple sources of data were provided by municipalities or water utilities to determine the locations of septic systems. A cross-check was completed to ensure there was no overlap of these data to avoid double-counting of septic systems. Location information for septic systems were assembled into a single-feature digital dataset, by county, consisting of 241,733 sites located within the ACF River Basin.

Stream hydrography was derived from the USGS National Hydrography Dataset at a resolution of 1:24,000 (*http://nhd.usgs.gov/*). Drainage basin boundaries for each measurement point are needed as a first step in determining basin characteristics. Basin boundaries were delineated using a National Elevation Dataset (NED) digital elevation model at a 10-meter (m) horizontal resolution (U.S. Geological Survey, 2009). The watershed processing tool for the ArcHydro data model uses measurement locations and the conditioned elevation data to delineate the drainage area upstream of the measurement point. Using the polygonal boundaries generated for each basin, a variety of basin characteristics were determined (table 1).

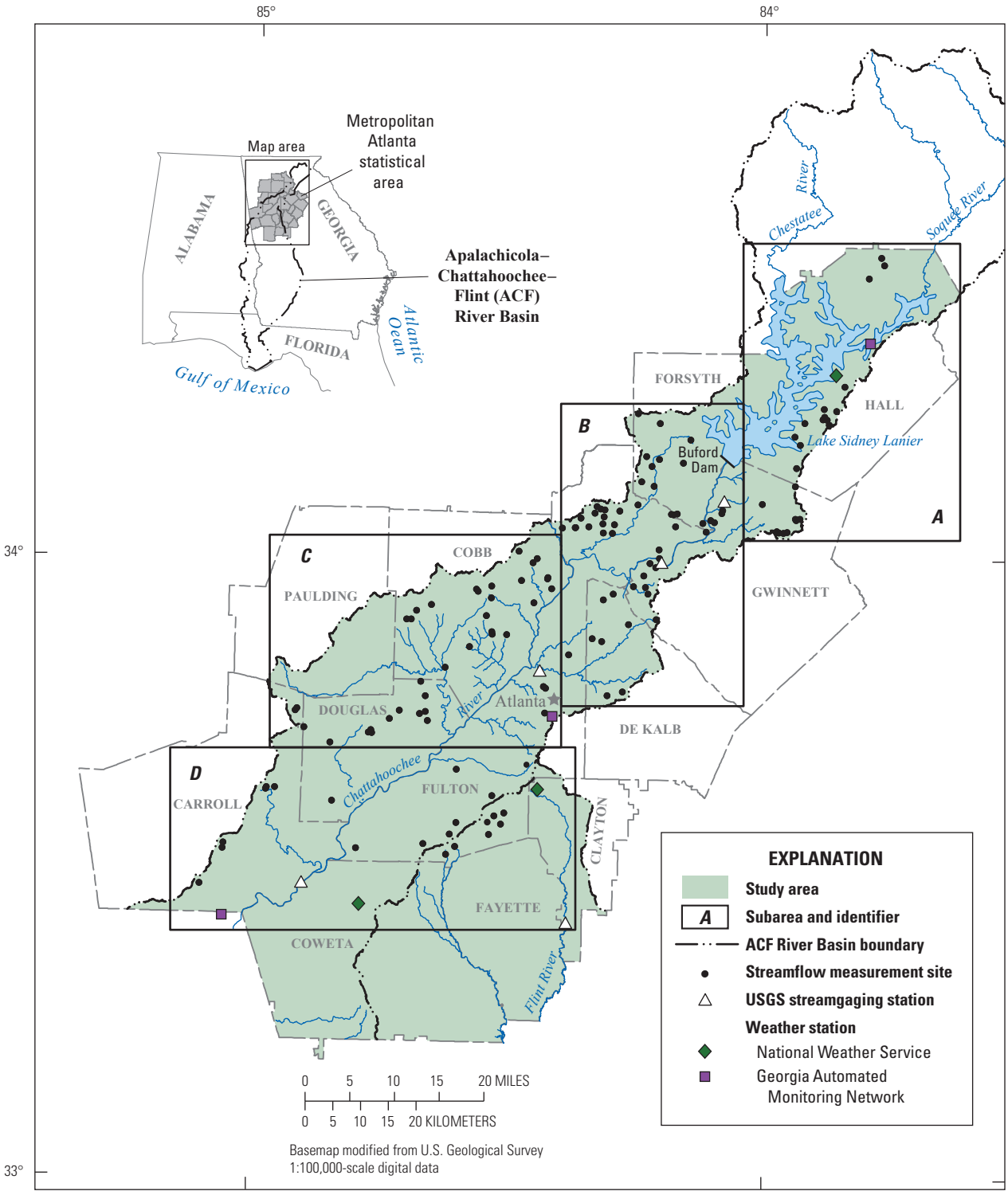
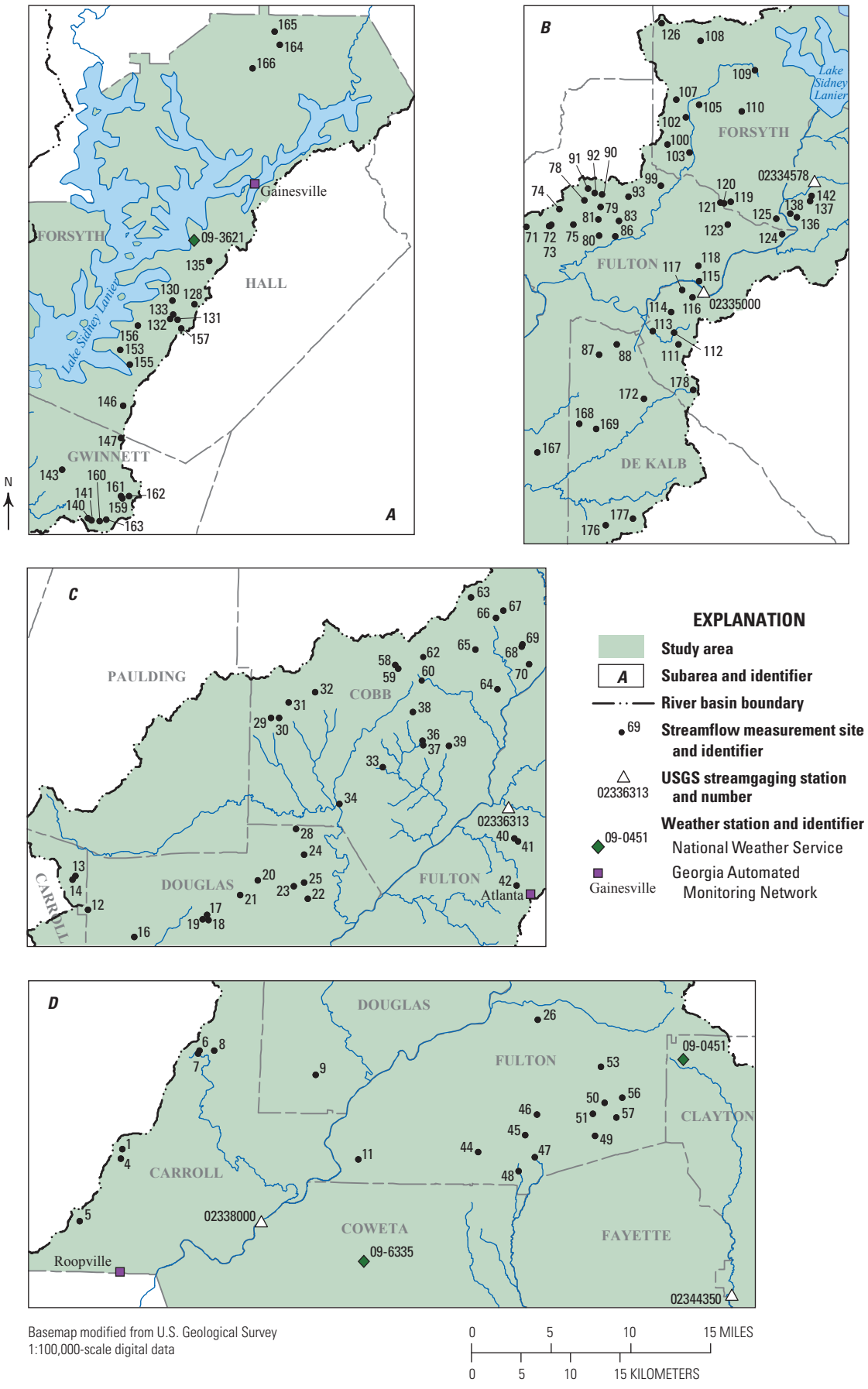


Figure 1 (pages 4 and 5). Location of Metropolitan Atlanta, Georgia, study area and data-collection sites. See facing page for enlargement of subareas *A*–*D*.



Basemap modified from U.S. Geological Survey
1:100,000-scale digital data

0 5 10 15 MILES
0 5 10 15 KILOMETERS

Table 1. Sources of basin characteristic and population data.

[m, meter; DEM, digital elevation model; NA, not applicable]

Data layer	Sources of data	Method	Units
Drainage area	10-m horizontal resolution National Elevation Dataset DEM (U.S. Geological Survey, 2009)	Area within the watershed boundary, which is represented as a polygon of cells that flow to the measurement point based on the primary down-slope flow direction of the DEM	Feet
Mean, maximum, minimum elevation	10-m horizontal resolution National Elevation Dataset DEM (U.S. Geological Survey, 2009)	Area-weighted average, maximum elevation value of the DEM within the watershed boundary, minimum elevation value of the DEM within the watershed boundary	Percent rise
Basin slope	10-m horizontal resolution National Elevation Dataset DEM (U.S. Geological Survey, 2009)	Mean of the DEM percent slope grid values within the watershed boundary	Percentage
Land usage by major category including industrial and commercial; residential; forest; institutional; agricultural; transitional; golf courses, parks and cemeteries; and transportation and highways	Atlanta Regional Commission LandPro 2009. Accessed May 5, 2010, at *http://www.atlantaregional.com/info-center/gis-data-maps/gis-data*	(Land-use category surface area / drainage area)×100	Percentage
Percentage of impervious area	Multi-Resolution Land Characteristics Consortium (2006) impervious surface, 30-m resolution (*http://www.mrlc.gov/nlcd06_data.php*)	(Impervious surface area/drainage area)×100	Percentage
Soil permeability	U.S. Department of Agriculture. U.S. General Soil Map (STATSGO2) Georgia. Accessed September 3, 2013 at *http://websoilsurvey.nrcs.usda.gov/*	Area weighted average	Inches per hour
Depth to high water table within the soil	U.S. Department of Agriculture. U.S. General Soil Map (STATSGO2) Georgia. Accessed September 3, 2013, at *http://websoilsurvey.nrcs.usda.gov/*	Area weighted average	Inches
Depth to bedrock within the soil	U.S. Department of Agriculture. U.S. General Soil Map (STATSGO2) Georgia. Accessed September 3, 2013, at *http://websoilsurvey.nrcs.usda.gov/*	Area weighted average	Inches
Septic system locations	County and city information—based on billing records analysis or proximity to sewer lines (see table 2 for details)	Count of septic system locations contained within the basin polygon extent	Count
Population	Census 2010 block data—National Historical Geographic Information System (*http://nhgis.org*)	Converting the block data into a raster dataset were each cell within a block was given an equal distribution of the total population for the block. Using Zonal Statistics, a total population was determined by summing the population of each raster grid cell where the centroid falls within the basin boundary	Persons
Average household water use	Atlanta Regional Commission	Attributed each system with the average household water use for the county in which it resides	Gallons per day
Hydrography	National Hydrography Dataset (NHD)-*http://nhd.usgs.gov/data.html*	Locations of streams and other water bodies	NA
Geology	Atlanta area geologic map by McConnell and Abrams (1984)	Locations of geologic areas	NA

Table 2. Sources of information and procedures used to estimate septic system locations.

[NA, not applicable]

County	City	Type of information
Carroll	NA	Provided a list of address for water customers and a list of sewer customers. Determined the difference between the two and georeferenced the addresses. Using a parcel dataset and the number of bathrooms assigned to each parcel we generated an improved parcel dataset. Joined the georeferenced water only customer locations to the nearest improved parcel and attributed those as septic parcels.
Clayton	NA	Provided a table of improved parcels and addresses of sewered customers. The parcelid from the table was linked to the spatial dataset of parcels in Paulding County. The improved parcels that were remaining we attributed as septic.
Cobb	NA	Provided water only customers.
Cobb	Austell	Provided a table of septic tank locations. Georeferenced the addresses and created a point feature dataset.
Cobb	Marietta	Provided a spatial dataset of parcels that were not on sewer. Those were considered septic parcels.
Cowetta	NA	Provided address of sewered addresses, improved parcel dataset. Took the remaining improved parcels and attributed as septic.
DeKalb	NA	Provided Street address of septic system.
Douglas	NA	Provided Street address of septic system.
Fayette	NA	Provided a table of improved parcels and addresses of sewered customers. The parcelid from the table was linked to the spatial dataset of parcels in Paulding County. The improved parcels that were remaining we attributed as septic.
Fayette	Newnan	Provided sewer lines and water only billing addresses.
Forsyth	NA	Provided a feature dataset of water and sewer customers.
Fulton	NA	Provided feature dataset of septic system locations.
Hall	Gainesville	Provided metered parcels that were not sewered. Took the cell centroid of the parcel- attributed as septic.
Gwinnett	NA	Provided feature dataset of septic system locations.
Hall	NA	Provided parcel data and sewer lines. Those parcels >100 feet from the sewer line were attributed as septic.
Paulding	NA	Provided a table of improved parcels and addresses of sewered customers. The parcelid from the table was linked to the spatial dataset of parcels in Paulding County. The improved parcels that were remaining we attributed as septic.

To quantify base flow, 133 small watersheds (less than 5-mi^2 drainage area) with similar land use, soil, geologic, and topographic conditions were selected for evaluation. To ensure a large contrast in septic system density, study basins were subdivided into three categories:

- High density septic (HDS)—the upper 33 percent of sites in terms of septic system density, ranging from 179 to 903 septic systems/mi^2 (46 sites);
- Low density septic (LDS)—the lower 33 percent of sites in terms of septic system density, ranging from 0 to 37 septic systems/mi^2 (45 sites); and
- Middle range—the middle 33 percent of sites in terms of septic system density, ranging from 38 to 178 septic systems/mi^2 (43 sites).

This grouping is in contrast to the classification of Landers and Ankcorn (2008), who designated an arbitrary cutoff of less than 100 systems/mi^2 for LDS basins and greater than 200 systems/mi^2 for HDS basins.

In each basin, groundwater contribution to streamflow (base flow) was quantified using synoptic measurements from September 10 to 13, 2012, during drought conditions. Discharge was measured using volumetric methods at culvert outfalls or velocity-area methods in the channel as described in Rantz (1982). With each discharge measurement, field measurements of specific conductance, water temperature, dissolved oxygen, and pH of stream water were collected using a calibrated multiparameter water-quality meter (Wilde and others, 1998). Because many of the streamflow measurements were made during extremely low-flow conditions, the margin of error is increased, with many measurements having errors greater than 10 percent. Measurement accuracy is listed in appendix 1.

Streamflow and field water-quality properties were compared between HDS and LDS basins. Because of the large size of the study area and associated variations in geologic setting, topography, land use, impervious area, elevation and slope, soil properties, and population, data collected in September 2012 were evaluated using a number of groupings. These groupings were developed in an attempt to reduce or eliminate other basin characteristics that might affect base flow (fig. 2). The four groupings are (1) all sites, (2) septic density range within a 45-meter stream-buffer area, (3) four geographic subareas, and (4) three geologic areas.

Streamflow data from HDS and LDS basins were compared using a variety of statistical approaches:

- Scatterplot and boxplot to summarize streamflow data and basin characteristics,
- Linear regression to determine the relation of streamflow to septic system density and basin characteristics, and
- Wilcoxon rank-sum testing to determine whether the median differences in streamflow and field water-quality properties between HDS and LDS watersheds are statistically significant.

Scatterplots and boxplots provided a visual means to assess the distribution of data among the various groupings. The multiple linear regression analysis was completed by culling zero streamflow values from the 133 sites measured in September 2012 (including HDS, LDS, and "middle range" sites), resulting in a dataset of values from 94 sites.

The Wilcoxon testing procedure involved comparing the ranks of two data populations and assessing whether the median of each group was statistically the same or different. The null hypothesis is that the median for HDS watersheds is higher than for LDS watersheds, and the alternative hypothesis is that the median for HDS watersheds is the same as the median for LDS watersheds. A computed p-value equal to or less than the significance level of 0.05, was used as a basis for acceptance of the null hypothesis.

To evaluate how base flow varies on a seasonal basis, daily data from two USGS streamgages were evaluated using the computer program HYSEP (Sloto and Crouse, 1996), which separates streamflow into base-flow and runoff components. HYSEP uses three methods to separate base flow: fixed interval, sliding interval, and local minimum. Each method uses a different algorithm to separate base flow systematically from runoff by connecting low points on the streamflow hydrograph. The duration of surface runoff is calculated based on the relation

$$N = A^{0.2}, \quad (1)$$

where

N is the number of days for runoff to cease, and
A is the basin drainage area (Linsley and others, 1982).

The local-minimum method was applied whereby streamflow is evaluated to determine whether each daily measurement is the lowest streamflow value for one-half the interval minus 1 day ($0.5(2N \times -1)$ days), with no overlap of intervals allowed (Sloto and Crouse, 1996). This procedure tends to reduce overestimation of base flow (Priest, 2004).

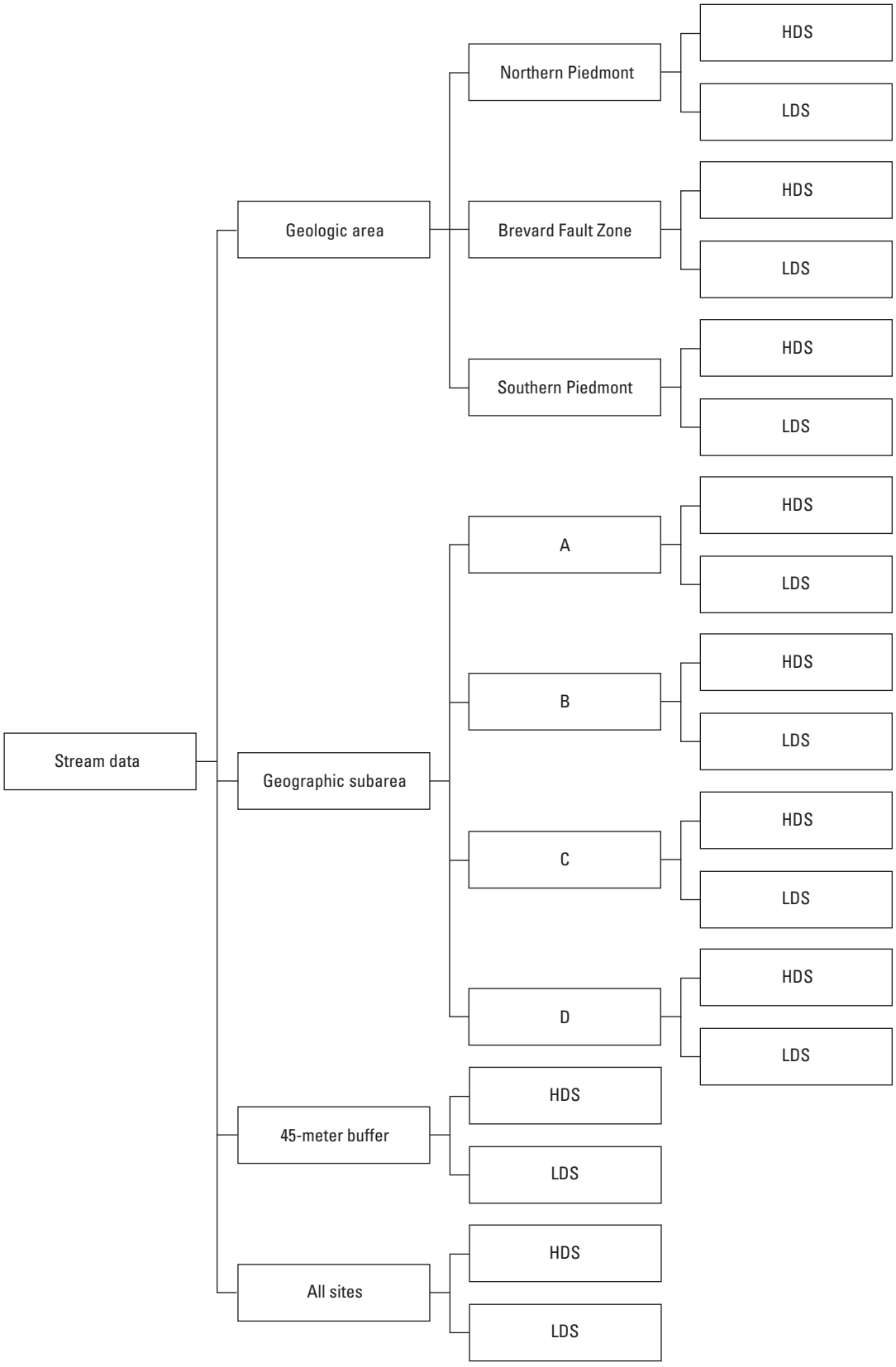


Figure 2. Flowchart showing procedure for evaluating basins with high and low density of septic systems. [HDS, high density septic; LDS, low density septic]

Description of Study Area

The ACF River Basin includes parts of Alabama, Florida, and Georgia (fig. 1). The study area covers 2,539 mi^2 in the upper part of the ACF River Basin in Georgia. All or parts of 12 counties that include and surround Metropolitan Atlanta in the 28-county Metropolitan Atlanta area are within the study area (U.S. Department of Housing and Urban Development and U.S. Census Bureau, 2005).

The study area is part of the 15-county Metropolitan North Georgia Water Planning District established by the Georgia General Assembly in 2001 to facilitate "development of comprehensive regional water resources plans that protect water quality and water supply in and downstream of the region, protect recreational values of the waters in and downstream of the region and minimize potential adverse impacts of development on waters in and downstream of the region" (Metropolitan North Georgia Water Planning District, 2013).

Physiography

The study area lies in the Piedmont physiographic province, an area characterized by rolling hills and isolated mountains (fig. 3). Elevation ranges from as high as 2,586 ft to the northeast in Hall County, Ga., upstream of Lake Sidney Lanier, to as low as 563 ft to the southwest in Coweta County, Ga. (fig. 4). Slope is less than 12 percent over most of the study area and greatest in tributary stream valleys adjacent to the Chattahoochee River, where values generally range between 24 and 36 percent (fig. 5).

Clark and Zisa (1976) designated four physiographic districts within the study area: Central Uplands, Gainesville Ridges, Winder Slope, and Greenville Slope (fig. 3). The northeast trending geologic structure of the Central Uplands and Gainesville Ridges Districts control the course of the Chattahoochee River and its tributaries. In the Gainesville Ridges District, faults and fractures produced a rectangular drainage pattern in the Chattahoochee River Basin. Within the Central Uplands and Gainesville Ridges Districts, elevations range from about 1,500 ft in the northeast and to about 1,000 ft in the southwest.

The Winder and Greenville Slope Districts are characterized by gently rolling topography. The Greenville Slope District underlies the headwaters of the Flint River, with elevations ranging from 800 to 1,000 ft along the southern extent of the study area. The district is characterized by dendritic drainage patterns in which broad, shallow valleys are separated by broad, rounded divides.

Geology

The Piedmont physiographic province is underlain by structurally deformed metamorphic and igneous rocks. Major, long-inactive fault zones divide the Piedmont into several belts that generally have a northeastern strike. One of the most prevalent of these features, the Brevard fault zone, is a primary control on the path of the Chattahoochee River (fig. 6).

McConnell and Abrams (1984) described the geology of the greater Atlanta area, delineating several major geologic formations and groups that are subdivided into rocks of the northern and southern Piedmont, separated by the Brevard fault zone. The northern and southern Piedmont consist of structurally deformed, metamorphosed volcanic and sedimentary rocks and are intruded by granite plutons in parts of the area (McConnell and Abrams, 1984). Major lithologies include granite gneiss, quartzite, schist, and amphibolite.

The Brevard fault is a zone of ductile shearing that is traceable from Alabama through Georgia and South Carolina into North Carolina. Rocks in the Brevard fault zone include mylonite, button schist, and gneiss that are sheared and fractured, forming parallel ridges that control much of the course of the Chattahoochee River.

Climate

The study area has a humid subtropical climate. Climatic conditions in the study area are reported as the climatic normals during the 1971–2000 period at three National Weather Service stations within the study area: Gainesville, in Hall County (09-3621, fig. 1*A*); Atlanta Airport, in Clayton County (09–0451, fig. 1*D*); and Newnan, in Coweta County (096335, fig. 1*D*). Mean daily temperatures peak during July, ranging from about 87 degrees Fahrenheit (°F) at Gainesville, to 89 °F at Atlanta Airport and Newnan. Minimum annual temperatures occur in January, ranging from 31.4 °F at Gainesville, to 33.5 °F at Atlanta Airport.

Average annual rainfall ranges from 50.22 inches at Atlanta Airport, to 54.72 inches at Gainesville. Seasonal rainfall is generally highest in January at Gainesville (5.91 inches), and in March at Atlanta Airport (5.15 inches) and Newnan (5.54 inches). Minimum rainfall occurs in June at Gainesville (3.87 inches) and in October at Atlanta Airport (3.34 inches) and Newnan (3.07 inches).

Average annual potential evapotranspiration (PET) was computed at Georgia Environmental Monitoring Network sites at Gainesville, Atlanta Airport, and Roopville (fig. 1*A*, *C*, *D*) using the Priestley-Taylor method (Stewart and Rouse, 1976). PET is a measure of the ability of the atmosphere to remove water through the processes of evaporation and transpiration, whereas actual evapotranspiration is the actual quantity of water removed by evaporation and transpiration.

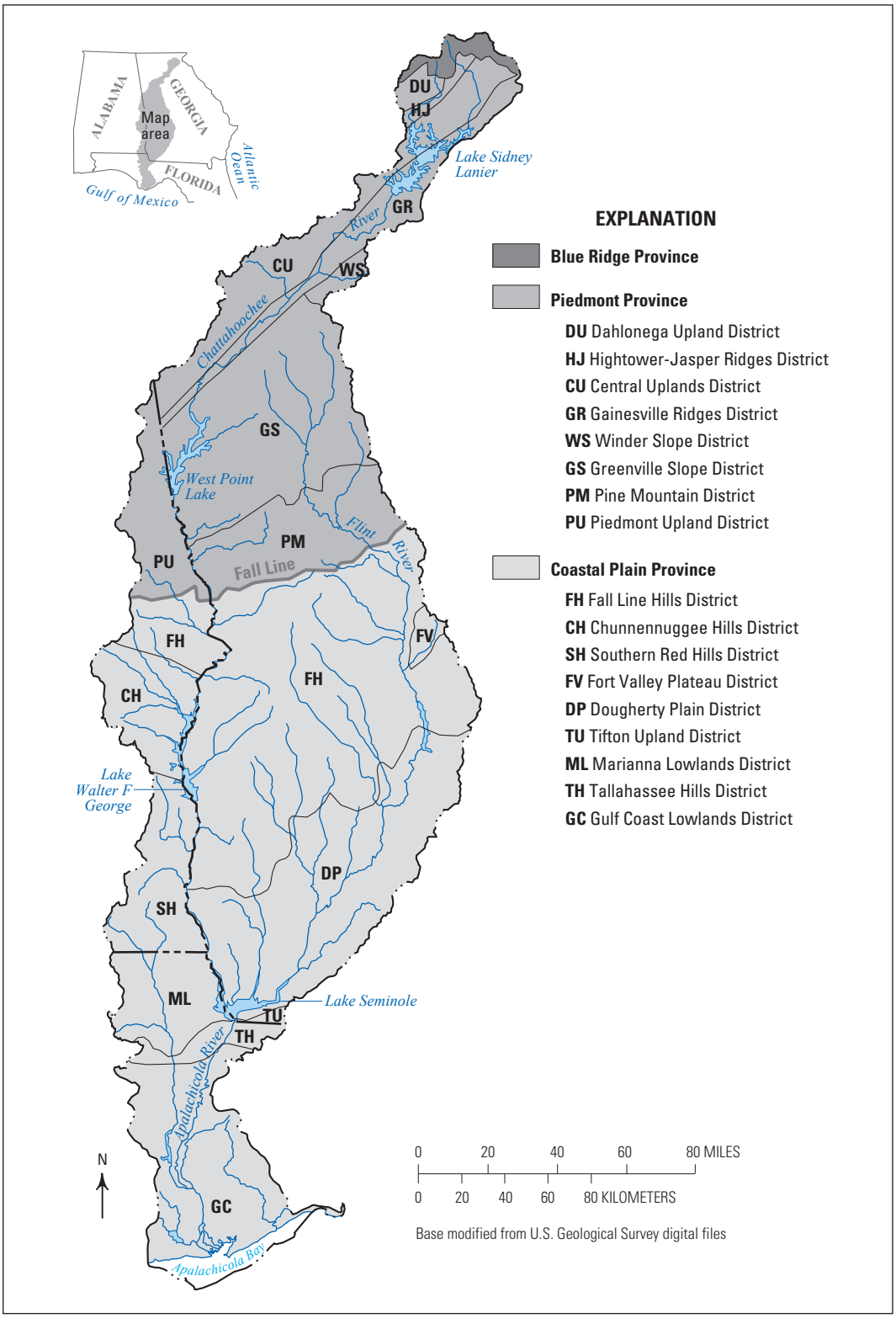


Figure 3. Physiographic provinces and districts of the Apalachicola–Chattahoochee–Flint River Basin (modified from Copeland, 1968; Clark and Zisa, 1976; Lietman and others, 1983).

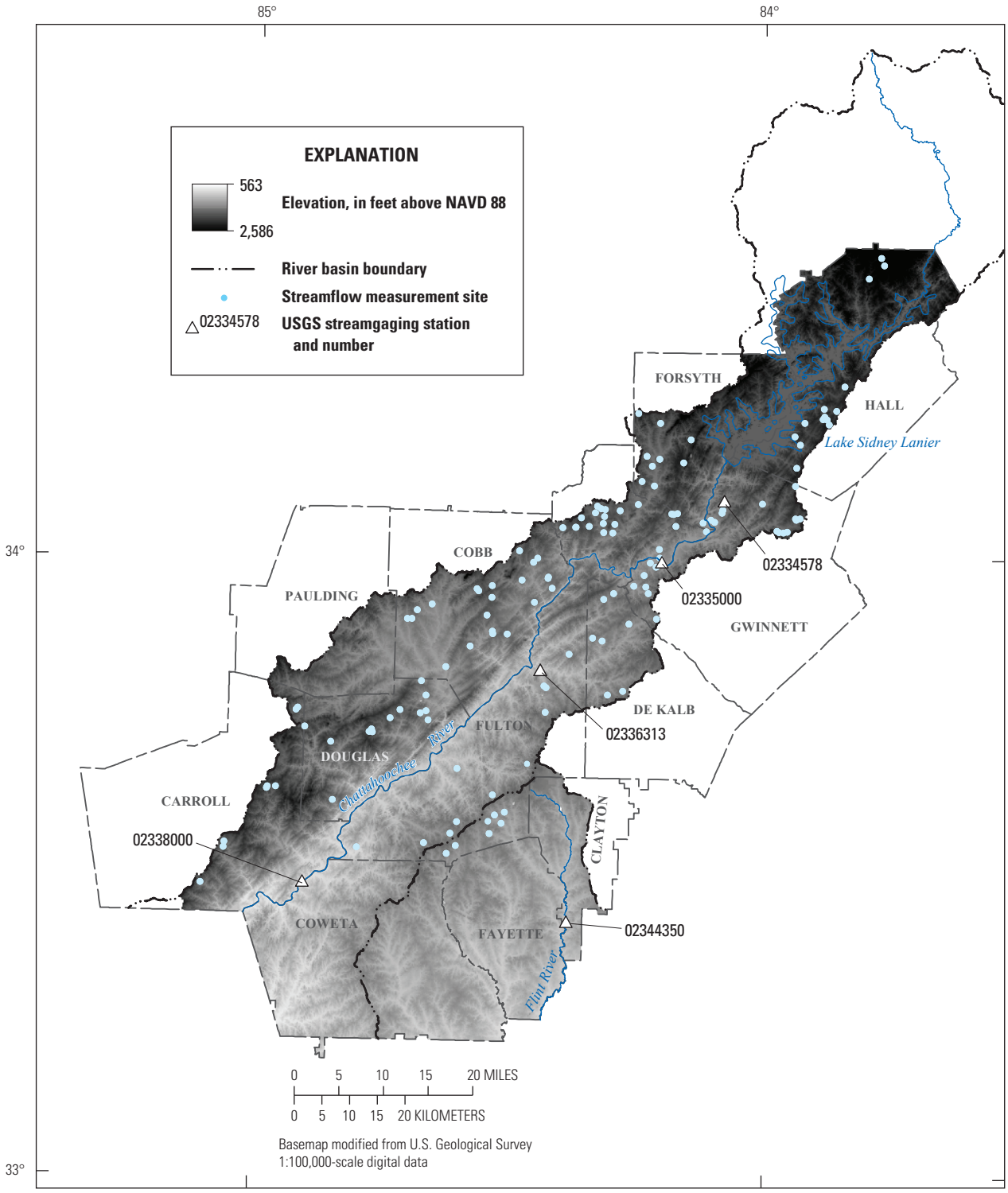


Figure 4. Elevation in the study area (data from U.S. Geological Survey, 2009).

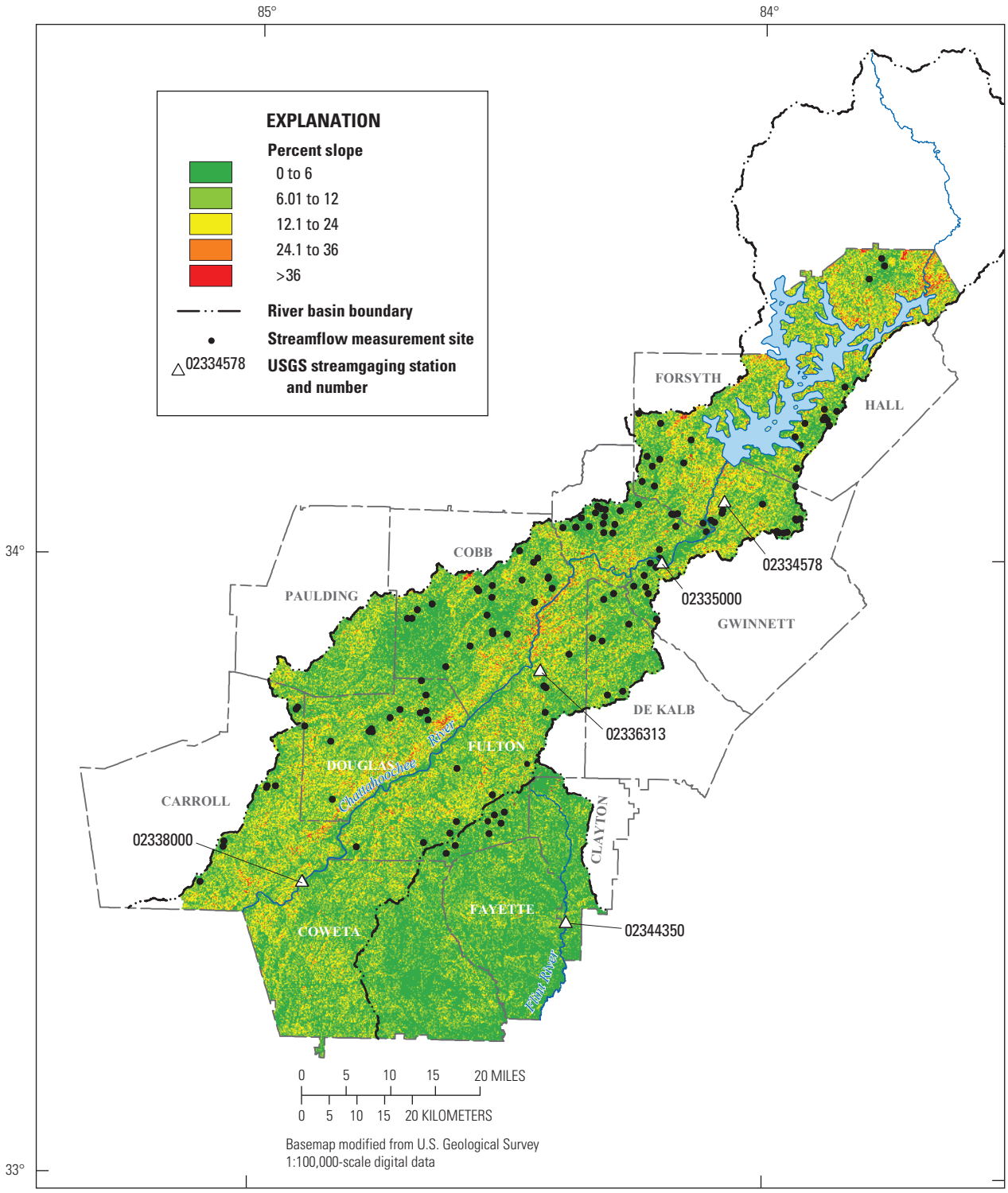


Figure 5. Percent slope in the study area (data from U.S. Geological Survey, 2009).

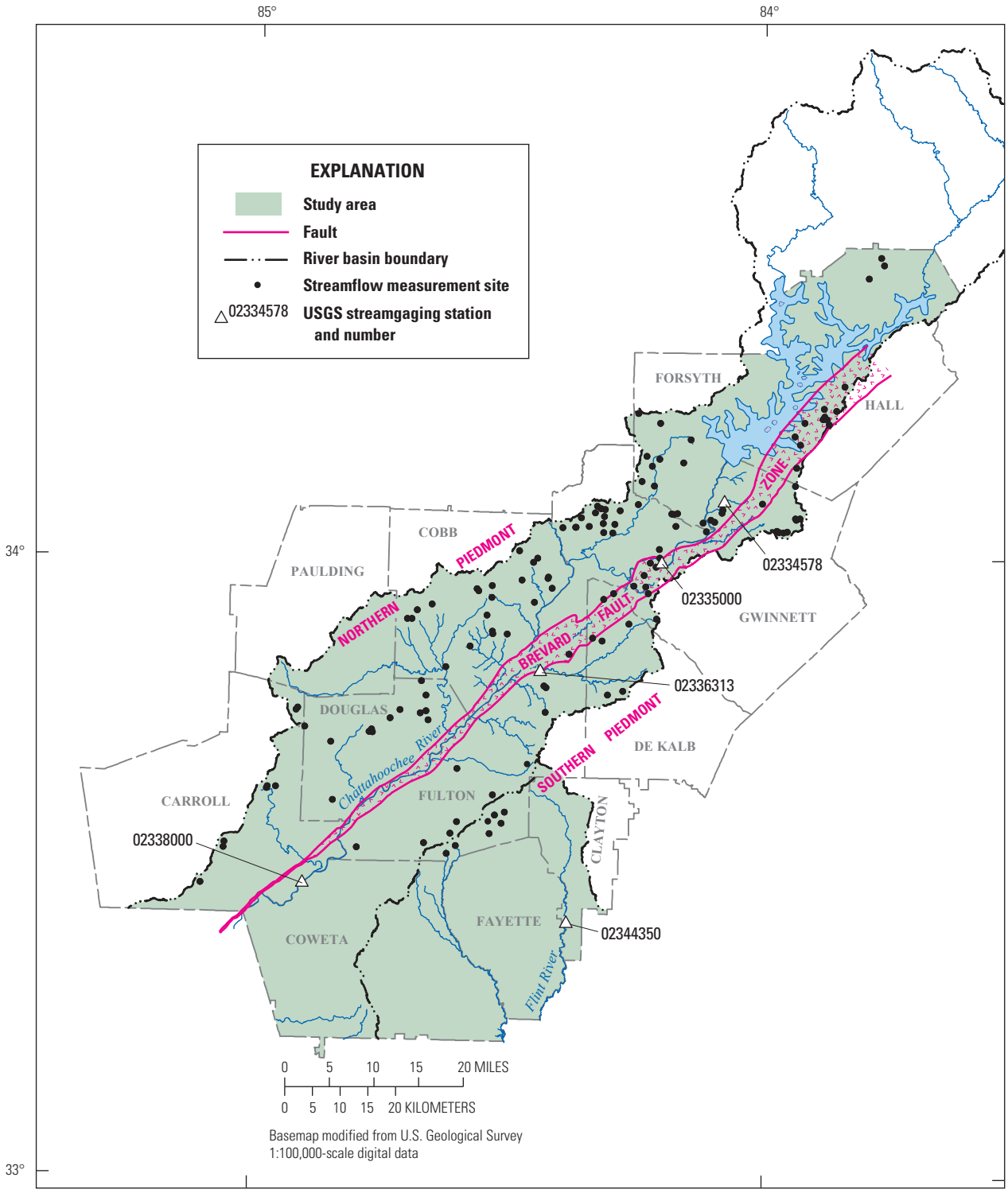


Figure 6. Geologic areas of northern Georgia (modified from McConnell and Abrams, 1984).

During 1971–2000, average annual PET was 18.98 inches at Gainesville, 19.73 inches at Atlanta Airport, and 19.07 inches at Roopville (Georgia Automated Environmental Monitoring Network, 2013). PET is greatest during the summer months, ranging from 5.97 inches at Roopville in June to 6.38 inches at Atlanta Airport in July. Minimum PET occurs during the winter months (December) ranging from 0.4 inch at Gainesville to 0.46 inch at Atlanta Airport.

A larger proportion of precipitation is available to recharge groundwater and provide base flow to streams during periods of maximum precipitation and minimum evapotranspiration. Conversely, minimum recharge and base flow to streams occurs during periods of maximum evapotranspiration and minimum precipitation. During extreme drought conditions, little water is available in the soil for loss to evapotranspiration, and PET is greater than the actual amount of evapotranspiration.

Surface-Water Hydrology

The study area lies within the upper part of the ACF River Basin in Georgia, and includes Lake Sidney Lanier in Hall County and headwaters of the Flint River in Clayton, Fayette, and Coweta Counties. The flow of the Chattahoochee River is regulated primarily by Buford Dam, which forms Lake Sidney Lanier, a 1,040-mi^2 impoundment operated by the U.S. Army Corps of Engineers. The Chattahoochee and Flint Rivers provide drinking water and serve as the primary repository for treated wastewater effluent in the study area. The two rivers merge downstream of Lake Seminole to form the Apalachicola River, which discharges into Apalachicola Bay in the Gulf of Mexico (fig. 3).

The flow and drainage area of the Chattahoochee River both increase downstream through the study area. Monthly mean flow at the Chattahoochee River at the Norcross gage (02335000, fig. 1*B*) during water years[1] 2011–12 ranged from 860 cubic feet per second (ft^3/s) on February 2012, to 3,495 ft^3/s on March 2011. Further downstream at the Whitesburg gage (02338000, fig. 1*D*), monthly mean flow was higher, ranging from 1,252 ft^3/s in September 2012, to 6,601 ft^3/s in March 2011. In the Flint River Basin, flow at gage 02344350 near Lovejoy (fig. 1*D*) during water years 2011–12 ranged from 10.6 ft^3/s in September 2012 to 360 ft^3/s in March 2011.

This study focuses on small basins within the study area that cover less than 5 mi^2 because lower streamflow should make it easier to quantify base-flow variations between the streams that result from the presence of septic systems than in larger basins with higher streamflow. The flow characteristics of such small watersheds are illustrated by the hydrographs of two streamgages: 02334578, Level Creek at Suwannee Dam Creek near Suwannee, Ga., and 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, Ga. (fig. 7). Streamflow at the two gages shows a flashy response to rainfall events, both peaking during storms and receding to base-flow conditions quickly.

Groundwater Hydrology

Groundwater in the Piedmont primarily resides in regolith and fractures in the bedrock (Cressler and others, 1983). Shallow groundwater flow and most groundwater storage occur in the regolith, which consists of soil, alluvium, and weathered bedrock or saprolite. Groundwater flow in the regolith generally occurs within surface-water basins, whereby water enters (recharges) in upland areas and discharges to streams. Water moving into bedrock is controlled, in part, by the depth and orientation of structural features, such as joints and fractures, and may not be restricted to surface-water basin boundaries. The geology of the study area is considerably more complex at a local scale than that shown on the regional map (fig. 6); therefore, geologic variations that might affect groundwater flow and base-flow yield may not be captured by the analysis presented in this report.

[1]A water year is defined as the 12-month period October 1, for any given year through September 30, of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2012 is called the "2012" water year.

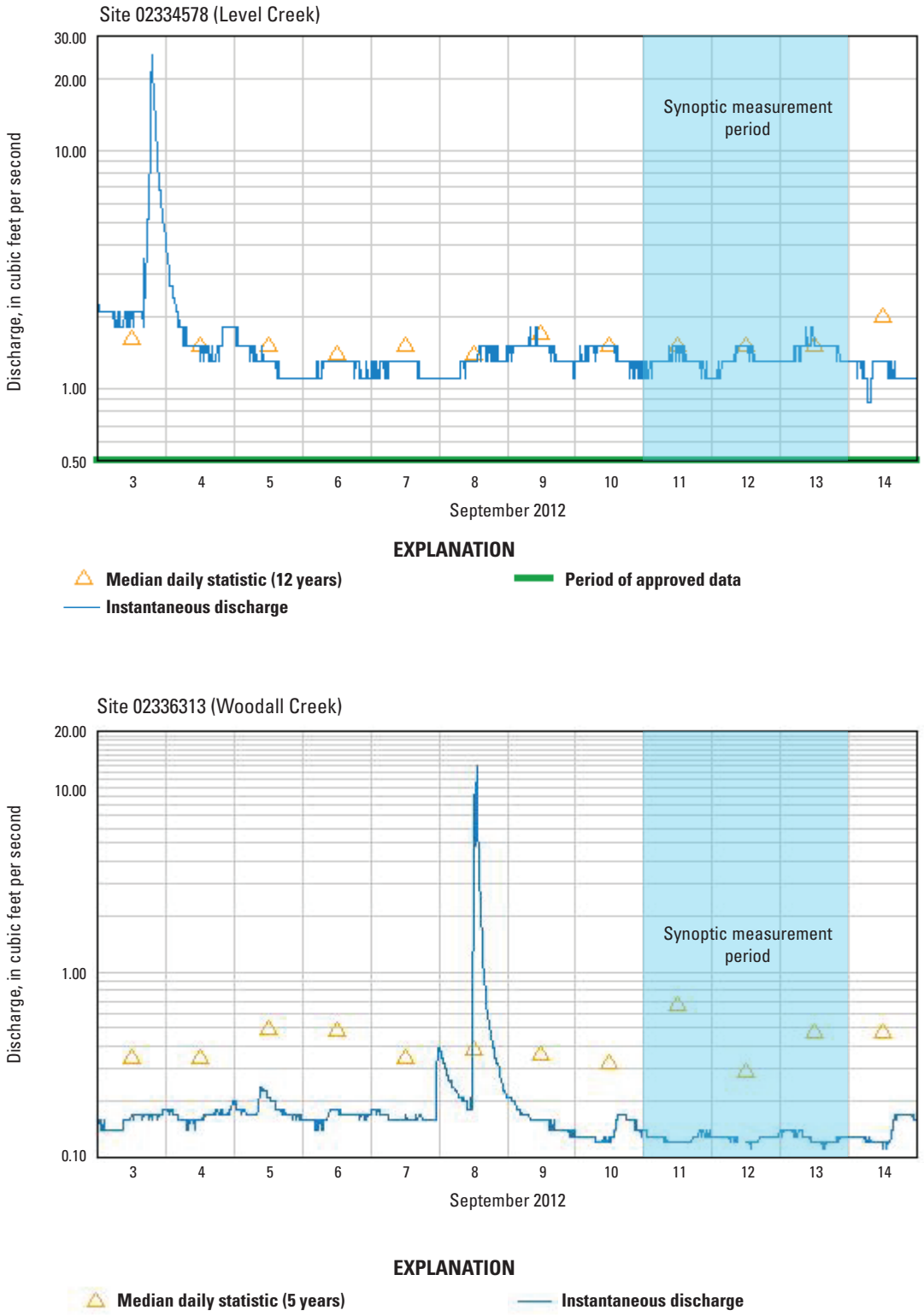


Figure 7. Stream discharge at USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA, September 3–14, 2012.

Land Use

The largest land use category in the study area is residential (37 percent), followed by forest (28 percent), and agricultural (12 percent). Other land use classifications include transportation and highways; industrial and commercial; water bodies, golf courses, parks, and cemeteries; and transitional (fig. 8). Impervious area was based on the 2006, 30-meter National Land Cover Database (NLCD) delineation (*http://www.mrlc.gov/nlcd06_data.php*, fig. 9). Impervious areas block infiltration of precipitation to the groundwater system and affect streamflow. Streams in basins having a large percentage of impervious area tend to be flashy, with higher flood peaks and lower base flow relative to other basins. In the study area, impervious area is greatest in the vicinity of the city of Atlanta in Fulton, Dekalb, Cobb, and Gwinnett Counties, and south of Atlanta in Clayton County.

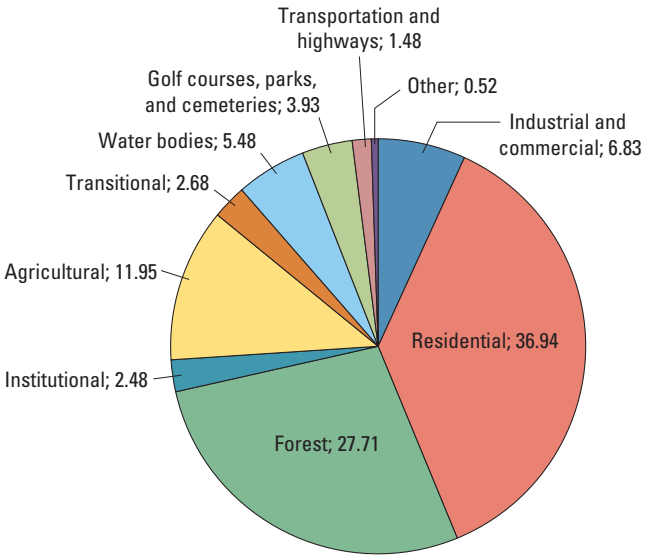


Figure 8. Land use in the study area, 2009 (data from Atlanta Regional Commission, 2009).

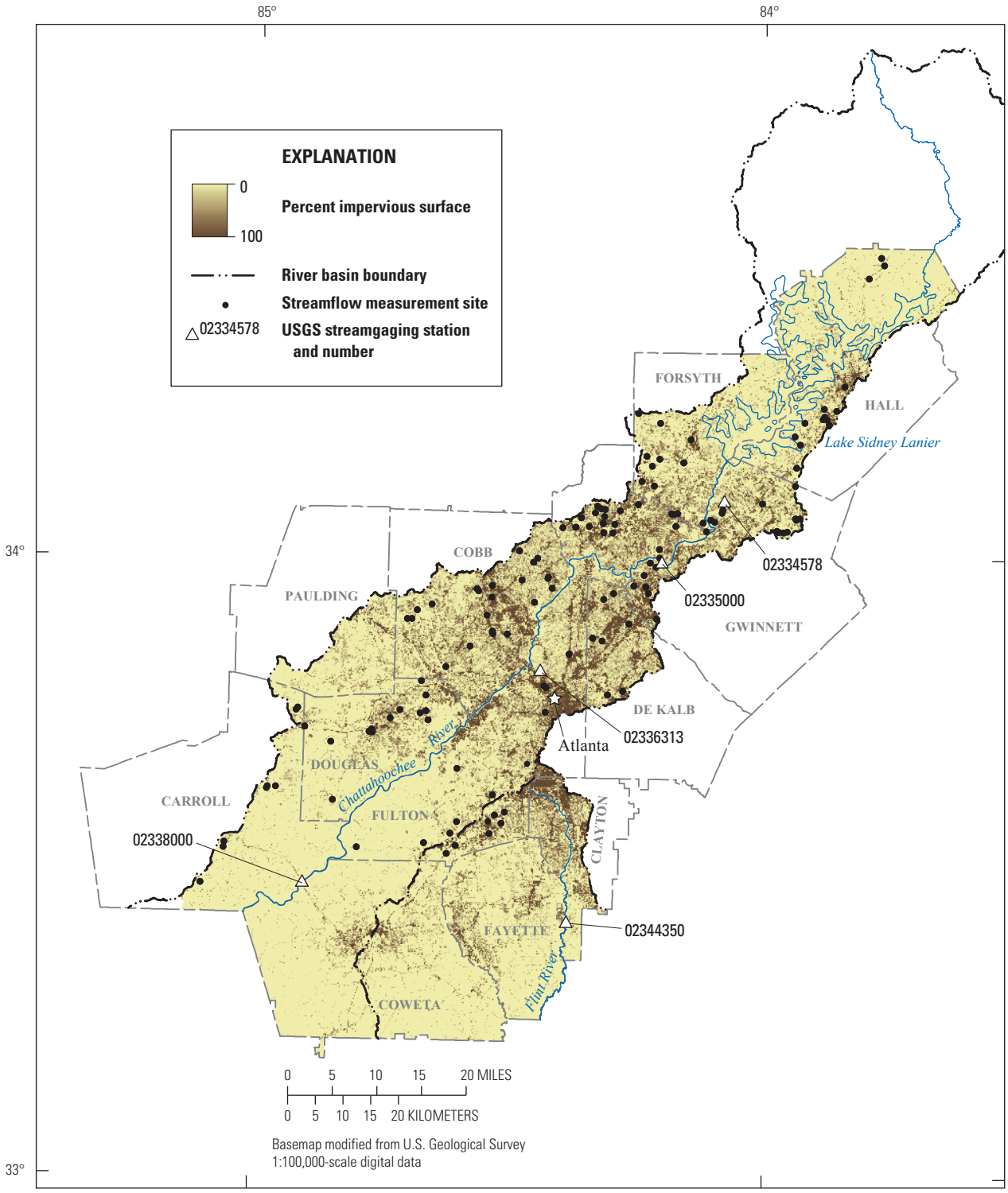


Figure 9. Percentage of impervious area in the study area, 2006 (see table 1 for data source).

Water Use

During 2010, water from the Chattahoochee and Flint Rivers supplied 456 million gallons per day (Mgal/d) in the 12-county study area, with 277 Mgal/d or 61 percent returned to streams as treated discharge from sewer systems (Steven J. Lawrence, U.S. Geological Survey, written commun., December 12, 2013). Of the remaining 39 percent, some of the water is discharged to streams outside of the basin or is (1) lost to evapotranspiration; (2) incorporated into a product or a crop; (3) consumed by humans or animals; or (4) is discharged into shallow groundwater from septic systems, leaky pipes, or land application of effluent discharge.

Streamwater withdrawal and discharge vary across the ACF River Basin (fig. 10). In general, water is withdrawn from the upper part of the basin and is moved downstream toward more populated areas in the middle part of the basin where it is subsequently discharged. In the upper Chattahoochee Basin, water withdrawal exceeds discharge, with respective amounts of 358 and 92 Mgal/d. Further downstream, in the middle Chattahoochee Basin, water discharge (178 Mgal/d) exceeds withdrawal (78 Mgal/d). In the upper Flint Basin, water withdrawal (21 Mgal/d) exceeds discharge (6.8 Mgal/d). Here, several water utilities use land-application systems to discharge sewage effluent, which may account for the smaller discharge in this area.

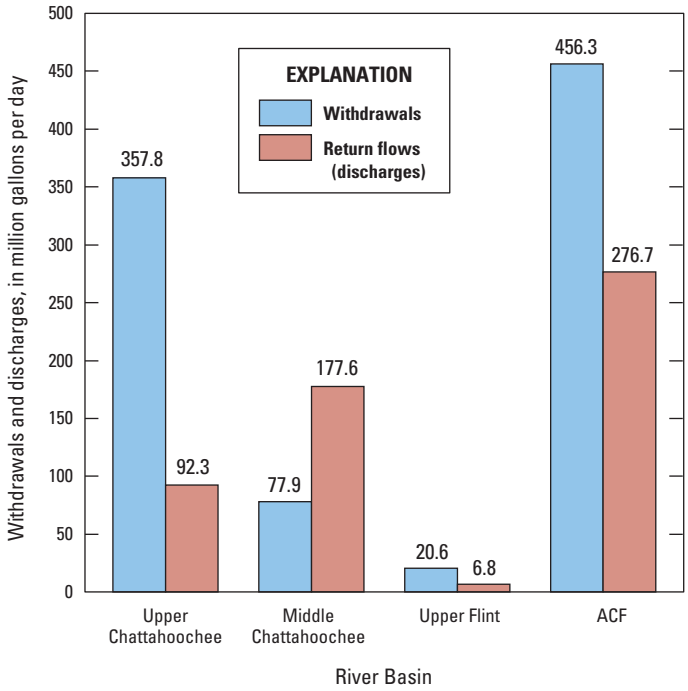


Figure 10. Average annual surface-water withdrawals and return flows within the upper and middle Chattahoochee, upper Flint, and Apalachicola–Chattahoochee–Flint (ACF) River Basins in the study area, 2010.

Influence of Septic Systems on Stream Base Flow

Septic systems—also referred to as septic tanks, individual sewage management systems, on-site sewage management systems, or on-site wastewater treatment systems—generally consist of a watertight septic tank and an effluent-disposal absorption field. The septic tank and soil surrounding the absorption field break down waste though biological, chemical, and physical processes. Most solid wastes are trapped in the septic tank, with liquid wastes flowing into an absorption field consisting of perforated drainage pipes that distribute the septic tank effluent in shallow trenches filled with a porous medium (U.S. Environmental Protection Agency, 2002; Georgia Division of Public Health, 2007). Over time, solids accumulate in the septic tank, and if not properly cleaned and maintained, may clog the absorption field. Other causes of system failure include unsuitable soil and location, age, excessive water use, poor maintenance, and surface runoff (Metropolitan North Georgia Water Planning District, 2006).

Water from the absorption field infiltrates through the unsaturated zone and into the water table (fig. 11). According to Landers and Ankcorn (2008), a typical septic installation in Metropolitan Atlanta consists of a 1- to 4-ft-deep absorption-field trench, with a minimum distance of 2 ft above the maximum groundwater table or any impervious layer. The rate of infiltration into groundwater depends on the permeability of the soil beneath the absorption field, the depth of the water table, and the amount of wastewater entering the septic system. In addition, clogging in the septic tank and absorption field may diminish infiltration. In some instances, vegetation located over the absorption field may transpire water that otherwise would have infiltrated into groundwater.

Beneath the absorption field, the infiltrating water raises the local water table, increasing the hydraulic gradient from the absorption field to nearby streams. Once water enters the groundwater system, some is lost to evapotranspiration, with the remaining portion discharging to streams as base flow or moving into deeper parts of the groundwater system. The amount of evapotranspiration loss is mitigated by design manuals, which specify that absorption fields be located away from large vegetation with deep root structure (Georgia Division of Public Health, 2007). As groundwater flows away from the absorption field, the amount of evapotranspiration is controlled by the depth of the water table and the presence of high-water-demand plants with deep root structure.

Domestic water use can be classified into two principal categories: household use, such as for drinking water and food preparation, baths and showers, washing machines, toilets, and dishwashers; and outdoor use, principally for lawn or garden irrigation. Most household water passes through septic systems, whereas outdoor water is applied directly to the landscape. Because household use varies little during the

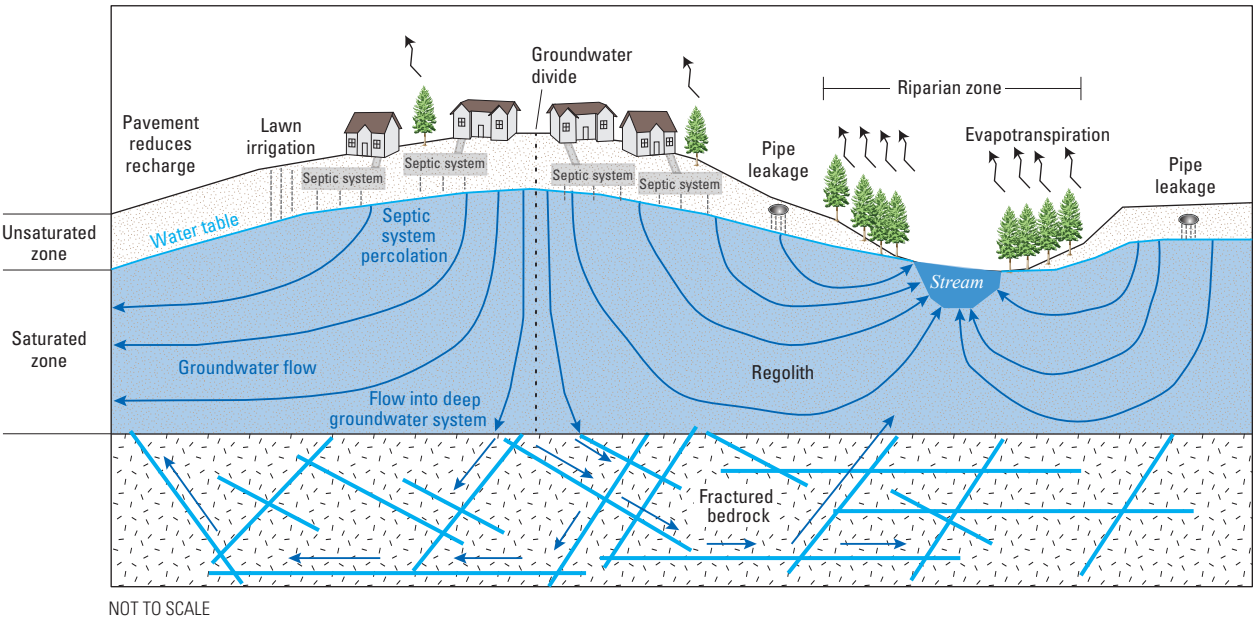


Figure 11. Conceptual diagram of groundwater flow in the vicinity of septic systems, groundwater divides, and streams during dry hydrologic conditions. Septic system includes absorption field. Pipe leakage includes water mains, sanitary sewers, and storm drains.

year, properly designed septic systems, installed at sufficient depths and away from vegetation with deep root systems, are believed to provide a constant source of water to the shallow groundwater system. Outdoor use can be substantially higher during the summer irrigation period. A portion of this irrigation water may recharge the shallow groundwater system and discharge into streams.

The amount of groundwater reaching streams is dependent on how much is intercepted by plants or infiltrates to deeper parts of the groundwater system. Evapotranspiration varies seasonally and is greatest during the growing season. Thus, it is likely that greater amounts of groundwater discharge into streams during the nongrowing season.

In addition to septic systems, leaking water mains and sanitary sewers, storm water drains, and runoff diversion and storage structures can contribute to enhanced groundwater recharge. A groundwater modeling and end-member mixing study of water chemistry by Yang and others (1999) found that water-main and sewer leakage contributed over 70 percent of the recharge in an urban setting in Nottingham, England.

Distribution of Septic Systems

Data from local utilities were compiled to develop a GIS database of septic system locations. In the study area, more than 241,733 septic systems were identified and the density per square mile within each drainage basin was determined (fig. 12). The highest density of septic systems is in the southern part of Forsyth County where the density exceeds 350 systems/mi^2. Other areas having HDS include southeastern Paulding, central Douglas, and south-central Hall Counties, where density exceeds 250 systems/mi^2.

The Metropolitan North Georgia Water Planning District (2006) completed a survey of septic systems that indicated

- 26 percent of housing units in the district are served by septic systems;
- 40 percent of septic systems are more than 20 years old;
- the minimum permitted lot size for septic systems ranges, by county, from 0.46 to 1.6 acres; and that
- septic systems generally are located outside the extent of sewer lines; however, this is not always the case.

These findings indicate a large number of homes in the area are served by septic systems, with a potential large effect on base flow. Because a relatively large number of systems are more than 20 years old, there is increased potential for clogging and system failure, which might change the amount of water reaching the groundwater system.

Site Characteristics of Study Area Basins

Land use characteristics were categorized according to the HDS/LDS classification and are listed in appendix 2 and summarized in figure 13. The largest percentage of land use for both HDS and LDS basins was medium-density residential, which accounted for 45 and 32 percent, respectively of the total land use. The percentage distribution for forest, transitional, and other land-use classifications was similar in HDS and LDS basins. LDS basins had large percentages of land use for commercial and industrial, transportation, multifamily residential, and institutional classes, whereas HDS basins had larger percentages of agricultural and low- and medium-density residential classes. This breakdown is generally consistent with the following expected distribution of septic systems:

- More septic systems would be expected in residential areas, as indicated by greater low- and medium-density residential classifications, and in rural areas, as indicated by greater agricultural classification.
- Fewer septic systems would be expected in more urban settings that are typically covered by sewer lines, as indicated by greater commercial and industrial, multifamily residential, and institutional classifications.

In addition to land use classification, drainage area, impervious area, and topographic and soil characteristics were compiled and summarized according to the HDS/LDS classification (fig. 14). HDS basins had a slightly higher median water-table depth, bedrock depth, and average elevation than LDS basins. LDS basins had a higher median population density and impervious area than HDS basins.

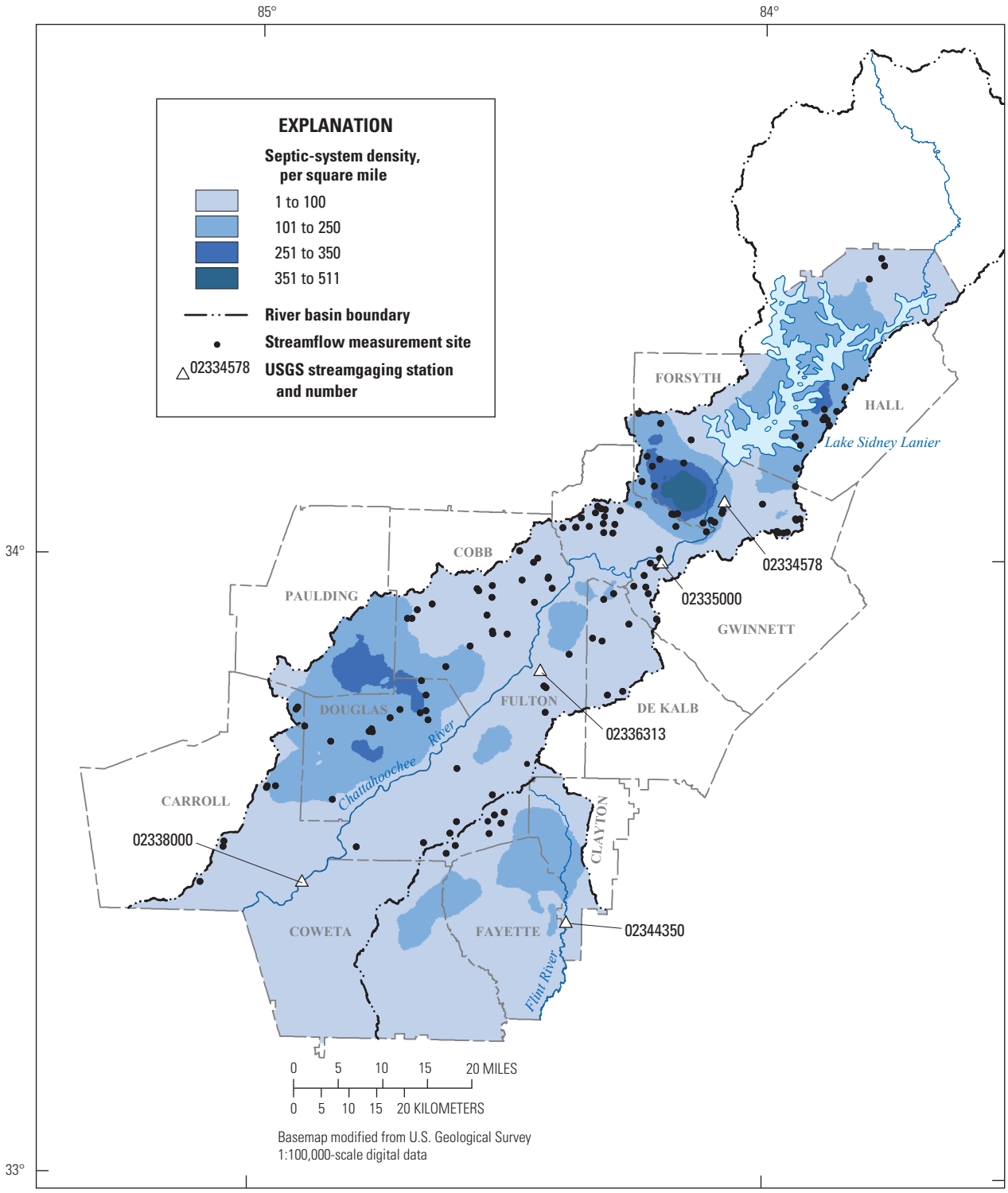


Figure 12. Septic system density in study area, 2012 (see table 2 for data sources).

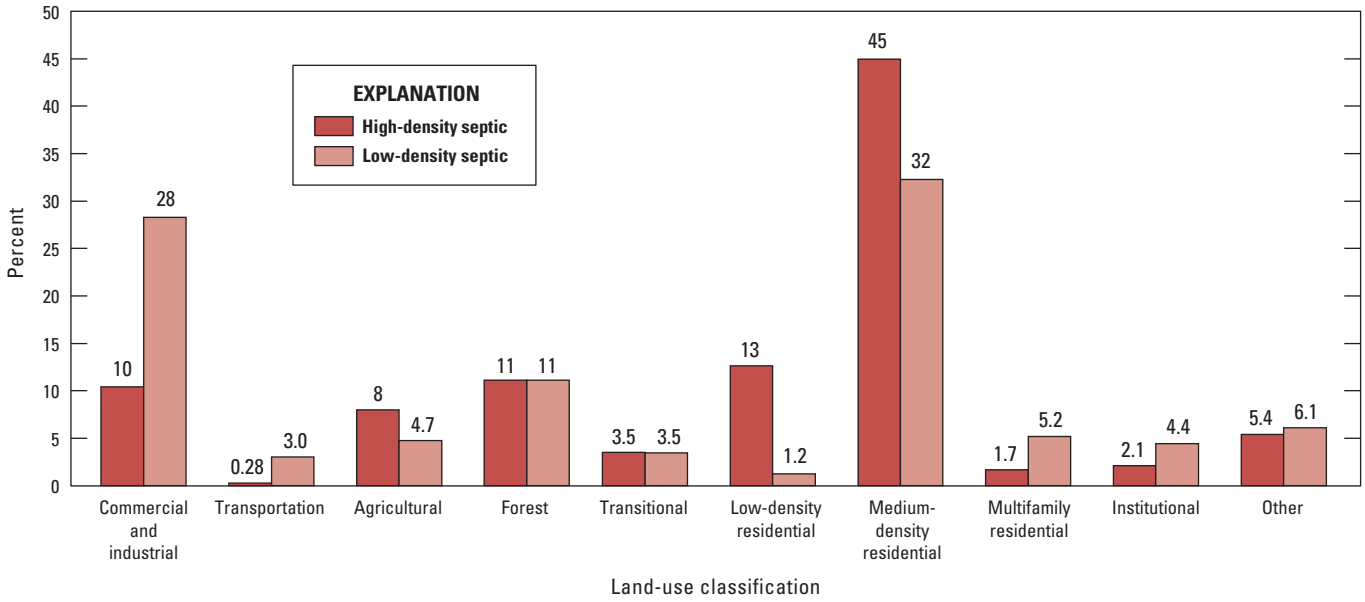


Figure 13. Land-use characteristics for basins with high and low density of septic systems in the study area, 2009 (data from Atlanta Regional Commission, 2009).

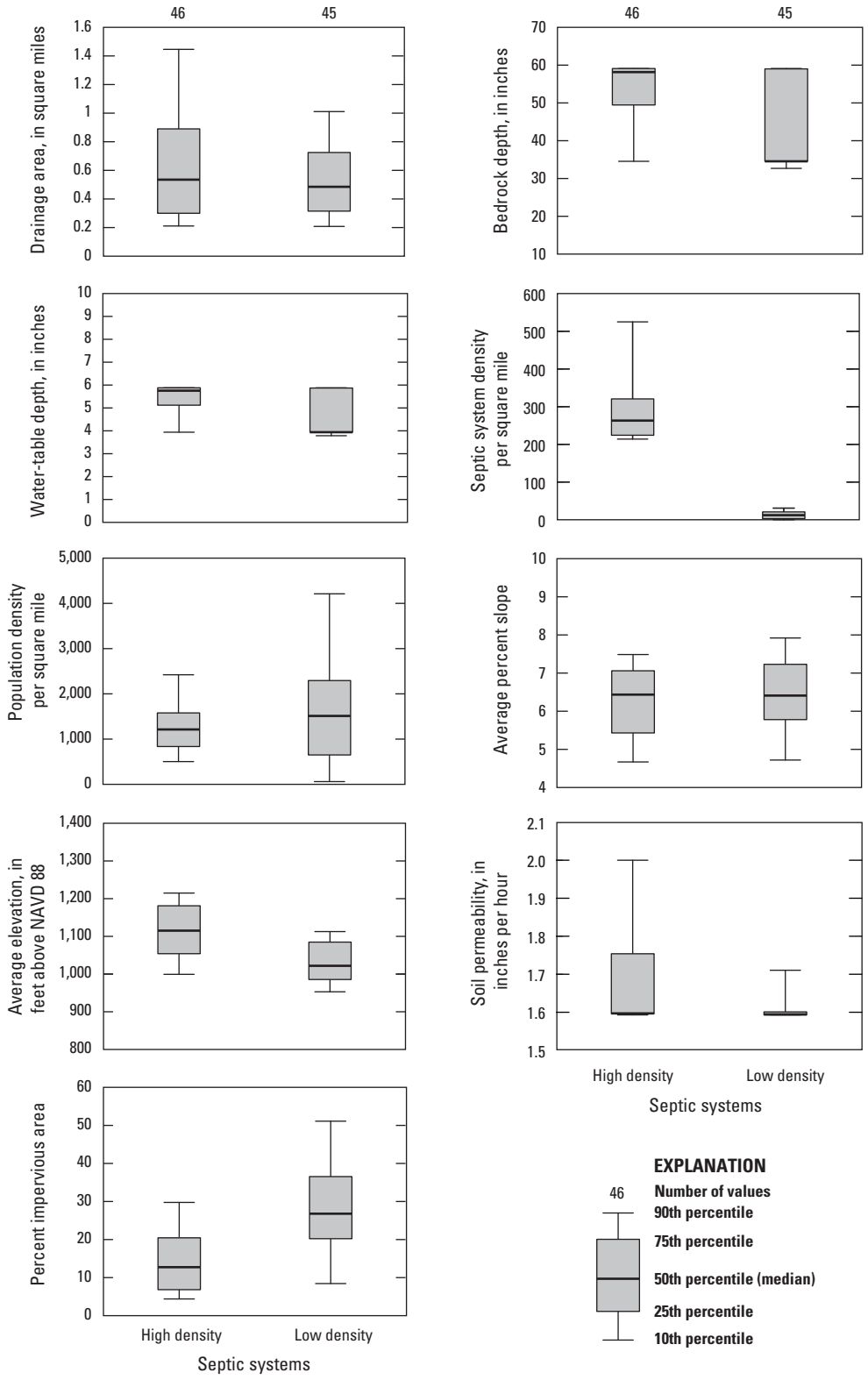


Figure 14. Boxplots showing drainage area, impervious area, and topographic and soil characteristics of basins with high and low density of septic systems in the study area.

Base Flow in September 2012

Groundwater contribution to streamflow (base flow) was quantified using synoptic measurements at 133 ungaged sites and daily streamflow data from two gaged sites during drought conditions in September 10–13, 2012 (appendix 1). Of the 135 sites, 46 were in HDS basins, 45 in LDS basins, and 44 were in the middle range. Discharge, normalized for drainage area (base-flow yield) and expressed in cubic feet per second per square mile, ranged from 0 to 2.07; 39 of the sites were dry. Of the 39 dry sites, 17 were in HDS basins, 15 in LDS basins, and 7 in middle range basins. Field water-quality measurements were collected at 94 of the 133 ungaged sites, including water temperature, specific conductance, dissolved oxygen, and pH. The remaining 39 sites were dry and no water-quality measurement was possible. Water temperature ranged from 17.25 to 24.98 °C; specific conductance ranged from 13 to 675 microsiemens per centimeter (µS/cm) at 25 degrees Celsius, dissolved oxygen ranged from 0.5 to 9.99 milligrams per liter (mg/L), and pH ranged from 5.57 to 9.34. Figure 15 shows base-flow yield and selected water-quality properties for HDS and LDS sites to illustrate variations between the groups; data for middle range sites are not included but are listed in appendix 1.

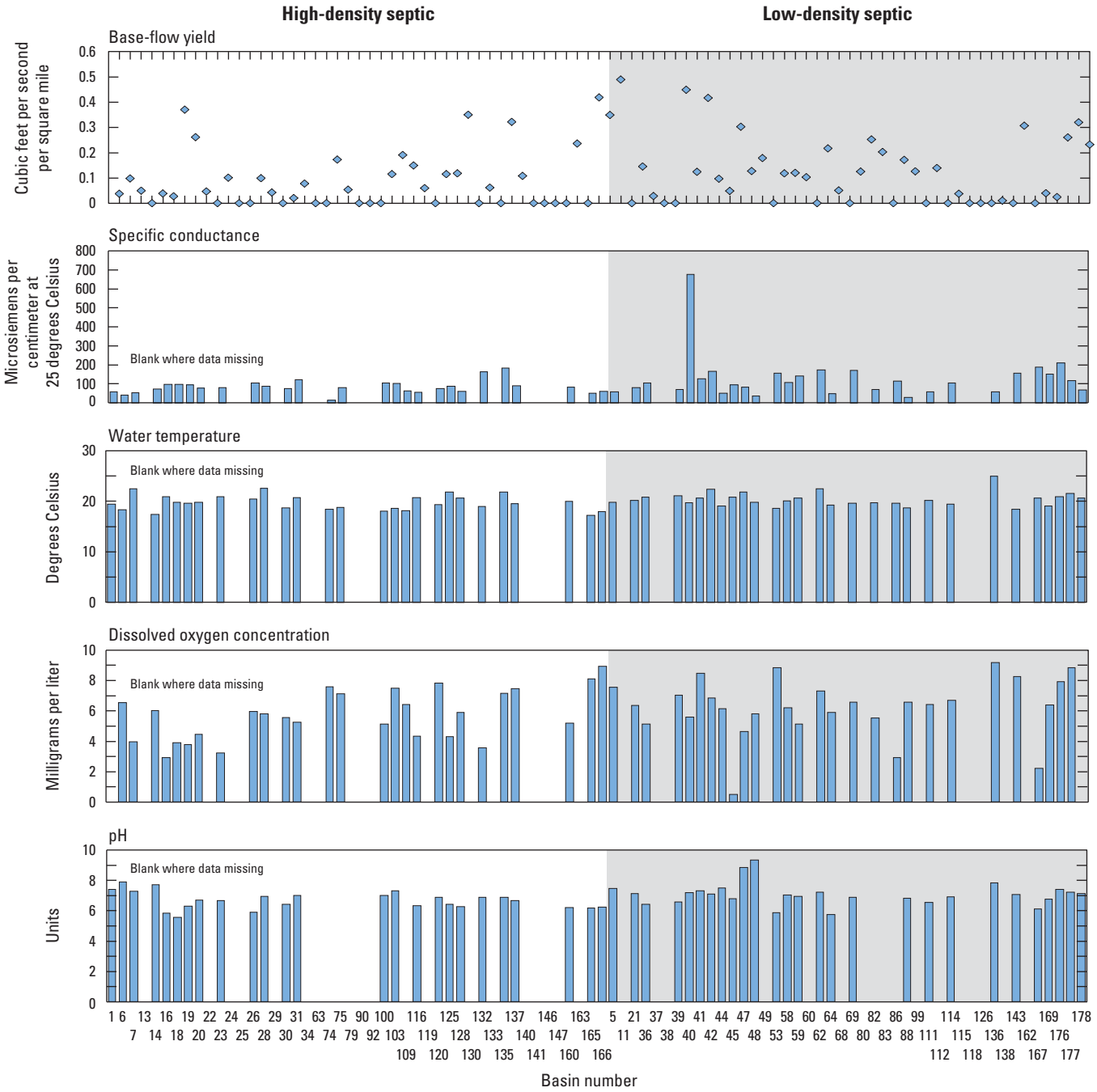


Figure 15. Base-flow yield and selected water-quality parameters in the study area, September 10–13, 2012.

During the synoptic event, moderate to severe drought conditions existed in the northeastern part of the study area and extreme to exceptional drought conditions existed in the southwestern part (fig. 16). This variation creates differences in soil moisture and the amount of water available for evapotranspiration, as well as the amount of groundwater available for base flow to streams. During the synoptic event reported by Landers and Ankcorn (2008) in October 2007, all basins in their considerably smaller study area were experiencing more uniform conditions, namely severe drought.

Graphs showing daily precipitation and PET at Georgia Environmental Monitoring Network sites at Gainesville, Atlanta Airport, and Roopville for the week before and during the synoptic event (September 2–13, 2012) were plotted to provide information about climatic conditions throughout the study area (fig. 17). During the prior week of September 2–9, isolated rainfall events occurred at the three sites: September 3 at Gainesville and Roopville, September 6 at Roopville, and September 8 at all three sites. Average PET during September 2–14 was –0.12 to –0.14 inch at the three sites. Net precipitation, the difference between rainfall and PET, was negative throughout the 2-week period, with the exception of the isolated rainfall events. Thus, streamflow measurements were made during a period of drought and high PET, with little water available for base flow to streams.

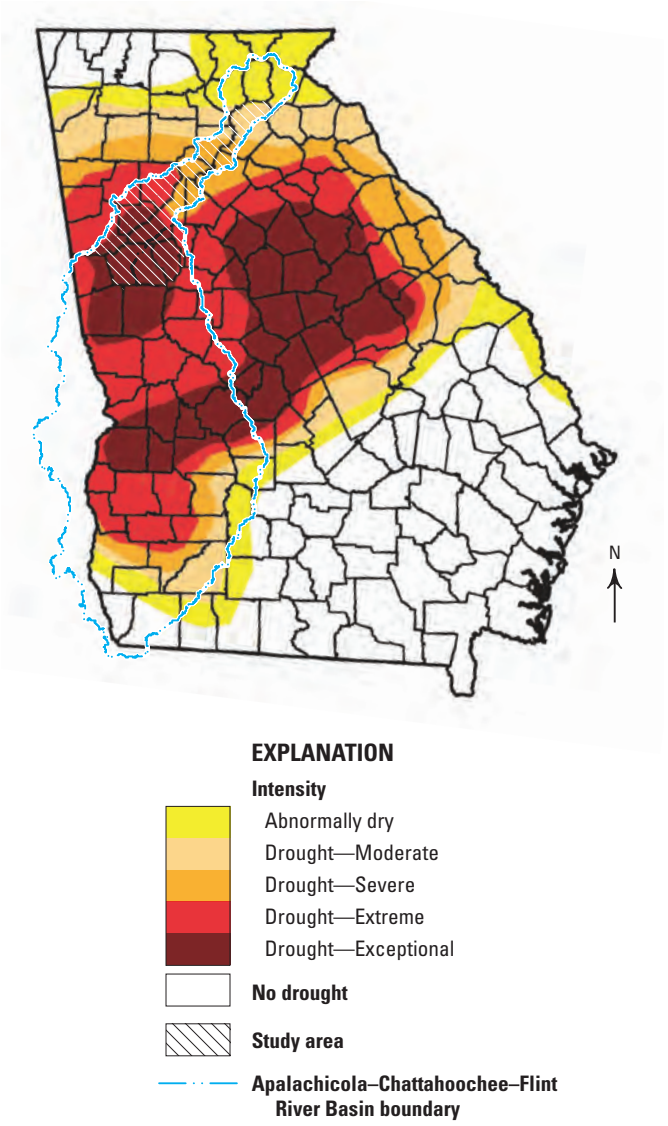


Figure 16. Intensity of drought in Georgia, September 11, 2012 (modified from Drought Mitigation Center, 2013).

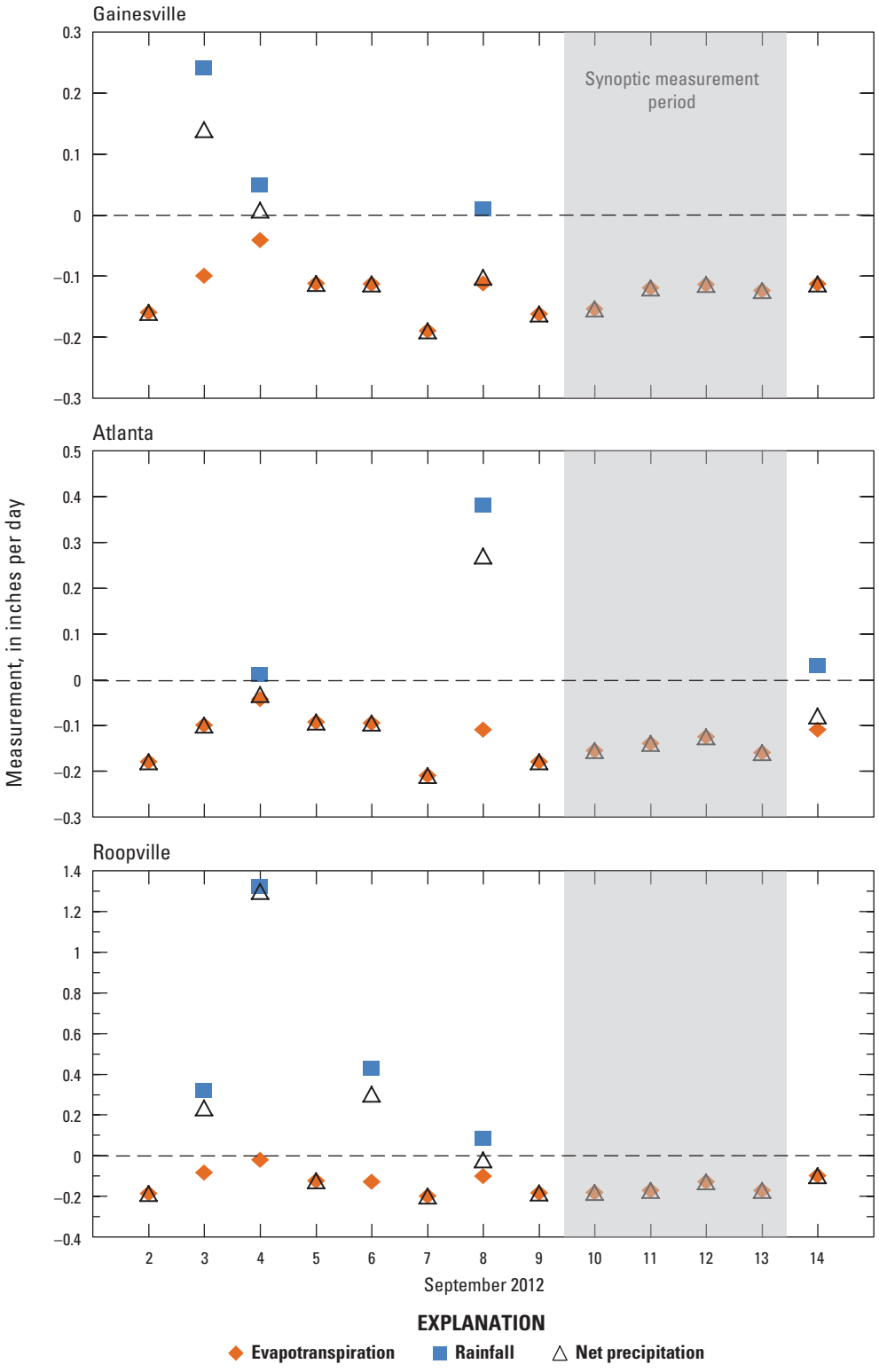


Figure 17. Daily total rainfall, potential evapotranspiration, and net precipitation at Georgia Environmental Monitoring Network sites at Gainesville, Atlanta, and Roopville, September 2–14, 2012. Net precipitation is the difference between precipitation and potential evapotranspiration.

Influence of Septic System Density

Data were subdivided on the basis of HDS/LDS classification to assess the influence of septic systems on stream base flow (figs. 18 and 19, table 3). The median base-flow yield was 0.04 $(ft^3/s)/mi^2$ for HDS sites, ranging from 0 to 0.42 $(ft^3/s)/mi^2$, and 0.10 $(ft^3/s)/mi^2$ for LDS sites, ranging from 0 to 0.49 $(ft^3/s)/mi^2$. A Wilcoxon rank-sum test indicated the median base-flow yield was statistically the same, with a p-value of 0.345 (table 3).

Water-quality data were also compared on the basis of septic system density. The median of HDS and LDS samples for dissolved oxygen, stream temperature, and specific conductance were statistically the same, as indicated by results of a Wilcoxon rank-sum test (table 3). The median pH was 6.66 for HDS sites and 7.06 for LDS sites, and this difference was considered statistically significant based on a Wilcoxon rank-sum test (p-value 0.013).

Median specific conductance was 81 µS/cm for HDS sites, ranging from 13 to 183 µS/cm, and 105 µS/cm for LDS sites, ranging from 29 to 675 µS/cm (table 3). A Wilcoxon rank-sum test of the median values of specific conductance from HDS and LDS sites also indicated that differences were insignificant (p-value 0.082).

Measurements collected in September 2012 did not indicate any statistically significant relation between septic system density and base-flow yield (fig. 20). Both data groups showed a poor best-fit line, with r^2 values of 0.018 for HDS sites and 0.049 for LDS sites.

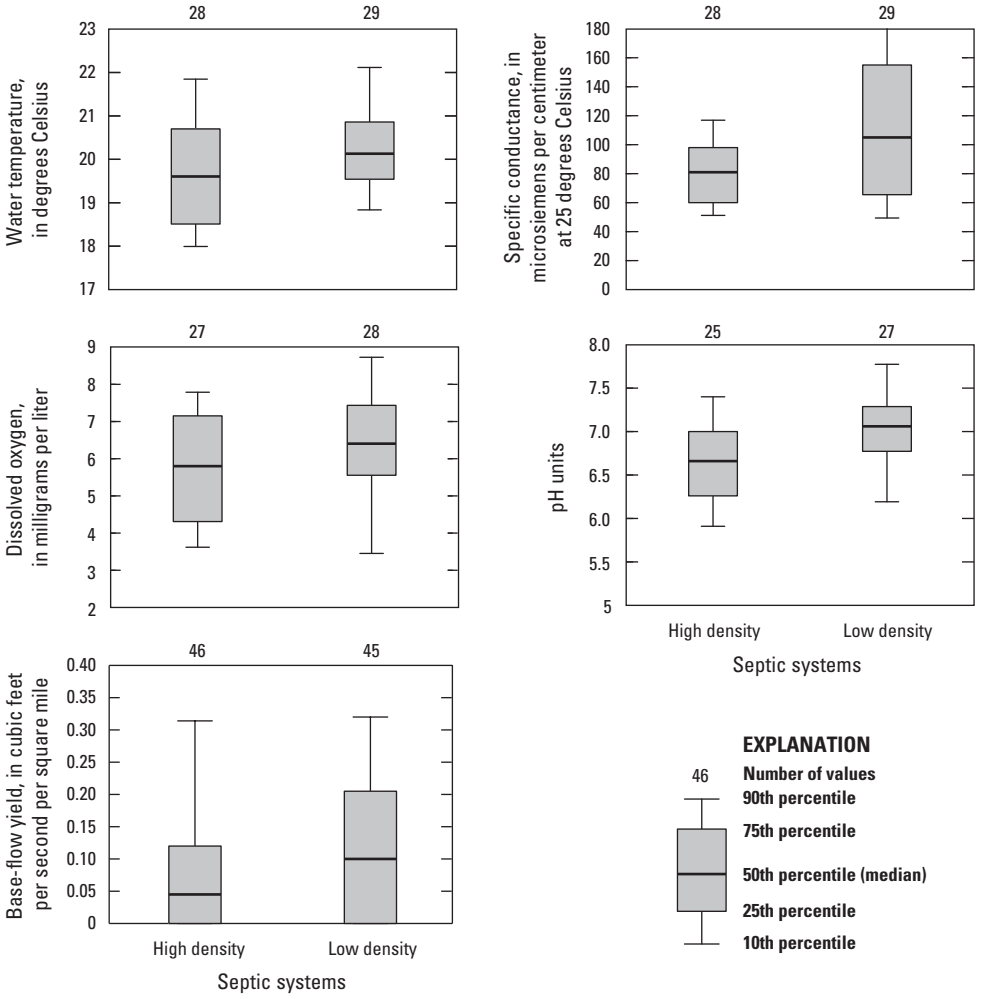


Figure 18. Boxplots showing base-flow yield and selected water-quality parameters of basins with high and low density of septic systems in the study area, September 10–13, 2012.

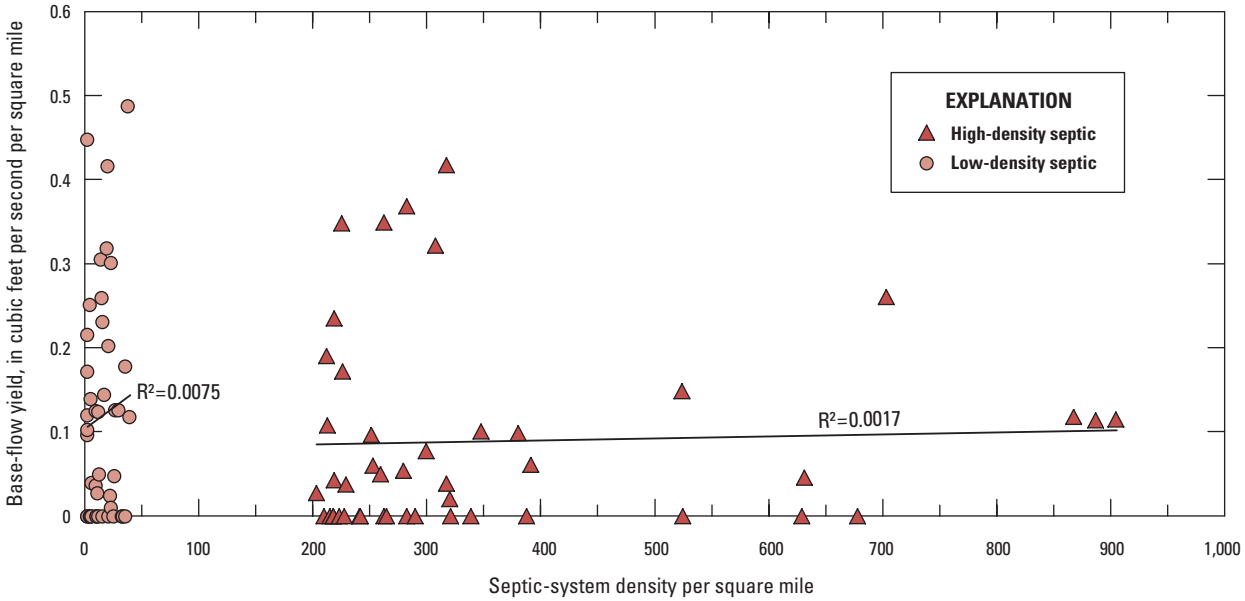


Figure 19. Base-flow yield and septic system density for basins with high and low density of septic systems in the study area, September 10–13, 2012.

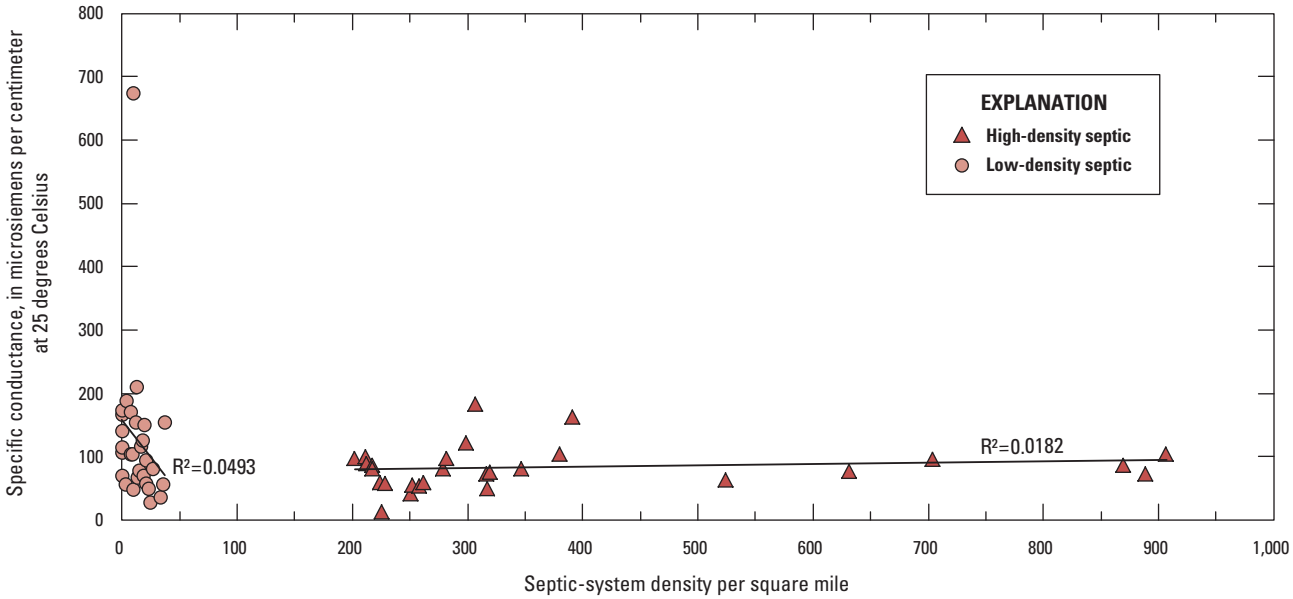


Figure 20. Specific conductance and septic system density for basins with high and low density of septic systems in the study area, September 10–13, 2012.

Table 3. Statistical summary of base-flow yield, and selected water-quality parameters, September 10–13, 2012.

[HDS, high density septic; LDS, low density septic]

Field measurement	All sites				HDS				LDS				Wilcoxon rank-sum test to compare HDS and LDS median	
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count	p-value	Remarks
Base-flow yield, in cubic feet per second per square mile	0.00	0.06	2.07	133	0.00	0.04	0.42	46	0.00	0.10	0.49	44	0.345	No difference in median
Water temperature, in degrees Celsius	17.25	19.70	24.98	91	17.25	19.61	22.54	28	18.40	20.13	24.98	29	0.102	No difference in median
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	13	76	675	91	13	81	183	28	29	105	675	29	0.082	No difference in median
Dissolved oxygen, in milligrams per liter	0.50	6.36	9.99	89	2.93	5.80	8.93	27	0.50	6.41	9.18	28	0.138	No difference in median
pH, in units	5.57	6.90	9.34	77	5.57	6.66	7.91	25	5.75	7.06	9.34	27	0.013	LDS median pH statistically higher than HDS median pH

Influence of Basin Characteristics

Additional evaluations were completed to determine if there were other factors besides septic system density that may be influencing base flow in the HDS and LDS basins. A multiple linear regression was completed by culling zero streamflow values from the 133 ungaged sites measured in September 2012 (including HDS, LDS, and middle range sites) yielding a dataset of 94 sites. Base-flow yield was related to soil permeability, water-table depth, bedrock depth, percent impervious area, percent slope, septic density, average elevation, and population density (table 4). The resulting regression model showed a poor correlation between these parameters and base flow, with an adjusted r^2 value of 0.07. Table 4 includes a listing of the coefficients for each parameter; a positive coefficient indicates that an increase in a particular basin characteristic may result in an increase in base-flow yield, with the opposite response for a negative coefficient. Increased base-flow yield was associated with increased impervious area, bedrock depth, slope, and elevation; however, the only statistically significant parameters were percent impervious area and elevation, with p-values of 0.005 and 0.041, respectively. The regression model indicated that septic system density was a statistically insignificant parameter, with a p-value of 0.328.

Comparison of regression model (predicted) and observed base-flow yield and the difference in these values (residuals) were made (fig. 21). Predicted values are within 491 to –56 percent of observed values. In general, the model yields the poorest results at low base-flow yield values; residuals are greater than 100 percent for most values below 0.15 $(ft^3/s)/mi^2$.

Table 4. Statistics for multiple linear regression model comparing base-flow yield to selected basin characteristics, September 10–13, 2012. Includes data from sites with high, middle, and low density of septic systems.

Regression statistic	Value
Multiple r	0.388
r square	0.150
Adjusted r square	0.070
Standard error	0.253
Observations	94

Parameter	Coefficients	Standard error	t statistic	p–value
Intercept	12.1678	13.723	0.887	0.378
Percent impervious area	0.006217	0.00217	2.860	0.005
Average elevation, in feet	0.000635	0.00031	2.070	0.041
Septic density per square mile	–0.000150	0.00015	–0.984	0.328
Bedrock depth, in inches	0.640312	0.65589	0.976	0.332
Water-table depth, in inches	–8.08779	8.3102	–0.973	0.333
Soil permeability, in inches per hour	–1.98238	2.2595	–0.877	0.383
Slope, in percent	0.015310	0.02406	0.636	0.526
Population density per square mile	0.000009	0.00003	0.340	0.735

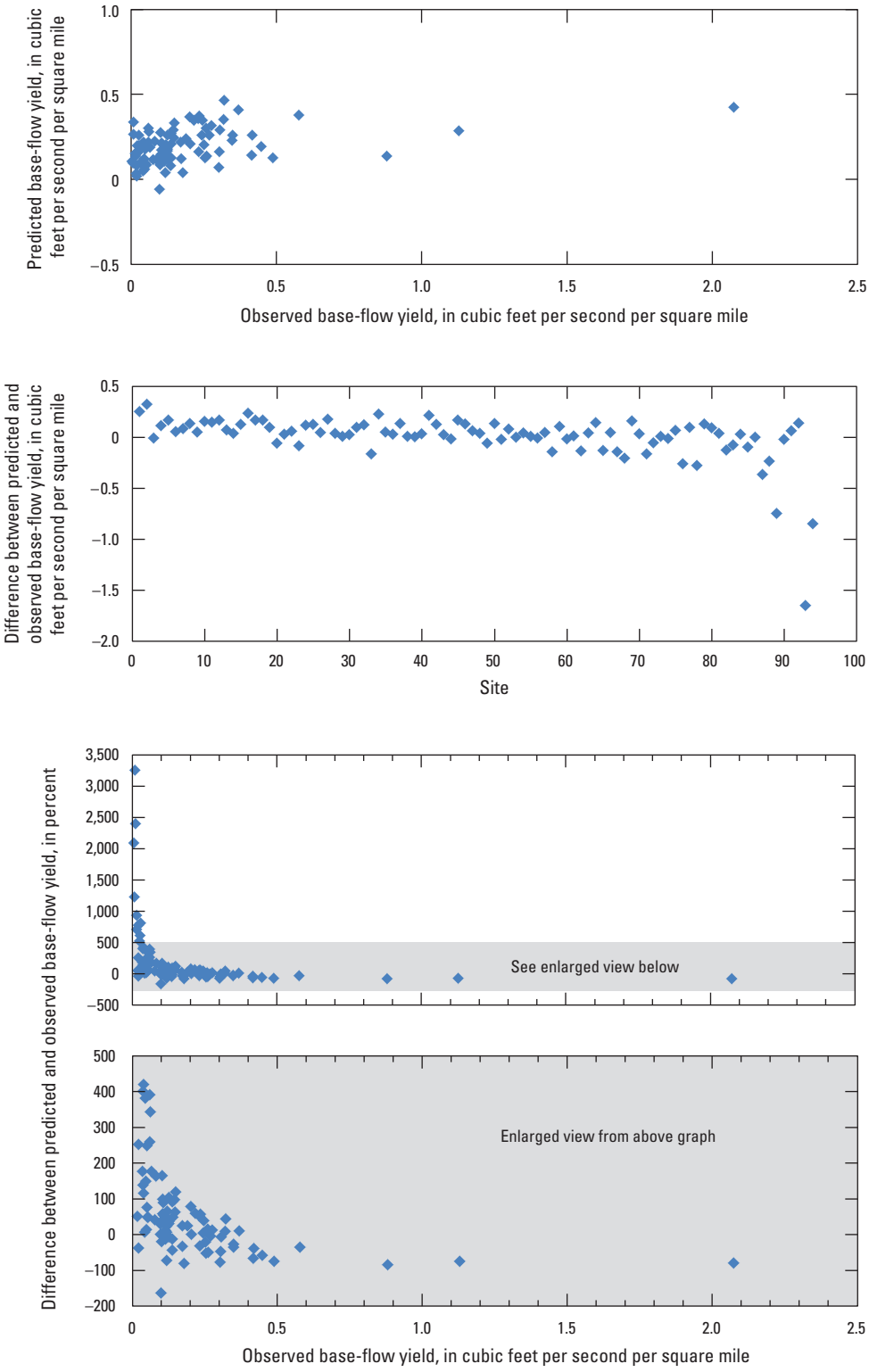


Figure 21. Predicted and observed base-flow yield and residuals for multiple linear regression model.

Influence of Geologic Area

Data were subdivided on the basis of geologic area to see if any difference in base-flow yield could be discerned within an area having similar geology and geographic extent (fig. 22). The three geologic areas in the study area are the northern Piedmont, Brevard fault zone, and southern Piedmont. These areas also subdivide the study area on the basis of location relative to the Chattahoochee River: the northern Piedmont is located mostly north of the river and the southern Piedmont is generally south of the river, with the Brevard fault zone generally following the river's course between the northern and southern Piedmont areas (see locations, fig. 6). Basin characteristics within the three geologic areas are summarized in figure 23.

Between the three geologic areas, the following median basin characteristics were similar: elevation, slope, water-table depth, impervious percentage, soil permeability, and population density. Median bedrock depth was lowest in the northern Piedmont and higher and similar in the Brevard fault zone and southern Piedmont. Septic system density was greatest in the northern Piedmont, followed by the Brevard fault zone and southern Piedmont.

Median base-flow yield was statistically the same in the northern Piedmont and Brevard fault zone, and was higher in the southern Piedmont with values of 0.05 and 0.12 $(ft^3/s)/mi^2$, respectively (fig. 24). Within each geologic area, base-flow yield in HDS and LDS basins was plotted and evaluated using a Wilcoxon rank-sum test (fig. 24, table 5). Within each of the three geologic areas, the median base-flow yield and specific conductance was statistically the same for HDS and LDS basins (table 5).

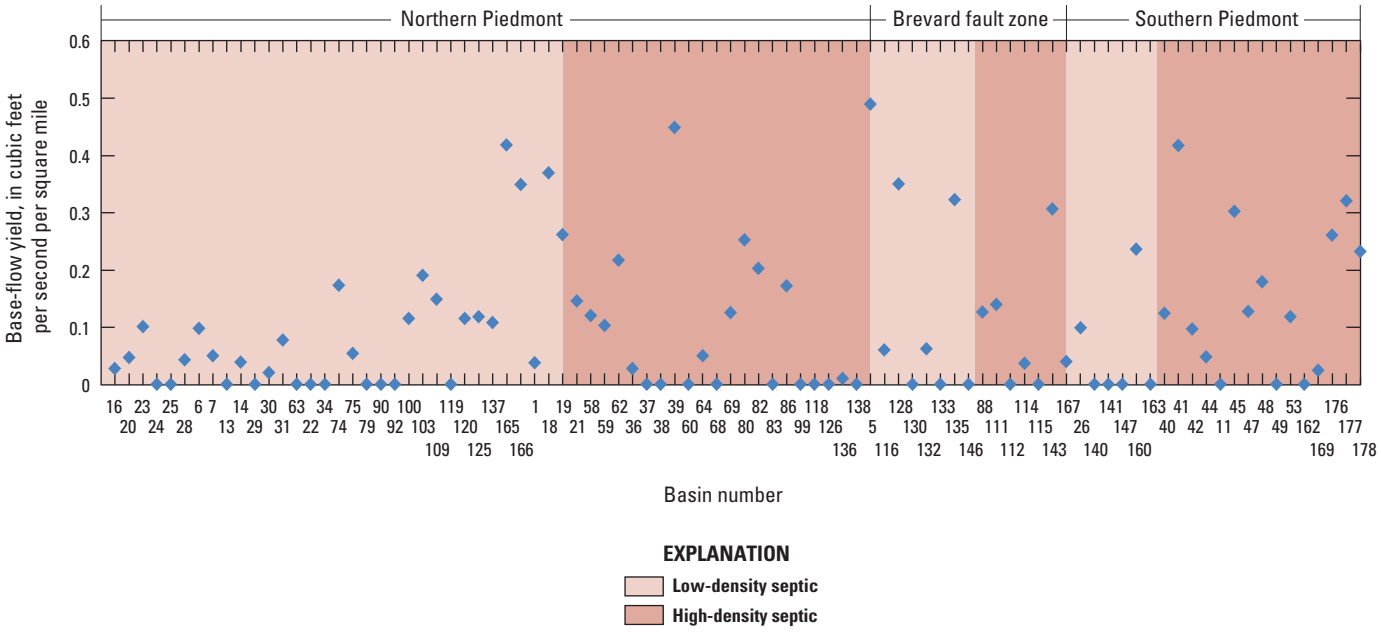


Figure 22. Base-flow yield by geologic area, September 10–13, 2012.

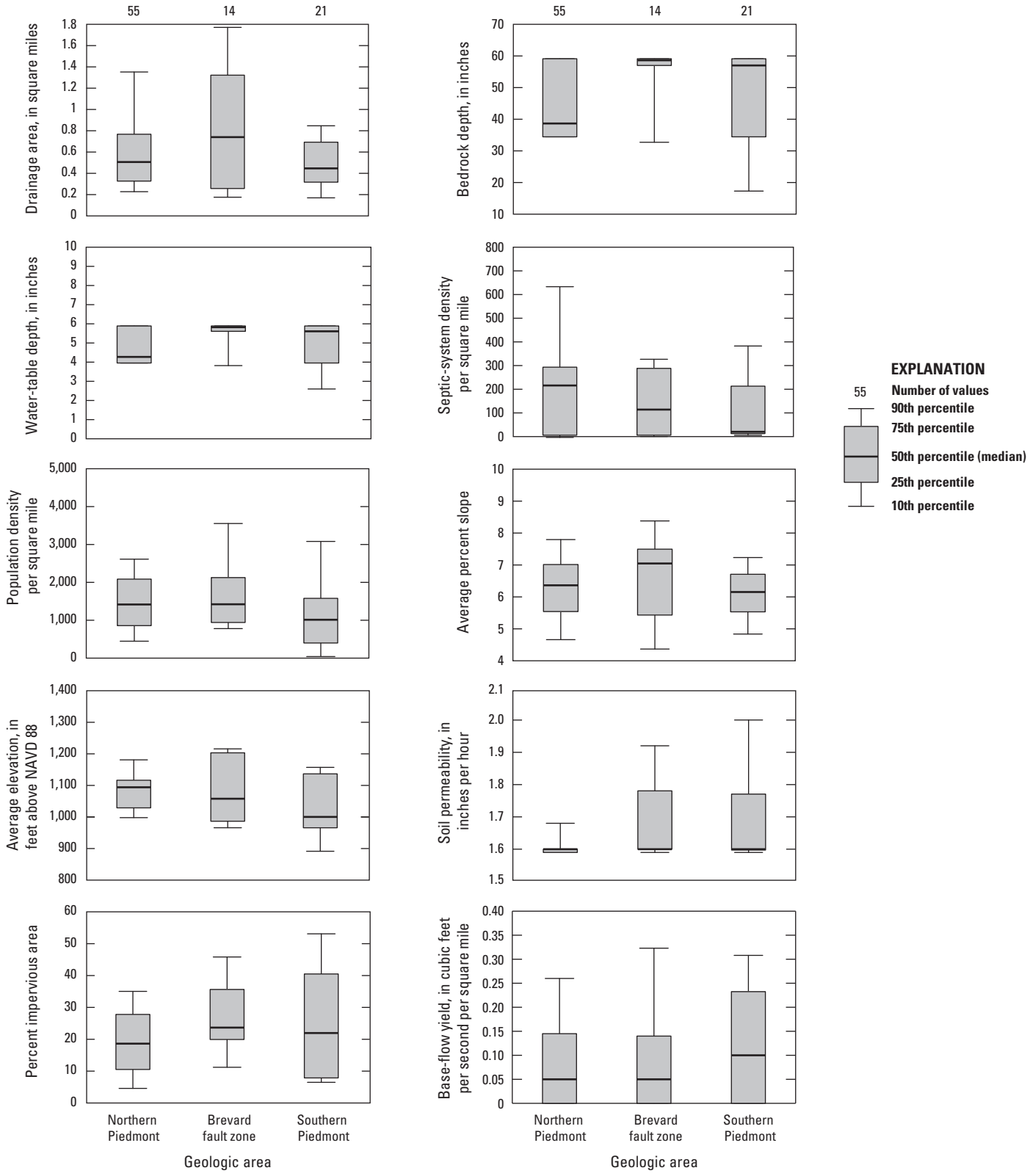


Figure 23. Boxplots showing base-flow yield, drainage area, impervious area, and topographic and soil characteristics of basins by geologic area.

Table 5. Statistical summary of base-flow yield and specific conductance by geologic area, September 10–13, 2012.

[HDS, high density septic; LDS, low density septic]

Geologic area	Base-flow yield, in cubic feet per second per square mile								Wilcoxon rank-sum test to compare HDS and LDS median values	
	HDS				LDS				p-value	Remarks
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count		
Northern Piedmont	0.00	0.05	0.42	33	0.00	0.04	0.49	22	0.888	Medians same
Brevard fault zone	0.00	0.06	0.35	7	0.00	0.04	0.31	7	1.000	Medians same
Southern Piedmont	0.00	0.00	0.24	6	0.00	0.12	0.42	15	0.088	Medians same

Geologic area	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius								Wilcoxon rank-sum test to compare HDS and LDS median values	
	HDS				LDS				p-value	Remarks
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count		
Northern Piedmont	13	79	122	22	49	92	174	12	0.2561	Medians same
Brevard fault zone	56	111.5	183	4	29	105	189	5	0.9048	Medians same
Southern Piedmont	82	93	104	2	36	121.5	675	12	0.1281	Medians same

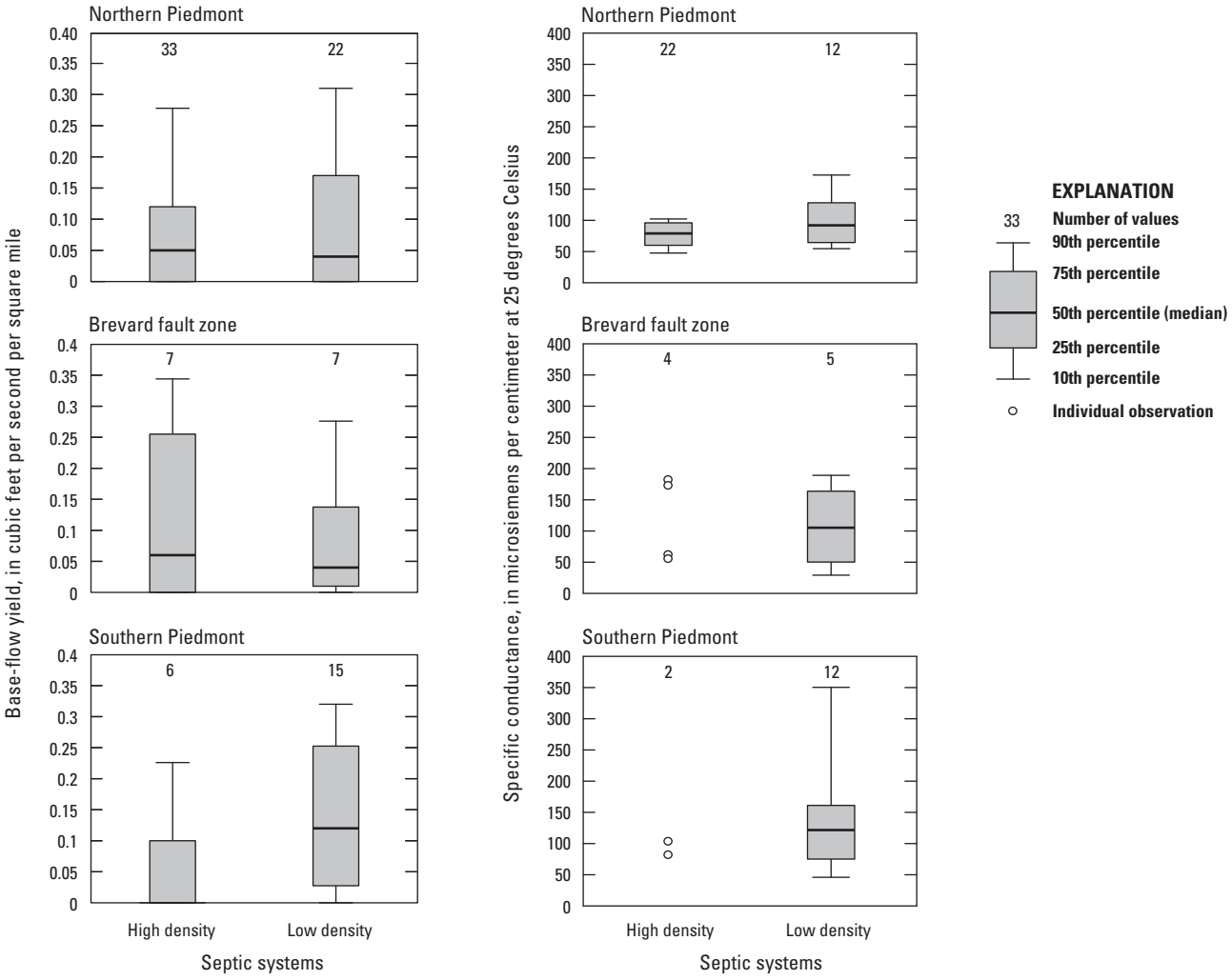


Figure 24. Boxplots showing base-flow yield and specific conductance by geologic area and septic system density.

Influence of Subareas

Because base-flow measurements were collected over a large area of differing climatic, geologic, land use, and basin characteristics, data were subdivided into four areas to determine if septic system density may have an influence on base flow within areas of smaller extent (fig. 25). Smaller subareas may demonstrate more uniform basin characteristics, making comparison of HDS and LDS sites more appropriate. From northeast to southwest, the subareas are A, B, C, and D (see locations, fig. 1).

The four subareas had similar median percent slope and water table depth (fig. 26). Median soil permeability was higher in subarea A, with similar values in subareas B, C, and D. Median bedrock depth was similar in subareas A, B and D and was somewhat deeper in subarea C. Elevation was highest in subarea A and similar in subareas B, C, and D. Population density was lowest in subarea D and similar in subareas A, B, and C. The percentage of impervious area was highest in subareas B and C and lowest in subarea D. Median septic system density was greatest in subarea A and about the same in subareas B, C, and D.

Median base-flow yield was highest in subarea D and lowest in subarea A (fig. 26). Within each of the subareas, base-flow yield and specific conductance were compared for HDS and LDS basins (fig. 27). With the exception of subarea B, base-flow yield was highest in basins with LDS; however, the difference was statistically insignificant as indicated by a Wilcoxon rank-sum test (table 6). Although median specific conductance was higher in LDS basins, this difference was also statistically insignificant as indicated by Wilcoxon rank-sum test results (table 6).

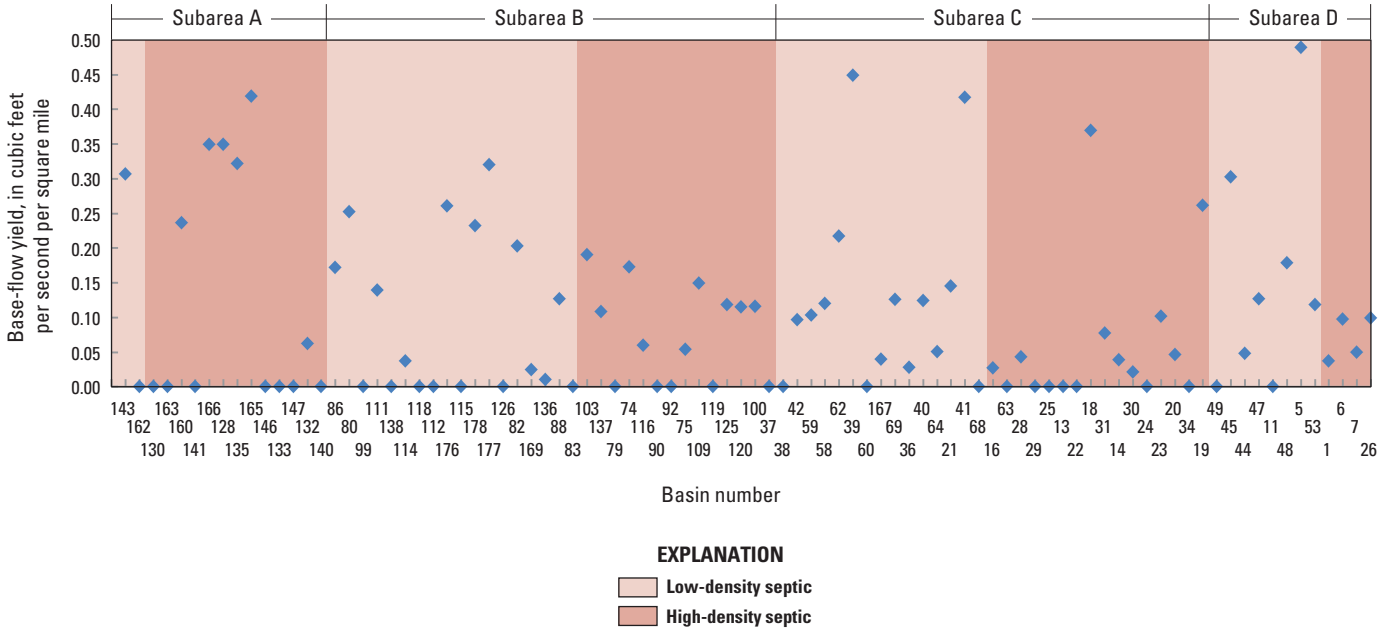


Figure 25. Base-flow yield by subarea, September 10–13, 2012.

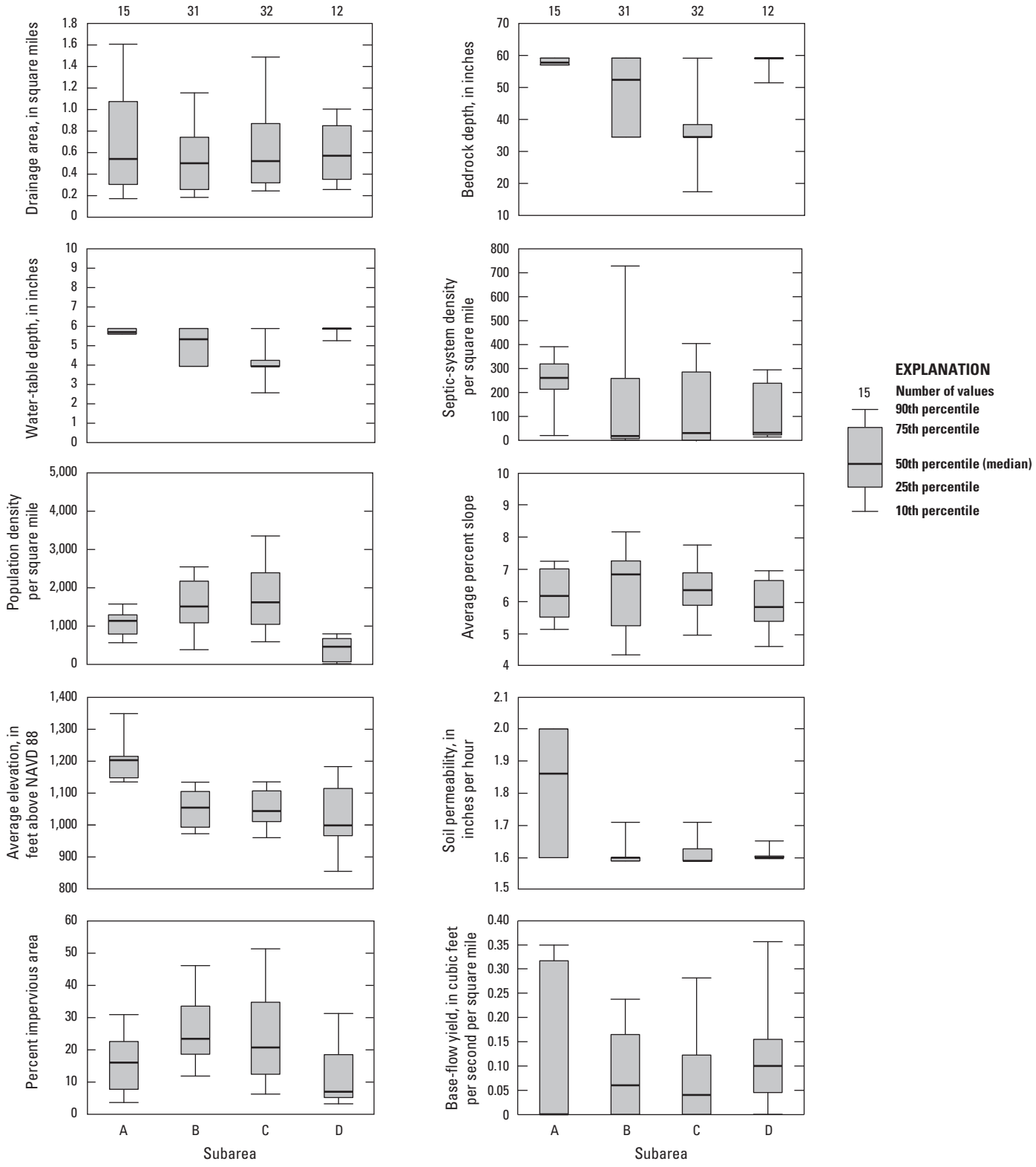


Figure 26. Boxplots showing base-flow yield, drainage area, impervious area, and topographic and soil characteristics of basins by subarea.

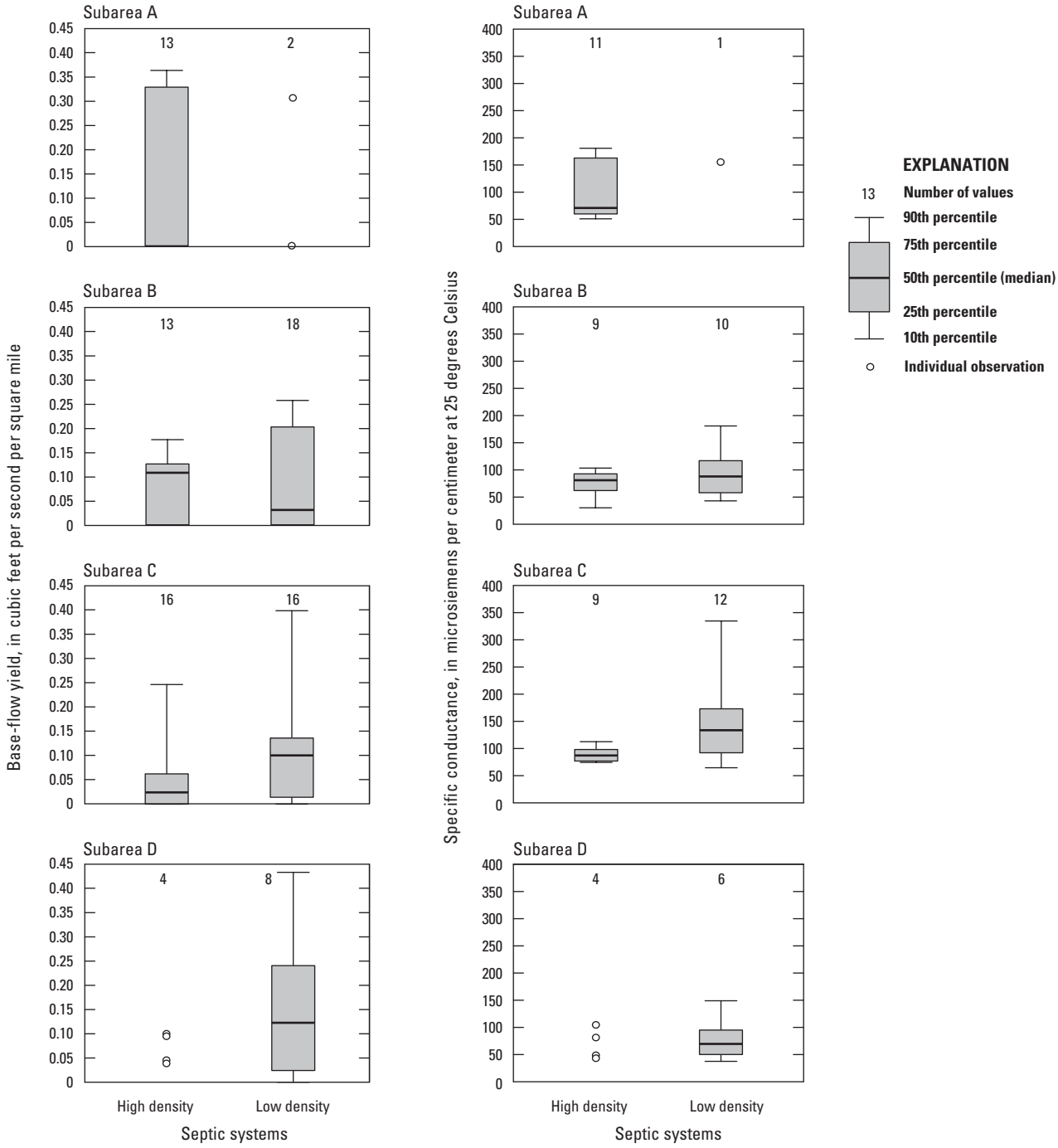


Figure 27. Boxplots showing base-flow yield and specific conductance by subarea and septic system density.

Table 6. Statistical summary of base-flow yield and specific conductance by subarea, September 10–13, 2012.

[HDS, high density septic; LDS, low density septic]

Subarea	Base-flow yield (cubic feet per second per square mile)								Wilcoxon rank-sum test to compare HDS and LDS median values	
	HDS				LDS				p-value	Remarks
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count		
A	0.00	0.00	0.42	13	0.00	0.15	0.31	2	1.000	Medians same
B	0.00	0.11	0.19	13	0.00	0.03	0.32	18	0.854	Medians same
C	0.00	0.02	0.37	16	0.00	0.10	0.46	17	0.080	Medians same
D	0.04	0.07	0.10	4	0.00	0.12	0.49	8	0.444	Medians same

Subarea	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)								Wilcoxon rank-sum test to compare HDS and LDS median values	
	HDS				LDS				p-value	Remarks
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count		
A	29	71	183	11	155	155	155	1	0.176	Medians same
B	13	81	105	9	29	88	211	10	0.414	Medians same
C	73	87	122	9	49	134	675	12	0.051	Medians same
D	42	56	104	4	36	70	155	6	0.931	Medians same

Influence of Septic System Density in the Riparian Zone

The riparian zone is typically an area of groundwater discharge and may have high rates of evapotranspiration because of the abundance of vegetation and trees near streams (fig. 11). In such areas, septic percolation may have a more direct pathway to provide base flow to streams. To evaluate the influence of septic systems in and near the riparian zone, a 45-meter (147.6 ft) buffer surrounding streams in each watershed was delineated and land use, soil, geologic, and topographic conditions within this area were computed using GIS and compared on the basis of HDS or LDS (fig. 28). Within these buffer zones, there were from 0 to 37 septic systems, with a density ranging from 0 to 560 systems/mi^2. The density of septic systems within the buffer zone were classified using a scheme similar to the that used for the entire study area: septic system density above the 66th percentile was classified as HDS, and septic system density below the 33rd percentile was classified as LDS. Using this approach, HDS ranged from 34 to 560 systems/mi^2, and LDS was classified as 0 systems/mi^2.

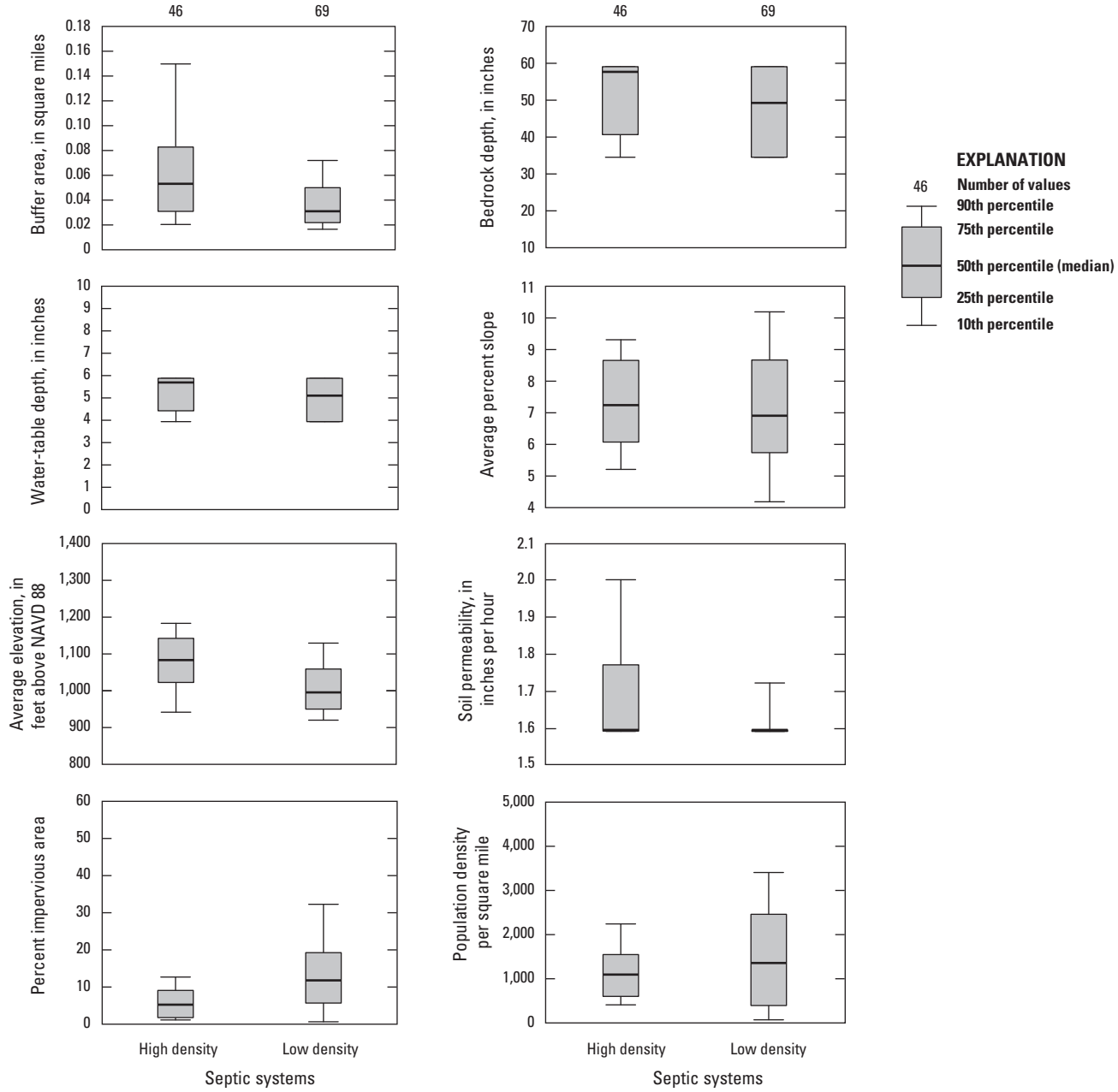


Figure 28. Boxplots showing drainage area, impervious area, and topographic and soil characteristics within the 45-meter buffer by septic system density.

Within the 45-meter buffer zone, median population density and the percentage of impervious area was higher in LDS areas (fig. 28), which would be expected in more urban settings. The median of all other characteristics were either the same or greater in HDS buffer zones. Base-flow yield and specific conductance was greater in LDS buffer areas (fig. 29); however, the difference was statistically insignificant, as indicated by results of a Wilcoxon rank-sum test with p-values greater than 0.05 (table 7).

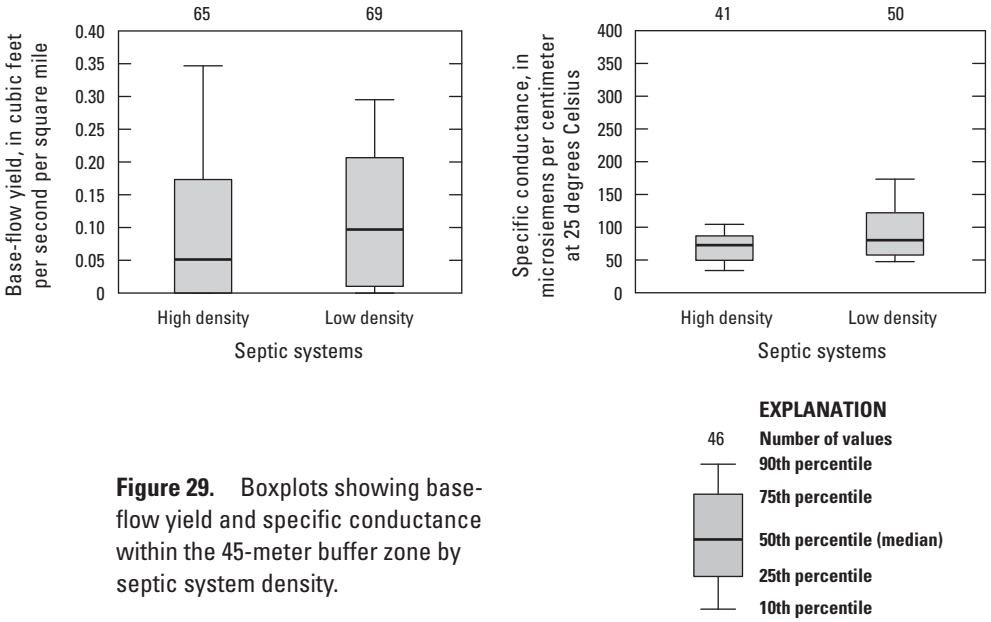


Figure 29. Boxplots showing base-flow yield and specific conductance within the 45-meter buffer zone by septic system density.

Table 7. Statistical summary of base-flow yield within 45-meter buffer zone for areas with high and low density of septic systems, September 10–13, 2012.

[HDS, high density septic; LDS, low density septic]

Field measurement	HDS				LDS				Wilcoxon rank-sum test to compare HDS and LDS median values	
	Minimum	Median	Maximum	Count	Minimum	Median	Maximum	Count	p-value	Remarks
Base-flow yield, in cubic feet per second per square mile	0.00	0.05	1.13	65	0.00	0.10	2.07	69	0.058	No difference in median
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	13	73	183	41	16	81	675	50	0.135	No difference in median

Base-Flow Analysis of Continuous Streamflow Data

Streamflow was evaluated at the Level Creek (02334578) and Woodall Creek (02336313) streamgages to determine amounts of base flow and runoff during 2011–12. The two sites are small watersheds that illustrate a range of basin characteristics and septic system density, as shown in figure 30.

The Level Creek Basin (02334578) drains a 5.08-mi^2 area (fig. 31) and is located in a more rural area with higher septic system density, average elevation, population density, rock depth, and water-table depth than the Woodall Creek Basin (02336313). The Woodall Creek Basin drains a 2.8-mi^2 area (fig. 32) in an urban setting near downtown Atlanta and has a higher percentage of impervious area than Level Creek. Near Level Creek, land use is primarily residential (61 percent) and forest (24 percent), whereas near Woodall Creek, land use is primarily industrial and commercial (51 percent) and transportation and highways (18 percent; fig. 30).

The two sites are located within different geologic areas. The Level Creek Basin is located in the northern Piedmont, and the Woodall Creek Basin is located within the southern Piedmont. In the septic system classification scheme developed for this study, the Level Creek Basin would be in the middle range, having a septic system density of 101 systems/mi^2 and thus falling between the 33rd and 66th percentile of septic system density (fig. 30). The Woodall Creek Basin is classified as an LDS site, having a septic system density of 18 systems/mi^2. Although Level Creek is considered in the middle range, its septic system density is 5.6 times greater than at Woodall Creek.

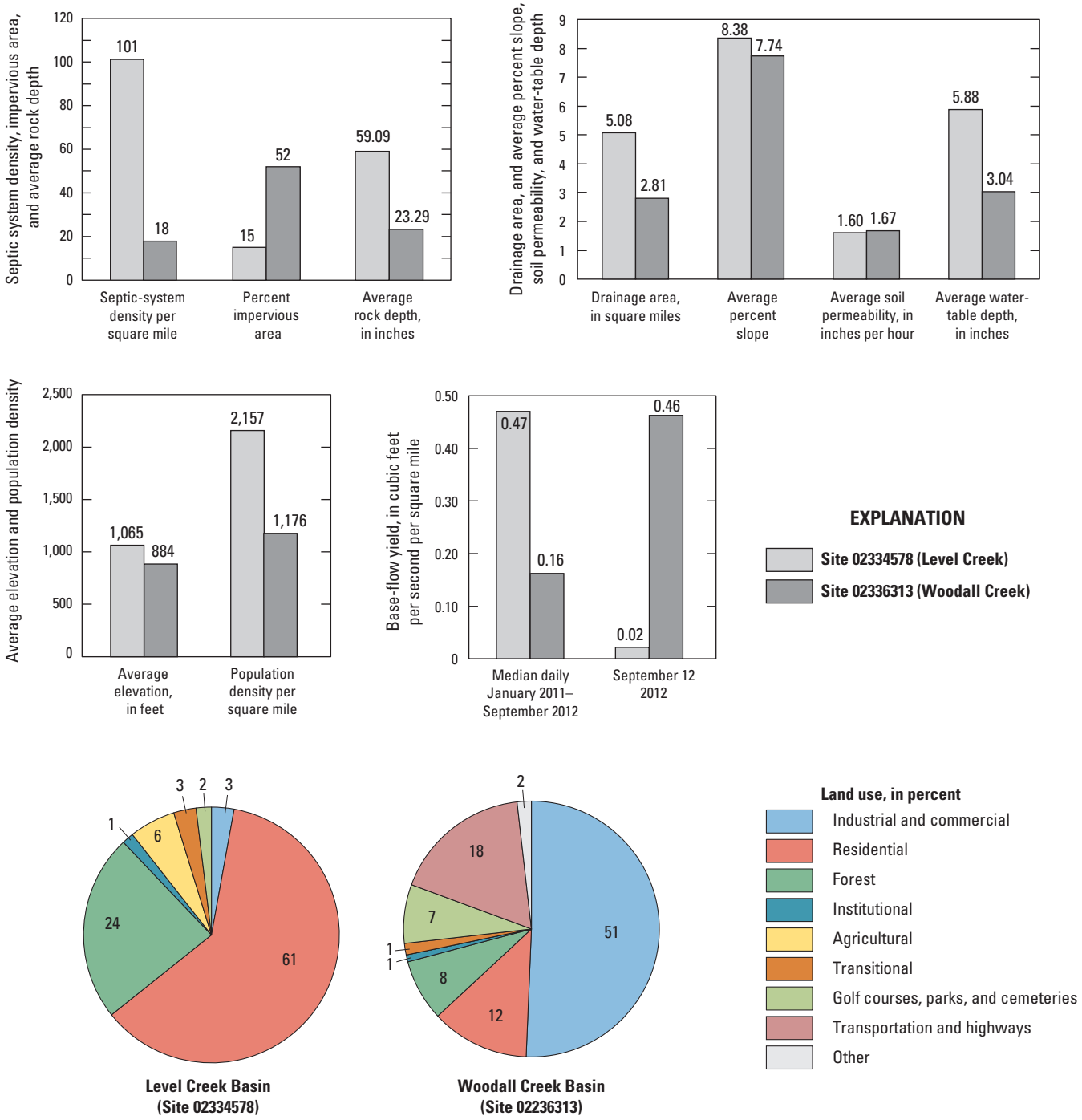


Figure 30. Base-flow yield and basin characteristics of USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA (see table 1 for data sources).

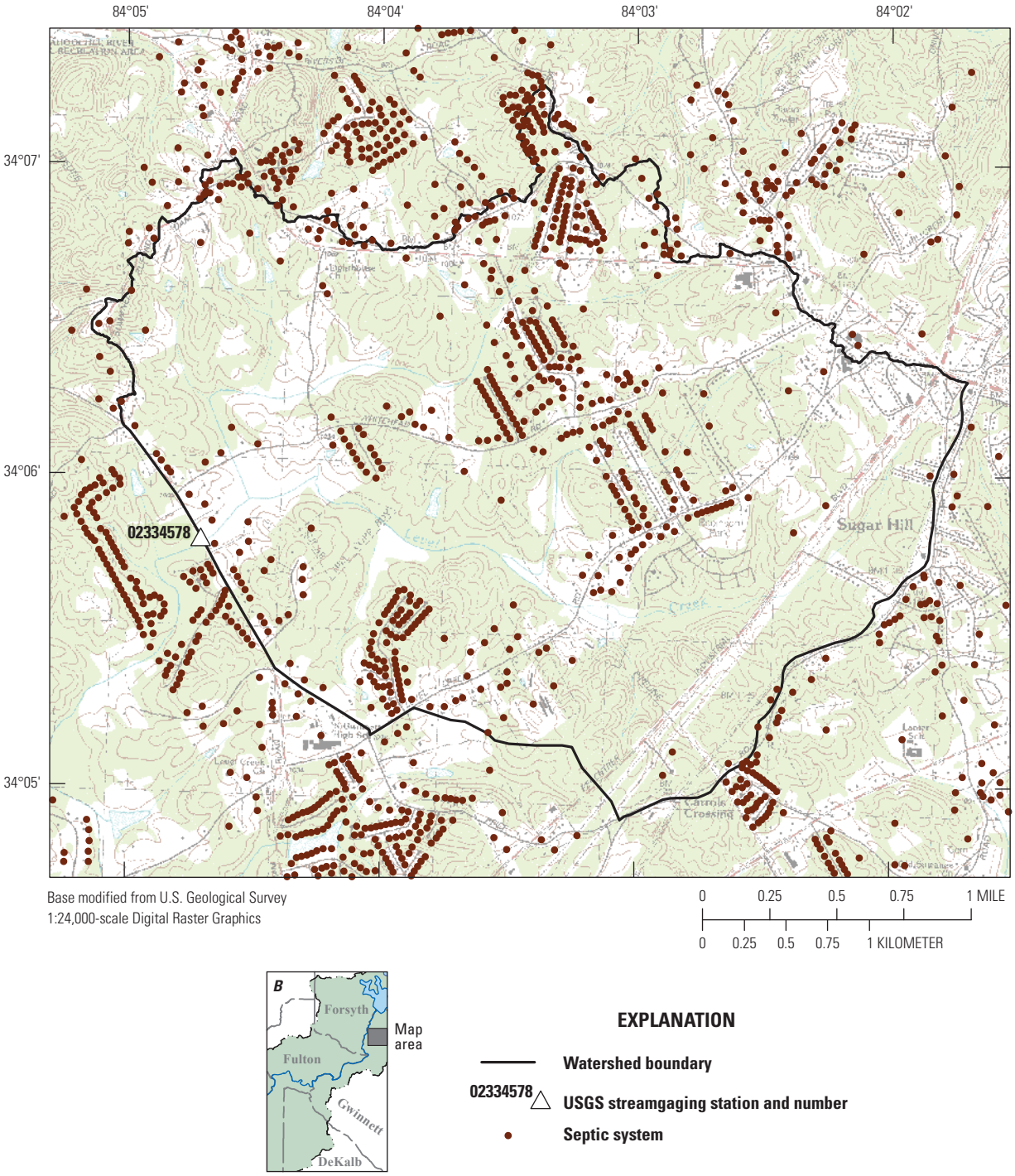


Figure 31. Drainage area and location of USGS site 02334578, Level Creek at Suwanee Dam Road near Suwanee, GA.

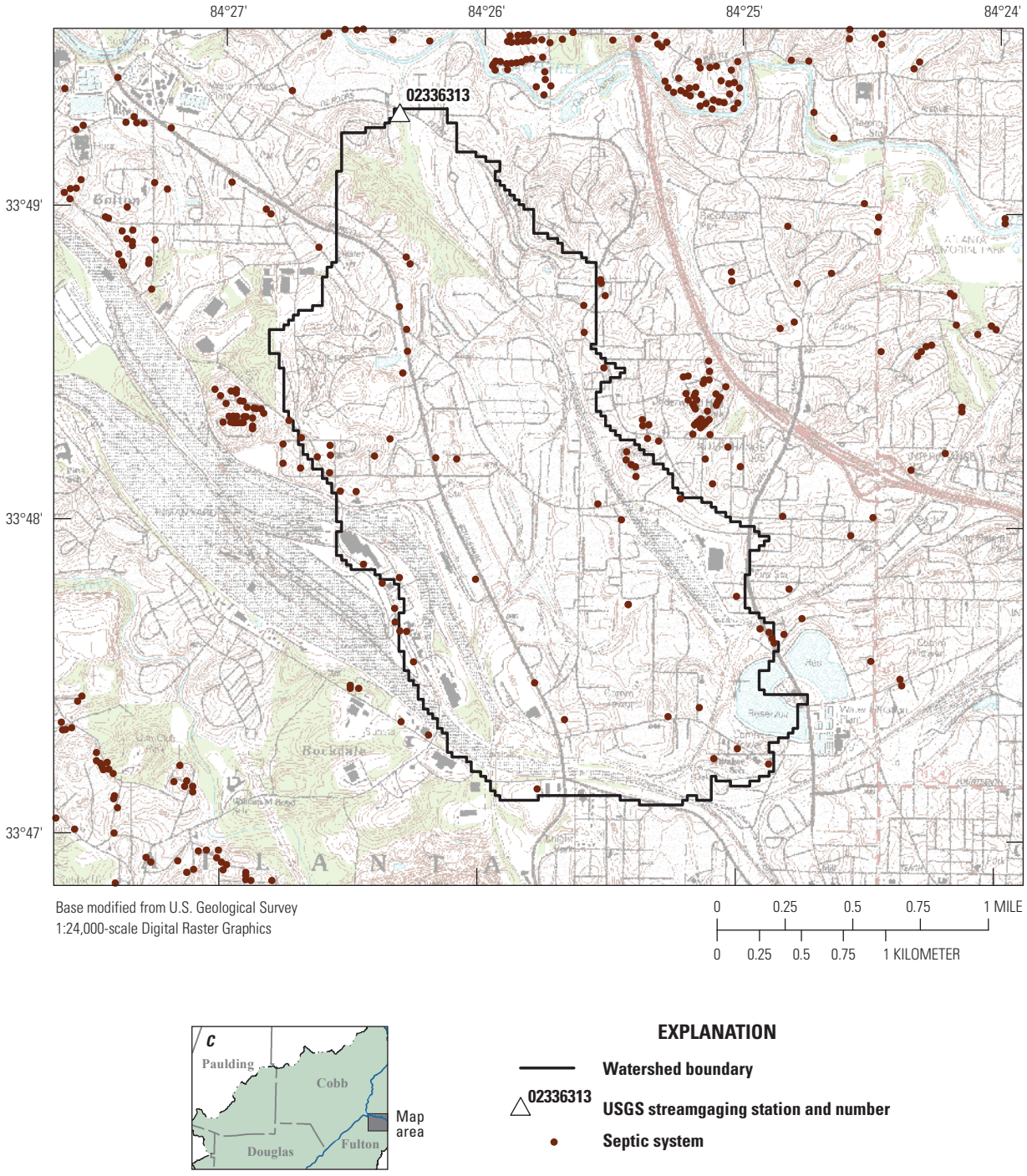


Figure 32. Drainage area and location of USGS site 02336313, Woodall Creek at Defoors Ferry Road, at Atlanta, GA.

To provide a more complete estimate of base flow at the two sites, daily streamflow data collected during 2011–12 were analyzed using the USGS computer program HYSEP (Sloto and Crouse, 1996). HYSEP separates streamflow hydrographs into base flow and runoff components, providing an indication of the percentage of total streamflow provided by base flow (fig. 33).

Daily mean base flow in the Level Creek Basin during January 2011–September 2012 ranged from 0.33 to 19 ft^3/s, with a median of 2.4 ft^3/s (table 8). Normalizing these flows for drainage area, base-flow yield ranged from 0.07 to 3.8 $(ft^3/s)/mi^2$ with a median of 0.48 $(ft^3/s)/mi^2$. Base flow provided over 75 percent of total daily streamflow during most of the period (fig. 34).

Daily mean base flow in the Woodall Creek Basin during the same period ranged from 0.13 to 2.2 ft^3/s with a median of 0.43 ft^3/s. Equivalent base-flow yield during 2011–12 ranged from 0.05 to 0.85 $(ft^3/s)/mi^2$ with a median of 0.17 $(ft^3/s)/mi^2$. Base flow provided over 75 percent of total streamflow during most of the year (fig. 34).

During 2011–12, base flow at each of the sites was highest in winter and lowest in the late summer and fall (fig. 33). Base-flow yield was highest in the Level Creek Basin, where flows exceeded 0.19 $(ft^3/s)/mi^2$ over 90 percent of the time, compared to 0.07 $(ft^3/s)/mi^2$ in the Woodall Creek Basin (table 8). Although other site factors may have some influence, the lower base-flow yield at Woodall Creek during 2011–12 may be accounted for, in part, by a 3.5-times greater percentage of impervious area and 5.6-times lower septic system density (fig. 30).

During the synoptic measurement effort on September 11–13, 2012, base-flow yield was over 20 times higher in the Woodall Creek Basin than in the Level Creek Basin, with values of 0.16 and 0.004 $(ft^3/s)/mi^2$, respectively (appendix 2). The higher base-flow yield in the more urban Woodall Creek Basin was not expected, given its greater impervious area cover and lower septic system density (fig. 30). The reason for the higher base flow at Woodall Creek during this period is unknown; however, the more urban setting at Woodall Creek suggests that base flow could be enhanced by outside interferences such as pipe leakage or unreported surface-water discharges.

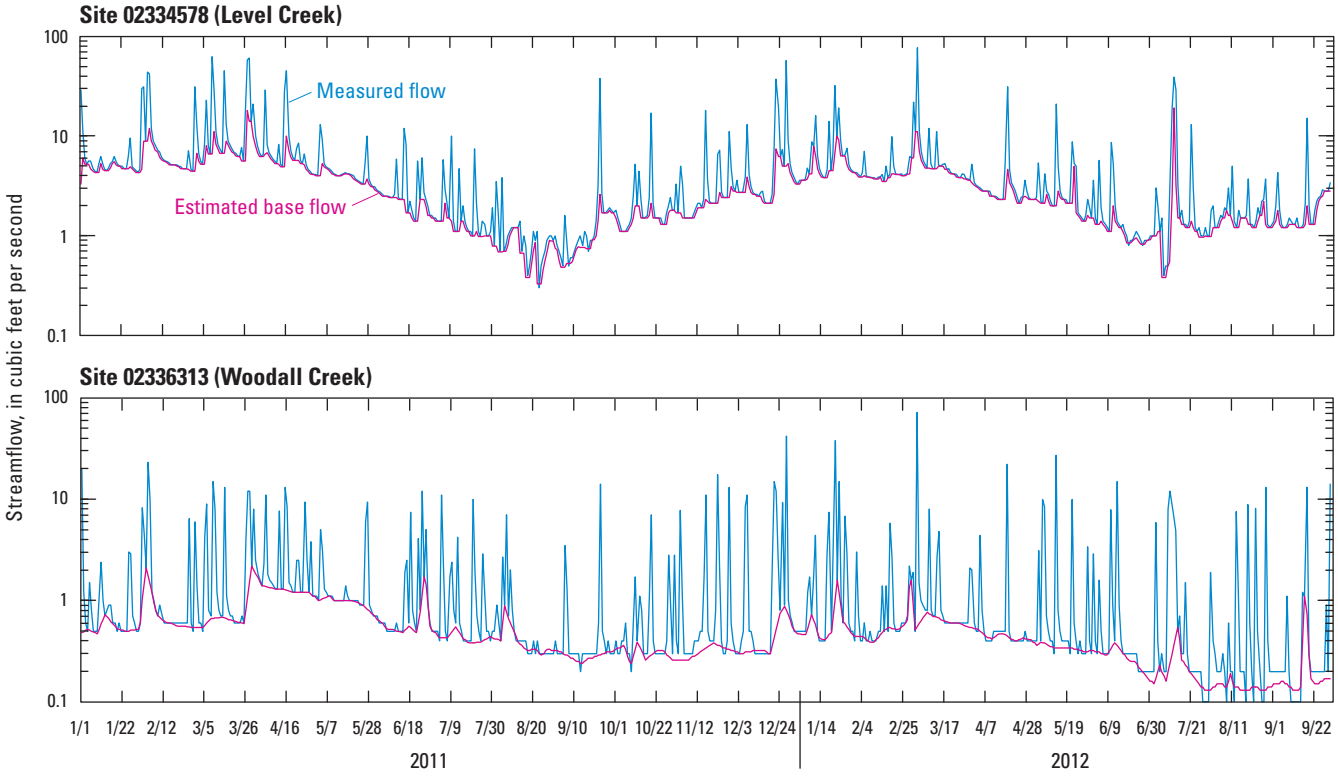


Figure 33. Base-flow separation using the local-minimum method for daily streamflow during January 2011 through September 2012 at USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, and USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA (see fig. 1 for locations).

Table 8. Summary of streamflow, estimated base flow, and base-flow yield during January 2011 through September 2012 at sites 02334578 (Level Creek) and 02336313 (Woodall Creek).

[p.10, 10th percentile; p.25, 25th percentile; p.75, 75th percentile; p.90, 90th percentile]

Statistical measure	Station: 02336313 Woodall Creek at Defoors Ferry Rd at Atlanta GA			Station: 02334578 Level Creek at Suwanee Dam Road near Suwanee GA		
	Cubic feet per second		Base-flow yield, in cubic feet per second per square mile	Cubic feet per second		Base-flow yield, in cubic feet per second per square mile
	Mean daily streamflow	Estimated base flow		Mean daily streamflow	Estimated base flow	
Minimum	0.1	0.13	0.05	0.3	0.33	0.07
p.10	0.2	0.17	0.07	1.08	0.93	0.19
p.25	0.3	0.30	0.12	1.5	1.3	0.26
Median	0.5	0.43	0.17	2.9	2.4	0.48
p.75	1.1	0.60	0.23	5.1	4.3	0.86
p.90	4.92	1	0.38	8.72	4.3	0.86
Maximum	72	2.2	0.85	77	19	3.8

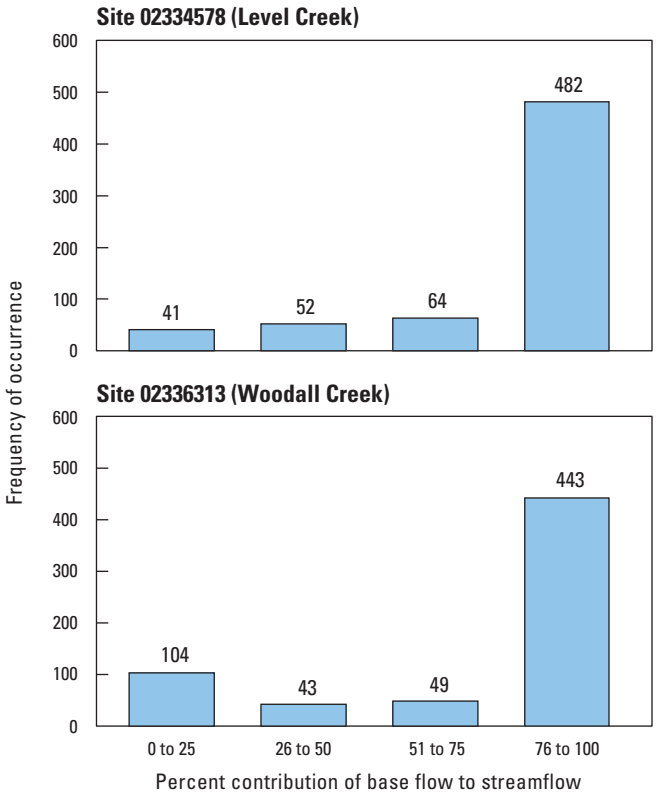


Figure 34. Percentage contribution of base flow to streamflow during January 2011 through September 2012 at USGS sites 02334578 (Level Creek) and 02336313 (Woodall Creek).

Influence of Septic System Percolation on Base Flow

The influence of septic system percolation on base flow was assessed during the period leading up to and including the synoptic base-flow sampling (September 2–13, 2012) and for the January 2011–September 2012 period (figs. 35, 36). The graphs in figures 35 and 36 show base flow determined using hydrograph separation, and the estimated maximum septic system percolation rate.

Septic system percolation rates were estimated based on records of septic systems and household water use in each basin. These septic percolation estimates are the maximum possible contribution as it is likely that some portion of household water use is lost to evapotranspiration because of irrigation at the homesite or consumed as part of domestic household practices. As water flows from the septic absorption field through the riparian zone and into a stream, some of the water is probably lost to evapotranspiration during the growing season (fig. 11). Evapotranspiration is seasonally dependent and can be a large component of the water budget during the summer growing season. Because plants are still active during the month of September, it is likely that evapotranspiration diminished base flow in both basins during the September 2012 synoptic measurement period, as plants uptake groundwater within the basin that otherwise would have discharged into the stream.

During base-flow periods, streamflow consists primarily of groundwater inflow as it drains from the regolith and fractures in the bedrock. Groundwater inflow may be augmented by external components such as water main and sewer line leakage, irrigation, and septic system inflows, and diminished by pumping and PET. In addition to groundwater inflow, base flow may be influenced by unreported surface-water discharges and unreported pumpage from groundwater and streams. Unreported surface-water discharges may include illicit discharges, swimming pool backwash, and car washing. Groundwater and surface-water pumping in the two study basins is considered negligible. Lawn irrigation may also contribute to base flow; however, this amount is also unknown.

Leakage from water and sewer mains can be a major contributor to streamflow, especially in urban areas where infrastructure is old; however, this is difficult to quantify. Landers and Ankcorn (2008) reported that water main leakage in Gwinnett County, Ga., was 3.5 percent of total finished water in 2007 according to George Kaffezakis (Gwinnett Department of Water Resources, written commun., January 2008). Lerner (2002) reported leakage rates of 20 to 25 percent are common for water mains.

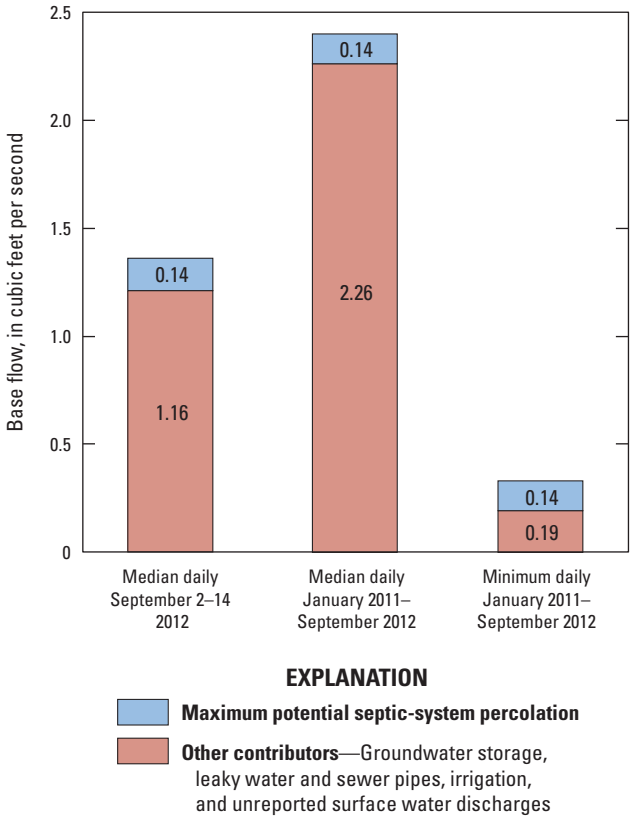


Figure 35. Base flow contributed by maximum potential septic system percolation and other contributors, USGS site 02334578 Level Creek at Suwannee Dam Creek near Suwannee, GA, January 2011–September 2012.

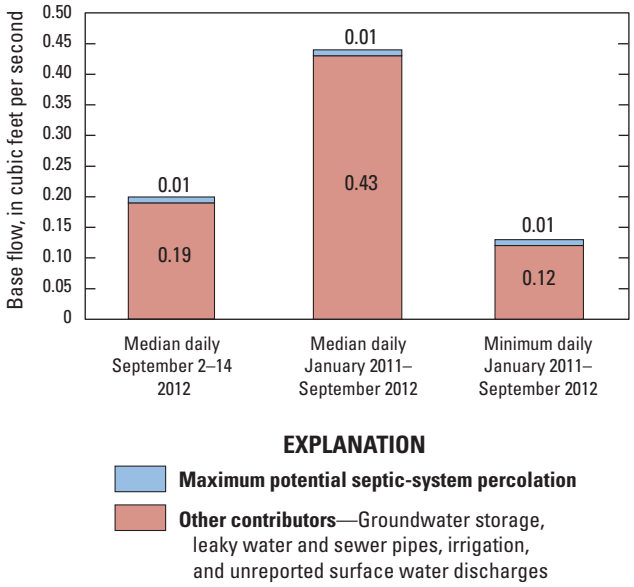


Figure 36. Base flow contributed by maximum potential septic system percolation and other contributors, USGS site 02336313 Woodall Creek at Defoors Ferry Road, at Atlanta, GA, January 2011–September 2012.

Level Creek Basin

At Level Creek in Gwinnett County (02334578), there are 515 septic systems in the 5.08-mi^2 drainage area, for a septic system density of 101 systems/mi^2 (figs. 30 and 31). Multiplying the number of sites by the average single family household use for 2009 for Gwinnett County of 173.5 gallons per day (gal/d; Metropolitan North Georgia Water Planning District, 2011) yields an average potential influx of septic system water of 89,368 gal/d or 0.14 ft^3/s.

Figure 35 shows the amount of base flow at Level Creek potentially contributed by septic system percolation for (1) median daily base flow during September 2–14, 2012, and (2) for median and minimum daily base flow during January 2011–September 2012. The maximum amount of estimated septic system percolation that might contribute to base flow is 0.14 ft^3/s, which is about 6 percent of median daily base flow during 2011–12. Maximum septic system percolation would contribute a considerably higher percentage during low-flow periods, providing about 11 percent of the base flow in September 2012, and 42 percent of minimum daily base flow measured during 2011–12. The balance of base flow is contributed by unknown sources. These percentages illustrate that detection of septic system contributions is more feasible during extreme low-flow periods; however, the low-flow volume results in less accurate flow measurements and may obscure the contribution. Since these numbers are maximum possible septic percolation, the actual contribution to flow is likely considerably smaller resulting in even greater difficulty in quantifying septic contribution to base flow.

Woodall Creek Basin

At Woodall Creek in the city of Atlanta, Fulton County (02336313), there are 50 septic systems in the 2.8-mi^2 drainage area, for a septic system density of 17.8 systems/mi^2 (figs. 30 and 32). Multiplying the number of sites by 125 gal/d, the average single-family household use for 2009 in the Atlanta service area (Metropolitan North Georgia Water Planning District, 2011), yields a maximum potential influx of septic system water of 6,250 gal/d or 0.01 ft^3/s.

The maximum potential septic system percolation rate for the LDS Woodall Creek Basin is 0.01 ft^3/s, which is 14 times lower than in the HDS Level Creek Basin, accounting for only 2 percent of median daily base flow during 2011–12, 5 percent of the daily base flow during September 2–14, 2012, and 8 percent of the minimum daily base flow during 2011–12 (fig. 36). Since these numbers are maximum possible septic percolation, the actual contribution to flow is likely considerably smaller resulting in even greater difficulty in quantifying septic contribution to base flow.

Maximum Potential Septic System Percolation Rate

An estimate of the maximum potential contribution from septic systems in the study area was computed by determining the number of septic systems in a given county and multiplying this by the average single family household use for that county in 2009 as listed in table 9 (Metropolitan North Georgia Water Planning District, 2011). A map showing the estimated maximum percolation from septic systems is shown in figure 37. Potential septic system contribution was highest in areas of greatest density: Forsyth, southeastern Paulding, central Douglas, and south-central Hall Counties. Estimated maximum percolation from the 241,733 septic systems in the study area is 62 ft^3/s or 40 Mgal/d, of which 52 ft^3/s (33.4 Mgal/d) is in the Chattahoochee River Basin and 10 ft^3/s (6.5 Mgal/d) is in the Flint River Basin.

Much of the residential water used in homes served by septic systems is unlikely to discharge to streams because some is lost to outdoor household use, evapotranspiration, and recharge to deep groundwater systems. An estimate of the potential contribution of septic system percolation to daily mean streamflow during January 2011 through September 2012 was made at the two farthest downstream streamgages in the study area—site 02338000, Chattahoochee River near Whitesburg (drainage area 2,430 mi^2), and site 02344350, Flint River near Lovejoy (drainage area 130 mi^2, fig. 38). Daily mean streamflow at the two sites during water year 2012 was rated fair, with an associated accuracy of 15 percent.

At the Chattahoochee River site, daily mean streamflow ranged from 909 to 14,100 ft^3/s during this period, with a maximum potential septic system percolation throughout the basin of about 0.4 to 5.7 percent of daily median flow (fig. 38). Maximum potential septic system percolation represents such a small percentage of streamflow that it is unlikely it would be detected, given the approximately 15-percent uncertainty associated with daily streamflow measurements.

At the Flint River site, daily mean streamflow ranged from 5.6 to 1,900 ft^3/s, with maximum potential septic system percolation throughout the basin ranging from 0.5 to 179 percent of the flow. The maximum potential septic percolation rate at the Flint River site exceeded 50 percent of daily mean streamflow several times during dry periods in August–November 2011, and May–September 2012 (fig. 38). Potential septic system percolation represents a large percentage of flow at the Flint River site, in part, because the drainage area and associated streamflow is lower than at the Chattahoochee River site.

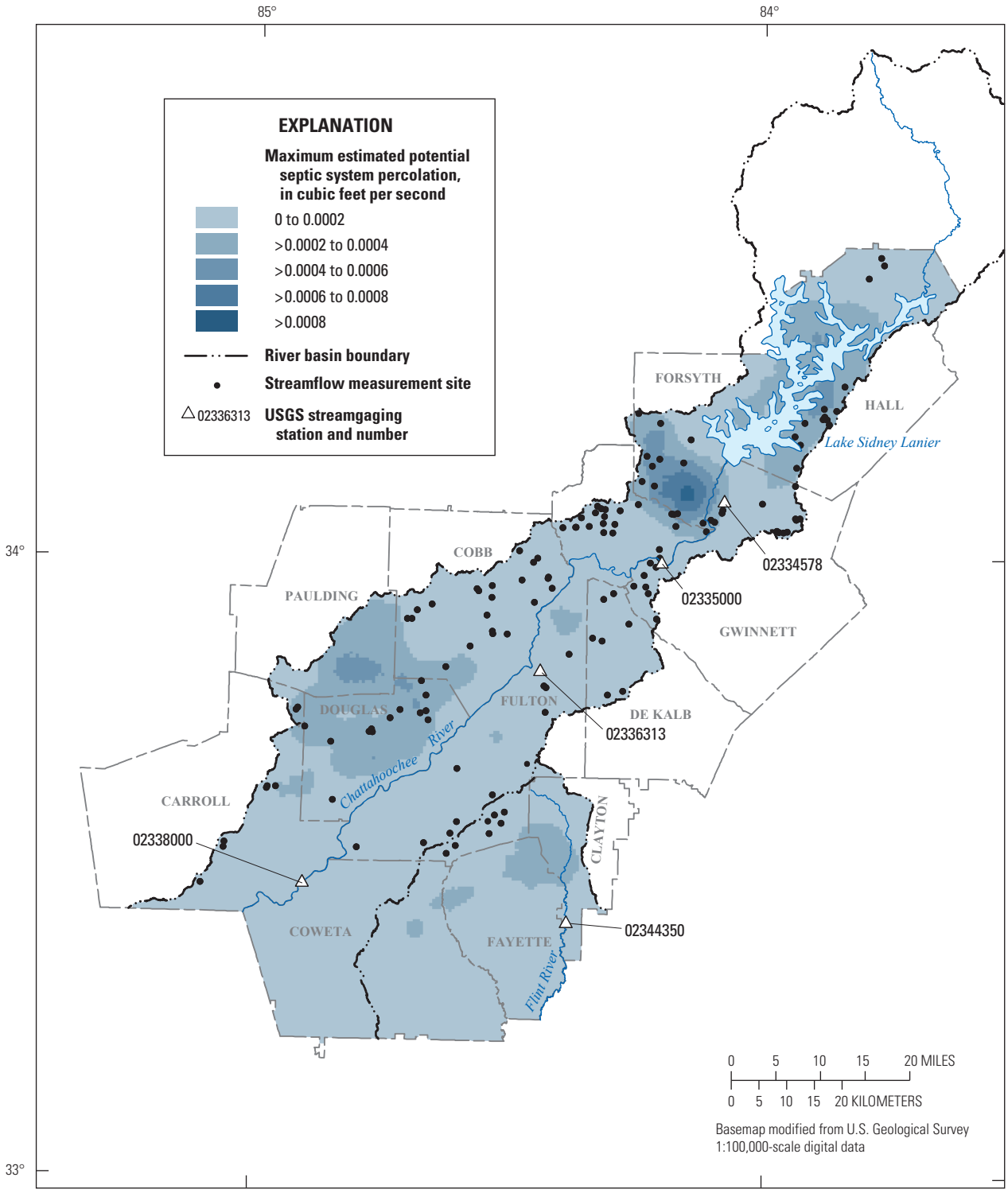


Figure 37. Maximum estimated potential septic system percolation rate in the study area.

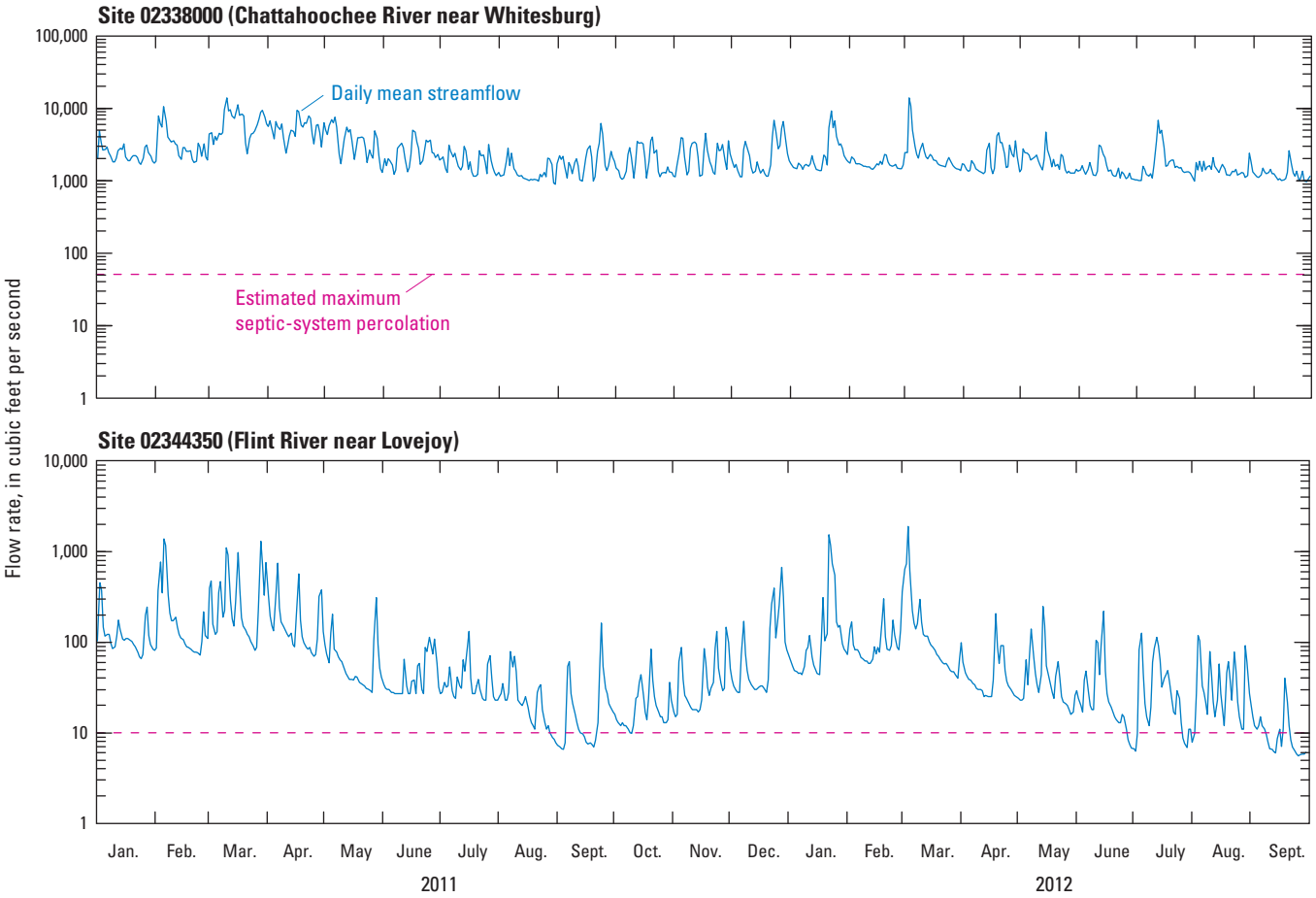


Figure 38. Daily mean streamflow at USGS site 02338000 Chattahoochee River near Whitesburg, GA, and USGS site 02344350 Flint River near Lovejoy, GA, and maximum potential contribution from septic system percolation, January 2011–September 2012 (see fig. 1 for locations).

Table 9. Average daily single family residential water use, 2009 (data from Metropolitan north Georgia Water Planning District, 2011).

[—, not applicable]

County	Average number of persons in household	Average 2009 single family household use, in gallons per day	Remarks
Clayton	2.8	150	
Cobb	2.6	155	Average of values reported by Cobb County Water System and Marietta Power and Water.
Carroll	—	—	
Cowetta	2.8	161	Average of values reported by Cowetta County Water and Sewer Authority and Newnan Utilities.
Douglas	2.7	150	Average of values reported by Douglasville–Douglas County Water and Sewer Authority and City of Villa Rica.
DeKalb	—	—	
Fayette	2.8	170	
Forsyth	2.8	173	
Fulton	2.4	172	Average of values reported by Fulton County Water System and City of Union City.
Gwinnett	2.8	174	
Hall	2.9	172	Average of values reported by City of Flowery Branch and City of Gainesville.
Paulding	2.8	148	
Average	**2.7**	**162**	

Limitations of Analysis

The assessment of the influence of septic system percolation on streamflow is limited by the accuracy of datasets and field measurements relative to the percent contribution to base flow by septic systems. Variations in rainfall patterns across the study area immediately prior to the synoptic measurement effort in September 2012 may have resulted in elevated base flow in parts of the area.

Elevation and slope are based on a 30-meter-resolution digital elevation model, so variations within smaller areas are not depicted. Soils data, including permeability, water table, bedrock depth, were derived from the Natural Resources Conservation Service State Soil Geographic (STATSGO) dataset (*http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml*), a broad-based inventory of soils and non-soil areas shown at a scale of 1:250,000, designed for broad planning and management uses covering State, regional, and multistate areas. Variations at smaller scales may not be captured by this analysis.

The geology of the Piedmont physiographic province is considerably more complex than the delineation of geologic areas used in this report. Local variations in rock type and geologic structure that may affect groundwater flow and stream base flow are not captured by the coarse resolution data used in this study.

The method to delineate locations of septic systems was based largely on an analysis of billing records and locating septic systems at the center of land parcels by geocoding addresses. On large land parcels, the location of septic systems at the center of the property may put a septic system into the wrong basin and result in differences in the analysis.

Because many of the streamflow measurements were made in extremely low-flow conditions, the margin of error is wide, within many measurements having errors greater than 10 percent (appendix 1). These errors may obscure detection of differences in base flow between basins attributed to septic system recharge, as illustrated in the Level Creek and Woodall Creek Basins. Using the 10-percent measurement accuracy reported for daily mean discharge at Level Creek (02334578, appendix 1), the margin of error for (1) the 2011–12 median discharge would be 0.24 ft^3/s; (2) the 2011–12 minimum discharge would be 0.04 ft^3/s, and; (3) the discharge measured during the measurement period in September 2012 would be 0.12 ft^3/s. The maximum potential septic system percolation rate for the Level Creek Basin is 0.14 ft^3/s. Thus, detection of differences in base flow attributed to septic system percolation could be obscured by measurement errors for median conditions during 2011–12 because its magnitude (0.14 ft^3/s) is lower than the measurement error (0.24 ft^3/s). During the September 2012 measurement period, the contribution of septic systems to base flow would be unlikely to be detected, as the maximum potential septic system percolation rate of 0.14 ft^3/s is only slightly larger than the error in base-flow measurements of 0.12 ft^3/s.

Assuming a measurement accuracy of 10 percent at Woodall Creek, the margin of error for (1) the 2011–12 median would be 0.04 ft^3/s; (2) the 2011–12 minimum would be 0.01 ft^3/s, and; (3) the September 2012 would be 0.02 ft^3/s. The maximum potential septic system percolation rate for the Woodall Creek Basin is 0.01 ft^3/s. Thus, detection of differences in base flow attributed to septic system percolation could be obscured by measurement errors for all three conditions because its magnitude (0.01 ft^3/s) is lower than the measurement error (0.01 to 0.04 ft^3/s).

Comparison of base flow between HDS and LDS basins was complicated by a variety of other factors that may obscure any gains in base flow attributed to septic system percolation. This includes increased groundwater recharge caused by leaky water or sewer mains and high rates of evapotranspiration during the synoptic period in September 2012. Completing a synoptic measurement effort during a dry period later in the year during the dormant season, when evapotranspiration effects are diminished, may produce a more pronounced difference in base flow between HDS and LDS basins. Collection of water samples for analysis of nitrates and bacteria would also provide some confirmation of the contribution of base flow from septic system percolation.

Summary and Conclusions

Septic system percolation may locally be an important component of streamflow in small drainage basins where it augments natural groundwater recharge, especially during extreme low-flow conditions. The amount of groundwater reaching streams depends on how much is intercepted by plants or infiltrates to deeper parts of the groundwater system that flows beyond a basin divide and does not discharge into streams within a basin. Evapotranspiration varies seasonally and is greatest during the growing season. In addition to septic systems, leaking water mains and sanitary sewers, stormwater drains, and runoff diversion and storage structures can contribute to enhanced groundwater recharge and base flow.

Septic systems were identified at 241,733 sites in a 2,539-square-mile (mi^2) study area that includes all or parts of 12 counties in the Metropolitan Atlanta area. The highest density of septic systems was in the southern part of Forsyth County, where the density exceeds 350 systems per square mile (systems/mi^2). Other counties having high density of systems (HDS) include southeastern Paulding, central Douglas, and south-central Hall Counties, where density exceeds 250 systems/mi^2.

The potential maximum percolation from septic systems in the study area is 62 cubic feet per second (ft^3/s)

or 40 million gallons per day (Mgal/d), of which 52 ft^3/s (33.4 Mgal/d) is in the Chattahoochee River Basin and 10 ft^3/s (6.5 Mgal/d) is in the Flint River Basin. These maximum percolation rates represent 0.4 to 5.7 percent of daily mean streamflow during the 2011–12 period at the farthest downstream gaging site (02338000) on the Chattahoochee River, and 0.5 to 179 percent of daily mean streamflow at farthest downstream gaging site on the Flint River (02344350).

Maximum septic system percolation represents such a small percentage of streamflow at the Chattahoochee River site that it is unlikely it would be detected, given that the uncertainty of most of the discharge measurements is greater than 10 percent. Maximum septic system percolation represents a larger percentage of streamflow at the Flint River site because this site has a nearly 19-times smaller drainage area than at the Chattahoochee River site. Septic system contribution is, therefore, more likely to be detected within the measurement accuracy of streamflow.

To determine the difference in base flow between basins having different septic system densities, hydrograph separation analysis was completed using daily mean streamflow data at Level Creek (station number 02334578), with a relatively high septic system density of 101 systems/mi^2, and Woodall Creek (station number 02336313), with a relatively low septic system density of 18 systems/mi^2. Results indicated that base-flow yield during 2011–12 was higher at Level Creek, with a median of 0.47 cubic feet per second per square mile ([ft^3/s]/mi^2), compared to a median of 0.16 (ft^3/s)/mi^2 at Woodall Creek. Septic system percolation contributed only a minor portion of total base flow, with the balance contributed by unknown contributions from external components such as water main and sewer line leakage, irrigation, and unreported surface-water discharges. At the less urbanized Level Creek site, there are 515 septic systems with a daily maximum percolation rate of 0.14 ft^3/s, accounting for 11 percent of the base flow in September 2012. At the more urban Woodall Creek site, there are 50 septic systems with an average daily maximum percolation rate of 0.0097 ft^3/s, accounting for 5 percent of base flow in September 2012.

Streamflow measurements at 133 small drainage basins (less than 5 mi^2 in area) during September 2012, indicated no statistically significant difference in flow or specific conductance between basins having high and low density of septic systems (HDS and LDS). The median base-flow yield for HDS sites was 0.04 (ft^3/s)/mi^2 of drainage area ranging from 0 to 0.52 (ft^3/s)/mi^2 and for LDS sites was 0.10 (ft^3/s)/mi^2 ranging from 0 to 0.49 (ft^3/s)/mi^2. A Wilcoxon rank-sum test indicated the median base-flow yields for HDS and LDS sites were not statistically different, with a p-value of 0.345. The mean specific conductance for HDS sites was 83.39 microsiemens per centimeter at 25 degrees Celsius (µS/cm) ranging from 13 to 183 µS/cm, and for LDS sites the mean value was 126.46 µS/cm, ranging from 29 to 675 µS/cm. A Wilcoxon rank-sum test run on median values of specific conductance from HDS and LDS sites indicated that differences in median values were insignificant (p-value 0.082).

Because of the large size of the study area and associated variations in basin characteristics, data collected in September 2012 were also evaluated using a number of groupings in an attempt to reduce or eliminate other basin characteristics that might affect base flow. Within each grouping, data were subdivided into HDS and LDS basins; the three groupings used are geologic area, four geographic subareas, and 45-meter buffer zone. Regardless of grouping, there was no statistically significant difference between median base-flow yield for HDS and LDS basins. Detection of the septic percolation component of base flow was likely obscured by the uncertainty of streamflow measurements, which may exceed the amount of flow contributed by septic system percolation. In addition, because the measurement effort was completed during a period of active evapotranspiration, much of the septic percolation may have been intercepted prior to discharging into a stream. Detection of septic system percolation in HDS basins may also have been complicated by leaky water and sewer mains, which may have resulted in higher streamflows in LDS basins relative to HDS basins.

The lack of a statistically significant difference in mean base-flow yield or specific conductance for HDS and LDS sites differs from a previous study, which reported base-flow yield was 90 percent greater in HDS than in LDS watersheds and that specific conductance of base flow was generally higher in the HDS watersheds than in the LDS basins in Gwinnett County, Ga. Compared to the present study, the previous Gwinnett County study was completed in a considerably smaller study area during a period of extreme drought; thus, site conditions were more uniform over the study area and variations attributed to septic system percolation were more readily detected. In addition, the LDS sites in the previous study were more rural and not on sewer systems, thus minimizing the possibility that contributions from leaking sanitary sewers or water mains interfere with detecting septic system percolation.

It is likely that the contribution from septic system percolation at many of the sites visited in September 2012 was obscured by a combination of measurement error and evapotranspiration. Future synoptic measurement efforts would have a better chance of identifying variations attributed to septic system percolation if they were conducted later in the year when evapotranspiration effects are diminished. Stream-water samples analyzed for nitrate, bacteria, or other sewage tracers would provide an independent indicator of septic system percolation. Additional streamgages in small drainage basins in HDS and LDS areas would enable further analysis using hydrograph separation techniques to provide a more complete seasonal evaluation of the relative contributions attributed to septic system percolation.

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Appendixes

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012.

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
1	333212085031901	High	9/12/2012	1340	0.01	0.04	25	19.43	58	—	7.4	—
4	333173085030401	Mid	9/12/2012	1417	0.01	0.02	25	20.19	120	5.28	7.3	—
5	332850085053601	Low	9/12/2012	1458	0.33	0.49	8	19.75	57	7.57	7.46	—
6	333785084582201	High	9/12/2012	1143	0.02	0.10	25	18.35	42	6.56	7.91	—
7	333760084585101	High	9/12/2012	1230	0.05	0.05	10	22.49	54	3.97	7.29	—
8	333753084570601	Mid	9/12/2012	1059	0.09	0.10	10	18.5	38	5.18	7.46	—
9	333649084507001	Mid	9/11/2012	1714	0.23	0.23	10	19.79	31	7.04	6.34	—
11	333165084479101	Low	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	Culvert dry.
12	334347084543301	Mid	9/12/2012	—	0.00	0.00	Dry	—	—	—	—	Culvert dry.
13	334516084544201	High	9/12/2012	—	0.00	0.00	Dry	—	—	—	—	Dry downstream of culvert.
14	334517084552301	High	9/12/2012	0850	0.03	0.04	25	17.44	73	6.01	7.71	—
16	334245084505801	High	9/11/2012	1620	0.02	0.03	25	20.88	98	2.93	5.85	—
17	334347084460401	Mid	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	Dry approximately 75 feet downstream of culvert.
18	334308084460601	High	9/11/2012	1734	0.06	0.37	25	19.82	98	3.92	5.57	—
19	334351084464401	High	9/11/2012	1710	0.10	0.26	25	19.65	96	3.78	6.31	—
20	334575084429401	High	9/11/2012	1602	0.01	0.05	50	19.8	77	4.45	6.7	—
21	334414084435201	Low	9/11/2012	1631	0.10	0.15	25	20.17	79	6.36	7.12	—
22	334406084393601	High	9/11/2012	1525	0.00	0.00	Dry	—	—	—	—	Completely dry at culvert.
23	334594084406501	High	9/11/2012	1510	0.06	0.10	50	20.92	81	3.23	6.66	—
24	334620084390101	High	9/11/2012	1436	0.00	0.00	Dry	—	—	—	—	—
25	334512084397901	High	9/11/2012	1447	0.00	0.00	Dry	—	—	—	—	—
26	333989084361501	High	9/10/2012	—	0.04	0.10	10	20.42	104	5.97	5.91	—
28	334842084406601	High	9/11/2012	1337	0.04	0.04	50	22.54	87	5.8	6.94	—
29	335454084425001	High	9/11/2012	1213	0.00	0.00	Dry	—	—	—	—	Stream dry 50 feet upstream of culvert.

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012. —Continued

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
30	335487084410601	High	9/11/2012	1145	0.01	0.02	50	18.71	76	5.57	6.44	—
31	335486084400301	High	9/11/2012	1123	0.04	0.08	50	20.7	122	5.27	7	—
32	335592084393801	Mid	9/11/2012	1107	0.01	0.01	50	19.28	147	4.23	6.8	—
33	335110084344001	Mid	9/11/2012	1245	0.13	0.24	50	20.03	53	7.27	6.76	—
34	334909084376801	High	9/11/2012	1307	0.00	0.00	Dry	—	—	—	—	Dry upstream of culvert.
36	335384084328301	Low	9/11/2012	1559	0.04	0.03	50	20.8	105	5.15	6.44	—
37	335216084314001	Low	9/10/2012	1635	0.00	0.00	Dry	—	—	—	—	Stream dry downstream of culvert.
38	335421084322201	Low	9/10/2012	1540	0.00	0.00	Dry	—	—	—	—	Culvert completely dry.
39	335221084307501	Low	9/10/2012	1657	0.14	0.45	50	21.09	71	7.05	6.57	—
40	334713084257401	Low	9/12/2012	1240	0.04	0.12	10	19.68	675	5.59	7.2	—
41	334799084258901	Low	9/12/2012	1311	0.18	0.42	10	20.58	126	8.49	7.31	—
42	334566084257601	Low	9/12/2012	1136	0.06	0.10	10	22.34	167	6.86	7.09	—
44	333253084392101	Low	9/11/2012	0732	0.04	0.05	25	19.07	50	6.14	7.51	—
45	333361084360701	Low	9/11/2012	1156	0.33	0.30	10	20.84	95	0.5	6.81	—
46	333402084350501	Mid	9/11/2012	1104	0.03	0.05	10	19.45	78	3.98	8.27	—
47	333226084362101	Low	9/11/2012	1311	0.08	0.13	10	21.78	82	4.65	8.85	—
48	333163084377901	Low	9/11/2012	1413	0.09	0.18	10	19.82	36	5.8	9.34	—
49	333328084327001	Low	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	—
50	333524084314601	Mid	9/11/2012	0830	0.03	0.02	10	18.9	91	4.83	7.5	—
51	333481084327901	Mid	9/11/2012	0944	0.08	0.12	10	20.14	62	6.8	7.35	—
53	333777084314901	Low	9/10/2012	—	0.04	0.12	50	18.63	155	8.83	5.87	—
56	333525084304101	Mid	9/10/2012	—	0.05	0.03	50	20.67	61	6.21	6.29	Water smells like sewage.
57	333486084309501	Mid	9/11/2012	—	0.02	0.00	50	19.25	73	3.8	6.91	—
58	335711084336401	Low	9/10/2012	—	0.06	0.12	50	20.05	107	6.22	7.04	—

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012. —Continued

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
59	335636084331601	Low	9/10/2012	—	0.05	0.10	50	20.62	141	5.12	6.95	—
60	335653084327801	Low	9/10/2012	1502	0.00	0.00	Dry	—	—	—	—	—
62	335783084323101	Low	9/10/2012	1343	0.20	0.22	10	22.5	174	7.3	7.22	—
63	340033084286101	High	9/11/2012	1006	0.00	0.00	Dry	—	—	—	—	Stream dry 40 feet downstream of culvert.
64	335563084274401	Low	9/10/2012	1745	0.02	0.05	50	19.25	49	5.89	5.75	—
65	335843084285701	Mid	9/11/2012	0855	0.10	0.30	50	19.34	80	7.06	6.92	—
66	335903084270001	Mid	9/11/2012	0912	0.00	0.00	Dry	—	—	—	—	—
67	340016084260501	Mid	9/11/2012	0936	0.41	0.11	10	19.36	98	4.94	7.02	—
68	335806084250001	Low	9/11/2012	0815	0.00	0.00	Dry	—	—	—	—	—
69	335843084258501	Low	9/11/2012	0826	0.05	0.13	50	19.59	172	6.57	6.89	—
70	335740084252201	Mid	9/11/2012	0745	0.03	0.07	50	18.43	68	5.62	6.13	—
71	340388084232801	Mid	9/10/2012	1550	0.06	0.08	50	21.6	39	7.62	—	—
72	340335084221901	Mid	9/10/2012	1442	0.09	0.14	10	19.7	65	7.99	—	—
73	340326084223201	Mid	9/10/2012	1445	0.08	0.13	50	19.4	64	8.03	—	—
74	340468084215901	High	9/11/2012	0856	0.06	0.17	50	18.4	13	7.58	—	—
75	340373084209801	High	9/11/2012	—	0.05	0.05	50	18.8	81	7.13	—	—
78	340497084191301	Mid	9/11/2012	0925	0.00	0.00	Dry	—	—	—	—	Stream dry.
79	340430084180201	High	9/11/2012	1034	0.00	0.00	Dry	—	—	—	—	Stream dry.
80	340254084197601	Low	9/11/2012	0125	0.13	0.25	50	—	—	—	—	—
82	343’97084196601	Low	9/11/2012	1222	0.11	0.20	10	19.7	70.9	5.52	—	—
83	340395084176801	Low	9/11/2012	1300	0.00	0.00	Dry	—	—	—	—	Stream dry.
86	340215084178701	Low	9/11/2012	1340	0.07	0.17	25	19.6	115.3	2.94	—	—
87	335698084186801	Mid	9/11/2012	0836	0.00	0.00	Dry	—	—	—	—	—
88	335647084175401	Low	9/11/2012	0802	0.03	0.13	25	18.7	29	6.59	6.84	—

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012. —Continued

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
90	340484084188301	High	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
91	340566084199701	Mid	9/11/2012	0945	0.02	0.04	50	21.2	60.5	3.43	—	—
92	340506084190401	High	9/11/2012	1004	0.00	0.00	Dry	—	—	—	—	Stream dry.
93	340405084175201	Mid	9/12/2012	1104	0.09	0.11	10	19.8	68.9	5.35		—
99	340589084149301	Low	9/12/2012	0845	0.00	0.00	Dry	—	—	—	—	—
100	340711084141901	High	9/12/2012	1020	0.05	0.12	10	18.07	105	5.13	7	—
102	340974084133501	Mid	9/12/2012	1135	0.01	0.02	25	19.75	125	2.33	6.42	—
103	340794084134701	High	9/12/2012	0940	0.10	0.19	10	18.62	101	7.5	7.33	—
105	340941084128701	Mid	9/12/2012	1111	0.35	0.88	10	18.5	16	6.24	—	—
107	341030084139301	Mid	9/12/2012	1208	0.01	0.01	25	18.1	16	6.45	—	—
108	341303084122601	Mid	9/12/2012	0836	0.09	0.26	10	17.6	53	6.33	—	—
109	341169084087301	High	9/12/2012	0918	0.03	0.15	10	18.1	64	6.42	—	—
110	340936084092301	Mid	9/12/2012	0957	0.02	0.06	25	18.7	30.3	6.83	—	—
111	335699084135901	Low	9/10/2012	0938	0.14	0.14	10	20.13	57	6.42	6.54	—
112	335755084148501	Low	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
114	335857084144401	Low	9/10/2012	1233	0.01	0.04	50	19.4	105	6.7	6.92	—
115	340039084127601	Low	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
116	335971084129301	High	9/10/2012	1312	0.01	0.06	25	20.7	56	4.34	6.35	—
117	335950084136901	Mid	9/10/2012	1347	0.31	0.20	10	19.8	73	7.08	6.84	—
118	340184084123401	Low	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
119	340406084105801	High	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
120	340448084103101	High	9/10/2012	1647	0.09	0.11	10	19.37	74	7.84	6.9	—
121	340424084107701	Mid	9/10/2012	1618	0.03	0.14	25	19.48	48	7.28	6.78	—
123	340375084100101	Mid	9/10/2012	1520	0.00	0.01	50	22.5	105	6.3	6.35	—

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012. —Continued

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
124	340263084064901	Mid	9/11/2012	1201	0.02	0.14	25	19.6	74	7.47	6.52	—
125	340304084074201	High	9/11/2012	1225	0.03	0.12	25	21.84	87	4.3	6.43	—
126	341478084145701	Low	9/12/2012	0801	0.00	0.00	Dry	—	—	—	—	No flow at culvert.
128	341450083515301	High	9/10/2012	1043	0.28	0.35	50	20.65	60	5.9	6.27	Possible rain effect.
130	341424083532001	High	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
131	341377083525601	Mid	9/10/2012	1321	0.03	0.25	50	—	—	—	—	Possible rain effect.
132	341343083539001	High	9/10/2012	1418	0.04	0.06	50	19	163	3.58	6.89	Possible rain effect.
133	341333083524801	High	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
135	341621083506101	High	9/10/2012	1701	0.52	0.32	50	21.85	183	7.16	6.9	Possible rain effect.
136	340398084056501	Low	9/11/2012	1324	0.00	0.01	5	24.98	58	9.18	7.84	—
137	340461084054901	High	9/11/2012	1407	0.15	0.11	25	19.56	90	7.46	6.66	—
138	340395084065101	Low	9/11/2012	1342	0.00	0.00	Dry	—	—	—	—	Stream dry.
140	340283083586301	High	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
141	340236083582701	High	9/10/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
142	340418084047701	Mid	9/11/2012	1450	0.01	0.02	50	—	—	—	—	No sonde readings taken.
143	340533084007501	Low	9/11/2012	0951	0.40	0.31	10	18.4	155	8.27	7.06	—
146	340977083566301	High	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
147	340709083561301	High	9/11/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
153	341268083560001	Mid	9/12/2012	0832	0.12	0.28	10	17.8	48	9.62	7.07	Possible rain effect.
155	341197083556901	Mid	9/12/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
156	341386083557001	Mid	9/12/2012	1116	0.92	1.13	8	18.79	53	9.99	7.26	Possible rain effect.
157	341326083528301	Mid	9/12/2012	1344	0.10	0.58	10	18.77	69	7.72	6.69	Possible rain effect.
159	340332083569301	Mid	9/12/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
160	340274083576401	High	9/12/2012	1659	0.04	0.24	25	19.94	82	5.19	6.21	—

Appendix 1. Streamflow, base-flow yield, and selected water-quality parameters during September 10–13, 2012. —Continued

[Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. —, data not available]

Basin number	Site number	Septic-system density classification	Date	Time (Eastern Standard)	Streamflow (cubic feet per second)	Base-flow yield (cubic feet per second per square mile)	Error percentage	Water temperature (degrees Celsius)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen concentration (milligrams per liter)	pH (units)	Remarks
161	340499083568701	n/c	9/13/2012	0750	0.20	0.15	10	17.55	67	7.76	6.58	—
162	340496083554401	Low	9/13/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
163	340252083570101	High	9/13/2012	—	0.00	0.00	Dry	—	—	—	—	Stream dry.
164	342833083450401	n/c	9/13/2012	1032	0.13	0.27	10	17.89	45	8.95	6.41	—
165	342936083464801	High	9/13/2012	1135	0.12	0.42	10	17.25	50	8.1	6.18	—
166	342778083478001	High	9/13/2012	1233	0.21	0.35	10	17.96	60	8.93	6.23	—
167	335016084222501	Low	9/12/2012	0952	0.01	0.04	25	20.66	189	2.22	6.13	Possible rain effect.
168	335221084207201	n/c	9/12/2012	0855	0.03	0.11	25	21.65	375	6.43	7.37	Possible rain effect.
169	335215084193501	Low	9/12/2012	0808	0.02	0.02	25	19.04	151	6.39	6.76	Possible rain effect.
172	335377084153801	n/c	9/11/2012	0937	0.88	2.07	10	20.44	96	7.35	7.06	Possible rain effect.
176	334613084180901	Low	9/12/2012	1430	0.21	0.26	10	20.92	211	7.91	7.4	—
177	334792084161101	Low	9/12/2012	1530	0.25	0.32	10	21.56	117	8.83	7.22	—
178	335451084128101	Low	9/11/2012	1055	0.03	0.23	25	20.65	68	—	7.12	Possible rain effect.
179	02336313	Low	9/12/2012	—	0.46	0.16	10	—	—	—	—	Streamgage site, daily mean streamflow.
180	02334578	n/c	9/12/2012	—	0.02	0.004	10	—	—	—	—	Streamgage site, daily mean streamflow.

Appendix 2. Characteristics of basins upstream of stream sites used for evaluation of septic system effects on streamflow.

[Geologic area: B, Brevard Fault Zone; NP, northern Piedmont; SP, southern Piedmont. Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. Units: mi^2, square mile; in/hr, inch per hour; in., inch; ft^3/sec, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Basin number	Site number	Subarea	Geologic area	Drainage area (mi^2)	Average soil permeability (in/hr)	Average water-table depth (in.)	Average bedrock depth (in.)	Impervious area (mi^2)	Number of septic sites	Septic system density		Average elevation (feet above NAVD 88)	Average slope (percent)	Total population in 2010	Population density (count per mi^2)
										Sites per mi^2	Classification				
1	333212085031901	D	NP	0.27	1.60	5.88	59.1	4.4	61	229	High	1,106	6.59	133	500
4	333173085030401	D	NP	0.33	1.60	5.88	59.1	1.4	34	102	Mid	1,106	5.61	158	475
5	332850085053601	D	NP	0.68	1.61	5.87	59.0	4.7	24	35	Low	1,122	6.05	68	100
6	333785084582201	D	NP	0.22	1.60	5.88	59.1	6.1	54	251	High	1,186	5.20	96	446
7	333760084585101	D	NP	0.96	1.68	5.82	58.7	6.8	248	259	High	1,181	6.72	679	708
8	333753084570601	D	NP	0.89	1.65	5.85	58.8	1.6	84	94	Mid	1,172	6.50	242	271
9	333649084507001	D	NP	1.00	1.79	5.74	58.1	6.5	175	176	Mid	1,078	7.35	337	338
11	333165084479101	D	SP	0.43	1.60	5.88	59.1	0.5	13	30	Low	829	7.50	10	23
12	334347084543301	C	NP	0.55	1.94	5.64	57.3	18.7	103	186	Mid	1,160	6.13	324	585
13	334516084544201	C	NP	1.86	1.70	5.81	58.6	3.8	448	241	High	1,114	5.98	1,125	606
14	334517084552301	C	NP	0.79	1.62	5.86	59.0	6.8	252	317	High	1,108	5.43	672	846
16	334245084505801	C	NP	0.62	1.88	5.68	57.6	4.7	126	202	High	1,140	6.52	182	291
17	334347084460401	C	NP	0.49	1.60	5.88	59.1	17.2	23	47	Mid	1,143	5.39	542	1,113
18	334308084460601	C	NP	0.15	1.60	5.17	50.1	51.4	42	282	High	1,144	7.51	129	867
19	334351084464401	C	NP	0.37	1.60	5.88	59.1	19.1	264	704	High	1,164	5.02	586	1,563
20	334575084429401	C	NP	0.26	1.59	3.94	34.5	20.7	163	632	High	1,108	6.30	448	1,736
21	334414084435201	C	NP	0.67	1.59	3.94	34.5	31.5	10	15	Low	1,133	6.05	1,004	1,506
22	334406084393601	C	NP	0.71	1.59	3.94	34.5	11.5	201	282	High	998	5.89	755	1,059
23	334594084406501	C	NP	0.59	1.59	3.94	34.5	11.2	206	347	High	1,073	6.89	609	1,028
24	334620084390101	C	NP	0.59	1.59	3.94	34.5	18.6	199	338	High	1,008	5.53	866	1,471
25	334512084397901	C	NP	1.81	1.59	3.94	34.5	12.7	436	240	High	1,028	6.76	2,943	1,623
26	333989084361501	D	SP	0.38	1.64	5.85	58.9	5.6	146	380	High	866	6.71	262	684
28	334842084406601	C	NP	0.93	1.59	3.94	34.5	4.0	202	218	High	1,043	7.80	492	530
29	335454084425001	C	NP	1.41	1.60	5.88	59.1	10.5	321	227	High	1,032	6.35	2,222	1,572
30	335487084410601	C	NP	0.29	1.60	5.88	59.1	6.6	92	319	High	1,025	4.67	303	1,054
31	335486084400301	C	NP	0.52	1.60	5.88	59.1	12.7	154	299	High	1,047	6.90	970	1,882
32	335592084393801	C	NP	1.15	1.60	5.88	59.1	9.6	131	114	Mid	1,018	6.71	1,624	1,411
33	335110084344001	C	NP	0.53	1.59	3.94	34.5	35.8	63	119	Mid	1,043	6.01	1,783	3,358

Appendix 2. Characteristics of basins upstream of stream sites used for evaluation of septic system effects on streamflow.—Continued

[Geologic area: B, Brevard Fault Zone; NP, northern Piedmont; SP, southern Piedmont. Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. Units: mi^2, square mile; in/hr, inch per hour; in., inch; ft^3/sec, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Basin number	Site number	Subarea	Geologic area	Drainage area (mi^2)	Average soil permeability (in/hr)	Average water-table depth (in.)	Average bedrock depth (in.)	Impervious area (mi^2)	Number of septic sites	Septic system density		Average elevation (feet above NAVD 88)	Average slope (percent)	Total population in 2010	Population density (count per mi^2)
										Sites per mi^2	Classification				
34	334909084376801	C	NP	0.20	1.59	3.94	34.5	15.9	135	679	High	975	7.83	246	1,239
36	335384084328301	C	NP	1.35	1.59	3.94	34.5	34.4	12	9	Low	1,011	6.37	5,748	4,262
37	335216084314001	C	NP	0.85	1.59	3.94	34.5	28.5	0	0	Low	1,020	6.83	2,664	3,146
38	335421084322201	C	NP	0.32	1.59	3.94	34.5	24.5	0	0	Low	1,083	3.44	825	2,615
39	335221084307501	C	NP	0.32	1.59	3.94	34.5	25.8	0	0	Low	1,048	4.52	991	3,090
40	334713084257401	C	SP	0.31	1.71	2.58	17.5	57.3	3	10	Low	911	6.73	19	63
41	334799084258901	C	SP	0.44	1.71	2.58	17.5	51.5	8	18	Low	910	6.64	280	633
42	334566084257601	C	SP	0.63	1.71	2.58	17.5	30.4	0	0	Low	1,001	6.57	2,650	4,208
44	333253084392101	D	SP	0.81	1.60	5.88	59.1	7.2	19	24	Low	1,001	5.59	386	478
45	333361084360701	D	SP	1.11	1.60	5.88	59.1	11.7	23	21	Low	999	4.31	1,113	1,007
46	333402084350501	D	SP	0.17	1.60	5.88	59.1	2.8	24	141	Mid	998	7.84	77	449
47	333226084362101	D	SP	0.66	1.60	5.88	59.1	25.3	18	27	Low	998	6.41	1	2
48	333163084377901	D	SP	0.48	1.60	5.88	59.1	7.2	16	33	Low	997	4.72	17	35
49	333328084327001	D	SP	0.89	1.60	5.87	59.0	39.6	7	8	Low	948	5.60	591	665
50	333524084314601	D	SP	1.66	1.59	3.94	34.5	9.4	221	133	Mid	966	6.57	1,578	952
51	333481084327901	D	SP	0.64	1.59	3.95	34.7	23.4	72	113	Mid	984	6.20	752	1,175
53	333777084314901	D	SP	0.32	1.59	3.94	34.5	27.8	12	37	Low	984	5.56	40	125
56	333525084304101	D	SP	1.43	1.59	3.94	34.5	17.7	111	78	Mid	964	6.91	2,215	1,549
57	333486084309501	D	SP	4.29	1.59	4.07	36.1	20.1	330	77	Mid	953	6.55	7,211	1,683
58	335711084336401	C	NP	0.50	1.59	3.94	34.5	18.4	0	0	Low	1,106	6.29	1,041	2,088
59	335636084331601	C	NP	0.49	1.59	3.94	34.5	29.4	0	0	Low	1,099	6.89	1,060	2,186
60	335653084327801	C	NP	0.35	1.59	3.94	34.5	36.1	1	3	Low	1,104	6.23	658	1,863
62	335783084323101	C	NP	0.93	1.59	3.94	34.5	41.0	0	0	Low	1,112	6.33	2,205	2,365
63	340033084286101	C	NP	1.05	1.59	3.94	34.5	16.4	228	217	High	1,094	5.21	2,609	2,488
64	335563084274401	C	NP	0.30	1.65	3.92	34.4	21.2	3	10	Low	1,023	5.85	745	2,504
65	335843084285701	C	NP	0.33	1.59	3.94	34.5	18.3	30	91	Mid	1,053	7.24	506	1,542
66	335903084270001	C	NP	0.46	1.59	3.94	34.5	9.4	32	70	Mid	1,054	7.00	935	2,044
67	340016084260501	C	NP	3.87	1.59	3.94	34.5	13.6	330	85	Mid	1,084	7.75	9,758	2,524

Appendix 2. Characteristics of basins upstream of stream sites used for evaluation of septic system effects on streamflow.—Continued

[Geologic area: B, Brevard Fault Zone; NP, northern Piedmont; SP, southern Piedmont. Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. Units: mi^2, square mile; in/hr, inch per hour; in., inch; ft^3/sec, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Basin number	Site number	Subarea	Geologic area	Drainage area (mi^2)	Average soil permeability (in/hr)	Average water-table depth (in.)	Average bedrock depth (in.)	Impervious area (mi^2)	Number of septic sites	Septic system density		Average elevation (feet above NAVD 88)	Average slope (percent)	Total population in 2010	Population density (count per mi^2)
										Sites per mi^2	Classification				
68	335806084250001	C	NP	0.21	1.59	3.94	34.5	20.5	7	33	Low	1,025	7.92	402	1,903
69	335843084258501	C	NP	0.40	1.59	3.94	34.5	37.0	3	8	Low	1,019	6.27	786	1,973
70	335740084252201	C	NP	0.46	1.63	3.93	34.4	37.4	34	75	Mid	1,035	4.03	935	2,054
71	340388084232801	B	NP	0.68	1.59	4.20	37.9	24.7	85	126	Mid	1,111	5.88	1,392	2,055
72	340335084221901	B	NP	0.64	1.59	4.38	40.2	10.3	112	176	Mid	1,139	4.95	842	1,325
73	340326084223201	B	NP	0.63	1.59	4.35	39.8	10.1	112	178	Mid	1,140	4.93	832	1,321
74	340468084215901	B	NP	0.32	1.60	5.12	49.5	8.3	73	225	High	1,149	4.98	406	1,254
75	340373084209801	B	NP	0.89	1.59	3.94	34.5	10.7	248	279	High	1,117	4.34	1,361	1,531
78	340497084191301	B	NP	0.33	1.64	4.96	47.6	12.2	34	103	Mid	1,089	6.15	448	1,360
79	340430084180201	B	NP	0.47	1.59	3.94	34.5	25.8	102	217	High	1,106	4.67	567	1,207
80	340254084197601	B	NP	0.50	1.59	3.94	34.5	23.9	1	2	Low	1,060	6.62	495	999
82	343’97084196601	B	NP	0.54	1.59	3.94	34.5	51.1	10	19	Low	1,095	5.43	61	114
83	340395084176801	B	NP	0.52	1.59	3.94	34.5	34.7	16	31	Low	1,087	6.84	783	1,509
86	340215084178701	B	NP	0.41	1.59	3.94	34.5	25.0	0	0	Low	1,053	7.42	434	1,051
87	335698084186801	B	NP	0.77	1.59	3.94	34.5	17.2	32	42	Mid	1,046	7.77	2,141	2,793
88	335647084175401	B	B	0.25	1.59	3.94	34.5	19.9	6	24	Low	1,030	6.83	552	2,252
90	340484084188301	B	NP	1.45	1.63	4.26	38.7	18.6	381	262	High	1,102	4.33	3,569	2,455
91	340566084199701	B	NP	0.41	1.83	5.72	57.9	16.3	54	133	Mid	1,102	4.51	430	1,059
92	340506084190401	B	NP	0.51	1.67	5.33	52.4	12.6	134	264	High	1,094	4.06	1,074	2,117
93	340405084175201	B	NP	0.83	1.59	3.94	34.5	24.9	72	87	Mid	1,091	5.23	2,638	3,197
99	340589084149301	B	NP	0.41	1.59	4.22	38.1	28.9	1	2	Low	1,067	5.94	2	5
100	340711084141901	B	NP	0.43	1.60	5.88	59.1	18.6	393	907	High	1,124	7.06	518	1,195
102	340974084133501	B	NP	0.37	1.60	5.88	59.1	9.1	32	86	Mid	1,091	6.76	51	136
103	340794084134701	B	NP	0.53	1.60	5.88	59.1	30.2	111	211	High	1,084	6.55	158	301
105	340941084128701	B	NP	0.40	1.60	5.88	59.1	3.9	29	73	Mid	1,109	7.97	138	347
107	341030084139301	B	NP	0.62	1.60	5.88	59.1	9.0	77	124	Mid	1,107	7.55	335	537
108	341303084122601	B	NP	0.36	1.60	5.88	59.1	1.6	40	112	Mid	1,140	7.30	107	301
109	341169084087301	B	NP	0.21	1.60	5.88	59.1	35.0	109	524	High	1,225	7.08	279	1,340

Appendix 2. Characteristics of basins upstream of stream sites used for evaluation of septic system effects on streamflow.—Continued

[Geologic area: B, Brevard Fault Zone; NP, northern Piedmont; SP, southern Piedmont. Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. Units: mi^2, square mile; in/hr, inch per hour; in., inch; ft^3/sec, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Basin number	Site number	Subarea	Geologic area	Drainage area (mi^2)	Average soil permeability (in/hr)	Average water-table depth (in.)	Average bedrock depth (in.)	Impervious area (mi^2)	Number of septic sites	Septic system density		Average elevation (feet above NAVD 88)	Average slope (percent)	Total population in 2010	Population density (count per mi^2)
										Sites per mi^2	Classification				
110	340936084092301	B	NP	0.26	1.60	5.88	59.1	29.6	30	114	Mid	1,235	3.62	64	240
111	335699084135901	B	B	1.00	1.59	4.63	43.2	23.4	3	3	Low	1,026	7.94	1,520	1,514
112	335755084148501	B	B	1.51	1.60	5.88	59.1	41.6	14	9	Low	1,022	8.50	1,510	1,003
114	335857084144401	B	B	0.27	1.60	5.88	59.1	22.5	2	7	Low	987	7.42	572	2,125
115	340039084127601	B	B	0.15	1.60	5.88	59.1	25.7	2	13	Low	954	1.92	256	1,684
116	335971084129301	B	B	0.17	1.60	5.88	59.1	35.6	42	253	High	968	7.27	352	2,113
117	335950084136901	B	NP	1.52	1.60	5.88	59.1	30.6	203	134	Mid	982	6.84	2,824	1,858
118	340184084123401	B	NP	0.48	1.66	5.84	58.8	28.4	4	8	Low	975	7.23	2,056	4,241
119	340406084105801	B	NP	0.54	1.60	5.88	59.1	20.3	340	630	High	1,110	6.81	1,120	2,076
120	340448084103101	B	NP	0.78	1.60	5.88	59.1	21.1	698	889	High	1,117	7.11	2,100	2,676
121	340424084107701	B	NP	0.22	1.60	5.88	59.1	25.2	30	139	Mid	1,115	6.54	827	3,828
123	340375084100101	B	NP	0.40	1.63	5.86	58.9	42.9	17	42	Mid	1,123	3.92	57	142
124	340263084064901	B	NP	0.15	1.60	5.88	59.1	21.7	6	41	Mid	955	2.84	162	1,112
125	340304084074201	B	NP	0.24	1.60	5.88	59.1	20.5	213	870	High	972	7.13	604	2,467
126	341478084145701	B	NP	0.22	1.60	5.88	59.1	8.6	4	18	Low	1,222	7.22	96	438
128	341450083515301	A	B	0.81	1.60	5.88	59.1	22.8	212	262	High	1,215	5.13	1,070	1,321
130	341424083532001	A	B	3.22	1.78	5.75	58.1	18.3	673	209	High	1,203	6.17	2,269	704
131	341377083525601	A	B	0.13	1.69	5.82	58.6	26.4	14	108	Mid	1,211	6.29	239	1,835
132	341343083539001	A	B	0.66	2.00	5.60	57.0	11.8	259	391	High	1,203	5.44	804	1,215
133	341333083524801	A	B	0.86	1.86	5.70	57.7	23.3	299	350	High	1,203	6.87	710	830
135	341621083506101	A	B	1.61	1.60	5.88	59.1	54.9	495	307	High	1,224	4.65	5,121	3,177
136	340398084056501	B	NP	0.19	1.94	5.64	57.3	18.4	4	21	Low	978	8.51	270	1,412
137	340461084054901	B	NP	1.39	1.77	5.76	58.2	13.2	295	212	High	1,054	8.79	1,859	1,337
138	340395084065101	B	NP	0.50	1.90	5.67	57.5	17.2	2	4	Low	983	7.92	461	921
140	340283083586301	A	SP	0.28	1.95	5.64	57.3	8.0	146	525	High	1,134	6.16	392	1,410
141	340236083582701	A	SP	0.31	2.00	5.60	57.0	7.6	68	222	High	1,155	6.28	348	1,138
142	340418084047701	B	NP	0.27	1.68	5.82	58.6	20.3	16	58	Mid	1,014	6.34	636	2,321
143	340533084007501	A	B	1.32	1.60	5.88	59.1	31.0	16	12	Low	1,087	7.24	1,027	779

Appendix 2. Characteristics of basins upstream of stream sites used for evaluation of septic system effects on streamflow.—Continued

[Geologic area: B, Brevard Fault Zone; NP, northern Piedmont; SP, southern Piedmont. Septic-system density classification: low, lower one third; mid, middle third; high, upper one third. Units: mi^2, square mile; in/hr, inch per hour; in., inch; ft^3/sec, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Basin number	Site number	Subarea	Geologic area	Drainage area (mi^2)	Average soil permeability (in/hr)	Average water-table depth (in.)	Average bedrock depth (in.)	Impervious area (mi^2)	Number of septic sites	Septic system density		Average elevation (feet above NAVD 88)	Average slope (percent)	Total population in 2010	Population density (count per mi^2)
										Sites per mi^2	Classification				
146	340977083566301	A	B	0.52	1.91	5.66	57.5	6.8	167	321	High	1,205	8.37	487	934
147	340709083561301	A	SP	0.41	1.60	5.88	59.1	16.0	159	388	High	1,214	5.48	497	1,211
153	341268083560001	A	B	0.44	2.00	5.60	57.0	4.6	56	127	Mid	1,189	9.13	280	636
155	341197083556901	A	B	0.47	2.00	5.60	57.0	4.5	44	93	Mid	1,170	7.80	177	375
156	341386083557001	A	B	0.81	2.00	5.60	57.0	7.6	131	161	Mid	1,193	6.21	410	504
157	341326083528301	A	B	0.18	1.75	5.78	58.3	24.6	24	135	Mid	1,255	7.12	47	265
159	340332083569301	A	SP	1.45	1.74	5.78	58.3	14.2	231	160	Mid	1,172	6.07	2,189	1,513
160	340274083576401	A	SP	0.17	2.00	5.60	57.0	22.0	36	218	High	1,161	7.25	261	1,578
161	340499083568701	A	SP	1.36	1.73	5.79	58.4	14.4	228	168	Mid	1,175	5.99	2,104	1,549
162	340496083554401	A	SP	0.04	2.00	5.60	57.0	19.4	1	23	Low	1,145	5.84	51	1,179
163	340252083570101	A	SP	0.54	2.00	5.60	57.0	8.2	116	214	High	1,144	7.06	453	836
164	342833083450401	A	SP	0.49	1.60	5.88	59.1	5.2	82	169	Mid	1,402	4.48	130	267
165	342936083464801	A	NP	0.30	1.60	5.88	59.1	0.1	94	317	High	1,422	6.75	168	566
166	342778083478001	A	NP	0.60	1.60	5.88	59.1	3.6	135	224	High	1,348	5.61	300	498
167	335016084222501	C	B	0.25	1.71	2.58	17.5	44.7	1	4	Low	972	7.50	1,772	7,011
168	335221084207201	B	SP	0.26	1.59	3.94	34.5	23.0	11	43	Mid	992	6.89	816	3,164
169	335215084193501	B	SP	0.66	1.59	3.94	34.5	22.4	13	20	Low	972	7.23	1,535	2,336
172	335377084153801	B	SP	0.42	1.59	3.94	34.5	63.3	20	47	Mid	1,006	6.05	1,837	4,349
176	334613084180901	B	SP	0.80	1.59	3.94	34.5	43.0	10	13	Low	1,010	4.93	4,475	5,597
177	334792084161101	B	SP	0.77	1.59	3.94	34.5	52.2	13	17	Low	1,022	5.93	1,694	2,193
178	335451084128101	B	SP	0.15	1.59	3.94	34.5	54.1	2	14	Low	1,038	5.18	231	1,574
179	02336313	C	SP	2.81	1.67	3.04	23.3	52.1	50	18	Low	884	7.74	3,305	18
180	02334578	B	SP	5.08	1.60	5.88	59.1	15.0	515	101	Mid	1,065	8.38	10,968	61

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