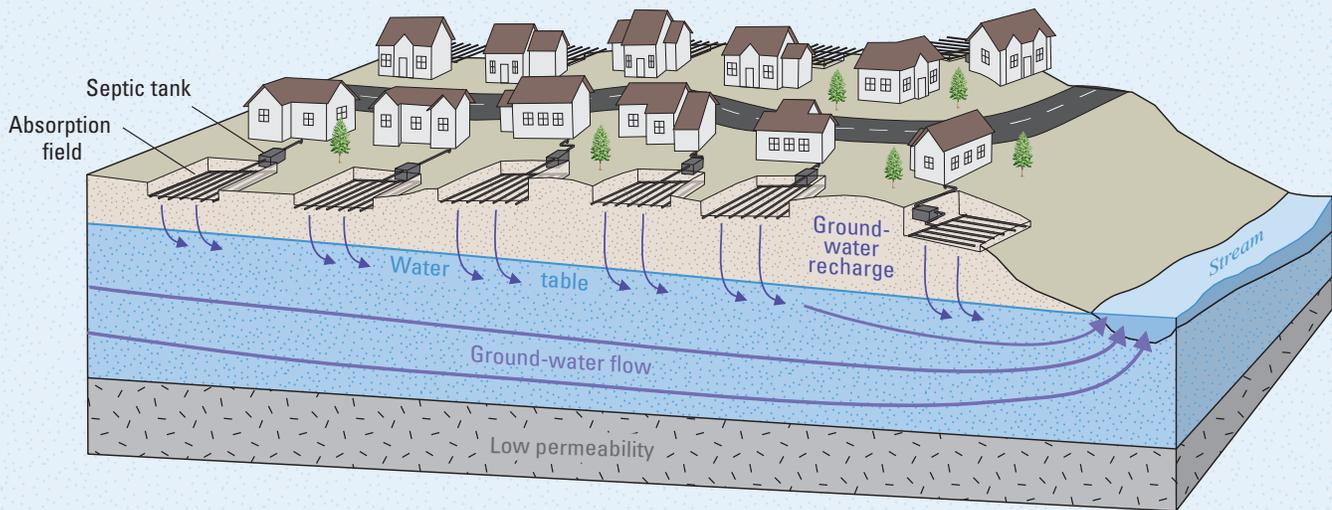


Prepared in cooperation with the Georgia Environmental Protection Division

Methods to Evaluate Influence of Onsite Septic Wastewater-Treatment Systems on Base Flow in Selected Watersheds in Gwinnett County, Georgia, October 2007



Scientific Investigations Report 2008–5220

Cover. See figure 1 on page 3.

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By Mark N. Landers and Paul D. Ankorn

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Conversion Factors

Multiply	By	To obtain
Length		
inch	2.54	centimeter (cm)
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)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	0.003785	cubic meter (m ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
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)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Methods to Evaluate Influence of Onsite Septic Wastewater-Treatment Systems on Base Flow in Selected Watersheds in Gwinnett County, Georgia, October 2007

By Mark N. Landers and Paul D. Ankorn

Abstract

The influence of onsite septic wastewater-treatment systems (OWTS) on base-flow quantity needs to be understood to evaluate consumptive use of surface-water resources by OWTS. If the influence of OWTS on stream base flow can be measured and if the inflow to OWTS is known from water-use data, then water-budget approaches can be used to evaluate consumptive use. This report presents a method to evaluate the influence of OWTS on ground-water recharge and base-flow quantity. Base flow was measured in Gwinnett County, Georgia, during an extreme drought in October 2007 in 12 watersheds that have low densities of OWTS (22 to 96 per square mile) and 12 watersheds that have high densities (229 to 965 per square mile) of OWTS. Mean base-flow yield in the high-density OWTS watersheds is 90 percent greater than in the low-density OWTS watersheds. The density of OWTS is statistically significant (p-value less than 0.01) in relation to base-flow yield as well as specific conductance. Specific conductance of base flow increases with OWTS density, which may indicate influence from treated wastewater. The study results indicate considerable unexplained variation in measured base-flow yield for reasons that may include: unmeasured processes, a limited dataset, and measurement errors. Ground-water recharge from a high density of OWTS is assumed to be steady state from year to year so that the annual amount of increase in base flow from OWTS is expected to be constant. In dry years, however, OWTS contributions represent a larger percentage of natural base flow than in wet years. The approach of this study could be combined with water-use data and analyses to estimate consumptive use of OWTS.

Introduction

The influence of onsite septic wastewater-treatment systems (OWTS) on base-flow quantity needs to be understood to evaluate consumptive use of surface-water resources by OWTS. Consumptive water use by OWTS has become an important water-management issue in Metropolitan Atlanta, Georgia, because of growing demands for limited water resources (Georgia Environmental Protection Division, 2008). An estimated 26 percent of the single-family housing units in Metropolitan Atlanta are served by OWTS—a higher percentage than is typical of most large cities in the United States (U.S. Department of Housing and Urban Development and U.S. Census Bureau, 2005). The number of OWTS in Metropolitan Atlanta during 2005 was estimated to be 526,000, of which 90 percent are residential, and about 13,000 new systems are installed each year (Metropolitan North Georgia Water Planning District, 2006). Surface water supplies more than 98.5 percent of the water used in Metropolitan Atlanta because the underlying aquifers typically do not support high-yield wells (Fanning, 2003). Surface-water use may be classified as consumptive when water is removed from a source and is not returned to the source for reuse immediately downstream (U.S. Geological Survey, 2002; Draper, 2006). Based on this definition, surface water treated in OWTS is nonconsumptive to the extent that water is returned to the source stream as base flow so that it is available for reuse downstream. If the influence of OWTS on stream base flow can be measured, and if the inflow to OWTS is known from water-use data, then water-budget approaches can be used to evaluate consumptive use.

Purpose and Scope

A reconnaissance-level investigation was conducted by the U.S. Geological Survey (USGS)—in cooperation with the Georgia Environmental Protection Division and the Gwinnett County Department of Water Resources—to compare stream base flow in watersheds with low and high densities of OWTS. Base flow was measured during October 2007 in 24 watersheds in an area of consistent geologic setting in southeastern Gwinnett County, Georgia. Spatial data were analyzed to characterize natural and anthropogenic watershed characteristics. The purpose of this report is to describe a method to evaluate ground-water recharge and base flow from OWTS, and to determine if OWTS density can be used to explain changes in base-flow quantity. This report does not include the water-use information needed to evaluate consumptive use by OWTS, and it does not include the water-chemistry analyses needed to evaluate the influence of OWTS on water quality.

Previous Studies

Previous studies found measurable changes in base flow that were attributed to recharge from OWTS, although most studies of OWTS have focused on water quality and the hydraulics of wastewater flow in the subsurface (McCray and Christopherson, 2008). In analyzing 22 years of stream-flow records, Simmons and Reynolds (1982) found that base flow declined from greater than 80 percent to less than 20 percent of total annual flow, and the decline was coincident with increased imperviousness and a transition from OWTS to centralized sanitary sewer systems in two urban watersheds in Long Island, New York. Base-flow declines during the same period were only about 10 percent in two nearby watersheds that were undergoing increased urbanization but were unsewered. Increased impervious surfaces and constructed channels have been found by many researchers to decrease infiltration and reduce base flow in urban areas (Leopold, 1968; Klein, 1979; Calhoun and others, 2003; Landers and others, 2007). However, Lerner (2002) reviewed studies of several cities that reported rising ground-water levels from leaking water-supply mains, wastewater, and drainage networks that more than offset the effects of reduced infiltration resulting from imperviousness. Urban ground-water recharge in Nottingham, United Kingdom, was evaluated by Yang and others (1999) using a combined solute-balance and water-balance approach that evaluated OWTS, leaking water mains and sewers, infiltration ponds, and natural sources. They found that the combined influence of these sources resulted in rising ground-water levels and increasing base flow. Heisig (2000) measured base-flow chemistry (but not quantity) over four seasons in 33 first- and second-order streams in the Croton River watershed in New York and

found a strong, positive relation between OWTS density and nitrate concentration. Burns and others (2005) found that base flow increased with residential density in three small watersheds in New York. Elevated nitrate and sulfate concentrations indicated that the increase was attributable to OWTS return flow, and the increased base flow was equivalent to the estimated flow into the OWTS from the watershed. These studies support the premise that increased ground-water recharge from OWTS may cause measurable increases in base flow.

Study Area

The study area is in northeastern Metropolitan Atlanta, Georgia, and has a mean annual precipitation of about 50 inches (National Weather Service, 2007). The area was in extreme drought during 2007, with a precipitation deficit of about 20 inches for the year. In the crystalline-rock aquifers underlying much of Metropolitan Atlanta, water transport and storage is primarily in regolith and fractures (Cressler and others, 1983). Annual ground-water recharge is approximately equal to annual base flow in unregulated streams in this geologic setting (Leeth and others, 2007). The small watersheds selected for this study are in the Ocmulgee and Oconee River Basins, which drain to the Altamaha River and the Atlantic Ocean. Public water, however, is supplied by interbasin transfer from the Chattahoochee River Basin, which drains to the Gulf of Mexico. Wastewater treatment in new neighborhoods of the study area is primarily through centralized systems, but older neighborhoods primarily use onsite OWTS.

Hydrology of Onsite Septic Wastewater-Treatment Systems

A typical OWTS consists of a watertight septic tank and an effluent-disposal absorption field (fig. 1). Wastewater is treated in OWTS by biological, chemical, and physical processes that take place in the septic tank and in the soil surrounding the absorption field. Large wastes are trapped in the septic tank by baffles and settle to the bottom of the tank where they are anaerobically digested. The absorption field typically is composed 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). An absorption-field trench typically is 1 to 4 feet (ft) deep, with a minimum distance of 2 ft above the maximum ground-water table or any impervious layer. This description is typical of most residential OWTS in Metropolitan Atlanta (Metropolitan North Georgia Water Planning District, 2006), although there are a wide variety of septic-system designs in use.

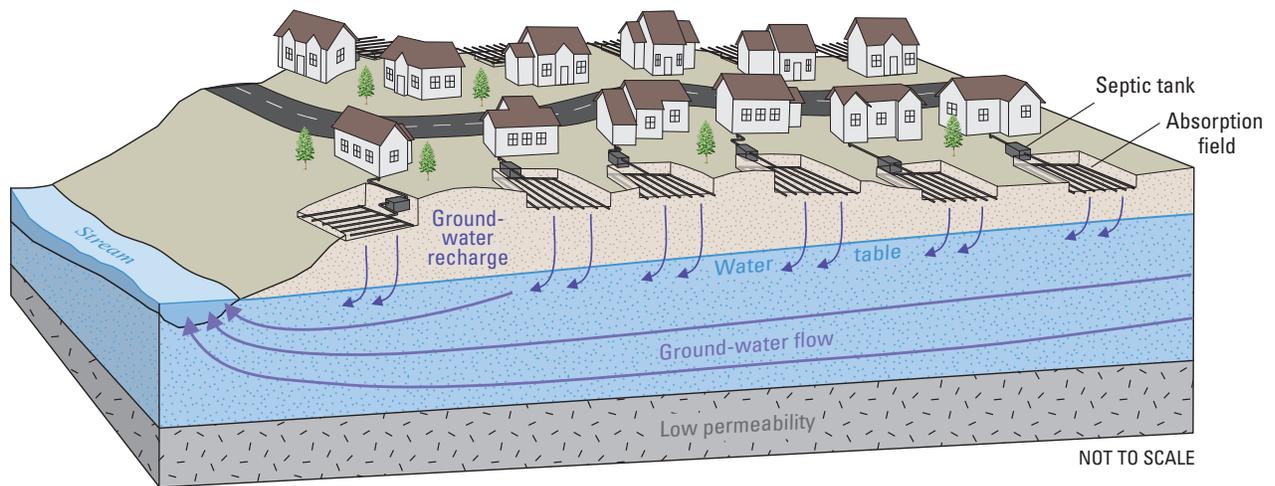


Figure 1. Conceptual diagram of ground-water recharge and increased base flow from onsite septic wastewater-treatment systems.

Mean indoor residential water use and septic-system outflows are relatively steady over time, in contrast to seasonal and annual variations of ground-water recharge from precipitation, which can be substantial in this region (Clarke and Peck, 1991). Evapotranspiration causes some seasonal losses (consumption) of septic-system outflows; however, design manuals specify that absorption fields be located away from large vegetation with deep root structure (Georgia Division of Public Health, 2007). Paul (2007) found evapotranspiration losses to be only 1 percent of septic-system outflows in a highly detailed water-budget study. Steady-state recharge from a high density of OWTS causes a localized rise in ground-water levels that increases hydraulic gradient and ground-water discharge (McCray and others, 2008). Stream base flow increases with increased hydraulic gradient where water tables are connected to streams, and this process can occur before recharge from a network of OWTS reaches the stream. Under the assumptions that recharge is equal to base flow and that a steady increase in hydraulic gradient develops as a result of septic-system recharge, increased base flow, initially from water in storage, roughly equals nonconsumptive septic-system recharge. If an annually steady-state ground-water-flow field to nearby streams is established from a dense network of OWTS, the question of travel time is not critical to

the effects on base-flow quantity or consumptive use. Thus, the ground-water recharge and increased base flow from a network of absorption fields and increased base flow are assumed to be annually constant. This assumption is limited to the specific geologic setting of the study area in which shallow ground-water recharge is approximately equal to base flow and surface- and ground-water basin divides typically coincide. This assumption also is limited to areas in which high densities of OWTS are likely to develop distinct ground-water-flow fields.

As an example, a hypothetical watershed with 640 OWTS per square mile (1 OWTS per acre) with indoor household water use of 200 gallons per day (gal/d), would receive ground-water recharge from OWTS absorption fields equivalent to about 2.7 inches per year (in/yr) over the watershed, assuming transpiration losses are negligible. Clarke and Peck (1991) estimated the mean ground-water recharge in southern Metropolitan Atlanta to be 6.5 in/yr and 0.8 in/yr during the severe drought of 1954. Steady inflow from a high density of OWTS, thus, could increase ground-water recharge by more than 100 percent during severe drought conditions. The annual contribution to base flow from OWTS would be constant (assuming steady-state water use and recharge-to-base-flow conditions), but the percentage of increase in base flow would be larger in dry years than in wet years.

Methods

An extensive reconnaissance was conducted to select 12 watersheds with a high density of OWTS (HDS) and 12 watersheds with a low density of OWTS (LDS). An arbitrary threshold of less than 100 OWTS per square mile was set for LDS and greater than 200 OWTS per square mile for HDS watersheds. Other watershed-selection criteria included similar geologic setting, precipitation, climate, accurate base-flow measurement locations, and available spatial datasets of natural, infrastructure, and water-use characteristics. Watershed boundaries and monitoring locations are shown in figure 2.

Watershed characteristics were determined using geographic information systems analysis of spatial datasets. Detailed spatial data were provided by the Gwinnett County Department of Water Resources, including a 1-ft digital elevation model, hydrography, water-supply pipe networks, detailed impervious area, and land lots designated with or without OWTS (Gwinnett County Information Technology Services, 2006). Land-use data were obtained from the 2005 regional dataset developed by the Atlanta Regional Commission (2007). Catchment boundaries were delineated and spatial data were determined for each watershed as listed in table 1. Point locations of OWTS were assigned to the centroid of land lots designated as having OWTS. The distance from each septic-system point to the nearest stream also was computed.

Table 1. Characteristics of selected watersheds in Gwinnett County, Georgia.

[ID, identification; mi², square mile; (ft³/s)/mi², cubic foot per second per square mile; μ S/cm, microsiemens per centimeter]

Watershed ID (see fig. 2 for locations)	High density (HDS) or low density (LDS) of septic systems	Drainage area (mi ²)	Count of septic systems	Density of septic systems (per mi ²)	Median distance septic systems to stream (feet)	Watershed impervious area, (percent)	Mean watershed slope (percent)	Base-flow yield, October 16–17, 2007 [(ft ³ /s)/mi ²]	Specific conduc- tance (μ S/cm)
1	LDS	3.24	70	22	534	4.2	8.8	0.140	42
2	LDS	0.60	15	25	415	3.3	10.6	0.378	72
3	LDS	1.03	37	36	534	4.3	8.5	0.178	42
4	LDS	0.24	22	93	563	11.6	7.3	0.146	39
5	LDS	0.57	30	52	281	5.4	5.8	0.068	60
6	LDS	2.04	82	40	353	4.1	6.5	0.087	75
7	LDS	0.43	20	46	295	6.3	10.6	0.402	52
8	LDS	0.49	22	45	309	3.0	9.2	0.147	67
9	LDS	1.14	81	71	522	7.8	7.7	0.174	56
10	LDS	1.70	152	89	389	7.3	8.3	0.228	55
11	LDS	1.62	105	65	392	7.6	7.8	0.162	64
15	LDS	0.65	62	96	460	15.2	4.6	0.105	59
12	HDS	1.27	378	299	344	12.3	9.1	0.454	55
13	HDS	3.40	779	229	383	13.2	8.0	0.196	59
14	HDS	0.67	245	366	341	16.1	8.5	0.464	62
16	HDS	1.00	486	485	326	26.4	5.7	0.177	77
17	HDS	0.65	384	595	454	20.1	7.5	0.568	82
18	HDS	0.38	302	797	494	18.4	7.4	0.463	89
19	HDS	0.07	72	965	346	20.3	7.8	0.729	96
20	HDS	0.21	159	752	273	18.3	6.0	0.338	43
21	HDS	0.44	246	555	208	17.5	8.6	0.280	116
22	HDS	0.75	304	406	206	18.9	7.0	0.089	53
23	HDS	0.20	120	604	213	18.4	7.3	0.120	94
24	HDS	0.26	172	656	179	20.0	7.6	0.373	91
Mean	LDS	1.15	58	57	421	6.7	8.0	0.185	57
Mean	HDS	0.78	304	559	314	18.3	7.5	0.354	76

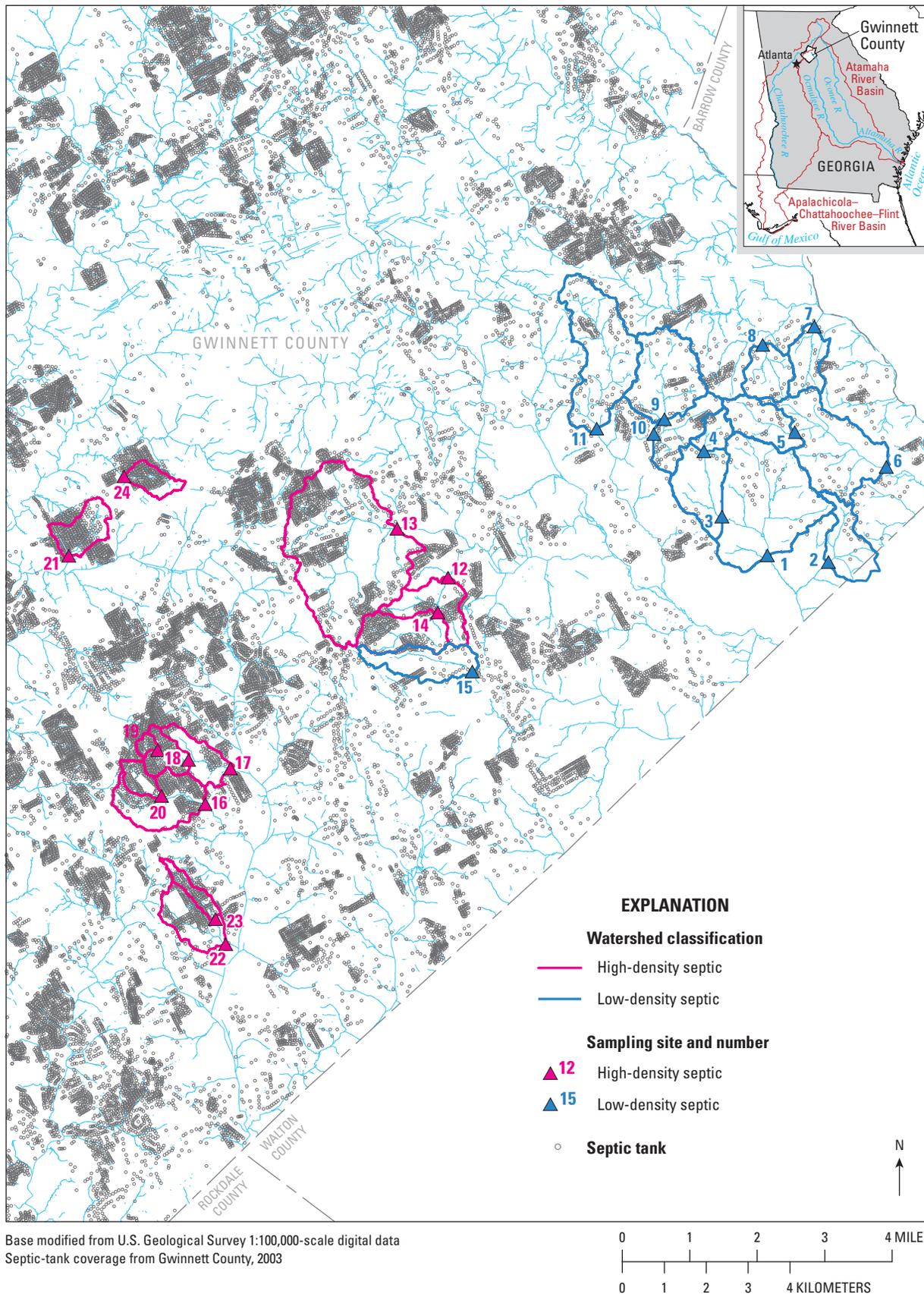


Figure 2. Locations of the study area, 24 watershed boundaries, sampling sites, and septic systems, Gwinnett County, Georgia.

Field-Measurement Methods

Stream base flow, specific conductance, water temperature, and fluorescence were measured in the outfalls of the 24 selected watersheds October 16–17, 2007, during extreme drought conditions. Only one set of field measurements was made during this reconnaissance-level investigation. Discharge was measured by using volumetric (11 sites) or velocity-area (13 sites) methods described in Rantz (1982), and specific conductance and water temperature were measured by using a calibrated multiparameter water-quality meter (Wilde and others, 1998). Specific conductance has been found to increase above local background levels with increasing wastewater inflows and increasing urbanization (Dow and Zampella, 2000; Dow and others, 2006; Rose, 2007).

Fluorescence was measured and analyzed as a potential sewage tracer by using methods described by Hartel and others (2007). Increased fluorescence may indicate the presence of optical brighteners, a component of most household laundry

detergents. Water samples were collected in amber glass bottles and analyzed before and after exposure to ultraviolet (UV) light to differentiate between other fluorescing organic compounds and optical brighteners, which rapidly degrade in UV light. Hartel and others (2007) found that optical brighteners likely were present when the fluorescence of the water before and after UV light exposure changed by more than a given percentage.

Influence of Onsite Septic Wastewater-Treatment Systems on Base Flow

The selected watersheds have OWTS densities ranging from 22 to 96 per square mile for the LDS watersheds and from 229 to 965 per square mile for the HDS watersheds (table 1). Two watersheds with high (watershed 14) and low (watershed 15) OWTS densities are shown in figure 3.

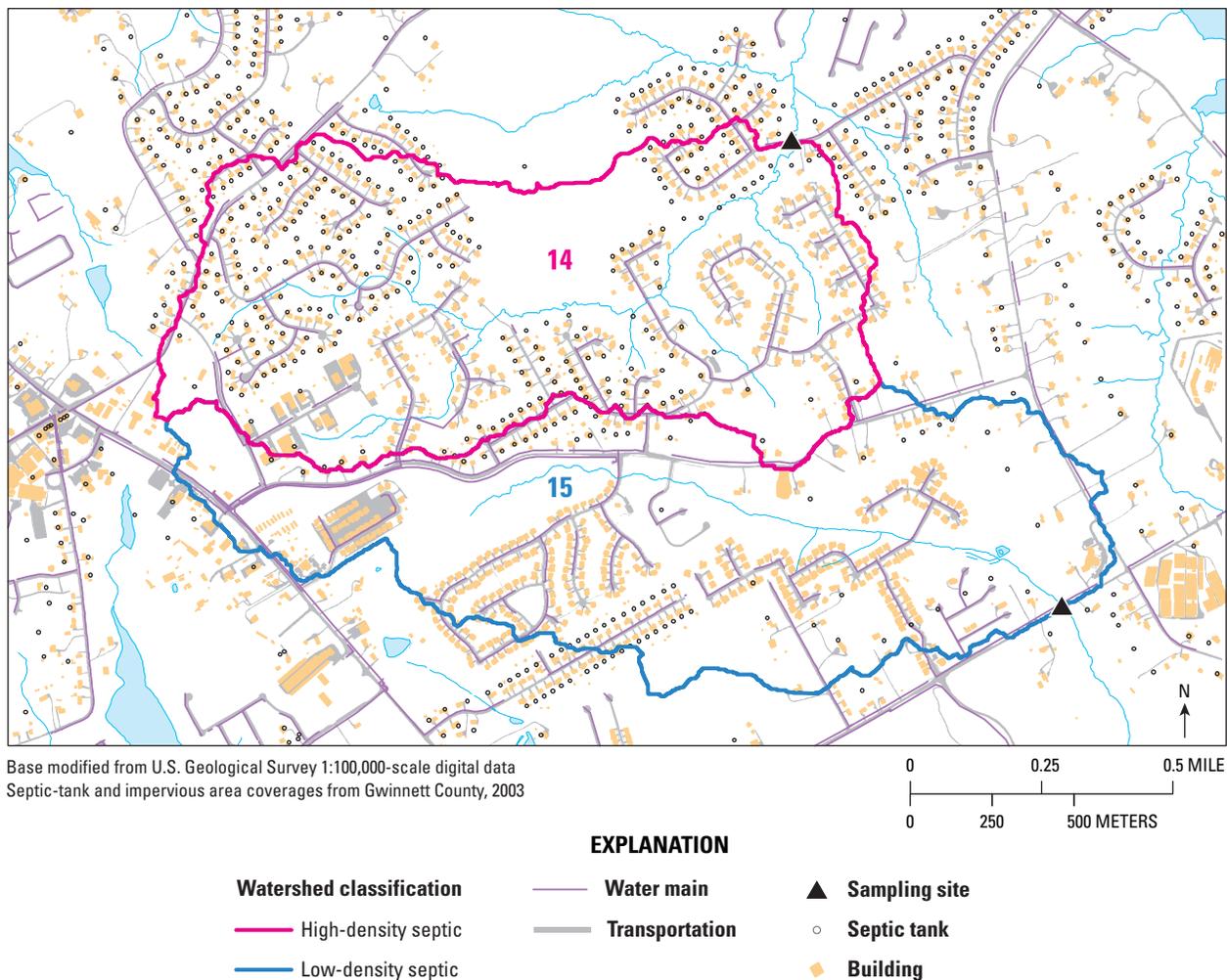


Figure 3. Locations of watershed boundaries, streams, sampling sites, septic systems, water mains, and building and transportation impervious areas for two watersheds—one with a high density of septic systems (watershed 14) and one with a low density of septic systems (watershed 15), Gwinnett County, Georgia.

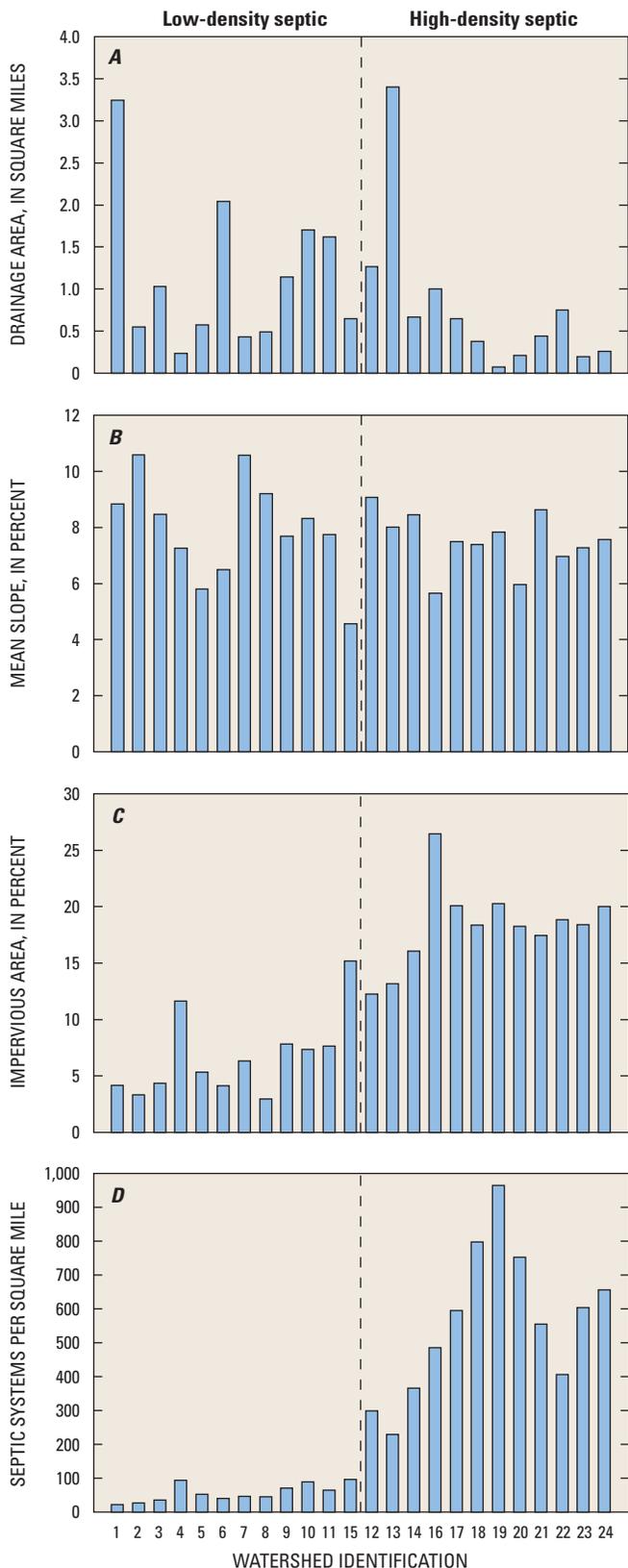


Figure 4. Watershed characteristics of (A) drainage area, (B) mean slope, (C) percentage of impervious area, and (D) septic-system density in 24 selected watersheds, Gwinnett County, Georgia.

The high-density OWTS network in the northwestern section of watershed 14 illustrates the coverage of ground-water recharge points that could cumulatively affect stream base flow. These watersheds include older residential areas served primarily by OWTS and newer residential areas served primarily by centralized sewer systems.

The LDS and HDS watersheds have similar ranges of drainage area and slope (table 1; fig. 4). Watersheds range in size from 3.40 to 0.07 square mile (mi²). Land use in the LDS watersheds is primarily agriculture (31 percent), forest (28 percent), and low-density residential (21 percent; typical lot sizes range from 2 to 5 acres). Land use in the HDS watersheds is primarily medium-density residential (typical lot sizes range from 0.25 to 2 acres), which averages 81 percent compared with only 10 percent in the LDS watersheds. The average impervious area is 6.7 percent in the LDS watersheds in contrast to 18.3 percent for the HDS watersheds (table 1, fig. 4C). Mean OWTS density in the LDS and HDS watersheds is 57 and 599 systems per square mile, respectively (table 1, fig. 4D).

Changes in Base-Flow Quantity and Quality

Base flow and specific conductance were measured in the 24 selected watersheds (figs. 5, 6). Base-flow yield (base flow per square mile) generally was higher in the 12 HDS watersheds than in the 12 LDS watersheds (fig. 6A,B). Mean base-flow yield in the HDS watersheds (0.35 cubic feet per second per square mile ($\text{ft}^3/\text{s}/\text{mi}^2$)) is 90 percent greater than in the LDS watersheds ($0.18 \text{ ft}^3/\text{s}/\text{mi}^2$). Results of a two-sample t-test of the base-flow yield measurements in the HDS and LDS watersheds indicate that the mean values are statistically different at a p-value equal to 0.01.

Measured specific conductance was generally higher in the HDS watersheds than in the LDS watersheds (fig. 6C). The mean specific conductance of the HDS and LDS watersheds is 76 and 57 microsiemens per centimeter, respectively. Results of a two-sample t-test of the specific conductance measurements in the HDS and LDS watersheds indicate that the mean values are statistically different at a p-value equal to 0.01. The higher specific conductance in HDS watersheds is indicative of increased base flow from OWTS recharge, but may also indicate the effects of other urban features.



Figure 5. Measurement of streamflow and water quality in a small watershed with a high density of septic systems, Gwinnett County, Georgia, October 16, 2007.

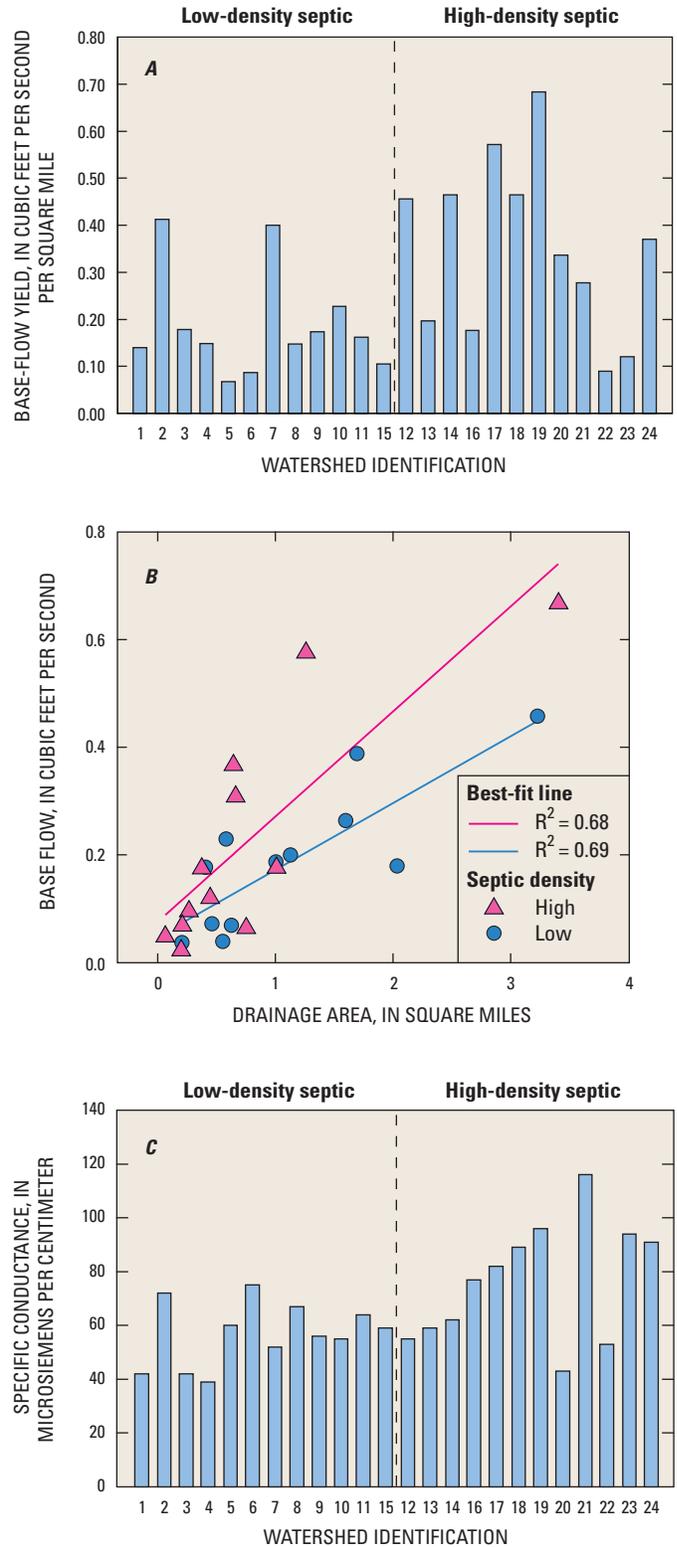


Figure 6. Streamflow characteristics of (A) base-flow yield, (B) base flow and drainage area, and (C) specific conductance measured during October 16–17, 2007, in 24 selected watersheds, Gwinnett County, Georgia.

Measured fluorescence before and after UV-light exposure did not change significantly between the HDS and LDS watersheds. This result indicates that septic-system treatment processes are effective in removing optical brighteners from water, and that no detectable failing OWTS were present in the watersheds during the measurement period. Hartel and others (2007) found that increased fluorescence was indicative of the presence of failing septic-system leachate. Measured water temperature did not vary significantly between the HDS and LDS watersheds.

Relation of Onsite Septic Wastewater-Treatment Systems to Changes in Base Flow

The results of this study indicate that base-flow yield is likely to be significantly higher in watersheds with high densities of OWTS. The density of OWTS is statistically significant (p-value less than 0.01) in relation to base-flow yield (fig. 7). The density of OWTS also is statistically significant (p-value less than 0.01) in relation to specific conductance. The amount of increase in base flow from OWTS is expected to be fairly constant, based on assumptions of steady-state septic-system recharge rates. However, the percentage of increase in base flow varies between dry and wet years with changes in natural recharge and base flow.

The results of this study indicate considerable variance in measured base-flow yield, as illustrated in figure 6A. Sources of variance may include discharge measurement error, which increases with very low discharge measurements, and unaccounted-for factors that affect base flow. The study approach attempts to account for most of the natural and anthropogenic factors affecting base flow. Natural factors that

can affect base flow in the study area include precipitation, drainage area, geology, evapotranspiration, land cover, and slope. The HDS and LDS watersheds in the study area have similar precipitation and geologic setting. Evapotranspiration was assumed to be negligible in the fall season when the measurements were made. Statistical analysis indicates that the correlation of base flow to OWTS density remains significant after accounting for the influences of drainage area, slope, and percentage of forest cover. Anthropogenic factors affecting base flow may include altered land cover, excess irrigation, streamflow withdrawals and returns, impoundments and regulated flows, OWTS, and leakage from water-supply mains. Water-main leakage was estimated to be 3.5 percent of total finished water during 2007 (George Kaffezakis, Gwinnett Department of Water Resources, written commun., January 2008). The density of OWTS remains statistically significant in relation to base-flow yield after normalizing for estimated water-main leakage. The selected watersheds are not influenced by impoundments, regulation, withdrawals, or return flows. The effects of excess irrigation are assumed to be negligible because a complete watering ban was in effect for about 20 days prior to making the base-flow measurements.

Landers and others (2007) found that impervious surfaces can decrease base flow in the study area; however, the influence of impervious surfaces is not accounted for in this study because the study design and data are not adequate for the analysis. Mean impervious area in the HDS watersheds is about 2.7 times higher than in the LDS watersheds, which reduces recharge from precipitation. However, the effect of additional recharge from OWTS appears to be greater than the effect of reduced recharge from precipitation because of impervious surfaces.

The consumptive use of OWTS could be estimated by extending the approach that is used in this study of comparing base flow in HDS and LDS watersheds. The extended approach would require base-flow measurements over multiple seasons, normalized for nonOWTS factors, and related to indoor water use. An estimate of annual consumptive use would require a series of base-flow measurements made seasonally, throughout the year. Although OWTS ground-water recharge may be steady state, the influence on base flow may be seasonal because of seasonal changes in storage and potentiometric surfaces. The extended approach would require normalizing measured base flow for additional factors, such as water-main leakage, to obtain the best estimate of increased base flow resulting from recharge from high densities of OWTS. The extended approach to estimate consumptive use also would require a best estimate of indoor water use in residences with OWTS in the selected watersheds. Consumptive use then could be estimated using a simple water balance between indoor water use and additional base flow per OWTS in the HDS watersheds. The consumptive-use estimate would be limited to the specific soils and geologic setting of the study area. The extent to which locally varying soil types and other geologic factors affect base flow in northern Georgia is uncertain, and many areas may have more complex geologic terrains than those of the study area.

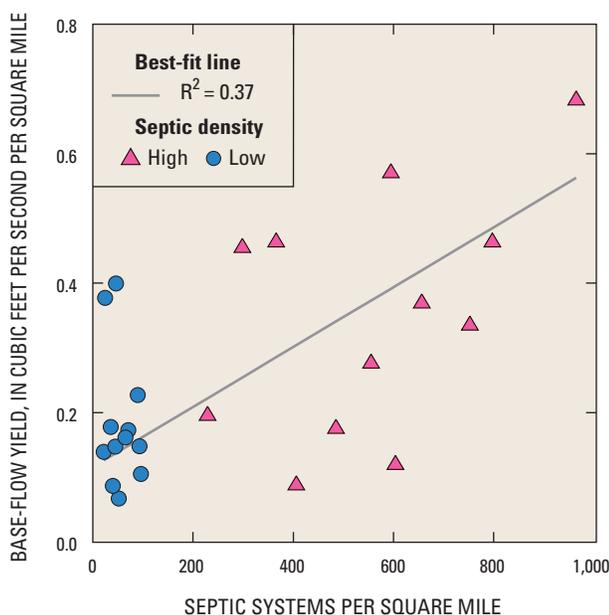


Figure 7. Base-flow yield and septic-system density in 24 selected watersheds, Gwinnett County, Georgia.

Summary

The results of this study indicate that base-flow yield is likely to be significantly higher in watersheds with high densities of onsite septic wastewater-treatment systems (OWTS) than in watersheds with low densities of OWTS, as examined in the specific geologic setting of the study area during the fall of 2007. The mean base-flow yield of the HDS watersheds (0.35 cubic feet per second per square mile) is 90 percent greater than that of the LDS watersheds (0.18 cubic feet per second per square mile). Specific conductance above background levels, a simple wastewater indicator, also was higher in the HDS than in the LDS watersheds. Results of two-sample t-tests of measurements in the HDS and LDS watersheds indicate that the mean values of both base-flow yield and specific conductance are statistically different and the density of OWTS in the watersheds is a significant factor in explaining increased base-flow yield. However, much unexplained variation remains for reasons that may include unmeasured processes, a limited dataset, and measurement errors.

Ground-water recharge from a high-density of OWTS is assumed to be steady state on an annual basis, resulting in a fairly constant increase in base flow from OWTS. In dry years, however, this amount represents a larger percentage of natural base flow than in wet years.

The results of this study indicate that the reconnaissance-level approach could be extended to estimate consumptive use of OWTS. An extended approach to calculate consumptive-use estimates would include base-flow measurements made in multiple seasons and normalized for non-septic-system factors, as well as indoor water-use estimates. Consumptive use could then be calculated using a water balance equaling the difference between indoor water use and increases in annual base flow resulting from OWTS. This approach would be applicable in geologic and climatic settings similar to those of this study.

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