science for a changing world

Prepared in Cooperation with the New York City Department of Environmental Protection

Effects of Residential and Agricultural Land Uses on the Chemical Quality of Baseflow of Small Streams in the Croton Watershed, Southeastern New York

Data on the chemical quality of baseflow from 33 small streams that drain basins of differing land-use type and intensity within the Croton watershed were collected seasonally for 1 year to identify and characterize the quality of ground-water contributions to surface water. The watershed includes twelve of New York City's water-supply reservoirs. Baseflow samples were collected a minimum of three days after the most recent precipitation and were analyzed for major ions, boron, and nutrients.

Findings—

- Concentrations of selected chemical constituents in baseflow were strongly affected by the predominant land use in a given basin. Land uses included forested undeveloped, unsewered residential, sewered residential, and agricultural (horse and dairy farms).
- A positive linear relation was indicated for chloride concentration in baseflow and the basin's annual rate of road-salt application (or density of two-lane roads). Chloride concentration exhibits a relatively stable relation to road-salt application rate or 2-lane road density throughout the year.
- Positive linear relations were indicated for nitrate concentration in baseflow and the basins unsewered housing density. Nitrate is characterized by a different relation to unsewered housing density for each season, with the highest observed nitrate concentrations during the winter and the lowest concentrations during the summer.
- Baseflow nitrate concentrations in sewered basins, and in unsewered basins with riparian wetland buffers between residential development and the stream, were lower than concentrations predicted from unsewered-housing density.

Croton watershed stream under baseflow conditions

U.S. Geological Survey
Department of the Interior

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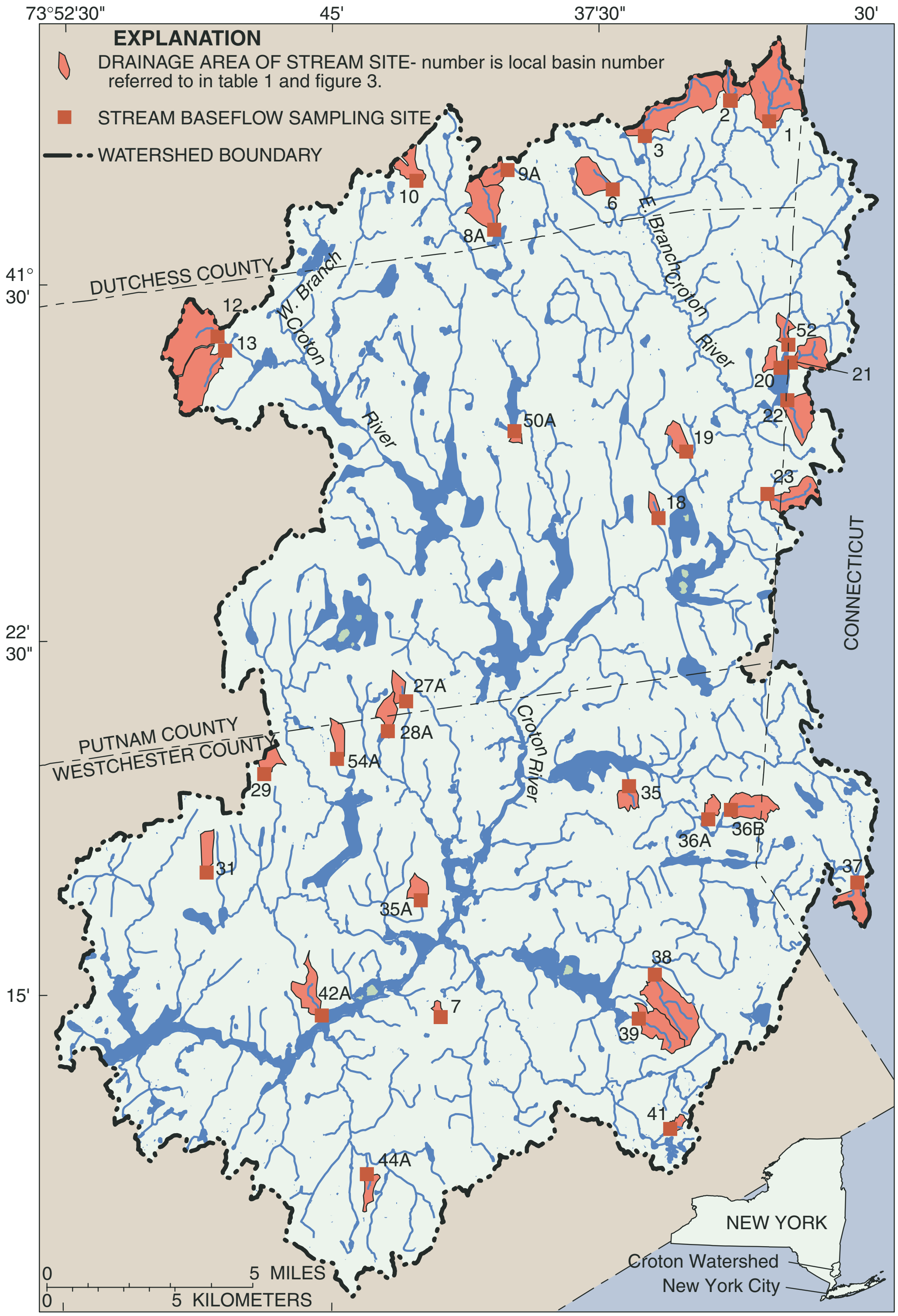


Base from U.S. Geological Survey
digital data, 1:100,000, 1983

Figure 1. Locations of the 33 baseflow-sampling sites and their respective basins within the Croton watershed in southeastern New York.

INTRODUCTION

The Croton watershed, a 374 mi^2 basin in southeastern New York, contains 12 reservoirs that together provide about 10 percent of New York City's water supply (fig. 1). The area is underlain by igneous and metamorphic bedrock mantled by a discontinuous cover of till of variable thickness in upland areas, and alluvium, peat-muck, and outwash in the main valleys. The watershed, which is directly north of the City and encompasses parts of Westchester, Putnam, and Dutchess Counties, has undergone significant suburban development. Undeveloped forested land is still predominant (57 percent) in the watershed, followed by residential development (25 percent) and agriculture (including fallow fields and parks) (7 percent) (Linsey and others, 1999). The population of the watershed in 1990 was about 176,000 (U.S. Department of Commerce, 1990). Deterioration of reservoir water quality and the possibility of federally mandated filtration of the water supply has resulted in increased regulation, monitoring, and investigation of watershed processes and human activities. In 1996, the United States Geological Survey (USGS) began a cooperative study with the New York City Department of Environmental Protection (NYCDEP) to assess ground-water quality within the Croton watershed.

Ground-water discharge is a major contributor to streams that feed New York City's water-supply reservoirs. The relatively stable flow of streams during periods of little or no precipitation, referred to as baseflow, is sustained totally or in large part by ground-water discharge (except in streams downgradient of reservoirs and lakes) (fig. 2). Ground-water discharge accounts for at least 60 percent of total annual streamflow, as indicated by physical separation of stream-discharge hydrographs (Rutledge, 1993) from two well-drained basins (minimal wetlands and surface-water impoundments) within the Croton watershed. Thus, the chemical quality of baseflow from a given stream basin gives an indication of the composite quality of the shallow ground water within that basin. Baseflow quality can differ from ground-water quality; nutrient concentrations in ground water may be diminished by bacterially mediated chemical transformations in and immediately below the streambed (hyporheic zone) as the water discharges to the stream, and the concentration of dissolved nutrients within the stream can be further diminished through algal and plant uptake. Nevertheless, baseflow samples provide a more accurate and cost-effective measure of the chemical quality of ground water contributions to the reservoirs than would ground-water samples from a regional well network.

This report documents the effects of land use on baseflow water quality at the 33 small (first- and second-order) streams that drain basins representative of the different type(s) and intensities of land use within the Croton watershed (fig. 2, table 1). Emphasis was given to identification of the effects of unsewered residential development on the chemical quality of baseflow because of the prevalence of this land use in the watershed. Small basins with drainage areas of 0.06 to 1.55 mi^2 were chosen over larger stream basins for: 1) better

Table 1. Physical and land-use characteristics of stream basins sampled in Croton watershed in southeastern New York, 1996-97.

[mi^2, square miles; mi/mi^2, miles per square mile; $tons/mi^2$, tons per square mile; $(tons/mi^2)/yr$, tons per square mile per year. Basin and station locations are shown in fig. 1.]

Local basin no.	USGS surface-water station no.	Basin characteristics			
		Area (mi^2)	Road density (mi/mi^2)	Road-salt-application rate [$(tons/mi^2)/yr$]	Housing density (per mi^2)
1††	0137448710	1.55	2.61	96.6	49.8
2	0137448720	0.32	1.19	43.9	12.5
3*	0137448605	1.33	4.04	149.3	207.8
6	0137448812	0.52	1.38	51.0	25
7	0137491450	0.06	14.20	474.8	600
8A	0137463580	0.74	1.26	43.2	35.1
9A	0137449120	0.28	0.61	22.4	17.9
10	0137462530	0.34	7.69	691.5	82.4
12	0137454950	1.27	2.43	155.8	2.4
13	0137454960	1.16	0.92	88.0	0
18	0137449520	0.11	14.96	553.7	839.3
19	0137449510	0.26	0.59	21.9	38.8
20	0137449440	0.15	25.76	980.9	1,020.1
21	0137449435	0.52	7.04	311.3	427.5
22	0137449445	0.57	15.18	576.9	714.3
23	0137449487	0.58	1.88	69.5	67.1
27A	01374853	0.17	7.91	363.5	494.1
28A	01374849	0.26	12.17	493.3	621.2
29 *	0137494905	0.23	1.65	64.2	121.7
31*	0137494710	0.25	14.07	520.5	944.9
33A	0137497652	0.23	5.60	164.1	182.6
35	01374790	0.22	1.32	48.8	4.5
36A	01374783	0.15	0.00	0	0
36B	01374785	0.58	1.03	38.2	13.8
37	0137470990	0.43	8.94	330.9	556.8
38	01374889	1.08	1.12	41.5	2.8
39	01374893	0.67	0.27	10.2	1.5
41	0137490520	0.12	9.15	335.8	208.3
42A	0137498830	0.49	3.03	98.9	61.2
44A†	0137498290	0.19	12.14	482.2	363.2
50A	0137464640	0.06	25.14	820.2	1,100
52	0137449430	0.19	5.25	355.8	347.4
54A	01374936	0.25	6.93	256.3	308.9

* Sewered
† 30-percent sewered
†† Horse and dairy farms

control over the type and intensity of land use(s) within each basin, and 2) rapid return to baseflow conditions after storms (within 3 days; based on flow records from USGS gaging station 0137497600, which has a drainage area of 3.01 mi^2). Other criteria used in the selection of study sites included 1) the absence of upgradient point-source discharges (typically from sewage-treatment plants), (2) the absence of upgradient surface-water bodies (other than small ponds or wetlands) that could store and contribute water derived from previous storms or increase biological activity (nutrient uptake) by increasing surface-water residence times, and 3) basin-wide distribution of sites, including representation of major metamorphic and igneous bedrock types.

The stream network was sampled four times (July-August 1996, October-November 1996, January 1997, and May 1997) to document seasonal baseflow water quality at each site. Grab samples collected from each stream at least 3 days after the most recent storm were analyzed for major ions, boron, and nutrients (nitrogen and phosphorus compounds) by the USGS National Water Quality Laboratory in Arvada, Colo. Field measurements included specific conductance, pH, dissolved oxygen, and temperature. The field data and results of the laboratory analyses are given in Butch and others (1998). Analyses of nitrate plus nitrite are herein referred to as nitrate because nitrite is an unstable, low concentration (or undetected), intermediate product of nitrification that is ultimately converted to nitrate.

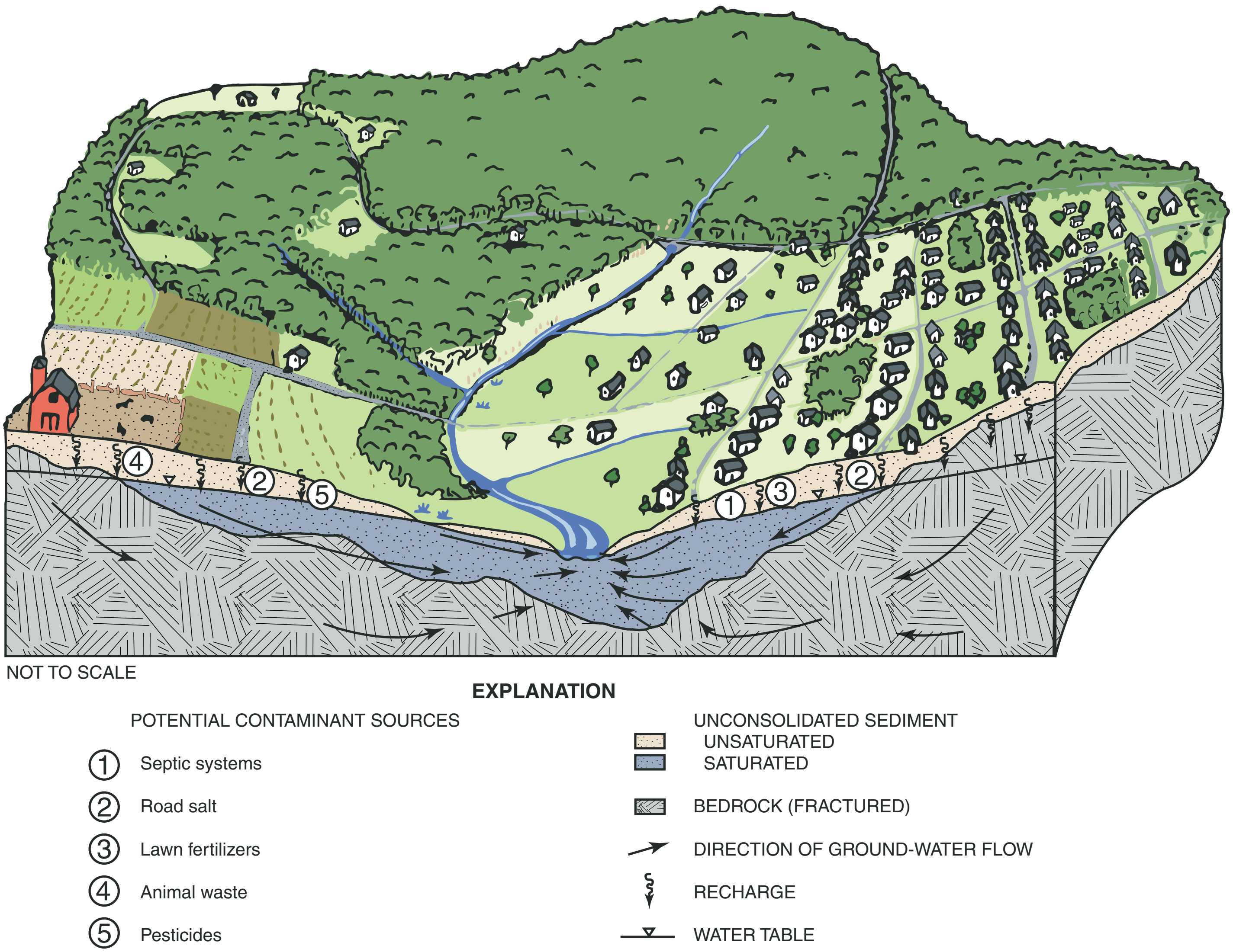


Figure 2. Hypothetical stream basin within the Croton watershed showing ground-water flow toward the stream along with potential contaminant sources associated with residential development and agriculture.

DOES LAND-USE TYPE AFFECT BASEFLOW CHEMICAL QUALITY?

Baseflow chemical quality differs among streams that drain basins dominated by one of four major land uses within the Croton watershed: 1) undeveloped forested, 2) unsewered residential, 3) sewered residential, and 4) agricultural (herein referred to as horse and dairy farms). Chemical quality of baseflow from the four basins with the highest percentage or intensity of each of these land uses is depicted in figure 3 and discussed below.

Undeveloped Forested (Basin 36A)

Basin 36A (fig. 1) is the only entirely forested basin sampled during this study; therefore, its baseflow chemical quality reflects natural undisturbed conditions and provides a standard for comparison with other basins. The baseflow in this basin has the lowest average concentrations of all constituents studied--the median concentrations of ammonia, total phosphorus, and orthophosphate were below detection limits (fig. 3). Increases in specific conductance and chemical constituents in the other basins relative to those in the forested undeveloped basin (36A), are expressed as an "enrichment factor" representing the number of times by which the value for the given developed basin exceeds that for the forested undeveloped basin.

Unsewered Residential (Basin 20)

Each home in unsewered residential areas is served by an on-site septic system that ideally discharges wastewater to the unsaturated zone, where it percolates downward to the water table and becomes shallow ground water. The basin with the greatest density of septic systems is basin 20 (fig. 1), which contains part of a lakeside community and is characterized by high densities of houses (1,020 houses/mi^2) and roads (25.8 mi /mi^2). Specific conductance and the concentrations of all constituents except the phosphorus species (which were below detection limit) exceeded those found in the baseflow of the undeveloped forested basin (fig. 3). The specific conductance of baseflow from basin 20 exceeds that in the undeveloped forested basin baseflow by a factor of 14. Baseflow from basin 20 also has higher average concentrations of chloride (93x), sodium (47x), sulfate (2x), boron (5x), nitrate (25x) and ammonia (greater than 4x) than that in the forested undeveloped basin. These values reflect the high intensity of unsewered residential development in basin 20.

High concentrations of chloride and sodium are primarily attributed to winter application of salt on the many roads that accompany intensive residential development, as discussed later. Less elevated levels of chloride and sodium are also characteristic of domestic wastewater.

Sulfate, boron, ammonia, and organic nitrogen are initially present in septic effluent (Robertson and others, 1991; Harmon and others, 1996; LeBlanc, 1984), but in properly working septic systems, most organic nitrogen and ammonia are oxidized to nitrate during transport through the unsaturated zone to the water table. Therefore, nitrate is the dominant nitrogen species in ground-water discharge to streams, although reduced nitrogen species can persist in ground water and surface water, as in basin 20 (fig. 3; table 1), where the unsaturated zone is thin or of low permeability, or where septic systems fail. Fertilizers applied to lawns are a secondary source of nutrients that may vary with lawn size and neighborhood affluence. The high housing density, small lot size, and hillside setting within basin 20 limits lawn area and thus may limit fertilizer application. Nitrate concentrations can be diminished through 1) denitrification as ground water passes through organic-rich sediments or wetland areas prior to reaching a stream and 2) biologic (algal and plant) uptake after discharge to the stream.

Phosphorus species typically found in septic effluent were not detected in baseflow samples from basin 20; their absence is attributed to mineral precipitation and strong adsorption onto sediments upon discharge from septic systems to ground water. These processes greatly retard downgradient migration relative to the velocity of the local ground water. Phosphorus species may reach streams where sorption sites are saturated; this is most likely to occur where septic systems have been in service for many years (Harmon and others, 1996). Phosphorus concentrations in ground water discharging to streams can be decreased through uptake by algae and plants.

Sewered Residential Areas (Basin 31)

Sewered residential areas are served by sanitary sewers that route domestic wastewater away from these areas to a sewage-treatment plant that typically treats and discharges the effluent to a point downstream of the basin. In instances where sewering post-dates the housing, a small number of houses may still be served by septic systems. Basin 31 has the highest density of housing of the three sewered residential basins sampled, but the housing density (945 houses/mi^2) and road density (14.1mi/mi^2) are lower than in basin 20 (unsewered) because the house lots are larger.

Constituent concentrations were higher in baseflow from the sewered residential basin (basin 31) than in the undeveloped forested basin, but were lower (except for the phosphorus species) than in the unsewered residential basin. This basin's enrichment values for specific conductance (9x), chloride (37x), and sodium (18x) are much less than those from the unsewered residential basin, largely because the sewered basin's road density is lower; the general lack of septic system discharges could also contribute to lower concentrations. The enrichment factors for sulfate (1.7x) and boron (4x) are similar to those from the unsewered residential basin, whereas the enrichment factors for nitrate (7x) and ammonia (>2x) are lower, and the orthophosphate value (>3x) is higher. Potential sources of these constituents include leaky sanitary sewer lines, septic discharges from the few homes not connected to sanitary sewers, and lawn fertilizers. Leakage from sanitary sewer lines is a likely source because the main sewer line in the basin closely follows the stream course, in which case 'breakthrough' of orthophosphate from sewer line to stream might occur. The elevated boron concentration is probably derived from the first two sources because (1) it is typically not an ingredient of homeowner-applied fertilizers (although it may be present in professionally applied fertilizers), and 2) bedrock is not an important source, as indicated by low concentrations of boron in baseflow samples from undeveloped forested basins with different bedrock types.

Horse and Dairy Farms (Basin 1)

Most horse and dairy farms are in the eastern part of the Croton watershed. Basin 1 contains the highest percentage of this land use (about 12 percent of the basin) sampled in this study; the remaining land uses in this basin are fallow fields, undeveloped forested, and low-density unsewered residential. The housing density (50 houses/mi^2) and road density (2.6 mi/mi^2) are much lower than in the residential basins.

The average water quality of baseflow from basin 1 is consistent with the types and intensities of land use previously described. The low enrichment values for specific conductance (4x), chloride (6x), and sodium (3x) reflect the low number of roads in an agricultural area and the low enrichment values for sulfate (1.2x) and boron (1.3x) reflect the low housing and septic-system density in the area. All nutrient concentrations in baseflow from basin 1 are among the highest of any of the basins sampled and appear to indicate animal-waste inputs. The enrichment values for ammonia (>5x), total ammonia and organic N (>1.5x), and total phosphorus (>4x) are greater than those for the two residential basins (20 and 31). The nitrate enrichment value (9x) is similar to that for the sewered residential basin and is well below the value for the unsewered residential basin. Orthophosphate enrichment (>2x) in this basin is similar in magnitude to the value for the sewered residential basin (basin 31).

Elevated concentrations of nutrients in baseflow from basins with horse and dairy farms may be derived from sources other than shallow ground-water discharge; for example, animal waste can enter streams directly where livestock are allowed to roam in and around the streams, and small, contaminated ponds or temporary impoundments can gradually drain into streams. Nutrients from these surface sources can enter streams in dissolved and particulate forms whereas nutrients in ground-water discharge presumably are only in dissolved form.

Dissolved phosphorus in a stream can be removed through sorption onto sediment particles or through uptake by algae, thereby becoming particulate phosphorus (measured as part of total phosphorus) that is largely unavailable to the stream until scoured and suspended by higher flows. Dissolved phosphorus can also be removed from the stream through uptake by aquatic plants.

Elevated concentrations of reduced nitrogen species (organic nitrogen and ammonia) in baseflow are indicative of a surface- or ground-water source that is near the stream; this implies short residence time for these nitrogen species at land surface or within a shallow ground-water environment prior to reaching the stream. Otherwise, ammonia is transformed (through nitrification) to nitrate, a stable form of nitrogen, under oxidizing conditions. Particulate organic nitrogen, like particulate phosphorus, may be derived directly from surface sources or from discharge of dissolved forms from ground water with subsequent uptake by algae. Dissolved nitrogen species may be derived from either ground-water discharge or surface sources (impoundments).

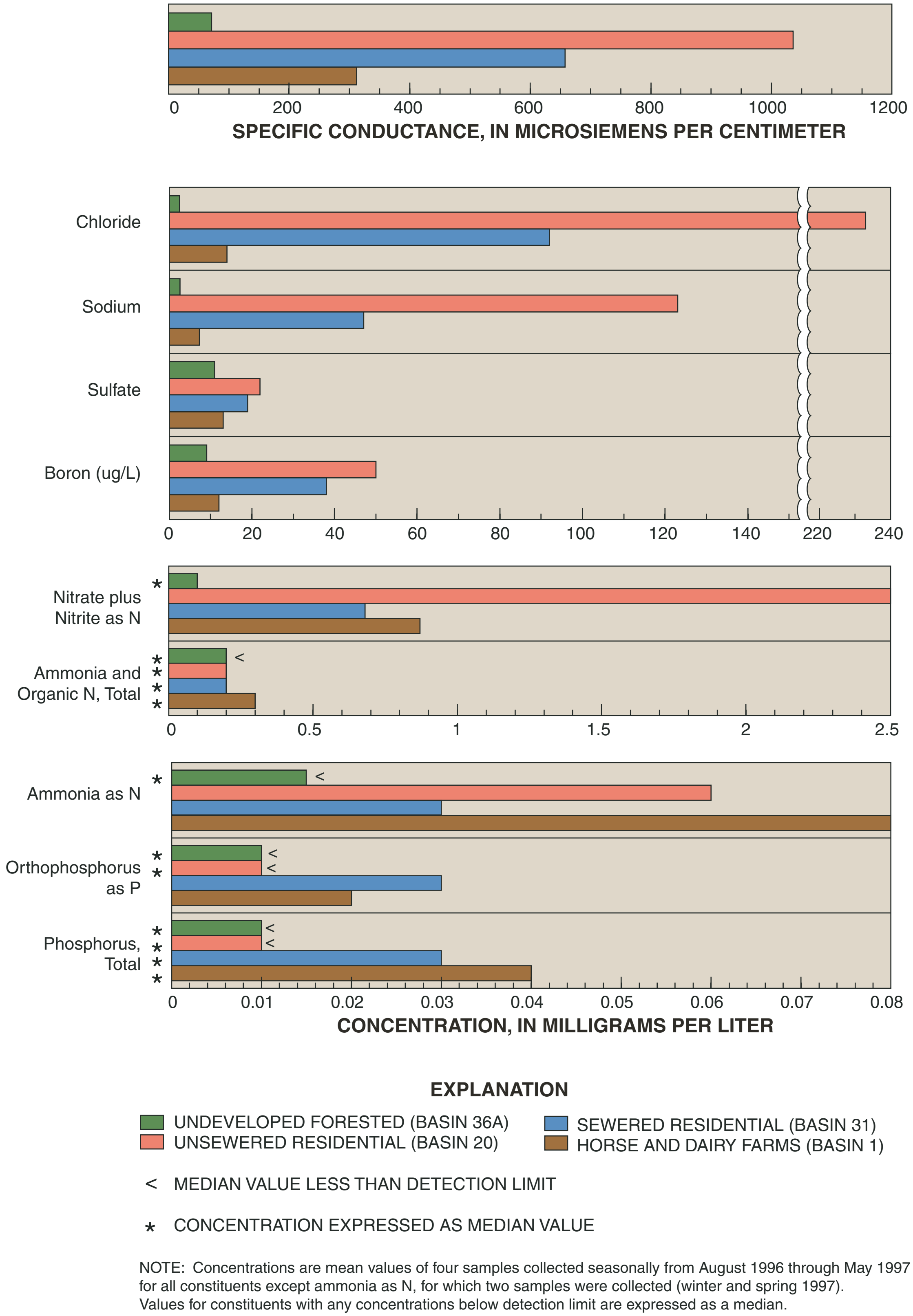


Figure 3. Baseflow chemical quality from four small stream basins (identified in parenthesis) representing four different land uses within the Croton watershed in southeastern New York (locations are shown in figure 1).

DOES THE INTENSITY OF RESIDENTIAL DEVELOPMENT AFFECT THE CHEMICAL QUALITY OF BASEFLOW IN A PREDICTABLE WAY?

Residential development is the most common form of development within the Croton watershed, and domestic wastewater is most commonly disposed of through individual septic systems. The intensity of the main solute-generating activities associated with unsewered residential development (road-salt application and domestic-wastewater disposal) was estimated and compared with baseflow chemical quality through simple statistical procedures. The intensity of unsewered residential development in each basin was estimated by calculating (1) the density of roads per square mile along with estimation of annual road-salt application per square mile, and (2) the density of housing (septic systems) per square mile. The responses of baseflow water-quality constituents to the intensity of road-salt application or domestic wastewater disposal varies from marked to no discernible effect; these responses, with emphasis on chloride and nitrate, are discussed in the following sections.

Land-use-percentage data for each basin were not used to evaluate effects of land use on baseflow chemical quality because this data set is limited to two broadly defined housing-density categories that preclude evaluation of unsewered residential development as a continuum. Furthermore, residential land-use percentages are derived from land-cover data of limited resolution (30-m by 30-m pixels) and have a lower limit of 30 percent constructed area per pixel for designation as residential land use (U. S. Geological Survey, 1998). The result is that some areas of low-density residential development are not recognized and are erroneously assigned to non-residential land-use categories.

Road-Salt Application

Deicing salts applied to roads during the winter are a primary source of solutes to ground water in the study area. Sodium chloride in solid form is the most commonly used deicing salt, but calcium- and magnesium-chloride salts (liquid and solid forms) are used in some areas. The liquid salts provide immediate deicing action upon application to roads and are generally applied as an additive on slower and longer acting sodium chloride and sand mixtures.

Quantifying Road Salt Application

The intensity of road-salt application in each sampled basin was quantified as an annual application rate (AAR), in tons per square mile of basin. Basin areas were determined from topographic maps, and the number of road miles within each basin was obtained from geographic information system (GIS) road coverages modified from Linsey and others (1999). Adjustments were made to both data sets after field verification. Values for each basin are given in table 1. The annual average amount of road salt purchased, and the number of road miles salted were obtained through telephone interviews with town, county, and State officials. Annual application rates per lane of town roads were virtually the same as those for county and State roads, including the Taconic Parkway (fig. 1), but the rate per lane for Interstate 84 (fig. 1) was 3 to 4 times higher than for the other road types.

The road classifications, and their respective application rates, are given in the table below.

The AAR for each basin was calculated as the sum of the road salt application amounts associated with each road category divided by the basin area. Road-salt application amounts by road category are equal to total road miles within the basin multiplied by the percentage of road miles represented by the given road category, multiplied by the corresponding application rate listed above.

AARs for the 33 basins ranged from 0 to 980 (tons/mi²)/yr (table 1).

[Location of four-lane roads are shown in fig. 1.]

Road Category	Road-salt-application rate, in tons per mile of roadway per year
Town, County, and State Roads (2 lane)	37
Taconic Parkway (4 lane)	75
Interstate 84 (4 lane)	298

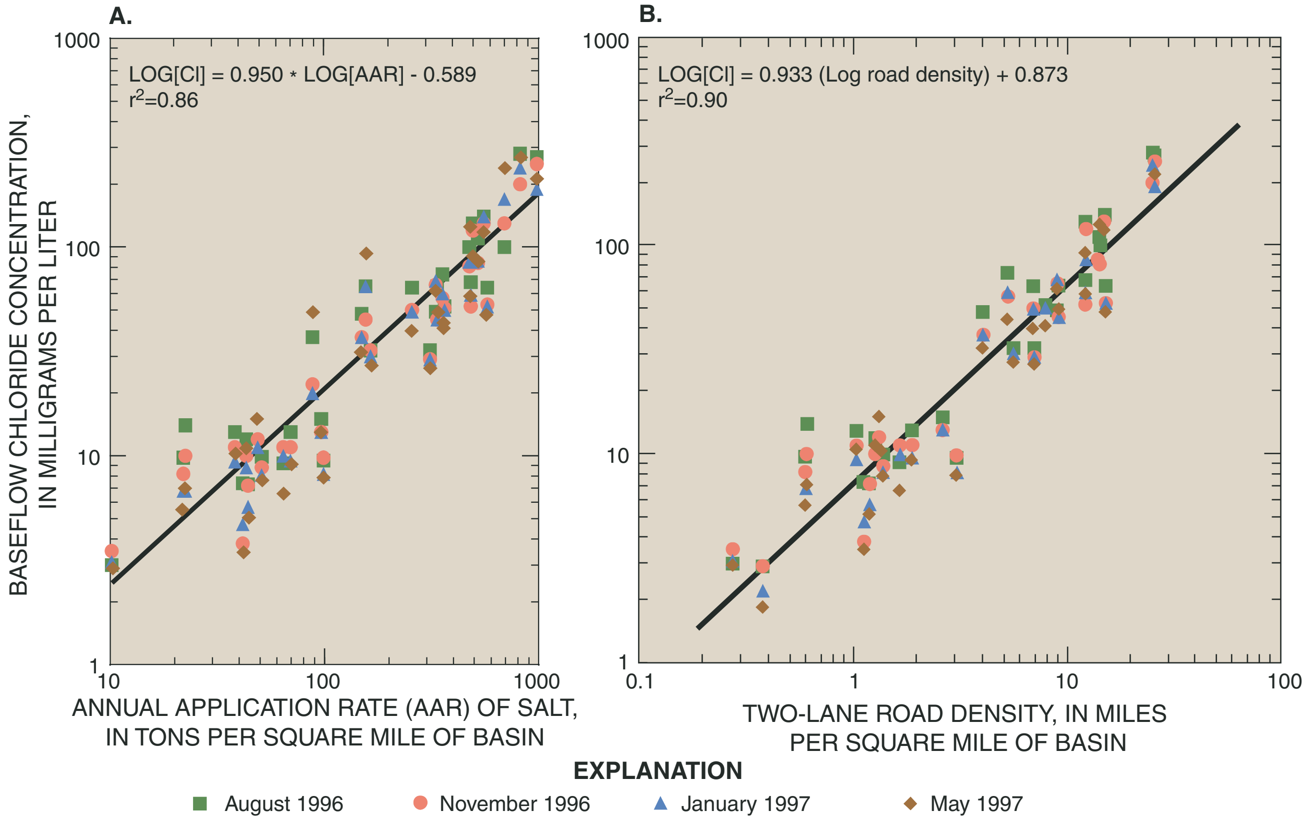


Figure 4. Relation of the concentration of chloride in baseflow in small streams in the Croton watershed in southeastern New York, August 1996 through May 1997, to: A. Annual road-salt application. B. Density of two-lane roads.

Solid forms of sodium chloride and calcium chloride used in the Northeast are 98 and 97 percent pure, respectively (Granato, 1996); thus, chloride, sodium, and calcium, (as well as magnesium, where magnesium chloride salt is used) are the primary solutes associated with road salting activities that might affect the chemical character of baseflow in streams. Chloride is the best indicator of road-salt application because it is a primary component of all road-deicing compounds and because it is chemically unreactive in most environments. The concentrations of chloride in baseflow of streams sampled in this study ranged widely—from 1.8 to 280 mg/L.

Secondary sources of chloride include domestic-wastewater and water-softening-unit discharges. Robertson and others (1991) documented 24 and 38 mg/L of chloride in the cores of wastewater plumes from two septic systems. Water-softening units discharge spent brine as well as calcium and magnesium ions to ground water through septic systems or dry wells; annual sodium chloride (halite) usage of 700 to 1,000 pounds per unit is commonplace. These treatment systems are most likely to be used in households that draw their water supply from marble bedrock or unconsolidated sediments containing marble, although their use for removal of iron is apparently widespread.

Sodium, calcium, and magnesium vary in their usefulness as indicators of road-salt application in the study area, but may be more useful in other areas. Sodium is the second-best indicator after chloride because sodium chloride is used in most areas. High concentrations, of sodium, however, may be decreased by exchange for calcium and magnesium at exchange sites on sediments in the unsaturated-zone and the shallow ground-water flow system. Secondary sources of sodium are domestic-wastewater and water-softening system discharges. Calcium and magnesium are less reliable indicators than sodium because (1) their use in road salting within the watershed is sporadic, (2) weathering of marble bedrock is a major source locally, (3) domestic-wastewater and water-softening-system discharges are secondary sources, and (4) their concentrations can be decreased through cation-exchange processes.

Log chloride concentrations in baseflow are plotted as a function of log annual application rate (AAR) of road salt in figure 4A which represents all 33 basins and all three road categories (see highlighted box). Log chloride concentration also can be plotted as a function of log road density mi^2 of basin for those basins with only two-lane roads, as described above (fig. 4B). Both plots indicate strong positive relations that provide two ways of predicting chloride concentrations in stream baseflow. The relation of log chloride to log AAR (fig. 4A) is most useful in basins with more than one road category, and the relation of log chloride to log two-lane-road density (fig. 4B) is most useful in basins without major highways. This latter relation has the advantage that it does not require road-salt application-rate estimates (AAR), but rather, road mileage, which is relatively easy to determine.

The seasonal variability in chloride concentrations at the sampled sites tends to increase with increasing chloride concentration; however, individual regression lines for each sampling period (not shown) are generally parallel and tightly clustered around the regression line for all samples. This indicates that the ground waters that sustain baseflows are a consistent source of chloride, unlike stormflows, which typically have the highest chloride concentrations during the winter and spring (Ku and Simmons, 1986). The consistency of chloride concentrations in ground water may be due to several factors. First, salts can be held at land surface or in the unsaturated zone, rather than being completely flushed downward to the water table during the spring, as evidenced by observations of salt crusts along some roads throughout the year. Thus, rain that infiltrates land surface at other times of year can dissolve this salt and transport it downward into the unsaturated zone or to the water table. Rises in the water table in response to recharge resaturates portions of the unsaturated zone and may also dissolve stored salt. Peak concentrations of chloride in ground water may be decreased through dispersion during transport and by dilution through convergence with water from deeper zones (with potentially lower chloride concentrations) at discharge areas.

Several other factors can potentially decrease or increase the concentrations of chloride in the baseflow of a given stream, and contribute to the scatter or bias seen in figures 4A and 4B. Application rates can be lower than predicted if narrow roads are salted in one pass rather than two, and application rates can be higher than predicted if unpaved roads are present, because they generally require more frequent salt applications than paved roads. Decreases in baseflow chloride might be expected in basins in which efficient stormwater routing, including curbed streets and storm sewers, transports a larger percentage of road salt out of a basin during stormflows than in basins without such infrastructure. Similarly, steep-sided basins may also transport a larger percentage of road salt in stormflows than gently sloped basins. Chloride concentrations in streams that drain sewered basins may be lower than those in unsewered basins because the sewers route domestic wastewater (and its chloride content) outside the basins to treatment plants. However, baseflow concentrations of chloride from sewered basins 31 and 29 show little departure from the regression lines, indicating little effect from sewering. Finally, the proximity of roads and housing to the stream might influence baseflow chloride concentrations; higher chloride concentrations might be expected where roads and housing are concentrated near the stream because ground-water transport distance and dispersion of chloride are minimized.

Domestic Wastewater Disposal

Disposal of domestic wastewater through septic systems is an important source of solutes to the shallow ground-water system. Effluent plumes emanating from septic-system leach fields typically have slightly to moderately elevated concentrations of most major ions and of nitrate (Robertson and others, 1991), as well as boron, which is used in detergents. Nitrate, boron, and sulfate are the most reliable indicators of domestic wastewater in stream baseflow; chloride, sodium, calcium, and magnesium are less reliable because they can be derived from multiple sources.

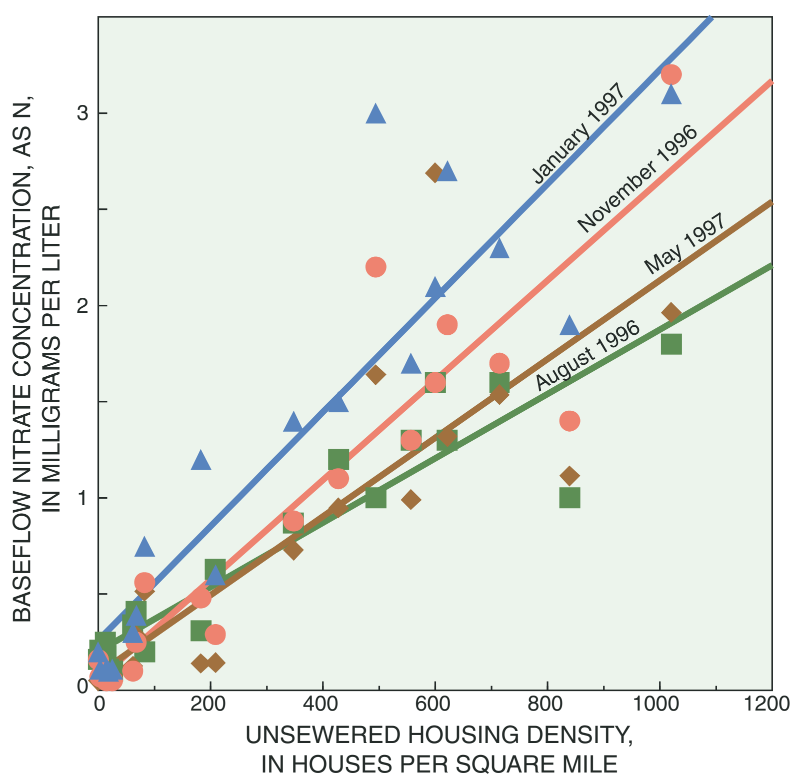
The nutrients nitrogen and phosphorus in domestic wastewater are a particular water-quality concern because they can spur algal growth in streams upon discharge from ground water. Ammonia is typically the dominant nitrogen species in domestic wastewater, but upon discharge to the unsaturated zone from septic system leach fields, it is transformed to nitrate by microbial nitrification under aerobic conditions. Ammonia may persist in unsaturated-zone and ground-water-plume environments where anaerobic conditions exist, such as in sediments of low permeability (Robertson and Blowes, 1995) or where the unsaturated zone is thin. Nitrate from wastewater plumes can be removed through denitrification (converted to nitrous oxide or nitrogen gases and released to the atmosphere) before or during ground-water discharge to streams in the presence of organic matter (within streambed sediments, in wetland areas). Nitrate was selected for analysis in this study because it is the most common nutrient in baseflow; concentrations at the sampled sites ranged from less than 0.05 to 3.2 mg/L. Phosphorus in the form of orthophosphate is an important nutrient in domestic wastewater, but it is largely removed through sorption on aquifer sediments or through precipitation of phosphate minerals. Phosphorus may persist, however, in ground water downgradient from old septic systems where sorption sites have been filled or where waters are oversaturated with respect to phosphate minerals (Robertson and others, 1991).

The intensity of domestic wastewater disposal was estimated from the housing (and thus septic system) density (houses/mi^2) within each unsewered basin. Housing densities were estimated from topographic maps and then revised after field checks of housing location and basin area. Basins that were omitted from analysis included: (1) two influenced by horse and dairy farms (basins 1 and 35), (2) three fully or partially sewered residential basins (basins 29, 31, 44A), (3) two basins with wetlands downgradient of development and adjacent to the stream (basins 50A, 54A) (because nitrate concentrations could be affected by denitrification and, thus, may not be representative of housing density), and (4) five mostly undeveloped basins (8A, 12, 13, 19, 39) with large wetland areas.

Linear regressions of baseflow nitrate concentrations as a function of unsewered housing density in 21 basins for the four sampling periods provided differing positive relations that indicate seasonal variability in nitrate concentrations (fig. 5). Nitrate concentrations at most sites were highest during the winter and progressively decreased through the late fall and late spring to their lowest point during the summer. A major seasonal control on baseflow nitrate concentration at any given site appears to be temperature, which affects (1) algal production and plant growth and, therefore, the rate of biological uptake within the stream, and (2) the rate of microbial denitrification within or immediately below the streambed. Nitrate appears to affect algal populations substantially, in that algal (diatom) growth was most commonly noted in streams that drain basins with moderate- to high-density housing. Similarly, the greatest seasonal variations in nitrate concentration occurred in basins with moderate- to high-density housing. Plant uptake and microbial denitrification are most likely to be important in low-gradient streams where there has been accumulation of bed material or where wetlands exist.

Nitrate concentrations of baseflow are highest in the winter and lowest in the summer. The low summer nitrate concentrations however, are accompanied by increased algal biomass, such as diatom populations on sandy streambeds, which can be suspended during stormflows and degrade water quality by increasing the load of organic carbon and nutrients moving downstream to the reservoirs.

Departures from the regression line for the relation of baseflow nitrate concentration to housing density in January 1997 (fig. 5)



August 1996	f(x) = 0.0017x+0.202	r^2 = 0.87
November 1996	f(x) = 0.0026x+0.056	r^2 = 0.86
January 1997	f(x) = 0.0029x+0.279	r^2 = 0.83
May 1997	f(x) = 0.0020x+0.086	r^2 = 0.74

Figure 5. Relation of the concentration of nitrate in baseflow in small streams to the density of unsewered housing in the Croton watershed, New York.

indicate that other physical and biological factors influence baseflow nitrate concentrations. Such factors might include the length of ground-water flowpaths prior to discharge at the stream, basin slope, and aquifer permeability, all of which affect ground-water residence time and, therefore, the contact time in environments that favor biochemical transformation of nitrate. Two conditions that are essential for such transformations in the unsaturated zone, the shallow ground-water flow system, and wetlands are the presence of organic carbon and environments with little or no oxygen. A limiting factor for algal growth is the amount of sunlight reaching streams; thus, the degree of shading along streams, and the compass orientation and topography of basins together can affect algal productivity and nutrient uptake. Another factor contributing to departures from the relation could be the variable rates of lawn-fertilizer application among basins, as described earlier.

WHAT EFFECTS DO SEWERING AND RIPARIAN WETLANDS HAVE ON BASEFLOW NITRATE CONCENTRATIONS?

The effectiveness of sanitary sewers and wetlands in decreasing baseflow nitrate concentrations are important watershed-management issues. Sewer effectiveness is the ability to transport domestic wastewater to a treatment facility without significant leakage to ground water. Assessment of sewer effectiveness, however, is complicated by 1) incomplete sewering in neighborhoods established prior to sewer installation, 2) other sources of nitrate, such as lawn fertilizers, and 3) loss of nitrate, particularly during the summer months, through biological activity. Wetland areas along streams (riparian wetlands) and downgradient of development represent an additional level of biological activity over and above that indicated in well-drained basins with no appreciable wetland area (fig. 5). Baseflow nitrate concentration is plotted as a function of unsewered housing density during the winter and summer in figures 6A and 6B, respectively; these plots include six additional basins not used in figure 5. Two of the basins are sewered but have no wetland area (31, 44A is 30 percent sewered), two are sewered and have wetland areas (3, 29), and two are unsewered with wetland areas (50A, 54A). The scatter of data indicates that sewering and riparian wetlands downgradient of development decrease the concentrations of nitrate in baseflows in the receiving streams in nearly all cases. Sewering decreases baseflow nitrate concentration consistently throughout the year, whereas riparian wetland areas decrease baseflow nitrate concentrations most effectively during the summer months.

The three entirely sewered basins (31, 29, 3), two of which (29, 3) also have riparian wetland areas, plot below the regression line in figure 6; baseflow nitrate concentrations in these streams during the winter, when the effects of biological activity in wetlands are minimal, range between 49 and 68 percent lower than the values predicted for unsewered basins. The effectiveness of sewering in decreasing baseflow nitrate concentration can be constrained only in general terms because: 1) there are other sources of nitrate to ground water other than leakage from sewer lines and 2) nitrate is not always conservative (stable) during transport to or within streams. Additional nitrate sources include application of lawn fertilizers and, in residential developments sewered after the initial development, domestic wastewater from houses still on septic systems and residual leachate from abandoned septic systems. Nitrate can be removed from ground water through denitrification in the presence of organic matter or by uptake from vegetation. In surface waters, nitrate can be taken up by wetland or riparian vegetation and algae.

The only sewered basin without any wetland area (31) provides the best indication of the effectiveness of sewering. Sewers were installed after the residential development was established, so a small number of houses (<5) may still be served by individual septic systems and thereby contribute wastewater to the local ground-water system. Baseflow nitrate concentration in this basin is 57 percent lower than the concentration predicted for an unsewered basin with the same housing density. This value represents a minimum effectiveness, however, as the nitrate contributions from remaining septic systems and lawn fertilizer usage are not accounted for.

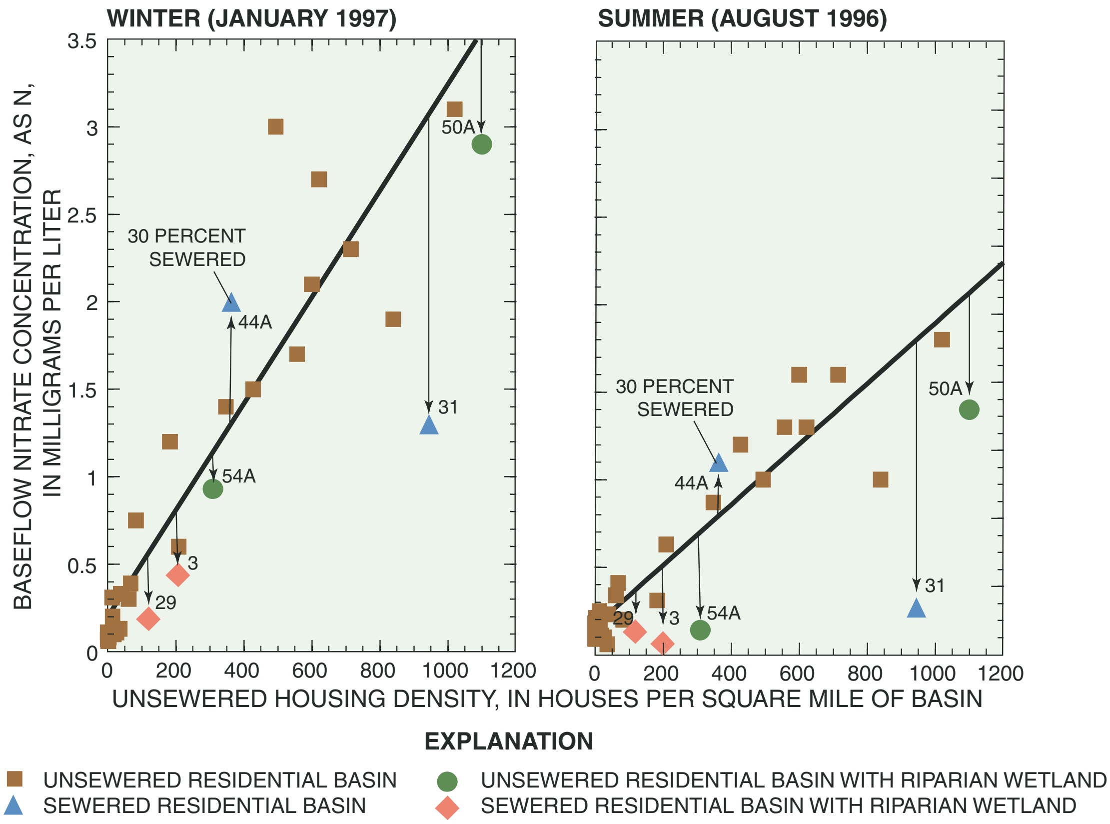


Figure 6. Relation of the concentration of nitrate in the baseflow of small streams to the density of housing in basins with unsewered and sewered residential development, and the presence of riparian wetlands downgradient from residential development: A. Winter 1997. B. Summer 1996. [Basin locations are shown in fig. 1.]

Baseflow nitrate concentrations from one partly sewered (30 percent) basin (44A) in figure 6 plots 41 percent above the concentration predicted by the winter (January 1997) regression line. The upper reaches of this basin contain large houses with large, well-maintained lawns; thus, widespread lawn-fertilizer application may potentially contribute to the elevated concentration of baseflow nitrate in this basin.

The concentrations of nitrate in baseflows from two basins (54A, 50A) with narrow riparian wetlands that are downgradient of unsewered residential development are less than those predicted through the regression equations (fig. 5). Baseflow nitrate concentrations show the greatest negative departures during the summer and the least negative departures during the winter (fig. 6, table 2). These departures are attributed to greater biological activity (denitrification, plant and algal uptake) in basins with riparian wetlands than in basins with no riparian wetland area. Wetlands upgradient of residential development probably have less effect on baseflow nitrate concentrations than those downgradient of development because these wetlands do not receive ground water derived from the developed area.

Table 2. Baseflow nitrate concentration departures from concentrations predicted by the August 1996 and January 1997 regression equations (in fig. 5) for streams with riparian wetlands downgradient of unsewered residential development

Basin	Departure, in milligrams per liter Summer (August 1996)	Winter (January 1997)
54A	-0.59	-0.24
50A	-0.67	-0.57

SUMMARY

Concentrations of selected chemical constituents in stream-baseflow samples representing ground-water discharge from 33 small basins within New York City's Croton watershed were evaluated in relation to land use and two measures of the intensity of unsewered residential development. Four samples were collected at each site, one during each season from July 1996 through May 1997, and analyzed for major ions, boron, and nutrients. Estimates of ground-water discharge (baseflow) from two well-drained (minor wetland area) stream basins in the watershed indicate that it constitutes at least 60 percent of total annual streamflow.

Baseflow concentrations of the selected chemical constituents were elevated to differing degrees relative to concentrations in the undeveloped forested (control) basin, depending on the predominant land use (unsewered residential, sewered residential, or agriculture [horse and dairy farms]) in the given basin. Baseflows in the undeveloped forested basin had the lowest concentrations of all detectable constituents. The unsewered residential basin was characterized by the highest baseflow concentrations of chloride and sodium, predominantly from winter road-salting, and the highest baseflow concentrations of nitrate, sulfate, and boron, primarily from domestic wastewater disposal through septic systems. The sewered residential basin had elevated baseflow concentrations of all constituents (especially chloride, sodium, and nitrate), but to a lesser extent (except orthophosphate) than the unsewered basin; the elevated concentration of orthophosphate could be derived from leaking sewer lines near the stream, lawn fertilizers, or, less likely, housing that has not been connected to the sanitary sewers. The agricultural basin with the highest percentage (12 percent) of horse and dairy farms had the highest baseflow concentrations of ammonia, total ammonia plus organic nitrogen, and total phosphorus, and the second highest concentrations of the other nutrients. Concentrations of major ions and boron in baseflow from this basin were most similar to those of baseflow in the undeveloped forested basin, as a result of the low density of roads and septic systems.

The intensity of unsewered residential development was quantified through estimation of annual road-salt-application rates (or road density) and housing (septic system) density for each basin. Linear regressions of nitrate concentration in baseflow and housing density in unsewered basins as well as chloride concentration in baseflow and annual road-salt application rate (or road density for basins with only two-lane roads) indicate that these measures of unsewered residential development can be used to predict effects on baseflow chemical quality. Chloride concentrations in baseflow show relatively stable positive linear relations with annual road-salt application rates and density of two-lane roads throughout the year. Baseflow nitrate concentrations show a different positive linear relation with unsewered housing density for each season; the highest nitrate concentrations were during the winter, and the lowest were during the summer. This seasonal variation reflects increased biological activity, such as algal uptake of nitrate within streams, or microbial denitrification within riparian wetlands or beneath the streambeds, during the summer.

Nitrate concentrations in baseflow from sewered basins and from unsewered basins with riparian wetland between residential development and the stream were lower than those predicted by the relation of unsewered housing density to baseflow nitrate. Nitrate concentrations in baseflow from the two sewered basins were 49 and 68 percent below the values predicted for unsewered basins. Summer nitrate concentrations in baseflow from two unsewered basins with riparian wetlands downgradient of residential development were about 0.6 mg/L lower than those predicted by the regression equation.

The results of this study indicate that local land use affects shallow ground water and that ground-water discharge is both an important source of streamflow and a control on surface-water quality. Nitrate concentrations in baseflow of small streams that drain unsewered basins can be predicted from the density of housing (septic systems) in the basins. Chloride concentrations in baseflow of sewered or unsewered basins can be predicted from annual road-salt application estimates or from the density of two-lane roads in the basins. Nitrate concentrations in baseflow from a sewered basin indicate that sewering is at least 57 percent effective in preventing nitrate from entering baseflow. Additional nitrate contributions from leaking sewer lines, lawn fertilizers, and remaining septic systems are unknown.

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REFERENCES CITED

Butch, G. K., Lumia, Richard, and Murray, P. M., 1998, Water resources data, New York, water year 1997, Volume 1, eastern New York excluding Long Island: U. S. Geological Survey Water-Data Report NY-97-1, 350 p.

Granato, G. E., 1996, Deicing chemicals as a source of constituents in highway runoff: National Research Council, Transportation Research Board, Transportation research record No. 1533, p. 50-58.

Harmon, J., Robertson, W. D., Cherry, J. A., and Zanini, L., 1996, Impacts on a sand aquifer from an old septic system--nitrate and phosphate: Ground Water, v. 34, no. 6, p. 1105-1114.

Ku, H. F. H. and Simmons, D. L., 1986, Effect of urban stormwater runoff on ground water beneath recharge basins on Long Island, New York: Water-Resources Investigations Report 85-4088, 67p.

LeBlanc, D. R., 1984, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts: U. S. Geological Survey Water-Supply Paper 2218, 28 p.

Linsey, K. S., Wolcott, S. W., and Schoonmaker, N. B., 1999, Identification of potential water-resources-monitoring sites in the Croton reservoir system, southeastern New York: U. S. Geological Survey Open-File Report 97-638, 36 p.

Robertson, W. D., and Blowes, D. W., 1995, Major ion and trace metal geochemistry of an acidic septic-system plume in silt: Ground Water, v. 33, no. 2, p. 275-283.

Robertson, W. D., Cherry, J. A., and Sudicky, E. A., 1991, Ground-water contamination from two small septic systems on sand aquifers: Ground Water, v. 29, no. 1, p. 82-92.

Rutledge, A. T., 1993, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge from streamflow records: U. S. Geological Survey Water-Resources Investigations Report 93-4121, 45 p.

U.S. Department of Commerce, Bureau of Census, 1990, 1990 census of population and housing: Public Law 94-171.

U.S. Geological Survey, 1998, Digital map file of New York State Land Cover, Version 98-07: Sioux Falls, S.D., EROS Data Center, 1:100,000-scale.

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