DISSOLVED CONSTITUENT CONCENTRATIONS AT 21 STREAM-WATER MONITORING SITES IN THE CITY OF ATLANTA FROM 2003 TO 2006

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REFERENCE: *Proceedings of the 2007 Georgia Water Resources Conference*, held March 27–29, 2007, at The University of Georgia, Athens, Georgia.

Abstract. During the summer of 2003, the U.S. Geological Survey, in cooperation with the City of Atlanta, began routine manual stream-water sampling of 21 sites with drainage areas ranging from 3.7 to 232 square kilometers (km^2). During approximately 12 manual sampling visits per year, concurrent equal width increment (EWI) and grab or point samples are collected to evaluate the homogeneity of the stream-water chemistry in the cross section. In addition, real-time water-quality and discharge monitoring at 11 sites is augmented by automatic samplers for collection of samples during storms. For the routine samples, 2,441 have been collected through June 2006; the samples were analyzed for a broad suite of dissolved and sediment-associated constituents. This paper summarizes an evaluation of inorganic properties including specific conductance (K_{SC}, a general measure of the amount of dissolved solutes in the stream water) dissolved oxygen, pH and turbidity, and concentrations of major dissolved ions, nutrients (nitrogen and phosphorus), and bacteria among sites and with respect to watershed characteristics. The concentrations of all major dissolved constituents and nutrients were the same in EWI and grab samples for each site indicating that the streams are well-mixed. However, the concentrations are statistically different among sites for several constituents, despite high variability both within and among sites. Mean K_{SC} varied with respect to the percentage of commercial and industrial land use. The highest mean K_{SC} were in two streams with drainages having the highest percentage of industrial and commercial land use; the lowest mean K_{SC} were in streams draining high percentages of residential-plus-forested areas. Although the maximum nitrate-nitrogen concentration (3 milligrams per liter—$mg\ l^{-1}$) was much less than the public health standard for potable water (10 $mg\ l^{-1}$), the average concentration at two sites was greater than 1 $mg\ l^{-1}$, which was significantly higher than any other sites. The drainage area for one site contains the highest percentage of high-density residential area and golf course area. Most of the sample concentrations were below reporting limits for dissolved total phosphorus (51 percent) and phosphate (83 percent). Fecal coliform bacteria concentrations of several individual samples at each site exceeded Georgia's water-quality standard for any water-use class including public water supply, recreation, or fishing. The bacteria concentrations at most sites were statistically indistinguishable due to the large within-site concentration variability. Statistically significant differences for some properties and constituents were identified among sites.

INTRODUCTION

The Clean Water Atlanta Program (CWA) developed a Long-Term Watershed Monitoring Program (LTWMP) during December 2002 to (1) evaluate the effects of wastewater treatment infrastructure upgrades on water quality, (2) evaluate sewage overflow/spill monitoring, and (3) augment a state-mandated requirement to monitor stormwater quality and quantity (Horowitz and Hughes, 2006). As part of the LTWMP, the U.S. Geological Survey (USGS), which is responsible for collecting and analyzing streamflow and water-quality data to meet the program goals, initiated routine sampling during the summer 2003. The LTWMP goals include (1) assessment of baseline water-quality conditions, (2) identification of sources of impairment, (3) determination of water-quality trends with respect to changes in wastewater infrastructure, and (4) providing information that can be used to make management decisions to improve water quality. Potential sources of wastewater to streams in the City of Atlanta (COA) include leaking or overflowing sanitary sewers, six combined sewer overflows (CSOs) (Fig. 1), illegal discharges, contaminant spills, storm runoff, and leachate from septic systems. There are no discharges of treated municipal wastewater effluent upstream from the CWA sampling sites. The objectives of this paper are to evaluate differences among sites with respect to field properties and concentrations of the dissolved major ions, trace metals, nutrients, and bacteria and to evaluate water-quality differences among sampling sites with respect to differences in land-use characteristics among watersheds.

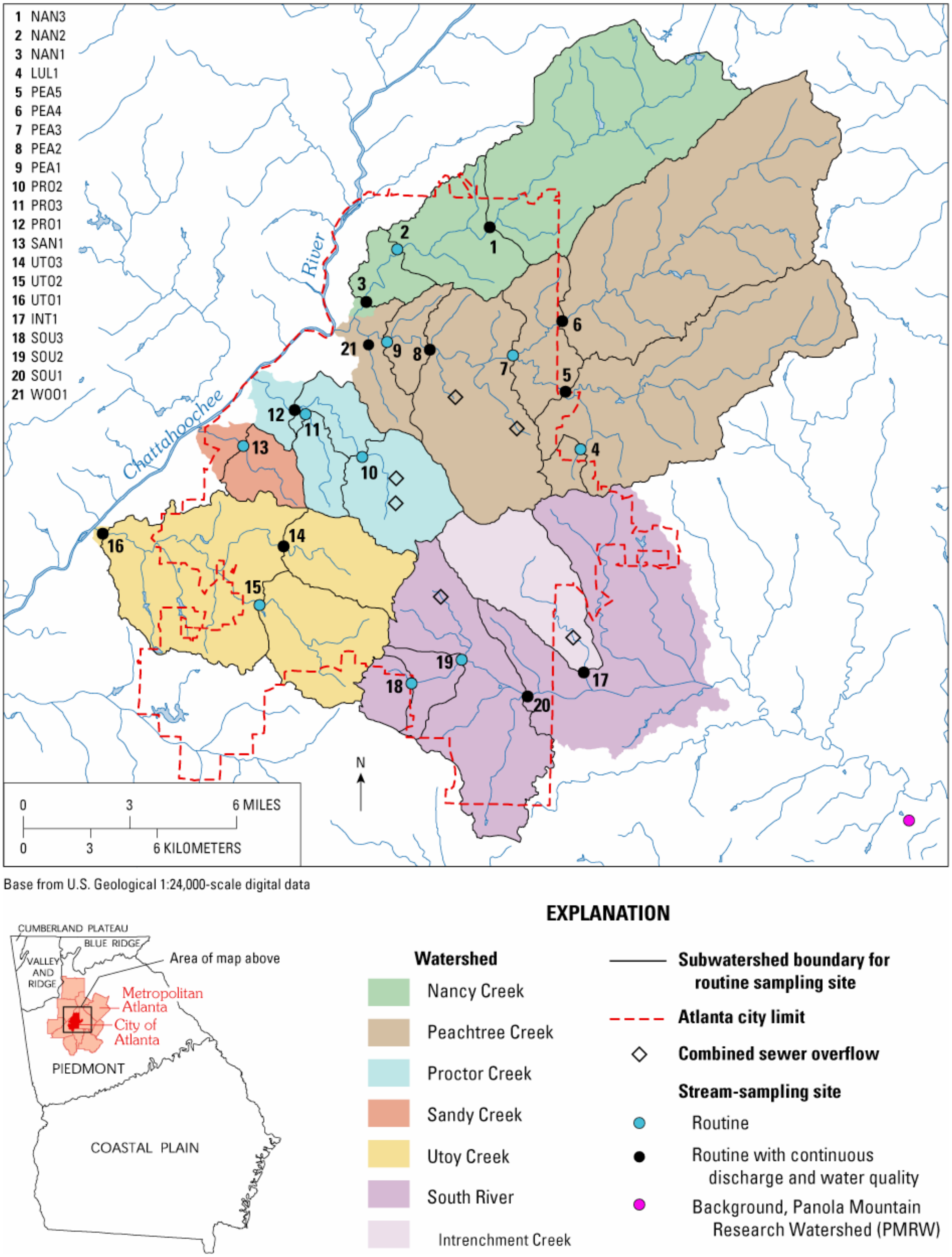

Figure 1. Routine and real-time stream-sampling sites, City of Atlanta, Georgia.

CHARACTERISTICS OF THE STUDY AREA AND SAMPLING METHODS

The LTWMP primarily consists of a routine network of 21 regularly sampled stream sites with watersheds ranging in size from 3.7 to 232 km^2 (Fig. 1). A broad suite of dissolved compounds was analyzed. The analytes include (1) inorganic properties—temperature (T), specific conductance (K_{SC}), pH, dissolved oxygen (DO), alkalinity (ANC), turbidity; (2) major ions—calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO_4), silica (SiO_2); (3) nutrients—ammonium (NH_4N), nitrite (NO_2N), nitrate (NO_3N), phosphate (PO_4), total dissolved phosphorus (TP); (4) indicator bacteria—fecal coliform, total coliform, *Escherichia coli*; and (5) metals—aluminum (Al), iron (Fe), barium (Ba), strontium (Sr). Eleven of the sampling sites were instrumented with real-time (RT) water-quality monitors for inorganic properties (T, K_{SC}, pH, DO, and turbidity) and continuous stage monitors for estimating discharge. Sampling consisted of equal width increment (EWI) and manual grab sampling at each site and automated pump sampling during rainstorms at the RT sites. To monitor outflows from the COA, seven routine sites (NAN3, PEA1, PRO1, SAN1, UTO1, INT1, and SOU1) are located at the most downstream location of the seven major tributary watersheds shaded in Figure 1; the site locations and watershed areas are listed in Table 1. To monitor inflows to the COA, three routine sites (NAN1, PEA4, and PEA5) are located at the most upstream site within the COA on tributary streams have substantial drainage areas outside of the city limits (Fig. 1, Table 1).

The COA encompasses 343 km^2 and is approximately centered within the 10-county Atlanta Regional Commission (ARC) planning area (4,780 km^2). All but four of the LTWMP sampling sites are within the COA boundary (Fig. 1). Urban land use extends across 79 to 98 percent of the watersheds of the 21 routine sampling sites (Table 2), with most of the remaining land use being forested (Atlanta Regional Commission, 2004). The 10-county Atlanta metropolitan area is a sprawling urbanized and suburbanized complex in which the population has increased from 1.1 million during 1960 to 3.67 million people during 2003 (Atlanta Regional Commission, 2003). The average population density for the metropolitan area is less than 800 people per km^2 compared to more than 1,250 people per km^2 within COA. The region is in the Piedmont physiographic province (Fig. 1), which is hilly and underlain by late Paleozoic crystalline and metamorphic rock.

On average, the study area receives 1,270 millimeters (mm) of precipitation annually, which generally is distributed uniformly during the year (Carter and Stiles, 1983).

Table 1. Routine stream water-quality monitoring sites, City of Atlanta, Georgia.

[USGS, U.S. Geological Survey; km^2, square kilometer; see Figure 1 for location]

Site designation	USGS station number	Stream name and station location	Watershed area (km^2)
INT1	02203700	Intrenchment Creek at Constitution Road	27.4
LUL1	02336228	Lullwater Creek at Lullwater Parkway	3.7
NAN1	02336410	Nancy Creek at West Wesley Road	95.4
NAN2	02336380	Nancy Creek at Randall Mill Road	88.2
NAN3	02336360	Nancy Creek at Rickenbacker Drive.	67.1
PEA1	02336311	Peachtree Creek at Bohler Road	227.7
PEA2	02336300	Peachtree Creek at Northside Drive	220.5
PEA3	02336267	Peachtree Creek at Piedmont Road	176.9
PEA4	02336120	North Fork Peachtree Creek, Buford Highway	90.2
PEA5	02336240	South Fork Peachtree Creek, Johnson Road	70.8
PRO1	02336526	Proctor Creek at Jackson Parkway	36.2
PRO2	02336517	Proctor Creek at Hortense Way	19.8
PRO3	023365218	Proctor Creek Trib at Spring Road	7.8
SAN1	02336644	Sandy Creek at Bolton Road	8.8
SOU1	02203655	South River at Forest Park Road	58.8
SOU2	02203620	South River at Macon Drive	13.5
SOU3	02203603	South River at Springdale Road	6.1
UTO1	02336728	Utoy Creek at Great Southwest Parkway	89.0
UTO2	02336706	South Utoy Creek at Childress Drive	24.0
UTO3	02336658	North Utoy Creek at Peyton Road	17.2
WOO1	02336313	Woodall Creek at DeForrs Ferry Road	6.7

During the spring and summer from April through September, rainstorms are convective (high intensity and short duration). During the remainder of the year, precipitation is dominated by synoptic-scale weather systems (low intensity and long duration). The runoff coefficient (RC; runoff as a fractional percentage of precipitation) of the watersheds ranges from approximately 30 to 40 percent; the highest RCs are in watersheds with the highest percentages of impervious area (Rose and Peters, 2001). Stream baseflow varies seasonally, with the lowest flows occurring during the summer growing season when evapotranspiration is the highest, and the highest baseflow occurring during winter when evapotranspiration is the lowest.

RESULTS AND DISCUSSION

In general, constituent concentrations and parameter values vary widely within a site and the distribution for most is positively skewed, that is, asymmetrical with most values clustered at the lower end of the scale (Fig. 2). In some cases, the skew was so pronounced the data were transformed for the figure using a base-10 logarithm (turbidity and bacteria). Most sites have been sampled at least 30 times since the study began and several of the RT sites with autosamplers were sampled more than 150 times. Many of the nutrient species had many values below the analytical reporting limit; the percentage of data below the reporting limit was 49 for NO_2N, 36 for NH_4N, 51 for TP, and 83 for PO_4. The data analysis for these constituents will require more specialized statistical evaluation specific to nondetectable values than was used for the other constituents in this paper. The evaluation of those data is not included herein.

Some sites exceeded Georgia water-quality standards (Georgia Department of Natural Resources, Environmental Rule 391-3-6-03, Water Quality Control: Water Use Classifications and Water Quality Standards, 2006). Samples collected at four sites (PEA2, PRO3, SOU1, UTO1) exceeded the minimum DO standard (< 4 mg l^{-1}), although the exceedances were few, that is, no more than three samples at any site. The streams are generally well aerated and stream water was more than 75 percent saturated with DO for more than 75 percent of the measurements at each site. The monitoring program was not designed to compute geometric means for fecal coliform bacteria concentrations, but the instantaneous concentrations at each site, as well as the 90^{th} percentile of the sampling at most sites, exceeded Georgia water-quality standards for any usage class, that is, public water supply, recreation, or fishing. The headwater site on the South River (SOU3) exceeded the pH standard (6–8.5) for all water classes, having routinely low pH as discussed below, whereas LUL1, NAN2, and WOO1 exceeded the pH standard with several samples having high pH.

Water-Quality Differences among Sites

Some properties and constituent concentrations differ markedly among stream sampling sites. A one-way analysis of variance with a t-test evaluation of each pair of sites was used to determine the statistical differences among the sites for each property and dissolved constituent, except those affected by censoring. Despite the comparisons conducted herein, note that some of the identified differences among sites may be an artifact of the sampling. The autosamplers at the RT sites provided a much more thorough characterization of the chemical conditions of stream water during storms than at sites where only manual samples were collected.

The sampling site on the South River at Springdale Road (SOU3) has significantly lower pH, lower ANC, higher K_{SC}, and higher SO_4, NO_3N, Al, Fe, and Mn concentrations than other sites (Fig. 2), and it is likely that stream transport can explain the stream-water concentrations of some constituents at downstream sites (Fig. 1), for example, high SO_4 and Mn concentrations at SOU2. The pronounced chemical differences are attributed to transport of leachate, derived from the dissolution of residual alum waste, through ground water to the stream. An alum plant in the watershed generates the waste, but it no longer uses surface impoundments for the alum, which likely had a severe impact on the stream (Tracy Hillick, City of Atlanta, oral commun., 2006). Alum is an aluminum sulfate compound containing K, Na, or NH_4N. The later form, ammonium alum, is used in water treatment for coagulation, which causes settling of suspended particles. Alum is relatively soluble and upon dissolution, produces an acidic solution high in Al and SO_4. The relatively higher NO_3N concentrations than at other sites would likely result from the oxidation of NH_4 released from the dissolution of ammonium alum, which is an additional acidifying reaction.

Both SOU3 and INT1 have significantly lower bacteria and higher Fe and NO_3N concentrations than most other sites. For perspective, the highest NO_3N concentration of any sample was 3 mg l^{-1} at PRO1, which is less than the public health standard for potable water of 10 mg l^{-1}. The mean NO_3N concentrations of SOU3 and INT1 were only 1 mg l^{-1}. The acidic and related high metal content of stream water at SOU3 also is toxic to biota and may be the cause of the low bacteria concentrations at SOU3. Furthermore, no fish were reported during the surveys conducted at SOU3 during 2001, 2003, or 2005 (Chrissy Thom, CH2M HILL, written commun., 2006). INT1 is on Intrenchment Creek, which is downstream from the Intrenchment CSO (Fig. 1). Streamflow at INT1 is dominated by the CSO releases when the CSO is discharging to the stream. The samples with the low bacteria concentrations have high Na and Cl concentrations. A likely scenario is that the high concentrations of Na and Cl probably are associated with treatment of the CSO with sodium hypochlorite, which generates chlorine to kill the bacteria. At the end of January 2006, CSO management included the addition of sodium bisulfite to neutralize the residual chlorine before the CSO discharges to the stream, which should have a positive effect on stream biota.

The Lullwater Creek (LUL1) sampling site, which is in the headwaters of Peachtree Creek, had significantly higher Cl and NO_3N concentrations and lower turbidity than most other sites. The stream drains the smallest watershed monitored (3.7 km^2). The LUL1 drainage area is the only one without industrial land use, but the watershed has the highest area percentage of golf courses (Table 2).

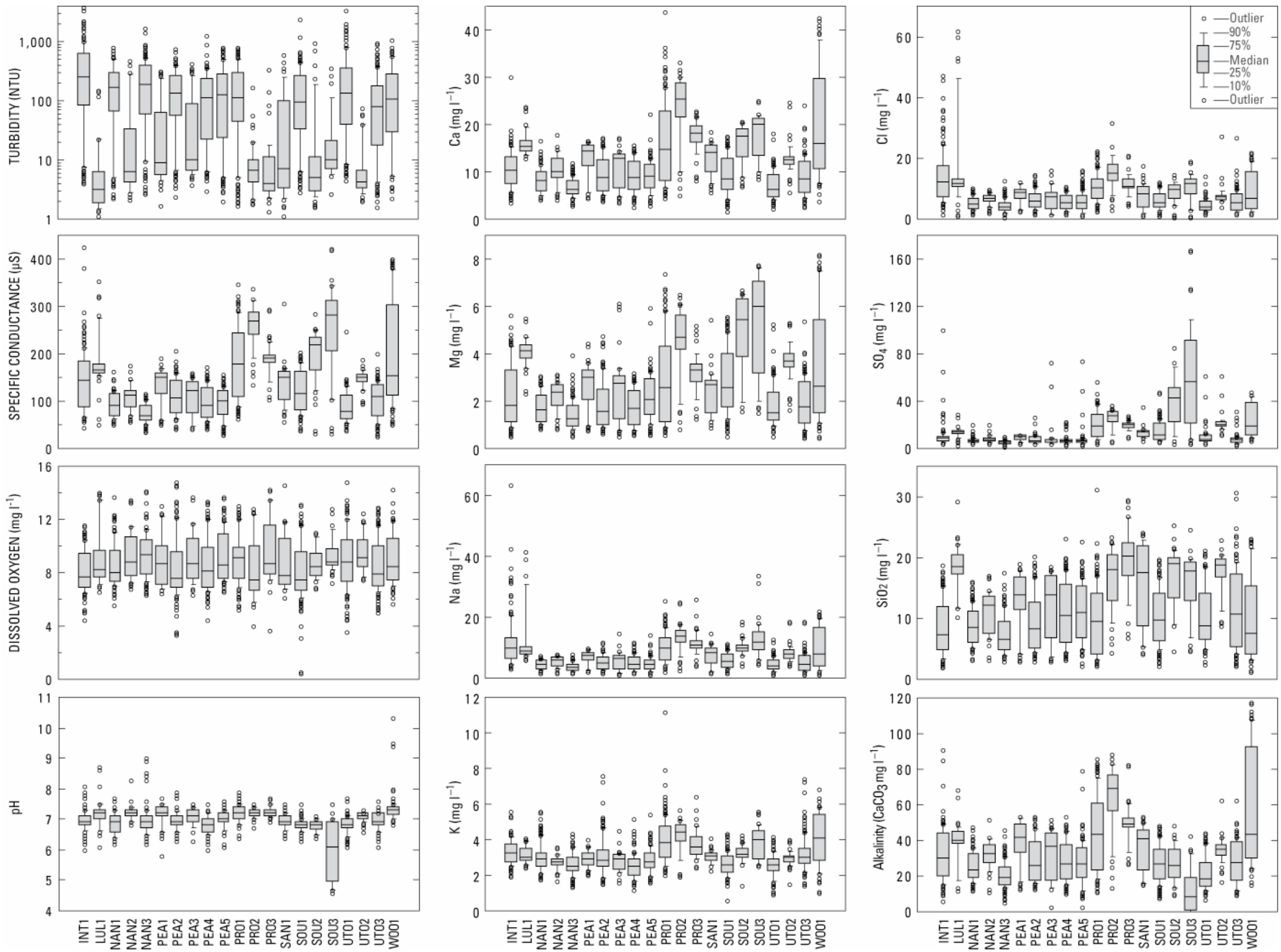

Figure 2. Box plots of properties and constituent concentrations at routine stream water-quality monitoring sites, City of Atlanta, Georgia, from 2003 to 2006.

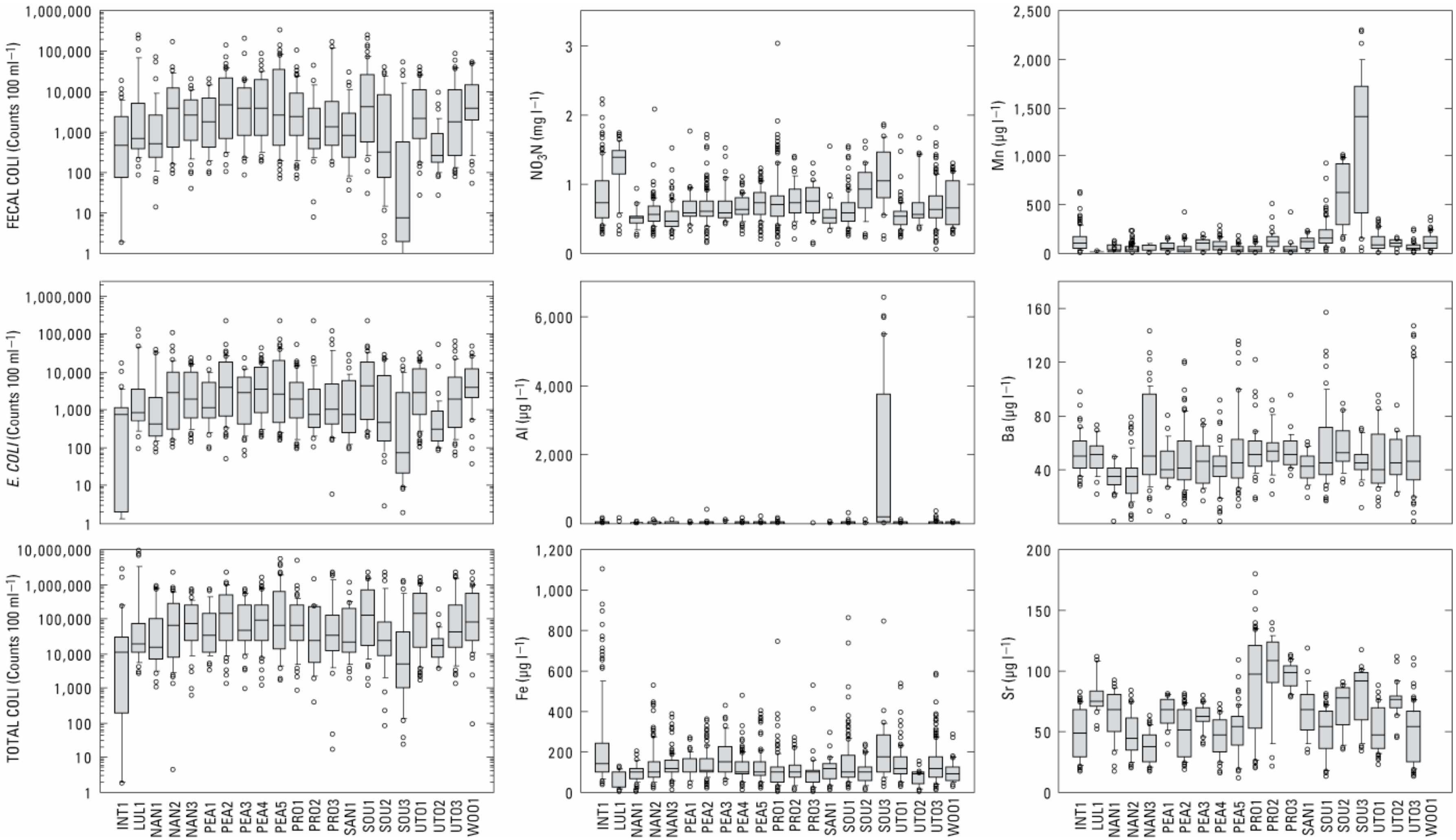

Figure 2. Box plots of properties and constituent concentrations at routine stream water-quality monitoring sites, City of Atlanta, Georgia, from 2003 to 2006—Continued

Table 2. Percentage land use of basin area for stream water-quality monitoring sites, City of Atlanta, Georgia (derived from Atlanta Regional Commission, 2004).

[See Table 1 for site designation; see Figure 1 for location]

Land-use type	INT1	LUL1	NAN1	NAN2	NAN3	PEA1	PEA2	PEA3	PEA4	PEA5	PRO1	PRO2	PRO3	SAN1	SOU1	SOU2	SOU3	UTO1	UTO2	UTO3	WOO1
Agricultural	0.0	0.0	0.4	0.5	0.0	0.1	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Cemeteries	0.9	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.8	1.8	0.0	7.5	0.0	0.4	0.4	0.0	2.4	0.4	11.9	7.3
Commercial	14.5	8.6	14.5	15.4	16.9	14.5	14.8	12.9	14.7	10.7	9.3	13.5	6.6	6.5	11.8	16.6	12.2	4.5	6.3	5.3	1.6
Industrial & commercial	6.2	0.0	1.1	1.1	1.5	6.6	6.8	6.9	7.2	6.8	7.5	12.2	0.0	0.0	12.1	9.4	11.1	4.8	3.2	3.5	52.8
Industrial	2.1	0.0	2.2	2.4	3.1	0.5	0.6	0.4	0.8	0.0	0.2	0.0	0.0	0.0	1.7	6.7	12.9	0.2	0.0	0.1	0.0
Forest	7.9	2.0	2.9	2.8	3.3	3.4	3.5	3.9	2.4	5.6	8.7	3.1	10.6	9.9	15.1	6.6	5.1	20.0	9.7	9.5	8.9
Golf courses	0.0	7.2	1.4	1.5	2.0	0.5	0.4	0.4	0.0	0.9	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.4	1.6	0.0	0.0
Institutional, extensive	0.0	0.0	0.9	1.0	1.3	1.9	2.0	2.5	1.4	4.4	2.0	0.0	1.9	0.0	0.0	0.0	0.0	4.0	7.9	4.2	0.0
Institutional, intensive	5.1	0.6	4.2	3.3	3.9	3.5	3.5	2.7	2.6	3.2	6.9	9.4	4.2	3.6	3.5	3.5	5.7	1.2	1.6	0.8	0.0
Limited access highways	3.4	0.0	2.9	2.7	3.2	2.9	2.8	2.7	3.1	1.9	0.8	0.9	1.6	10.4	4.0	6.8	0.5	1.5	1.4	0.6	0.0
Parkland, extensive	0.0	2.6	1.1	1.2	0.0	1.5	1.4	1.0	0.8	1.6	0.8	0.0	0.0	2.4	1.7	0.0	0.0	2.5	2.0	2.6	0.0
Parks	1.9	0.0	0.7	0.7	1.0	0.3	0.3	0.2	0.3	0.2	1.1	1.2	2.1	0.5	0.9	0.0	0.0	0.5	0.7	0.4	0.0
Quarries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Reservoirs	0.2	0.0	0.3	0.3	0.4	0.2	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.0	0.0
Residential, low density	0.7	0.0	5.1	2.7	0.7	0.4	0.4	0.5	0.0	1.2	0.0	0.0	0.0	0.0	0.7	0.8	0.5	4.5	0.3	0.0	0.0
Residential, medium density	26.6	26.6	52.4	54.0	50.8	46.7	45.9	49.7	52.7	47.8	32.5	25.9	60.0	60.2	21.4	18.8	9.8	39.0	52.4	27.7	5.0
Residential, high density	13.4	41.0	0.9	1.0	1.3	4.6	4.8	3.3	0.0	5.4	11.9	21.5	0.0	0.0	16.4	23.1	31.6	6.7	2.1	31.9	0.0
Residential, mobile homes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.7	1.0	0.0	0.0	0.0	0.7
Residential, multi-unit	5.2	5.7	7.0	7.3	8.0	9.6	9.5	10.0	10.9	7.7	5.1	5.2	5.6	3.7	4.4	4.9	6.3	4.6	7.6	1.1	4.3
Transitional	0.7	0.0	0.6	0.7	0.9	0.5	0.5	0.3	0.1	0.4	2.3	0.5	0.0	0.0	1.5	0.4	0.8	0.9	0.4	0.0	0.7
Transportation, etc.	1.8	1.3	0.9	1.0	1.3	1.2	1.2	1.4	2.1	0.6	5.6	1.9	0.0	0.3	1.0	1.4	2.4	0.8	1.2	0.4	14.1
Urban, other	9.6	4.6	0.4	0.4	0.5	0.8	0.8	0.6	0.6	0.3	2.4	3.4	0.0	1.8	1.2	0.0	0.0	0.8	1.4	0.1	4.4
Wetland	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.3	0.0	0.0	0.0

Fertilizer use is the likely source of the NO_3N, but note that the concentrations are less than the 10 mg N l^{-1} water-quality standard. Also, land disturbance is likely at a minimum in this basin. The basin contains an established residential area and golf course resulting in the low turbidity. Three of the samples at LUL1 had higher turbidity, and although turbidity in these samples generally was low compared to other sites (maximum of 150 nephelometric turbidity units [NTU], see Fig. 2), the bacteria concentrations of the high turbidity samples were some of the highest observed at any site. Most sites display a statistically significant positive correlation among the bacteria concentrations (fecal coliform, total coliform, and *Escherichia coli*) and between the bacteria concentrations and turbidity, which is consistent with results from the BacteriALERT Program (U.S. Geological Survey, 2006). LUL1 also had comparable Cl concentrations to INT1 and the highest individual Cl concentrations of any site. These results indicate that LUL1 is likely a more dynamic stream with respect to water quality than the current sampling shows. LUL1 drains the smallest watershed and the stream is more susceptible to minor changes in the watershed than the other streams.

The headwater site on Proctor Creek (PRO2) has significantly higher K_{SC} and concentrations of Ca, Mg, Sr, ANC, and SiO_2, while having lower turbidity than most sites. Although concentrations and property values are less and slightly more variable downstream at PRO1, PRO1 seems to be affected by the higher concentrations of several of these properties and constituents, which is similar with respect to the effects of SOU3 on downstream stations as noted earlier. In addition, all three sites in the Proctor Creek basin tend to have higher pH than most other sites. As occurs for INT1 and SOU3, all Proctor Creek sites had high Cl concentrations particularly when compared to the sites on Nancy, Peachtree, and Utoy Creeks. In contrast, sites on Nancy Creek have lower Ca concentrations (median Ca concentration on PRO2 is 25 mg l^{-1} and those of the Nancy Creek sites are less than 10 mg l^{-1}). PRO2 has some of the highest basin-area percentages of commercial-plus-industrial land use of any site, except for WOO1 and each site on the South River, but an association with sources or processes affecting the concentrations of these properties and constituents is not known. The high ANC, pH, and Ca and Mg concentrations suggest a carbonate source either in bedrock or from materials such as concrete and cement.

Woodall Creek, which is a tributary to Peachtree Creek with the confluence near but upstream from the confluence of Nancy and Peachtree Creeks (Fig. 1), had a composition more similar to PRO2 than any other site with respect to K_{SC}, Ca, ANC, and pH. Woodall Creek drainage contains the highest percentage of commercial-plus-industrial land use (52.8 percent) and transportation, communications, and utilities (14.1 percent). The RT data for this site show marked pH increases to greater than 9 during stormflow. The high pH cannot be explained by the dissolution of carbonate minerals, and is more likely associated with leaching of a liquid calcium base or dissolution of calcium oxide (lye). The higher percentage of commercial-plus-industrial, and transportation, communications, and utilities land use is indicative of more impervious surface than in other watersheds, many of which are likely composed of concrete and cement.

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