RESULTS FROM THE CITY OF ATLANTA WATER-QUANTITY AND WATER-QUALITY MONITORING PROGRAM: SUSPENDED SEDIMENT, TRACE ELEMENT, AND NUTRIENT FLUXES, 2004–2005

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Abstract. During 2003, the U.S. Geological Survey established a major long-term water-quantity and quality-monitoring network for the City of Atlanta (COA). During 2004 and 2005, suspended sediment fluxes from the COA to downstream receiving waters amounted to about 150,000 t y^{-1}; ≥94% of the transport occurred in conjunction with stormflow, which also accounted for ≥65% of the annual discharge. This occurred despite the relatively short duration of most runoff events, which cumulatively ranged from a minimum of 6 to a maximum of 35% of the year, depending on the drainage basin. Based on annual median chemical concentrations for baseflow and stormflow, the annual fluxes of ≥75% of trace elements (e.g., Cu, Pb, Zn,), major elements (e.g., Fe, Al), and total P occurred in association with suspended sediment; in turn, ≥90% of the transport of these same constituents occurred in conjunction with stormflow. As such, baseflow sediment-associated and all dissolved contributions represent a relatively insignificant portion of the total annual load. One of the few exceptions is total N, whose sediment-associated fluxes range from 50 to 60%; even so, the annual storm-related transport of this constituent typically exceeds 80.

INTRODUCTION

During 2001, the City of Atlanta (COA) asked the U.S. Geological Survey (USGS) to design and implement a water-quantity and water-quality monitoring program to function as a "backbone" for addressing current and future water-quality issues/evaluations. The objectives for the program are: (1) consolidate all water-quality monitoring into a single consistent program; (2) determine current water-quality conditions; (3) locate sources of water-quality impairment; (4) document water-quality changes in response to infrastructural improvements; (5) assess long-term water-quality trends; and (6) over time, as monitoring data accrue, adjust the network to address changing issues, limit costs, and improve effectiveness (Horowitz and Hughes, 2006). Initial site surveys and site selection, as well as equipment procurement and installation occurred during 2002 and well into 2003 (Fig. 1). Actual sample collection and analyses began in late 2003.

Many of the problems and approaches associated with operating urban hydrology monitoring networks of differing sizes and complexity have been detailed in the literature (Driver and Troutman, 1989; Ellis, 1999; Larsen et al., 1999; Rose and Peters, 2001; Goodwin et al., 2003; Old et al., 2003; Leeks et al., 2006). A description of the approaches and problems encountered during program startup and implementation, for the COA network, may offer some additional help for similar, large-scale urban hydrology programs elsewhere. The initial results (2004–2005) from the COA monitoring program, covering the annual fluxes of suspended sediment, trace elements, major elements, and nutrients, are described herein.

PROGRAM DESIGN AND METHODS

The COA water-quality monitoring network consists of 21 long-term sites (Fig. 1). Eleven are "fully instrumented" to provide real-time measurements of water temperature, pH, specific conductance, dissolved oxygen, turbidity [a surrogate for suspended sediment concentration (SSC)], water level (gage height, a surrogate for discharge), and rainfall; these parameters are measured every 15 minutes. Two of the remaining sites are instrumented to measure water level and rainfall. The remaining eight sites are used to assess water quality. All the fully instrumented sites are equipped with programmable refrigerated autosamplers to capture stormflows because substantial suspended sediment, sediment-associated, and dissolved chemical transport can occur at these times (e.g., Horowitz, 1995; Peters and Kandell, 1999; Rose and Peters, 2001). Only data from the fully instrumented sites are discussed herein.

The real-time data collection system is complemented with a manual sampling program consisting of the collection of scheduled and nonconvective storm samples. Manual sampling follows standard USGS depth- and width-integrated isokinetic procedures to ensure the collection of cross-sectionally representative samples (e.g., Edwards and Glysson, 1999). Each site is sampled 12 times per year; however, due to the linkage between discharge and water quality, scheduled sampling is not calendar- but hydrologically based (e.g., Horowitz, 1995). The intent is to collect samples covering from at least 80 to 85% of the annual range of discharges.

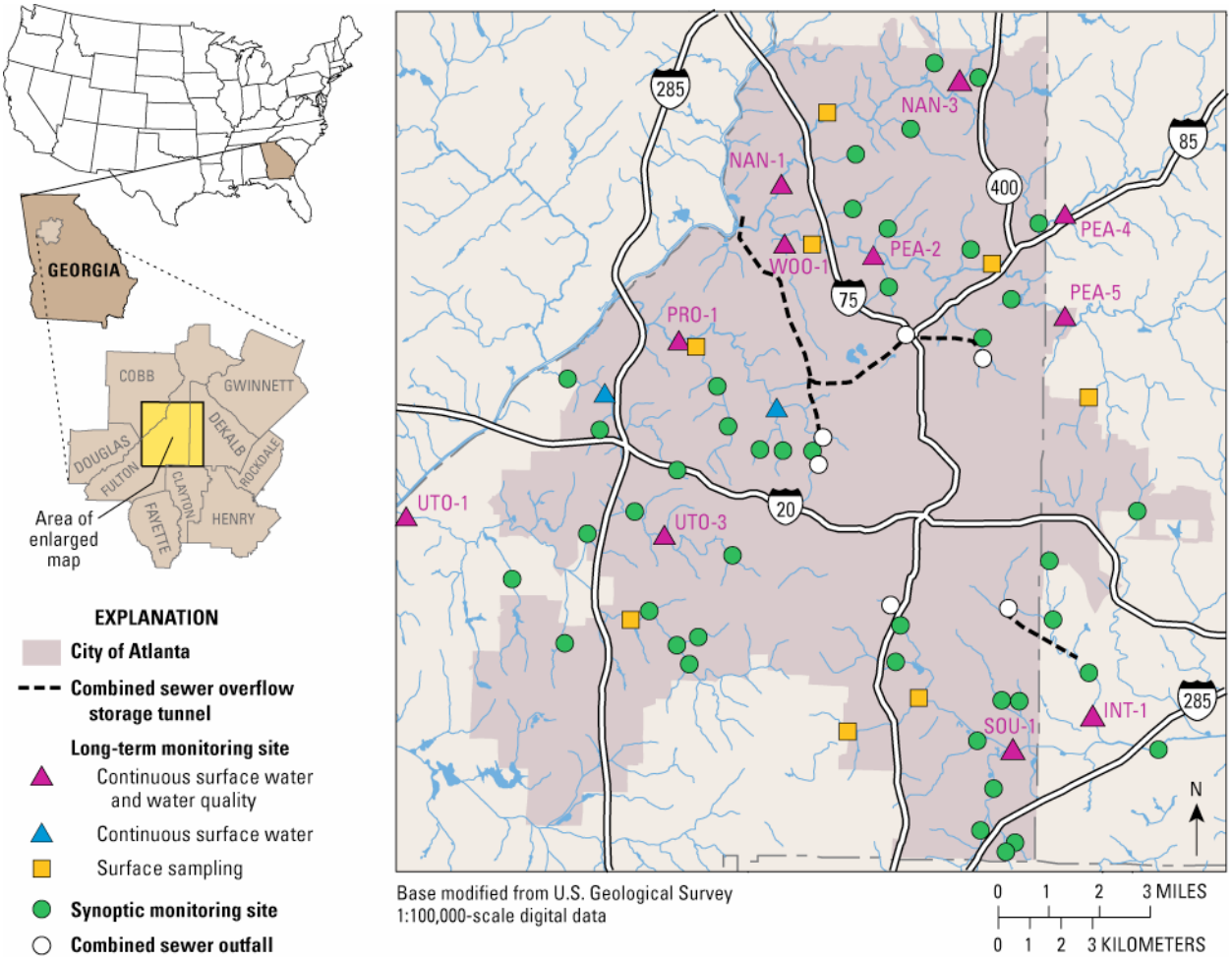

Figure 1. Location map for the City of Atlanta water-quality and water-quantity monitoring program; the fully instrumented sites are marked with a solid triangle and are NAN (Nancy Creek), PEA (Peachtree Creek), WOO (Woodall Creek), PRO (Proctor Creek), UTO (Utoy Creek), SOU (South River), and INT (Intrenchment Creek).

The manual sampling program provides data on chemical parameters that cannot be obtained with real-time measuring equipment (e.g., trace elements, nutrients). It also is used to calibrate/validate the real-time data sondes, and the material collected by the autosamplers. This accrues because the sondes and samplers are at fixed positions in each stream cross section; thus, they collect point measurements/samples that may not be cross-sectionally representative (e.g., Horowitz, 1995; Edwards and Glysson, 1999). To evaluate this issue, and to develop appropriate correction factors, if necessary, a series of concurrent (two simultaneous) measurements/samples have to be collected across a range of flow conditions. Both samples are then analyzed for the same constituents (e.g., SSC, trace elements, nutrients) and compared. Analytical procedures are detailed elsewhere (Horowitz et al., 2005; Horowitz and Hughes, 2006). When necessary, appropriate correction factors are developed so that the data from the autosamples are cross-sectionally representative (e.g., Horowitz, 1995). Typically, it takes between 20- and 30-paired measurements/samples, collected across a range of flows, to evaluate the need for, and to develop, correction factors.

RESULTS AND DISCUSSION

Flux Calculations

The metric of choice for determining spatial and temporal trends in the COA monitoring program is annual flux. Initially, the fluxes of suspended sediment, and dissolved and sediment-associated constituents were to be calculated by summing a series of daily instantaneous fluxes for each calendar year using the following formula:

$$\text{Flux (tonnes day}^{-1}) = [Q(\text{ft}^3\ \text{sec}^{-1})][\text{Conc. (mg l}^{-1})]\ [0.00245]$$

Where: Q = mean-daily discharge
Conc. = concentration

Fluxes are converted to metric units by using an appropriate constant (Porterfield, 1977). Suspended sediment-associated constituent fluxes also were to be determined using the same formula. However, as the chemical analyses were performed on dewatered and dried material, concentrations had to be

converted from mass mass^{-1} (e.g., mg kg^{-1}) to mass volume^{-1} (e.g., mg l^{-1}) units; this was done as follows:

Conc. (mg l^{-1}) = [Chem. Conc. (µg g^{-1})][SSC Conc. (g l^{-1})]/1,000
Where: Chem. Conc. = sediment-associated constituent concentration
SSC Conc. = suspended sediment concentration of the dewatered sample

Initial annual flux estimates for SSC, using the above-cited approach in conjunction with site-specific sediment rating curves, appeared to be lower than expected. Subsequent analyses of flow-duration curves and SSC data raised questions about the applicability of using mean-daily discharge (a single daily time-step calculation) to estimate annual fluxes for the small, relatively "flashy" COA urban streams. Subsequent detailed calculations for sites in the COA monitoring network clearly indicated that the use of mean-daily discharge, in conjunction with a single SSC value obtained from a site-specific sediment rating curve, could produce underestimates of annual sediment loads ranging from 25 to nearly 65% (Table 1). As a result, all estimates were calculated using 15-minute time steps, although longer steps could have produced annual flux estimates within the expected range of errors (±15 to 20%; Table 1) associated with the measurement of discharge and SSC (e.g., Horowitz, 2003).

A drawback to using 15-minute time steps is missing data; a substantial issue in urban hydrology (e.g., vandalism, damaged equipment, trash in the water). When there are insufficient data to actually determine a mean-daily discharge, the USGS infers a value based on available data and/or in conjunction with measured values from nearby sites; this approach cannot be employed to fill the 15-minute record. Hence, the mean-daily discharge record is almost invariably more complete than the record of 15-minute values. Even so, when annual fluxes are calculated using mean-daily discharges (even enhanced with inferred values), and compared with estimates based on 15-minute time-step calculations, the latter still generates higher flux estimates; albeit, the differences are less than those cited in Table 1. Therefore, all the fluxes cited herein were calculated using 15-minute time steps.

A drawback with using fluxes for determining trends accrues because, by their nature, they reflect changes in flow. Hence, low-flow years typically have lower annual fluxes than high-flow years, regardless of potential environmental changes. To limit this problem, flow-weighted concentrations (annual flux/annual discharge) will be used to evaluate interannual trends when there are marked differences in interannual discharge.

Table 1. Examples of the effects of using different calculation time steps in estimating annual suspended sediment fluxes.

Sampling frequency (hours)	Annual flux (tonnes)	Affect on flux estimate (percent)
Intrenchment Creek @ Constitution Parkway (INT-1)		
24	9,600	–64
12	15,000	–43
8	20,000	–28
6	20,000	–25
4	23,000	–16
3	24,000	–13
2	25,000	–8
1	26,000	–3
0.25	27,000	
Nancy Creek @ Rickenbacker Way (NAN-3)		
24	13,000	–49
12	18,000	–27
8	21,000	–17
6	22,000	–12
4	23,000	–6
3	24,000	–4
2	24,000	–2
1	25,000	–1
0.25	25,000	
Utoy Creek @ Great Southwest Parkway (UTO-1)		
24	28,000	-38
12	35,000	-23
8	39,000	-15
6	41,000	-10
4	42,000	-8
3	43,000	-6
2	43,000	-5
1	44,000	-3
0.25	46,000	

Concurrent Sampling

During the first two full years of the program, about 100 concurrent samples were collected under a range of flows, and subsequently analyzed. The results indicate that for a majority of the concurrent samples, there may be little difference between concentrations (suspended sediment and sediment-associated constituents) obtained from material collected with the autosamplers and that collected manually (e.g., NAN-1, Fig. 2). A number of concurrent samples displayed markedly different SSCs, but similar chemistries (e.g., NAN-3; Fig. 2) or similar SSCs, but substantial chemical differences (e.g., PEA-5; Fig. 2). In a few cases, neither the SSCs nor the chemistries matched. However, no consistent bias was detected. Taken as a whole, in conjunction with a knowledge of the range of short-term spatial and temporal SSC and chemical variability often displayed by suspended sediment collected at the same site (e.g., Horowitz, 1995), it appears that during stormflow, cross-sectional suspended sediment distributions are relatively homogeneous. Further, during baseflow, SSC is so low (≤10 mg l^{-1}) that cross-sectional inhomogeneities are unlikely. Hence, correction factors would not substantially improve the data quality from either the sondes or the autosamplers.

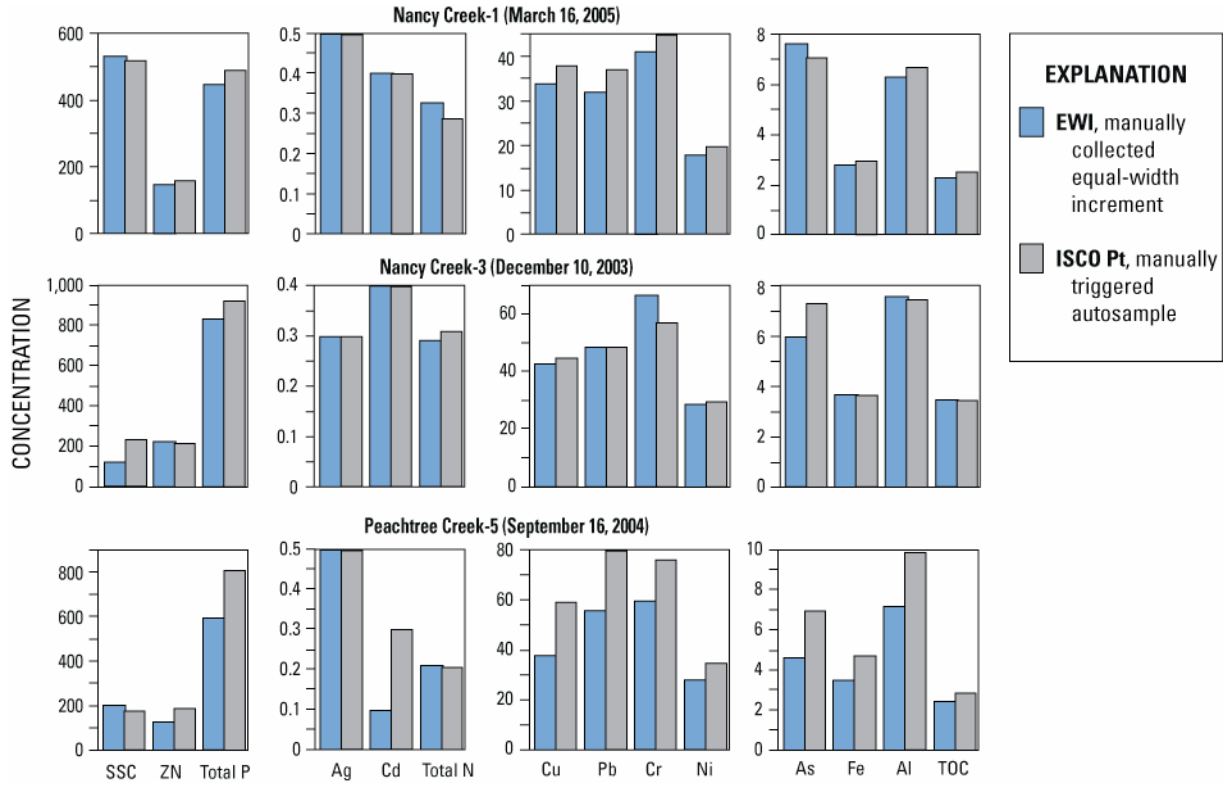

Figure 2. Selected concurrent sample (simultaneous manual EWI and autosampler) results for SSC and sediment-associated constituent concentrations from various fully instrumented sites. The NAN-3 data are from a concurrent sample that had markedly different SSC but similar chemistries, whereas the PEA-5 sample had similar SSCs but markedly different chemistries. The units for the various constituents are SSC (mg l^{-1}), Ag, Cu, Pb, Cd, Cr, Ni, and As (mg kg^{-1}); and total P, total N, TOC, Fe and Al (weight percent).

Site-Specific Rating Curves and Annual Estimates of Suspended Sediment Flux

At the end of 2005, using data from samples collected manually or with the autosamplers, it was possible to construct a series of site-specific sediment rating curves to predict SSC (Fig. 3). Each set consists of two curves and regression equations: (1) SSC vs. discharge (Q); and (2) SSC vs. turbidity (FTU—formazine turbidity units). Either curve can be used to predict SSC in the absence of actual samples. Note that while the general shapes of the rating curves (and their concomitant regression equations) for sites within the same watershed tend to be similar, they are not interchangeable (Fig. 3). Typically, the SSC vs. turbidity rating curve had a higher R^2 than the concomitant SSC vs. discharge curve; a not particularly surprising result because the relationship between SSC and turbidity is more direct than with discharge (e.g., Walling and Webb, 1981; 1988; Christensen, 2001). Unfortunately, at least for the 2004–2005 period, the turbidity records had more missing data (Table 2) than the discharge records at most of the fully instrumented sites. Hence, the majority of the predicted SSC values used to estimate annual suspended sediment and sediment-associated chemical constituent fluxes were generated from the SSC vs. discharge rating curves.

The data for 2004–2005 reveal important patterns of suspended sediment transport in general, and in urban environments in particular (Table 2). With the exception of the Utoy Creek 3 (UTO-3) site during 2004, ≥94% of the sediment transport, and with few exceptions, ≥66% of the annual water discharge occurred in conjunction with stormflow. Lastly, stormflow occurred only for relatively limited parts of each year, ranging from 6 to 35%. For the majority of sites, stormflow occupied ≤20% of the year. While the relative contributions from the different sites varied between 2004 and 2005, partially as a result of differing amounts of missing data, the overall sediment fluxes from the COA watersheds were about 150,000 t y^{-1} (Table 2). Also, the annual water discharge from the COA did not substantially change from 2004 (0.33 x 10^6 m^3) to 2005 (0.36 x 10^6 m^3), and that 2004 (15%) and 2005 (7%) were slightly above average (about 1,250 mm y^{-1}) rainfall years (National Climate Data Center, 2006).

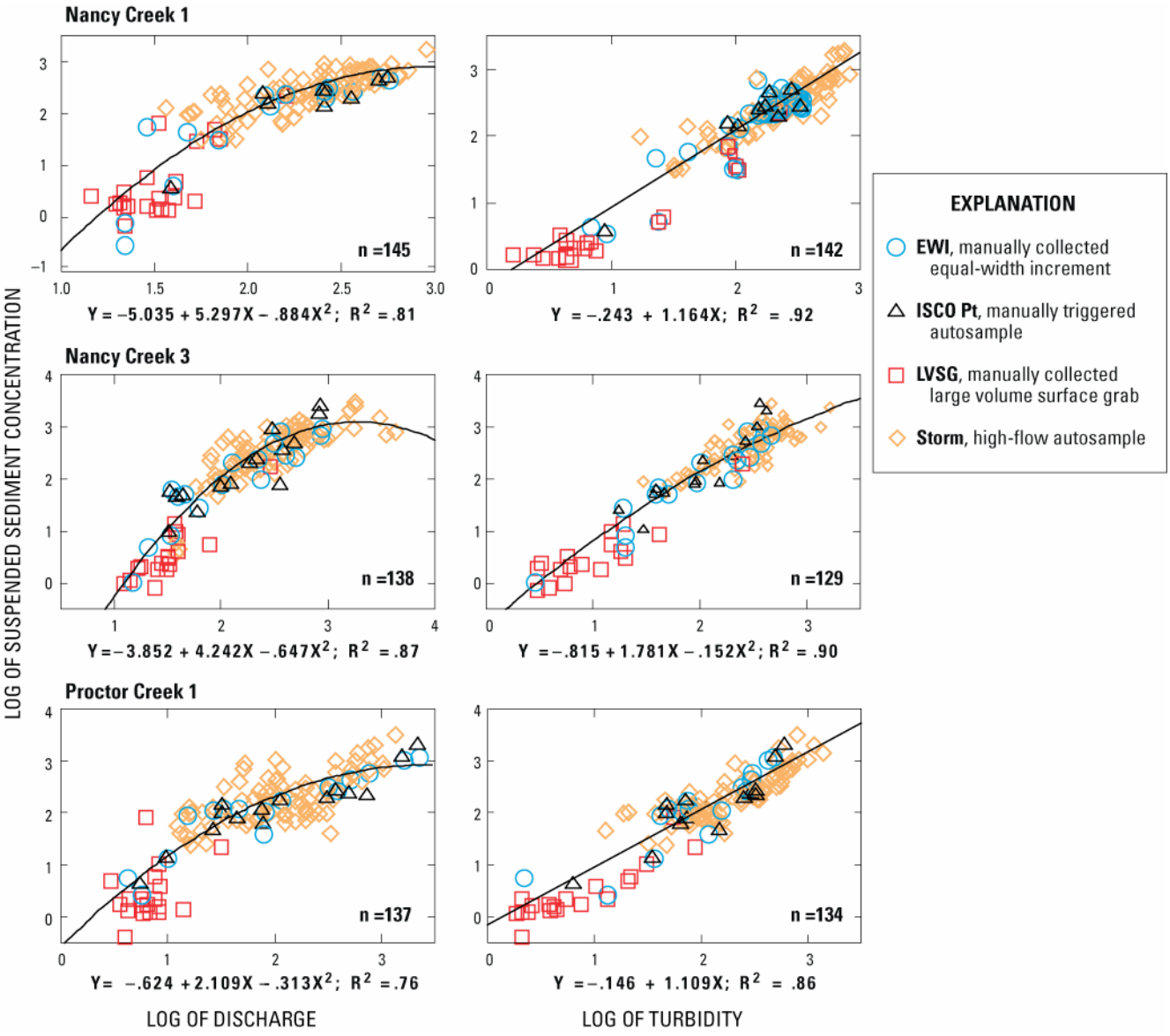

Figure 3. Sediment rating curves for three sites. Note that although the two Nancy Creek sites are less than 10 river kilometers apart, the curves/regression equations are not interchangeable. The EWI and ISCO Pt samples are collected concurrently.

Annual Fluxes of Suspended Sediment, Trace Elements, Major Elements, and Nutrients

The majority of suspended sediment-associated and dissolved chemical concentrations display marked spatial, temporal, and hydrologic (baseflow vs. stormflow) variability (Table 3). The median stormflow concentrations for most sediment-associated constituents are substantially lower than those collected during baseflow, probably as a result of the incorporation of coarser-grained material that contains lower concentrations of sediment-associated constituents (e.g., Horowitz, 1995). Two exceptions are Al and Ti. The higher stormflow concentrations of these elements may indicate increasing amounts of coarser aluminosilicates (e.g., feldspar, plagioclase) that are suspended and transported during storms, and which also may be acting as diluents for the finer-grained, more constituent-rich fractions. The concentrations of the majority of the sediment-associated constituents, whether collected under baseflow or stormflow, are elevated relative to typical background levels (Table 3; e.g., Horowitz et al., 1991; Horowitz, 1995).

Table 2. Summary of the estimated annual suspended sediment fluxes for the COA sites for 2004 and 2005 and associated errors.

Summary of Sediment Discharge from the City of Atlanta, 2004											
Sample site	**Predicted annual flux (tonnes)**	**Percentage of event-related flux**	**Annual vol. of water x 10^6 (m^3)**	**Percentage of event-related water**	**Percentage of year for events**	**Number of calibration samples**	**Actual calibration flux (tonnes)**	**Predicted calibration flux (tonnes)**	**Estimated error (percent)**	**Missing data (days)**	**Independent variable**
NAN-3	25,000	>99	51	69	19	62	830	750	–10	6.8	Q[1]
NAN 1	18,000	99	59	67	19	77	230	220	–5	4.4	Q
PEA-4	27,000	>99	62	77	19	83	548	485	–11	3.0	Q
PEA-5	18,000	>99	51	72	18	49	359	320	–11	1.6	Q
PEA-2	36,000	>99	136	75	35	64	337	308	–9	15	Q + T[2]
SOU-1	14,000	98	37	66	14	79	270	228	–16	2.7	Q
INT-1	27,000	94	20	62	6	72	797	718	–10	8.9	Q
PRO-1	8,600	94	17	67	9	58	202	200	–1	28.7	Q
UTO-3	3,200	86	11	58	7	42	39	45	15	7.9	T + Q
UTO-1	46,000	>99	59	76	18	54	80	87	9	**23.1**	T + Q
									Total	**102.1**	
									Percent of total	3	
Total annual flux for COA streams (NAN-1 + PEA-2 +SOU-1 + INT-1 +PRO-1 + UTO-1) = 150,000 tonnes											
Summary of Sediment Discharge from the City of Atlanta 2005											
NAN-3	20,000	98	51	66	18	39	158	197	25	**32.9**	T + Q
NAN-1	16,000	98	54	60	16	46	201	182	–10	**31.0**	Q
PEA-4	22,000	99	65	75	19	50	214	249	17	**7.4**	Q
PEA-5	21,000	99	60	73	18	46	87	99	13	**10.6**	Q
PEA-2	48,000	99	161	79	29	62	414	422	2	**19.8**	Q
SOU-1	8,900	97	34	64	15	56	104	123	23	**10**	Q
INT-1	12,000	97	17	64	8	49	141	179	27	**4.8**	Q
PRO-1	9,600	99	23	73	11	46	169	145	–14	**41.5**	Q
UTO-3	3,200	97	8	66	8	63	23	28	22	**36.5**	T + Q
UTO-1	56,000	99	71	74	18	58	160	148	–8	**1.1**	Q
									Total	**194.5**	
									Percent of total	**5**	
Total annual flux for COA streams (NAN-1 + PEA-2 +SOU-1 + INT-1 +PRO-1 + UTO-1) = 150,000 tonnes											

[1]Q, discharge
[2]T, turbidity

On the other hand, median stormflow dissolved concentrations tend to be higher than median baseflow levels (Table 3). At first glance, this may appear surprising because rainwater tends to function as a diluent; a view supported by the sharp drop in instream specific conductance (indicative of reduced dissolved solids) at the onset of a storm event. However, soon after the "first flush" of rainwater, instream specific conductance rises in conjunction with the dissolved concentrations of a number of constituents. The rise in both conductance and dissolved constituent concentrations probably derives from nonpoint-sources as a result of the solubilization of dryfall from impervious surfaces or surface soils (e.g., Ellis, 1999). It also may indicate the discharge of near-surface groundwater due to infiltration (e.g., Ellis, 1999; Shepherd et al., 2006). Several median dissolved concentrations exceed current USEPA water-quality criteria (Table 3, U.S. Environmental Protection Agency, 2006). Also, a number of the dissolved total P (TP) and total N (TN) levels exceed USEPA recommended levels for Ecoregion 45 (Piedmont) streams (Table 3, U.S. Environmental Protection Agency, 2000).

An objective of the COA monitoring program is the calculation of annual fluxes for a variety of sediment-associated and dissolved chemical constituents to evaluate the impact of the COA on downstream water quality, as well as to identify any temporal water-quality trends. Despite the variety of surrogate measurements available from the fully instrumented sites, no useful surrogates were found for predicting sediment-associated or dissolved trace element, major element, or nutrient concentrations. When this has occurred elsewhere, chemical fluxes were calculated using annual mean/median concentrations derived from baseflow and stormflow samples (e.g., Horowitz, 1995; Horowitz et al., 2001). Typically, in these prior cases, the majority of the constituent concentrations displayed limited interannual variability (usually within, or close to the level of analytical error), despite substantial differences in annual discharge and/or SSC (e.g., Horowitz, 1995; Horowitz et al., 2001).

Table 3. Summary of median chemical concentrations by sample media for 2004/2005 for instrumented COA sites.

[mg kg^{-1}, milligram per kilogram; µg l^{-1}, micrograms per liter; mg l^{-1}, milligrams per liter; Md., median; N/A, data unavailable]

Site name	Flow	Type	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	Cd mg kg^{-1}	Cr mg kg^{-1}	Ni mg kg^{-1}	Ba mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Al mg kg^{-1}	TP mg kg^{-1}	TN mg kg^{-1}
Sediment-Associated Constituents														
Intrenchment Creek @ Constitution Pkwy	Base	Md.	92	103	355	1.5	90	48	480	7,200	1,200	7,800	3,600	10,000
	Storm	Md.	81	100	290	0.8	70	40	440	47,000	880	86,000	1,200	4,000
South River @ Forest Park Road	Base	Md.	150	94	860	2.9	130	87	420	84,000	2,300	77,000	2,400	9,000
	Storm	Md.	98	110	530	1.5	75	45	400	42,000	2,100	74,000	930	3,500
South Fork Peachtree Creek@ Johnson Rd.	Base	Md.	69	73	370	0.6	140	75	510	70,000	1,900	74,000	2,200	8,900
	Storm	Md.	59	62	265	0.5	67	30	490	37,000	1,200	73,000	870	3,300
North Fork Peachtree Creek@ Buford Hwy.	Base	Md.	53	49	360	0.6	75	37	460	67,000	2,400	79,000	1,600	8,100
	Storm	Md.	38	41	240	0.4	38	16	510	34,000	1,800	80,000	700	3,300
Peachtree Creek @ Northside Drive	Base	Md.	99	84	390	0.9	95	62	500	66,000	1,900	78,000	2,600	9,000
	Storm	Md.	62	62	270	0.5	46	21	520	36,000	1,100	80,000	880	3,900
Nancy Creek @ Rickenbacker Dr.	Base	Md.	57	48	270	0.5	79	48	440	60,000	1,900	57,000	1,800	7,800
	Storm	Md.	38	40	210	0.3	46	24	500	34,000	1,200	70,000	670	2,000
Nancy Creek @ West Wesley Road	Base	Md.	53	58	260	0.4	120	62	520	56,000	2,300	67,000	1,800	7,400
	Storm	Md.	51	52	240	0.4	56	29	510	36,000	1,700	73,000	885	3,800
Proctor Creek @ State Road 280	Base	Md.	64	95	260	0.9	72	35	405	42,000	860	36,000	2,350	9,800
	Storm	Md.	76	110	280	0.7	46	25	450	38,000	880	79,000	1,000	4,200
North Fork Utoy Creek @ Peyton Road	Base	Md.	55	87	300	0.5	79	37	540	59,000	2,100	74,000	2,100	8,100
	Storm	Md.	38	70	200	0.5	39	19	540	30,000	1,200	59,000	1,000	2,100
Utoy Creek @ Great Southwest Parkway	Base	Md.	85	86	1,400	0.8	115	69	605	76,000	1,750	100,000	2,300	6,500
	Storm	Md.	70	68	665	0.6	65	39	620	45,000	1,550	100,000	1,000	4,100
Background[1]			30	25	120	1.0	30	30	600	30,000	600	55,000	1,000	500

Site name	Flow	Type	Cu µg l^{-1}	Pb µg l^{-1}	Zn µg l^{-1}	Cd µg l^{-1}	Cr µg l^{-1}	Ni µg l^{-1}	Ba µg l^{-1}	Fe µg l^{-1}	Mn µg l^{-1}	Al µg l^{-1}	TP mg l^{-1}	TN mg L^{-1}
Dissolved Constituents														
Intrenchment Creek @ Constitution Pkwy	Base	Md.	2.4	0.3	13	0.07	0.2	1.6	50	150	170	6.0	0.03	1.8
	Storm	Md.	5.8	0.9	14	0.07	0.8	33	220	160	66	22	0.14	1.4
South River @ Forest Park Road	Base	Md.	2.3	0.1	41	0.18	0.09	2.1	51	110	300	5.0	0.01	1.1
	Storm	Md.	6.9	0.7	41	0.12	0.2	1.9	40	130	110	20	0.01	1.0
South Fork Peachtree Creek@ Johnson Rd.	Base	Md.	1.5	0.2	6.0	0.06	0.1	0.6	48	160	69	4.0	0.01	0.9
	Storm	Md.	5.4	0.4	13	0.15	0.3	1.0	39	120	27	22	0.03	1.2
North Fork Peachtree Creek@ Buford Hwy.	Base	Md.	1.4	0.13	7.0	0.06	0.06	0.6	45	120	150	4.0	0.01	0.9
	Storm	Md.	3.3	0.4	20	0.11	0.2	0.9	41	120	49	25	0.01	1.0
Peachtree Creek @ Northside Drive	Base	Md.	2.1	0.14	7.0	0.06	0.2	0.6	40	180	100	8.0	0.01	1.0
	Storm	Md.	9.3	1.0	32	0.09	0.3	1.4	41	100	31	33	0.03	1.1
Nancy Creek @ Rickenbacker Dr.	Base	Md.	1.4	0.2	6.0	0.4	0.2	0.6	37	130	110	6.0	0.01	0.9
	Storm	Md.	3.1	0.4	7.4	0.07	0.3	0.9	46	120	33	26	0.01	0.9
Nancy Creek @ West Wesley Road	Base	Md.	1.2	0.2	18	0.13	0.10	0.5	34	130	67	5.5	0.01	0.8
	Storm	Md.	4.1	0.4	8.8	0.08	0.28	1.1	36	100	26	22	0.03	1.0
Proctor Creek @ State Road 280	Base	Md.	2.8	0.7	13	0.05	0.09	1.8	52	110	73	6.0	0.07	1.3
	Storm	Md.	11	1.4	24	0.07	0.4	1.9	52	97	26	31	0.09	1.2
North Fork Utoy Creek @ Peyton Road	Base	Md.	1.4	0.2	6.0	0.1	0.1	0.7	49	120	66	4.5	0.01	1.0
	Storm	Md.	6.7	1.2	25	0.11	0.22	1.5	39	130	68	24	0.04	1.1
Utoy Creek @ Great Southwest Parkway	Base	Md.	1.4	0.2	84	0.04	0.12	1.0	42	120	250	8.0	0.01	0.8
	Storm	Md.	5.7	0.6	78	0.1	0.23	1.5	41	140	71	27	0.01	1.0
Aquatic Criteria[2]	Cont.[3]		9.0	2.5	120	0.25	74	52	N/A	1,000	N/A	87	0.034	0.624
	Max.[4]		13	65	120	2.0	570	470	N/A	N/A	N/A	750		

[1]Background - from Horowitz et al., 1991
[2]U.S. Environmental Protection Agency, 2006, National Recommended Water Quality Criteria
[3]Cont. - continuous exposure
[4]Max. - maximum exposure
[4]Reference conditions for level III Ecoregion 45 streams, U.S. Environmental Protection Agency, 2000

The interannual variability of the median chemical concentrations for the COA sites is substantially greater than analytical error, but typically does not exceed a factor of two. This level of variability is not atypical in urban areas where there are a large number of diverse point- and nonpoint-sources, and as a result of the chemical impacts of differing lengths of antecedent dry conditions on the chemistry of successive storm events (Larsen et al., 1999; Shepherd et al., 2006). As a result of the interannual variability between median chemical concentrations, data interpretations for either spatial and/or temporal differences/trends need to be substantial to be considered significant.

With the relatively consistent exception of TN, the majority (≥75%) of the annual fluxes of Cu, Pb, Zn, Cd, Cr, Ni, Ba, Fe, Mn, Al, and TP occur in association with suspended sediment (Fig. 4). Further, and again with the exception of TN, ≥90% of the annual fluxes of these same constituents are transported by stormflow (Fig. 4). Although there are some exceptions, typically 40 to 60% of TN occurs in association with suspended sediment, and ≥80% is transported during storms (Fig. 4). These results confirm the view that stormflow, rather than baseflow, and nonpoint- rather than point-sources, are the major source(s) for the annual fluxes of suspended sediment and various chemical constituents derived from the COA watersheds (e.g., Horowitz et al., 2005).

The Impact of the COA on Annual Fluxes in the Peachtree and Nancy Creek Basins

Peachtree (PEA-4, PEA-5, and PEA-2) and Nancy Creeks (NAN-3 and NAN-1) have multiple fully instrumented sites that permit some assessment of the impact of the COA on downstream water quality, the annual fluxes of suspended sediment, and a variety of chemical constituents (Fig. 1; Table 4). In Nancy Creek, during both 2004 and 2005, more sediment entered the system than was discharged. However, visual observation indicates active, but localized erosion (e.g., streambank undercutting). Hence, it appears that the Nancy Creek watershed represents an area of sediment exchange resulting in a net decline in sediment loads. Further, it appears that the sediment load during 2005 was less than during 2004 (Table 4). However, this should be viewed with caution because there were substantially greater amounts of missing data during 2005 (Table 4). In 2004, with the exception of TN (which showed an increase), processes within the watershed did not substantially impact the chemical loadings in Nancy Creek. On the other hand, during 2005, these same processes did generate changes in the chemical loadings: Cu, Pb, Fe, and TN doubled, whereas Zn and TP quadrupled (Table 4).

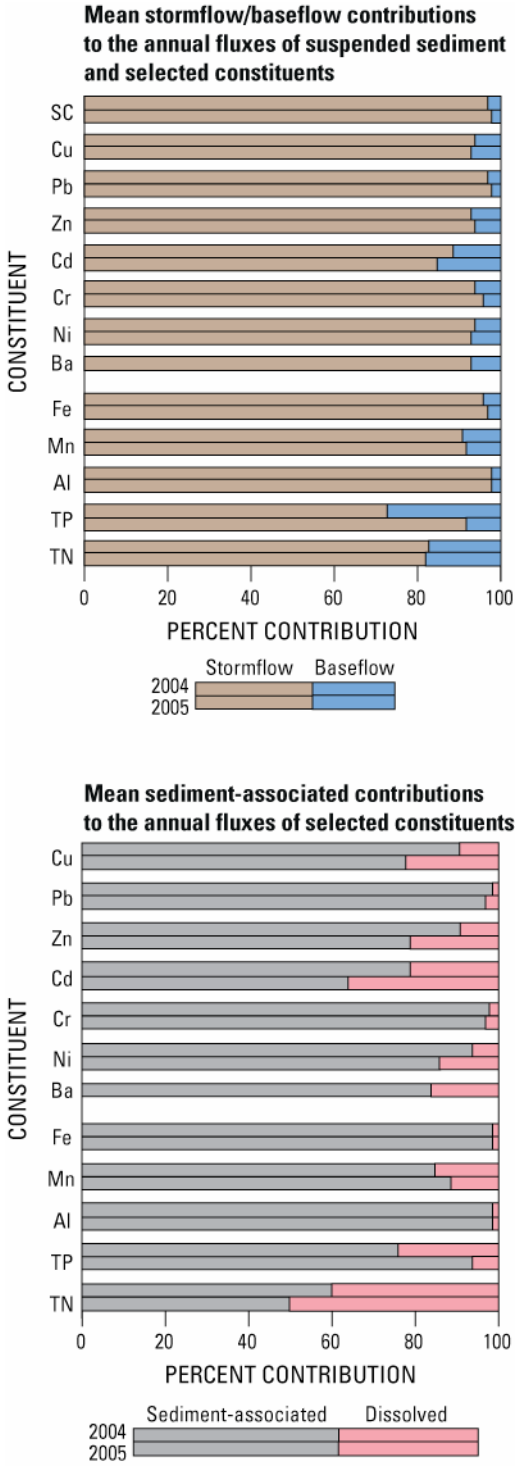

Figure 4. A summary, for suspended sediment and selected constituents, of the relative importance of stormflow versus baseflow and sediment-associated versus dissolved contributions, to annual fluxes.

Table 4. Downstream changes in the annual fluxes of suspended sediment and selected chemical constituents in Nancy and Peachtree Creeks during 2004 and 2005.

[m^3, cubic meter; t, tonnes]

Lcation, suspended sediment, and chemical constituent	Nancy Creek Watershed				Peachtree Creek Watershed			
	2004		2005		2004		2005	
	NAN-3	NAN-1	NAN-3	NAN-1	PEA-4 + PEA-5	PEA-2	PEA-4 + PEA-5	PEA-2
Relation location	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Discharge (m^3 x 106)	51	59	51	54	114	136	125	161
SSC (t)	25,000	18,000	20,000	16,000	45,000	36,000	43,000	48,000
Cu (t)	0.9	1.1	0.5	1.1	2.5	2.4	2.5	3.9
Pb (t)	1.0	1.1	0.4	0.7	2.3	2.4	2.1	3.1
Zn (t)	5.1	5.0	1.7	6.8	12	11	13	18
Cd (t)	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03
Cr (t)	1.1	1.2	0.5	0.8	2.2	2.0	2.2	2.6
Ni (t)	0.5	0.7	0.3	0.5	1.2	0.9	1.1	1.2
Ba (t)	14	12	*	*	25	26	*	*
Fe (t)	810	770	270	580	1,700	1,500	1,600	1,800
Mn (t)	39	40	12	32	73	58	76	77
Al (t)	1,700	1,400	820	1,000	3,600	3,300	3,100	3,600
Total P (t)	17	18	4.5	17	58	43	36	57
Total N (t)	96	130	60	110	270	250	240	430
Missing data (days)	6.8	4.4	32.9	31.0	4.6	15.0	18.0	19.8

*Dissolved Ba data were only generated during 2004.

During 2004, Peachtree Creek mirrored Nancy Creek and showed a net decline in suspended sediment loading, along with marginal declines in the fluxes of Mn, TP, and TN (Table 4). However, these observations should be viewed with caution because they may have resulted from the greater amount of missing data from the most downstream site relative to the two upstream sites (4.6 vs. 15 days). On the other hand, during 2005, Peachtree Creek showed a net increase in suspended sediment loading that was accompanied by substantial increases in the fluxes of Cu, Zn, TP, and TN. These changes are unlikely to have been caused by missing data because during 2005, the upstream and downstream data losses were roughly equal (Table 4).

CONCLUSIONS

1. Accurate flux estimates in the relatively small and "flashy" COA urban streams require shorter time-step calculations than are needed in larger systems; at a minimum, based on the potential errors associated with measuring discharge and SSC, the time-steps have to be on the order of every 2 to 3 hours.

2. During 2004 and 2005, the COA watersheds discharged some 150,000 tonnes of suspended sediment to downstream receiving waters; ≥94% of the transport occurred in conjunction with stormflow, which also accounted for ≥65% of the annual discharge, and occurred for time periods amounting to ≤20% of the year.

3. The annual median chemical concentrations of sediment-associated constituents tend to be higher in baseflow samples than in stormflow samples; but typically in either case, are elevated compared to normal background levels.

4. On the other hand, the chemical concentrations of dissolved constituents tend to be higher in stormflow than in baseflow samples; a number of these constituent concentrations exceed USEPA water-quality criteria (trace/major elements) and/or recommendations (nutrients).

5. Based on annual median chemical concentrations for baseflow and stormflow, with the exception of TN, the annual fluxes of ≥75% of trace elements, major elements, and TP occurred in association with suspended sediment; in turn, ≥90% of the transport of these same constituents occurred in conjunction with stormflow.

6. Sediment-associated TN fluxes range from 50 to 60% of the annual total; even so, storm-related transport of TN typically exceeds 80% of the annual load.

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Chemical abbreviations: Ag, silver; Al, aluminum; As, arsenic; Ba, barium; Cd, Cr, chromium; Cu, copper; Fe, iron; Mn, manganese; N, nitrogen; Ni, nickel; P, phosphorus; Pb, lead; Ti, titanium; TN, total nitrogen; TP, total phosphorus; Zn, zinc