GEOCHEMICAL AND SOLUTE-DISCHARGE HYSTERESIS COMPARISON OF TWO ATLANTA METROPOLITAN REGION WATERSHEDS

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Abstract. The major ion geochemistry (Ca, Na, Mg, K, $SiO_{2\ aq}$, SO_4, HCO_3, and specific conductance) of Peachtree Creek and Sweetwater Creek was analyzed during the period between 2000–2001. Peachtree Ck. drains one of the most urbanized basins within the Atlanta metropolitan region while Sweetwater Ck. drains a far less developed basin, ~35km west of Atlanta. Although all major ion parameters met safe drinking water standards, total dissolved solute concentrations in Peachtree Ck. were ~30% greater than within Sweetwater Ck. Sweetwater Ck. is underlain by a higher percentage of relatively soluble amphibolite and therefore the higher solute concentrations cannot be attributed to lithological differences between the two watersheds. It is not clear what mechanism is responsible; however, it is possible that leaky sewer pipes may be at least partially responsible for the higher solute loads within the Peachtree Ck. watershed, particularly that portion of the basin underlying the City of Atlanta. Most of the concentration-discharge (C/Q) loops associated with Peachtree Ck. were characterized by clockwise rotation and concave curvature. Such hysteresis dynamics can be most readily explained by a two-end member mixing model where "pre-event water" mixes with "event" water during storm periods. In contrast, the C/Q loops for Sweetwater Ck. were for the most part characterized by "anticlockwise hysteresis" indicative of three-component mixing.

OBJECTIVE AND STUDY AREA

The objective of this study was to analyze differences in major ion chemistry of stream flow between a highly urbanized Atlanta metropolitan region (Peachtree Ck.; 225 km^2 watershed area) basin and a less developed basin (Sweetwater Ck.; 647 km^2 watershed area) with similar geologic and hydrologic characteristics (Table 1 and Figure 1). An understanding of systematic geochemical differences that characterize these streams can lead to a better understanding of the hydrodynamic effects of urbanization upon Piedmont watersheds.

The Sweetwater Ck. basin is located ~35km^2 west of Peachtree Ck. basin and is underlain by a high percentage of amphibolite schist and biotite gneiss (Rose, 2002 and Alhadeff et al., 2000). The Peachtree Ck. basin is underlain by a lower percentage of mafic metamorphic rock, an important factor that needs to be considered in the interpretation of the hydrochemistry of both basins. Both basins receive similar yearly rainfall inputs; however, Peachtree Ck. which is 55% urbanized converts 66% of its annual runoff to direct storm runoff whereas only 48% of the total runoff within the Sweetwater Ck. basin is discharged as storm flow (Rose, 2002). Another important difference between the two basins in that the annual hydrograph for Peachtree Ck. is characterized by many more storm peaks with shorter duration recessions than its less-urbanized counterpart (Rose and Peters, 2001). Other comparative hydrological features of the two basins are given in Table 1.

METHODS

Water samples from both streams were acquired using a polypropylene sampler lowered into mid-stream at or immediately downstream from the USGS flow gauging location. Most of the sampling occurred between August 2000 and July 2001. Samples were acquired under a range of runoff conditions varying from 30–3,040 cfs for Sweetwater Ck. and 15–2,800 cfs for Peachtree Ck. Details of the chemical procedures are given in Rose (2002). Real-time discharge measurements were acquired from the USGS web site (http://ga.waterdata.usgs.gov/). The precision associated with cation and anion analyses was generally better than 5% and 10% respectively.

DISCUSSION OF RESULTS

TDS concentrations in both streams are relatively dilute as would be expected for streams draining aluminosilicate basins. The maximum TDS concentration for both basins was 128 mg/L observed within a Peachtree baseflow sample, which is only ~25% of the MCL for drinking water. The chemistry of both streams was dominated by Ca, Mg, and HCO_3 and there was only slight variation between water types associated with baseflow and storm runoff (Rose, 2002).

Table 1. Comparative characteristics of the Sweetwater Creek and Peachtree Creek basins

[km, kilometer; ft, feet; a.s.l., at sea level; %, percent; mm, millimeter]

Characteristic	Sweetwater Creek Basin	Peachtree Creek Basin
Area (km')	637	225
Latitude/Longitude (at gauge)	33°46'22"/84°36'53"	33°49'10"/84°24'28"
Elevation (at gauge in ft a.s.l.)	857	764
County (at gauge)	Douglas	Fulton
Percent Urban/Percent Forest	13.8% / 65.8%	54.7% / 42.0%
Population Density (people/km^2)	<250	1,000–2,500
Mean Slope (%)	2.4	2.6
Stream Density (length[km]/area[km^2])	0.87	0.85
Annual Rainfall (mm)	1,370	1,350
Total Runoff (mm)	489	546
Runoff Coefficient (runoff/rainfall)	0.36	0.40
Storm Runoff (mm; [%total])	237 [48%]	358 [66%]

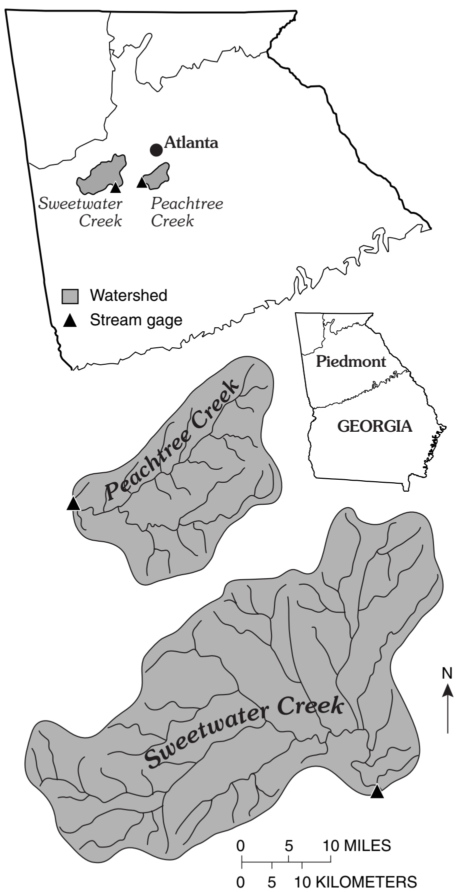

Figure 1. Map of the study area showing sampling sites.

The major difference between the major ion chemistry of these streams is that the average TDS concentration for Peachtree Ck. baseflow (103 mg/L) was 31% greater than the average baseflow concentration for Sweetwater Ck. (71 mg/L). This difference cannot likely be explained by mineral weathering, in that the Sweetwater Ck. basin is underlain by a higher percentage of more soluble mafic minerals. A possible explanation for the higher TDS concentrations is that there is some source of pollution, such as leaky sewage pipes, elevating solute concentrations within Peachtree Ck. baseflow. This is supported by higher sulfate and chloride concentrations within Peachtree Ck. baseflow.

Peachtree Ck. storm water is diluted to a higher degree than Sweetwater Ck. storm water. The average TDS for Peachtree Ck. storm flow (56 mg/L) was only 55% of the average baseflow concentration. In contrast, the average TDS of Sweetwater Ck. storm flow (52 mg/L) was 73% that of baseflow. This prominent dilution trend for storm and recession samples can be attributed to the proportionally greater contribution of street runoff within the urban basin from large diameter storm pipes. Sulfate concentrations within Sweetwater Ck. storm flow were slightly higher than in baseflow. This was the only ion that exhibited this 'reverse dilution' behavior, which might be attributed to the desorption of sulfate from shallow soils in the near-stream zone during the prolonged (i.e. ~4–7 day) recession periods characteristic of Sweetwater Ck.

Another marked contrast between the two basins is that pairs of major ions within Peachtree Ck. stream flow tend to regress with one another linearly while this is not the case with respect to Sweetwater Ck. stream chemistry. For example, the regression coefficients (r^2 values) between Ca, Mg, Na, and HCO_3 concentrations for Peachtree Ck. varied between 0.65 and 0.94. The regression coefficients for the same set of parameters were only between 0.27 and 0.65 in Sweetwater Ck. samples. The degree to which these regression coefficients vary suggests that mixing processes within the urban basin highly conform with a two end-member mixing (storm flow and prestorm flow) model while mixing dynamics within the less-developed Sweetwater Ck. basin cannot be neatly explained with such a simple model.

Concentration-discharge (C/Q) plots for four Peachtree Ck. and three Sweetwater Ck. storm/recession cycles indicated that the two streams responded differently to the input of storm runoff. C/Q plots for nine major ion geochemical parameters representative of the urbanized Peachtree Ck. watershed were almost exclusively characterized by clockwise rotation and concave curvature ("C3" type hysteresis of Evans and Davies, 1998). These hysteresis patterns are characterized by decreasing concentrations on the rising limb of the hydrograph followed by increasing concentrations on the falling limb (see Figure 2). This hysteresis pattern most likely results from two-component mixing in which the concentration of the "pre-event" water (ground water) is greater than the "event" water (storm runoff). Both the rising and falling limb of the hydrograph are dominated by the input of storm water. The two-component mixing model is consistent with the very short recession periods which allow little time for soil water to enter the mixture and the high regression coefficients for many of pairs of the geochemical parameters.

The hysteresis dynamics for the less-urbanized Sweetwater Ck. basin are more complicated; however, the dominance of anticlockwise-concave C/Q loops ("A3" type of Evans and Davies, 1998) for two of the three storm events suggests that three-component mixing may be occurring. These loops further suggest that the concentration of a given component is greater in ground water than in soil water which in turn is greater than the concentration within the event water. Three-component mixing is consistent with the low regression coefficients (r^2<0.45) for most pairs of geochemical parameters and with the characteristically longer recession periods associated with Sweetwater Ck. that might allow more time for soil water to contribute to stream flow.

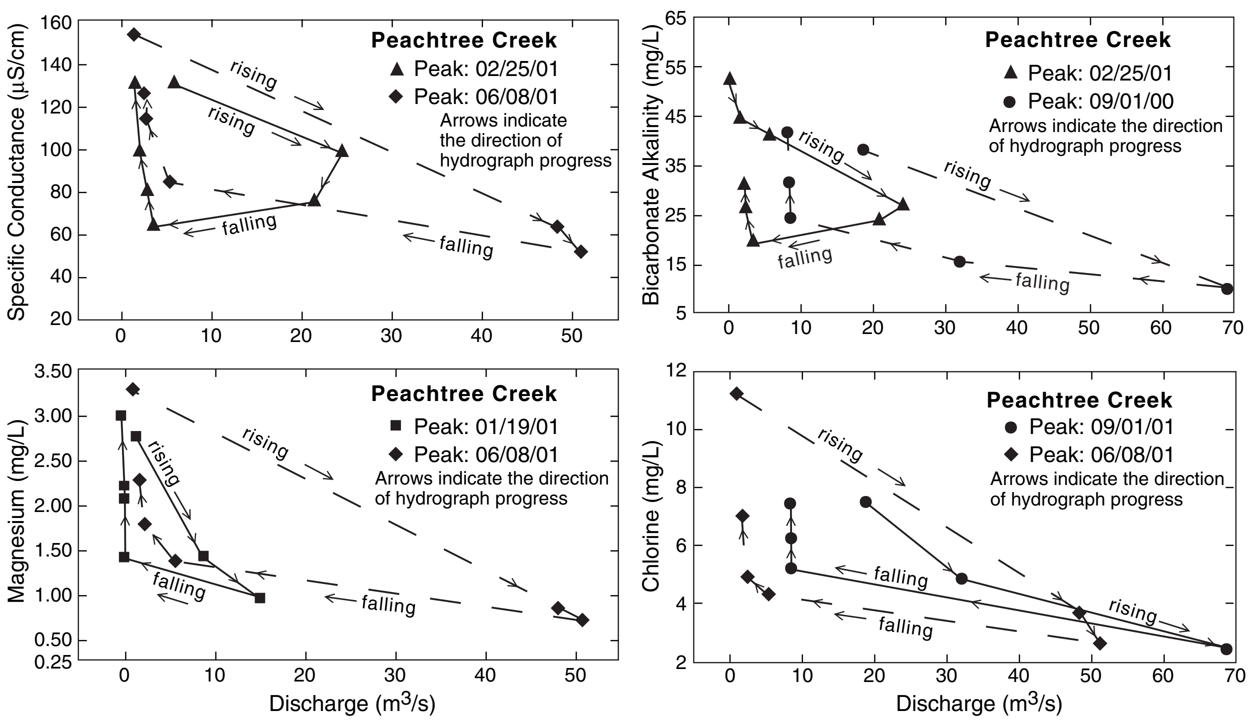

Figure 2. Concentration/Discharge (C/Q) loops for specific conductance, magnesium, bicarbonate alkalinity, and chloride for two storm events sampled from Peachtree Creek. Note the clockwise hysteresis patterns for these parameters.

Table 2. Mean concentrations of major ion parameters

[All concentrations in mg/L; number in parenthesis is the standard deviation]

Ion/Parameter	Peachtree Creek baseflow/late recession, n=18	Sweetwater Creek baseflow/late recession, n = 15	Peachtree Creek stormflow/early recession, n = 16	Sweetwater Creek stormflow/early recession, n = 17
Calcium	11.9 (2.9)	6.3 (1.5)	7.1 (2.0)	4.6 (0.7)
Magnesium	2.4 (0.7)	2.0 (0.3)	4.1 (1.1)	3.4 (1.5)
Sodium	6.5 (1.9)	5.5 (1.3)	4.0 (1.7)	3.9 (0.7)
Potassium	3.1 (0.7)	1.5 (0.4)	2.5 (0.4)	1.7 (0.3)
Bicarbonate	47.1 (12.8)	30.0 (6.7)	32.4 (8.2)	18.3 (5.4)
Sulfate	9.6 (2.7)	5.3 (2.4)	6.5 (2.1)	5.8 (1.9)
Chloride	7.8 (3.0)	6.1 (2.3)	4.8 (2.1)	4.4 (2.1)
Nitrate	2.8(1.8)	2.3 (0.8)	2.4 (1.5)	2.4 (1.4)
Dissolved Silica	11.7 (2.9)	12.5 (1.7)	5.4 (1.4)	9.5 (1.7)
pH	6.9 (0.2)	6.9 (0.2)	6.4 (0.2)	6.5 (0.2)
TDS	103 (24)	71 (9)	56 (17)	52 (8)
Conductivity (µS/cm)	123 (27)	85 (11)	75 (25)	63 (9)

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