URBANIZATION EFFECTS ON STREAMFLOW IN THE ATLANTA, GEORGIA AREA

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Abstract. For the period from 1958 to 1996, streamflow and rainfall characteristics of a highly urbanized watershed were compared with less-urbanized and nonurbanized watersheds in the vicinity of Atlanta, Georgia. Water levels in several wells completed in surficial and crystalline-rock aquifers also were evaluated. Annual runoff coefficients (runoff as a fractional percentage of precipitation) ranged from 0.31 to 0.34 and were not significantly different for the urban stream (Peachtree Creek). Peak flows for the largest 25 stormflows at Peachtree Creek were 30 to 80 percent greater than peak flows for the other streams. A 2-day storm recession constant for Peachtree Creek was much larger, that is streamflow decreased more rapidly, than for the other streams. Average low flow of Peachtree Creek was 25 to 35 percent less than the other streams, possibly the result of decreased infiltration caused by the more efficient routing of stormwater and the paving of ground-water recharge areas. The timing of ground-water level variations was similar annually in each well, reflecting the seasonal recharge. Although water-level monitoring only began in the 1980s for the two urban wells, water levels displayed a notable decline compared to non-urban wells since then—this is attributed to decreased ground-water recharge in the urban watersheds due to increased imperviousness and related rapid storm runoff. Likewise, the increased urbanization from the 1960s to the 1990s of the Peachtree Creek watershed produced more runoff than urbanization in the less urbanized Big Creek and Sweetwater Creek watersheds.

INTRODUCTION

Urbanization has a significant effect on many of the processes that control streamflow (McCuen, 1998). Hydrologic effects of urbanization include (1) a higher proportion of precipitation appears as surface runoff; (2) catchment response to precipitation is accelerated and the lag time between precipitation and runoff is decreased; (3) peakflow magnitudes are increased for all but the largest storm events; (4) low flow is decreased due to reduced contributions from ground-water storage; and (5) water quality is degraded by effluent discharges and non-point sources (Shaw, 1994). This paper compares and contrasts streamflow responses of urbanized streams with less-urbanized streams in the Atlanta area and discusses the effects of urbanization on stormflow response. This paper is a summary of a more extensive analysis of streamflow in the region by Rose and Peters (*in press*).

Methods

Four unregulated Georgia streams in the Piedmont Province were selected based on the availability of long-term (35 to 38 years) streamflow and precipitation data (table 1). The drainage basins vary from urbanized (Peachtree Creek watershed) to less urbanized (Sweetwater Creek and Big Creek watersheds) to rural (Middle Oconee River watershed).

Daily mean streamflow was extracted from the U.S. Geological Survey (USGS) database; daily precipitation was obtained from National Climatic Data Center records (EarthInfo Inc., 1996). Watershed characteristics were compared among sites including drainage area, mean slope, and topographic index, $ln(a/tan\beta)$ (Kirkby, 1975). For the topographic index, a is the area draining through a point from upslope and $\tan\beta$ is the local slope angle. The mean slope and topographic index were derived from 1 degree (1:250,000 scale) digital elevation model (DEM) data (USGS1-degree DEM, 2000). Land-use change was semi-quantitatively assessed through an analysis of census data for 1970, 1985 and 2000 (Atlanta Regional Commission, 2000a); and 1998 multi-resolution land characteristics and national land-cover data (U.S. Environmental Protection Agency MRLC NLCD, 2000) using ArcView 3.2[1/].

[1/]The use of brand names in this report is for information purposes only and does not imply endorsement by the U.S. Government.

Table 1. Characteristics of select streams and watersheds in the Atlanta area

[AA = Atlanta WSO Airport; AB = Atlanta Bolton; AWS = Athens WSO Airport; Da = Dallas; Dg = Douglasville; Dl = Dahlonega 2 NW; G = Gainesville; My = Maysville; N = Norcross; W = Winder

Station name	USGS station number	Drainage area (square kilometer)	Period of record	Gage elevation (meter)	Mean *ln(a.tan/β)*	Mean slope (percent)	Rain gages	1998 Land use (percent)					
								Open water	Wetland	Urban	Forest	Agriculture	Other
Middle Oconee River near Athens	02217500	1,015	1958-95	169	5.4	3.4	AWS, G, My, W	0.3	1.0	4.0	64.0	30.3	0.5
Big Creek near Alpharetta	02335700	186	1961-95	293	5.9	2.6	Dl, N	0.5	1.3	13.0	65.5	18.7	0.9
Peachtree Creek in Atlanta	02336300	225	1958-95	233	5.8	2.6	AA, AB, N	0.4	0.0	54.7	42.0	2.6	0.2
Sweetwater Creek near Austell	02337000	396	1958-95	261	5.8	2.4	Da, Dg	0.9	3.0	13.8	65.8	15.6	0.9

Four parameters were used to assess stream hydrographs—

- annual runoff coefficient (RC: annual runoff divided by annual precipitation);
- peak daily discharge for the largest 25 stormflow events;
- 2-day recession constant (k_2) for events that produced a daily stormflow maximum of 15 millimeters (mm)/day (after Domenico and Schwartz, 1998);

$$Q_2 = Q_p e^{-kt} \quad (1)$$

$$k_2 = (1/t) \ln Q_p/Q_2 \quad (2)$$

  where Q_p = peak discharge, Q_2 = discharge 2 days after peak, t = 2 days, and k_2 = 2-day recession constant (hr^{-1}); and
- lowest daily runoff during the summer (May through September).

For each parameter, one-tailed t-tests were used to determine statistically significant differences between runoff characteristics of Peachtree Creek and the three other streams. Daily mean ground-water levels also were extracted from the USGS database for three long-term monitoring wells in the area. The ground-water level variations were compared for a relatively non-urban well screened in the surficial aquifer (Spalding County), that is in residuum, and two urban wells in the crystalline-rock aquifer (Dekalb County and Fulton County).

RESULTS AND DISCUSSION

During the 35 to 38 years of record, annual precipitation averaged 1340 mm (±190 mm) and was similar among streams. Annual runoff averaged 440 mm (± 115 mm) resulting in annual runoff coefficients (RCs) of 31 to 34 percent.

Annual runoff coefficient: Regression of annual runoff on precipitation for each stream strongly suggests that the primary factors controlling runoff are evapotranspiration and total annual precipitation. The intercept is negative for all streams, indicating that a minimum amount of annual precipitation is required to generate runoff. Although the average annual RCs and the slopes of the regressions are similar, the regression for Peachtree Creek differs subtly from the other streams. The intercept is the smallest indicating that less precipitation is required to generate runoff than for the other streams. This result is consistent with the rapid runoff response of highly urbanized watersheds, that is due to increased imperviousness and construction (typically concrete) of drainage systems (Schueler, 1994; Arnold and Gibbons, 1996).

Peak runoff: Rapid channeling of street runoff through large diameter storm drains is probably the most distinguishing characteristic of urban runoff. To characterize peak runoff, the 25 largest magnitude daily runoff events were selected for each stream. The daily runoff for the 25 highest magnitude daily stormflows for Peachtree Creek (35-71 mm) is significantly higher than the other streams ($\alpha<0.01$). Median runoff for 25 daily stormflows at Peachtree Creek (43 mm) was the largest of all streams. Furthermore, median runoff for Peachtree Creek was 30 percent greater than Big Creek, and more than 80 percent greater than either Sweetwater Creek or the Middle Oconee River.

2-day recession constants: For Peachtree Creek, 148 storm events generated runoff exceeding 15 mm/day magni-tude, which were from 2 to 3 times more than the other watersheds. Also, storm recession constants for Peachtree Creek were significantly higher (t-tests, $\alpha< 0.0001$) than the recession constants of the other watersheds. For example, the average 2-day recession constant for Peachtree Creek (1.19 per day) was significantly higher than the other streams, and in particular, than less urbanized Big Creek (0.80 per day) and Sweetwater Creek (0.44 per day). These results indicate that storm recessions in the highly urbanized watersheds are not sustained, and the hydrograph is ìspikyî compared with less-urbanized watersheds.

Low flow: Low-flow values of Peachtree Creek (average = 0.19 mm/day) were significantly lower ($\alpha \leq 0.05$) than the other streams. The average low flow value for Peachtree Creek was from 25 to 35 percent less than low-flow values for the less-urbanized Big Creek and Sweetwater Creek watersheds. This result indicates that storm runoff is much more efficiently conveyed to streams during storm events and results in a very brief recession period.

Ground-water level variations: Ground-water levels in the Atlanta area vary seasonally, with the highest water table and associated highest baseflow occurring during the dormant winter ground-water recharge period, and lowest during the growing season in summer. Monthly mean ground-water levels in the urban wells are highly correlated ($\alpha<0.01$) with the non-urban well for a given year, that is the water level in each well varies seasonally. However, water levels in the urban wells have decreased compared to those in non-urban areas, as shown by the decadal change in the relation between the urban and non-urban wells (fig. 1). This result suggests that urbanization, and in particular the increased imperviousness, increases runoff and decreases ground-water recharge.

Effects of land-use changes: Population and associated land use changed in the watersheds—these changes were not uniform among the watersheds (table 2). The percentage population increase from the years 1970 to 1985 for the two less-urbanized streams—Big Creek and Sweetwater Creek—is higher (79 and 90 percent, respectively) than for the urban stream—Peachtree Creek (20 percent). However, population density of Peachtree Creek increased by more than three times that of either Big Creek or Sweetwater Creek. To assess this effect, temporal variations in annual runoff coefficients of Peachtree Creek were compared with those of the two adjacent, rapidly urbanizing watersheds. For each year, the difference between the RC of Peachtree Creek and that of Big Creek and Sweetwater Creek were computed and evaluated for each decade from the 1960s to the 1990s (fig. 2). The RC difference is a measure of the relative effects of urbanization on annual water yield for Peachtree Creek compared to the other streams. The urbanization of Peachtree Creek results in a progressive, statistically significant ($\alpha<0.01$)), decadal increase in annual water yield relative to the other streams. These results indicate that the relatively higher population density increase in the Peachtree Creek watershed results in an increase in annual runoff (greater imperviousness, and less recharge or evapotranspiration) than in the less urbanized Big Creek and Sweetwater Creek watersheds.

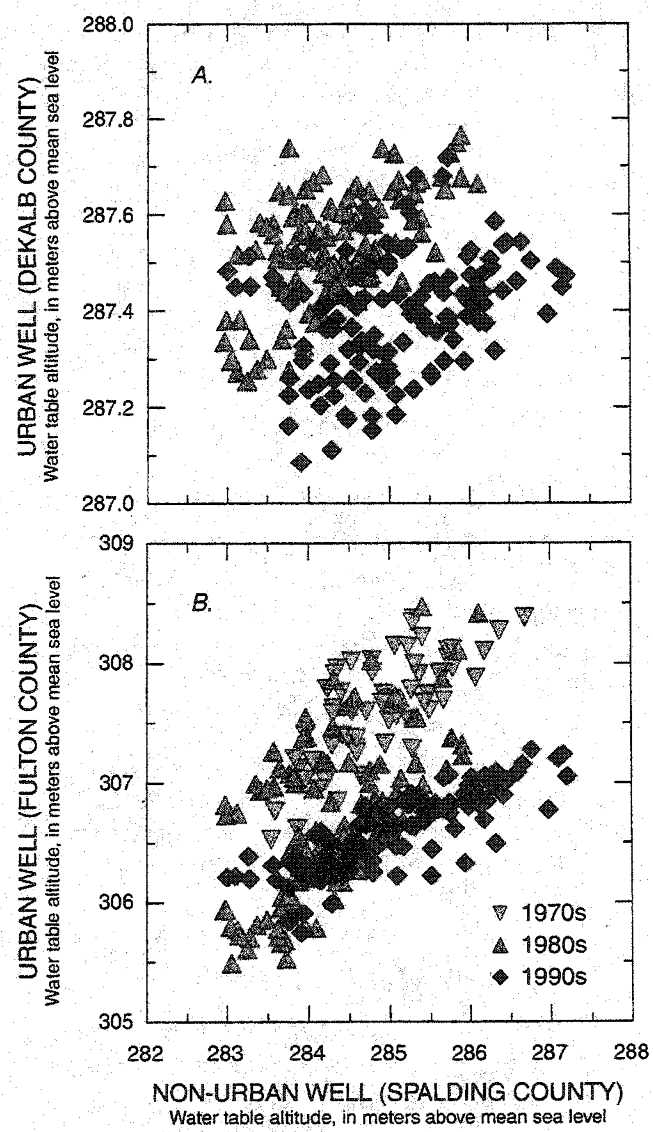

Figure 1. Relations between monthly mean ground-water levels in two urban wells with a non-urban index well. Each relation shows the decadal variations.

Table 2. Population density of watersheds for the streams in the Atlanta area (Atlanta Regional Commission, 2000b)

Stream	Population Density (people per square kilometer)		Change (percent of 1970)
	1970	1985	
Middle Oconee River near Athens	187	260	40
Big Creek near Alpharetta	53	95	79
Peachtree Creek in Atlanta	1,220	1,470	20
Sweetwater Creek near Austell	75	140	90

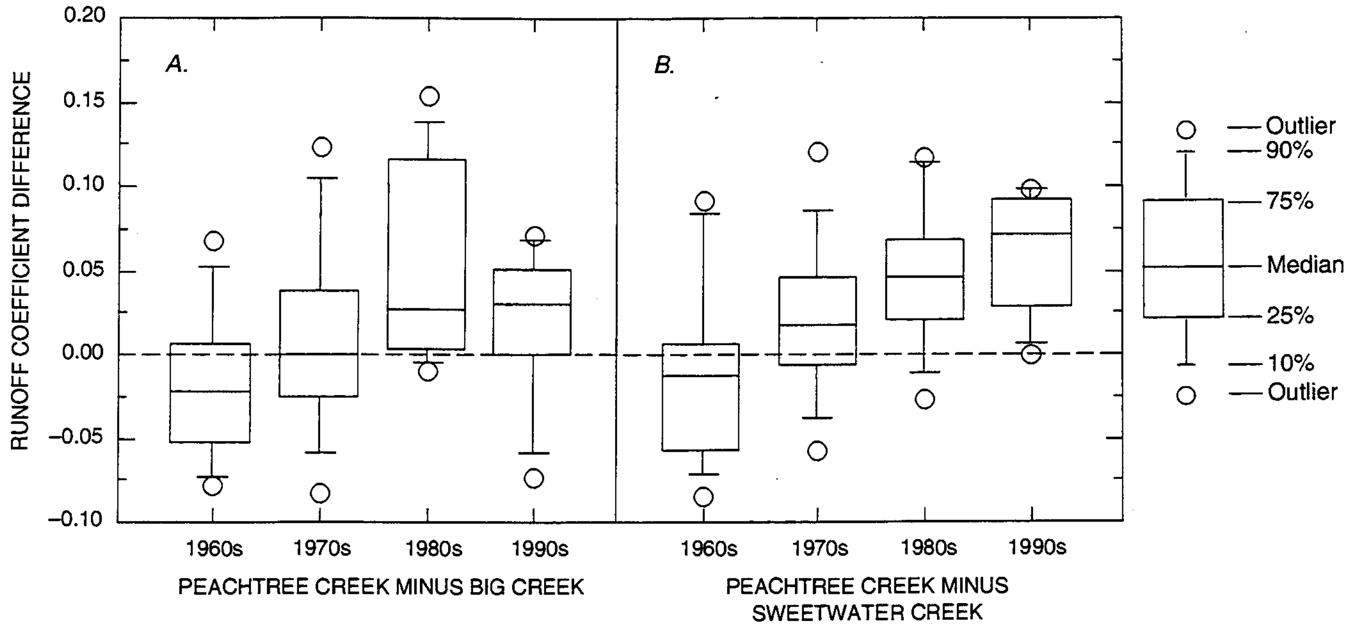

Figure 2. Decadal differences in the annual runoff coefficients between Peachtree Creek and *(A)* Big Creek and *(B)* Sweetwater Creek.

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