

## Urbanization effects on the hydrology of the Atlanta area, Georgia (USA)

**NORMAN E. PETERS**

*US Geological Survey, 3039 Anawiler Road, Suite 130, Atlanta, Georgia 30360, USA*

c-mail: [nepeters@usgs.gov](mailto:nepeters@usgs.gov)

**SETH ROSE**

*Department of Geology, Georgia State University, Atlanta, Georgia 30303, USA*

**Abstract** For the period from 1958 to 1996, streamflow and rainfall characteristics of a highly urbanized watershed were compared with less-urbanized and non-urbanized watersheds in the vicinity of Atlanta, Georgia (USA). 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% 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% less than the other streams, possibly the result of decreased infiltration caused by the more efficient routing of storm water and the paving of groundwater recharge areas. The timing of groundwater level variations was similar annually in each well, reflecting the seasonal recharge. Although water level monitoring only began during the late 1970s and early 1980s for the two urban wells, water levels in these wells have been declining compared to non-urban wells since then. The water level decline is attributed to decreased groundwater 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.

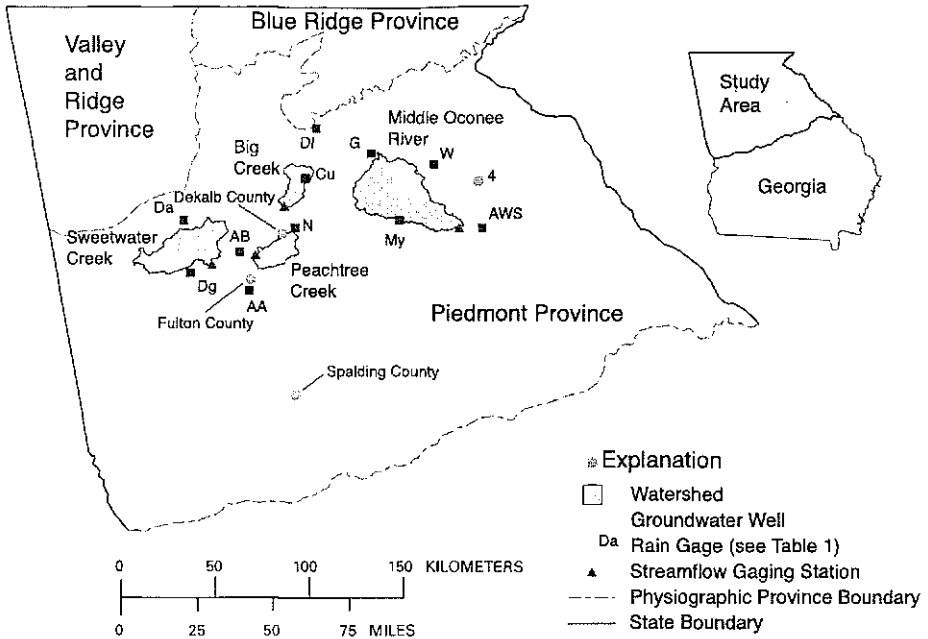
**Key words** baseflow recession; groundwater recharge; Piedmont Province (Georgia, USA); stream runoff; urban runoff, urban watersheds; water yield

### INTRODUCTION

Urbanization has a significant effect on many of the processes that control streamflow (McCuen, 1998). Hydrological effects of urbanization include: (a) a higher proportion of precipitation appears as surface runoff; (b) catchment response to precipitation is accelerated and the lag time between precipitation and runoff is decreased; (c) peak flow magnitudes are increased for all but the largest storm events; (d) low flow is decreased due to reduced contributions from groundwater storage; and (e) 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 and urban and rural groundwater levels in the Atlanta area, and discusses the effects of urbanization on stormflow and groundwater.

## METHODS

Four unregulated Georgia streams in the Piedmont Province were selected based on the availability of long-term (35 to 38 year) streamflow and precipitation data (Fig. 1 and 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).



**Fig. 1** Map of study area showing locations of watersheds, streamgauges, raingauges (see Table 1 for identifier), and wells for the Atlanta area.

Daily mean streamflow was extracted from the US 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 the 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 a one-degree (1:250 000 scale) digital elevation model (DEM) data (USGS 1-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 (US Environmental Protection Agency MRLC NLCD, 2000) using ArcView 3.2\*.

Four parameters were used to assess stream hydrographs:

- annual runoff coefficient ( $RC$ : annual runoff divided by annual precipitation);

\* The use of brand names in this report is for information purposes and does not imply endorsement by the US Geological Survey.

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

| Station name                    | USGS station number | Drainage area (km <sup>2</sup> ) | Period of record | Gauge elevation (m) | Mean $\ln(a/\tan\beta)$ | Mean slope (%) | Rain gauges*  |
|---------------------------------|---------------------|----------------------------------|------------------|---------------------|-------------------------|----------------|---------------|
| Middle Oconee River near Athens | 02217500            | 1015                             | 1958–1995        | 169                 | 5.4                     | 3.4            | AWS, G, My, W |
| Big Creek near Alpharetta       | 02335700            | 186                              | 1961–1995        | 293                 | 5.9                     | 2.6            | DI, N         |
| Peachtree Creek in Atlanta      | 02336300            | 225                              | 1958–1995        | 233                 | 5.8                     | 2.6            | AA, AB, N     |
| Sweetwater Creek near Austell   | 02337000            | 396                              | 1958–1995        | 261                 | 5.8                     | 2.4            | Da, Dg        |

\* Raingauge abbreviations: AA = Atlanta WSO Airport; AB = Atlanta Bolton; AWS = Athens WSO Airport; Da = Dallas; Dg = Douglasville; DI = Dahlonega 2 NW; G = Gainesville; My = Maysville; N = Norcross; W = Winder.

| Station name                    | 1998 Land use (%): |         |       |        |             |       |
|---------------------------------|--------------------|---------|-------|--------|-------------|-------|
|                                 | Open water         | Wetland | Urban | Forest | Agriculture | Other |
| Middle Oconee River near Athens | 0.3                | 1.0     | 4.0   | 64.0   | 30.3        | 0.5   |
| Big Creek near Alpharetta       | 0.5                | 1.3     | 13.0  | 65.5   | 18.7        | 0.9   |
| Peachtree Creek in Atlanta      | 0.4                | 0.0     | 54.7  | 42.0   | 2.6         | 0.2   |
| Sweetwater Creek near Austell   | 0.9                | 3.0     | 13.8  | 65.8   | 15.6        | 0.9   |

- 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 mm day<sup>-1</sup> (after Domenico & Schwartz, 1998):

$$Q_2 = Q_p e^{-k_2 t} \quad (1)$$

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

where  $Q_p$  = peak discharge,  $Q_2$  = discharge 2 days after peak,  $t = 2$  days, and  $k_2$  = 2-day recession constant (h<sup>-1</sup>); and

- lowest daily runoff during the summer (May through to 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 groundwater levels also were extracted from the USGS database for three long-term monitoring wells in the area (Fig. 1). The groundwater 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 streamflow record, annual precipitation averaged 1340 mm ( $\pm 190$  mm) and was similar among streams. Annual runoff averaged 440 mm ( $\pm 115$  mm) resulting in annual runoff coefficients (RCs) of 31% to 34%.

**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 & Gibbons, 1996).

**Peak runoff** Rapid channelling 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 ( $p < 0.01$ ). 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% greater than Big Creek, and more than 80% greater than either Sweetwater Creek or the Middle Oconee River.

**2-day recession constants** For Peachtree Creek, 148 storm events generated runoff exceeding  $15 \text{ mm day}^{-1}$  magnitude, which were from two to three times more than the other watersheds. Also, storm recession constants for Peachtree Creek were significantly higher (t-tests,  $p < 0.0001$ ) 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 the 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 “spiky” compared with less-urbanized watersheds.

**Low flow** Low-flow values of Peachtree Creek (average =  $0.19 \text{ mm day}^{-1}$ ) were significantly lower ( $p \leq 0.05$ ) than the other streams. The average low flow value for Peachtree Creek was from 25% to 35% 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.

**Groundwater level variations** Groundwater levels in the Atlanta area vary seasonally, with the highest water table and associated highest baseflow occurring during the dormant winter groundwater recharge period, and lowest during the growing season in summer as shown for streamflow and groundwater levels from an urban well in Fig. 2. The groundwater level response lags the streamflow response by several weeks during most of the year. Furthermore, monthly mean groundwater levels in the urban wells are highly correlated ( $p < 0.01$ ) with the non-urban well for a given year, indicating that the water level in each well varies seasonally. Water levels in the urban wells, however, have decreased compared to those in non-urban areas, as shown

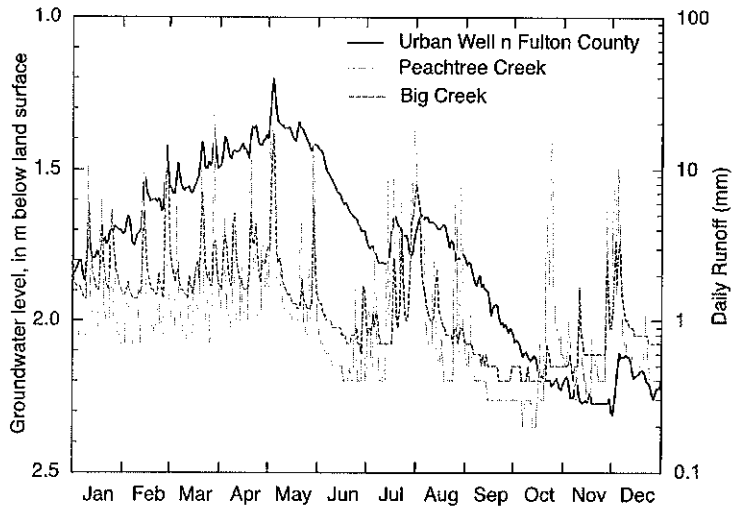


Fig. 2 Temporal variability for 1983 in daily groundwater level in an urban well in Fulton County and daily runoff from two streams, urbanized Peachtree Creek and less-urbanized Big Creek, in the Atlanta area.

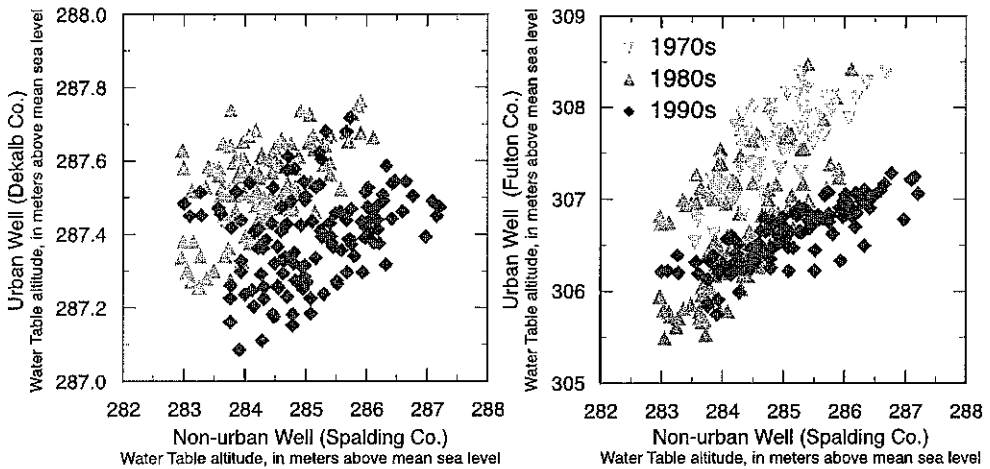


Fig. 3 Relations between monthly mean groundwater levels in two urban wells with a non-urban index well in the Atlanta area. Each relation shows the decadal variations.

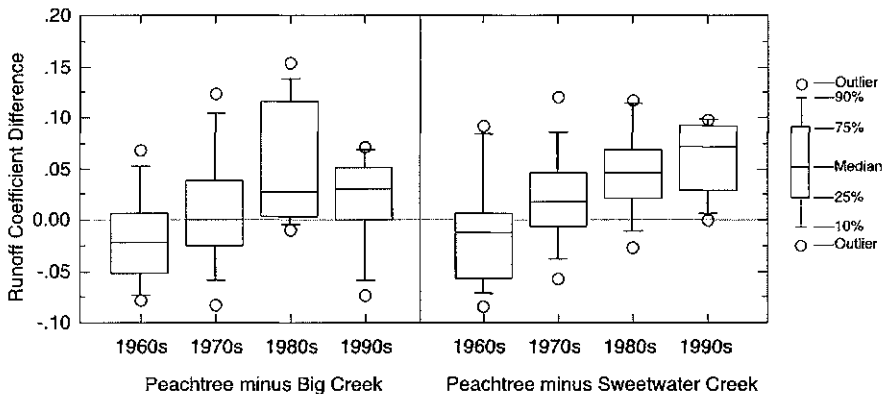
by the decadal change in the relation between the urban and non-urban wells (Fig. 3). This result suggests that urbanization, and in particular the increased imperviousness, increases runoff and decreases groundwater recharge.

**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%, respectively) than for the urban stream—Peachtree Creek (20%). However, the population density of Peachtree Creek increased by more than three times that of either Big Creek or Sweet-

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

| Stream                          | Population density (people per km <sup>2</sup> ): |      | 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      | 1220  | 1470 | 20                       |
| Sweetwater Creek near Austell   | 75  | 140  | 90                       |

water 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. 4). 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 ( $p < 0.01$ ), 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.

**Fig. 4** Decadal differences in the annual runoff coefficients between Peachtree Creek and Big Creek and between Peachtree Creek and Sweetwater Creek in the Atlanta area.

## REFERENCES

- Arnold, C. L. J. & Gibbons, C. J. (1996) Impervious surface coverage: the emergence of a key environmental indicator. *J. Am. Planning Assoc.* **62**, 243–256.
- Atlanta Regional Commission (2000a) *Population of the Atlanta Region: 1900–1999*. [http://www.atlantaregional.com/regional\\_data/99tables\\_and\\_charts/pop99tbl1.html](http://www.atlantaregional.com/regional_data/99tables_and_charts/pop99tbl1.html) [accessed 29 September 2000].
- Atlanta Regional Commission (2000b) *Population Density, 1999*. [http://www.atlantaregional.com/movers/about\\_region.html](http://www.atlantaregional.com/movers/about_region.html) [accessed 29 September 2000].
- Domenico, P. A. & Schwartz, F. W. (1998) *Physical and Chemical Hydrogeology* (second edn). Wiley, New York, USA.

- EarthInfo Inc. (1996) *USGS Daily Values*. EarthInfo CD<sup>2</sup> Reference Manual, CD-ROM.
- Kirkby, M. (1975) Hydrograph modelling strategies. In: *Processes in Physical and Human Geography* (ed. by R. Peel, M. Chisholm & P. Haggett), 69–90, Heinemann, London, UK.
- McCuen, R. H. (1998) *Hydrologic Analysis and Design* (second edn). Prentice Hall, Upper Saddle River, New Jersey, USA.
- Schucler, T. R. (1994) The importance of imperviousness. *Watershed Protection Techniques* 1(3), 100–111.
- Shaw, E. M. (1994) *Hydrology in Practice* (third edn). Chapman & Hall, London, UK.
- US Environmental Protection Agency MRLC NLCD (2000) <http://www.epa.gov/mrlc/nlcd.html> [accessed 29 September 2000].
- USGS 1-degree DEM (2000) <http://edcwww.cr.usgs.gov/doc/edchome/ndcldb/ndcldb.html> [accessed 21 September 2000].