EFFECTS OF URBAN DEVELOPMENT ON NUTRIENT LOADS AND STREAMFLOW, UPPER CHATTAHOOCHEE RIVER BASIN, GEORGIA, 1976–2001

Daniel L. Calhoun, Elizabeth A. Frick, and Gary R. Buell

AUTHORS: Hydrologists, U.S. Geological Survey, 3039 Amwiler Road, Suite 130, Peachtree Business Center, Atlanta, Georgia 30360-2824.
REFERENCE: *Proceedings of the 2003 Georgia Water Resources Conference*, held April 23–24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. The use of secondary and tertiary treatment of wastewater and the treatment of stormwater in the Metropolitan Atlanta area has mitigated many of the water-quality problems associated with urbanization in the upper Chattahoochee River Basin. However, treatment has not reduced total nitrogen. The engineering of urban watersheds to efficiently convey stormwater runoff has succeeded in moderating flooding in urban areas; however, increased stormflow volumes and streamflow velocities have degraded the physical structure of some streams and reduced the baseflow component of total streamflow. Nationwide, urbanization is increasing the volume of wastewater that requires treatment.

For this study, effluent discharge-monitoring data reported by wastewater-treatment plants (WWTPs) with outflows greater than 1 million gallons per day (Mgal/d) were analyzed in conjunction with instream nutrient concentrations to estimate phosphorus and nitrogen loads for the Chattahoochee River. Phosphorus loads have decreased from 1976 through 2001, primarily as a result of reductions in the use of phosphorus and improved removal processes at WWTPs. Ammonia nitrogen loads also have decreased during this period whereas nitrate nitrogen loads have increased. These changes result from increases in tertiary treatment that oxidizes ammonia to produce nitrate nitrogen. Effluent volume discharged from WWTPs has increased as population increased from 1976 through 2001.

Hydrograph separations for streams tributary to the upper Chattahoochee River indicate that urbanization reduces baseflows, increases stormflows, and may reduce the assimilative capacity of the Chattahoochee River, making the task of restoring the designated uses of area streams more difficult.

INTRODUCTION

Dramatic improvements during and since the 1980s in the water quality and biological integrity of the upper Chattahoochee River have been highlighted in national publications (U.S. Geological Survey, 1999; U.S. Environmental Protection Agency, 2000). Despite these improvements, continuing urban growth and nonpoint-source runoff of contaminants and stormwater are expected to challenge these historic gains (U.S. Environmental Protection Agency, 2000).

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program collected water-quality data within the framework of a land-use based design in the Apalachicola-Chattahoochee-Flint River Basin (Gilliom and others, 1995; Wangsness, 1997) from 1993 to present (2003). Analysis of these data, as well as data from a statewide monitoring network established by the Georgia Environmental Protection Division (GaEPD), has demonstrated that both urban and agricultural land uses contribute significant nutrient and suspended sediment loads to tributaries of the upper Chattahoochee River (Frick and Buell, 1999).

Urbanization is known to impact the hydrologic and aquatic integrity of urban streams. Simmons and Reynolds (1982) reported decreases of as much as 70 percent in baseflow in streams draining Long Island, New York, from 1948 through 1970. Spinello and Simmons (1992) updated the study to extend the period from 1976 through 1985. Both studies attributed the alteration of flow components to the installation of sanitary sewers for the conveyance of treated wastewater to tidewater, the routing of stormwater directly to streams, and an increase in impervious surfaces throughout the watersheds. Researchers studying Metropolitan Atlanta area streams have noted declines in low flows during late summer and increases in high flows associated with runoff events (Wallace, 1971; Rose and Peters, 2001). Native aquatic insect communities become less abundant and diverse in streams impacted by urbanization (Garie and McIntosh, 1986; Jones and Clark, 1987). The effects on the aquatic environment begin when watershed imperviousness reaches 12 percent and become severe when that level reaches 30 percent (Klein, 1979). Recent research suggests that effects are considerable at much lower levels of imperviousness (Booth and Jackson, 1997).

METHODS

Instream constituent loads reported herein were estimated using the LOADEST2 computer model (Crawford, 1996), which employs the rating curve method for load calculations (Cohn and others, 1989; Crawford, 1991). Point-source contributions of nutrients to the Chattahoochee River were estimated from discharge monitoring reports (DMRs) provided to the GaEPD by WWTPs. Data were obtained for 11 plants in Metropolitan Atlanta that discharge more than 1 Mgal/d of treated effluent to surface waters in the upper Chattahoochee River Basin downstream from Buford Dam and within Metropolitan Atlanta. Loads were calculated by multiplying the monthly mean discharge by the monthly mean constituent concentrations reported by the facilities.

The period of record of daily discharge (data collected by the USGS stream-gaging program) for six tributary streams in the Metropolitan Atlanta area (Fig. 1), with at least 5 years of record, were analyzed using HYSEP, a computer program that automates the process of hydrograph separation (Sloto and Crouse, 1996).

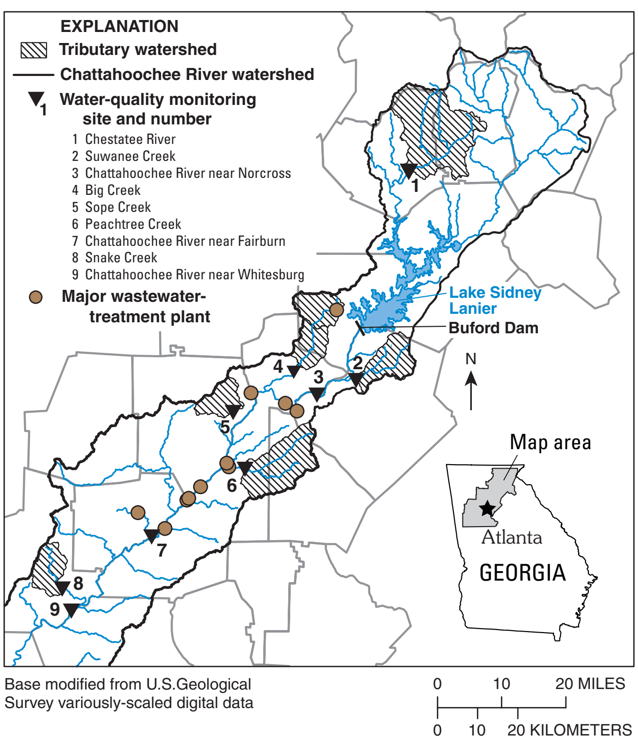

Figure 1. Water-quality monitoring sites and wastewater-treatment plants with estimated nutrient loads, upper Chattahoochee River Basin, 1976–2001.

The *local-minimum method* was chosen based on its close approximation to the straight-line method of manual hydrograph separation. Long-term patterns in baseflow and storm runoff were analyzed and interpreted.

RESULTS AND DISCUSSION

Annual nutrient loads in the Chattahoochee River downstream from Metropolitan Atlanta (site number 9 in Fig. 1) decreased by more than a factor of three for total phosphorus from 1990 to 1998 (Fig. 2) and for ammonia from 1975 to 1998 (Fig. 3). By 2001, the contribution of total phosphorus to the Chattahoochee River from point sources was nearly equal to the estimated loads upstream of Atlanta (site number 3 in Fig. 1), an area largely unaffected by point sources. The significant decreases in total phosphorus loads from point sources and in the Chattahoochee River downstream from Atlanta are primarily the result of legislated restrictions on the use of phosphate detergents and improved efficiencies of phosphorus removal by WWTPs (DeVivo and others, 1995; Wangsness and others, 1994). However, the improved treatment efficiency at WWTPs that oxidizes ammonia nitrogen to nitrate nitrogen has resulted in increased nitrate loads in the Chattahoochee River downstream from Metropolitan Atlanta (Fig. 3). The oxidation of ammonia to nitrate in the WWTPs rather than in the receiving streams is beneficial to fish;

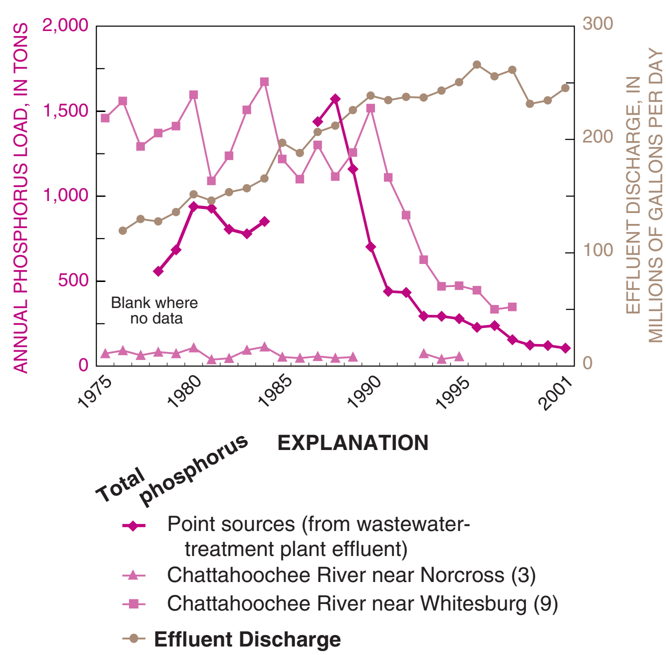

Figure 2. Annual instream and point-source total phosphorus loads and effluent discharge to the Chattahoochee River, 1975–2001 (number in parentheses is site number in figure 1).

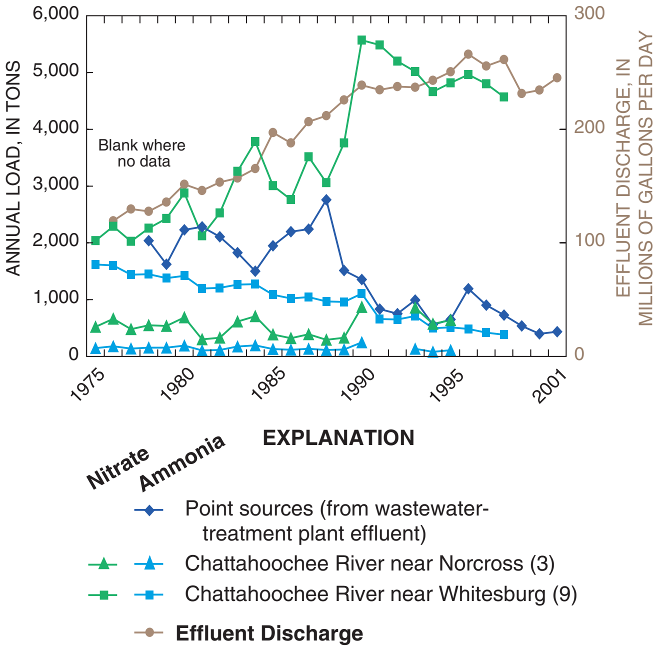

Figure 3. Annual instream and point-source ammonia and nitrate loads and effluent discharge to the Chattahoochee River, 1975–2001 (number in parentheses is site number in figure 1).

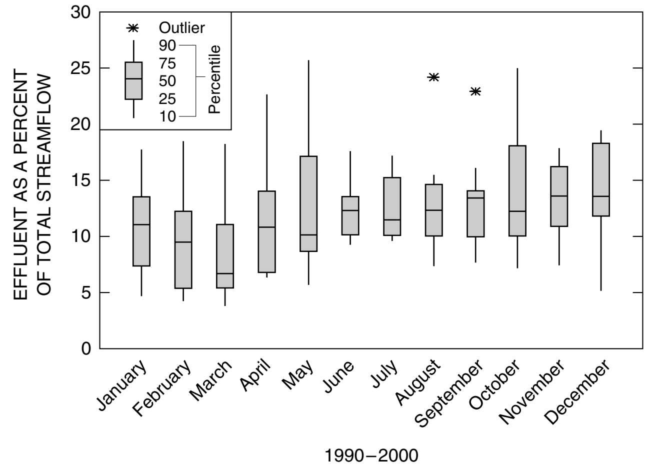

Figure 4. Percent of monthly average streamflow at the Chattahoochee River near Fairburn that was discharged upstream as treated wastewater, 1990–2000.

however, this oxidation does not significantly reduce the total nitrogen load to streams that may contribute to eutrophication in downstream water bodies. As population and urban development have increased in Metropolitan Atlanta, effluent discharged from WWTPs has continued to increase (Figs. 2 and 3), requiring more dramatic improvements to WWTP efficiencies to decrease nutrient loads from point sources.

The volume of municipal treated effluent discharged to water bodies in the upper Chattahoochee River has doubled from 1976 to present (2003) (Figs. 2 and 3). Effluent currently represents from 4 to 25 percent of the average monthly flow of the Chattahoochee River downstream from Metropolitan Atlanta during the period from 1990 through 2000 (Fig. 4), with a median range from approximately 7 to 13 percent. Effluent contribution during summer is the least variable; however, summer and fall have the highest percentage of effluent in streamflow.

The full range of baseflow alterations resulting from urbanization can be observed in the Metropolitan Atlanta area (Fig. 5). Peachtree Creek drains much of downtown Atlanta and is densely urbanized, with more than 20 percent impervious surfaces covering the tributary watershed. The baseflow component of total streamflow in Peachtree Creek has declined from approximately 50 to 30 percent of total streamflow since continuous streamflow measurements began in 1958. Equilibrium in the baseflow decline does not appear to have been reached in this watershed, and it can be extrapolated that without any additional increase in urbanization, further declines in baseflow will occur. Conversely, baseflow components of total streamflow in Snake Creek and the Chestatee River, watersheds that had little to no urban development, have been more consistent over time. The estimated baseflows of these streams have high inter-annual variability and the highest percentages of baseflow for the records studied. The streams that occupy the middle range of the baseflow component of total streamflow, Suwanee Creek and Big Creek, are in the middle stages of urbanization. Because of limited streamflow record, the past baseflows of Suwanee Creek and Sope Creek cannot be estimated. However, the current annual baseflows in Sope Creek are approaching the estimated baseflows of Peachtree Creek.

Estimates of impervious surfaces from 1995 land-use data were derived for the watersheds shown in Figure 5 (Evelyn Hopkins, U.S. Geological Survey, written commn. with Daniel L. Calhoun, 2002). Figure 6 illustrates how impervious area can be used as a predictor of the baseflow component of total streamflow; likewise, the percentage of runoff that occurs as stormwater can be ascertained from this figure. A clear gradient of response exists in the median percent baseflow for the 1990s relative to the level of impervious area. An extrapolation from the slope of the trend line in Figure 6 shows that for each percent increase in impervious area in a watershed, there is a corresponding decrease in baseflow of approximately 2 percent. Because of continued urbanization in Metropolitan Atlanta, the estimates of percent impervious area—based on 1995 land-use data—underestimate percent of impervious area in these watersheds in 2003.

SUMMARY AND CONCLUSIONS

Despite successes in the wastewater treatment industry, water quality in many if not most Metropolitan Atlanta urban streams remains impaired (Georgia Department of Natural Resources, 2002). Improved treatment technology has decreased ammonia loads but has done little to reduce total nitrogen. Effluent discharges are increasing, resulting in higher percentages of effluent in streamflow. Urbanization decreases the baseflow component of streamflow and increases the stormwater component. Estimates of percent impervious surface within a tributary watershed to the upper Chattahoochee River can be used to predict the baseflow component of total streamflow of that tributary stream.

Drought conditions, future increases in effluent discharge, decreased baseflows as a result of increased urbanization, and a proposed decrease in minimum flows released from Buford Dam to the Chattahoochee River all likely will increase the percent of streamflow in the Chattahoochee River that is comprised of effluent discharge. Mitigating the effects of urbanization will be needed to protect the water quality and to maintain the baseflow and the physical structure of Metropolitan Atlanta streams.

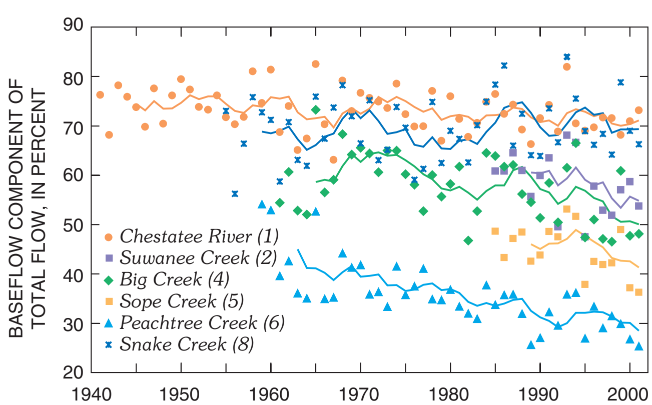

Figure 5. Annual percent of streamflow that occurred as baseflow in tributary streams to the upper Chattahoochee River, 1941–2001. (Trend line is a 5-year moving average; number in parentheses is site number in figure 1.)

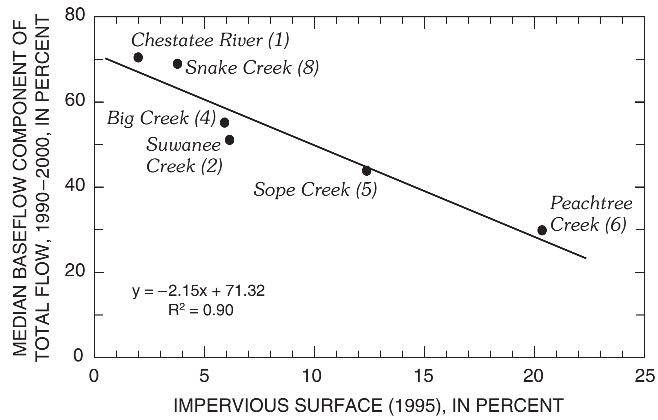

Figure 6. Relation of median baseflow component of total streamflow to percent impervious surface in six tributary watersheds to the Chattahoochee River, 1990–2000 (number in parentheses is site number in figure 1).

LITERATURE CITED

Booth, D.B., and C.R. Jackson. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation: Journal of the American Water Resources Association, v. 33, no. 5, pp. 1077–1090.

Cohn, T.A., L.L. Delong, E.J. Gilroy, R.M. Hirsh, and D.K. Wells. 1989. Estimating constituent loads: Water Resources Research v. 25, no. 5, pp. 937–942.

Crawford, C.G. 1991. Estimation of suspended-sediment rating curves and mean suspended-sediment loads. Journal of Hydrology 129: pp. 331–348.

———1996. Estimating mean constituent loads in rivers by the rating-curve and flow-duration, rating-curve methods. Ph.D. dissertation, Indiana University, Bloomington, Indiana, 245 pp.

DeVivo, J.C., E.A. Frick, D.J. Hippe, and G.R. Buell. 1995. National Water-Quality Assessment Program: Effect of restricted phosphate detergent use and mandated upgrades at two wastewater-treatment facilities on water quality, metropolitan Atlanta, Georgia, 1988–93. *In* Proceedings of the 1995 Georgia Water Resources Conference, April 11–12, 1995, K.J. Hatcher (ed.), Carl Vinson Institute of Government, The University of Georgia, Athens, Ga., pp. 54–56.

Frick, E.A., and G.R. Buell. 1999. Relation of land use to nutrient and suspended–sediment concentrations, loads and yields in the Upper Chattahoochee River Basin, Georgia, 1993–98. *In* Proceedings of the 1999 Georgia Water Resources Conference, April 11–12, 1995, K.J. Hatcher (ed.), Carl Vinson Institute of Government, The University of Georgia, Athens, Ga., pp. 170–179.

Garie, H.L., and A. McIntosh. 1986. Distribution of benthic macroinvertebrates in a stream exposed to urban runoff. Water Resources Bulletin v. 22, no. 3, pp. 447–455.

Georgia Department of Natural Resources. 2002. Water quality in Georgia, 1998–1999. Georgia Department of Natural Resources, Environmental Protection Division, unnumbered report, variously paginated. (Accessed on December 17, 2002, at URL: http://www.state.ga.us/dnr/environ/ (click on "Georgia's Environment" and scroll to bottom.)

Gilliom, R.J., W.M. Alley, and M.E. Gurtz. 1995. Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions. U.S. Geological Survey Circular 1112, 33 pp.

Jones, R.C., and C.C. Clark. 1987. Impact of watershed urbanization on stream insect communities. Water Resources Bulletin v. 23, no. 6, pp. 1047–1055.

Klein, R.D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin v.15, no. 4, pp. 948–963.

Rose, Seth, and N.E. Peters. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): A comparative hydrologic approach. Hydrological Processes 15, pp. 1441–1457.

Simmons, D.L., and R.J. Reynolds. 1982. Effects of urbanization on base flow of selected South-Shore streams, Long Island, New York. Water Resources Bulletin, v.18, pp. 797–805.

Sloto, R.A., and M.Y. Crouse. 1996. HYSEP: A computer program for streamflow hydrograph separation and analysis. U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 pp.

Spinello, A.G., and D.L. Simmons. 1992. Base flow of 10 south-shore streams, Long Island, New York, and the effects of urbanization on base flow and flow duration. U.S. Geological Survey Water-Resources Investigations Report 90-4205, 34 pp.

U.S. Environmental Protection Agency. 2000. Upper Chattahoochee River Case Study *in* Progress in Water Quality: An evaluation of the national investment in municipal wastewater treatment. EPA-832-R-00-008, pp. 10-1 to 10-16.

U.S. Geological Survey. 1999. The quality of our nation's waters - nutrients and pesticides. U.S. Geological Circular 1225, 82 pp.

Wallace, J.R. 1971. The effects of land use change on the hydrology of an urban watershed. Report to The Environmental Resource Center, Georgia Institute of Hydrology, ERC-0871, 63 pp.

Wangsness, D.J. 1997. The National Water-Quality Assessment Program: Example of study unit design for the Apalachicola–Chattahoochee–Flint River basin, 1991–97. U.S. Geological Survey Open-File Report 97-48, 29 pp.

Wangsness, D.J., E.A. Frick, G.R. Buell, and J.C. DeVivo. 1994. Effect of the restricted use of phosphate detergent and upgraded wastewater treatment facilities on water quality in the Chattahoochee River near Atlanta, Georgia. U.S. Geological Survey Open-File Report 94-99, 4 pp.