THE EFFECT OF URBANIZATION ON WATER RUNOFF IN THE BIG CREEK WATERSHED

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Abstract. This study examines the effect of urban growth on a watershed in north Atlanta. Aerial photography and a geographic information system are used to assess vegetation change between 1986 and 1993 while daily precipitation and water runoff data for the watershed are examined for changes in runoff. A model of the relationship between precipitation and runoff reveals the extent to which the land development between 1986 and 1993 has affected water drainage in this region. Results indicate prior planning is wise to avoid potential drainage and flooding problems that can develop in rapidly growing areas. Keywords: aerial photography, GIS, urbanization, water runoff, flooding.

INTRODUCTION

The change from rural to urban landcover is occurring in metropolitan areas all over the United States and the resulting effect on natural resources is many faceted. Issues of habitat fragmentation, water quality, and landfill and sewer system limitations and overflows frequently arise. Urbanized areas also tend to have increased frequencies and intensities of flooding, due to the increase in impermeable surfaces, decrease in vegetative cover, and more sewers and storm drains accelerating runoff. This paper will examine development in Atlanta's northern suburbs, specifically within the Big Creek watershed, between 1986 and 1993, and will correlate this development with the changing relationship between precipitation and Big buildings. Such changes in land cover cause the natural Creek's daily discharge. Quantifying these changes will bring to light the powerful effects of development within a watershed, and could be useful in urban planning, engineering, and real estate development.

BACKGROUND AND RELATED WORK

Every year in Georgia more land is paved over, changing forest or agricultural land into black asphalt and buildings. Such changes in land cover cause the natural drainage of a watershed to be altered. Some of the fastest growth in the country in the last decade has occurred in the Big Creek watershed in the north Atlanta suburbs. Within the watershed lies the city of Alpharetta, once a rural farming community and today proving to be one of the hottest areas of development in metro Atlanta. The 1990s have brought record-setting numbers of building permit requests for Alpharetta (Atlanta Business Chronicle 1997), located in north Fulton County. Its neighboring county of Forsyth was ranked number one in America in growth potential, based on population growth and per capita income increase in the 1990s (American City Business Journals 1997).

By reducing forest cover, increasing the extent of impermeable surfaces such as pavement, and installing more storm sewers and drains, stream runoff has been shown to increase, creating greater problems with flooding and erosion (Crawford 1969; Tong 1990; Kostadinor & Mitrovic 1994; Goudie 1994). Flood-frequency studies in Georgia have shown total impermeable area to be a significant factor in urban watershed runoff (Inman 1995). Runoff issues have been noted to be particularly problematic in smaller metropolitan areas like Alpharetta, in Atlanta's northern suburbs. Smaller urban areas can experience more dramatic population increases and can find themselves unprepared to handle the development problems, such as flooding, of a large urban area (Platt 1987).

GIS and aerial photography are useful means for determining land cover change over time. Land use changes and vegetation losses can be quantified through longitudinal studies of air photos (Turner 1990; Peccol et al 1996) and such research has helped locate areas of potential erosion, runoff problems, and potential areas of flood zones (Jenson & Berger 1981). Incorporating GIS enables the impact of urbanization on water discharge levels and water quality to be assessed (Johnston et al 1988). Today aerial photography is used widely for assessing human impact on the land, from wetlands (Williams & Lyon 1991; Bakker et al 1994), to forests

(MacLean et al 1992; Hester et al 1996), to America's suburbs.

EXPERIMENTAL DESIGN

The hypotheses of this study are: 1) there has been a significant vegetation loss from the study area between 1986 and 1993, 2) there has been an increase in runoff between 1986 and 1993, and 3) this change in runoff is due at least in part to rapid urban development.

Vegetation change will be quantified from aerial photography from the two years. Using regression analysis, a model is developed to examine how the relationship between precipitation and runoff has changed through the time period. The model has two components: one is the storm runoff process as represented by the rainfall-runoff relationship, and the other is the process of groundwater depletion that maintains the baseflow of the stream. A comparison between 1986 and 1993 runoff levels will then be possible, allowing conclusions to be drawn about the effect of urbanization on runoff patterns.

METHODS

Study Area

Big Creek originates near Cumming, Georgia, and its watershed drains into the Chattahoochee River just southwest of Alpharetta. There are no lakes or other appreciable water bodies within the watershed, which is 104 square miles (17,930 hectares) in size. The region is located in the piedmont plateau of Georgia, with an elevation ranging from 300 to 400 meters above mean sea level and a relatively mild relief. The soil is predominately well drained, with clayey to loamy subsoil. The climate is humid with hot summers and mild winters.

Mean annual precipitation is approximately 54 inches, and is fairly evenly distributed by season, with slight peaks in the springtime (National Climatic Data Center 1997). Afternoon convective thunderstorms in the spring and summer are typically short in duration, but potentially fierce with much precipitation. Winter rains tend to be associated with frontal activities and are longer lasting. 1986 in particular had 42.1 inches of rainfall while 1993 had 45.1 inches. The standard deviation of daily rainfall from the daily mean was 0.32 for each year, indicating a similarity in rain events between the two years.

The study area incorporates the lower half of the watershed, including Alpharetta and surrounding areas (Figure 1). This area, 13,390 hectares in size,

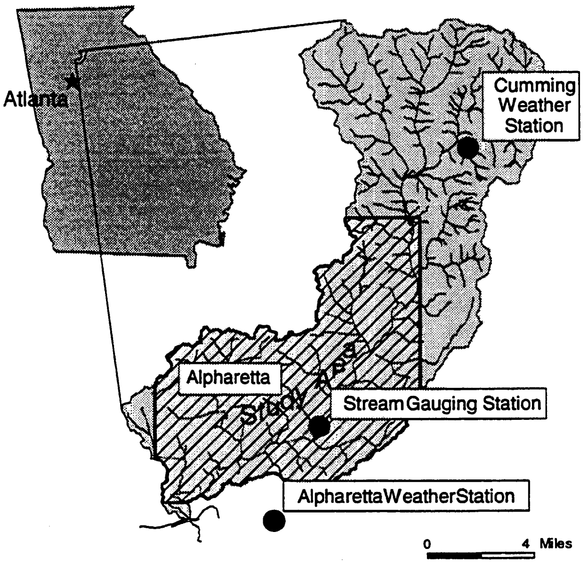

Figure 1. Big Creek watershed and study area.

encompasses a region of significant growth, both residential and non-residential, around Alpharetta and north of the Chattahoochee River.

Data Sources

Aerial photographs (1:39,000) from 1986 and digital orthophoto quarterquadrangles (DOQQs) (1:12,000) from 1993 were used to reveal land cover change within the study area. Land cover in 1986 and 1993 was then classified from the images by digitizing the vegetated regions. Vegetation coverages for the two years were then overlaid in a GIS to determine the areas of change.

The second phase of the project involved the analysis of precipitation and runoff within the watershed. Daily precipitation totals (inches) from two weather stations, Alpharetta and Cumming, were obtained (National Climatic Data Center 1997), and daily averages for the two stations calculated and tabulated for the years 1986 and 1993. Historical streamflow daily values (cubic feet per second) for the Big Creek gauging station were obtained from the U.S. Geological Survey web site (waterdata.usgs.gov/nwis-w/US).

Statistical Analysis

Regression analysis focused on the correlation between precipitation and runoff and how this has changed over the time period examined. Daily runoff was the dependent variable, while the preceding-day runoff and daily precipitation were considered as the independent variables. This analysis allowed predictions of runoff based on the rainfall that occurred in 1986 and 1993. Based on the predicted levels of runoff, 1986 and

Table 1. Regression models based upon 1986 and 1993 precipitation and runoff.

Year	Regression Model	R^2 Value
1986	$R_i = 7.34 + 0.65*R_{i-1} + 108.2*P_i$	$R^2 = 0.77$
1993	$R_i = 11.72 + 0.63*R_{i-1} + 296.4*P_i$	$R^2 = 0.63$

where R_i = same-day runoff; R_{i-1} = previous-day runoff; P_i = same-day precipitation.

1993 could be compared using the model.

RESULTS AND DISCUSSION

The regression models had statistically significant coefficients, with R^2 of 0.77 for 1986 and 0.63 for 1993, respectively (Table 1). Regression coefficients show an increase in runoff per unit of precipitation between 1986 and 1993, from 108.2 CFS to 296.4 CFS. Additionally, the current daily runoff was 63% of the preceding-day runoff in 1993, decreased from 65% in 1986. This suggests that groundwater depletion has become faster when there was no rain because of reduced recharge area. The intercepts of the models displayed a small increase from 7.34 CFS to 11.72 CFS, probably caused by the increased baseflow due to outdoor water use, such as lawn irrigation.

Using these equations, daily runoff was simulated based on daily precipitation values, allowing graphic comparison of 1986 and 1993 (Figure 2).

The vegetation change analysis revealed that there was significant vegetation loss within the study area between the years 1986 and 1993 (Figure 3). A reduction in vegetation from 6,404 hectares (48% of study area) to 5,227 hectares (39% of study area) occurred. Furthermore, much of the vegetation loss can be attributed to the paving and building that have been characteristic of the Alpharetta region in the 1980s and 1990s. Such an increase in impervious ground cover is a widely touted cause of runoff increase. In this study, the impact of urbanization on streamflow was clearly implied by the pattern of change in the rainfall-runoff relationship.

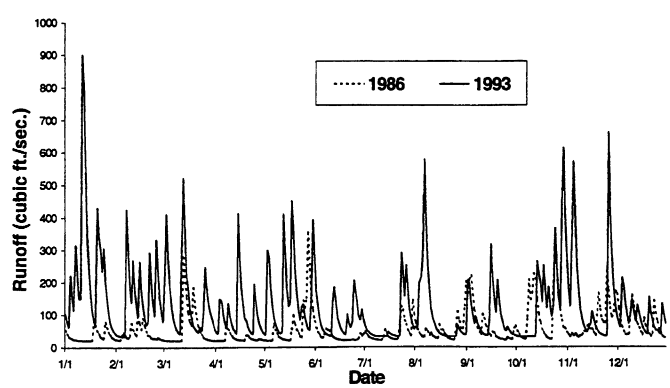

Figure 2. Predicted runoff based on 1986 and 1993 model equations (1986: $R_i = 7.34 + 0.65*R_{i-1} + 108.2*P_i$. 1993: $R_i = 11.72 + 0.63*R_{i-1} + 196.4*P_i$).

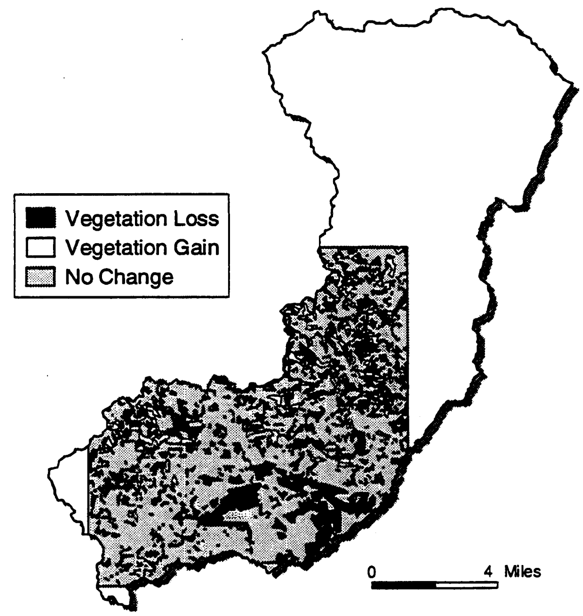

Figure 3. Vegetation change within the Big Creek study area, 1986-1993.

CONCLUSION AND RECOMMENDATIONS

The regression models in this study indicate that runoff has indeed increased dramatically per unit of precipitation. When applied to the daily rainfall data for 1986 and 1993, the models graphically shows a marked increase in predicted runoff over the seven years (Figure 2). Runoff would clearly increase rapidly with multiple inches of precipitation, indicating a potential runoff problem during heavy precipitation events.

Maximum discharge produced by an intense rainstorm is the result of two relatively independent components of the runoff process: one, identifying the precipitation-runoff relationship and two, the control or management of surface runoff (Brater and Sangal 1969).

Regarding the Alpharetta region, the first factor has been examined in this study, and indicates that there has been a dramatic increase in runoff per unit of precipitation. The second component, however, is for the planners in Alpharetta to examine. Building in flood plains, inadequate bridge openings for stream passage, and inadequate storm sewers and culverts can create high peak flows and flooding situations during and after storms. These are conditions that will need to be assessed and addressed as Alpharetta and its growth move into the 21st century.

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LITERATURE CITED

Atlanta Business Chronicle, 1997. www.amcity.com/atlanta

American City Business Journals, 1997. www.amcity.com

Bakker, S.A., N.J. Van Den Berg, and B.P. Speleers, 1994. Vegetation transitions of floating wetlands in a complex of turbaries between 1937 and 1989 as determined from aerial photographs with GIS. *Vegetatio* 114(2): 161-167.

Brater, E.F. and S. Sangal, 1969. "Effects of urbanization on peak flows." In W.L. Moore and C.W. Morgan, eds., *Effects of watershed changes on streamflow,* Austin, TX, pp. 201-214.

Crawford, N, 1969. "Analysis of watershed changes." In W.L. Moore and C.W. Morgan, eds., *Effects of watershed changes on streamflow,* Austin, TX, pp. 27-34.

Goudie, A, 1994. *The human impact on the natural environment*. Cambridge, MA.

Hester, A.J., D.R. Miller, and W. Towers, 1996. Landscape-scale vegetation change in the Cairngorms, Scotland, 1946-1988: Implications for land management. *Biological Conservation* 77(1): 41-51.

Inman, E, 1995. *Flood-frequency relations for urban streams in Georgia, 1994 update*. Atlanta: U.S. Geologic Survey, Water-Resources Investigations Report 95-4017.

Jenson, J.R. and Z. Berger, 1981. *Remote Sensing Quarterly* 3(1): 4-20.

Johnston, C.A., N.E. Detenbeck, J.P. Bonde, and G.J. Niemi, 1988. Geographic information systems for cumulative impact assessment. *Photogrammetric Engineering and Remote Sensing* 54(11): 1609-1615.

Kostadinov, S.C. and S.S. Mitrovic, 1994. *Journal of Soil and Water Conservation* 49(4): 382-386.

Maclean, A.L., D.D. Reed, G.D. Mroz, G.W. Lyon, & T. Edison, 1992. Using GIS to estimate forest resource changes. *Journal of Forestry* 90: 22-25.

National Climatic Data Center, 1997. Summary of the Day, East, CD-ROM. EarthInfo, Inc. Boulder, CO.

Peccol, E., A.C. Bird, and T.R. Brewer, 1996. GIS as a tool for assessing the influence of countryside designations and planning policies on landscape change. *Journal of Environmental Management* 47: 355-367.

Platt, R.H, 1987. *Regional management of metropolitan floodplains, Monograph #45*. Boulder, CO.

Tong, S.T.Y, 1990. The hydrologic effects of urban land use: A case study of the little Miami River basin. *Landscape and Urban Planning* 19(1): 99-105.

Turner, M.G, 1990. Landscape changes in nine rural counties in Georgia. *Photogrammetric Engineering and Remote Sensing* 56(3): 379-386.

Williams, D.C. and J.G. Lyon, 1991. Use of a geographic information system data base to measure and evaluate changes in the St. Marys River, Michigan. *Hydrobiologia* 219: 83-95.