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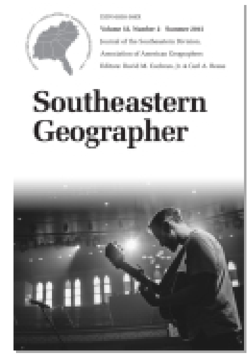

Mario A. Giraldo, Paula Jackson, Wayne Van-Horne

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Suburban Forest Change and Vegetation Water Dynamics in Atlanta, USA

MARIO A. GIRALDO
California State University Northridge

PAULA JACKSON
Kennesaw State University

WAYNE VAN-HORNE
Kennesaw State University

*In the suburban area of northwestern Atlanta, this project tests the hypothesis that tree species composition affects the hydrological response of forest patches and therefore should be considered when assessing the effect of land cover change in the water cycle of suburban areas. In a typical mixed forest fragment a diverse canopy with a rich tree species composition of several deciduous and evergreen tree species was found. The results show a relationship of more than 2:1 water flow under different soil moisture levels, for the broadleaf deciduous (*Liquidambar styraciflua *L.) compared to the evergreen pine tree species (*Pinus taeda *L.). The land cover change analysis for the lower Etowah watershed and five counties of northwestern Atlanta from 1992 to 2007 indicates forest cover loss, disturbance within the forest areas, changes from evergreen forest into mixed forest, and localized process of transition from forest towards urbanization. Overall, this research suggests that the water cycle in northern Atlanta may be affected by forest cover decrease, and by changes in the species composition of the forest fragment towards mixed forest.*

*En el área suburbana del noroeste de Atlanta, este proyecto pone a prueba la hipótesis de que la composición de especies arbóreas afecta la respuesta hidrológica de los parches forestales y por lo tanto, debe considerarse al evaluar el efecto del cambio de la cubierta de tierra en el ciclo de agua de las zonas suburbanas. En un típico fragmento de bosque mixto se encontró una diversa cubierta forestal con una rica composición de especies de árboles caducifolios y perennes. Los resultados muestran una relación de más de 2:1 del flujo de agua para los árboles caducifolios (*Liquidambar styraciflua *L.) que para las especies de pinos perennes (*Pinus taeda *L.) bajo diferentes niveles de humedad del suelo. El análisis del cambio de la cubierta de tierra en la cuenca baja Etowah y cinco condados del noroeste de Atlanta entre 1992 y 2007 indica una pérdida de cubierta forestal, un desajuste dentro de las áreas forestales, cambios de bosque perenne a bosque mixto y un proceso localizado de transición de bosque a urbanización. En general, esta investigación sugiere que el ciclo del agua en el norte de Atlanta puede verse afectado por la disminución de la cubierta forestal y por los cambios en la composición de especies del fragmento forestal hacia un bosque mixto.*

KEY WORDS: land cover change, Atlanta, forest fragments, urban, hydrology

PALABRAS CLAVE: cambio de cubierta de tierra, Atlanta, fragmentos forestales, urbano, hidrología

INTRODUCTION

Cities create a state of disequilibrium in the landscape; they generate a local gradient of disturbance and are considered one of the most homogenizing human activities in the physical environment (Mckinney 2006). Urban growth is expected to affect the dynamics of local ecosystems by modifying the hydrogeology of the landscape, introducing nonnative species, altering nutrient cycle, changing local atmospheric conditions and affecting forest health (Zipperer 2002; Wear and Greis 2010). At the regional scale, urban infrastructure creates a complex mosaic of land uses where high spatial and temporal variation of hydrological processes is expected to occur. In comparison with other land uses, forested areas provide quantity and quality of fresh water for human consumption and as such are becoming critical resources for a city's long-term sustainability (Neary et al. 2009). As urban growth continues, remaining forest fragments, especially those located at the headwaters and in riparian zones become refugees of native animal and plant species (Barrett and Guyer 2008; Burton et al. 2009), and hence are considered priority areas for conservation for the city and the region (Dawson 1995).

In the southeastern U.S.A., climate and vegetation are considered to play a larger role in the water budget with a strong effect of forest cover on regional evapotranspiration (Lu et al. 2003). Decreases in the forest cover are found to increase water yield with a large spatial variation, where changes from forest to urban areas will produce the highest impact in a region particularly those with high precipitation (Sun et al. 2005).

Historically, during the late nineteenth century, colonization of north Georgia transformed the landscape and its forest cover into agriculture and livestock areas (Turner and Ruscher 1988). As agriculture and extensive cattle ranching moved west, processes of forest regeneration took place in the early 20th century interrupted only by the growth of the Atlanta metropolitan area in the last thirty years (Turner and Ruscher 1988). In fact, the period between 1979 and 1997 the city of Atlanta's impermeable surfaces increased substantially. This increase was predominantly in industrial, commercial, and small residential complexes that substituted the previous forest cover for a mosaic of forest fragments (Gilliesa et al. 2003).

Within forest fragments, differences in tree species diversity, and dominant tree species may affect the physical and ecological process to which the forest contributes. Landscape fragments are spatial units in which biophysical factors interact (Hay et al. 2002; Nagendra et al. 2004). Within landscape fragments, hydrological process presents a behavior that is significantly different from the adjacent ones under different conditions of soil type, land use, or both (Giraldo et al. 2009). Changes in the tree species composition of a forest may affect the water dynamics since individual species have a dominant role in processes such as evapotranspiration, interception, or infiltration within the forest (Ford and Vose 2007). This is considered a potential source of error in predictive models that assume tree cover to have a homogeneous behavior regardless of tree species composition within study areas (Zhang et al. 2001).

Research has been conducted on the contributions of forest resources and fragments to the hydrological cycle in the southeastern United States. However, little research has been done in studying the fragmented landscape of suburban Atlanta resulting from urban sprawl and the water dynamics within forest fragments (Burton et al. 2009). Studying the environmental processes at the fragment level becomes a first step in analyzing the spatial variation caused by the city at the regional level and its effects on the water cycle.

Satellite data is considered an efficient way to produce a regional ecosystem assessment, to provide information regarding land cover patterns and environmentally impacted areas, and to verify the context of environmental stress over broad scales as a cost efficient means to monitor ecosystem health (Styers et al. 2009). This research produces a land cover and vegetation change analysis, quantifying forest change from 1992 to 2007 in five counties of Northwestern Atlanta and the lower Etowah watershed using satellite data; it produces a botanical description of dominant tree species composition within typical forest fragments; and it quantifies water dynamics in two dominant tree species as an indicator of water dynamics for the study area. The project hypothesized that there are differences in the hydrological response of individual tree species within forest fragments in suburban Atlanta, and that these differences will affect at the landscape scale the role that forest cover change has in the hydrological cycle under scenarios of rapid urban growth in Northern Atlanta.

METHODS

This research includes the assessment of land cover change and the spatial analysis of forest change using Landsat satellite imagery and geographic information systems in north western Atlanta, a field survey to assess species composition of typical forest fragments and two dominant tree species, and the assessment of variation in the soil/water relationships in dominant trees using sap flow, soil moisture and weather data. At the local scale the study area includes a forest fragment located in a suburban area northwest of Atlanta, U.S.A. At the regional scale the study includes the Little Etowah Watershed (LEW) and the counties of Bartow, Cobb, Floyd, Paulding and Polk (Figure 1).

Hydro-climatic assessment on local vegetation

A forest fragment located five kilometers east of the city of Kennesaw, Georgia, was selected to evaluate sap flow differences among two dominant tree species. Evapotranspiration and soil moisture were estimated from a 25-year-old suburban forest naturally regenerated from a previously grassy area. The forest fragment was surveyed and six trees from two species, *Pinus taeda* L. (commonly known as loblolly pine) and *Liquidambar styraciflua* L. (a broadleaf commonly known as Sweetgum; Table 1) of similar age and diameter were chosen to measure sap flow, and to estimate evapotranspiration during a 12 week period in late spring 2012. Both tree species are considered dominant in the canopies in successional forests of the southeastern U.S. (Ford et al. 2005; Stoy et al. 2006).

Thermal dissipation probes (TDP), a data Logger (Dynamax Probe12 Sap Flow instrument) powered by a battery and a solar panel were used to collect data from trees located inside the forest fragment. Water consumption by plant species was

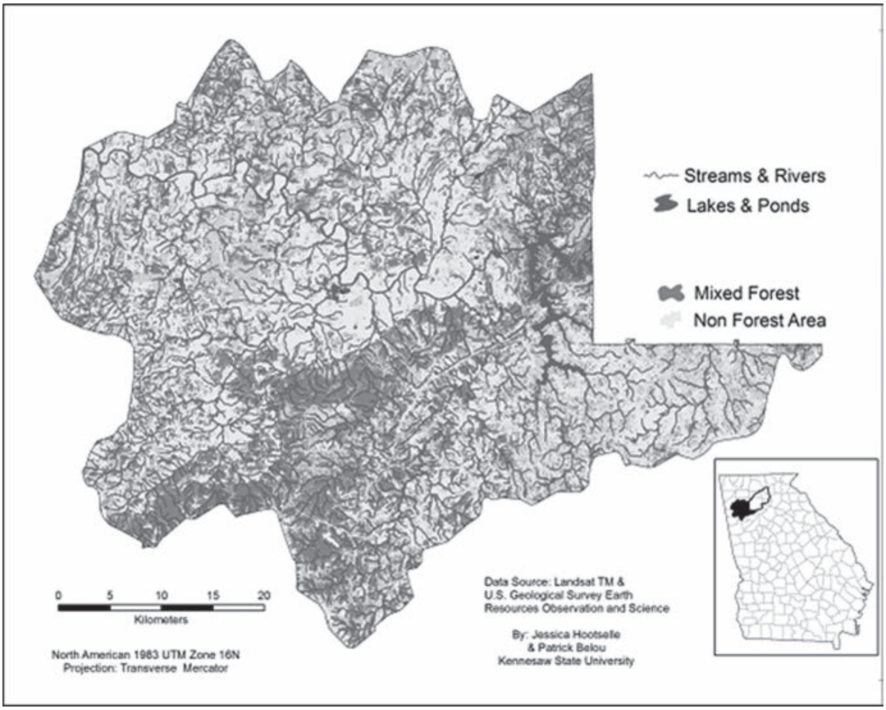

Figure 1. Location of the study area.

Table 1. Pine and Sweetgum values for sap areas estimated from tree circumferences. For this study, all sapwood was considered active unless heartwood was observed.

Tree species	Range DBH cm	Range Sap area cm^2
Pine	36.6 – 42.2	372.4 – 504.4
Sweetgum	30.7 – 47.0	262.2 – 624

estimated as variation in sap flow using the Granier method (Granier 1987) over a period of twelve weeks from April to July 2012. These months correspond to periods of active growth (although no limited to them) for both evergreen and broadleaf trees. (TDPs of 3 cm in length were installed in each tree, in a vertical alignment 4 cm apart at 1.5 m from the ground. The probes consisted of one upper heated probe and one lower reference probe containing a thermo-couple junction. The TDP estimates water flow by measuring the difference in temperature between the sensors and associating these temperature differentials to an empirically derived formula (equation 2). Granier (1987) found that a dimensionless parameter K was related to temperature such that (equation 1):

$$K = (dTM - dT)/T \qquad (1)$$

where dT is the difference in temperature between the heated and reference probe, and dTM is the maximum difference in temperature, which occurs when there is no sap flow. Sap flow velocity is related to K in that

$$V = 0.0119 \times K^{1.231} \text{ (cm/s)} \quad (2)$$

Knowing the sapwood area, velocity (v) is then transformed to sap flow rate as:

$$F = A \times V\ 3600 \text{ (s/h) (cm}^3\text{/h)} \quad (3)$$

where *F* is flow rate, *A* is the sap wood cross-sectional area.

Probe installation included shaving the bark from the trees at breast height on the north side of each tree, drilling the tree and inserting the probes entirely into the xylem. The probes were protected with a foam block and reflective insulation bubble wrap. The reflective wrap protects the sensor from the elements and prevents radiation from influencing temperature of the probes. Sap flow values for each tree type were summarized and averaged by tree type and expressed in g/hr.

Linking soil moisture with sap flows has been shown to provide information regarding the ecological role of tree species within the ecosystem (Kume et al. 2007). Continuous soil moisture data was collected using a DeltaT Soil Moisture Probe that works under the principle of Time Domain Reflectometry (TDR) (Ford et al. 2005). A soil moisture sensor was pre-calibrated for the soil conditions of the study site. A weather station located *in situ* and the edge of the forest fragment was used to continuously record precipitation, relative humidity, wind speed, and air temperature. Also, similar weather records from a weather station operated by the National Weather Service near Kennesaw, 5 km away from the research site, were used to check the accuracy of our own data. Statistical analyses of sap flow differences were performed establishing tree type behavior and comparisons between the two types of trees at days with minimum and higher soil moisture values (Ford et al. 2005). Soil moisture change rates were calculated to estimate residence time of moisture in the upper layer of the soil. Finally, comparisons between sap flow and weather variables such as evapotranspiration and air pressure were established for selected days

Composition of forest fragments

In the early 20th century, Georgia went through a process of natural reforestation of the landscape that was interrupted by the growth of the city of Atlanta. In order to assess the tree composition of typical natural forest fragments in northwestern Atlanta, a site was selected that is believed to have been undisturbed for the last 50 years. At this site a vegetation survey was conducted to serve as indicator of the composition of *typical* forest fragments. The survey was conducted in a 20 ha forest fragment located 6 km north of the city of White, Georgia (Bartow County). Tree species composition was assessed over three 50 m long transects across the property. From the forest fragment survey dominant tree species were identified and the relationships between deciduous and evergreen trees within the fragment was established. The results of this survey were used to select dominant tree species that serve as indicators of variation in tree species function in the ecosystem.

Land cover change satellite data analysis

For the assessment of land use change between 1992 and 2007, two sets of Landsat Thematic Mapper (TM) satellite data path 19 and rows 36 and 37 were used. The datasets were in the Universal Transverse Mercator projection, zone 16, and datum and spheroid WGS 84. Landsat multispectral bands 1 to 5 with 30 m spatial resolution were obtained from the United States Geological Survey data center, geometrically and radiometrically corrected and stacked in a single multispectral file. After stacking the bands, the scenes (rows 36 and 37) were used to generate a mosaic of a single multispectral file for each year (Jensen 2005). The mosaic process used a seamless line to account for small color balancing differences in the scenes of an overlapping area. Anniversary cloud free data was not available for the study area. Therefore, the analysis used data that shared similar phenological leaf-off characteristics (Jensen 2005). For the 1992 data late fall November scenes were selected while for the 2007 data early spring, May data sets were used. The May dataset was visually and spectrally inspected to make sure it corresponded to a leaf off period. Shape files of the Georgia counties of Bartow, Cobb, Floyd, Paulding, and Polk, as well as for the lower Etowah watershed were used as areas of interest to clip and subset the Landsat scenes. The resulting six study areas were individually classified using a supervised classification approach with 24 classes, recoded to the 6 final classes: Evergreen forest, mixed forest, other vegetation, no vegetation, and water. For the classification approach, at least 10 signatures were collected for each of the six classes and the final file, classified using a maximum likelihood parametric rule. After classification, several visual and quantitative accuracy assessment analyses were performed to identify problematic areas from which new signatures were collected. Accuracy assessment used 10 pixels for each of the five summary classes in the dataset. The classification process was considered satisfactory when the study area showed higher than 90 percent accuracy for all classes (Jensen 2005). After classification, change matrixes from 1992 to 2007 were produced for each of the six sub set areas estimating total values and percentage of change for each class in each sub set area. Change matrixes are summarized in Table 5.

RESULTS

Forest fragment survey

Two similar types of forest were identified in this research. For the assessment of plant composition and diversity, the forest fragment surveyed in this research was classified as Allegheny-Cumberland Dry Oak Forest and Woodland, equivalent to a typical Eastern Forest, Oak-Pine Forest According to the USGS Forest Cover Types: National Atlas of the United States (USDA Forest Service and USGS). The results of the survey are listed in table 2.

The forest fragment instrumented for the hydroecological analysis was classified as Southern Appalachian Low-elevation Pine Forest. Summary information for this type of forest is reported in the national atlas of North America for the Bailey's ecological region as Southern Ridge and Valley/Cumberland Dry Calcareous Forest. This forest ecosystem includes dry to dry-mesic calcareous forests of the Southern Ridge and Valley region of Alabama and Georgia, extending north into Tennessee, Kentucky, Virginia, and adjacent West Virginia. It includes calcareous forests on lower escarpments of the Cumberland Plateau and other related areas. Examples

Table 2. List of tree species found in a field survey of an undisturbed forest area.

Genus / Species	Common Name	Plot A	Plot B	Plot C	Total
Acer leucoderme vel aff.	Chalk Maple	10		1	11
Acer rubrum	Red Maple	1	1	21	23
Carpinus caroliniana	Ironwood	2			2
Carya spp.	Hickory	23	14	16	53
Celtis sp.	Hackberry	4			4
Cornus florida	**Flowering Dogwood**	**11**	**30**	**51**	**92**
Juniperus virginiana	Eastern Red Cedar	20	9		29
Liquidamber styraciflua	Sweetgum			16	16
Liriodendron tulipifera	Tuliptree			1	1
Nyssa sylvatica	Blackgum	5	3	13	21
Ostrya virginiana	Eastern Hophornbeam	9			9
Pinus virginiana	**Virginia Pine**	**4**		**10**	**14**
Prunus serotina	Black Cherry	8	3	3	**14**
Quercus spp.	**Oak**	**17**	**7**	**29**	**53**
Ulmus alata	Winged Elm		2	4	6
Total		114	69	165	348

occur on a variety of different landscape positions and occur on generally deeper soils than glade systems of the same regions. For both forest fragments, *Pinus taeda* L. commonly known as loblolly Pine and *Liquidambar styraciflua* L. commonly known as Sweetgum are considered dominant of the canopies in southeastern U.S. in successional forest (Stoy et al. 2006).

The United States Department of Agriculture Web Soil Service (2014) lists the soil properties of the area of Madison as clay loam, 6 to 10 percent slopes, severely eroded, well drained with more than 2 m depth, moderate water capacity (20 cm), moderate to high (1.5 to 5 cm/hr) water infiltration with a clay loam upper layer, followed by clay and sandy clay layers. These properties suggest a good drainage under wet conditions and poor water retention during dry conditions that may affect plant species distribution if either of these events occurs for extended periods of time.

Soil moisture

The graph of precipitation and soil moisture shows agreement between the precipitation and soil moisture increases, with an increase in soil moisture values at 10 cm depth almost immediately when a strong rain event occurred (Figure 2a). In a similar way, the figure of cumulative precipitation reaching the forest ground and maximum soil moisture per day (Figure 2b) shows agreement between the timing of the events. Despite the agreement between precipitation and soil moisture, only few rain events produced changes in surface soil moisture. In fact, in the period between May 15th and July 22nd, 67 episodes of rain larger than 0.5mm were recorded by the

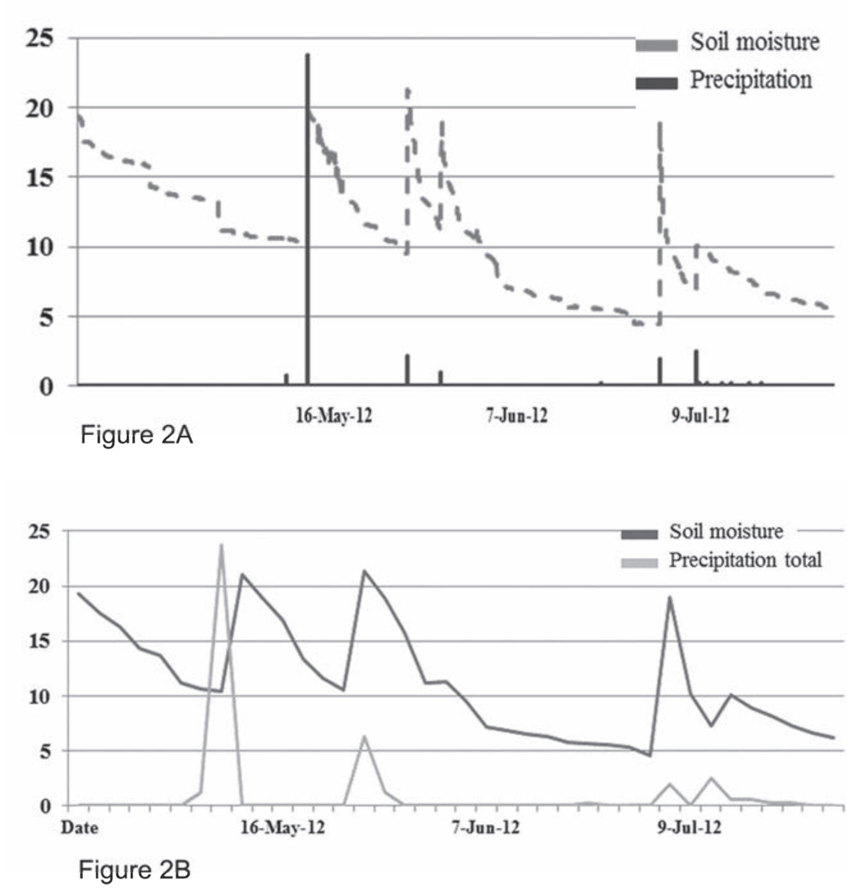

Figure 2. a. Precipitation and soil moisture distribution;
b. total daily precipitation (lt) and maximum soil moisture (v/v) per day.

in-situ weather station, but only 15 of them (22 percent) were strong enough to go through the forest canopy and be recorded by the rain gage within the forest. Within this period soil moisture increases above 0.25 percent in only 22 occasions showing a clear effect of the forest canopy on the loss of water in the ecosystem through interception and evapotranspiration. Estimated over a period of 24 hours, volumetric soil moisture decreases at a rate of 0.04 percent and 0.32 percent per hour during the dry (<10 percent) and wet (14–22 percent) end of the drying process, which indicates a fast drying process of the upper soil layer. This fast drying process of the soil is in agreement with the information reported earlier from the USDA soil survey for the region. No consistent amount of rain was found to cause increases in soil moisture (Figure 2). This may be explained by the characteristics of the forest

Table 3. t-test statistical comparison of mean values for average sap flow between Pine and Sweetgum (SWG) under wet (>18% v/v), normal (≈12% v/v) and dry (< 5% v/v) soil moisture conditions.

t-Test: Paired Two Sample for Means

	Pine Normal vs SWG Normal	Pine Wet vs SWG Wet	Pine dry vs SWG dry	Pine Normal vs Pine Wet	SWG Normal vs SWG Wet	Pine Normal vs SWG dry
Observations	50.0	50.0	50.0	50.0	50.0	50
Pearson Correlation	0.9	1.0	0.7	0.9	0.9	0.9
Hypothesized Mean Difference	0.0	0.0	0.0	0.0	0.0	0
Df	49.0	49.0	49.0	49.0	49.0	49
t Stat	19.5	−13.1	−20.9	7.6	8.5	−20.4
P(T<=t) one-tail	0.0	0.0	0.0	0.0	0.0	0.0
t Critical one-tail	1.7	1.7	1.7	1.7	1.7	1.6
P(T<=t) two-tail	0.0	0.0	0.0	0.0	0.0	0.0
t Critical two-tail	2.0	2.0	2.0	2.0	2.0	2.0
	Pine Normal	Pine Wet	Pine dry	SWG Nor	SWG Wet	SWG dry
Mean	354.1	293.9	69.0	1487.8	1140.6	795.4
Variance	5387.2	14198.5	194.4	272623.9	325934.6	65032.7

structure, the topographic variation of the terrain, the heterogeneous nature of the forest understory, forest floor disturbance and by the different levels of soil moisture conditions when the rain occurs. A more detailed analysis of infiltration and soil moisture distribution throughout the soil profile may be required to establish such a relationship (Giraldo et al. 2009a; Miller et al. 2007).

Sap flow

Both tree species exhibited a diurnal pattern of peak sap flow readings during mid-late afternoon. Comparisons for sap flow were conducted for selected days with three types of soil moisture values defined as wet conditions (>18 percent volumetric soil moisture), normal conditions (≈12 percent volumetric soil moisture), and dry conditions (< 5 percent volumetric soil moisture) (Table 3). On a given day sap flow showed a strong correlation (Pearson > 0.9) with soil moisture. Mean flow values indicate that Sweetgum trees had significantly higher sap flow than pine trees under normal and stress conditions (dry or wet) (Figure 3, Table 3). Comparisons of sap flow means for periods of hydric stress were significantly different (< 0.01 probability level) for the same tree type, and between tree species under both wet and dry stress conditions (t stat > t critical in Table 3). Pine trees were notoriously more affected by severe dry periods than Sweetgum, which seemed to be able to continue transpiring under low surface soil moisture conditions (Figure 4).

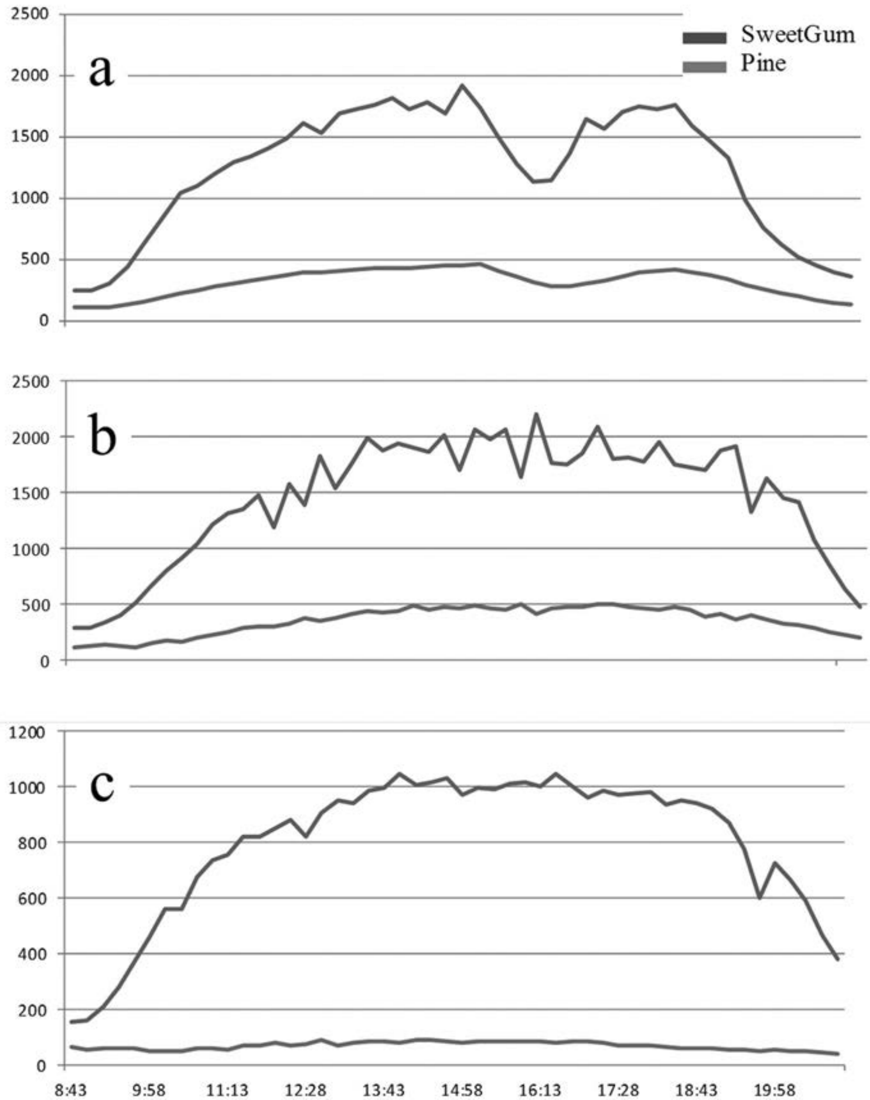

Figure 3. Sap flow by tree types under periods of hydric stress a. wet, b. normal and c. dry conditions. Total daily precipitation (lt) and maximum soil moisture (v/v) per day.

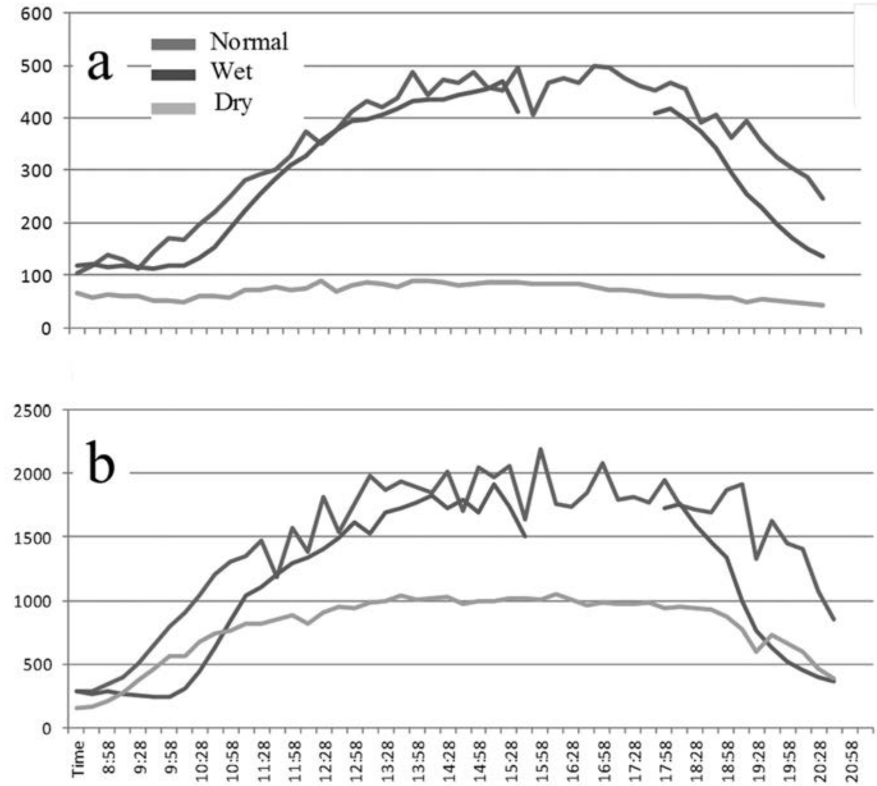

Figure 4. a. Pine and b .Sweetgum Sap flow (gr/hr) for a day under hydric stress. There is a 2h missing records for the Pines. Total daily precipitation (lt) and maximum soil moisture (v/v) per day.

Land cover assessment

The land cover assessment shows that by 1992, 57–85 percent of the counties (Figures 5–8) and 76 percent of the lower Etowah watershed (LEW) (Figures 9–10) areas were covered by forest. In the last fifteen years, these areas showed a great decrease in forest cover values, with Paulding County, LEW and Cobb County presenting 22 percent, 20 percent, and 10 percent decreases in forest cover respectively. Two counties had lower decreases in forest cover and one, Polk County, showed an increase of 1.6 percent of forest cover in its total area. These results suggest a heterogeneous dynamic of forest transformation within the study area with site-specific characteristics at the county level. Although for the LEW forest loss had similar values for evergreen and mixed forests with 11 percent and 9.2 percent respectively, at the county level the losses of evergreen forest (5 to 18 percent) were greater than that of mixed forests. In fact, two out of the six study areas showed losses of deciduous forest areas. The exception to this trend was again Polk County where evergreen forest increased in 16 percent and

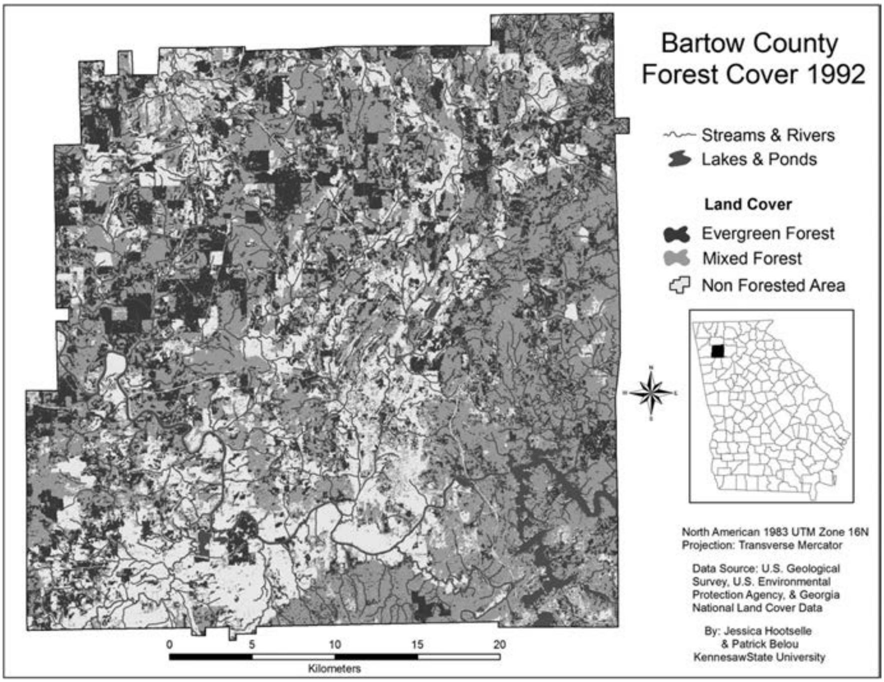

Figure 5. Bartow County forest cover 1992.

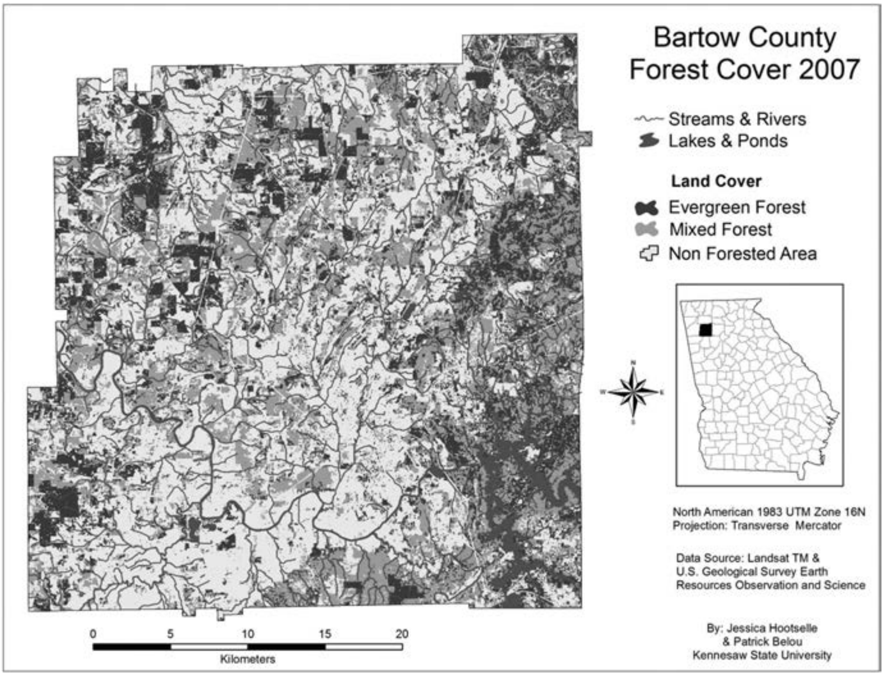

Figure 6. Bartow County forest cover 2007.

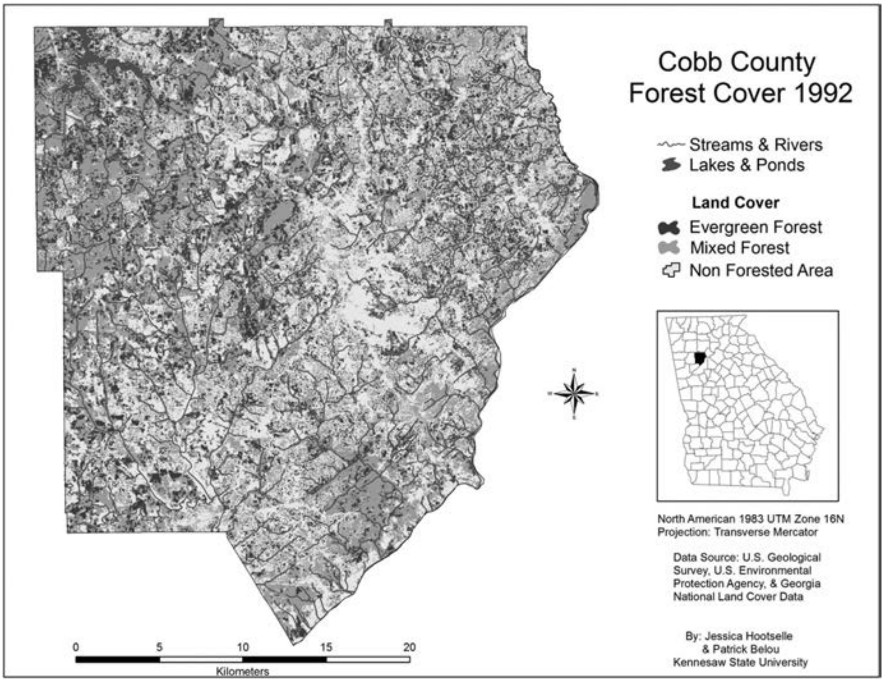

Figure 7. Cobb County forest cover 1992.

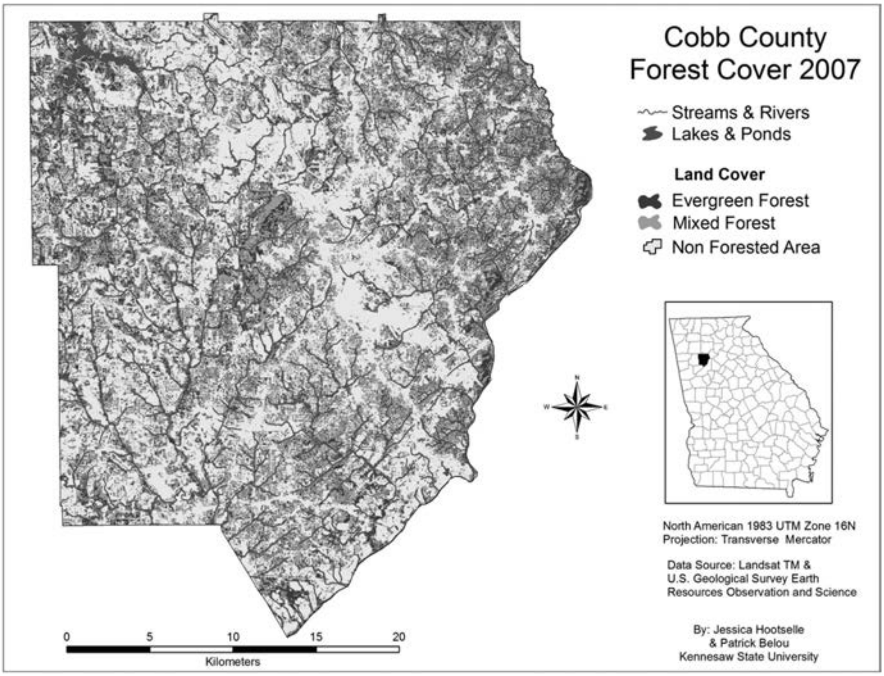

Figure 8. Cobb County forest cover 2007.

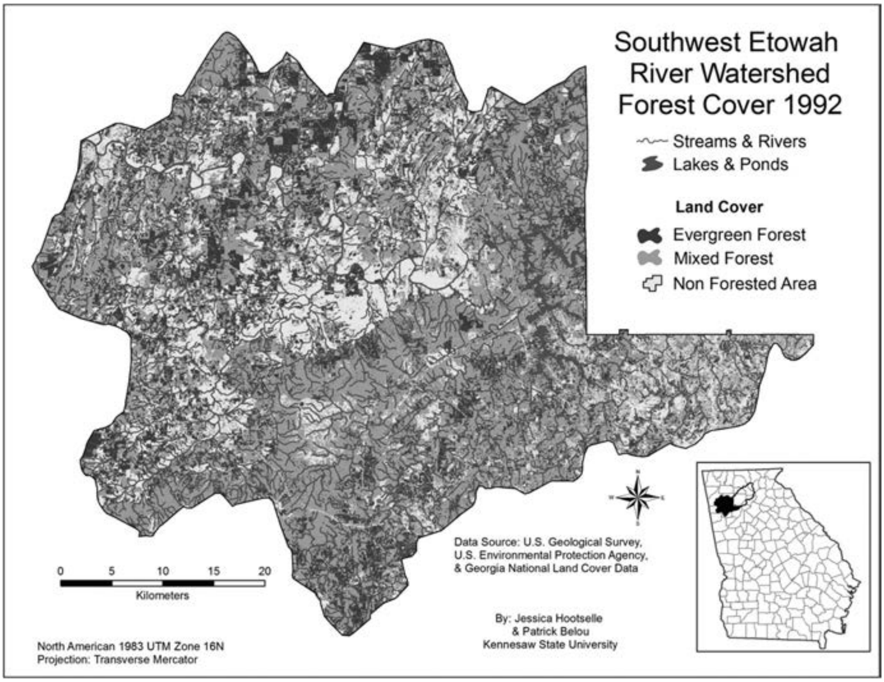

Figure 9. Forest cover for the Little Etowah Watershed (LEW) 1992.

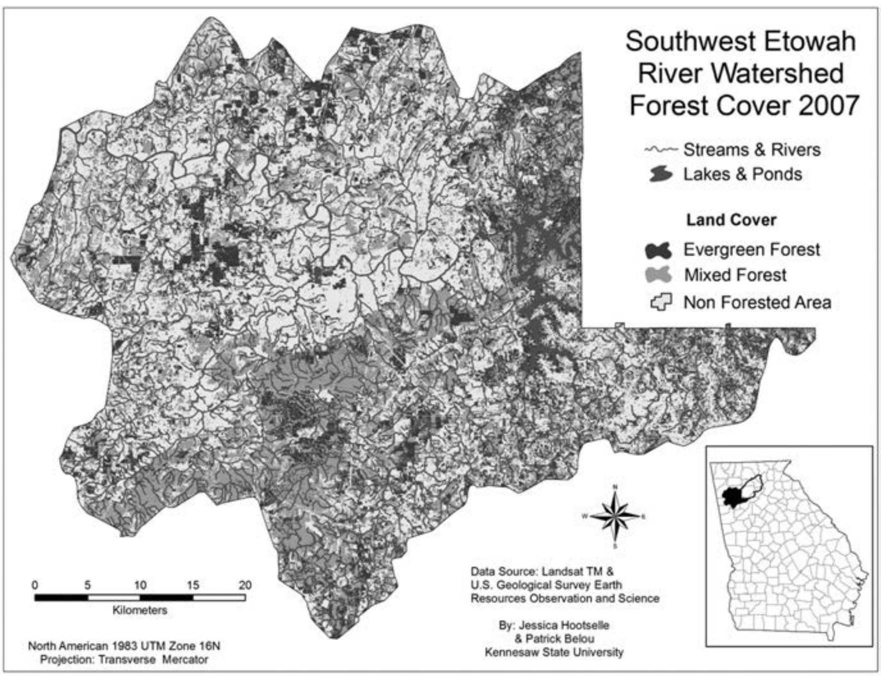

Figure 10. Forest cover for the Little Etowah Watershed (LEW) 2007.

Table 4. Percentage of total area covered by evergreen, mixed and total (evergreen plus mixed), and summary values for loss and gain, for five counties and the Lower Etowah watershed, Georgia, USA, between 1992 and 2007. Change 1992–2007 negative values indicate loss while positive values indicate gain.

	Etowah		Floyd		Cobb		Bartow		Paulding		Polk	
	1992	**2007**	**1992**	**2007**	**1992**	**2007**	**1992**	**2007**	**1992**	**2007**	**1992**	**2007**
Evergreen forest	**30.1**	19.2	**51.4**	42.0	**31.9**	22.8	**25.8**	20.6	**35.8**	17.0	19.2	**35.2**
Mixed forest	**46.4**	37.0	18.5	24.2	**34.2**	33.7	39.5	41.9	**49.1**	45.7	48.4	34.0
Forest total	**76.5**	**56.3**	**70.0**	**66.2**	**66.1**	**56.5**	**65.3**	**62.5**	**84.9**	**62.7**	**67.6**	**69.2**
Other vegetation	12.8	29.0	24.0	24.7	6.6	5.8	18.3	14.5	6.3	17.4	26.7	17.9
No vegetation	9.3	13.2	4.6	7.7	26.2	36.4	14.4	20.8	7.4	19.2	5.2	10.9
Water	1.4	1.5	1.5	1.4	1.1	1.3	1.9	2.1	1.3	0.7	0.5	2.0

Change 1992–2007	**Etowah**	**Floyd**	**Cobb**	**Bartow**	**Paulding**	**Polk**
Change Evergreen	−10.9	−9.5	−9.1	−5.2	−18.8	16.0
Change Mixed	−9.3	5.7	−0.5	2.4	−3.5	−14.4
Forest total change	−20.2	−3.8	−9.6	−2.8	−22.3	1.6

mixed decreased by 14 percent accounting for the difference at the LEW level (Table 4). These results suggest that in some areas the losses of evergreen forest are due to a transformation towards mixed forest and not necessarily a forest cover lost to no vegetated areas.

Forest cover change

The results showed for the landcover classes *evergreen* and *mixed forest* an average of 41 percent and 54 percent of their area unchanged from the 1992 values, while an average of 48 percent of the class *other vegetated* areas still remain unchanged from its 1992 values (Table 5). The results suggest and active process of intervention and disruption in the forest areas with more than 50 percent of the forest areas affected by land cover changes and confirms our previous observations that forest changes have occurred from evergreen to mixed in certain areas of the study.

In the period 1992 to 2007 areas under no vegetation have experienced the largest change, with an average of 65 percent and up to 85 percent (Polk county) of change from their values in 1992 for the six study areas. These are the areas more likely to see a process of urban growth, confirming previous observations of the active process of urbanization of rural Atlanta (Miller 2012). The areas under other vegetation may be considered areas of transition in the continuum from forest to urban. Under that scenario, Paulding County is the only one of the five counties that presented large increases of area under this land cover and hence is becoming the greater contributor to the LEW gains in this category. The matrix of land cover change for the forest areas (Table 5) shows that on average, 11.5 percent of the area previously under evergreen forest was substituted by mixed forest vegetation while only 6 percent of the area previously under mixed

Table 5. Change matrix for evergreen and mixed forest from 1992 to 2007. Values are expressed as percentage of the county area. Values represent only areas in forest and their landuse change in the 15 years. Highlighted values indicate areas of no change.

		2007 Land cover				
Study area	**1992 Land cover**	Evergreen	Mixed Forest	Other Veg	No Veg	Water
Bartow	Evergreen	**11.7**	9.2	2.0	2.7	0.2
	Mixed forest	6.3	**24.2**	3.7	5.3	0.1
Cobb	Evergreen	**13.5**	8.3	1.0	9.0	0.2
	Mixed forest	6.3	**16.4**	1.1	10.3	0.1
Etowah	Evergreen	**12.0**	9.2	5.0	3.8	0.2
	Mixed forest	5.6	**23.4**	11.5	5.8	0.1
Floy	Evergreen	**28.3**	12.2	8.0	2.7	0.2
	Mixed forest	8.7	**6.6**	2.2	0.9	0.1
Paulding	Evergreen	**11.2**	13.1	5.3	6.1	0.1
	Mixed forest	4.4	**30.0**	7.9	6.7	0.1
Pork	Evergreen	**11.3**	17.2	5.6	1.0	0.1
	Mixed forest	4.4	**23.2**	5.3	1.0	0.0

forest was replaced by evergreen forest. This suggests a trend of forest change in the study area towards mixed forest. Cobb, Paulding, and Bartow have seen the greatest loss of forest cover towards no vegetated areas, suggesting an active process of urbanization in these counties.

In summary, the results of the land cover change analysis indicate loss of forest cover, high level of disturbance within the forest areas, the transformation of evergreen forest into mixed forest, localized processes of urbanization and localized processes of transition from forest towards urbanization for the six sub study areas. The results also suggest heterogeneous processes of land cover change within the LEW affected by site-specific dynamics at the county level.

DISCUSSION

At the scale of the forest fragment, forest cover have a variety of dominant tree species, including *Pinus taeda* L. and *Liquidambar styraciflua* L. The analysis of sap flow for these tree species showed significant differences between them during the growing season that could have important implications for the management of forest fragments and in deciding forest regeneration strategies for the city. Previous studies suggested that coniferous forests were likely to have higher evapotranspiration and therefore larger sap flow during the growing season compared to broadleaf forests (Stoy et al. 2006). Our results showed the contrary effect with a larger sap flow found for the broadleaf species. However, our results are in agreement with similar recent studies in the southern Appalachian where broadleaf trees were found to have a twofold and three fold difference in evapotranspiration when compared with Pines (Ford 2010). Physiological differences between Pine and hardwood are considered to contribute as much as differences in tree structure (Ford et al. 2010) affecting interception, water intake, and infiltration. In a similar way, our results are in agreement with studies that showed broadleaf species less affected by changes in soil moisture compared to Pine trees (Stoy 2006), which is particularly important for the southeastern U.S. where severe drought has been more frequent in recent years.

At the landscape scale, our study found northwestern suburban Atlanta to be a heterogeneous region where the dynamics of land cover change are affected by decisions at the county level. Recent studies have showed a dynamic process of forest loss, forest fragmentation, and forest composition change in the counties surrounding the city of Atlanta (Miller 2012). In this way active processes of urbanization in Cobb, Bartow, and Paulding are contrasted by slow urban growth and regeneration of the forest cover in Polk County. Forest dynamics were also found to have different characteristics among the different counties where Paulding and Cobb showed an active loss of evergreen forest that other counties did not show. Polk County was a notorious exception presenting gains in its forest cover due to processes of re-vegetation with an evergreen forest cover at the expense of deciduous forest.

Change in the forest cover of a region has important effects in the evapotranspiration and interception components of the water budget, affecting potential regional water yield. Although it is clear that a reduction in the forest cover increases the water yield by decreasing evapotranspiraton (Zhang et al. 2001), effects in the water budget caused by changes in species composition of the forest rather than in the forest cover area are less evident but may be equally important. In fact, local water regimes are expected to show variations affected by tree species (Ford and Vose 2007), and forest types (Lu et al. 2001) due to the variation of individual tree species water use. In this way, our results suggest that in addition to the large scale changes in the hydrological regime brought about by the changes in the forest cover of the region, changing the species composition of the forest dominant tree species may have also an important additional effect on the hydrological regime particularly during periods of hydric stress (Gardner et al. 2009).

Recent regional assessments in the southeastern U.S. suggest that land cover areas of pine plantations will increase at the expense of hardwood forest (Stoy et al. 2006). This has the potential to modify the local contributions of forest fragments to the water cycle of the region.

The results are in agreement with increasing literature in the area of ecohydrology (Vose et al. 2011) suggesting that traditional approaches where forests are lumped into a single land cover need to be revisited since the different contribution of tree species to the forest water dynamics are very important. We found that the study of suburban forest fragments is of significance since tree species composition changes happening at the scale of the forest fragments are expected to play a significant role in the hydrological budget of the region as well as in other critical ecological events such as the conservation of native species of plants, and animal habitats for local species. At the watershed level, drastic land cover changes and change in forest cover composition caused by urbanization are expected to produce changes in the composition of riparian vegetation (Burton et al. 2009) that in addition to modifying the hydrological budget has effects on other elements of the hydrological system. Some of those changes include decreases of channel base-flow, sediment increases during storm-flow (Schoonover et al. 2007), the transformation of the channel sediment characteristics, and changes in the solute transport of the stream network (Ryan and Packman 2006).

In this way, a better understanding of the individual contributions of tree species to the water budget are particularly important in hydrological studies, especially in those seeking to refine conceptual computer base hydrological models that have been unable to describe the hydrological process of southern forest ecosystems (Sun et al. 2005). We found that a multidisciplinary approach to the study of the water budget is required to account for the different variables and components of the regional water system. In this case we found that in addition to the hydrological analysis, the use of GIS remote sensing tools allows us to quantify the effects of local decisions at different landscape scales.

CONCLUSIONS

We found that forest patches in suburban northwestern Atlanta have a diverse canopy with a rich tree species composition of several deciduous and evergreen tree species. When considered at the regional scale, different behavior between trees species may have an important impact in the estimations of the water cycle. In this research, we tested the hypothesis that tree species within forest patches have a different behavior regarding water intake. The results showed a relationship of more than 2:1 for the broadleaf deciduous (*Liquidambar styraciflua* L.) compared to the evergreen pine tree species (*Pinus taeda* L.).

We found also that the study area in northwestern Atlanta shows a great level of disturbance in the forest cover, with forest cover loss, changes from evergreen forest into mixed forest, and localized process of transition from forest towards urbanization. In addition to the negative impact in the water cycle of the area caused by a decrease in forest area of up to 20 percent in all the five counties of the Etowah watershed, additional disruptions to the water budget may be expected by changes in the dominant tree species composition of the forest fragments due to the differences in water use between tree species.

The change in forest cover and species composition within the canopy are expected to have a combined effect within the water cycle that is not considered in studies where mixed forest covers are considered homogeneous areas. Our results suggest that the species composition of the forest should be considered when studying the overall impact of land cover change over the water cycle with special attention to those forests with mix canopy cover. Although a more comprehensive modeling of the combined effects of forest cover and species composition change in the water budget are beyond the scope of this paper, it is suggested to be a natural follow up of this research.

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MARIO A. GIRALDO PH.D. is a geographer interested in urban ecosystems and in land use, land cover change effects in hydrological

process. He analyzes spatial fragmentation of agriculture and urban landscapes and study water dynamics on plant species. In watersheds in the colombian Andes he studies climatic variables in mountain gradients and spatial variation of vegetation. He teaches general ed courses and specializes in remote sensing, GIS applications to the environment, biogeography and conservation.

PAULA JACKSON PH.D. is a professor of ecology, modern biology, tropical ecology, interested in studying the ecology and physiology of plants. Her research focuses in the interplay between water availability, plant photosynthetic rates, and plant distribution patterns incorporating both classical ecological methods (e.g. quadrats and transects to look at patterns of distribution), and new techniques such as stable isotopes.

WAYNE VAN-HORNE PH.D. is an ethnologist, ethnohistorian and ecological anthropologist. His research areas includes ecology and conservation issues in the Southeastern U.S., and the role of warfare in social evolution of the American Indian cultures of the Southeastern United States. He teaches a variety of courses in both ecological and cultural Anthropology.