Journal of Hydrology: Regional Studies 5 (2016) 276–292

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

The effects of current landscape configuration on streamflow within selected small watersheds of the Atlanta metropolitan region

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ARTICLE INFO

Article history:
Received 18 March 2015
Received in revised form 30 October 2015
Accepted 10 November 2015
Available online 26 November 2015

Keywords:
Atlanta
Curve number
Landscape configuration
Streamflow
Thornthwaite water balance

ABSTRACT

Study region: This study investigated impacts of current landscape configuration on streamflow within selected small watersheds of the Atlanta, Georgia metropolitan region (AMR).
Study focus: To determine effects of current landscape arrangement on watershed-wide Hydrologic Unit Code (HUC)-12 land cover/land use (LC/LU), the configurational metric of contagion was chosen. Contagion-adjusted curve numbers (CNs) were calculated for all 405 HUC-12 watersheds in the AMR. 6 watersheds were chosen for Thornthwaite Water Balance (TWB) model evaluation based upon having a stream gage record of the 5 year (60 month) period most closely associated with contagion and CN values derived from the 2011 National Land Cover Dataset (NLCD). 4 watersheds out-performed their original CN watershed simulations based upon: Nash–Sutcliffe efficiency (NSE); room mean square error (RMSE)-standard deviation ratio (RSR); and Akaike Information Criteria (AIC) analysis.
New hydrological insights: Configurational metrics related to contagion of the aggregation index (*AI*) and clumpiness index (*CI*) indicated possible reasoning to explain differences found between the 4-watershed and 2-watershed categories. The *AI* of agricultural LC/LU within the 2-watershed category suggested greater landscape heterogeneity due to agricultural patch disaggregation, whereas the *CI* suggested greater overall disaggregation and landscape dispersion for all non-water LC/LU patches within the 2-watershed category and pointed towards greater landscape heterogeneity driven by higher dispersal of non-water patches. Both may lead to complex flow patterns not easily estimated within streamflow simulations.

1. Introduction

Land cover/land use (LC/LU) is of significant importance to determining the runoff (streamflow) characteristics of all watershed-based stream networks (Wu and Haith, 1993). This is due to precipitation (*P*) conversion to streamflow being controlled by watershed characteristics, such as LC/LU and soil properties, and these controls imposing further structure on streamflow time series, as compared with just *P* (Pan et al., 2012). The type of LC/LU contained within a particular watershed not only modifies streamflow time series via evapotranspiration (ET) and infiltration processes, but through altering excess water quantities available for streamflow distribution via overland and groundwater flow processes (Wu and Haith, 1993).

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http://dx.doi.org/10.1016/j.ejrh.2015.11.002

Unfortunately, the magnitude and distribution of the effects of LC/LU on runoff processes still remain somewhat unclear, even as water resource quantity issues are a growing concern throughout the United States (US) due to increases in population and as demand for land development continues (Feyereisen et al., 2008).

This is especially true of the Southeastern (SE) US, where rapid population growth and conversion of LC/LUs have impacted stream hydrology (Schoonover et al., 2006). Although numerous studies have correlated landscape (LC/LU) composition (the variety and abundance of LC/LU types without regard to their spatial character or arrangement) to streamflow processes in the region (Bosch et al., 2006; Cruise et al., 2010; Feyereisen et al., 2008, 2007; Griffin et al., 2013; Isik et al., 2013; Magilligan and Stamp, 1997; McMahon et al., 2003; Olivera and DeFee, 2007; Pan et al., 2012; Schoonover et al., 2006; Van Liew et al., 2007; Viger et al., 2011; Wu and Haith, 1993), only two studies since the beginning of 2000 from McMahon et al. (2003) and Olivera and DeFee (2007) have attempted to quantify the relationship between landscape configuration (the spatial character and arrangement, position, and orientation of LC/LU types) and streamflow within the region. Within the McMahon et al. (2003) study, the authors determined that strong correlations existed between streamflow flashiness and the spatial arrangement of developed LC/LU within the Birmingham, Alabama area. In the Olivera and DeFee (2007) study, it was concluded that landscape configuration was correlated with annual runoff over a 52 year period within a smaller watershed located just northwest of Houston, Texas. These findings are important based upon other studies also indicating that landscape configuration has been correlated to not only streamflow processes (Feikema et al., 2011), but water quality phenomena including overland runoff-induced erosion and non-point source nitrogen (N) and phosphorus (P) enrichment (Roberts, 2009; Roberts et al., 2009; Roberts and Prince, 2010; Shi et al., 2013)

From a landscape configurational perspective, LC/LU patterns within watersheds may play a critical function in determining connectivity of hydrologic cycle processes, such as evapotranspiration, infiltration, soil moisture, and runoff over time (Shi et al., 2013). The majority of studies estimating effects of LC/LU on streamflow within catchments have not considered the function of LC/LU, as influenced by spatial arrangement (Feikema et al., 2011). Even though previous research has indicated that landscape configuration influences hydrologic cycle connectivity and controls watershed response, it is still typically disregarded during management strategies (Zhang et al., 2013). Additionally, streamflow response of a watershed is complicated based upon various hydrologic-influencing components, such as LC/LU and soil properties, being distributed heterogeneously throughout the drainage area (Isik et al., 2013). Therefore, comprehension of the correlations between landscape configuration and hydrologic processes, such as streamflow, is of practical concern to watershed planning and management entities and additional investigations of this particular influence on streamflow is warranted (McMahon et al., 2003; Olivera and DeFee, 2007; Shi et al., 2013). Thus, in this paper, the effects of current landscape configuration on streamflow within selected, small watersheds of the Atlanta, Georgia metropolitan region (AMR) will be addressed.

The AMR was chosen as the study area for this paper due to its long held status of being the "economic engine" of the SE US (Clark, 2014; Hu and Lo, 2007; Lo and Quattrochi, 2003; Lo and Yang, 2002; Wright et al., 2012). The region consists of 29 counties within northern GA and has undergone tremendous population growth and LC/LU change over the past 100 years (Liu and Yang, 2015). Between 1910 and 1950, population within the city of Atlanta alone rose by 114 percent (%) to approximately 330,000 and since 1950, the city's population has gained another 27% to a level of 420,000 (Merry et al., 2014). According to Lo and Quattrochi (2003), Atlanta's population increased 27% between 1970 and 1980 and 33% between 1980 and 1990. Additionally, Atlanta's population has increased 40% between 1990 and 2000 (Lo and Yang, 2002). For the past several decades, the region has been recognized as one of the nation's fastest growing metropolises and has expanded significantly, as suburbanization in counties adjacent to the city have transformed agricultural and forest LC/LUs to urban LC/LUs (Lo and Yang, 2002). This suburbanization has also reached the outer counties regionally. Thus, while population estimates within the official city limits of Atlanta are quite small, the larger metropolitan region has a population of over 5 million and has been found to have recent (2005–2009) losses in forest LC/LU of about 0.46% per year (Merry et al., 2014)

The large and abrupt changes in LC/LU composition over the past 100 years within the AMR should have significant implication on current landscape configuration. In smaller watersheds, control factors, such as LC/LU and soil properties, yield greater influences and any changes to their complexity, such as configuration, will be imposed on streamflow time series (Pan et al., 2012). However, quantification of streamflow patterns based upon time series is of significant importance for attenuating extreme hydrologic events, such as flooding and droughts (Pan et al., 2012). According to Shepherd et al. (2011), regions of the SE US face increasing vulnerability to extreme hydrologic events due to population growth and increasing population density. Such events in the form of flooding in late 2009 and drought in the mid-2000s have occurred recently in the region (Jeffcoat et al., 2009; Shepherd et al., 2011; Wright et al., 2012). Thus, improved comprehension of these extreme hydrologic events should assist in future development of best management practices (BMPs) for not only flood and drought forecasting methods, but LC/LU policies implemented at the watershed-wide scale.

2. Data and methods

2.1. AMR watersheds and 2011 National Land Cover Dataset (NLCD)

Environmental Systems Research Institute (ESRI) shapefiles of the urbanized core (Fig. 1a) and 29 counties (Barrow; Bartow; Butts; Carroll; Cherokee; Clayton; Cobb; Coweta; Dawson; DeKalb; Douglas; Fayette; Forsyth; Fulton; Gwinnett; Haralson; Heard; Henry; Jasper; Lamar; Meriwether; Morgan; Newton; Paulding; Pickens; Pike; Rockdale; Spalding; and Walton) (Fig. 1b) comprising the AMR were initially added within ArcGIS 10.2 and overlain by Hydrologic Unit Code