SYNTHESIS OF 10-YEARS OF ECOHYDROLOGIC STUDIES ON TURKEY CREEK WATERSHED

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Abstract—Since the establishment of a collaborative study 10 years ago, research on the third-order, 5240 ha forested Turkey Creek watershed in South Carolina's coastal plain has advanced the understanding of rainfall-runoff relationships, stream hydrograph characteristics, and water table dynamics for dominant soil types. Surface water dynamics were shown to be regulated primarily by the water table, which is dependent upon precipitation and evapotranspiration. The baseflow is, however, highly variable, resulting in zero streamflow about one-third of the time, on average. These processes regulate upland freshwater runoff and mediate material export into the tidally influenced larger river downstream. Analysis of pre- and post-Hurricane Hugo streamflow data showed the resiliency of this coastal forest to extreme events. A high-resolution LiDAR-based digital elevation model (DEM) was shown to have increased accuracy in drainage area delineation on this low-gradient coastal plain compared to available topographic maps and DEMs, potentially influencing site hydrology and engineering designs.

INTRODUCTION

Long-term monitoring and datasets from watersheds provide an important opportunity for advancing our understanding of forest ecohydrologic processes, detecting trends, reducing model and parameter uncertainty, and assessing the impacts of climate change and anthropogenic and natural disturbances on water quantity and quality (Algerich and others 2013; Amatya and Skaggs 2011, Furniss and others 2010, Jayakaran and others 2014, Jones and others 2009). Indeed, much of our current understanding about the relationships among forests, climate and climate variability, and streamflow comes from long-term gauged forested watersheds within the Forest Service, U.S. Department of Agriculture's Experimental Forests and Ranges (Vose and others 2014). However, the preponderance of that knowledge and literature is derived from high-energy piedmont and mountain watersheds with different climate and topography (Endale and others 2006, Ford and others 2011, Swank and others 2001, Tajchman and others 1997). The low-gradient coastal watersheds generally have a lower water yield, lower runoff ratio, and higher evapotranspiration (ET) than upland-dominated watersheds (Sun and others 2002). Only a very few observational studies have been conducted on the forested landscapes of the humid semitropical coastal plain in the southeastern U.S., with shallow water table soils potentially controlling the runoff.

Recent population growth, rapid urbanization, and development on the southeastern Atlantic coastal plain have prompted regulators, land managers, and researchers to try to better understand the functional relationships between watershed processes and valued ecosystem services (ESS) and their interactions with climate and forest resources in order to develop sustainable management strategies. To this end, regional stakeholders formed the Turkey Creek Watershed Research Initiative (TCWRI) in late 2004. The main goal of the TCWRI is to identify how land use and climate change could affect water availability, flooding, water table, water quality, and other associated ESS in the Turkey Creek watershed (Amatya and Trettin 2007b). In this way, the TCWRI can serve as reference or representative system within the rapidly urbanizing landscape of the South Carolina lower coastal plain.

Through cooperation with multiple interests, the TCWRI reestablished a real-time stream monitoring gauge on the Turkey Creek watershed (WS 78), headwaters of the East Branch of the Cooper River, on the Santee Experimental Forest (Fig. 1) (Amatya and others 2005). The collaborative approach for conducting ecohydrological studies using the monitoring and modeling framework for the TCWRI was summarized by Amatya and Trettin (2007c).

The objective of this paper is to synthesize the findings of the research since 2005 that have advanced the

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knowledge on ecohydrologic processes, including watershed characteristics, runoff generation, storm event characteristics, water budget, ET, and surface and subsurface flows and their pathways, particularly on Turkey Creek and similar low-gradient coastal watersheds. These include the Hobcaw Barony site maintained by Clemson University in Georgetown and the Dixie Plantation site maintained by the College of Charleston. This approach is based on the early vision of understanding water balance, soil moisture, and precipitation-runoff relationships at varying scales in coastal areas by monitoring experimental watersheds of multiple sizes at the Santee Experimental Forest (USDA FS 1963, Young 1966, 1968). A chronology of studies conducted on the watershed since 2004 is presented in Table 1.

WATERSHED DESCRIPTION

The Turkey Creek watershed (WS 78) is a third-order blackwater stream system draining approximately 5240 ha. It is located about 60 km northwest of Charleston, South Carolina near Huger, in Berkeley County, South Carolina (33° 8' N, 79° 48' W) (Fig. 1). WS 78 was originally gauged in 1963, and it was monitored until 1981. The gauging station was recommissioned in late 2004 with real-time gauges/sensors both for rainfall and flow monitoring (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) (Fig. 1) on SC Highway 41 N near Huger, in cooperation with the United States Geological Survey (USGS), the College of Charleston, and the South Carolina Department of Transportation. The present gauging station is approximately 800 m upstream of the original gauging station. WS 78 was intended to compliment three other lower order watersheds (WS 77, WS 80, and WS 79) within the Santee Experimental Forest (Fig. 1) to provide a basis for large-scale ecohydrological monitoring and modeling (Amatya and Trettin 2007b). Conrads and Amatya (2015) highlighted the statistics of 10 years of streamflow data and emphasized the long-term data as a basis for understanding natural variability, testing models and reducing their uncertainty, and developing new hypotheses.

The elevation of the watershed varies from approximately 2 m above mean sea level at the stream gauging station to 14 m above mean sea level at the headwaters (Haley 2007) (Fig. 1). The subtropical climate is characteristic of the coastal plain, with hot and humid summers and moderate winter seasons. The minimum and maximum air temperatures, based on a 50-year (1951-2000) record at the Santee Experimental Forest, were recorded as –8.5 °C and 37.7 °C, respectively, with an average daily temperature of 18.4 °C. Annual rainfall at the site varied from 830 mm to 1940 mm, with an average of 1370 mm

Table 1—Chronology of studies on the Turkey Creek watershed (WS 78)

Year	Studies/References
2007	Hydrologic Modeling using SWAT—*Haley (2007),* MS Thesis
2007	Forest Hydrologic Research 1) at Santee Experimental Forest—*Amatya and Trettin (2007a)* and 2) Turkey Creek Watershed—*Amatya and Trettin (2007b*)
2007	Estimates of Annual ET—*Amatya and Trettin (2007c)*
2007	Flow Dynamics of Three Coastal Forest Watersheds—*Amatya and Radecki-Pawlik (2007)*
2008	Seasonal Relationships of Rainfall and Runoff—*La Torre Torres (2008)*
2008	Development of a GIS-based Depressional Storage Capacity Model—*Amoah (2008),* PhD Dissertation
2009	Hydrology and Water Quality of Turkey Creek Watershed—*Amatya et al. (2009)*
2010	Outflow Characteristics of Turkey Creek watershed—*Amatya and Trettin (2010)*
2011	Seasonal Rainfall-Runoff Relationships on a Forest Watershed—*La Torre Torres and others (2011)*
2011	Determination of plant characteristics used in discharge capacity—*Miroslaw-Swiatek and Amatya (2011)*
2011	Evaluating SWAT Model for a Low-gradient Forest Watershed—*Amatya and Jha (2011)*
2012	Quantifying Watershed Depression Storage—*Amoah and others (2012)*
2012	Estimating groundwater recharge in lowland watersheds—*Callahan and others (2012)*
2012	Groundwater–surface water interactions in a lowland watershed—*Garrett and others (2012)*
2013	Application of LiDAR data for Hydrologic Assessments—*Amatya and others (2013)*
2014	Storm-event Flow Pathways in Lower Coastal Plain Forested…—*Griffin et al. (2014)*
2014	Hurricane Impacts on a Pair of Coastal Forested Watersheds…—*Jayakaran and others (2014)*
2014	Assessing various potential ET (PET) methods for forest—*Amatya and others (2014)*

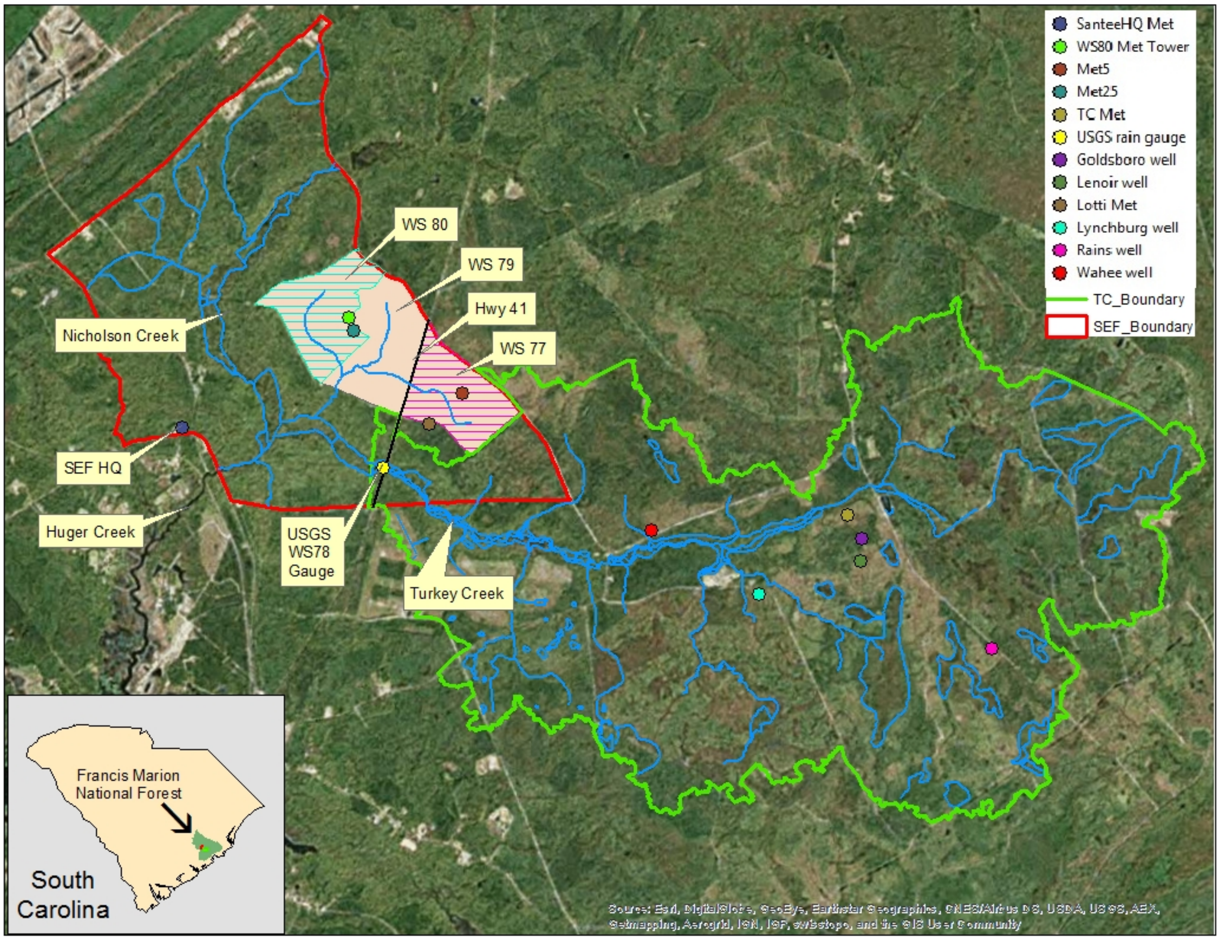

Figure 1—Turkey Creek (TC) watershed (WS 78) in green boundary mapped using high-resolution LiDAR data in 2011 (Table 1). Blue lines are streams and wetlands based on National Hydrography Dataset data. Locations of weather stations, stream gauges, and ground water wells are also shown, including for three other adjacent first- (WS 77 and WS 80) and second- (WS 79) order watersheds within the Santee Experimental Forest (SEF) (red boundary).

based on the 50-year (1951-2000) data (Amatya and others, 2009).

The watershed is underlain by Santee Limestone approximately 20 m below ground surface (bgs) in the western side of the watershed and about 13 m bgs in the eastern area (Williams 2007). Initial groundwater data at the site suggest that the Santee Limestone is overlain by a dense, approximately 10 m-thick semiconsolidated unit (Parkers Ferry Formation). This formation acts as a confining layer to groundwater flow between the shallow surficial sediments and the deeper Santee Limestone only in the watershed's western portion (Williams 2007). The watershed is dominated by poorly drained soils of the Wahee series (clayey, mixed, thermic *Aeric Ochraquults*) mostly on the northern part (or right bank, looking downstream) of the stream and Lenoir series (clayey, mixed, thermic *Aeric Paleaquults*) with shallow argillic horizons with less than 3 m depth (NRCS 1980) mostly on the southern part (left bank) of the stream. Williams and Amatya (2015) presented the soil matrix and classifications relating to drainage for the South Carolina Coastal plain and their implications to shallow water table dynamics that drive the forest hydrology.

Land use within the watershed comprises 44 percent pine forest, mostly loblolly (*Pinus taeda* L.) and longleaf (*Pinus palustris*) pine, 35 percent thinned pine forest, 10 percent forested wetlands, 8 percent mixed forest, and 3 percent agricultural, roads, open areas, and impervious areas (Haley 2007). Most of the current forests on the watershed are a mixture of remnant large trees and natural regeneration that is approximately 25 years old, regenerated since the area was impacted by Hurricane Hugo in 1989 (Hook and others 1991).

Details of the study site and ecohydrologic monitoring procedures are described elsewhere (Amatya and Trettin 2007b, Amatya and others 2009, 2013, Callahan and

others 2012, Haley 2007). Table 2 shows the chronology of various monitoring installations on the Turkey Creek watershed.

DISCUSSION OF WATERSHED STUDIES

Watershed Drainage Area

Amatya and others (2013) demonstrated the effects of uncertainty in drainage areas obtained by digital elevation models (DEMs) of varying resolution and delineation method, starting from the historical period to recent use of LiDAR (light detection and ranging), on the average annual runoff coefficient (ROC) for this low-gradient watershed (Table 3). The authors also highlighted the potential effects of lower resolution DEMs on many hydrologic monitoring and modeling studies prior to LiDAR technology.

Using the initial (1964) drainage area of only 3240 ha, the average ROC for the Turkey Creek watershed was estimated to be 0.38 (Table 3). The 2011 drainage area of 5240 ha, obtained using new DEMs based on high-resolution LiDAR data with field verification for culverts and roadbeds, was found to be 27.8 percent smaller (Amatya and others 2013) than the 2008 estimate of 7260 ha obtained by Haley (2007) using 10 m x 10 m interpolated DEMs, but only 6.5 percent larger than the 2004 area of 4920 ha obtained using 30 m x 30 m DEMs (Amatya and Radecki-Pawlik 2007), ultimately affecting the calculated average annual ROCs. Without considering the effects of culverts in 2011 LiDAR-based DEMs, the calculated drainage area was 5880 ha, consistent with the USGS area at its gauge site. Maceyka and Hansen (2015) recently used LiDAR and high-resolution aerial photos of the Francis Marion National Forest containing this watershed and found the largest changes in georeferencing of streams and legacy water management structures, enabling their better mapping. Although the LiDAR-based DEM is presently considered the most accurate for mapping low-gradient coastal plain watersheds with implications for water resources management, some potential limitations of software used in raw data processing and in watershed delineation algorithms should be acknowledged. Furthermore, careful inspection of LiDAR data using manual edits and hand digitizing with field verification is necessary for accurate estimates of drainage areas and stream channels.

Runoff Dynamics

The runoff generation mechanism on the low-gradient coastal watershed is influenced by the position of the spatially distributed shallow water table threshold (Harder and others 2007, Dai and others 2010, Epps and others 2013). Williams and Amatya (2015) reported that the most important aspect of forest hydrology across the coastal plain is the presence of a shallow water table, which influences not only the forest water balance as a source for fulfilling ET demand from vegetation but also as a determinant of the rainfall that becomes streamflow. The author related differences in soil-drainable porosity and water table fluctuations on sandy subsoil (Georgetown, SC) and clay subsoils on Turkey Creek (WS 78) and WS 80 to the source of storm

Table 2—Chronology of monitoring installation and other activities on the Turkey Creek watershed (WS 78)

Year	Month	Activities/Disturbances
1963	November	Gauging station established
1964	January	Rain and streamflow monitoring started
1981	May	Streamflow monitoring discontinued, records mostly by old technology
2004	December	1st Cooperators’ meeting to initiate a collaborative research, concurrent with revitalization of the new USGS stream and rainfall gauging station upstream of old Highway 41N bridge
2005	March	New gauge/sensor moved downstream of new Highway 41N bridge
2005	October	Manual monitoring of water physical parameters initiated using Eureka™ Manta sonde
2005	October	Installation of a Campbell Scientific automated weather station
2006	July	Installation of four water table recording wells on Rains, Lenoir, Lynchburg, and Goldsboro soils
2006	June	Installation of a Teledyne Isco, Inc. automatic water sampler
2010	October	Establishing a new Turkey Creek tributary subwatershed streamflow monitoring at Conifer Road
2010	November	Establishing a new subwatershed streamflow monitoring at Eccles Road
2011	January	Establishing a fifth water table recording well on Wahee soil

Table 3—Drainage areas and calculated average annual runoff coefficients (ROC) for Turkey Creek watershed based on map or digital elevation model (DEM) types used during 1964-2011 period (*after Amatya and others 2013*)

Time	Map / DEM Type	Delineation Method	Drainage Area (ha)	ROC
1964	1" = 2 mile Topo	Manual	3240	0.38
1969	1" = 1 mile Topo	Manual	4575	0.27
2004	30 m DEM	ArcHydro	4920	0.25
2005	1:24,000 Topo, 10-foot contours	Manual	5880	0.21
2008	10 m DEM	AV/SWAT	7260	0.17
2010	Partial LiDAR	ArcSWAT	6510	0.19
2011	Full LiDAR	ArcSWAT	5240	0.24

LiDAR = light detection and ranging.
ArcHydro = An Extension with a set of data models and tools that operates within ArcGIS to support geospatial and temporal data analyses.
AV/SWAT = SWAT (Soil and Water Assessment Tool) Hydrologic Model in ESRI ArcView GIS platform;
ArcSWAT = SWAT (Soil and Water Assessment Tool) Hydrologic Model in ESRI ArcGIS platform

runoff. The storm runoff that generally occurs after complete saturation of soils depends also upon the spatial microtopography or effective surface depressional storage as determined by Amoah and others (2012) for this and five other lower coastal plain watersheds using the DEMs with varying grid resolutions, including the LiDAR-based DEM. In comparison to areas with high-gradient topography, the coastal flatwood watersheds are slower in response, with Turkey Creek flow peaking at about 40 to 45 hours, on average, with duration of 12 to 14 days, on average (Amatya and Trettin 2010, La Torre Torres and others 2011; La Torre Torres, 2008).

Using 13 years (1964-76) of previous data, La Torre Torres and others (2011) found a large seasonal variability in storm event ROC, potentially due to differences in forest evapotranspiration that affected seasonal soil moisture conditions. Mean event ROC was higher for wet periods and wet antecedent soil moisture conditions (based on 5-day and 30-day prior antecedent precipitation indices) than for dry periods. The authors suggested that antecedent soil moisture and groundwater table levels are important seasonal runoff generation mechanisms in the coastal soils. The results of storm event hydrograph characteristics using data from 2005-08 by Amatya and Trettin (2010) indicated a hydrologic recovery of forest since its regeneration after Hugo in 1989. The authors also suggested that the runoff and peak flow rates are dependent upon both the rainfall and its intensity, besides the antecedent conditions described better by initial water table positions, as recently demonstrated by Epps and others (2013) for the adjacent watershed (WS 80) and another coastal watershed in Georgetown, SC. The initial water table depth of spatially distributed shallow wells, a surrogate of soil moisture, is dependent upon rainfall and ET, which can be a substantial fraction (as much as 98 percent) of the annual rainfall (Amatya and Trettin 2010, Amatya and others 2009). The annual ROC varied from 0.34 in the wet year of 2005 with 1527 mm of rainfall to as low as just 0.09 for a dry year in 2007 with 994 mm of rainfall. The daily average water table was recorded as low as 2.39 m in late July-early August of 2006 at the well located on well-drained Goldsboro soil. Callahan and others (2012) inspected the water table recession behavior for Goldsboro, Lenoir, and Rains soils using water table hydrograph data. They saw a water table depth for Goldsboro of 2.49 m below ground during the extreme drought of 2007, and also 2.32 m for the Lenoir soil site and 1.8 m for the Rains soil site during the same time (see Figure 2). They also estimated water table recession coefficients of 0.015, 0.035, and 0.030 day^{-1}, respectively.

Stream flow ceased when the water table dropped below 50 cm in all wells. There was negligible stream flow from late March until November in 2007 as a result of dry conditions and high ET demands (Amatya and others 2009). On the other hand, a very large rain event (172 mm) on October 25, 2008 brought the water table to ponding as much as 17 cm above the surface in one of the wells, resulting in an extremely large discharge of 41.6 m^3 s^{-1} (Conrads and Amatya 2015).

A close examination of daily rainfall and flow data on the watershed showed almost no stream response for daily rainfall amounts below 15 mm in the dry summer and about 10 mm in the wet winter, respectively, for a 3-day antecedent dry period for both seasons (Amatya and Trettin 2010). Current daily stream gauging data indicate that this watershed has no stream flow nearly one-third of the time, on average, similar to another 30-

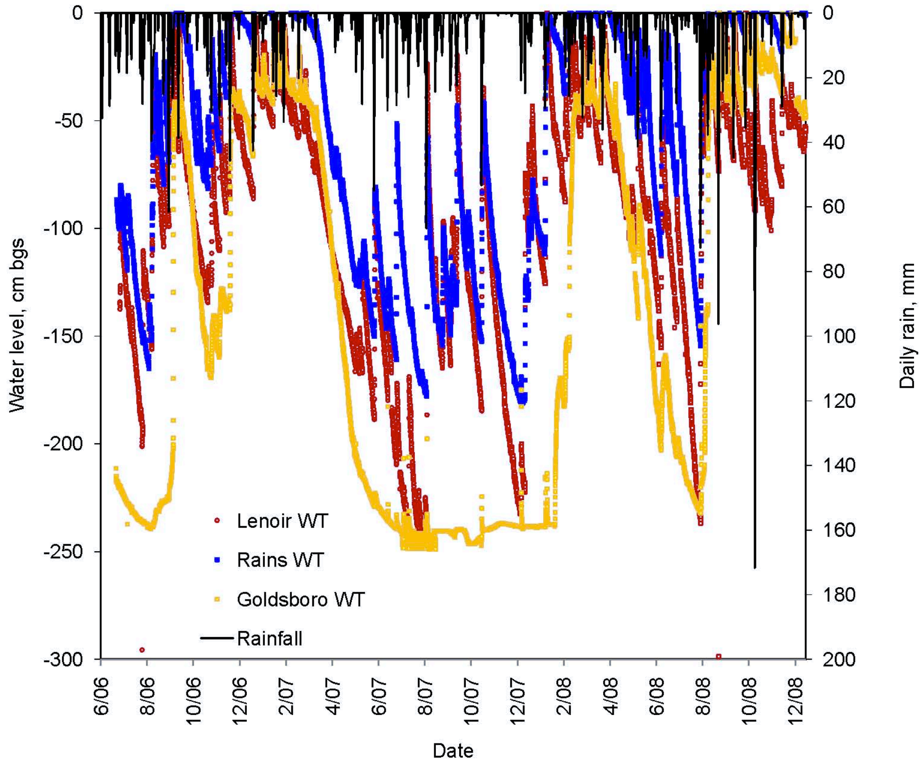

Figure 2—Daily rainfall and water levels in cm below ground surface for water table wells at three locations in the Turkey Creek watershed for the period June 2006 - December 2008 (from Callahan et al., 2012).

km^2 forest watershed in coastal North Carolina (Amatya and others 2003) but different from the upper coastal plain and upland watersheds of similar or smaller size, where baseflow is a significant component of streamflow (Bosch et al., 2004; Sun and others (2002). This may be due to the large surface and subsurface soil water storage and high growing-season ET demands typical of the forest ecosystems of the low-gradient Coastal Plain, as also shown by Sun and others (2002).

A study of daily stream flow dynamics compared early data from the Turkey Creek watershed (WS 78), which has some open lands, roads and wetlands, with two other adjacent completely forested first- and second-order watersheds on the Santee Experimental Forest. It was hypothesized that somewhat higher annual water yields from the larger (WS 78) compared to the smaller watershed (WS 80) were due to differences in their land use, soils, and topography, as well as increased base flows (Amatya and Radecki-Pawlik 2007) and potential errors in the drainage area calculated for the flow estimate of WS 78, as discussed above (Amatya and others 2013). As expected, the pre-Hugo daily flows persisted for 79 percent of the time with dampened peak flows in the larger WS 78 watershed with a larger storage, compared to only 65 and 60 percent in the second- and first-order watersheds, respectively. The frequency of daily flow occurrence on WS 78 dropped to about 68 percent of the time for the recent 2005-14 period, possibly because of increased ET due to higher temperatures (Dai and others 2013) and growing pine stands following Hugo (Jayakaran and others 2014).

Stormflow and Subsurface Flow

In their study using a simple linear baseflow separation method, La Torre Torres and others (2011) found baseflow contributing up to 56 percent to the total streamflow, with an average of about 28 percent. This is consistent with Amatya and Trettin (2010), who found similar results for recent data using the baseflow separation method by Arnold and Allen (1999) for this watershed. Using the SWAT model (Arnold and others 1998), Amatya and Jha (2011) found that the simulated average annual baseflow contributed 24 percent of streamflow. Recent studies that used end-member mixing analysis by comparing stream flow chemistry to that of precipitation and subsurface water have shown that the base flow contribution to stream flow is about 40 percent, on average, for the upper Turkey Creek system and for the adjacent WS 80 watershed (Garrett and others 2012, Griffin and others 2014). The uncertainty of baseflow separation, including by this chemical hydrograph method, is yet undetermined, but based on a water table fluctuation

method, the total groundwater recharge for the watershed ranged widely from 107 ± 39 mm per year (5-10 percent of annual precipitation) for a poorly-drained site (Rains soil) to 1140 ± 230 mm per year (62-94 percent of annual precipitation) for a moderately well-drained site (Goldsboro soil). Analyzing the water budget and range of conditions for vertical hydraulic gradients in the shallow aquifer, we estimated that the average aquifer recharge rate was 114 ± 60 mm per year. Callahan and others (2015) highlighted these studies related to storm runoff behavior in this coastal plain watershed using physical and chemical hydrograph separation techniques.

Evapotranspiration

Using 13 years (1964-76) of data, Amatya and Trettin (2007a) estimated annual ET as a difference between precipitation and streamflow. The 13-year mean annual ET was 983 mm, and the annual ET remained near the potential ET (PET) (>90 percent of average Thornthwaite PET of 1079 mm) for the years exceeding the long-term average rainfall and/or the years with just below the average but with a wet antecedent year. Years with consistently below-average annual rainfall yielded ET equivalent to 80 percent or less of the annual PET. This mean ET estimate was about 11 percent lower than the 1107 mm estimated by Richter (1980) for a 12-year period (1969-80) on the adjacent WS 77 watershed and only 6 lower than the long-term mean reported by Dai and others (2013) for the WS 79 watershed. However, the temporal and spatial ET dynamics of this watershed are still poorly understood. Recently, Amatya and others (2014) showed that the forest-based PET can be substantially higher than the commonly used grass-based PET estimates used in those earlier studies. _

Water Balance

The average annual water balance for this watershed using 13 years (1964-1976) of data yielded 1320 mm of precipitation with 312 mm of streamflow, using recent calculations of watershed area for the old gauge downstream of the current USGS gauge. This yielded a mean ROC of 0.23 with 95 percent confidence interval (CI) of 0.19-0.27 and an average annual ET of 1008 mm with a 95 percent CI of 932-1084 mm, assuming negligible storage and deep seepage. The recent 10 years (2005-2014) of data for this forest regenerated since Hugo in 1989 yielded mean precipitation of 1306 mm and streamflow of only 247 mm, resulting in an ROC of 0.18 and mean annual ET of 1059 mm. The results indicated that although the mean annual post-Hugo flow was lower than the pre-Hugo flow, there was no significant difference in mean annual ET, potentially indicating the return of hydrology to pre-Hugo levels.

Surface Depressional Storage

Amoah (2008) and Amoah and others (2012) quantified representative depressional storage capacity (DSC) of six lower coastal plain watersheds, including Turkey Creek (WS 78), by implementing a lumped DSC model to extract geometric properties of storage elements from DEMs of varying grid resolutions (including the LiDAR-based DEM) and employing a consistency zone criterion. Accordingly, the average DSC was estimated to be 100 mm for WS 78, in contrast with 93 mm and 10 mm for WS 80 and WS 77, respectively, potentially indicating some differences in hydrologic responses based on wetland size and storage as expressed in DSC.

Riparian Vegetation Effects on Discharge

Riparian vegetation type, composition, structure, and abundance on floodplains exert a strong influence on riparian surface and subsurface hydrology and discharges of rivers and streams, especially in low-gradient streams (Benjankar and others 2009, Rood and others 2005). Miroslaw-Swiatek and Amatya (2011) found a close agreement between the modeled stage-discharge relationship using a given stream/floodplain cross-section with friction parameters controlled by various vegetation types and that obtained by the USGS with actual field measurements (Conrads and Amatya 2015). In another study to evaluate the effects of roughness due to assumed shapes of Cypress knees found in the main channel and floodplain on Turkey Creek watershed discharge calculation, Miroslaw-Swiatek and Amatya (*in review*) showed larger calculated friction factors with reduced flow velocities and discharge when a conical knee shape was assumed compared to a cylindrical shape.

Watershed Hydrologic Modeling

A SWAT watershed modeling study conducted by Amatya and Jha (2011), extending the initial works by Haley (2007) on the watershed, found reliable streamflow predictions for the 2005-2010 calibration and validation periods. Although the model *performance was reasonable*, *f*urther model improvements were recommended using more representative LiDAR-based DEMs, field parameters, and testing for internal consistency for its further ecohydrologic applications. Furthermore, since the SWAT model is still unable to predict the daily water table dynamics for wetland hydrology and its functions and biogeochemical processes, efforts are ongoing to develop a simple analytical model to simulate daily water table dynamics on major soil types using the measured daily precipitation, PET, and soil water properties, as described by Amatya and others (2015).

Water Quality

Almost no detailed studies on water quality of this watershed have been conducted, except for the analysis of a 2.5-year (2006-08) data period. This analysis showed measured pollutant concentration values within the ranges for similar land use of the coastal plain, except for NH_4-N, which was slightly higher (Amatya and others 2009).

FUTURE DIRECTIONS AND NEEDS

The long-term studies developed through this collaborative research on the Turkey Creek watershed provide data necessary as "reference" conditions for water resources development and management, wetland restoration and conservation, and also for improving hydrologic assessment tools needed for management decisions on sustaining ecosystem services derived from this rapidly urbanizing landscape. However, some changes in watershed response are expected with time as the forest stands mature and are influenced by management practices and potential climate change. As this watershed is somewhat isolated from population pressure, and development near the coastal waters is expected to continue to increase in the southeastern United States (Hitchcock and others 2015), we recommend the following as topics for future research:

- Monitoring for mercury (Hg) and fecal coliform due to large areas of wet soils and wetlands
- Understanding processes, linkages, and transport mechanisms at the freshwater-tidal interface
- Consideration for monitoring Quinby Creek and others adjacent to Turkey Creek for baseline data needed for near-future developmental impacts
- Developing research techniques for activities that improve forest health and restore ecosystems such as thinning, landscape-scale prescribed fire, and hydrologic restoration
- Developing an accurate quantification of baseflow and storm flow contribution to streamflow
- Developing a quantification of spatial and temporal dynamics of evapotranspiration
- Assessing effects of land use and potential climate change on hydrology, water quality, and vegetation dynamics using validated hydrologic models like SWAT
- Studying watershed responses to wetland and stream restoration efforts such as those that might be considered in implementing the Revised Francis Marion National Forest Plan
- Studying the carbon dynamics and dissolved organic carbon in coastal blackwater streams as a concern for water treatment systems and consumer health

Francis Marion National Forest is in the process of revising the Forest Management Plan (US Forest Service 2015). Turkey Creek is identified as one of the priority watersheds for 1) improving hydrologic functions and watershed health based on past modifications as well as the rehabilitation of existing cross-drainage structures that affect wetland and riparian structure, biota, processes, and functions and 2) restoring longleaf pine ecosystem together with red-cockaded woodpecker (*Picoides borealis*) habitat as an at-risk species (Maceyka and Hansen 2015; Danaher 2015). Accordingly, opportunities may exist in the future for collaborative studies to address relevant issues on this watershed.

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