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STREAMFLOW CHARACTERISTICS OF A NATURALLY DRAINED FORESTED WATERSHED IN SOUTHEAST ATLANTIC COASTAL PLAIN

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ABSTRACT Information about streamflow characteristics e.g. runoff-rainfall (R/O) ratio, rate and timing of flow, surface and subsurface drainage (SSD), and response time to rainfall events is necessary to accurately simulate fluxes and for designing best management practices (BMPs). Unfortunately, those data are scarce in the southeastern Atlantic coastal plain, a highly urbanizing region characterized by poorly drained low-gradient forested landscape where runoff is dominated by shallow SSD and saturation excess overland flow. In this paper we evaluate these characteristics using four years (2005-08) of streamflow data measured on a 72 km² naturally drained forested watershed on the Francis Marion National Forest in coastal South Carolina. The calculated average event peak flow rate, time to peak, event duration, SSD as % of streamflow, and R/O ratio were 4.2 m³ sec⁻¹ km⁻², 14.6 hrs, 13.9 days, 29%, and 20%, respectively, for 12 events with rainfall amount varying from 153 mm to 34 mm. The events were similar to those from the historic data (1964-73) indicating a hydrologic recovery of forest since its regeneration after Hurricane Hugo in 1989. The average drainage response time to the rain was 7.8 hours. Results suggested that the runoff and peak flow rate of storm events are dependent upon both the rainfall and its intensity as well as the antecedent conditions described better by initial water table positions than the initial flow rate. These results, as a baseline reference, may have implications for regional water and water quality management assessments including the restoration efforts.

Keywords: Low-gradient landscape, Runoff-rainfall ratio, Base flow, Peak flow Rate, Time to Peak, Drainage Response time.

INTRODUCTION Watersheds in coastal regions of the southeastern United States are characterized by permeable surface soils and low-gradient drainage networks (Sheridan et al., 2002). Hillslope processes dominate the hydrology of upland watersheds, but the hydrologic processes on relatively low-gradient poorly drained coastal plain sites are usually dominated by shallow water table positions. Streamflow is a key controlling process for quantifying flood magnitude and duration, drought, and pollutant transport into receiving waters. The flow process on this landscape is dominated by shallow subsurface drainage from saturated areas and saturation excess overland flow or surface runoff that occurs when the water is at the surface or a shallow water table is present. This means that the streamflow rate depends on the frequency and duration of flooding

and on the dynamics of the water table, which are driven by rainfall and evapotranspiration (ET). Accordingly, information about streamflow characteristics e.g. runoff-rainfall ratio, timing of flow and their pathways via surface flow and subsurface drainage, and response time to rainfall events is necessary to accurately simulate fluxes and for designing best management practices (BMPs). Only a few studies have attempted to describe such characteristics (Amatya et al., 2000; Capece et al., 1988; Swindel et al., 1983a; Swindel et al., 1983b) for small watersheds. Sheridan (1994) reported hydrograph time parameters for flatland watersheds ranging from very small to large watersheds. Similarly, characteristics of peak flow rates were recently reported by Sheridan (2002) and Sheridan et al. (2002). In their study of hydrologic dynamics in a wetland dominated landscape, Todd et al. (2006) reported that the peak basin stream flow resulted from delivery of sub-basins runoff to a spatially linked drainage network during spring snowmelt and this may have implications to the variable source area concept for runoff generation. Similarly, Slattery et al. (2006) and James and Roulet (2007) reported on hydrologic connectivity and storm runoff generation processes in a small agricultural (<20 ha) and a small forested (11 ha) field, respectively. Their results may have implications for large watersheds due to scaling effects. Ogden and Dawdy (2003) studied a semi-humid 21.2 km² Goodwin Creek watershed and its 13 subcatchments in northern Mississippi for scaling behaviour on peak discharge characteristics. The authors found that there is a fundamental change in behaviour at an approximate area of 100 km² and the single runoff event peak flow could be described by a power law function. Ulrike et al. (2009) studied the artificial drainage discharge characteristics from 11 study sites. The authors found 37% of the yearly precipitation as drainage discharge, < four hours of response time, and less than two days of time to peak for these drained systems.

Event hydrograph characteristics resulting from wider range of storm events affected by anthropogenic and natural disturbances on a watershed scale are scarce in the southeastern Atlantic coastal plain, a region characterized by poorly drained low-gradient forested landscape that is highly urbanizing. As a result of the urbanization these streamflow (drainage) characteristics including the hydraulic pathways may alter drastically with increase in peak flow rates and storm flow volumes, decrease in response time, time to peak, storm event duration and base flow (subsurface drainage) all of which are the characteristics of flash floods, primarily due to reduced infiltration and ET and increase in water table levels. The land managers and developers often need the information on such stream hydrograph characteristics for pre-development conditions to design the BMPs for the post-development conditions.

The objective of this study is to characterize the event hydrographs from four years (2005-08) of data measured on a 72 km² naturally drained forested watershed at the Francis Marion National Forest in coastal South Carolina. These characteristics include seasonal flows (storm flow and base flow (subsurface drainage)) and event-based rainfall, initial flow rate and water table depth, peak flow rate, time to peak, total flow, runoff (R/O) ratio, and response time. The results are compared with those obtained from the historical data (1964-76) by La Torres (2008) to examine whether the characteristics were affected by the disturbance of the forest caused by Hurricane Hugo in 1989 (Hook et al., 1991).

METHODS

Site Description The study site is the Turkey Creek watershed (WS 78) (Fig. 1) originally established by the USDA Forest Service in 1964 and monitored through 1984; recognizing the importance of data from the forested watershed as a reference system in a rapidly changing coastal environment, the current gauging station in cooperation with the US Geological Survey (USGS) and the College of Charleston was re-established in 2004 (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) to facilitate a large-scale eco-hydrological monitoring and modeling program (Amatya et al., 2009).

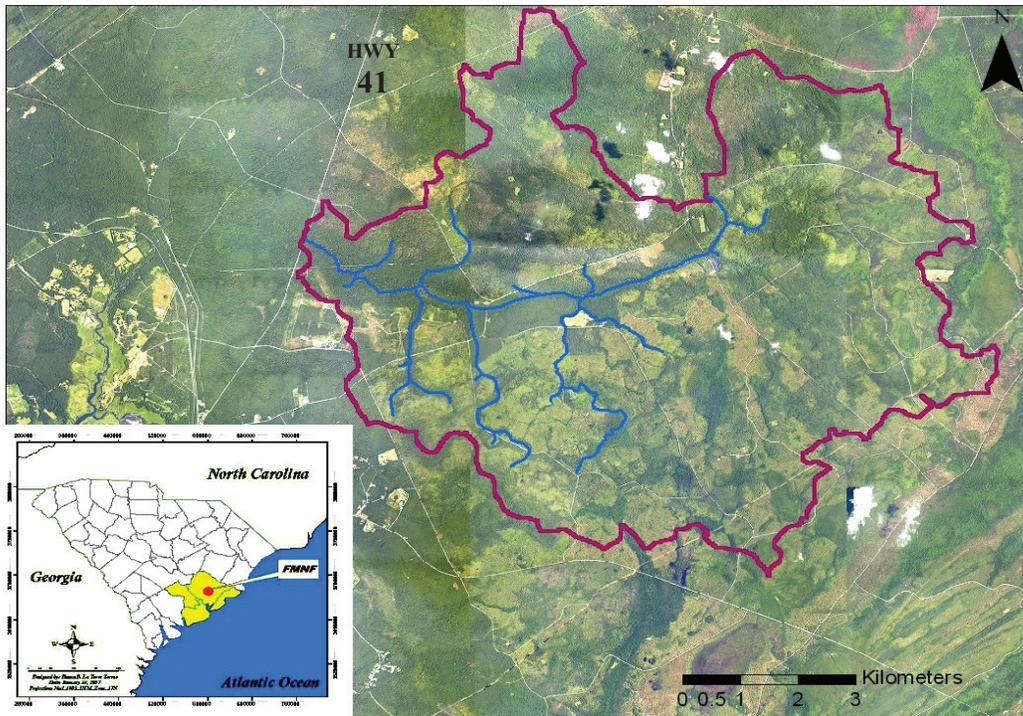


Figure 1. Location of the Turkey Creek watershed on Francis Marion National Forest in South Carolina lower coastal plain. The watershed boundary (red) with streams (blue) are delineated on an aerial photograph. (After Haley, 2007).

The Turkey Creek watershed is a 3rd order stream system draining an approximate area of 7,260 ha. It is located at 33° 08' N latitude and 79° 47' W longitude approximately 60 km north-west of City of Charleston near Huger, in Berkeley County of South Carolina (Fig. 1). It is the headwaters of East Cooper River, a major tributary of the Cooper River, which drains to the Charleston Harbor. Turkey Creek (WS 78) is typical of other watersheds in the south Atlantic coastal plain where rapid urban development is taking place. The topographic elevation of the watershed varies from 3.6 m at the outlet to 14 m above mean sea level (amsl). The sub-tropical climate is characteristic of the coastal plain having hot and humid summers and moderate winters. Accordingly, 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 based on the 50-year (1951-2000) data. Seasonally, the

winter is generally wet with low intensity long duration rain events and the summer is characterized by short duration, high intensity storm events; tropical depression storms are not uncommon.

Land use within the watershed is comprised of 88% pine forest (mostly regenerated loblolly (*Pinus taeda* L.) and long leaf pine (*Pinus palustris*)), 10% wetlands and water, and 2% agricultural lands, roads and open areas (Haley, 2007). The watershed was heavily impacted by Hurricane Hugo in September, 1989, and the forest overstory trees were almost completely destroyed (Hook et al., 1991). The current forests on the watershed are a mixture of remnant large trees and natural regeneration since then. The forests are managed using prescribed fire and thinning. The stand activities on the watershed for 2005 to 2008 period were as follows: 2005: no thinning or harvesting, 2006: 151.1 ha (373.3 ac) cut, 2007: 31.3 ha (77.4 ac) cut, and 2008: 48.6 ha (120 ac) cut. These numbers show that the largest area of 151.1 ha cut in 2006 was only 2.1% of the whole watershed area (7,260 ha). The watershed is dominated by poorly drained soils of Wahee (clayey, mixed, thermic *Aeric Ochraqults*) and Lenoir (clayey, mixed, thermic *Aeric Paleaquults*) series (SCS, 1980). The watershed also contains small areas of somewhat poorly and moderately well-drained sandy and loamy soils such as Goldsboro and Lynchburg (both fine loamy sand). Current management practices on the majority of the watershed include forestry, biomass removal for reducing fire hazards, prescribed fire and thinning for restoration of native longleaf pine and habitat management for red-cockaded woodpeckers (*Picoides borealis*), an endangered species. The watershed is also used for recreational purposes such as hunting, fishing, bird watching, hiking, canoeing, biking, historical tours, horse riding, all-terrain vehicle (ATV) use, and agriculture. More details about the study site including drainage network, hydrography, soil types, and land use can be found elsewhere (La Torres, 2008; Haley, 2007; Amatya et al., 2009).

Hydro-meteorological Measurements Only a brief description of these measurements is given below. Details are given elsewhere (Amatya et al., 2009).

Rainfall There are two automatic tipping bucket rain gauges in the study watershed. One gauge connected to a Campbell Scientific CR10X weather station is located near the middle of the Turkey Creek (TC) watershed and another gauge (USGS) located at the stream gauging station of the watershed. Data from the Lotti gauge was used for only January for the USGS gauge and for the whole year 2005 for the TC gauge when the respective gauges were still not in operation. Breakpoint event rainfall data from the loggers were processed to obtain daily, monthly, and annual totals for each of the three gauges.

Stream Flow Stream flow is obtained from real time stage measurements at 15-minute intervals using a Sutron data logger connected to a pressure transducer anchored on the stream bottom (Amatya and Trettin, 2007a) at the gauging station which is located at the outlet of the watershed near the bridge on Hwy 41 (Figure 1). The 15-minute data were integrated to obtain daily stream flows. An auto-filtering technique program developed by Arnold and Allen (1999) was used with the daily stream flow data to estimate daily, mean daily, and event-based base flows (primarily subsurface drainage) for the study period.

Data Analysis Fifteen-minute stream flow data were analyzed for examining the drainage characteristics for specific storm events identified in the four-year (2005-08) study period. The 15-minute data were further integrated to obtain daily, monthly, seasonal and annual streamflows. First the data were analyzed for annual and seasonal (wet and dry) flows as percentage of the rainfall. The wet season was assumed as the months from November to April and the dry season from May to October. For the event analysis, altogether 12 storm events (three in 2005, five in 2006, and four in 2008) were analyzed. No event was analyzed for the year 2007 with the lowest rainfall. Most of the events identified were single-peaked, except for event # 2 and #10 with rather small secondary peaks. The second criterion used was the amount of rainfall exceeding 25 mm similar to the criteria assumed by La Torres (2008). The event hydrograph characteristics calculated were initial flow rate, peak rate, time to peak, event total flow that includes subsurface drainage (base flow) and event duration. The amount of rainfall and maximum rainfall intensity attributed to each event were also identified using a judgement e.g. all rainfall from 12 hours prior to start of the storm was included in the analysis. Flow delay (or response time) was calculated as the time from the first burst of rain to the start of drainage (flow). Event runoff (R/O) ratio was calculated dividing the total flow by the rainfall total. A time lag between the average peak of the water table (WT) at four wells and the peak flow rate was also examined for events when the water table (WT) data was available. Basic statistics e.g. mean and coefficient of variation (CV) were calculated for all characteristics.

RESULTS AND DISCUSSION

Rainfall Rainfall data measured at different gauges located in and around the watershed are presented in Table 1 for the four-year (2005-08) study period and compared with the long-term (LT) average for the Santee Experimental Forest (SEF) headquarters.

Table 1. Annual rainfall at four gauges and hydrologic parameters from 2005 to 2008. LT is the long-term (1951-2000) average rainfall at Santee Experimental Forest station.

Year	<----- Rainfall ----->					P-M PET	Stream Flow	R/O Ratio	Base Flow	Mean WT Depth
	TC	USGS	LOTTI	SEF	LT Data					
	Mm	mm	mm	mm	mm					
2005	-	1527	1439	1631	1380	941	400	26.2	21	-
2006	1122	1131	1218	1265	1380	1229	86	7.6	29	70
2007	994	925	982	1041	1380	1176	68	7.1	41	105
2008	1463	1521	1478	1514	1380	1131	286	19.2	25	47
Average	1193	1276	1279	1363	1380	1119	210	15	29	74

Compared to the LT data, 2005 received the largest rain at all gauges, except for the TC gauge that was not in operation. Similarly, 2007 in which the USGS gauge received 33% less rainfall compared to the LT was the driest year followed by 2006 with 19% less rainfall at the TC gauge than the LT average. Overall, the cumulative rainfall is higher at the SEF gauge compared to the other gauges which are within or adjacent to the study watershed. Data observed at the two other gauges (USGS and TC) both within the watershed were consistent as expected. Somewhat larger month-to-month differences

were generally observed from June to September (not shown), the months characterized by high intensity, short duration storms on the coastal plains (Haley, 2007 and La Torre Torres, 2008). The four-year mean rainfall of 1363 mm at the SEF gauge was slightly (4%) higher than the 10-year (1964-73) mean of 1314 mm reported by La Torres (2008).

Annual and Seasonal Streamflows Annual streamflow, their subsurface drainage component as base flow and the R/O ratios are presented in Table 1. The R/O ratio varied from as low as 7.1% in 2007 with the lowest rainfall to as much as 26.2% in the wettest year (2005) with an average of just 15%. This mean annual R/O ratio is below 1 S.D. of the mean of 25% for the 10-year (1964-73) historic data reported by La Torres (2008). This was mainly due to below normal rainfall in two out of the four years in this limited study period and may also be an indicative of the regenerated forest stands coming back to pre-Hugo base line levels as reported by Amatya et al. (2009).

Base flow (subsurface drainage) varied accordingly from 21% in a wet year (2005) to as much as 41% in 2007 with the lowest rainfall, with an average of 29% of the total streamflow. Amatya et al. (2009) found similar estimates of base flow (30% of streamflow) using Darcy method with the ground water table data measured during this study period. This result is also consistent with the mean event-based base flow of 23% of the rainfall reported by La Torres (2008) for the 10-year historic data. This suggests that 70%, on average annual basis, of the streamflow from these low-gradient watersheds may be due to shallow saturation excess overland flow. In terms of seasonal flows, higher and lower R/O ratios were measured for the wet and dry periods, respectively, due to the effects of ET (Fig. 2). A high percentage of (41%) baseflow was estimated during the dry year of 2007 which primarily occurred during February-March when the water table was within 20 cm depth at least in two wells. The remaining flow > 1.0 mm was found to be a result of surface runoff as evidenced by water table ponding in three out of four wells during January-February. The high ET demands together with the lower than normal rainfall during the summer periods kept lower water table depths resulting in no flow (Amatya et al, 2009). The wet seasons with lower ET demands yielded as much as 31% of R/O ratio in 2006.

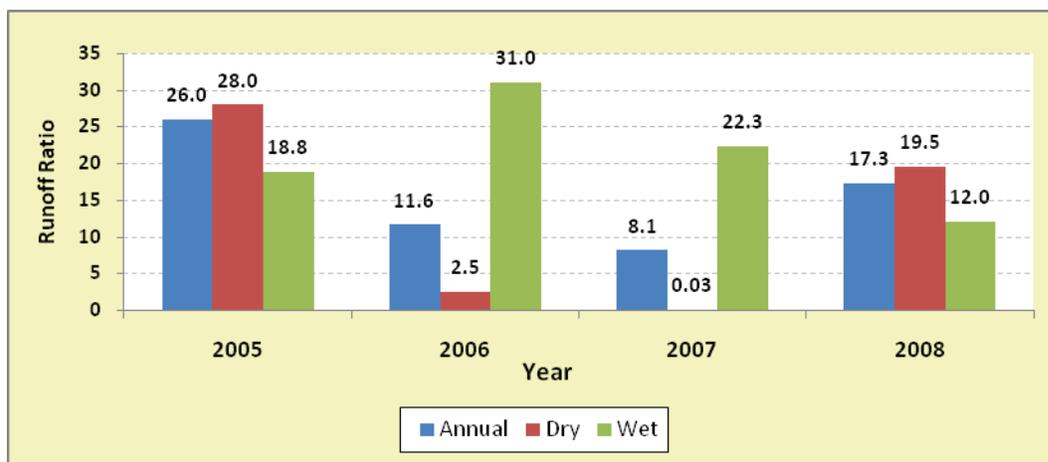


Figure 2. Annual and seasonal flow R/O ratios for the four-year (2005-08) period.

The large storms that occurred during the summer of 2005 resulted in higher R/O ratio for the dry period than the wet period (Amatya et al., 2009). Similarly, the high water tables

near or ponded during September-December 2008 (not shown) resulted in high surface runoff > 1 mm/day with annual R/O of 0.19 (Table 1). These results are consistent with other data reported for the coastal plain region with wetland dominated areas (Todd et al., 2006; Amatya et al., 2006).

Event Streamflow Characteristics The characteristics of 12 storm events selected for the analysis are presented in Table 2. These represented five events for the wet (#4, 5, 8, 9, and 10) and seven (#1, 2, 3, 6, 7, 11, and 12) for the dry periods reducing a potential bias. Although the event mean runoff (R/O) ratio of 0.22 was about 10% lower than the mean (0.25) reported by La Torres (2008) for 51 historic storm events on this watershed the 200-08 value was well within one standard deviation (± 0.16) of the historic data indicating no statistical difference. The event mean rainfall for this study (73.3 mm) was also similar to the historic (69.9 mm). This again tends to indicate the similar ET rates of these regenerated stands compared to the historic data. Coincidentally, the calculated event duration of 13.9 days was almost the same calculated for the 51 historic events. Similarly, the calculated mean peak flow rate of $4.2 \text{ m}^3 \text{ hr}^{-1}$ for these 12 events was also almost identical to the historical data ($4.1 \text{ m}^3 \text{ hr}^{-1}$). These stream event characteristics further testify that the hydrologic recovery has occurred on this watershed with regenerated stands since the Hurricane Hugo in September 1989 which destroyed >80% of the forest canopy in this region (Hook et al., 1991). Wilson et al (2006) reported increase in stream flows and nutrient loadings soon after this hurricane on the adjacent first-order watershed possibly due to decreased ET as a result of reduced canopy. Like the R/O ratio, the mean base flow of 2.76 mm (18% on average of the total flow) for this 4-year period (Table 2) was slightly lower than 2.96 mm for the historic data reported by La Torres (2008) who also used a different approach to estimate the base flow rates. There was no difference between wet and dry period event base flow although it was found to be higher value for the dry years on annual basis (Table 1).

Table 2. Event streamflow characteristics measured during the 2005-08 study period.

Event No.	Event Date	Initial Flow Rate cms	Peak Flow Rate Cm	Time to Peak hrs	Total Flow mm	Event Duration Day	Event Rainfall mm	Max Rain Intensity mm/hr	Runoff (R/O) Ratio	Flow Delay hr	Base Flow mm
1	8/7/2005	0.15	2.93	44.25	11.2	13.9	79.0	21.8	0.14	10.0	2.24
2	8/23/2005	0.05	13.24	24.25	38.1	13.8	131.1	50.0	0.29	3.5	4.08
3	10/6/2005	0.02	11.08	35.25	40.6	12.1	153.1	21.7	0.26	12.0	6.49
4	1/31/2006	0.11	2.24	108.75	15.3	20.3	52.8	12.8	0.29	8.8	4.92
5	2/25/2006	0.12	2.45	41.25	12.8	17.0	33.7	4.8	0.38	4.0	2.56
6	9/5/2006	0.14	3.85	21.50	9.9	7.0	51.5	14.0	0.19	1.8	1.17
7	9/13/2006	0.08	1.48	22.25	5.0	7.1	42.6	26.3	0.12	5.0	0.59
8	11/21/2006	0.03	1.24	44.25	6.6	16.9	67.9	7.2	0.10	5.0	1.56
9	1/17/2008	0.02	1.74	82.00	7.8	16.5	64.4	2.7	0.12	9.3	1.51
10	4/3/2008	0.22	2.56	37.50	17.7	15.7	59.5	24.6	0.30	12.0	3.22
11	9/25/2008	0.11	4.41	29.00	16.6	11.9	66.0	12.4	0.25	12.0	2.29
12	10/10/2008	0.10	3.00	58.00	17.8	14.0	77.7	7.7	0.23	10.5	2.51
Mean		0.10	4.19	45.69	16.6	13.9	73.3	17.2	0.22	7.81	2.76
Std Dev		0.06	3.86	26.15	11.4	3.9	35.1	13.0	0.09	3.73	1.69
COV		0.61	0.92	0.57	0.7	0.3	0.5	0.8	0.40	0.48	0.61

Event flow delay factors varied from 1.8 hrs for the event of September 5, 2006 to as much as 12 hrs (for three events) the maximum chosen for any event with an average of 7.8 hrs (Table 2), compared to < four hours for artificially drained systems (Ulrike et al., 2009). Although the rain amount, intensity, and R/O ratio were all lower than the all-storm average, this fastest drainage response with the smallest lag (4.5 hrs) between the peaking of the WT and the flow rate on September 5 event was expected as the WT on three out of the four well locations was at or near the surface (<10 cm) due to 5-day prior event with 61.5 mm rain (Amatya et al., 2009). The WT well on Goldsboro (a well drained soil) responded much slower to the rain than all other three soils. On the other hand, because there was no rain for 10 days prior to the event of April 3, 2008 with average WT depth below 22 cm in three wells, the response time resulted in longer (12 hrs) although the event rain, its intensity and R/O ratio were all larger than the September 5 event. Interestingly, the initial flow rate in April 3 event was lower than in the earlier event. These results suggest that the initial water table in the fields rather than the initial stream flow rate is primarily responsible for response time. Due to lack of rainfall intensity and water table data, these observations could not be verified in La Torres (2008) study. The high R/O ratio (>0.29) was observed for three winter storms (events 4, 5 and 10) in Table 2) with low ET demand, as expected. However, due to the effects of antecedent conditions very low R/O values (<0.12) occurred for winter events (#8 and 9) and the values higher than the average occurred for the dry season events (#2, 3, 11 and 12), consistent with the La Torres study (2008). The time to peak of 45.7 hrs (~ four days) are also more than double of those reported by Ulrike et al. (2009) for drained systems, as expected. The calculated peak flow rates yielded the greatest variability followed by the rain intensity, event flow, and base flow as shown by the coefficient of variation (COV) in Table 2. The variability observed in rainfall, R/O ratio, flow delay, initial flow rate, and time to peak were similar. The longest time lag of 72 hours (3 days) between the average time of peak of the WT and the peak flow rate occurred for the event #9 with below average rain, lowest rain intensity, deeper average initial WT depth, second in lowest R/O ratio and above average time to peak and duration, as expected.

As example of the typical events, plots in Figure 3 illustrate the characteristics of a small event caused by a 79 mm of rain as multiple bursts from August 7-21 and a large event as a response of 132 mm of rain from August 23-September 6 in 2005. To avoid the effects of antecedent moisture conditions in the analysis, both the events selected were from the month of August with high ET demand and also had no rainfall four days prior to their start. Interestingly, both the events yielded similar storm durations of 13.9 days (Table 2). The bulk of the rain (50 mm) for the first event occurred by August 08. Similarly, most of the rain (81 mm) occurred in two days (August 23-24) for the second large event. Although the initial flow rate was $0.15 \text{ m}^3 \text{ s}^{-1}$ with shallower WT depth for the first event both the total flow and the peak rate were much lower than those for the second event (Table 2) due to 40% lower rainfall and less than half the intensity than the second one. The two large rain intensities of about 32 mm hr^{-1} each during the second event (Fig. 3, right) resulted in two peaks with the second one as high as $13.2 \text{ m}^3 \text{ s}^{-1}$. This was 4.5 times larger than the first one with only $2.93 \text{ m}^3 \text{ s}^{-1}$ for the rain intensity of 27.6 mm hr^{-1} . As a result, the measured time to peak (24.25 hrs) for the large event was just about half of the first one (44.25 hrs) (Table 2). Although the R/O ratio of the large event was also double of the second one the base flow (drainage) occurred for a longer time in the later due to multiple rainfall events on this one. However, the estimated base flow (subsurface drainage) as a percent of the total flow was larger for the smaller event.

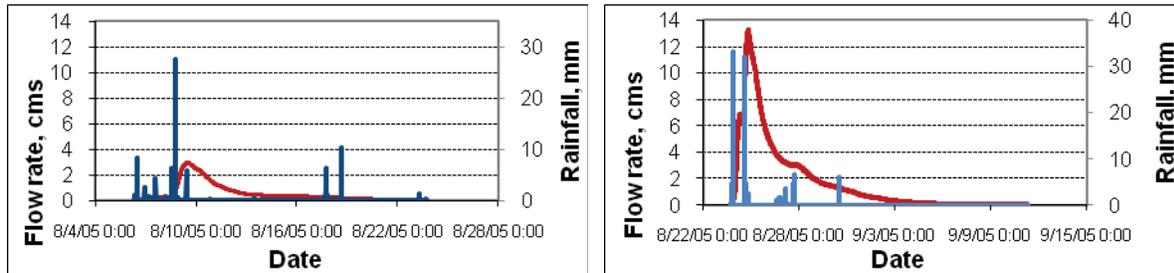


Figure 3. Storm event hydrographs for August 6, 2005 (left) and August 23, 2005 (right).

Data for these two events demonstrate that besides other factors like 5- and 30-day antecedent conditions discussed by La Torres (2008), the runoff event characteristics also depend upon rainfall intensity, and initial water table as antecedent condition (Slattery et al., 2006; Skaggs et al. 1991).

Results of the regression analysis of event flow and peak flow rate with the event rainfall showed a strong relationship (**Flow = 0.29*Rain - 5.1; $R^2 = 0.78$** and **PeakFlow = 0.096*Rain - 3.06; $R^2 = 0.76$**). The relationship between the peakflow and rainfall intensity was fair with **$R^2 = 0.50$** indicating that the peakflow is likely dependent upon both rainfall and its intensity. Taken together these relationships are stronger than those presented by La Torres (2008) for historical event data analyzed separately for wet and dry periods. The event flow relationship indicates that on average, there will be no stream flow for the rainfall less than 17.6 mm, on average, although this depends upon the antecedent conditions of the wet and dry periods as discussed earlier. A close examination of daily rainfall and flow data showed almost no stream response for the daily rainfall amount below 15 mm in the dry period and about 10 mm in the wet period, respectively, for a 3-day zero antecedent rain for both periods. One reason is the large surface storage including the canopy and subsurface storage of these forest ecosystems. However, the relationships of the R/O ratio with rainfall, the peak flow rate with the initial flow rate, and flow with the event duration, and peak flow rate with the flow lag time were all poor.

SUMMARY AND CONCLUSION This study was conducted to evaluate seasonal streamflow and its runoff hydrograph event characteristics using four years (2005-08) of rainfall and streamflow data from a 72.6 km² low-gradient forested watershed at Francis Marion National Forest in coastal South Carolina and to compare that period with the historic data collected during 1964-76 prior to Hurricane Hugo in September 1989. The limited results showed that the annual and seasonal stream flow and runoff ratio (fraction of the rainfall) were similar to the historic data suggesting that the hydrologic recovery of this forest with regenerated stands since Hugo has occurred to the base line levels. This conclusion was further supported by the seasonal event-based analyses which indicated similar runoff ratio, peak flow rate, base flow, and event duration. The mean annual runoff ratio of 15% was somewhat lower than other published data for similar coastal watersheds. It was concluded that the base flow or the flow generated by shallow subsurface drainage may comprise of 18 to 29% of the total stream flow based on the event to the mean annual basis. The stream event characteristics including tag times not only depend upon the rainfall amount and its intensity but also the antecedent conditions

indicated by water table positions which may be a better indicator than the initial flow rate on the watershed. It is also clear that the amount and percent of runoff and their relations to rainfall and water table is quite complex and variable due to their spatial and temporal variability.

The results have implications on water and pollutant management in the coastal plain dominated by shallow poorly drained soils, especially for design/development of best management practices. Seasonal rainfall and runoff data as well as storm event runoff hydrograph characteristics including the base flow, lag in runoff response time, lag between water table peak and flow peak (both representing the residence time of subsurface water) presented herein and also the historic data from this 3rd-order forested watershed can serve as a baseline reference for pre-development scenarios for urbanizing watersheds, stream and wetland restoration efforts.

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