INTERPRETING HISTORICAL STREAMFLOW DATA FROM A THIRD-ORDER COASTAL PLAIN WATERSHED: RUNOFF RESPONSE TO STORM EVENTS

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Abstract. Hydrological studies in the Southeastern U.S. have primarily focused on runoff generation processes in Piedmont and mountainous areas; much less is known about the relevant processes in Coastal Plain watersheds. Hydrologic processes between these two areas may differ considerably due to climate, topography and soil composition. Because of the population growth and subsequent development in the last few decades in the Lower Coastal Plain (LCP) of South Carolina (SC), it is important to understand natural hydrologic processes in the LCP for predicting hydrologic impacts of land management activities and designing Best Management Practices (BMPs). Past and current research and monitoring efforts by the US Forest Service and collaborators on protected lands within the Francis Marion National Forest (FMNF) in the LCP, 53 km northeast of Charleston, SC provide excellent opportunities to interpret hydrological processes such as rainfall-generated runoff under well-studied and controlled conditions.

This study describes relationships between seasonal rainfall patterns and stream flow for a third-order watershed, Turkey Creek, using ten years of historical rainfall and stream flow data (1964-1973). Storm event runoff-rainfall ratios were used to describe baseline runoff as a function of season and rainfall amount. It was hypothesized that runoff-rainfall ratios are smaller during the summer season and greater in the winter due to generally reduced flows as a result of increased evapotranspiration (ET) from the forests during summer-fall, and saturated soils with sustained flows in winter-spring. Alternatively, runoff-rainfall ratios may be directly proportional to the antecedent soil moisture condition (as estimated by rainfall amount during the 5 and 30 days preceding the storm event). Results showed statistically significantly ($p = 0.01$) higher runoff-rainfall ratios for storms occurring during wet antecedent conditions than for dry antecedent conditions.

BACKGROUND

Data Collection

Rainfall and stream flow data for the period 1964-1973 were analyzed. These data were collected by research hydrologists at the US-Forest Service Center for Forested Wetlands Research. Rainfall was measured using a manual gauge at a weather station located at Santee Experimental Forest Headquarters adjacent to the study site. The weather station, which initially consisted of a rain gauge and temperature recorder installed in 1946, was upgraded to automatic digital recorders (Campbell Scientific CR-10X) in 1996; at present there are two automatic tipping bucket gauges with electronic dataloggers (Amatya and Radecki-Pawlik, 2007). Daily rainfall data from only one manual recorder was used in this study; other gauges distributed along the Turkey Creek watershed collected rainfall data in a weekly basis. Stream flow data were collected from a flow gauging station established in 1964 about 800 meters downstream of the existing Turkey Creek bridge on Highway 41N, a few kilometers north of Huger, SC (Fig.1). Stream flow data were collected at 15 minute intervals when the flow occurred otherwise on a 24-hr basis. A new gauging station has recently been established upstream of the old abandoned station by the collaboration of the USGS and College of Charleston (Amatya and Radecki-Pawlik, 2007). Thus the difference in the temporal resolution of the collected data between stream flow and rainfall could present some interpretation problems in rainfall-runoff analysis.

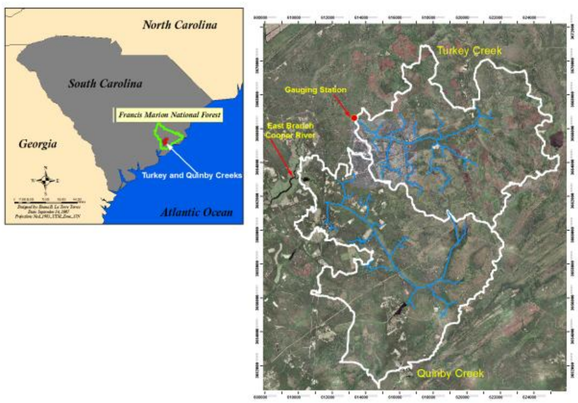

Figure 1. Location of the Turkey Creek and Quinby Creek watersheds within the Francis Marion National Forest, South Carolina.

METHODS

Rainfall and stream flow data from 1964 to 1973 were processed and analyzed to study seasonal event outflows (stream flow) and the relationship of outflow and antecedent soil moisture condition. Event duration, peak flow rate, time to peak, storm volume and runoff-rainfall ratios were calculated using stream flow and rainfall data. We considered storm events with outflows greater than 0.30m^3/sec, total rainfall values greater than 20 mm and periods of less than 48 hours between rain events. Multiple peak events were excluded from this analysis. Seasons were grouped as wet (winter-spring: December-May) and dry (summer-fall: June-November). Antecedent soil moisture conditions were also categorized as wet or dry based on previous rainfall amount, defined as the presence or absence of rainfall five days prior to the runoff event. Additionally, antecedent soil moisture conditions were inspected for thirty days prior to explain exceptions to the initial hypothesis that runoff: rainfall ratios are higher for wet soil conditions compared to dry (based on the antecedent five-days method).

A total of thirty-two storm events were evaluated. Total event flow volumes were estimated based on the approximate beginning and ending of the runoff and runoff-rainfall ratios were calculated. A linear regression analysis was used to determine the relationships between rainfall and runoff with respect to season and antecedent soil moisture conditions.

RESULTS AND DISCUSSION

Rainfall: Runoff Relationships

A significant (p=0.00) relationship between runoff and rainfall was observed for the wet period (season), whereas no relationship (p=0.05) was observed during the dry period (Fig. 2). Greater variability in runoff: rainfall ratios was observed for the dry period with coefficient of variation (COV) equal to 0.9, whereas the variability was less for the wet period (COV=0.3). The greater variability observed within the dry period influenced the results of the linear regression analysis.

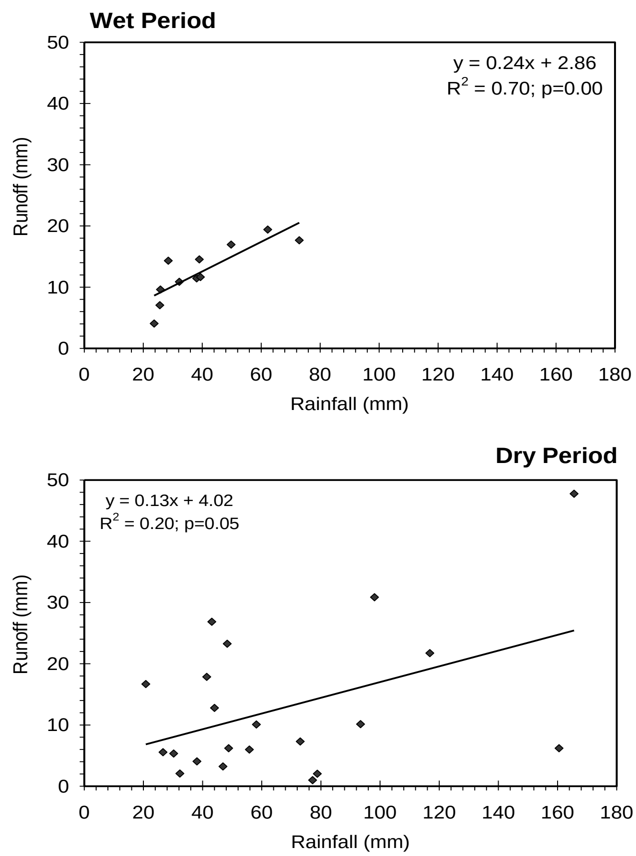

Figure 2: Event runoff and rainfall relationship for the wet (winter-spring; *n*=11) and dry (summer-fall; *n*=21) periods.

Similar results were observed for runoff and rainfall relationships for wet and dry antecedent conditions (Fig. 3). A significant (p=0.01) relationship was observed for wet conditions, while the relationship for dry conditions between runoff and rainfall was not significant (p=0.43).

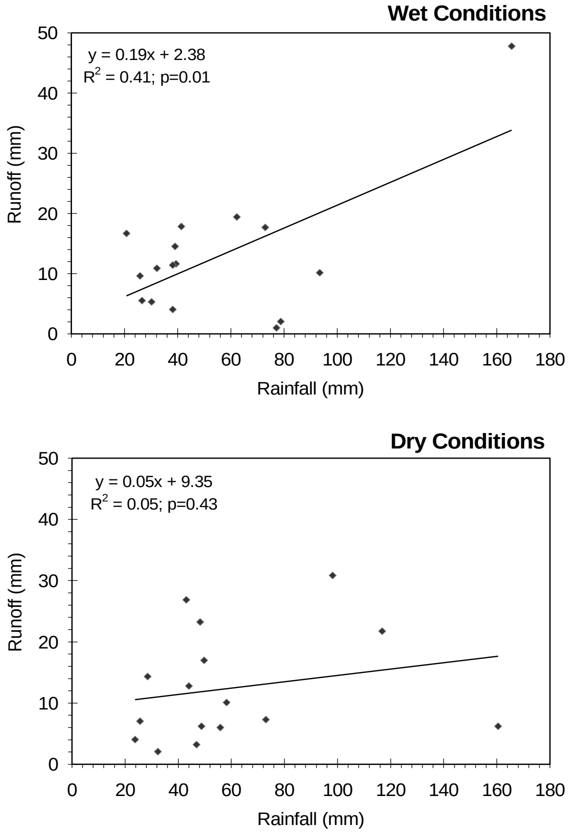

Figure 3. Runoff and rainfall relationships for events during wet (*n*=16) and dry (*n*=16) antecedent soil moisture conditions based on 5-day prior rainfall.

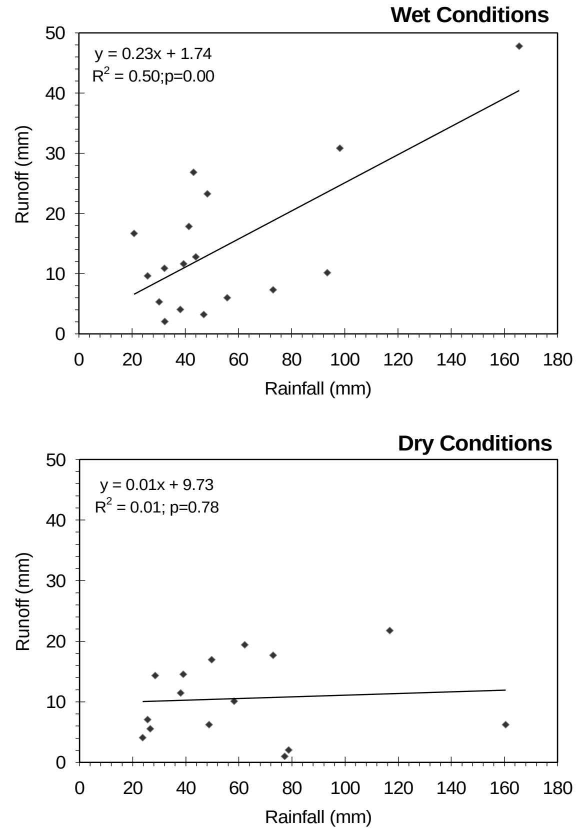

Figure 4. Runoff and rainfall relationships for events during wet (*n*=17) and dry (*n*=15) antecedent conditions based on 30-day prior rainfall.

Based on thirty-day prior rainfall (Fig. 4), a better relationship was observed between runoff and rainfall for wet (p=0.00) conditions, but during dry conditions rainfall and runoff were again poorly correlated (p=0.78). These results suggest that seasonal runoff: rainfall (R/R) dynamics in lowland watersheds are hard to predict due to interactions among other physical variables not considered in this study, such as rainfall intensity and spatial distribution, soil type, and depth to water table (i.e., soil storage volume). Therefore, it is necessary to address these factors when assessing the dynamics of rainfall and runoff in the LCP.

Variations in runoff responses were observed for wet and dry conditions in both cases. Specifically, seven storm events were selected and are presented in Table 1. Information of initial soil conditions using beginning event flow rates, runoff, and rainfall based on five and 30 day-prior the event were used to understand the hydrology dynamics of the Turkey Creek watershed. The differences observed in runoff response to similar rain amounts may be related to differences observed in initial conditions (begin flow), temporal distribution of rainfall amounts and duration of the event.

Interpreting individual storm events. Several storm events were inspected to test our hypotheses on the roles of rainfall amount, antecedent soil moisture (as inferred from rainfall amount to runoff-generating event), and season on R/R ratio (Table 1). For example, on day 224.5 (1964) a rainfall amount of 32.3 mm only produced a runoff response of 2.1 mm (runoff: rainfall = 0.06), whereas for day 230.6 (1964) a rain event of 20.8 mm produced a 16.7 mm runoff response (runoff: rainfall = 0.80). The second event occurred directly following the return to baseflow condition and had a significantly higher peak flow value, most likely due to a larger antecedent soil moisture condition. For the event on day 224.5, no rain was observed in the five days prior, yet nearly twice as much rain occurred in the 30 days before the event. It is likely the high evaporative and transpirative demand during the summer removed this moisture and circumvented runoff to the stream. Compare this with the event on day 230.6 where 2.6 mm of rain occurred in the five days prior. Apparently the near-term soil moisture condition plays a larger role in determining the runoff response during the summer season rather than a longer-term condition (thirty day

Table 1. Basic Hydrologic Data of Seven Main Outlier Events.

Season	Day of yr	Rain (mm)	Runoff Duration (Days)	Begin Flow (m^3/sec)	Peak Rate (m^3/sec)	Runoff (mm)	R/R Ratio	Rain Prev. 5 Day	Rain Prev. 30 Day
Summer '64	224.5	32.3	6.1	0.12	0.56	2.1	0.06	0.0	421.7
Summer '64	230.6	20.8	10.7	0.14	4.46	16.7	0.80	2.6	238.9
Winter '64	339.2	48.8	9.4	0.06	0.63	6.2	0.13	0.0	21.3
Summer '67	223.6	46.9	9.0	0.01	1.15	3.2	0.07	0.0	147.0
Fall '68	292.1	160.5	14.2	0.03	1.87	6.2	0.04	0.0	33.3
Summer '69	195.5	77.2	11.9	0.01	1.14	1.0	0.01	15.2	89.3
Fall '72	335.0	78.8	6.1	0.07	0.73	2.0	0.03	49.5	86.5

prior rainfall). Additionally, this event with saturated soil lasted longer (10.7 days) than the event at day 224.5 (6.1 days), which influenced the runoff volumes of these events.

Secondly, we infer that different antecedent soil moisture conditions affected runoff. Comparing two storm events of similar amount, a summer event on day 223.6 (1967) showed a runoff response of 3.2 mm for a rain amount of 46.9 mm. Conversely, for a winter event on day 339.2 (1964), a runoff response of 6.2 mm followed 48.8 mm of rain. Neither of the events was preceded by any rain five days prior. However, although the summer event experienced substantially more rain (147 mm) within thirty days prior to the runoff-generating event, this does not seem to have had any effect on runoff volumes as most of it would have been lost to evapotranspiration (ET). The initial conditions are slightly wetter for the winter event which may influence the response in runoff for this particular case; nonetheless, it is important to understand that the runoff response for the winter event may be influenced by the reduction in ET rates during this season. This information needs to be corroborated by other studies that could integrate this variable when analyzing the runoff-rainfall dynamics in the LCP.

As hypothesized, higher runoff: rainfall ratios were observed for the wet period (Fig.5). These results suggest that runoff response is related to seasonal weather variations typical of lowland watersheds of the Coastal Plain, in addition to the antecedent soil moisture conditions. Such findings are supported by Miwa et al. (2003); Amatya et al. (2006); and also by Harder et al. (2007), who concluded that daily outflows for a first-order watershed in the Lower Coastal Plain were sensitive to rainfall event size, storm frequency, and antecedent soil moisture (assessed from water table position). Possibly due to the lower-intensity storm conditions that are typical for winter and spring in the Lower Coastal Plain of the Southeast U.S., we assume storm events during these seasons did not produce substantial runoff unless the water table was close to or at ground level. However, due to the lack of rainfall intensity data, this aspect cannot be verified in this study. Finally, it is important to consider that while the interpretations of this data set can be applied to other watersheds, runoff dynamics in the Coastal Plain will differ in each watershed, given the differences in land use/land cover and soil composition, area and topographic gradient. However, this study provided an inspection of the range of possibilities in a typical lowland watershed of the Coastal Plain of the Southeast U.S.

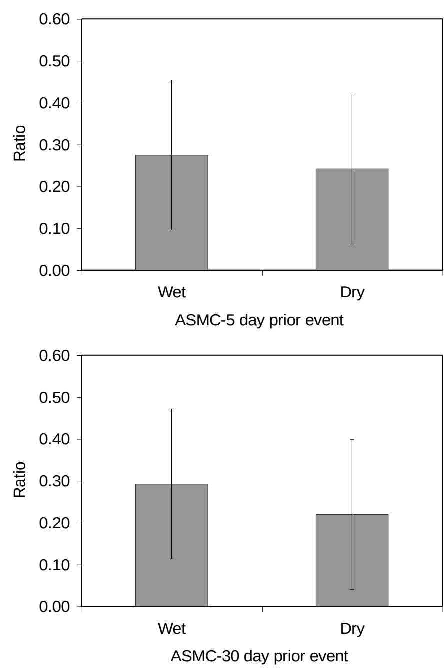

Figure 5. Runoff-rainfall ratios observed for wet and dry periods, wet and dry antecedent conditions (5-day prior rainfall) and wet and dry antecedent conditions (30-day prior rainfall, SD±0.18, respectively).

SUMMARY AND CONCLUSIONS

Results from the linear regression analysis showed that seasonal rainfall: runoff dynamics for the Turkey Creek watershed are not linear. Higher runoff-rainfall ratios were generally associated with the wet period (winter-spring) and wet antecedent soil moisture conditions (as measured from 5 and 30-day prior rainfall). Runoff: rainfall ratios may vary over time within and for the same time among watersheds in the LCP due to the differences in topographic gradients, soil characteristics, vegetation type, watershed area and climate variation.

Further investigation is needed to develop multivariate or non-linear models that account for the interactions observed among these physical variables. Successful development of a model will provide the necessary information to make runoff predictions for similar un-gauged watersheds. Additionally, studies should focus on groundwater dynamics as affected by the soils and storm types to better understand and manage the LCP runoff component.

Results generated by this study to date need to be considered carefully when land management practices are developed for watersheds in the LCP, such as the Turkey Creek. The hydrologic dynamics observed in the Turkey Creek watershed are complex and influenced by different components that together ameliorate the impact of storm events on downstream systems. Changes in the land use/land cover may significantly increase runoff response due to decreased ET as a result of removal of vegetation cover, and soil layers that are disturbed, but also by including impervious surfaces (urbanized areas). In addition to the increased runoff received by downstream systems , increased pollutants would also be expected. The intensity of these effects will be determined by the main land use and management of these areas; if the main type of use is urbanized areas then the amount of runoff will be higher than if it were agriculture uses. Therefore, scientists and land managers need to be aware of the different scale of impacts that different land uses will result in these areas.

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