Long-Term Forest Hydrologic Monitoring in Coastal Carolinas

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Abstract

Long-term hydrologic data are essential for understanding the hydrologic processes, as base line data for assessment of impacts and conservation of regional ecosystems, and for developing and testing eco-hydrological models. This study presents 6-year (1996-2001) of rainfall, water table and outflow data from a USDA Forest Service coastal experimental watershed on a natural pine-hardwood forest in South Carolina (SC) and a small, 29-yr old intensively managed, drained pine forest owned by Weyerhaeuser Company in coastal North Carolina (NC). Results from this study showed a wide variation in annual outflows as affected by water table position, which is dependent upon both rainfall and evapotranspiration (ET). Although average annual rainfall was lower, the undrained watershed in SC had much shallower water table depths with higher frequent outflows compared to the drained NC watershed. The study emphasized the need for long-term rainfall and ET data and soil water properties in comparative assessments of the hydrology of poorly drained coastal watersheds.

Keywords: rainfall, outflow, water table, drained pine plantation, naturally drained forest

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Introduction

Scientists and researchers have long recognized the need for long-term hydrologic monitoring of various watersheds to understand the basic hydrologic processes that occur as a result of both natural events and anthropogenic disturbances. Long-term monitoring provides us with a database for evaluating responses and generating new scientific hypotheses, and wider range of observational data for testing of hydrologic and water quality models. Yapo et al. (1996) concluded that nearly eight years of data are required to obtain model calibrations that are relatively insensitive to the period selected, because of year-to-year variation in weather that may be sometimes either extremely wet or dry. This may also be true for understanding the water table (hydroperiod) dynamics, hydrologic and nutrient cycling processes, water and nutrient budgets as well as their interactions with the ecosystem.

Forests are an important part of the ecosystem and play a great role in regulating the regional hydrologic patterns of the southern US where 55% of the region is covered by forests (Sun et al. 2002). Long-term hydrologic data from small, paired, experimental forested watersheds at Coweeta Hydrologic Laboratory in North Carolina (NC) integrated with an ecosystem approach have provided basic understanding of eco-hydrological processes for regional upland watersheds (Swank et al. 2001). Tajchman et al. (1997) reported the water and energy balance of a 39 ha central Appalachian watershed covered with 80-yr old upland oaks and cove hardwoods using 40 years of hydrologic data. However, there are only a few such observational studies done for the forest ecosystems that occur along the lowlands of southeastern coastal plains. Unlike the upland watersheds dominated by hillslope processes, hydrologic processes on relatively low gradient poorly drained coastal plains are usually dominated by shallow water table positions. Most of the outflows (surface runoff and subsurface drainage) from these watersheds, in fact, drain from saturated areas where the water is either at the surface or a shallow water table is present. This means the total outflow is dependent upon the position of the water table. Water budgets as well as water table management and water quality studies for drained pine plantations in coastal NC were presented by McCarthy et al. (1991) and Amatya et al. (1996, 1998). Most of these studies were limited to artificially drained lands. Recently Chescheir et al. (2003) documented the baseline forest outflow characteristics of 41 forested watersheds from coastal NC. These watersheds varying in sizes from 7 ha to 6,070 ha were on natural and managed pine forests and included data spanning 25 years (1976-2000).

Millions of hectares under silvicultural management in the lower coastal plain along the southeast and Gulf Coast region (Figure 1), however, consists of natural lands with non-pattern drainage systems. The types of forests managed on these lands vary widely from loblolly pine to bottomland hardwoods to pine flatwoods to even short rotation woody crops. More than one million acres in the coastal area are classified as pine flatwoods alone (Sun et al., 1998). Bottomland hardwood forests occupy nearly 300 million acres in the southeast. With the growing demand on timber and increased coastal urbanization in the southeast and Gulf Coast, there is an increased potential for developments of these forested lands as well. Therefore, researchers and land managers are not only challenged to understand the hydrologic processes for these coastal forest systems but also to address the issues related with the climatic and management impacts on water quantity and quality.

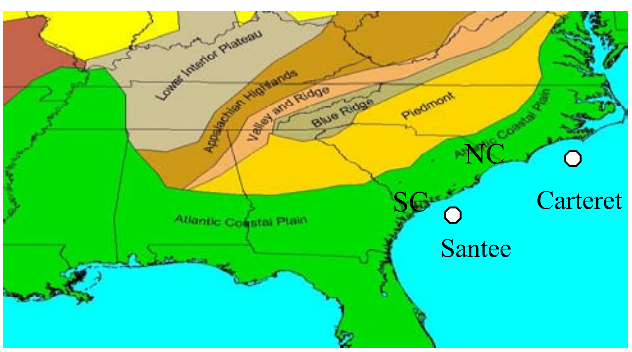

Figure 1. Location of Santee (WS 80) watershed in SC and Carteret (D1) watershed in NC.

A preliminary comparison of long-term water budgets for two paired coastal watersheds in headwater streams in South Carolina (SC) was recently conducted by Sun et al. (2000). Miwa et al. (2003) characterized stream flow dynamics and its relation to rainfall for the same two watersheds. A comparative study on long-term hydrologic characteristics (seasonal runoff patterns, water balances, stormflow patterns) of three watersheds in the southern US were presented by Sun et al. (2002). These watersheds included pine flatwoods of Florida, drained pine plantation site in coastal NC, and a hilly upland watershed at Coweeta in western NC. The study concluded that climate is the most important factor in the watershed water balances, and topography affecting streamflow patterns, is the key to wetland development in the southern US. Some long-term studies on pine flatwoods in Florida were conducted by Riekerk (1989). Most of the other long-term studies in the coastal plains were based on simulation models (Skaggs et al.1991, McCarthy et al. 1992, Amatya and Skaggs 2001, and Sun et al. 1998, 2000).

Recent report by Southern Forest Resource Assessment (Wear and Greis 2002) emphasized a need of research to assess the long-term cumulative non-point source impacts of silvicultural activities on water quality and overall watershed health. In order to evaluate the effects of these activities and develop database for reference wetlands on these various forest ecosystems, it is essential to understand the hydrologic processes and quantify the long-term hydroperiod dynamics and water and nutrient budgets. The objective of this study is to analyze the six-year (1996-2001) hydroperiod and outflow processes for two different watersheds in Coastal Carolinas (Figure 1) as affected by site specific climate regime and management practices. One of the watersheds is naturally drained and is on USDA Forest Service's Santee Experimental Forest in South Carolina established in 1937 for the long-term scientific study of the coastal forest ecosystems and their management. The other watershed, instrumented in 1987, is an artificially drained loblolly pine forest, owned and managed by Weyerhaeuser Company in coastal North Carolina. The site is being used to conduct long-term field studies to examine the impacts of different water management and silvicultural treatments on the hydrology and water quality during the life cycle of the intensively managed pine forest (Figure 1).

Methods

Site description

Santee watershed (WS 80)

This naturally drained watershed is located in the Santee experimental forest, which is part of Francis-Marion National Forest (USDA Forest Service) near Charleston, South Carolina (Figure 1). This is one of the paired

Table 1. Comparison of watershed characteristics for Santee, SC and Carteret, NC sites.

Parameter	Santee watershed (WS 80)	Carteret watershed (D1)
Location	Latitude 33°N, longitude 80°W	Latitude 34°N, longitude 76°W
Elevation above Mean sea level	7.0 m	3 m
Watershed size	206 ha	25 ha (ditched)
Long-term annual precipitation	1350 mm	1340 mm
Long-term mean annual air temperature	18.7°C	16.2°C
Topography/slope	<4%	<0.2%
Drainage type	Natural, first order stream	Artificially drained, pattern drainage

Note: Long-term climate data for Santee watershed taken from Charleston International Airport (1971-2000) and long-term data for Carteret taken from Morehead City (1971-2000).

watersheds (with WS77) on headwater stream draining to Turkey Creek on the lower Atlantic Coastal Plain. It is on a marine terrace of the Pleistocene epoch (Gartner and Burke, 2001). The area has low relief with surface elevations ranging from 4.0 to 10.0 m above mean sea level (Table 1).

Loblolly pine, longleaf pine, cypress, and sweet gum are dominant forest species in the watershed (Sun et al. 2000). Soils are primarily (loams) strongly acid, infertile Aquults, characterized by seasonally high water tables and argillic horizons at 1.5 meters depth with low base saturation (Gartner and Burke 2001). The climate of the research area is classified as humid subtropical with long hot summers and short mild winters (Sun et al. 2000). Mean annual precipitation is about 1350 mm with the highest rainfall in July-August and the lowest rainfall in the November-April period as the driest months. Meteorological data (daily maximum and minimum air temperatures and precipitation) have been collected since 1976 at Met-25 station inside the watershed and since 1946 at a weather station located at Santee Headquarters, which is about 10 km from the watershed (Sun et al. 2000). A stream gauging station consisting of a compound V-notch and a flat concrete weir with a recording gage inside a stilling well was installed at the watershed outlet in 1968. However, flow measurements were interrupted in 1981 and did not start again until after Hurricane Hugo in September 1989. Automatic ISCO-4210 flow data loggers were installed only in 1996. Since flow data were missing for intermittent periods, annual flow data reported herein were complete only for the years 1997 and 1998. Water table measurements were measured using manual wells at several locations in the watershed until 1995 and one automatic recording well (WL-40) was installed in late 1995.

Long-term data for daily precipitation, air temperature, and stream flow from this study site is recently being made available through HYDRO-DB, a WEB based data sharing and harvesting site hosted by Oregon State University and sponsored by USDA Forest Service and National Science Foundation's Long term Ecological Research (LTER) study. The site is located at www.fsl.orst.edu/climhy/hydrodb/ and data from various participating sites are posted here for inter-site comparisons and other useful hydro-ecological assessments including forest fire.

Carteret watershed (D1)

Field measurements on the Carteret 7 research site, located in Carteret County, North Carolina, have been conducted since early 1988 (Figure 1). The research site consists of three artificially drained experimental watersheds on flat, poorly drained soils with shallow water tables. The depth to the restricting layer is about three meters. The soil is a hydric series, Deloss fine sandy loam (fine-loamy mixed, Thermic Typic Umbraquult). Results analyzed in this paper were obtained from the control watershed (D1), which was managed in conventional drainage mode throughout the study period. The watershed is drained by four 1.4 to 1.8 m deep lateral ditches spaced 100 m apart.

Total rainfall was collected with an automatic tipping bucket rain gauge backed up by a manual gauge in an open area on the western side of the watershed. Air temperature, relative humidity, wind speed and net radiation were collected on an hourly basis at an automatic weather station located near the study site.

An adjustable height 120° V-notched weir, located at the outlet of the watershed, allowed measurement of drainage outflow by continuously recording water levels upstream of the weir kept at 1 m below average ground surface for free drainage.

Data on soil, hydrology and vegetation parameters were collected on three rectangular plots within the watershed. Water table elevations were measured by continuous recording wells in two plots midway between the field ditches. Daily water table elevation for the watershed was calculated as average of the midpoint wells. Details of hydrologic measurements and their procedures are documented elsewhere (McCarthy et al. 1991, Amatya et al. 1996).

Average annual rainfall as well as its variability for the six-year period was higher at NC Carteret site (1450 mm) compared to SC Santee site (1330 mm), although the long-term (1971-00) average was nearly the same for both sites (Table 1). This greater variability in NC site was primarily due to frequent summer-fall hurricanes and tropical storms that hit NC in 1996, 1998, 1999, and 2000. This is evident from the average monthly rainfall compared for the two study sites in Figure 2. Average monthly rainfall for both sites was comparable, except for the months of July to September. Year 2001 was the driest year with only 852 mm at Carteret site and 1106 mm at Santee, respectively (Table 2). The higher average annual temperature at Santee site (18.8°C) compared to Carteret (16.4°C) indicates a higher potential ET at the former site. The highest difference was in 2001.

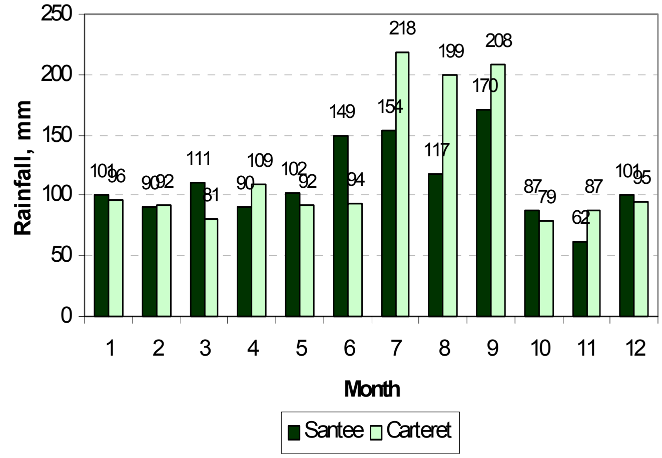

Figure 2. Comparison of average monthly rainfall at Santee (WS 80) and Carteret (D1) watersheds.

Results and Discussions

Annual temperature, rainfall, water table depths, outflow, and outflow as percentage of rainfall two measured at Santee (WS 80) and Carteret (D1) watersheds for 1996-2001 are presented in Table 2.

Table 2. Measured annual average temperature, total rainfall, average water table depths, and total outflow on Santee (WS 80), SC and Carteret (D1), NC watersheds for 1996-2001period.

	Santee watershed (WS 80)					Carteret watershed (D1)				
Year	Mean temp. ˚C	Total rain mm	Water table cm	Total outflow mm	Outflow as % of Rain	Mean temp. ˚C	Total rain mm	Water table cm	Total outflow mm	Outflow as % of Rain
1996	17.6	1303	N/A	372	29	15.8	1706	94	704	41
1997	18.7	1498	24	652	44	16.1	1408	107	397	28
1998	20.0	1463	35	858	59	17.7	1655	100	770	47
1999	18.5	1446	28	388 (i)	-	16.7	1362	88	614	45
2000	18.0	1167	30	280 (i)	-	15.6	1718	81	857	50
2001	19.8	1106	43	0 (i)	-	16.3	852	153	45	5

Santee watershed: Missing rainfall data were taken from Charleston International Airport. Total outflow was incomplete for full years of 1999 to 2001 and indicated as (i) beside total for available days. Outflow percent was not calculated for these years. Carteret watershed: Missing rainfall came from the gauges on adjacent watersheds and/or weather station.

Since water table position, as affected by rainfall and ET, is a dominating factor in generating outflow from these watersheds, measured water table depths for the Santee (WS 80) and Carteret (D1) watersheds were analyzed for the 1997 to 2001 period (Figure 3). One reason for the big difference in water table depths between the two watersheds during the summer was due to well depths, which was shallow (only 52 cm) for Santee watershed and 240 cm for the Carteret site. The water table remained within about 40 cm of the surface for most of the time during the winter and spring for the undrained Santee watershed, compared to drained Carteret site, which had deeper (~ 100 cm) depths for the same period. Average water table depth during this period at Santee watershed thus seemed to be shallower than about 47 cm reported for the 1992-95 study period (Sun et al. 2000). As a result of large event due to Hurricane Bonnie in late August of 1998, water table rose as high as 30 cm for a brief period at Carteret site in NC. Water table continued to decline below 150 cm from about May to the end of the year 2001 at Carteret site and, perhaps, at Santee watershed also, indicating a very dry period. The 5-year average water table depth at undrained Santee watershed was only 32 cm (probably, underestimated due to shallow well depth) compared to 106 cm at drained Carteret site, as expected (Table 2). A shallower depth to impermeable layer at Santee site may also explain this difference.

Earlier studies on Carteret site with the drained pine plantation (D1) had shown outflow occurring mostly as subsurface drainage when midpoint water table was within about 75 cm depth (Amatya and Skaggs 2001). Because of the depressional storage created by the plantation beds, surface runoff rarely occurs, except for the extreme events during the hurricanes such as Bonnie in August 1998 (Figure 3). For example, two years (1997-98) of daily flow data from both the watersheds were plotted together in Figure 4 to compare the flow regimes as affected by the water table depths. Outflows from naturally drained Santee (WS 80) watershed had very frequent and large storm outflows in both years compared to drained pine forest at Carteret site in NC. This coincides with much shallower near surface water table observed for a longer period on Santee WS 80 compared to Carteret site. Thus, the naturally drained Santee watershed yielded 46% and 59% of rainfall as outflow for the years 1997 and 1998, respectively (Table 2). Using five-years (1976-80; 1990-91) of data, Sun et al. (2000) found only 23% of the annual rainfall lost to outflow for the WS 80 watershed, with an average water table depth of 47 cm, which was deeper than those observed during this study period. These outflow values are also much higher than those observed for drained Carteret site (Table 2) for the same years. The six-year average annual outflow for

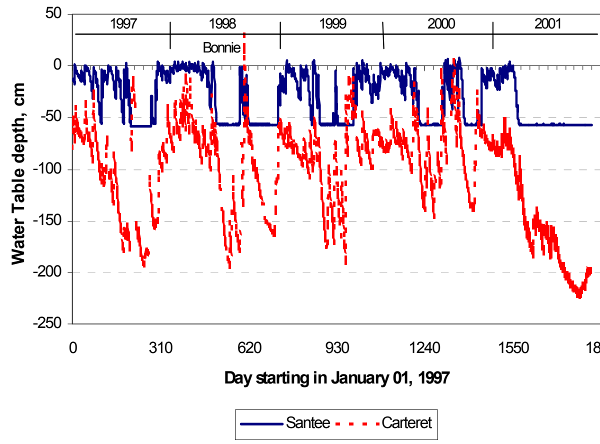

Figure 3. Measured water table depths for Santee (WS 80) and Carteret (D1) watersheds for 1997-01.

Carteret site was also higher than the 10-year data (Amatya and Skaggs, 2001), due to higher than long-term rainfall. The measured flows on Santee site, especially in wet winter (*La Niña*) of 1998 (Figure 4), may have been overestimated due to additional surface runoff from adjacent areas when the watershed was flooded. However, the event of Hurricane Bonnie in August 1998 had only a minimal effect on outflows from Santee compared to the Carteret site that resulted in a large storm outflow with a peak outflow of about 35 mm/day (Figure 4) due to 30 cm rise in water table (Figure 3). Flow ceased on both watersheds after this event.

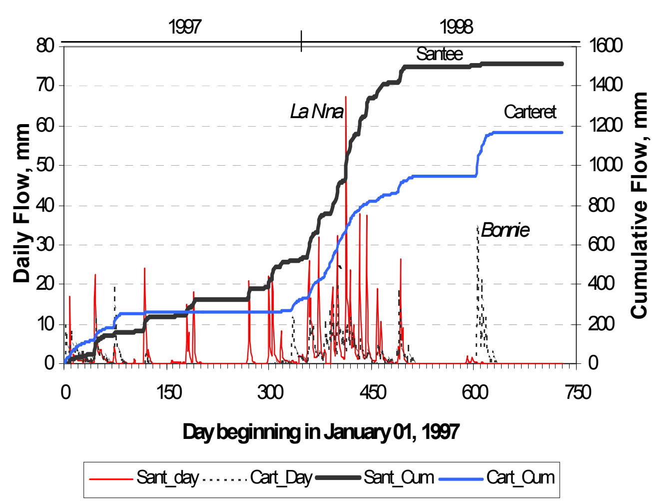

Figure 4. Daily and cumulative outflows at Santee and Carteret watersheds for the 1997-98 period.

Summary

A limited six years of rainfall, water table and outflow data from two long-term monitoring sites on coastal watersheds, a headwater stream draining a natural forest in SC and a drained pine forest in NC, showed a wide variation in annual rainfall pattern, especially in NC. As a result, watershed response, which depended upon the water table position, was found to be different from earlier studies on both of these sites. The drained NC site had deeper water tables than the undrained forest at the SC site. As a result of shallow near surface water tables, SC site yielded much higher outflows than the drained NC site for two years of data analyzed. Deeper water tables due to antecedent conditions resulted in low or near zero flows at both sites. Further study is needed to analyze the data in the context of rainfall, ET and soil conditions. This and past studies indicate that a long-term data monitoring is necessary for reliable comparative hydrologic assessments.

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