Hydrologic and Water Quality Monitoring on Turkey Creek Watershed, Francis Marion National Forest, SC

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REFERENCE: *Proceedings of the 2008 South Carolina Water Resources Conference*, held October 14-15, 2008 at the Charleston Area Event Center

Abstract. The re-initiation of a 7,260 ha forested watershed study on Turkey Creek, a 3rd order stream, within the Francis Marion National forest in South Carolina, completes the development of a multi-scale hydrology and ecosystem monitoring framework in the Atlantic Coastal Plain. Hydrology and water quality monitoring began on the Santee Experimental Forest in the 1960's, and represent an important long-term hydrological database for natural forested watersheds in the coastal plain. Understanding the functional linkages between terrestrial and marine environments is fundamental to sustainable management of coastal plain forests and to accommodate the rapidly expanding wildland-urban interface. The Turkey Creek Watershed Monitoring is a multi-collaborator effort, with a real time flow gauging station established in collaboration with the US Geological Survey to build upon the historical data (1964-1984), ground water wells that assess the surface-subsurface flow interactions by College of Charleston and Francis Marion National Forest, and weather station and stream water quality sampling stations by the Forest Service. The objective of the collaborative effort is to address the critical issues of sustainable water management for low-gradient forested wetland landscapes. Accordingly, a series of studies have been conducted in last few years to understand the hydrology, water quality, and ecosystem dynamics of this watershed. This paper attempts to summarize results of those studies that might help management decisions and monitoring assessments on coastal forest lands. They should also serve as reference eco-hydrologic units for comparison with more intensively managed forests, and developed lands in the coastal plain. The data may serve as background data for assessing allowable pollutant loading for receiving waters from similar coastal forested watersheds.

INTRODUCTION

The purpose of this paper is to synthesize data obtained from multi-collaborative studies being conducted on a low-gradient forested watershed within the Francis Marion National Forest (FMNF) in coastal South Carolina. Urban interface and population growth create increasing demands on the coastal resources. Hurricanes, flooding and wildfire are natural disturbances. Past land management has included forestry, rice culture, farming, hydrologic modification and road networks to support these activities. Hydrologic information is a crucial element for land managers, planners, and decision makers to consider to protect human health and ensure proper resource management. Data from the long-term studies in this watershed will improve understanding of the effects of disturbance phenomena on surface and subsurface hydrology of coastal areas. Information will be gathered on precipitation and weather patterns, stream flow dynamics including peak flow behavior following storms, flooding and pollutant transport; weather patterns for understanding storms and droughts; evapotranspiration (ET) and ground water table response. This information will be useful to identify and describe wetland hydrology, ponding/flooding dynamics and ground water influences and storages. Characteristics of water quality will be addressed as affected by disturbance, season, and climate. More importantly, information from this low intensity managed forest eco-system provides baseline or reference information for coastal forested watersheds that can be used to compare with more intensively managed forests. This information will also be helpful when quantifying water balance components and in developing best management practices (BMPs). The information will benefit developers, land managers, decision makers, regulators, and researchers involved in development of low-gradient forests.

BACKGROUND

Understanding the hydrology of watersheds along the coastal plain is becoming critical to address both the water quantity and quality impacts of anthropogenic factors and natural disturbances near the coastal waters and as hydrology is the primary driving force in flooding, nutrient cycling and loading dynamics. At the watershed scale, the hydrology can be quite complex due to the heterogeneity of land use, soil, climate conditions, vegetation, and geology (Fernandez et al., 2007). Land cover, particularly forest cover plays an important role in

regulating regional hydrologic patterns through water uptake and ET; however forested watershed dynamics in coastal plain differs considerable from upland environments due to low-gradient topography, climate, and soil composition, and is generally dependent upon the position of the water table (and hence the storage capacity of the soil).

Watershed-scale hydrologic models that simultaneously analyze topographic, soil, vegetation, land use, and vegetation spatial data together with climatic data over space and time are becoming valuable tools for making decisions on alternative BMP scenarios to mitigate the negative impact of anthropogenic activities on water quantity and quality (Bosch et al., 2004). Most models available are either for uplands (Arnold et al., 1998; Young et al., 1989) or for artificially drained low gradient systems (Amatya et al., 2004; Fernandez et al., 2007). Furthermore, only a few of these agricultural-based models, originally developed for agricultural systems, have been tested on forest ecosystems. Field measurements, testing, calibration and validation of these models are required before their operational application. Another goal of this program is to build strong partnership and collaborative effort for sustained comprehensive monitoring. This paper summarizes results from the collaborative monitoring studies being conducted on a 7,260 ha Turkey Creek watershed at FMNF in coastal South Carolina (Fig. 1).

METHODS

Site Description

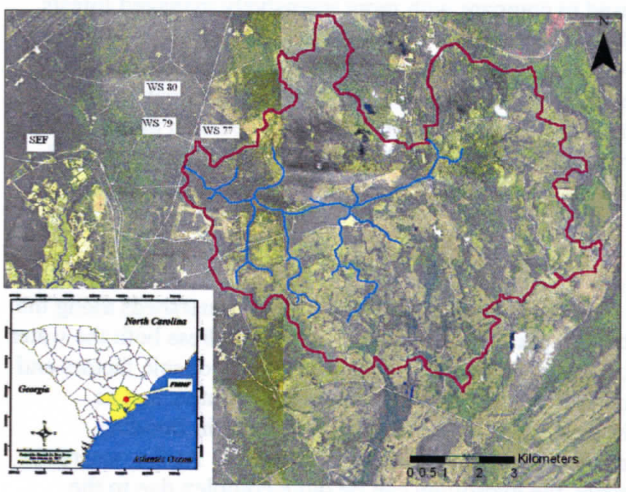

Figure 1. Location map and layout of Turkey Creek watershed at Francis Marion National Forest, SC.

The Turkey Creek, a third-order stream that drains approximately 7,260 ha is located at 33° 08' N latitude and 79° 47' W longitude approximately 60 km north-west of City of Charleston near Huger, South Carolina (Fig. 1). It is located within the East Branch of the Cooper River, which drains to the Charleston Harbor System, 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 stream gauging station to 14 m above mean sea level (a.m.s.l.). The sub-tropical climate is characteristic of the coastal plain having hot and humid summers and moderate winter seasons. The long-term (1951-2000) minimum and maximum daily temperatures recorded at the nearby Santee Experimental Forest were –8.5°C and 37.7°C, respectively, with an average daily temperature of 18.4°C.

Land use within the watershed is comprised of 57.7% (4,191 ha) loblolly (*Pinus taeda* L.) and long leaf pine (*Pinus palustris*) forest, 39.7% (2,884 ha) forested wetland and hardwood, and 2.6% (189 ha) in crop lands, roads and open areas (Haley, 2007). The watershed was heavily impacted by Hurricane Hugo in September 1989, and the forest canopy was almost completely destroyed (Hook et al., 1991). Most of the current forests on the watershed are a mixture of remnant large trees and natural regeneration. The watershed is dominated by poorly drained soils of Wahee (clayey, mixed, thermic *Aeric Ochraquults*) 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. Current management practices on the majority of the watershed include forestry, biomass and thinning removal for reducing fire hazards and improving forest health. Prescribed fire and thinning for restoration of fire dependant species common to native longleaf pine and savannah habitat such as the 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.

Rainfall

Rainfall and air temperature have been continuously measured since 1946 using a manual gauge and standard thermometer, respectively, at the weather station located at the Santee Experimental Forest Headquarters (Fig. 1). This was upgraded with an automatic instrumentation (Campbell Scientific CR-10X station) in 1996. Since 1964 a network of manual gauges across the watershed records rainfall on a weekly basis. At present there are

two tipping bucket rain gauges: one in the middle and one at the outlet of the watershed. There are three more automatic gauges adjacent to the watershed. Annual rainfall at the site has varied from 830 mm to 1940 mm, with an average of 1370 mm for the 1951-2000 period. 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.

Stream Flows

The original flow gauging station on Turkey Creek was 800m downstream of the existing site with measured stages of the stream from 1964 to 1984. Calculated stream flow data obtained from these historic records were digitized by Tetra-Tech, Inc., a project cooperator.

The current eco-hydrological monitoring and modeling program on Turkey Creek watershed (Amatya and Trettin, 2007a) was reactivated by the Forest Service, Southern Research Station, Center for Forested Wetlands Research (www.srs.fs.usda.gov/charleston/) by installing a real-time stream flow and rainfall gauging station on Highway 41N approximately 800 m upstream of the (waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) previous gauging station in cooperation with the US Geological Survey (USGS) College of Charleston (www.cofc.edu) and the. Flow rates were calculated using a stage-discharge relationship developed by the USGS.

Weather parameters

Historically only rain and temperature were available from the nearby Santee Experimental Forest (SEF) Headquarters station. Campbell Scientific CR10X weather stations were installed at the SEF site in 1996 and in the middle of the Turkey Creek watershed in 2005 to provide necessary meteorological data such as air temperature, soil temperature, relative humidity, wind speed and direction, and solar and net radiation needed for water balance and hydrological modeling studies (Amatya and Trettin 2007b; Amatya et al., 2008; Haley, 2007).

Water Table Depths

There are no historic ground water table data at the site. Four shallow ground water table monitoring wells provided by the Francis Marion National Forest were installed in four different soil types (Rains, Goldsboro, Lynchburg, and Lenoir series) in 2006 to measure water table up to 2.5 m depth. A cluster of deep wells (piezometers) measuring the water table depth up to 25 m was installed by College of Charleston in 2005.

Water Quality

Little water quality data were available for the Turkey Creek watershed, except some water samples were collected in 2001 from a section of the stream about one km upstream of the current gauging station on Turkey Creek as one of the three locations in Francis Marion National Forest used to examine several water quality parameters, including fecal coliform, methyl mercury, dissolved oxygen (DO), conductivity, total dissolved solids, and salinity (Plewa and Hansen, 2003).

A more complete characterization of water quality was initiated at the new gauging station in October, 2005. In June 2006 the sampling protocol was augmented with the addition flow proportional sampling of storm events using an ISCO-4200 automatic sampler. Both the grab and automatic samples are being analyzed for nutrients (NO_3-N, NH_4-N, Total N, and PO_4) and some other cations (Ca^+, K^+, Na^+,) and Cl^-. Furthermore, bi-weekly in-situ measurements of physical parameters such as (pH, dissolved oxygen (DO), temperature, and conductivity) are also being conducted using a Eureca in-situ meter.

RESULTS

Amatya and Trettin (2007c) presented a history of development of watershed research on Turkey Creek watershed until its revitalization plan in 2004 (Amatya and Trettin, 2007a) with the goal, objectives, and plans for a multi-cooperative monitoring effort on the watershed with current and future studies outlined.

Using 13 years (1964-76) of historic data, Amatya and Radecki-Pawlik (2007) conducted a study to compare the stream flow dynamics of Turkey Creek watershed (WS 78) with that of the adjacent 1st and 2nd order forested watersheds (WS 80 and WS 79) at the adjacent Santee Experimental Forest (Fig. 2). The mean annual runoff coefficient for the study site for the 13-yr period (1964-76) was 25%. The largest watershed (study site) with some open lands, roads, and wetlands yielded higher annual water yields compared to the two other smaller ones with mostly forest vegetation, possibly due to difference in land use, soils and topography as well as increased base flows. As expected, the daily flows persisted for 79% of the time on this largest 3rd order watershed with a larger storage compared to the 2nd and 1st order watersheds. The runoff coefficient varied from 11% in a dry year to as much as 38% in a wet year, with an average of 25%. Although the annual runoff coefficients presented here may provide insight on average watershed response, it is important to understand the seasonal dynamics as affected by soil moisture and ET.

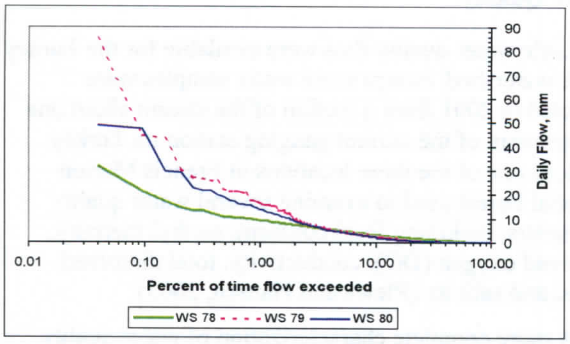

Figure 2. Daily flow duration curve of Turkey Creek watershed compared to 1st and 2nd order watersheds.

The flow frequency analysis with 13 years of data, employing Pearson III-type distribution, revealed the peak flows for 100-, 50-, 25-, 10-, and 5-year return periods as 1805, 1565, 1326, 1009, and 769 cfs, respectively. These results, which are in good agreement with published USGS data for the South Carolina Lower Coastal Plain, may have implications in design of engineering structures, water and nutrient management as well as in evaluation of impacts of development and natural disturbances on the forested lands in the region.

La Torres (2008) analyzed historic rainfall and stream flow data (1964-73) in which 51 storm events were identified for further analysis of rainfall-runoff relationships as affected by seasonal climate dynamics. The runoff ratios were higher during winter-spring possibly due to surplus water conditions (decreased ET) than the summer, but peak flow rates, on average, were larger during the summer than in winter, possibly due to high intensity summer storm events. Runoff ratios were found to be highly influenced by the antecedent moisture conditions (i.e. base flow values). Both the rainfall-runoff and rainfall-peak flow rate relationships were significant only for spring and summer seasons. These data were used to test the Rational and SCS-CN methods for predicting the peak flow rates and the runoff. The author concluded that these methods may not be applicable on this large 3rd order watershed due to limitation of scale.

Amatya and Trettin (2007b) evaluated four different methods of estimating annual ET using the forest cover data, 13 years (1964-76) of rainfall, temperature, and stream flow data. The measured mean annual ET, as the difference between the rainfall and stream flow, was 983 mm and the annual ET remained to be near potential ET (>90% 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 the wet antecedent year. Results of assessing the impacts of reduction in forest cover on mean annual runoff using Turner and Lu et al methods indicated an increase of as much as 62% runoff as a result of removal of 90% forest cover on the study watershed.

Haley (2007) tested the Soil and Water Assessment Tool (SWAT) hydrology model to calculate the water budget of the watershed for two years (2005 – wet and 2006 - dry) and to predict hydrological responses to storm events such as stream outflow, including surface and subsurface flows, and ET. Sensitivity analysis provided improvements to the calibration of Soil Conservation Services (SCS) curve numbers (CN), available soil water content, and Manning's roughness parameters in the model. Given the limited field measured data for calibration, the SWAT model produced satisfactory estimates of daily and monthly runoff.

Amatya et al (2008) refined the same calibration and validated the model with an additional data from 2007. Based on limited field measurements, results showed that the SWAT model with an improved one-parameter "depletion coefficient" can predict the daily and monthly stream flow processes of this watershed better than the classical CN method (Fig. 3). However, it was concluded that the refined model was still unable to accurately capture the flow dynamics of this forest ecosystem with high water table shallow soils for very wet saturated and very dry antecedent conditions warranting further investigations. Thus the three-year average annual runoff coefficient of 17% and ET of 900 mm predicted by the model for the period with two dry years (2006, 2007) with below normal rainfall were found reasonable compared to the published data for similar regions.

Based on detailed field survey data (Haley, 2007), most channels within Turkey Creek watershed are least 10 times larger in width than depth. The tributaries are typically about 1 m wide, but with floodplains often greater than 25 m. The results also showed that even with a maximum of error 9 meters for the GPS method used the field-mapped locations were different than the USGS location points for most of the headwater tributaries, indicating a need to field verify the existing USGS maps.

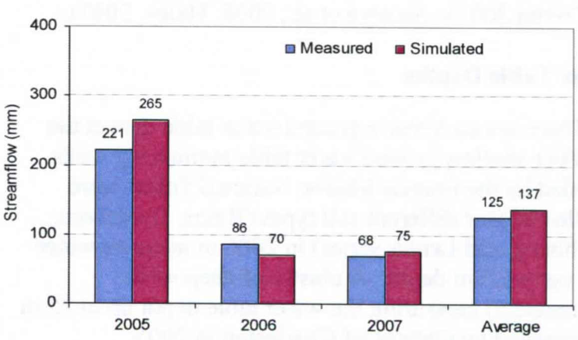

Figure 3. Measured and SWAT predicted annual stream flows for Turkey Creek watershed.

Owarek (2008) recently developed a GIS-based tool to estimate surface depressional storage coefficient (DSC) for forested wetlands in the coastal plain including the Turkey Creek watershed using the available digital elevation models (DEMs). The author reported an average DSC value of about 10 cm for this watershed. Estimate of DSC values are critical in surface runoff management and modeling, and wetland restoration.

CONCLUSIONS

The basic hydrologic and water quality monitoring and related studies conducted so far on this forested watershed on shallow water table soils show that the runoff process is dynamic (very dry to very wet with 25% of the annual rainfall lost to mean annual runoff) as affected by seasonal rainfall and ET. The mean annual estimated ET (900 to 980 mm) is consistent with similar other published results, and removal of forest vegetation may have a substantial impact on stream outflows primarily due to decreased interception and ET. Field verification of streams is necessary before applying the data in restoration and modeling works.

Additional efforts are already underway to describe surface-groundwater interactions for water balance, and the hydraulics of cross drainage structures for flow path description and water management on the study site. Thus the ongoing multi-collaborative monitoring effort on the Turkey Creek should be continued and expanded to include additional studies such as biogeochemical processes and in-stream transport, development of a well calibrated and validated model such as SWAT and others. Such models could then be used to fill further gaps in understanding the processes and address the "what-if" scenarios for management decisions facing the land managers working in the forested lands.

ACKNOWLEDGEMENTS

The authors would like to acknowledge John Erbland and Whitney for help with stream flow and rain data and Andy Harrison and Amy Edwards of Forest Service for help with weather and rainfall data from additional stations and GIS data.

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