WATER BUDGETS OF TWO FORESTED WATERSHEDS IN SOUTH CAROLINA

Ge Sun, Jianbiao Lu, David Gartner, Masato Miwa, and Carl C. Trettin[1]

ABSTACT: Wetland protection, restoration and management require detail information of the water budgets for a particular system. Relatively undisturbed systems with long-term hydrologic records are extremely valuable for developing reference wetlands and detecting effects of management. Two forested flatwoods watersheds in the lower coastal plain of South Carolina have been monitored by the USDA Forest Service since 1976 with a primary objective to study the effects of forest management (prescribed burning) on water quality. This study synthesized the accumulated hydrologic data including streamflow and shallow groundwater table with a goal to develop long-term monthly and annual water budgets for the two watersheds. Measured hydro-metrological data and a monthly time step computer simulation model, MRSWARM, were used for analysis. This study found that long-term annual evapotranspiration for undisturbed mature forests was about 913 mm or 75% of annual precipitation. On a hydrology-averaged day, about 25% of the forested wetland watersheds was in aerobic condition and over 50% had a water table within 40 cm from land surface.
KEY TERMS: wetland hydrology; water budgets; flatwoods

INTRODUCTION

Besides vegetation and soil factors, hydrology plays a critical role in wetland ecosystem process, function and values. Wetland protection, restoration and management require detailed information of the water budgets of a particular type of system since the objectives of those activities often focus on wetland hydroperiod and runoff quantity and quality. For example, wetland delineation requires site specific long-term water level information. However, hydrologic data for forested wetlands are relatively scares at a watershed scale, and wetland hydrology is often derived from other physical or biological evidences such as moss distribution on tree stems. This situation is primarily due to wetland hydrology has great natural variability in space and time, thus often expensive to characterize. Past studies have documented that southern pine flatwoods hydrology was mainly controlled by precipitation patterns. Evaportranspiration from wetlands is often high and the month balances between ET and precipitation determines dynamics of runoff and hydroperiod.

Two relatively undisturbed forested watersheds on South Carolina coastal plain that consist first-order streams were selected for this study. The objectives for this water balance study were: 1) to develop long-term annual watershed water balance; 2) Characterize the groundwater table dynamics in space and time within a watershed context.

[1]Respectively, Research Assistant Professor, Department of Forestry, North Carolina State University, Campus Mail Box 7260, NC 27606, ge_sun@ncsu.edu; Graduate Assistant, Department of Forestry, North Carolina State University, Raleigh, NC 27606. Mathematical Statistician, Center for Forested Wetlands Research, USDA Forest Service, SC 29414. Forest Hydrologist, International Paper Corporation, Bainbridge, GA 31717; Project Leader, Center for Forested Wetlands Research, USDA Forest Service, Charleston, SC 29414

METHODS

Study Site and Data Collection

The study site is located in the Santee Experimental Forest, part of the Francis Marion National Forest, on the lower Atlantic Coastal Plain, eastern South Carolina (33°N, 80°W) (Fig 1.). The two paired watersheds, control Watershed 80 (W80) (206 ha) and treatment Watershed 77 (W77) (151 ha), were delineated in 1968 and 1969, respectively. Streamflow gauges were installed during 1976 to evaluate the effects of prescribed burning on water quality. Each watershed consists of one first order stream as the main drainage pathway. The area has low topographic relief (< 4%) with surface elevation ranging from 4.0 - 10.0 m about mean sea level. Dominated tree species include loblolly pine, longleaf pine, cypress, and sweet gum. Soils are primarily sandy loams. The climate of the research area is classified as humid subtropical with long hot summers and short mild winters (Richter et al., 1983). Mean annual precipitation is about 1350 mm with July and August as the wettest months (28% of total) and April and November as the driest months (10% of total). Meteorological data for daily air temperature (Minimum and Maximum) and precipitation have been collected since 1976 at two locations inside the watershed and one at the headquarter of the Santee Experimental Forest which is about 15 km from the watersheds. Daily stream flow data during 1976-1991 were acquired for this study. Totally 79 shallow groundwater table wells have been monitored manually during 1992-1995. In 1995, manual measurements were terminated and three wells were installed with automatic water table recorders. Data from those three wells were used to predict the water table elevations for the rest of wells.

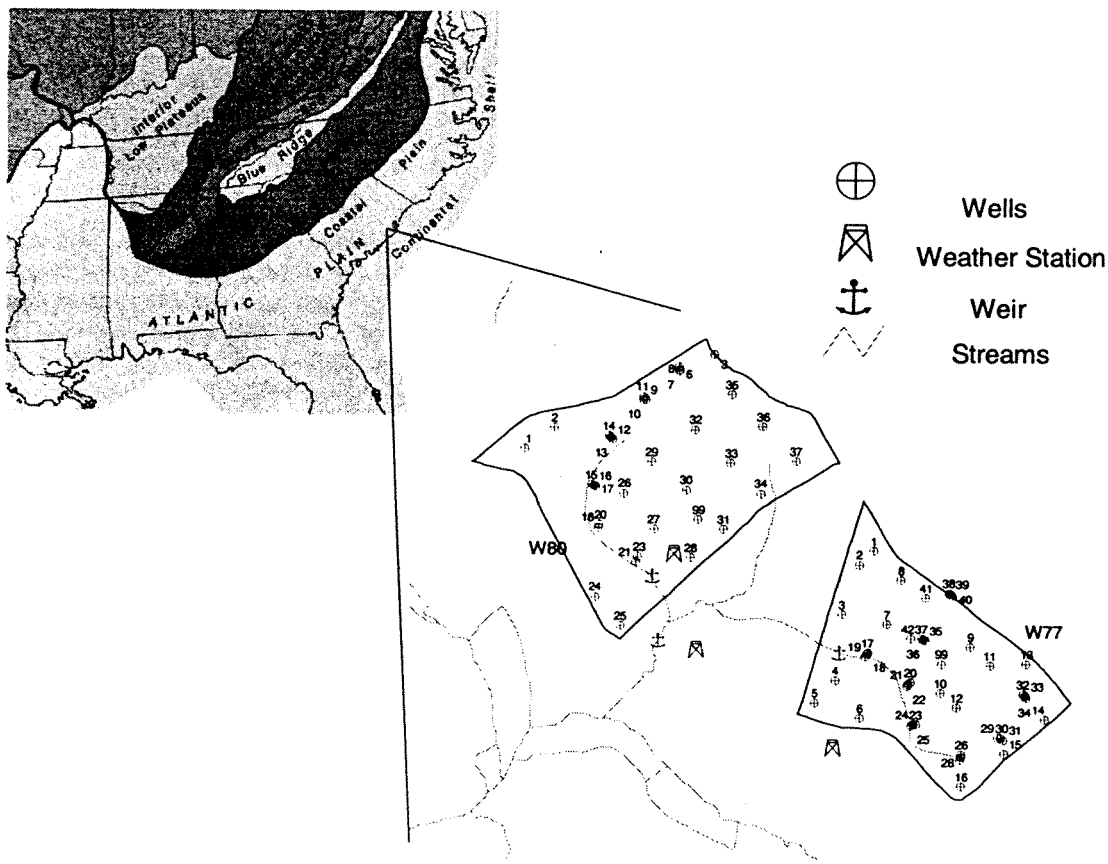

Figure 1. Location and Instrumentation at the Santee Experimental Watersheds.

Evapotranspiration (ET) including forest canopy interception and transpiration is the major water output from flatwoods ecosystems. In addition to the traditional watershed water balance method (ET=Precipitation-Runoff ± Change in storage), a monthly time step water balance model was used to estimate this component. The ESRI® GIS software was used for spatial analysis for the water table distribution in space and time. Assuming that the water table of each well characterizes the hydroperiod of a certain area with equal weight, the spatial distribution of water table in a watershed was quantified by accounting water table variations of each well. This study attempts to map the dynamics of the distribution of saturated areas (Variable Source Areas) on a watershed scale.

RESULTS

Annual Water Balance

During 1965-1992, annual streamflow for W77 ranged from 180 mm to 735 mm with a long-term average of 374 mm/year. Compared to W77, less streamflow was found for W80. Long-term average was about 290 mm/year ranging from 141 mm/year to 494 mm/year. Unfortunately, only five year's data (1976-1980; 1990-1991) were complete for annual water balance analysis (Fig. 2). Assuming annual total evapotranspiration is the difference between precipitation and stream flow in a calendar year, about 70% and 77% of precipitation is lost to the atmosphere as ET for W77 and W80, respectively. The water budget differences between the two watersheds might be caused mainly by: 1) W77 has a smaller watershed area but a higher percentage of wetlands (32% as wetlands as compared to 23% for W80). 2) After both watersheds were badly damaged by Hurricane Hugo on Sep 22, 1989, W77 was salvage logged, resulting much higher runoff ratio in 1990 and 1991 (Fig. 2). The water budget values are within the hydrologic range of the lower Atlantic Coastal Plain regions although runoff coefficients were found higher than that of a Florida pine flatwoods site (15%) but lower than a North Carolina pine plantation site (35%) (Sun et al. 2000; Amataya et al, 1996).

A generalized monthly time step, remote sensing data driven water balance model, MRSWARM, was tested and applied to W77 (Sun et al., 2000). Simulation was performed for the time period 1976-1988, just prior to the Hurricane Hugo, representing a non-disturbed mature forest condition. The 13-year average annual streamflow was found to be 438 mm or 28.4% (10.3% ~ 52.5%) of precipitation. Simulated values were compared well (no significant difference at 5% level by a t-test) with measured data, suggesting the simulation model with relative large time step (month) is sufficient to predicting annual and monthly water balance of coastal forested wetlands.

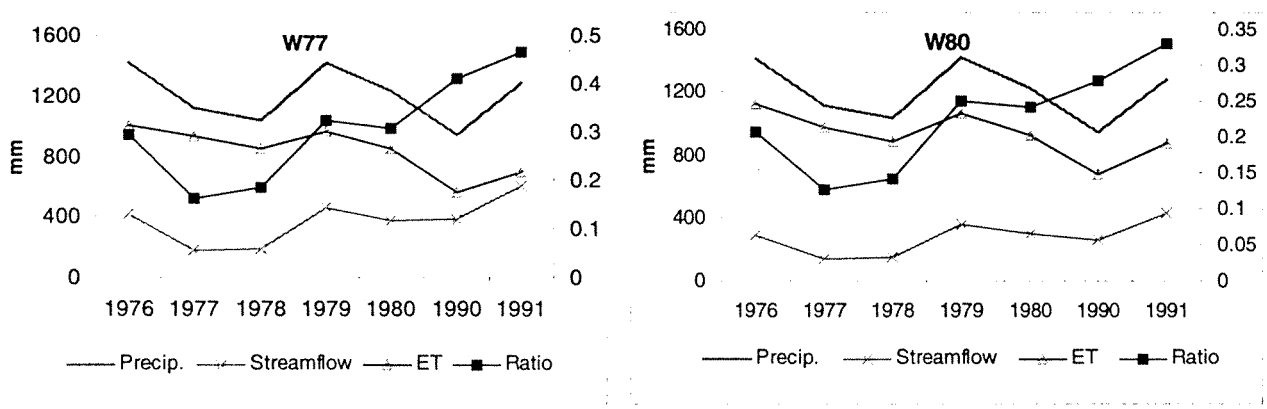

Figure 2. Annual Water Budgets of two Forested Wetland Watersheds.

Shallow Groundwater Table Dynamics

During the measurement period from January 1992 to January 1995, the southeastern U.S. experienced a sever drought in the summer of 1993 due to low precipitation in the spring and early summer months (Fig. 3). As a result, the two watersheds experienced the driest conditions on July 16, 1993. The averaged groundwater table depths across W77 and W80 were found to be as 177 cm and 182 cm below the ground surface, respectively. In contrast, year 1994 was a wet year with precipitation of 2020 mm or 50 % above long-term annual norm. Accordingly, the entire W77 watershed was submerged by an average of 23 cm of water on Oct 27, 1994 while 88% of the W80 was 17 cm under water. The averaged groundwater table depths across W77 and W80 for the entire measurement were about -45.4 cm (-28.3 cm ~ 63.5 cm) and -47.6 cm (-22.9 cm ~ -123.6 cm), respectively.

To estimate the water table distribution across a watershed, water table depth was classified as 6 categories: > 0 cm above ground (flooded), 0-20 cm, 20-40 cm, 40-80 cm, 80-120 cm, and > 120 cm below ground surface. By this scheme, when averaged over the measurement period, the water table distribution sequences for W77 and W80 were found as 0.0%, 0.0%, 38.1%, 61.9%, 0.0% and 0.0% and 0%, 0%, 39.4%, 54.5%, 3.0% and 3.0%, respectively. For a typical day, defined as 'similar to averaged' water table distribution, May 13, 1992 and May 6, 1992 for W77 and W80 respectively, the sequences were: 2.4%, 23.8%, 31.0%, 31.0%, 11.9%, and 0.0%, and 3.2%, 25.8%, 29.0%, 38.7%, 0.0%, and 3.2%. For both watersheds, on a typical day, about 60% of the entire watershed area has a water table depth less than 40 cm and 25% of the

watershed may be considered as anaerobic conditions assuming the water table capillary fringe is with 20 cm from soil surface.

CONCLUSIONS

Long-term hydro-metrological data from two first-order forested wetland watershed on South Carolina coastal plain were synthesized to construct annual watershed hydrologic balances and map spatial saturation areas. This study found that, in average, annual streamflow from forested wetland watersheds was about 25-30% of precipitation. However, simulation suggests that, depending annual rainfall patterns, the runoff coefficient of such systems may research as high as 50%. Tree removal greatly increased annual streamflow by reducing total ET. On a typical day, approximately 25% of a lower coastal watershed is under an anaerobic condition. Over half of a watershed may have a water table less than 40 cm. A forested wetland watershed might be completely dry or flooded depending on seasonal water balances.

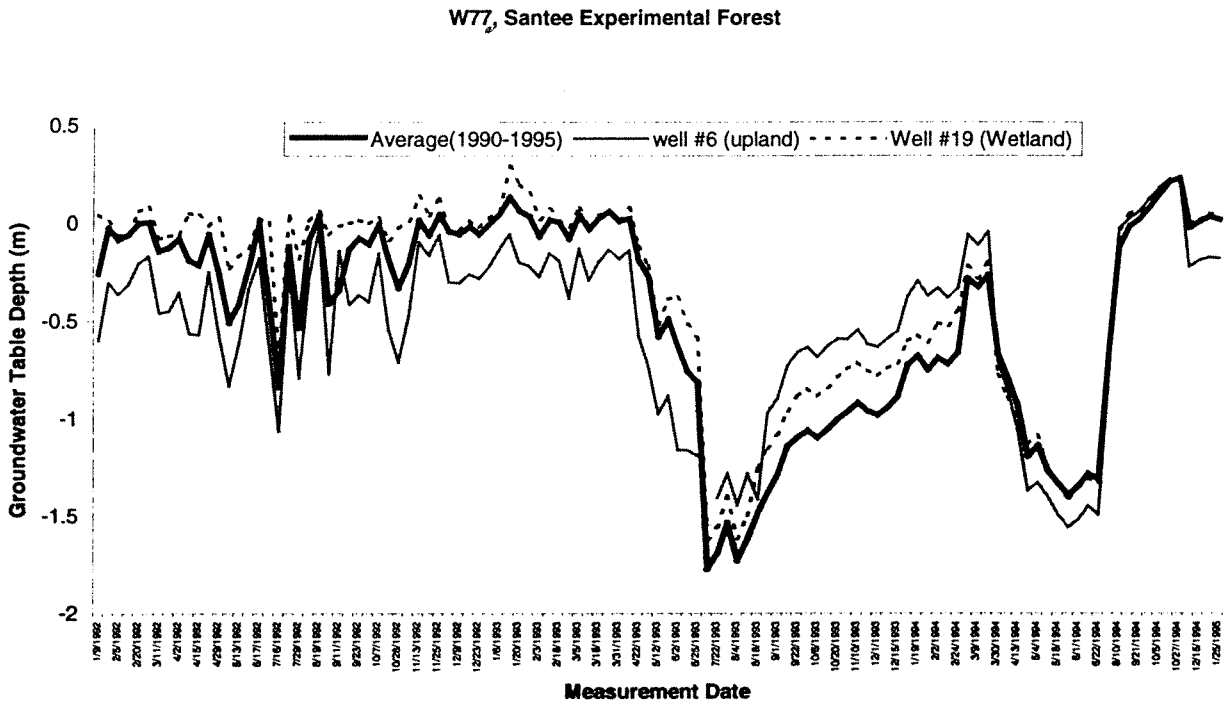

Figure 3. Variations of Groundwater Tables in Two Wells and the Average Across W77 from Jan 1990 to Jan 1995.

ACKNOWLEDGMENTS

This study was supported by the Southern Global Change Program, USDA Forest Service, Raleigh, NC, and The Center for Forested Wetlands Research, Southern Experimental Station, USDA Forest Service, Charleston, SC.

LITERATURE CITED

Amatya, D. M., Skaggs, R.W., Gregory, J.D., Herrmann, R.B., 1997. Hydrology of A Drained Forested Pocosin Watershed. Journal of the American Water Resources Association. 33, 1-12.

Richter, D.D., C.W. Ralston, and W.R. Harms. 1983. Chemical Composition and Spatial Variation of Bulk Precipitation at A Coastal Plain Watershed in South Carolina. Water Resources Research. 19:134-140.

Sun, G., S.G. McNulty, James P. Shepard, Hans Riekerk, Nicholas B. Comerford, Devendra M. Amatya, R. Wayne Skaggs, Lloyd Swift, Jr. 2000. Effects of Forest Management on Wetland Hydrology in the Eastern United States. Forest Ecology and Management (In Press).

Sun, G., R. Mickler, T. Earnhardt, and J. Moore. 2000. Characterizing the Hydrology of the Three Topographic Regions in North Carolina Using Remotely Sensed Data. 2000. In ASPRS 2000 Proceedings. Washington, D.C., May 22-26, 2000 (ABSTRACT).

REPRINTED FROM

PROCEEDINGS
AWRA
ANNUAL WATER RESOURCES CONFERENCE

WATER QUANTITY AND QUALITY ISSUES IN COASTAL URBAN AREAS

MIAMI, FLORIDA
NOVEMBER 6-9, 2000

EDITED BY

ROBERT W. HIGGINS, P.E.
HIGGINS ENGINEERING INC.
WEST PALM BEACH, FLORIDA

Printed in the United States of America
ISBN #: 1-882132-52-1
Library of Congress Catalog Card #: 00-131698
© 2000 by the
AMERICAN WATER RESOURCES ASSOCIATION
4 West Federal Street • P.O. Box 1626
Middleburg, Virginia 20118-1626
(540) 687-8390 • Fax: (540) 687-8395
E-Mail: info@awra.org
www.awra.org