Watershed Management to Meet Water Quality Standards and TMDLS (Total Maximum Daily Load)
Proceedings of the Fourth Conference 10-14 March 2007 (San Antonio, Texas USA)
Publication Date 10 March 2007
ASABE Publication Number 701P0207. Eds A. McFarland and A. Saleh

# Water Quality of Two First Order Forested Watersheds in Coastal South Carolina

**Devendra Amatya[1], Charles Harrison[1], and Carl Trettin[1]**
[1]Center for Forested Wetlands Research, USDA Forest Service, Charleston, SC

*Abstract. Understanding watershed hydrology and the concentrations of nutrients in stream waters are fundamental considerations for assessing water quality. Despite the fact that forests are generally recognized for providing clean water and used as a baseline for assessing the effects of other land uses, especially urbanization, there are ongoing concerns about the effects of forest management practices on receiving waters. Two first-order forested watersheds (WS 80 and WS 77) on poorly drained pine-hardwood stands at the USDA Forest Service Santee Experimental Forest in the South Carolina Coastal Plain have been monitored since mid-1960s to characterize their hydrology, water quality and vegetation dynamics. This study examined the nutrient concentrations and loading dynamics of these two watersheds using both outflow and concentration data collected since 2003. WS 80 remained as a reference throughout the study period, whereas WS 77 underwent a prescribed burning of the understory vegetation in May 2003 for Red-cockaded Woodpecker (Picoides barcalis) habitat management. Both watersheds were highly responsive of rainfall events with 8 to 46% of the annual rainfall lost to stream outflows depending upon years. Prescribed burning contributed to as much as 72% (147 mm) increase in outflows in 2005 for the treatment watershed (WS 77) compared to the pre-burning levels. However, by the first half of 2006 the effect reduced to only 13 mm increase. No difference was found in nutrient concentrations between the two watersheds, except for the $NH_4$-N, which seem to have increased. Both the nutrient concentrations and loading rates measured were small and were lower than the values published for pine forests in eastern North Carolina. Historic data and the data presented herein may serve as baseline information for assessing developmental impacts in the region and for assessing the Total Maximum Daily Loads (TMDLs).*
*Keywords. Outflows, Runoff Coefficient, Nutrient Concentration, Loading Rates, Prescribed Burning, Pine-hardwood stands, Understory Vegetation.*

## INTRODUCTION

In the last two decades, there has been a growing concern over the impact of both human activities (forest management, land use conversion, agriculture, and urbanization) and natural disturbances (droughts, fire, floods, and hurricanes) on the hydrologic, nutrient cycling, and export processes of forested wetlands (Amatya et al., 2005). Despite the fact that forests are generally recognized for providing clean water, there are ongoing concerns about the effects of forest management practices on receiving waters. As the extent of commercial forestry operations is predicted to increase in the South over the next 20 years (SOFRA 2002), this expectation increases the need to document the impact of silviculture on water quality in order to satisfy the public's desire to maintain high-quality water sources and industry's commitment to water quality precepts under the Sustainable Forestry Initiative. The SOFRA (2002) also emphasized that there is a need for research that will enable us to predict the long-term cumulative non-point source impacts of silvicultural management activities on water quality and overall watershed health. Research on watershed processes is needed to assure the public that providing benefits of clean and reliable sources of water is an integral part of managing forests and grasslands. (USDA Forest Service, 2006). Long-term experimental watershed studies conducted by Forest Service scientists have been key to understanding how healthy watersheds function (e.g., what processes enhance or impair the quantity and quality of water that comes from forests). Therefore, understanding both the watershed hydrology and the stream nutrient concentrations are fundamental considerations for assessing water quality. USEPA (2000) stated that water quality primarily includes stream nutrient concentrations and their loadings, as these constituents, particularly nitrogen and phosphorus, have been an issue of great concern for the aquatic health and inland waters.

Prescribed understory burning is one of the operational managements of the USDA Forest Service Francis-Marion National Forest (FMNF) in coastal South Carolina to maintain a healthy forest by reducing the potential risks of forest fire due to a large accumulation of biomass fuel on the forest floor and also for restoring endangered forest species (e.g. longleaf pine) and wildlife habitat, especially red-cockaded woodpecker. Zahner (1958) concluded that understory hardwoods complete significantly for soil moisture in upland pine forests of the Midsouth and may result in increased outflows when they are removed. However, the hydrologic and water quality effects of this management treatment are not well understood for the poorly drained low-gradient forested wetlands. Amatya et al. (2006) recently synthesized the hydrologic and water quality effects of prescribed burning using a long-term data set from two experimental watersheds at Santee Experimental Forest within the FMNF. Earlier studies on the same watersheds (Richter et al., 1980; 1983)

WS 77

This first-order watershed (155 ha) area was established in 1963. The water balance was first reported by Young (1968). Later this watershed served as a treatment watershed when the watershed (WS 80) was established. WS77 has received several silvicultural treatments over the past 40 years (Richter et al., 1982; Richter, 1982). This is a low-gradient watershed with elevations ranging from 9.98 m towards the northwest to about 5.8 m at the outlet (Miwa et al., 2003). Soils on the watershed are mostly poorly to moderately drained sandy loam to clayey soils with seasonally high water tables (SCS, 1980). Following Hurricane Hugo, this watershed was salvage harvested. Vegetation regenerated since then is comprised of loblolly pine, longleaf pine, and bottomland hardwoods in stream riparian zone. Mastication or mechanical mowing of understory vegetation occurred on portions of this watershed during February to November 2001. On May 10, 2003 prescribed fire affected about 84% of the watershed (Twomey, 2003).

WS 80

Gauging on this reference watershed (206 ha) watershed was established in 1968. In November 2001, a small part of the watershed in the northeastern corner was allowed to drain separately through a culvert reducing its area to only 160 ha. This is also a low-gradient watershed with elevation range from 4 to 6 m with 0 to 3% slopes. The watershed is also characterized by somewhat poorly to poorly drained soils. Before Hurricane Hugo, the vegetation was mostly old (> 80 yr) loblolly pine (*Pinus taeda L.).* After the hurricane, the watershed remained undisturbed with no timber (including the fallen trees) removed. The forest vegetation since then has regenerated with loblolly pine and hardwoods predominating. Detailed descriptions of this site and field measurements are given elsewhere (Amatya et al. 2005; Amatya and Radecki-Pawlik, 2006; Harder et al. 2006).

## METHODOLOGY

Rainfall

Rainfall has been measured using an automatic tipping bucket rain gauge (ONSET) with a HOBO data logger backed up by a manual gauge located at Met5 and Met 25 met-stations on watersheds WS 77 and WS 80, respectively (Figure 1). Breakpoint event rainfall data downloaded every two weeks were processed using MS Excel spreadsheet to obtain daily, monthly and annual values. Rainfall measurement methods and data prior to 2003 have been described recently by Amatya et al. (2006).

Stream Flow

Stream flow rates at the outlets of both the watersheds (WS 77 and WS 80) are determined using stage heights measured at 10-minute intervals by ISCO 4210 Flow meters upstream of the outlet weirs and the lookup table derived from stage discharge relationships. Details of the gauging stations and measurement methods have been described elsewhere (Amatya et al., 2006).

Stream Water Quality

Water samples at the watershed outlets have been collected using an ISCO 3700 sampler since January 2003 on WS 77 and since December 2003 on WS 80. Water samples are collected on a flow proportional basis. The sampling volume was calculated based on a median event volume for 15 events for WS 77 and 21 events for WS 80 using event flow data from 1997-98 period and four samples per bottle for 24 bottles to fill in one event. Bottles in the sampler are downloaded on a weekly basis or more frequently depending upon the storm size. Bottles preserved are frozen until the sample analysis at the Soil Chemistry laboratory in Charleston. Samples are analyzed for ammonia ($NH_4$-N), nitrate-nitrite ($NO_3$+ $NO_2$), total nitrogen (TN), total phosphorus (TP), chloride (Cl), dissolved organic carbon (DOC), calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na). In this paper we present the results for $NH_4$-N, $NO_3$+ $NO_2$, TN, and TP only. Ammonia in water was analyzed by QuikChem© Method, Flow Injection Analysis Colorimetry (Diamond, 1995; Knepel and Bogren, 2000). Nitrate-nitrite was determined by the QuikChem© Method 10-107-04-1, Flow Injection Analysis (Wendtwrp, 1995; Lynch, 2003). TP in water was determined by QuikChem© Method 10-115-01-3-E , FIA Colorimetry (In-Line Persulfate Digestion Method (Liao, 1996). TN in water was determined by QuikChem© Method 10-107-04-3-B, In-Line Digestion Followed By Flow Injection Analysis (Liao, 1997; Bogren, 2003). Concentration levels with below detection limits (BDL) (<0.2 mg $L^{-1}$ for $NO_3$-N until July 2005 after which it dropped to <0.02 mg $L^{-1}$ using a new method; <0.1 mg $L^{-1}$ for $NH_4$-N until July 2005 and <0.02 mg $L^{-1}$ after that; <0.3 mg $L^{-1}$ for total-N until July 2005 and 0.1 mg $L^{-1}$ after that; 0.1 mg $L^{-1}$ for Total-P until July 2005 and 0.01 mg $L^{-1}$ (or 10 $\mu g\ L^{-1}$) after that. For the analysis purpose, BDL itself was used for all measured BDLs. Other laboratory quality control was performed as per the procedures established at the Forest Service Soil Chemistry laboratory in Charleston, SC.

perhaps due to 25 mm more rain recorded on WS 80 than on WS 77 (Amatya et al., 2006). The differences in monthly outflows were as large as 25 mm for wet summer events in 2005. As a result, the ROC for the treatment in 2005 was nearly 30% higher than that for the reference. By June 2006, the outflows from the treatment watershed continued to be lower than the reference resulting in 11% ROC compared to 13% for the reference.

Table 2. Annual rainfall, stream outflow, and ROC from January 2003 to June 2006 and annual average nutrient concentrations (standard deviation) and loading rates for January 2003 to March 2006 for WS 77 and WS 80. No concentration data was available for WS 80 in 2003.

| Parameters | Watershed 77 (WS 77) | | | | Watershed 80 (WS 80) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2003 | 2004 | 2005 | 2006 | 2003[1] | 2004 | 2005 | 2006 |
| Rainfall, mm | 1770 | 976 | 1497 | 458 | 1671 | 962 | 1514 | 440 |
| Outflow, mm | 638 | 89 | 351 | 54 | 784 | 73 | 276 | 55 |
| R/O, % | 36 | 9 | 23 | 11 | 46 | 8 | 18 | 13 |
| $NO_3$-N, mg $L^{-1}$ | 0.22 (±0.098) | 0.2 (0) | 0.089 (± 0.09) | 0.037 (± 0.043) | N/A | 0.2 (±0.013) | 0.10 (±0.089) | 0.093 (± 0.27) |
| $NH_4$-N, mg $L^{-1}$ | 0.16 (± 0.11) | 0.17 (± 0.35) | 0.069 (± 0.043) | 0.05 (± 0.095) | N/A | 0.12 (± 0.04) | 0.065 (± 0.04) | 0.044 (± 0.069) |
| DIN, mg $L^{-1}$ | 0.38 | 0.37 | 0.158 | 0.087 | N/A | 0.32 | 0.165 | 0.137 |
| Total N, mg $L^{-1}$ | 0.64 (± 0.27) | 0.64 (± 0.2) | 0.64 (± 0.24) | 0.24 (± 0.14) | N/A | 0.69 (± 0.25) | 0.86 (± 0.28) | 0.35 (± 0.34) |
| DON, mg $L^{-1}$ | 0.26 | 0.27 | 0.482 | 0.153 | N/A | 0.37 | 0.695 | 0.213 |
| Total P, Mg $L^{-1}$ | 0.1 (0) | 0.1 (0) | 0.063 (± 0.044) | 0.011 (± 0.021) | N/A | 0.1 (0) | 0.065 (± 0.042) | 0.011 (± 0.003) |
| $NO_3$-N, kg $ha^{-1}$ | 0.58 | 0.11 | 0.43 | 0.018 | N/A | 0.15 | 0.29 | 0.054 |
| $NH_4$-N, kg $ha^{-1}$ | 0.36 | 0.077 | 0.25 | 0.027 | N/A | 0.092 | 0.18 | 0.024 |
| Total N, kg $ha^{-1}$ | 1.46 | 0.37 | 2.33 | 0.12 | N/A | 0.45 | 2.23 | 0.19 |
| Total P, Kg $kg^{-1}$ | 0.25 | 0.053 | 0.24 | 0.005 | N/A | 0.072 | 0.18 | 0.006 |

Nutrient Concentrations

Annual average total nitrogen (TN) concentrations remained the same (0.64 mg $L^{-1}$) for the treatment watershed WS 77 in all years, except in 2006 (Table 2) with data for only January to March and when the lower BDL was used. Similarly, $NO_3$-N levels diminished from 0.22 mg $L^{-1}$ in 2003 to 0.037 mg $L^{-1}$ by 2006 and $NH_4$-N levels from about 0.16-0.17 in 2003/2004 to 0.05 by 2006 perhaps for the same reason as TN. Dissolved inorganic nitrogen (DIN) as a sum of $NO_3$-N+ $NH_4$-N varied from as much as 0.38 mg $L^{-1}$ in 2003 to 0.087 by 2006 on WS 77. Accordingly, the dissolved organic nitrogen (DON) as a difference of TN and DIN remained the same around 0.26 mg $L^{-1}$ in 2003-04 but increased to 0.48 mg $L^{-1}$ in 2005 and again went back to 0.15 mg $L^{-1}$ for a 3-month period in 2006 (Table 2). The DON level was below 45% of the TN in first two years after burning which increased to more than 63 % by 2006. Although the annual average $NO_3$-N levels in WS 80 varied from 0.093 (with lower BDL) to 0.2 mg $L^{-1}$ (with higher BDL) they were within one standard deviation (Table 2), indicating no difference among years. The same observation was true for $NH_4$-N, which had concentration levels as high as 0.12 mg $L^{-1}$ in 2004 to 0.044 mg $L^{-1}$ for the 3-month period in 2006. In contrast with the treatment watershed (WS 77) the DON levels in all three years (2004-06) were higher than 50% of TN. The total phosphorus (TP) concentrations did not change from year-to-year on both the watersheds, except for 2006 with data only through March and lower BDLs.

Data in Figure 2 compares the measured annual average concentrations with standard deviations for all nutrients between the two watersheds for 2004 to 2006. TN concentrations were higher for the reference watershed (WS 80) than for the treatment (WS 77). The difference, however, was within one standard deviation indicating no significant difference in any of the nutrients between the two watersheds. Although the annual average TN was 0.86 mg $L^{-1}$ or less, a maximum of 2.77 mg $L^{-1}$ was observed on WS 77 in April of 2003. This was due to increase in both the $NO_3$-N and $NH_4$-N concentrations for very wet events.

vegetation removal by both the prescribed fire and earlier mastication in 2001. The increases were smaller in the very wet year 2003 and very dry year 2004 compared to 2005. These effects, however, were small by June 2006 with only a 13 mm increase, which is only 3% of the rainfall and may be well within be measurement errors. This may indicate the hydrologic recovery to pre-burning levels of early 2003 and 1996-99 with higher flows from WS 80. Further observation beyond June 2006 was limited by a new thinning treatment implemented on WS 77 in August 2006. The results observed here are different than those reported in earlier studies (Richter, 1980; Richter et al., 1982) which reported no significant effects of burning on stream flows when the watershed was burned up to only 60% over six years.

The evaluation for effects of burning on stream water chemistry in this study was affected by two factors: first, no measurements of nutrients were available in 2003 for the reference (WS 80), and secondly, the below detection limits (BDL) in laboratory measurement for all nutrients were lowered by almost an order of magnitude for samples starting in July 2005. As a result the comparison between watersheds was not possible for 2003 and comparison among years for each watershed was complicated. For the same reason the increased concentrations of both the $NO_3$-N and $NH_4$-N in 2003 and 2004 may possibly be due to reduction in vegetation uptake following the burning on the watershed in May 2003 as well as due to the use of one order of magnitude higher BDL in these years than in 2005-06. The $NO_3$-N concentrations observed here even with lower BDLs in 2005-06 are 4-5 times higher than those (average of 0.017 mg $L^{-1}$) reported by Binkley (2001) for these streams for the historic data (1976-81; 1990-94 post-Hugo data). However, the annual average $NH_4$-N levels in 2005-06 have remained similar to 0.045 mg $L^{-1}$ observed for the historic period. Based on the post-Hugo (1990-94) characteristic differences, there was no difference in annual average nutrient concentrations between two watersheds, except for the $NH_4$-N levels which seem to have increased as much as 79% in 2004 after prescribed burning.

The fact that the TN was slightly higher on WS 80 than on the WS 77 and the DIN was almost the same on both indicates the high DON in stream water draining the reference. DON levels were only 2-4 times higher than the DIN levels for both watersheds compared to the earlier data with greater than an order of magnitude difference (Binkley, 2001). Richter (1980) reported that the concentrations of $NO_3$-N, $NH_4$-N, and $PO_4$ on these watersheds were not related to stream outflows and their values were small compared with concentrations in rainfall, a consequence of biotic uptake, as well as retention of $PO_4$ by mineral soils. This was not verified in the study assuming it would not change. The concentrations observed on these watersheds were lower than those from other Southeastern forested watersheds dominated by conifers (Chescheir et al., 2003). Temporal trends observed in stream concentrations probably resulted from both fluctuations in outflows and seasonal factors, e.g. temperature and rainfall. Wolaver and Williams (1986) reported that mineral dissolution, forest floor litter decomposition in hardwood swamps, and atmospheric inputs (sea salts) all influence intermittent black water stream water geochemistry in coastal South Carolina.

The total inorganic nitrogen (TIN) loading observed in each of the years in this study was much less than half of 2.36 kg $ha^{-1}$ reported by Richter et al. (1983) for the atmospheric deposition at the site. This indicates that much of the TIN is stored in the system. However, the fact that the annual TP loading of 0.13 kg $ha^{-1}$ or less for both watersheds is similar or lower than the atmospheric deposition of 0.13 kg $ha^{-1}$ for $PO_4$ indicates that $PO_4$ may not have been stored in the watersheds. The nutrient exports in 2006 were similar to the post-Hugo data (Wilson et al., 2006). However, the higher nutrient loadings observed in 2003-05 (Table 2) compared to the post-Hugo (e.g. 0.02-0.11 kg $ha^{-1}$ for $NO_3$-N and 0.02-0.18 kg $ha^{-1}$ for $NH_3$-N) are most likely due to the higher BDL limits. Nutrient loadings in these systems were more influenced by the stream outflows, as the concentrations did not vary much. However, these loadings are much less than the data reported for coastal forests in eastern North Carolina (Chescheir et al., 2003).

Long-term data on stream outflows and nutrient concentrations from these experimental forested watersheds in the coastal South Carolina can serve as a baseline information as recently used by Lu et al. (2005) in developing a water quality model for Dissolved Oxygen for the Charleston Harbor System. These long-term data will continue to be a great information source for evaluating impacts of continuing urbanization near coastal waters (Tufford et al. 2003; Wahl et al., 1997). Furthermore, data from this study may serve as a basis for the new study being conducted at the site to evaluate the watershed-scale effects of thinning (August 2006) followed by prescribed burning (summer 2007) as a means of reducing forest biomass.

## SUMMARY AND CONCLUSIONS

A study was conducted to evaluate stream outflow and nutrient concentrations measured for a 42-month (2003-06) period from two paired first-order watersheds at USDA Forest Service Santee Experimental Forest in Coastal South Carolina. Prescribed burning of the understory vegetation on 84% of the area of the treatment watershed was implemented in May 2003. Burning in this scale implemented all at once increased the stream outflows by as much as 72% (147 mm) in the second year (2005) but reduced back to 30% (13 mm) by the first-half of the third year (2006) compared to the pre-burning period. Since no

Richter, D.D., C.W. Ralston, and W.R. Harms. 1982. Prescribed Fire: Effects on Water Quality and Forest Nutrient Cycling. Science, 215:661-663.
Richter, D.D. 1980. Prescribed Fire: Effects on Water Quality and Nutrient Cycling in Forested Watersheds of the Santee Experimental Forest in South Carolina. Unpublished PhD. Dissert., School of Forestry and Environmental Studies, Durham, NC: Duke University.
SOFRA 2002. Southern Forest Resource Assessment. D.N. Wear and J.G. Greis (eds.), *USDA Forest Service, Southern Research Station*, Asheville, NC, September 2002.
Soil Conservation Service (SCS). 1980. Soil Survey of Berkeley County, South Carolina. United States Department of Agriculture, 94 pp.
Sun, G., J. Lu, D. Gartner, M. Miwa, and C.C. Trettin. 2000. Water Budgets of Two Forested Watersheds in South Carolina. In: *Proc. of the Spring Spec. Conf., Amer. Wat. Res. Assoc.*, 2000.
Tufford, D. L., C. L. Samarghitan, H. N. Mckellar, Jr. D. E. Porter, and J. R. Hussey, 2003. Impacts of Urbanization on Nutrient Concentrations in Small Southeastern Coastal Streams. *J. of the Amer. Water Resou. Assoc.*, April, 2003.
Twomey, William. 2003. Personal Communications, USDA Forest Service, Francis Marion National Forest, Witherbee District Office, SC.
USDA Forest Service, 2006. *http://www.fs.fed.us/research/wfwar.html*. *US Department of Agriculture Forest Service, Wildlife, Fish, Water and Air Research.*
US EPA. 2000. National Water Quality Inventory:1998 Report to Congress at *http://www.epa.gov/owowwtr1/305b/98report/index.html.*
Wahl, M.H., H.N. McKellar, and T.M. Williams. 1997. Patterns of Nutrient Loading in Forested and Urbanized Coastal Streams. J. of Exp. Marine Bio. and Ecol. 213:111-131.
Wilson, L., D.M. Amatya, T.J. Callahan, and C.C. Trettin. 2006. Hurricane Impact on Stream Flow and Nutrient Exports for a First-Order Forested Watershed of the Lower Coastal Plain, South Carolina. In Press, Proceedings of *Second Interagency Conference on Research on Watersheds*, Coweeta Hydrologic Laboratory, Otto, NC, May 16-18, 2006.
Wolaver, T.G. and T.M. Williams. 1986. Storm Water Chemistry of a Small Forested Watershed on the South Carolina Coast. *Southeastern Geology*, Duke University Press, Durham, NC, 27(1):45-52.
Young, C. E. 1968. Water Balance of a Forested Coastal Plain Watershed on the Santee Experimental Forest. Technical Report FS-SE-1603, Study W-2, 45 p, Charleston, SC: USDA Forest Service.
Zahner, R. 1958. Hardwood Understory Depletes Soil Water in Pine Stands. Forest Science, 4(3):178-184.