

Identifying Nutrient Contributors in North Carolina's Coastal Plain Blackwater Rivers

¹Narayan B. Rajbhandari, ²Sushama Pradhan, ³Mauro Di Luzio, ¹Adugna Kebede and ¹Virginia Baker

¹NC DENR, Division of Water Resources, 512 North Salisbury Street, Raleigh, NC 27604, USA

²NC DHHS, On-site Water Protection Branch, 5606 Six Forks Road, Raleigh, NC, USA

³Texas Agri. Life Blackland Research and Extension Center, 720 East Blackland Road, Temple, TX 76502, USA

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Corresponding Author:

Narayan B. Rajbhandari

NC DENR, Division of Water

Resources, 512 North Salisbury

Street, Raleigh, NC 27604, USA

Email: narayan.rajbhandari@ncdenr.gov

Abstract: The goal of this study was to assess potential nitrogen and phosphorus contribution from point sources and non-point sources in North East Cape Fear River (NECFR) watershed in North Carolina. A watershed scale hydrologic model, Soil and Water Assessment Tool (SWAT), was used to quantify Total Nitrogen (TN) and Total Phosphorus (TP) loadings to North Carolina's Coastal Plain Blackwater Rivers. The model was calibrated to measured flow rate, TN, TP and suspended sediment concentrations. The model results suggest that nonpoint sources contribute more than 95% of the nutrient loads from the NECFR to the Lower Cape Fear River (LCFR), where low dissolved oxygen is a prime concern. Among the nonpoint sources, developed open space, forested wetland and agricultural land were responsible for approximately 20 to 35% of the total annual sediment loads (68838.60 tons) and the Total Phosphorus (TP) loads (452.20 tons) delivered to the LCFR. In addition forested wetlands, agricultural lands and forested lands contributed approximately 20 to 33% of the TN loads (3496.79 tons) to the river. While the forested wetlands assimilated more than 70% of the nutrient inputs, they also acted as sources of nutrients in the watershed. The results demonstrate that these wetlands were not substantially capable of trapping nutrient loading coming from adjoining lands for a longer period. Owing to the presence of more ditches, these wetlands functioned as a passive nutrient source by transporting significant amount of TN and TP into the river. However, these findings need to be further justified by conducting a field study to understand assimilative capacity of wetlands in the watershed.

Keywords: SWAT Model, Nitrogen, Phosphorus, Non-point Source, Wetlands

Introduction

Discharge of excess nutrients from upstream river watersheds into an estuary and its coastal area can reduce dissolved oxygen levels, thereby killing marine organisms (Mallin, 2000). Several studies have indicated that anthropogenic loads and the resulting eutrophication are the two major sources of nutrient loads in the blackwater river watersheds located in the Southeastern coastal plain of the United States, from Virginia south to northern Florida and in areas of the Gulf Coast (Mallin *et al.*, 1997; Cahoon *et al.*, 1999; Moran *et al.*, 1999; Seitzinger *et al.*, 2002; Graves *et al.*, 2004; Hendrickson *et al.*, 2007).

Blackwater Rivers are characteristically low gradient and flowing slowly through extensive flood plains, forested swamps and wetlands (Meyer 1990; Smock and

Gilinsky, 1992). As vegetation, animals and micro-organisms decay in water, organic matter consisting largely of fulvic acids are leached out to the river. Since surface soils in the coastal plains are mostly sandy and have a low capacity for sorption of organic matter, the decomposed organic matter remains soluble in water, resulting in transparent water that is darkly stained, resembling tea or coffee (Meyer, 1990). Hence the water body is called blackwater. Owing to major shifts in land uses in some blackwater watersheds, a large portion of Nitrogen (N) and Phosphorus (P) are retained within the colored decomposed organic matter (Graves *et al.*, 2004).

Since 1996 a portion of Lower Cape Fear River (LCFR), from Toomers Creek to Snows Cut (2,273 hectares), has been on North Carolina's 303(d) list of impaired waters for low Dissolved Oxygen (DO)

violations (NCDENR, 2007). Sources of low DO levels include natural and anthropogenic sources of oxygen consuming nutrients from the upstream blackwater rivers, such as: LCFR, Black River and Northeast Cape Fear River (NECFR). Several studies indicate that N and P addition to blackwater rivers due to land uses support algal blooms during selected period and stimulated growth of heterotrophic macroflora, which becomes source of labile biochemical oxygen demand and oxygen deficit (Mallin *et al.*, 2001; Seitzinger *et al.*, 2002). As a follow up to these studies, a watershed model based assessment was conducted to determine N and P loads entering the LCFR from a large blackwater river under different land use scenarios, including large-scale agricultural operations, intensive swine operations and conventional point-source discharges.

In this study N and P were chosen as key parameters due to the fact that they are the primary nutrient-limiting factors for plant, algal and microbial production in coastal systems. Higher concentration of these nutrients leads to oxygen deficit in the aquatic systems. A watershed model, Soil and Water Assessment Tool (Winchell *et al.*, 2009), was used to perform systematic analysis of these nutrient parameters to support the water quality evaluation and management plans for the LCFR watershed in North Carolina. SWAT model is a well-established watershed scale hydrologic model which has been used in numerous water quality assessment studies worldwide (Borah, *et al.*, 2006; Busteed *et al.*, 2009; Jha *et al.*, 2007; Kirsh *et al.*, 2002; Ouyang *et al.*, 2008; Niraula *et al.*, 2012; Veith *et al.*, 2005).

Materials and Methods

Study Sites

This study was conducted in Northeast Cape Fear River (NECFR) watershed in North Carolina. This river exhibits the typical blackwater characteristics (Mallin *et al.*, 2001) and occupies approximately 438,522 ha (1,693 square miles) of the LCFR watershed (Fig. 1). The watershed encompasses the two coastal plain counties: Duplin at the northern part and Pender at the southern part of the watershed. According to the 2007 agricultural statistics (NCDA&CA, 2007), Duplin County has included substantial part of swine operations in the Cape Fear River Basin since 1997. Most of the agricultural lands in the watershed were used for land spreading of hog waste, which contains large quantities of both organic and inorganic nitrogen and phosphorus (Mallin *et al.*, 1997). In addition, significant deposits of organic nutrients and low DO levels characterize wetlands in the watershed.

In the NECFR watershed nonpoint sources are comprised of agricultural land (32.74%), forested land (26.62%), range land/cattle field (4.79%), forested

wetland (30.11%), non-forest wetland (0.66%), urban land (1.50%), developed open space (3.00%) and barren land (0.12). Urban land includes residential, road and parking lots. Residential development is mostly concentrated at the lowermost part of the watershed. Developed open space mostly consists of vegetation in the form of lawn grasses, golf course, erosion control area and parks. The remaining land consists of water body (0.40%).

In this watershed, most of the farmers practice hog farming and hay cultivation. A few farmers plant corn, soybean and wheat but most of the cropping lands had been converted to Bermuda grass lands for hog farming. During the study period, approximately 571 hog farms were identified in the watershed from the North Carolina Division of Water-Resources (NCDWR) permit records, most of which are located in Duplin County (Fig. 1). Large quantity of hog waste was often sprayed on the Bermuda grasslands. In general, the hog waste was sprayed on Bermuda grasslands from March through September and small grain fields from September through March. The permitted amount of hog waste application rate varies with crop type, soil type, land slope and county. On an average, hog waste applied on agricultural lands was estimated to be 350-400 kg per hectare per year (Sloan *et al.*, 1999).

Based on the 2002 agricultural census conducted by Natural Services Conservation Service (NRCS) all rangelands in the NECFR watershed were assumed to be populated with approximately 23,000 beef/cattle. Following the Agriculture Waste Management Field Handbook (USDA, 2004), it was estimated that one cattle added 2.3 kg ha⁻¹ dry manure to the land each day for 240 consecutive days. Since the majority of the cattle were grazed at rangelands in the watershed, the estimated manure rates were applied to the rangelands only.

In additions, there were 31 different conventional point sources contributing nutrient directly to the NECFR. Nutrient discharges from these point sources are regulated under National Pollutant Discharge Elimination System (NPDES) programs in the NECFR watershed. These point sources contributed 416 kg day⁻¹ of TN (sum of organic nitrogen, ammonia, nitrate and nitrite) and 134 kg day⁻¹ of TP (sum of organic phosphorus and mineral phosphorus) during the study period.

While developing the SWAT model, TN was estimated to be comprised of 5% organic nitrogen and 95% of nitrate nitrogen and nitrite nitrogen point source discharged waters. Ammonia was considered to be negligible unless it was reported in the NPDES report to the North Carolina Division of Water Resources (NCDENR). Likewise, TP was estimated to be comprised of 30% organic phosphorus and 70% mineral phosphorus. (Source: NPDES database and personal communication with a point source expert in the DWR, Mr. Mike Templeton).

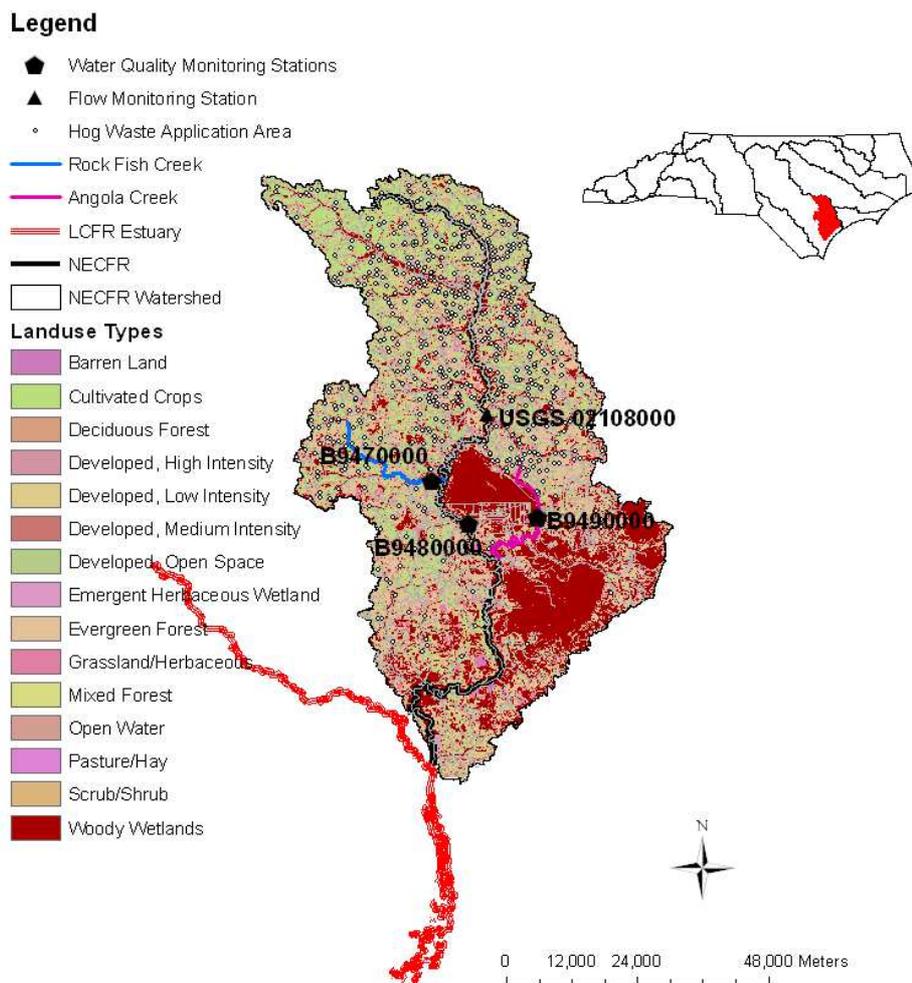


Fig. 1. Northeast cape fear watershed showing selected water quality and flow stations, hog farm sites and land use distribution

Model Selection and Dataset Used

The SWAT model was selected for this study because of its capability to assess N and P loadings from point and non-point sources in a large watershed with varying land uses and management conditions (Arnold *et al.*, 1998). The model is a physically based distributed-parameter simulation model that enables the user to simulate runoff and pollutant transport processes up to 100 years. This model can be used to study large watersheds with up to two thousand square miles area. The model has the capability to divide watersheds into hundreds of sub-basins and thousands of Hydrologic Response Units (HRUs).

The NECFR watershed was delineated into 23 sub-basins using the stream coverage Reach File (USGS 1:24000 topographic maps) and Digital Elevation Model (DEM) maps (30×30 m) to estimate watershed parameters. These include stream length, stream slope, stream dimensions, overland slope, slope length,

Manning's n, soil erodibility factor K, management practice factor P and crop factor C. The delineated sub-basin map was then overlaid with land use (2000 LANDSAT satellite imagery-USGS, 2005) and soil maps to identify 678 HRUs and the respective parameters, including bulk density, soil layer, available water, hydraulic conductivity and texture type (U.S. STATSGO database-USGS, 2007). In SWAT, each sub-basin can be characterized by eight major model components; hydrology, weather, sedimentation, soil temperature, plant growth, nutrients, pesticides and land management.

Climate data inputs are critical to watershed model simulation. Daily air temperature and precipitation data for the study periods (1999-2005) were acquired through the State Climate Office of North Carolina for the nearby weather stations of Warsaw, Wallace, Willard and Wilmington. These weather stations are located within NECFR watershed. Wind speed and

solar radiation were simulated using the weather generator built-in SWAT. The amount of rainfall in the area during 2000 through 2002 was less than the long-term mean annual rainfall of 1,378 mm (54 inches) (Table 2). According to the National Air Deposition Program (UIUC, 2007), rainfall carried approximately 1.3 mg L⁻¹ of N (0.43 mg L⁻¹ of NH₄ and 0.83 mg L⁻¹ of NO₃) in the NECFR watershed during the study period.

Model Calibration

The model was run from 1997 to 2005 for daily outputs. Considering warm-up period for the first two year the model estimated outputs from 1999 to 2005 were utilized for calibration off low, Suspended Sediment Concentration (SSC), Total Nitrogen (TN) and Total Phosphorus (TP). Since the SWAT model does not simulate tidal effects, calibration was not carried out at the outlet of the watershed where there are frequent tidal effects. Instead the calibration was carried out at the USGS Station, 02108000, for flows and the NCDWR ambient monitoring station, B9480000, for the water quality constituents (Fig. 1). Flow was recorded daily at the USGS Station, whereas the nutrient concentrations were recorded monthly during the study periods.

The terms Total Suspended Solids (TSS) and SSC are often used interchangeably in literature to describe concentration of the total suspended solid phase in a water column. However, these two terms are considered different in this study due to fact that the TSS analytical method does not include all sand particles. Therefore, in order to match the observed TSS with the model estimated sediment concentration, which includes the entire water-sediment mixture, the SSC was estimated using Equation 1. As suggested by Glysson *et al.* (2004), caution should be used in using the equation, especially to correct TSS values less than above 500 mg L⁻¹. The equation was, therefore, tested with original TSS data collected at the station B9480000 (Fig. 1) by assigning different suggested intercept values from 12.4 to 103 mg L⁻¹ (Glysson *et al.*, 2004). The value of 32 was found to be adequate to estimate correct TSS data for the watershed:

$$SSC = 32 + 1.0857 TSS \quad (1)$$

For flow calibration, the SWAT model estimates representative Curve Number (CN) values for various land covers and soil types. The default values as estimated by the model for all the HRUs were reduced by 10% to reflect existing hydrologic condition in the NECFR watershed. The Muskingum method was used

for simulating the channel routing process and the Hargreaves method for estimating potential evapotranspiration. In addition, other sensitive parameters for surface and ground water processes were adjusted during calibration as presented in Table 1. The initial nutrient concentrations for soils were formerly measured for the Orangeburge Loamy Sandy Soil in Duplin County, where swine operations were substantially practiced. Since the watershed encompasses the county in its northern part, the initial nutrient concentrations in soils were applied in almost half the upper watershed, above the ambient station B9480000, where hog farms were heavily and evenly distributed. Similarly, the initial concentrations in ground water were applied in the hog farming part of the watershed. The initial concentrations were estimated based on quarterly measurement from March 1998 through November 1999 at the Abertson site in Duplin County.

Performance Evaluation of Model

Model performance was evaluated through qualitative and quantitative measures, involving both graphical comparisons and statistical tests. For flow simulations where continuous records were available, both the qualitative and the quantitative techniques were adopted for the calibration station. However, the performance was not evaluated for daily flows due to some flow inconsistencies associated with localized rainfall distributions in the NECFR watershed. Therefore, model performance was assessed only for total monthly flow. For water quality constituents, the model performance evaluation was carried out based primarily on visual and graphical presentations as the frequency of observed data is inadequate for accurate statistical comparisons. However, annual mean of the observed values were compared with annual mean of the predicted values using paired t-test.

Statistical test such as Paired-Difference t-test, Nash-Sutcliffe model efficiency (NS), Coefficient of Determination (R-Square), Root Mean Square Error (RMSE) for mean and Relative Error (RE) were used to evaluate model prediction for flow. Paired-Difference t-test was employed to assess whether the average difference between observed and model predicted values was significantly different from zero. If the difference was not significantly different from zero, then the model prediction was considered to be acceptable. The NS was employed to quantitatively evaluate model performance. This value can range from negative infinity to 1. The NS values greater than 0.75 were considered "good" (Moriasi *et al.*,

2007). When the NS coefficients are 0 or less, model predictions are no better than the mean of the observed data over the evaluation period. The R-Square value was employed to evaluate relationship between observed and predicted values. If the R-Square value is close to one, then the model prediction is considered acceptable. The error measurements were employed to indicate the

difference between observed and simulated values relative to the observed data. If the RMSE and RE values are close to zero, then the model prediction is considered satisfactory. The United State Environmental Protection Agency's Technical Guidance Manual for performing Estuary Waste Load Allocations proposes acceptable error statistic criteria of 45% for nutrient parameters (USEPA, 1999).

Table 1. Parameters used for model calibration

Parameters	Calibration value	Sources
I. Hydrologic Parameters		
A. Evaporation		
1. Soil Evaporation Compensation Factors (ESCO)	0.95	Neitsch <i>et al.</i> (2002)
2. Plant Evaporation Compensation Factor (EPCO)	1.00	
B. Ground Water		
1. Re-Evaporation Coefficient (GW_REVAP)	0.1	Neitsch <i>et al.</i> (2002)
2. Deep Aquifer Percolation Factor (RCHRG_DP)	0.1	
C. Manning's n for Overland Flow		
1. Developed Land	0.1	Neitsch <i>et al.</i> (2002)
2. Pasture Land	0.4	
3. Forested Land	0.6	
II. Chemical Parameters		
1. Nitrogen Percolation Coefficient (NPERCO) 0.90		Neitsch <i>et al.</i> (2002)
2. Phosphorus Percolation Coefficient (PPERCO)	10.00	
3. Phosphorus Portioning Coefficient (PHOSKD)	100 m ³ /mg	
4. Residue Decomposition Coefficient (RSDCO)	0.10	
5. Phosphorus Sorption Coefficient (PSP)	0.015	
6. Biological Mixing Efficiency (BIOMIX)	0.40	
III. Physical Parameters		
1. Fraction Of Algal Biomass That Is Nitrogen (AI1)	0.090	Neitsch <i>et al.</i> (2002)
2. Fraction Of Algal Biomass That Is Phosphorus (AI2)	0.020	
IV. Upper Soil Layer¹		
1. Nitrate	5 mg kg ⁻¹	Shah <i>et al.</i> (2006)
2. Organic Nitrogen	920.00 mg kg ⁻¹	
3. Soluble Phosphorus	4 mg kg ⁻¹	
4. Organic Phosphorus	313 mg kg ⁻¹	
V. Ground Water¹		
3. Nitrate	8.65 mg L ⁻¹	Dahlen and Milosh (2002)
4. Soluble Phosphorus	0.20 mg L ⁻¹	

¹Values are applied to the upper part of the watershed, above the ambient station B9480000 (Fig. 1), where hog farms are heavily and almost evenly distributed

Table 2. Statistical measures to compare model simulation and observed flow at USGS 02108000 during the study period 1999 - 2005

Simulation year	Total Rainfall (mm)	Mean Flow (m ³ month ⁻¹)		Standard error for mean difference (×10 ⁷)	P > t	NS	R ²	RMSE	RE
		Simulated (×10 ⁷)	Observed (×10 ⁷)						
1999	1,851.38	11.76	10.79	1.20	0.430	0.92	0.92	0.40	0.09
2000	1,360.09	4.89	5.31	0.52	0.420	0.66	0.76	0.35	0.08
2001	1,018.86	3.30	3.45	0.42	0.720	0.84	0.85	0.42	0.04
2002	1,267.63	4.09	2.82	0.29	0.001	0.61	0.85	0.59	0.45
2003	1,763.52	8.94	9.54	0.82	0.480	0.76	0.81	0.30	0.30
2004	1,341.03	5.55	4.82	0.53	0.200	0.27	0.44	0.41	0.15
2005	1,455.02	3.66	4.18	0.45	0.270	0.62	0.77	0.39	0.12
Over All	1,436.79	6.02	5.85	0.26	0.480	0.89	0.88	0.40	0.31

Results and Discussion

Flow Calibration

Stream flows were calibrated by comparing simulated stream flows and observed stream flows at the USGS station 02108000 for the study period spanning from 1999-2005. Figure 2 illustrates the time series plot of the monthly observed flows and the model predicted flows. The model simulated the magnitude and trend of flows well in this watershed. Average simulated and observed flows were not significantly different at 0.05 confidence level, except 2002 (dry year) where the model simulated higher flows (Table 2). As a result RMSE was estimated slightly higher for 2002. In addition, the model simulated slightly higher flows during 2004, resulting lower values of R-Square and NS. However, the model predicted monthly averaged flows ($6.02 \times 10^7 \text{ m}^3$) were closer to the observed flows ($5.84 \times 10^7 \text{ m}^3$). Further agreement between observed and simulated flows was shown by high R-Square value (0.88) and NS value (0.89). Additionally, the low error values associated with the model prediction further confirmed the agreement. It should be noted that there were some daily flow inconsistencies associated with localized rainfall distributions in the NECFR watershed.

Nutrient Calibration

Field data collected at the NCDWQ ambient monitoring station (B9480000) was used to calibrate model simulated sediment, TN and TP concentrations. The simulated and predicted sediments, TN and TP are presented in Fig. 3 to 5, respectively. The distribution plot for sediment and TN indicated that the monthly-observed values were within the interquartile range of daily-predicted values in each month, suggesting that the model simulated concentrations were close to the observed concentrations during the calibration period. For TP, the simulated concentrations were also within the range of daily predicted concentrations, except during January through March (Fig. 5). The concentrations were slightly under predicted during the first three months

Overall, the analysis of variance results indicated that average model predicted values for all studied parameters were not significantly different from the field observed values ($p > 0.05$). The predicted overall concentration of sediment, TN and TP were 36.3, 1.3 and 0.2 mg L^{-1} , where the field observed values were 35.3, 1.2 and 0.2 mg L^{-1} , respectively.

Nutrient Contribution Assessment

The calibrated SWAT model was used to assess nutrient contributions from point sources and nonpoint point sources. Details are provided below.

Conventional Point Sources

The SWAT model was run with and without conventional point sources from 1999 to 2005 to estimate averaged load delivered from point sources. The nutrient contributions from the point sources were estimated substantially lower than nonpoint sources. Conventional point sources contributed only 0.4, 2.0 and 3.0% of total sediment, TN and TP concentrations, respectively (Table 3). It appears that almost all sediment loads from point sources were deposited and more than 70% of the nutrients were lost due to physical and biological processes in receiving wetlands. Studies have shown that freshwater wetlands could retain more than 60% of N and 70% of P (Saunders and Kalff, 2001; Reddy *et al.*, 1999). However, assimilation capacity of wetlands varies with site specific physical, biological and chemical conditions (Reddy *et al.*, 1999; Johnston, 1991).

Non-Point Sources

Model predicted nonpoint sources sediments, TN and TP and sediments loadings from various land use types are presented in Table 3.

Sediment

Developed open spaces, agricultural lands and forest wetlands are the major sources of sediment loadings from the NECFR watershed to the LCFR, which cumulatively contributed 61,394.31 tons per year. Although the developed open lands cover only 3% of the NECFR watershed, they contributed 35% of the total annual sediment load (68,838.60 tons). This could be because the open spaces in the watershed were comprised of impervious surface and erosion control areas. Since the SWAT model uses the USLE equation (Wischmeier and Smith, 1978), the combined effects of rainfall intensity factor (R) and crop cover factor (C) plays a significant role in estimating soil losses. High C value associated with open space would have enhanced soil erosion from the open spaces during high rainfall period. The C value is relatively low for agriculture lands due to Bermuda grass and hence soil loss from the agriculture lands appears to be 0.15 tons/ha as compared to 1.83 tons/ha from the developed open lands.

Total Nitrogen

Agricultural lands, forested lands and forested wetlands contributed a major portion of the load (Table 3). They respectively contributed approximately 28, 20 and 33% of the TN load from the NECFR watershed to the LCFR. Forested wetlands covered comparable amount of land area to agricultural and forested lands, but they contributed relatively higher TN load. While forested wetlands are generally considered as sinks for nutrients, the findings of this study suggest that these

wetlands acted as both sinks and sources for nutrients. The relatively higher contribution of nutrients from the

forested wetlands in the NECFR watershed could be due to the following four reasons:

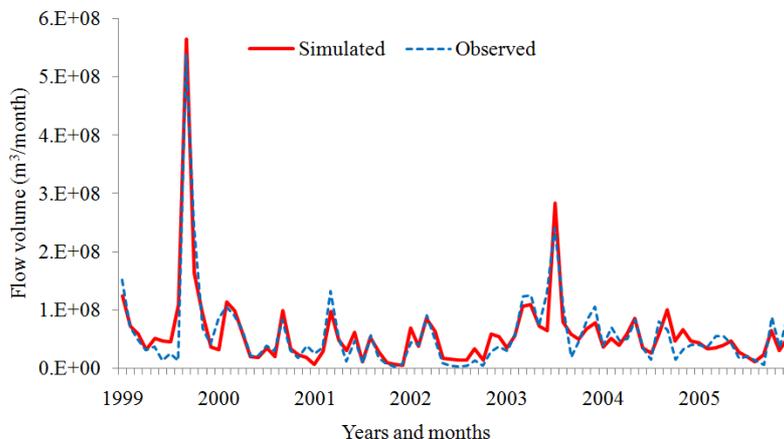


Fig. 2. Monthly total simulated and observed flow volumes at USGS 02108000

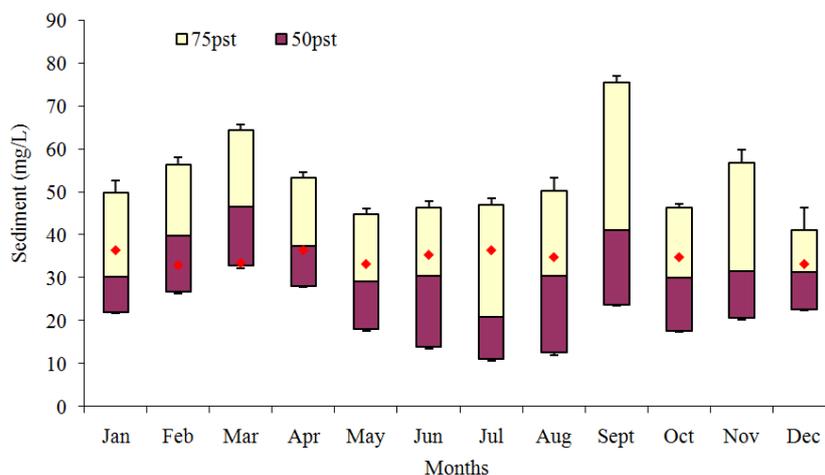


Fig. 3. Monthly observed concentration of suspended sediment Vs quantile distribution of predicted daily suspended sediment at ambient station B9480000

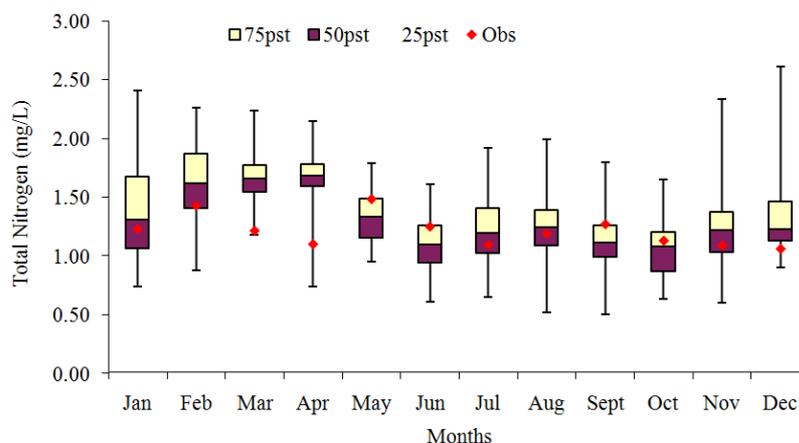


Fig. 4. Monthly observed concentration of total nitrogen Vs quantile distribution of predicted daily total nitrogen at ambient station B9480000

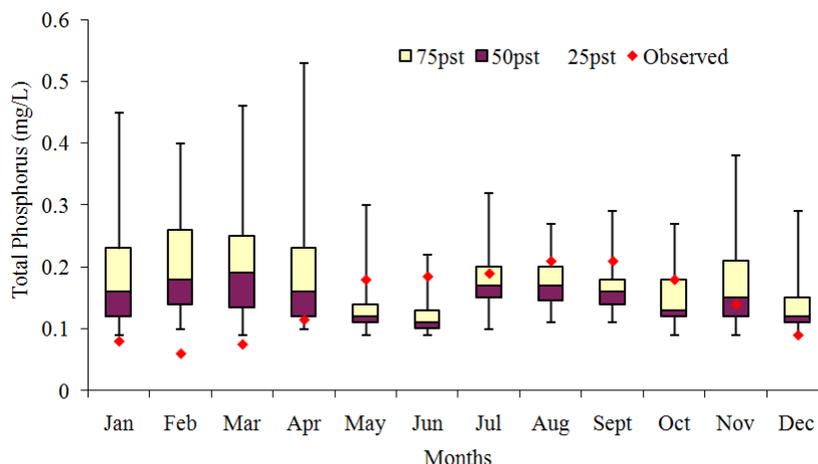


Fig. 5. Monthly observed concentration of total phosphorus Vs quantile distribution of predicted daily total phosphorus at ambient station B9480000

Table 3. Summary of simulated average annual pollutant loads delivered to the Lower Cape Fear River from different land-uses and point sources over the study period

Sources	Area		Sediment		TN		TP	
	km ²	%	tons yr ⁻¹	%	tons yr ⁻¹	%	tons yr ⁻¹	%
Urban Lands	65.94	1.51	1,648.97	2.4	123.25	3.52	10.47	2.32
Developed Open land	1,33.24	3.05	24,420.68	35.48	131.24	3.75	168.98	37.37
Agriculture	1,435.54	32.87	22,241.28	32.31	979.55	28.01	142.40	31.49
Cattle Fields	209.96	4.81	1,706.71	2.48	315.32	9.02	10.19	2.25
Forest Lands	1,167.42	26.73	2,329.42	3.38	706.66	20.21	18.33	4.05
Forest Wetlands	1,320.37	30.23	14,732.35	21.40	1,146.86	32.80	82.85	18.32
Non-forest Wetlands	29.17	0.67	380.27	0.55	21.82	0.62	2.04	0.45
Baren Lands	5.49	0.13	1,123.21	1.63	8.59	0.25	3.81	0.84
Point Sources			255.71	0.37	63.50	1.82	13.14	2.91
Total	4,367.14	100.00	68,838.60	100.00	3,496.79	100.00	452.20	100.00

First, the forested wetlands in the watershed appear that they were not designed to trap nutrient loads coming from adjoining lands. The wetlands functioned as nutrient sources in natural environment, where several streams/creeks drain nutrients through them from adjoining lands. Some of the wetlands are located at the highest reaches of the watershed at the head of and/or in association with first and second order intermittent and perennial stream channels. These wetlands are commonly known as headwater wetlands. Savage and Baker (2007) found that headwater wetlands located in upper reaches of natural watersheds do not have a better filtering capacity than headwater wetlands located in upper reaches of urban and developed watersheds in North Carolina coastal lands. They also concluded that headwater wetlands located in the more urban and highly agricultural watersheds, where hog farming are the prime concern, have lower water quality than wetlands in more natural areas in regards to nitrate and nitrite.

Second, dry biomass accumulation in the forested wetlands were second highest (8.84 tons ha⁻¹ yr⁻¹)

after the forested lands (Table 4), suggesting more Organic Nitrogen (ON) pool is available in the wetland soils of the NECFR watershed. The model prediction is further justified by the actual measured ON concentration during 2004 and 2005 at the ambient stations -B9490000 and B9470000 (Fig. 1). The station B9490000 was located in Angola Creek which flows through forested wetland; whereas the station B9470000 was located in Rock Fish Creek which flows through mixed land uses where agriculture and forested lands dominate the scenario. Organic Nitrogen concentration in Angola Creek remained substantially higher than in Rock Fish Creek throughout the years (Fig. 6). The result suggests that forested wetlands are comparatively critical sources of ON in the NECFR. It appears that mineralization of the ON was poor in the wetland sediment due to their sandy soils having a low capacity for sorption of organic matter. As a result the decomposed organic matter remained soluble in water.

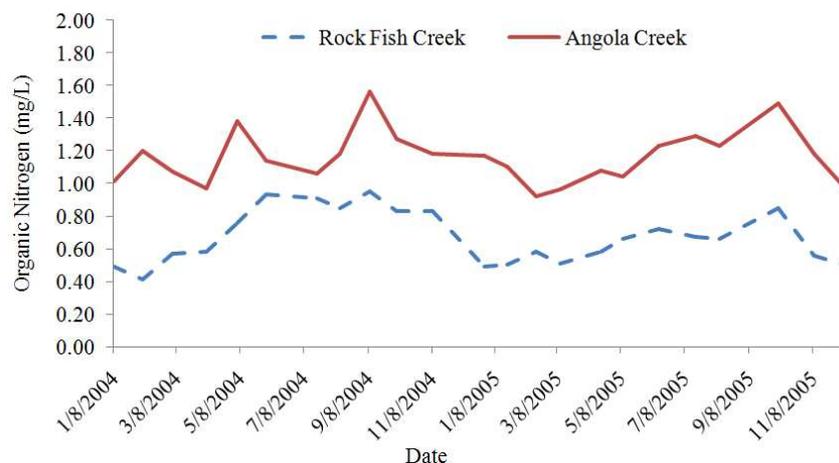


Fig. 6. Attenuation of nitrogen in streams flowing through forested wetland (Angola Creek at B9490000) and Mixed lands (Rock Fish Creek at B9470000) during 2004 and 2005

Table 4. Simulated nutrient dynamics at various land-use conditions

Land use types	Total biomass dry tons ha ⁻¹ yr ⁻¹	Denitrification kg ha ⁻¹ yr ⁻¹	Nitrogen plant uptake kg ha ⁻¹ yr ⁻¹	Phosphorus plant uptake kg ha ⁻¹ yr ⁻¹
Urban Lands	0.47	27.83	35.08	9.06
Developed Open land	3.35	6.03	26.01	6.39
Agriculture	6.59	11.03	47.37	12.64
Cattle Field	0.50	41.21	24.55	3.57
Forest Lands	10.17	25.33	21.59	3.51
Forest Wetlands	8.84	48.23	13.26	2.13
Non-forest Wetlands	5.21	23.2	32.69	12.62
Baren Lands	1.60	33.86	13.34	1.93
Total	36.74	216.71	213.89	51.85

Third, although the simulated denitrification rates in the forested wetlands were substantially higher than any other sources (Table 4), the denitrification rate still seems to be substantially less than the observed rate of 1,200 kg ha⁻¹yr⁻¹ measured in a managed riparian wetland in the Coastal Plain of North Carolina (Sloan *et al.*, 1999). Since the forested wetlands in the NECFR watershed were not managed lands and simulated denitrification rates were only 48.23 kg ha⁻¹yr⁻¹, the results suggest that the natural wetlands were not capable of depleting all of the nitrate sources from the surface like the managed wetlands.

Fourth, plant uptake of N in the forest wetlands were comparatively lower than in agricultural and forested lands (Table 4). As a result, more TN entering the forested wetlands ended up in LCFR through surface and subsurface flows. Compare to forested wetland (1,146.86 tons year⁻¹ of TN), forested lands contributed less TN load (706.66 tons year⁻¹) to the LCFR. The simulated TN loading rates from forested land was approximately 6.05 kg ha⁻¹yr⁻¹. This result is also supported by the study conducted by Chescheir *et al.* (2003) in forested land in the coastal plain of eastern North Carolina. They found less than 6.5 kg ha⁻¹yr⁻¹ of

TN exported from the forested watershed. So the model estimated TN loads was fairly close to their field based rate. Consequently, continuous conversion of forested land to hog farming land may tend to increase TN loads in the watershed.

Also, the SWAT model estimated forest biomass to be 10 tons ha⁻¹. In Eastern USA, forest biomass density ranges widely from 2 to 346 tons ha⁻¹ for softwood forests and from 36 to 344 tons/ha for hardwood forests (Brown *et al.*, 1999). The NECFR watershed is comprised of mostly mixed type of forest, suggesting that the model prediction lies within the range.

Lastly, contribution of TN from urban lands, cattle grazing fields, non-forested wetlands and barren lands were substantially lower compared to forested wetlands and agricultural lands (<10%). The small contribution could be due to the relatively smaller land area occupied by these land-uses in the watershed. These land areas covered only 1.5, 4.8, 0.7 and 0.1% of the total watershed area, respectively.

Total Phosphorus

The developed open spaces, agricultural lands and forested wetlands are the dominant TP contributing non-

point sources (Table 3). Although the developed open space covers only 3% of the watershed, it contributed 37% of the total load of 452 tons yr⁻¹ to the LCFR from the NECFR watershed. Additionally, the agricultural lands and forested wetlands also respectively contributed 31 and 18% of the total load. Since sorption capacity of phosphorus in soil is high, major portions of these loads were due to substantial amount of sediment loads contributed from these land-uses (Table 3). As the sediment loads from other non-point sources were substantially lower, their TP contributions to the river were relatively lower (2-3%) as well.

Like in TN, wetlands in the NECFR watershed could not decrease P loading to downstream aquatic systems. A mechanistic explanation of this observation is unavailable. A further study is required to understand regulation of the wetlands with respect to vegetation composition, periphyton and plankton, plant litter and detrital accumulation, soil physiochemical properties, water flow velocity, water depth, hydraulic retention time, length to width ratio, P loading and hydrologic functions (Reddy *et al.*, 1999).

Conclusion

Nutrient contributions from point and nonpoint sources were identified and assessed in the NECFR using the SWAT model. The SWAT model results suggested that nonpoint sources contributed more than 95% of the nutrient loads to the LCFR. Among the nonpoint sources, developed open spaces, agricultural lands and forested wetlands contributed substantial amount of sediment (61394.31 tons yr⁻¹) and TP loads (294.23 tons yr⁻¹). In addition, the agricultural lands, forested land and forested wetland contributed substantial amount of TN loads (2257.65 tons yr⁻¹) to the LCFR.

Since several streams/creeks drain nutrients from wetlands as well as from adjoining lands, the wetlands functioned as a passive source by transporting nutrients into streams in the natural environment. In addition, the wetlands receive higher amount of pollution input from surrounding agricultural land used for hog farming. However, the lack of research to document the relative contribution of nutrients from the hog farms to the wetlands has hindered to quantify the filtering capacity of the wetlands in this study. Nutrient reduction scenarios without considering the contribution-from wetlands could be a difficult task in this watershed. Therefore, the above findings need to be further justified by conducting a field study to understand assimilative capacity of wetlands in the watershed. Assessments of denitrification and mineralization processes in the forested wetlands are also important areas to consider for future research studies.

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Author's Contributions

Narayan B. Rajbhandari: Study design, data collection, data analysis, model selection, model set up, calibration and validation, manuscript development.

Sushama Pradhan: Model set up, data analysis and manuscript development.

Mauro Di Luzio: Model set up, model verification.

Adugna Kebede: Model performance, manuscript development.

Virginia Baker: Data interpretation, manuscript development.

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