Application of Soil and Water Assessment Tool for Northeast Cape Fear River Watershed

Draft 2

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Executive Summary

The State of North Carolina has initiated development of a Total Maximum Daily Load in the Lower Cape Fear River (LCFR) where low dissolved oxygen is a prime concern. Studies have shown that the presence of hog farms and wetland together with industrial and municipal point source discharges in the watersheds could add significant amount of nitrogen and phosphorus to the LCFR. In order to quantify the amount of nitrogen and phosphorus discharged to the LCFR, the Division of Water Quality and Lower Cape Fear River Basin Advisory Group jointly selected Northeast Cape Fear River (NECFR) watershed for a study on May 5, 2005. The main objectives of the study are:

- To estimate Total Nitrogen (TN) and Total Phosphorus (TP) loads discharged from NECFR to LCFR under varying land use and management conditions.
- To support the hydrodynamic and nutrient response model which will be used as a tool to develop a DO Total Maximum Daily Load (TMDL) for LCF estuary.

The NECF watershed occupies approximately 1693 square miles (438,523 ha). The watershed covers 33% of agricultural land, 31 % of forest land, 30% of Forested Wetland, 1% of Non-forest Wetland, 1.6% of Developed Land, 3% of Open Space, and 0.4% of Water Body.

The watershed represents blackwater systems in the North Carolina Coastal Plain. The majority of the watershed falls within the two coastal plain counties of Duplin at the northern part and Pender at the southern part of the watershed. According to the 1998 estimates, Duplin County has large number of swine operations in the watershed. Most of the agricultural lands in the watershed are spread with hog waste, which contains large quantities of both organic and inorganic nitrogen and phosphorus.

The ArcView Interfaced Soil and Water Assessment Tool (AVSWAT) model is used to estimate TN, TP, and DO loads discharged from different point and nonpoint sources in the NECFR watershed. It is a continuous model and enables the user to simulate runoff and pollutant transport processes up to 100 years. Large watersheds up to two thousand square miles can be studied, and selected heterogeneous watersheds can be divided into hundreds of sub-basins. Each sub-basin can be characterized under eight major components; hydrology, weather, erosion/sedimentation, soil temperature, plant growth, nutrients, pesticides, and land management.

The model is calibrated for flow, TN, TP, and DO for the period from 1999 through 2005. The USGS Station near Chinquapin (USGS 02108000) was selected for flow calibration and the ambient station near Burgaw (B9480000) was selected for nutrient calibration. Overall, the difference between simulated and observed flow volume and nutrient concentrations are not significant at 95% confidence level. The relative error associated with model prediction is well below the US EPA guidance value of 45% for TN and TP. The error value for DO is slightly above the guidance value of 15%. However, the model prediction of DO seems to be satisfactory, because the R-Square value is moderately high.

Comparing its results with FLUX estimation of daily nutrient loads validates the model. A reasonable agreement between the two models is observed.

The model results suggested that nonpoint sources contributed more than 90% of the nutrient loads to the Lower Cape Fear River. Among the nonpoint sources, agricultural land and forested wetland contributed a major portion of the load (Table A). They respectively contributed approximately 30% and 40% of the total nitrogen load and 60% and 20% of the total phosphorus load during normal and dry years. It is observed that the nutrient load was high during March for dry period and during September for normal period.

Table A: Annual average total nitrogen and total phosphorus loads under different land use conditions.

Constituents/ Land Uses	**Period**	
Total Nitrogen (lb)	**Normal**	**Dry**
Agriculture	2,367,953	1,448,846
Forest	1,857,372	878,482
Open Space	409,451	215,278
Urban	384,702	252,908
Wetland Forest	3,310,620	1,997,946
Wetland Non-Forest	64,825	37,194
TOTAL	**8,330,098**	**4,793,460**
Total Phosphorus (lb)		
Agriculture	434,553	270,391
Forest	62,415	22,702
Open Space	29,259	13,309
Urban	25,886	16,918
Wetland Forest	148,055	90,067
Wetland Non Forest	4,026	2,159
TOTAL	**700,168**	**413,387**

The model results conclude that the forested wetlands in the NECRF watershed were not designed to trap nutrient loading coming from adjoining lands. The wetlands functioned as a passive source by transporting nutrients into streams in the natural environment. Several streams/creeks drain nutrients from wetlands as well as from adjoining lands. In agricultural land, a significant portion of the phosphorus load was due to erosion. It accounts for 70% of the total load. Adoption of proper BMPs in the watershed would reduce the heavy nutrient loads.

INTRODUCTION

A portion of Lower Cape Fear River (LCFR), from Toomers Creek to Snows Cut (5,616.7 Acres), is currently on North Carolina's 303(d) list of impaired waters for low dissolved oxygen (DO) violations (Figure 1). This portion of the river has been considered impaired since the 1996 Cape Fear River Basinwide Water Quality Plan. Sources of low DO level include many discharges of oxygen consuming waste into this segment and to the tributary streams. There is a considerable volume of blackwater that may also contribute natural sources of oxygen consuming materials. In addition, the river is influenced by tides and high flows from the entire basin. Therefore, the river goes through many extreme changes in water column chemistry over the course of a year.

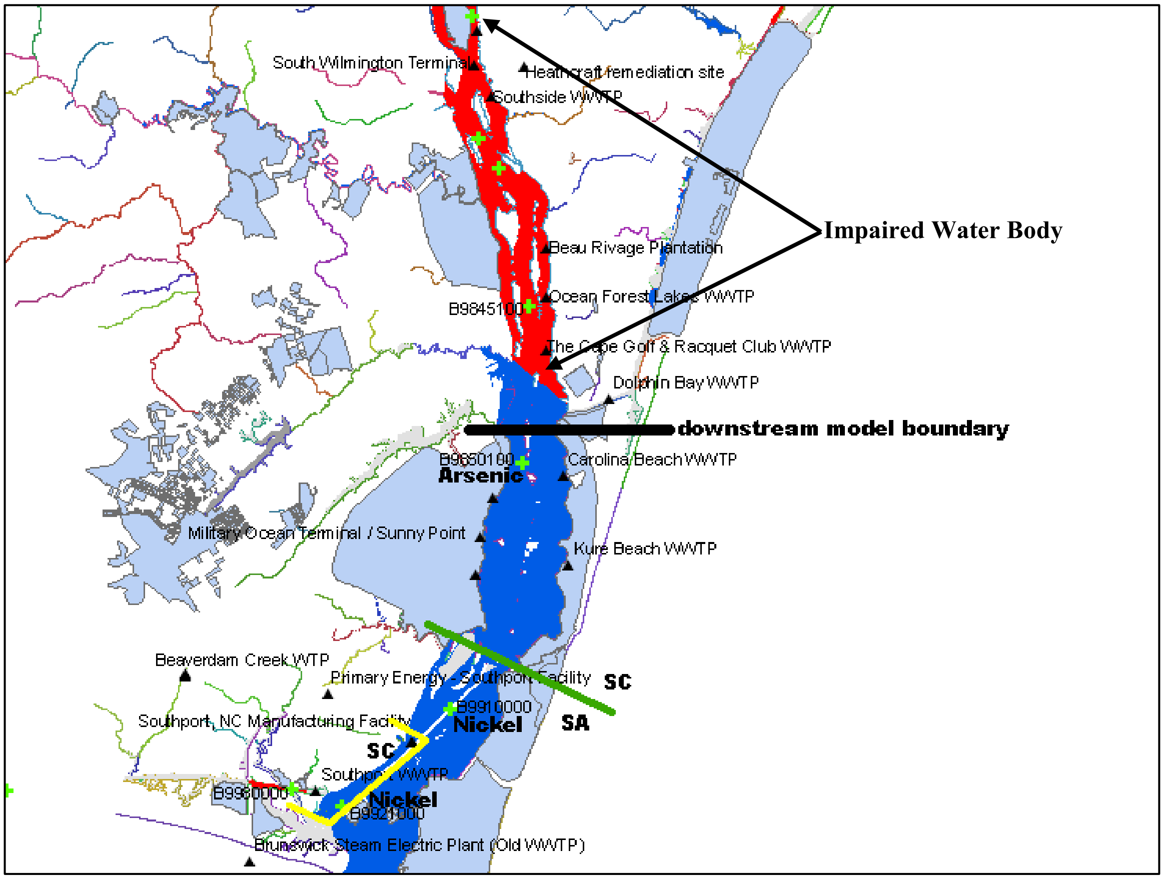


Figure 1. Low Do violation section in Lower Cape Fear River.

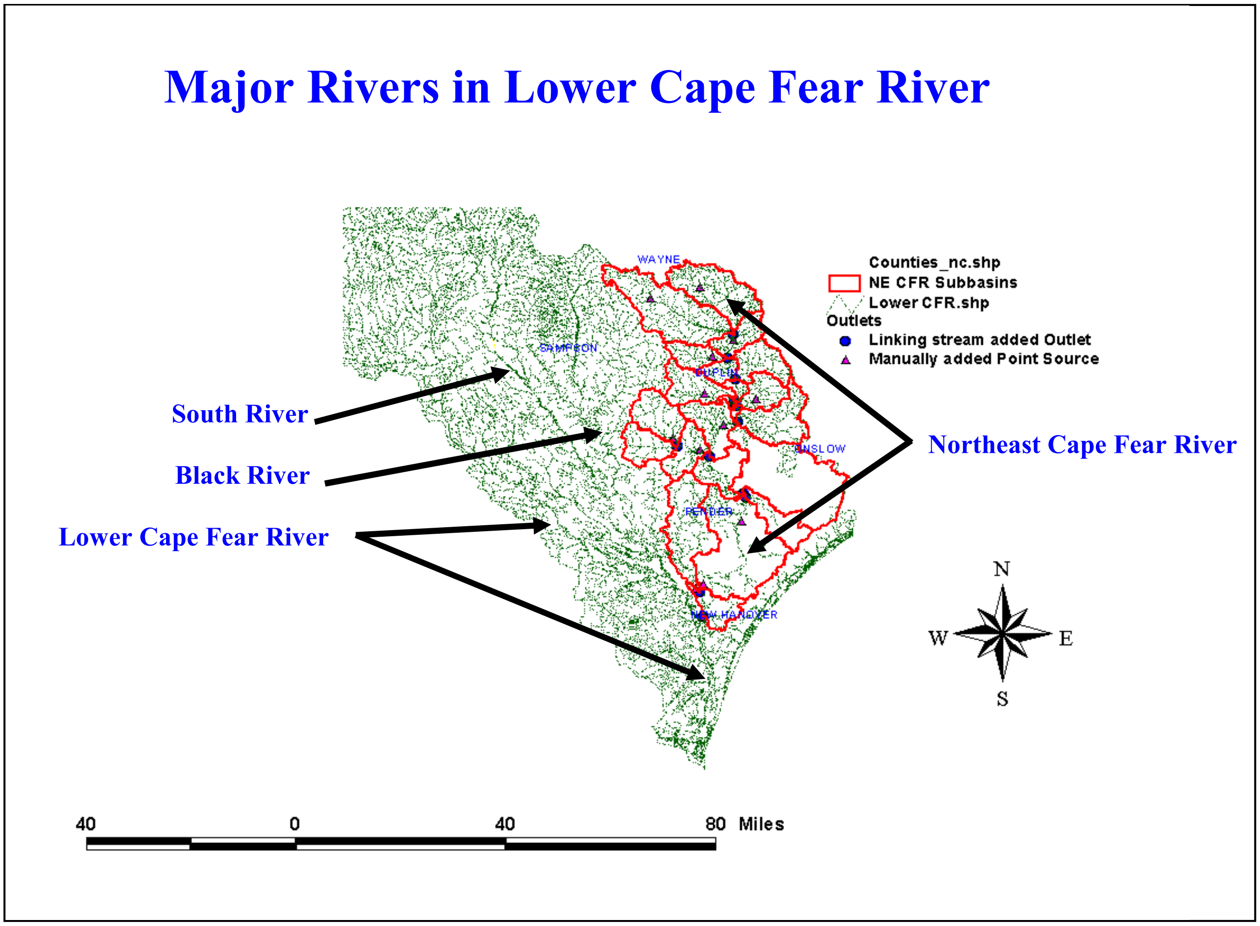


Figure 2. Location of major rivers feeding Lower Cape Fear River.

Three major tributaries, South River, Black River, and Northeast Cape Fear River, feed major portion of the LCFR (Figure 2). Streams within the watersheds of these tributaries drain predominantly agricultural land, forested land, and wetland.

On May 5, 2005, the Division of Water Quality and Lower Cape Fear River Basin Advisory Group jointly selected Northeast Cape Fear River (NECFR) watershed for a study to estimate total nitrogen (TN) and total phosphorus (TP) that are transported to LCFR from the watershed under different land use and management conditions. The watershed occupies approximately 1693 square miles (438,523 ha) across Samson, Wayne, Duplin, Onslow, Pender, and Hanover counties. The majority of the watershed falls within the two coastal plain counties of Duplin at the northern part and Pender at the southern part of the watershed. According to the 1998 estimates, Duplin County carries a greater part of swine operation in the Cape Fear River Basin. Most of the agricultural lands in the watershed are spread with hog waste, which contains large quantities of both organic and inorganic nitrogen and phosphorus (Mallin et al. 1997). In addition, heavy deposits of organic nutrients and low DO levels characterize wetlands in the watershed. Considering these complex characteristics, this watershed was selected for a study to determine sources of nutrient loads to LCFR.

This study addresses Total Nitrogen (TN), Total Phosphorus (TP), and Dissolved Oxygen (DO) discharged from NECFR to LCFR under varying land use and management conditions. Results from this study will be used to support the hydrodynamic and nutrient response model which will be used as a tool to develop a DO Total Maximum Daily Load (TMDL) for LCF estuary.

WATERSHED DESCRIPTION

Watershed Boundaries and Land Use

The NECFR flows 113 miles south from its origins (south of the Town of Mount Olive to the estuary in Wilmington). The drainage area of the river is 1693 square miles (438,523 ha). The majority of the study area lies within Duplin County at the northern part and Pender County at the southern part of the watershed (Figure 2). The remaining area along the periphery is distributed in Samson, Wayne, Onslow, and Hanover County. Land cover is estimated from 2000 satellite data. Based on the data, the watershed is comprised of agricultural land (33%), forest land (31%), forested wetland (30%), non-forest wetland (1%), developed land (1.6%), open space (3%), and water body (0.4%) (Figure 3). Developed land includes residential, road, and parking lands. Residential development is mostly concentrated at the lower most part of the watershed. Open space mostly consists of vegetation in the form of lawn grasses. It also includes some mixture of construction materials.

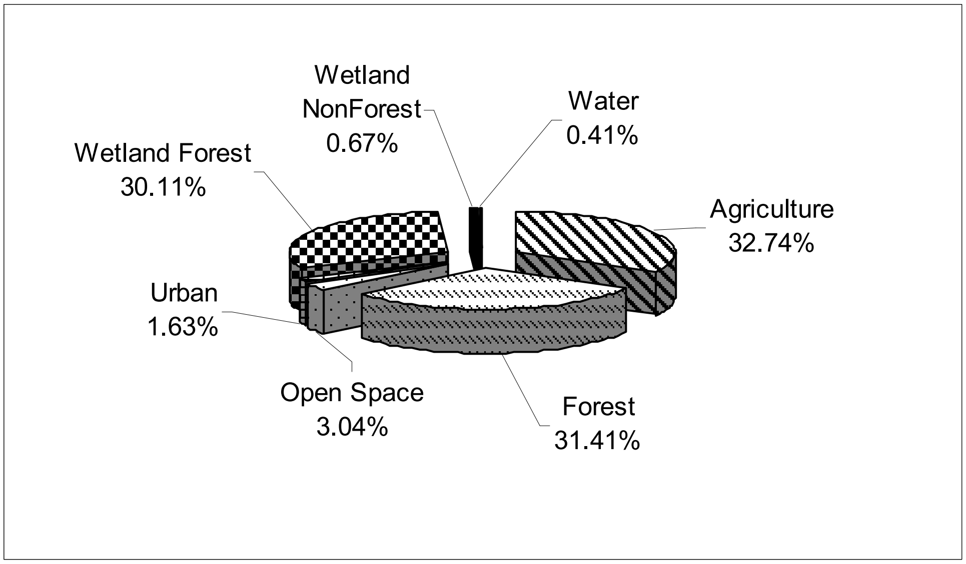


Figure 3. Land cover distribution in Northeast Cape Fear River Basin based on 2000 satellite data.

The NECFR represents blackwater system in the North Carolina Coastal Plain. The system is characterized by low topography, sandy sediments, extensive floodplains, and high concentration of dissolved organic matter (Meyer 1990, Smock and Gilinsky

1992, Philips et al. 2000. As cited by Mallin et al. 2001). Some water quality studies have indicated that both organic and inorganic N and P loading were high in the river. Sources include municipal and private point-source discharges and non-point source inputs from concentrated animal feeding operations and traditional agriculture (Mallin et al. July 1998 Report No. 315 & August 2002 Report No. 341).

Annual average flow of the NECFR near Chinquapin (Ambient Station B2920000, USGS Station 210800000) is 719 cubic feet per second (cfs), with a 7Q10 of 12.1 cfs. However, the low-flow characteristics decrease in the downstream because of poorly drained soil (Weaver and Benjamin, 2001).

Watershed Model Development

Watershed Model Selection

There are several watershed models that range from simple to complex nutrient loading models. For this study, Soil and Water Assessment Tool (SWAT), physically-based watershed model, was selected because of its capability to assess the impact of point and non-point sources on TN, TP, and DO in a large watershed with varying land use and management conditions. The USDA Agriculture Research Service first developed the model in the early 90s. Recently, the model has been interfaced with ArcView GIS in a software package known as AVSWAT (Luzio, et al. 2002). It is a continuous model that enables the user to simulate runoff and pollutant transport processes up to 100 years. Large watersheds up to two thousand square miles can be studied, and selected heterogeneous watersheds can be divided into hundreds of sub-basins. Each sub-basin can be characterized under eight major components; hydrology, weather, erosion/sedimentation, soil temperature, plant growth, nutrients, pesticides, and land management.

Model Description

Hydrology:

The watershed model computes surface runoff volume using a modification of the SCS curve number method and peak runoff rate predictions using a modification of the rational method. The model routes flow through the channel using a variable storage coefficient method or Muskingum routing method. For this study, the Muskingum method was used due to its ability to route flow in wide applications.

Water Quality:

The watershed model monitors five different pools of nitrogen in the soil. Two pools are inorganic forms of nitrogen, while the other three pools are organic forms of nitrogen. Fresh organic nitrogen is associated with crop residue and microbial biomass, while the active and stable organic N pools are associated with the soil humus. The organic nitrogen associated with humus is partitioned into two pools to account for the variation in availability of humic substances to mineralization. TN is the sum of organic and inorganic nitrogen.

The model considers six different pools of P in soils. Three pools are inorganic forms of P while the other three pools are organic forms of P. Fresh organic P is associated with crop residue and microbial biomass while the active and stable organic P pools are associated with soil humus. Soil inorganic P is divided into solution, active, and stable pools. TP is the sum of organic and inorganic P.

The model allows nutrient levels to be input as concentrations. However, it performs all calculations on a mass basis. To convert a concentration to a mass, the concentration is multiplied by a bulk density and depth of layer, and is then divided by 100.

Nutrient transformations in the stream are controlled by in-stream water quality component of the model. The in-stream kinetics used in the model for nutrient routing is adapted from the QUAL2E model (Brown and Barnwell, 1987). The model tracks nutrients dissolved in the stream and nutrients adsorbed to the sediment. Dissolved nutrients are transported with water, while the absorbed nutrients are deposited with the sediments on to the channel bed.

The watershed model computes the amount of DO entering the main channel with surface runoff using the QUAL2E model (Brown and Barnwell, 1987). Rainfall is assumed to be saturated with oxygen. To determine the dissolved oxygen concentration of surface runoff, the oxygen uptake by the oxygen demanding substance in runoff is subtracted from the saturation oxygen concentration. Details of the in-stream process of DO is given in Neitsch et al. 2002.

Model Setup

The NECFR watershed is delineated into sub-basins using the stream coverage Reach File and Digital Elevation Model (DEM) maps. The Reach File is initially digitized from the USGS 1:24000 topographic maps in ARC/INFO format. The DEMs in GRID format for the watershed are obtained from USGS. Resolution of the DEMs used for this study is 30 X 30 meters and is patched together in ARC/INFO for the NECFR watershed area. The patched DEMs are then exported into the AVSWAT model to delineate the watershed using automatic delineation tools. A total of 23 sub-watersheds are delineated to estimate watershed parameters such as stream length, stream slope, stream dimensions, overland slope, slope length, Manning’s n, soil erodibity factor K, practice factor P, and crop factor C. The AVSWAT model uses project mask to estimate watershed parameters and is subsequently checked and changed as needed.

The delineated sub-basin map is then overlaid with land use and soils. The land use/land cover data that is developed from 2000 LANDSAT satellite imagery is utilized to characterize the watershed land use distribution (Figure 3). The data is obtained from the United State Geological Survey database (USGS, April 2005). Soil parameters including bulk density, soil layer, available water, hydraulic conductivity, and texture type are acquired from the U.S. General Soil Map database (USGS, July 2007). There are fourteen types of soils in the watershed (Table 1).

The model assigns a hydrologic unit code to each land use and soil types in each sub-watershed to estimate hydrologic responses and nutrient pools. The estimated hydrologic responses and nutrients pools are then routed towards watershed outlets.

Table 1. Surface physical characteristics of soil types in Northeast Cape Fear River.

STMUID	Name	AREA	Bulk Density	Avialable Water	Hyd. Cond	Clay	Silt	Sand
		(%)	(lb/cft)	(in/in)	(in/hr)	(%SoilWt)	(%SoilWt)	(%SoilWt)
NC001	Johnston	6.85	89.46	0.18	1.91	11.50	43.23	45.27
NC003	Tarboro	0.11	105.21	0.09	5.98	7.50	9.02	83.48
NC011	Alpin	0.39	91.35	0.07	14.95	6.50	1.25	92.25
NC019	Baymeade	9.81	105.21	0.05	20.55	4.00	0.61	95.39
NC024	Croatan	1.13	18.90	0.35	9.34	10.00	45.00	45.00
NC028	Leaf	0.90	88.20	0.16	0.93	16.00	40.19	43.81
NC030	Woodington	0.58	97.65	0.15	3.62	11.50	26.01	62.49
NC033	Croatan	23.92	18.90	0.35	9.34	10.00	45.00	45.00
NC034	Rains	7.53	91.35	0.14	4.11	12.50	19.65	67.85
NC035	Norfolk	23.35	102.69	0.12	16.82	5.00	15.77	79.23
NC038	Autryville	16.50	103.95	0.06	11.21	6.00	1.88	92.11
NC039	Leon	7.17	86.94	0.08	39.24	3.00	1.51	95.49
NC040	Kureb	0.59	107.10	0.05	28.03	1.50	1.53	96.97
NC044	Woodington	1.17	97.65	0.15	3.62	11.50	26.01	62.49

Model Inputs

The SWAT model is set up with the following major input parameters: weather, agriculture management, air deposition, and point source discharge.

Weather:

Air temperature and precipitation data during the study periods (1999-2005) are acquired through the State Climate Office of North Carolina for the nearby weather stations of Warsaw, Wallace, Willard, and Wilmington. The amount of rainfall during 2001 and 2002 was less than the long-term mean annual rainfall of 54 inches (Figure 4). Therefore, these years were considered dry years. Wind speed and solar radiation are simulated for the weather stations using the weather generator in SWAT. Evapotranspiration is calculated within the model using the Hargreaves methods.

Agriculture Management:

In the NECFR 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. There are approximately 571 hog farms in the watershed and most of which are located in Duplin County (Figure 5). Large quantity of hog waste is often sprayed on the Bermuda grass land. In general, the hog waste is sprayed on Bermuda grassland from March through September and small grain field from September through March. The DWQ permitted amount of swine waste application rate varies with crop type, soil type, land slope, and county (NCSU, 1999). On an average, hog waste is applied at the rate of 135lb of nitrogen per acre in the watershed during a six month application period.

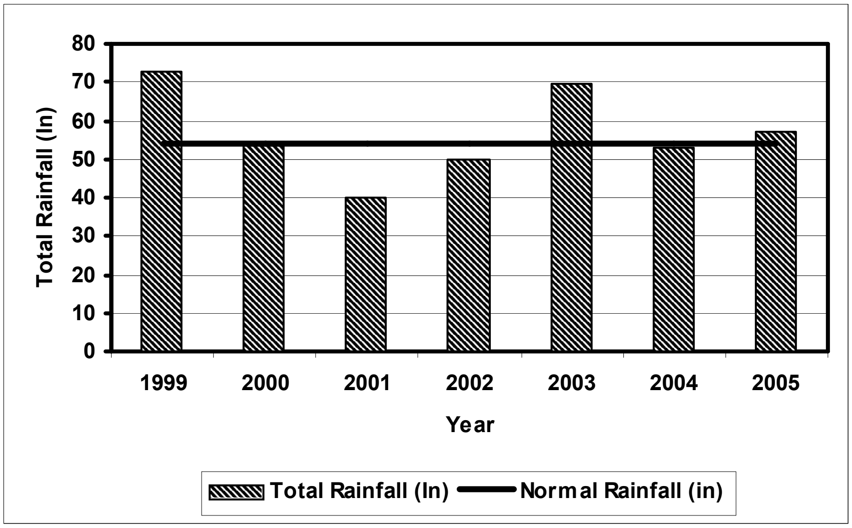


Figure 4. Total annual rainfall from 1999 through 2005 as compared to the average normal rainfall events from 1961 through 1990 in Northeast Cape Fear River.

(Source: http://www.met.utah.edu/jhorel/html/wx/climate/normrain.html.)

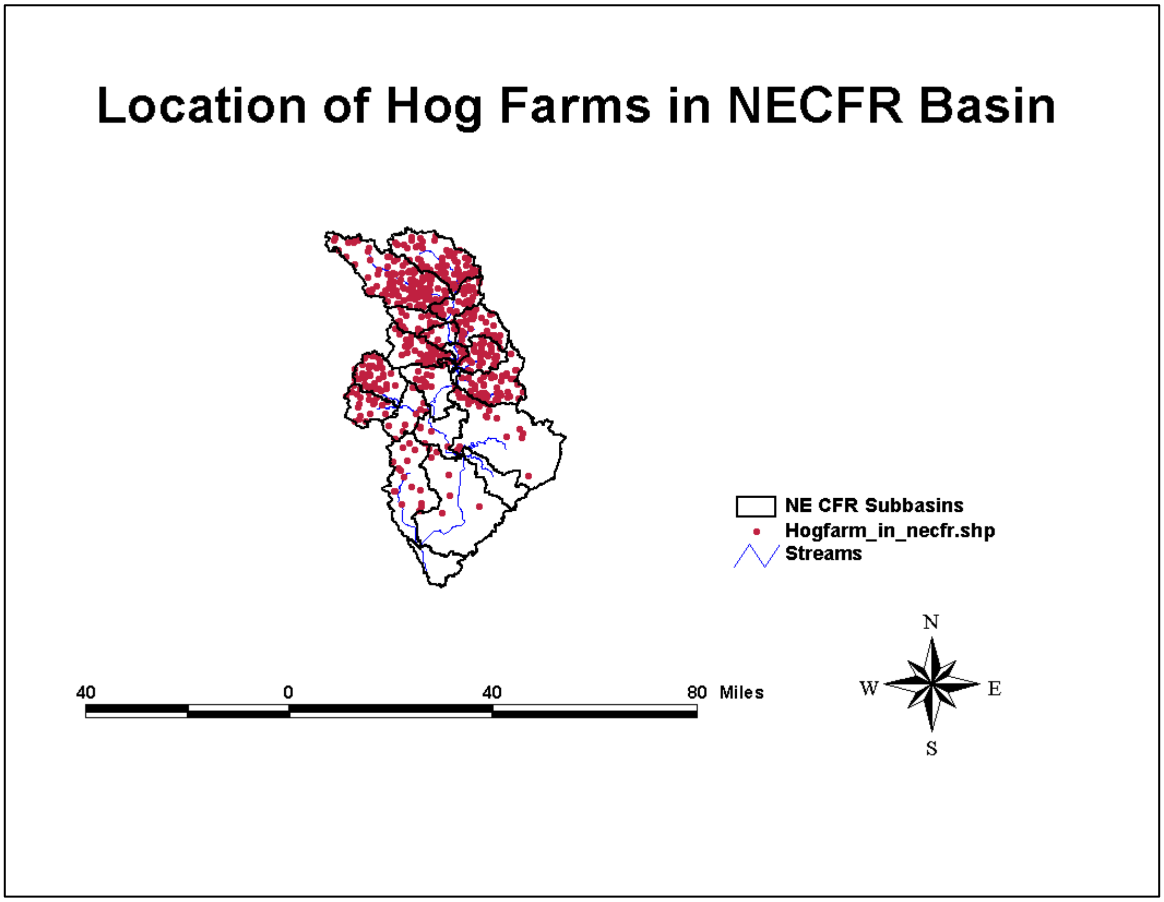


Figure 5. Distribution of hog farms in Northeast Cape Fear River Basin.

Air Deposition:

The North Carolina Department of Environment and Natural Resources (NCDENR) estimates that the swine population contributes approximately 46% of the NH3-N emission in North Carolina (NCDENR 1999). Based on the National Air Deposition Program (UIUC, 2007), precipitation carries approximately 1.3 mg/L of nitrogen (0.43 mg/L of NH4 and 0.83 mg/L of NO3) in the watershed.

Conventional Point Sources:

Conventional point sources are typically those that are regulated under National Pollutant Discharge Elimination System (NPDES) programs in the NECFR watershed. These facilities measure nutrient levels in their effluent at a frequency based on facility class and waste type. Currently there are thirty-one different conventional point sources that discharge wastewater to the NECFR (Table 2). Their annual reports of nutrient loads are presented in Appendix 1. The majority of these sources are distributed across the eastern portion of the watershed.

Table 2. List of NPDES Point Sources in Northeast Cape Fear River Basin.

Permit No.	Facility	No of outfalls
NC0003794	Wilmington Plant	2
NC0000817	Smith Creek WWTP	1
NC0023477	Southern States Chemical Inc	2
NC0058971	Wastec site	2
NC0039527	Walnut Hills WWTP	1
NC0049743	Landfill WWTP	1
NC0051969	Hermitage House Rest Home	1
NC0042251	Pender High School WWTP	1
NC0021113	Burgaw WWTP	1
NC0085481	Penderlea Elementary School	1
NC0056863	Rose Hill WWTP	1
NC0066320	Rose Hill Plant	1
NC0026018	Beulaville WWTP	1
NC0036668	Kenansville WWTP	1
NC0002763	Warsaw Mill	2
NC0058271	Kenansville Cogen plant	3
NC0063711	Albertson W&S District WTP	1
NC0001970	Dean Pickle & Specialty Prod	1
NC0002933	Calypso WTP	1
NC0003051	Mount Olive WTP #3	1
NC0086941	Southeastern Wayne S D WTP	1
NC0001112	Arteva Wilmington	2
NC0001228	Global Nuclear Fuel-Americas	2
NC0003875	Elementis Chromium LP	3
NC0020702	Wallace WWTP	1
NC0003450	Wallace WWTP #2	2
NC0003344	Wallace Processing Plant	1
NC0002305	Gulford East Mill WWTP	1
NC0020575	Mount Olive WWTP	1
NC0001074	Mount Olive Pickle Company	2
NC0086801	Golden Street Olive	1
NC0065307	Dixie Boy NO. 6	1
NC0002879	City of Wilmington	1
	Total Number of Inputs	45

MODEL CALIBRATION

Calibration is the procedure of adjustment of parameter values of a model to reproduce the response of reality within the range of accuracy consistent with the intended application of the model (Refsgaard and Henriksen, 2003). The SWAT model is calibrated for flow, TN, TP, and DO from 1999 to 2005 in order to verify that the adjustment of parameters in the model possesses a satisfactory range of accuracy.

Calibration Procedure

Site Selection for Flow Calibration

There are three USGS gauge stations on the main stream of NECFR (Figure 2). The stations are located in the NECFR near Seven Springs, Chinquapin, and Burgaw. The first station (USGS 210760000) and the third station (USGS 02108566) do not have long term flow data. The only station that has long term flow data is USGS 02108000. It has flow data from 1940 to date (USGS, October 2007). Therefore, the USGS Station 02108000 was selected for flow calibration. This station drains approximately 35% of the NECFR watershed. The observed flow data are tabulated in Appendix 2.

Site Selection for Nutrient Calibration

Water quality data collected by the NC DWQ at the station B9480000 during 1999 through 2005 are used to calibrate the SWAT model for the Northeast Cape Fear watershed (Figure 6). At the station, the DWQ also collected additional water quality data under a special study program to gain more information about water quality during a six weeks period from July 7 to August 11, 2004. The data used for nutrient calibration are tabulated in Appendix 3.

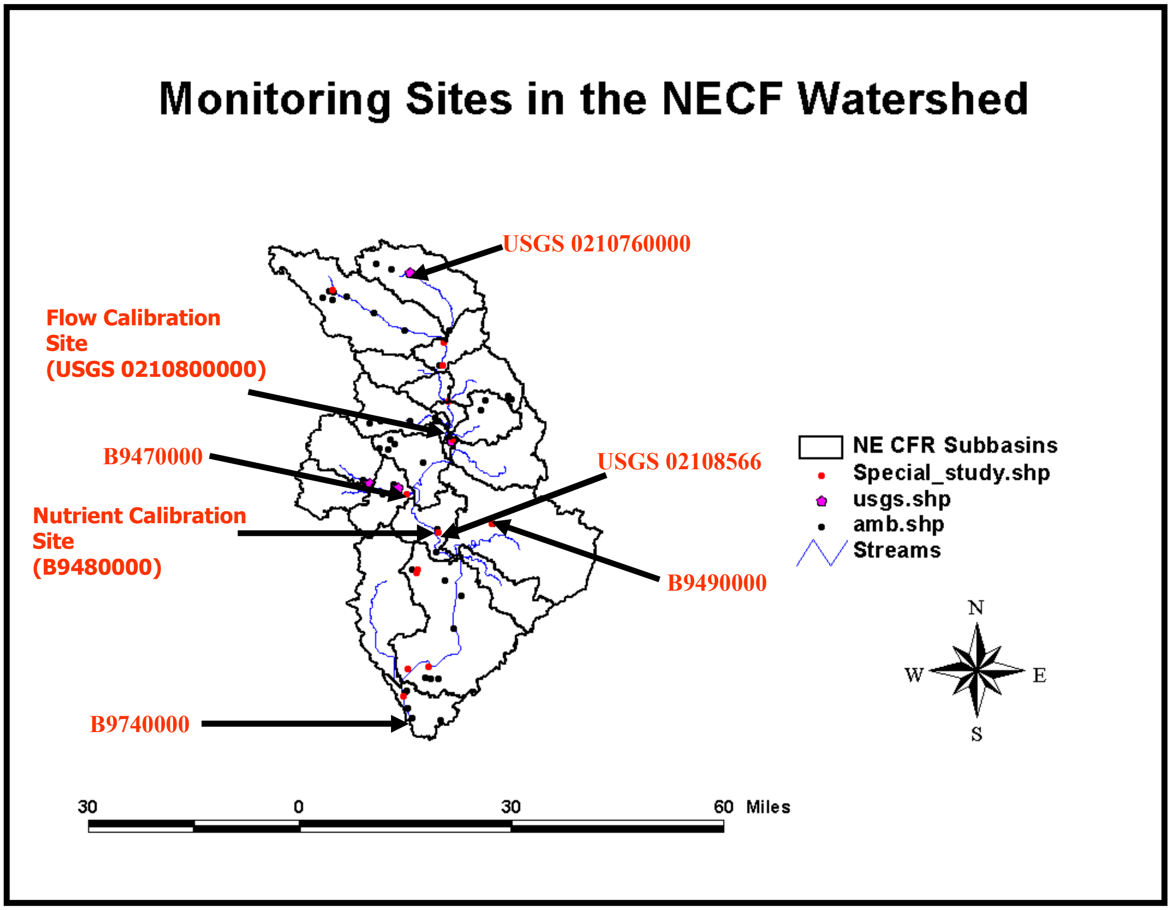


Figure 6. Model calibration location in the Northeast Cape Fear River Watershed.

There is an ambient station, B9740000, at the outlet of the NECFR watershed. However, the water quality collected at this station cannot be used for this calibration purpose because there are frequent tidal effects at the station. The SWAT model does not manage tidal effect.

Adjustment of Hydrologic Parameters

The SWAT model estimates representative CN2 values for various land covers and soil types using the table documented in SCS Engineering Division, 1986. In this study, the SCS CN2 values were reduced by 10% to reflect existing vegetation type, land use management, and soil type in the NECFR watershed. In addition, the following hydrologic parameters are adjusted for flow calibration. The respective values used for calibration are presented in Table (3). Description of the parameters is well documented in Neitsch et al. 2002.

Table 3. Hydrologic Parameters Used for Model Calibration.

Parameters	Calibration Value
A. Evaporation Parameter	
1. Soil Evaporation Compensation Factors (ESCO)	0.95
2. Plant Evaporation Compensation Factor (EPCO)	1.00
B. Ground Water Parameters	
1. Re-Evaporation Coefficient (GW_REVAP)	0.1
2. Threshold Depth In The Shallow Aquifer Factor (GWQMIN)	225mm
3. Deep Aquifer Percolation Factor (RCHRG_DP)	0.3
C. Manning's n for Overland Flow	
1. Developed Land	0.1
2. Pasture Land	0.4
3. Forested Land	0.6

Adjustment of Chemical Parameters

The following nutrient cycling coefficients were adjusted for nutrient calibration. Respective values used for calibration are presented in Table (4). Description of the parameters is well documented in Neitsch et al. 2002.

Table 4. Nutrient Cycling Coefficients.

Parameters	Calibration Value
1. Nitrogen Percolation Coefficient (NPERCO)	0.90
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)	0.4
6. Biological Mixing Efficiency (BIOMIX)	0.05

Adjustment of Physical Parameters

The following stream water quality coefficients were adjusted for DO calibration. Respective values used for calibration are presented in Table 5.

Table 5. Stream Water Quality Coefficients.

Parameters	**Calibration Value at 20^0C**
1. CBOD Deoxygenation Rate (RK1)	3.40 per day
2. Oxygen Reaeration Rate (RK2)	0.60 per day
3. CBOD Loss Rate Due To Settling (RK3)	0.36 per day
4. Benthic Oxygen Demand Rate (RK4)	246 mg/m^2 day
5. Fraction Of Algal Biomass That Is Nitrogen (AI1)	0.090 mg N/ mg alg
6. Fraction Of Algal Biomass That Is Phosphorus (AI2)	0.020 mg N/ mg alg

Description of the parameters stated in Table 5 is well documented in Neitsch et al. 2002. However, for this study, Oxygen reaeration rate and sediment oxygen demand are estimated using following procedures.

Oxygen reaeration rate (RK2): DO is gained in a stream through reaeration. The reaeration rate is measured using the following formula recommended by O'Conner-Dobbins (Chapra and Pelletier, 2003):

$$RK2 = 3.93 * [U^{0.5} / H^{1.85}] \text{ ------------------------ } (3)$$

U = velocity (m/s) and H = depth (m). The average RK2 value was estimated to be 0.60.

CBOD loss rate due to settling (RK3): Its value ranges between –0.36 and 0.36 in the stream at 20^0 C (Day $^{-1}$). For this study, the maximum value was selected.

Sediment oxygen demand (SOD) rate (RK4): The flux of oxygen from water required for oxidation is the sediment oxygen demand. The SOD rate was measured on November 20, 2003 in the NECFR upstream from Wilmington near the outlet of the NECR watershed for this study. The SOD test involves placing aluminum SOD chambers on the bottom sediment, securing them to prevent water infiltration, and monitoring oxygen change within each chamber. A dissolved oxygen sensor inside the chamber measures the rate of decrease in oxygen that is used by organic materials in the bottom sediments over a given period of time. The averaged measured SOD rate at that site is 0.2460 mg/m^2/day. The value is corrected to 20^0 C. For this study, the measured value is assumed to be uniform along the river.

Initial condition

The initial nutrient concentrations are presented in Table 6. For nutrient calibration, SWAT requires initial concentration of Nitrate (NO_3), organic N_2, soluble P, and organic P in soils and ground water. The initial values for soils were acquired from Department of Biological and Agricultural Engineering, North Carolina State University. (Source: personal contact with Dr. Sanjaya Shah.) The initial concentrations for soils were formerly measured for the Orangeburge Loamy Sand Soil in Duplin County. It was, however, assumed that the values were applicable to all soil types in the watershed for this study.

Table 6. Initial Nutrient Concentration in NECFR watershed.

Parameters	Average Value
A. Upper Soil Layer	
1. Nitrate	5 mg/kg
2. Organic Nitrogen	1474 mg/kg
3. Soluble Phosphorus	4 mg/kg
4. Organic Phosphorus	313 mg/kg
B. Ground Water	
4. Nitrate	8.65 mg/L
5. Soluble Phosphorus	0.20 mg/L

The initial value for ground water is acquired from Ground Water Unit, Planning Section, NCDWQ. (Source: Personal contact with Mr. Ray Milosh.) The value was estimated based on quarterly measurement from March 1998 through November 1999 at the Abertson site in Duplin County. The site is a swine operation located in an upland setting in the lower coastal plain. This site is selected because ground water and surface water from this site discharge into Cape Fear River (Dahlen and Milosh, 2002).

Evaluation of Model Prediction

Paired-Different t-test was performed to evaluate the SWAT model performance. This statistical procedure tests whether the average difference between observed and model prediction is significantly different from zero. If the difference is not significantly different from zero, then the model prediction is considered to be acceptable. The model prediction is tested at 95% significance level in this study.

Additionally, other procedures such as Coefficient of Determination (R-Square), Model Efficiency or Nash-Suttcliffe simulation efficiency (ME) (Nash and Suttcliffe, 1970), Root Mean Square Error (RMSE), and Relative Error (RE) were also used to evaluate model prediction. The R-Square value is an indicator of strength of relationship between observed and predicted values. Nash-Suttcliffe simulation efficiency implies how well the plot of observed versus predicted value fits the 1:1 line. The error measurements indicate the difference between observed and simulated values relative to the observed data.

If the R-Square and ME values are close to one, then the model prediction is considered acceptable. If the RMSE and RE values are close to zero, then the model prediction is considered appropriate. There is no specific value that distinguishes between the acceptable and unacceptable values for a watershed modeling purposes. However, the US EPA's Technical Guidance Manual for performing Estuary Waste Load Allocations (USEPA 1990) purposes acceptable relative error statistic criteria of 15% percent for DO and 40% for nutrient parameters.

Calibration error

The inability to accurately predict specific observation within SWAT can be attributed to model error, lack of sufficient information in source assessment, gaps in our scientific knowledge, natural variability in nutrient concentrations, field and laboratory measurement error, and lack of current site specific model input parameters. There are numerous potential errors that can occur in the measured input data and data used for calibration. For example, spatial variability error in rainfall, soils, and land use; errors in measuring flow; and errors caused by sampling strategies (Santhi et al., 2001). Robertson and Roerish (1999) found median absolute error in annual phosphorus loads up to 30 percent depending on sampling strategies. Because of the lack of certain site specific information, professional judgment and literature values were used to calibrate the model. The calibration should be interpreted in light of the model limitations and prediction uncertainty.

MODEL VALIDATION

Validation is the procedure to evaluate that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model. The USEPA (2002) indicates that a model can be evaluated by comparing model predictions of current conditions with laboratory tests, field data, analytical solutions, or synthetic test data sets not used in the model calibration process, or with comparable predictions from other well-accepted models or by other methods (e.g., sensitivity and uncertainty analysis). For this study, the SWAT model is validated by comparing its estimation of TN, TP, and DO loads with a statistical model called FLUX (Walker 1999).

The FLUX model has been approved by the USEPA and is widely used for estimating loadings of nutrients and other water quality components from actual monitoring data. Since nutrient measurement at the ambient station B9480000 was not continuous and the measurement was taken only once a month, the FLUX model is, therefore, selected to estimate nutrient loads for the intervening days. The FLUX estimation of daily loads is then compared with the SWAT estimation. The relationship between the two estimations is evaluated by calculating R-Square value. If the R-Square value is close to one, then the model validation is considered acceptable.

RESULTS AND DISCUSSIONS

Calibration

Flow

The SWAT model is calibrated at the USGS gauge station 02108000 near Chinguapin for flow (Figure 2). The model is run for the period from 1999 through 2005 and its simulated flow is compared with observed flow at the station. The simulated and observed total monthly flow volumes are significantly close during the simulation periods (Figure 7). Means and standard deviations of the observed and simulated flows are not significantly different since the p-value is greater than 0.05 (Table 7). Further agreement between observed and simulated flows is shown by high R-Square value of 0.89 and ME value of 0.90. Additionally, the low error values associated with the model prediction (RMSE =0.40 and RE = 0.27) further verify the agreement.

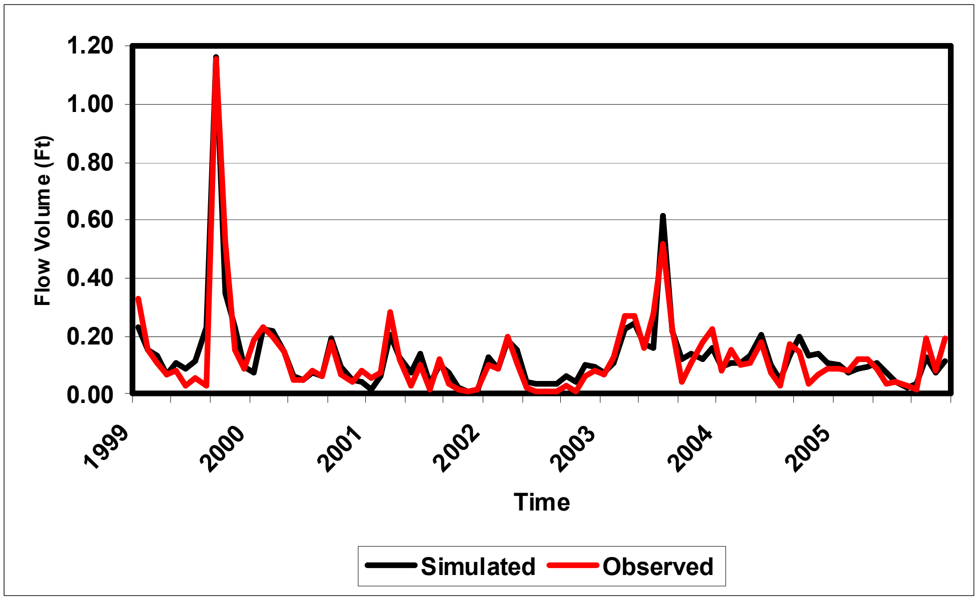


Figure 7. Observed and Simulated Monthly Total Flow at USGS 210800000.

Table 7. Statistical measures to compare model simulation and observed flow and nutrient concentration, 1999-2005.

Variables (units)	Mean		Standard Deviation		ME	R^2	RMSE (%)	RE	p
	Simulated	Observed	Simulated	Observed					
Monthly Total Flow Volume (ft) [1]	0.13	0.12	0.14	0.15	0.90	0.89	40.00	0.27	0.3
Total Nitrogen (mg/L) [2]	1.15	1.22	0.27	0.22	-5.9	0.07	22.00	0.19	0.4
Total Phosphorus (mg/L) [2]	0.16	0.15	0.04	0.04	-0.53	0.11	3.00	0.30	0.6
Dissolved Oxygen (mg/L) [2]	7.7	6.96	1.51	1.20	0.44	0.60	22.00	0.20	0.1

1. Monthly total flow volume estimated from daily flow recorded data at the USGS Station 21080000.
2. Daily nutrients concentration estimated from monthly water sample collected at the Ambient Station B9480000.

Nutrient Concentration

The average concentrations of TN, TP, and DO during the sampled periods, 1999 through 2005, are presented in Figures 7. Overall, difference between the simulated and observed TN, TP, DO concentrations are not significant at 95% confidence level since p-value is greater than 0.05 (Table 7). The error values associated with model prediction for TN and TP are also well below the US EPA guidance value of 45%. The error value for DO is slightly above the guidance value of 15%. However, the model prediction of DO seems to be satisfactory, because the R-Square value is moderately high.

Unlike DO, the R-Square value is substantially low for TN and TP concentrations. The low value suggests a weak relationship between simulation and observed concentrations. The weakness could be due to uncertainty associated with sampling frequency. Water samples were collected only once a month; therefore the uncertainty on the estimation would have increased due to missing data for intervening days (Preston et al. 1989; Hodgkins 2001).

The ME values is also estimated to be negative for TN and TP concentrations. The negative value indicates that the sum of squared model residuals exceeded variance of the observed concentration over the simulation period. The value, however, does not indicate any meaningful evaluation for this study (Lane and Richards, 2003).

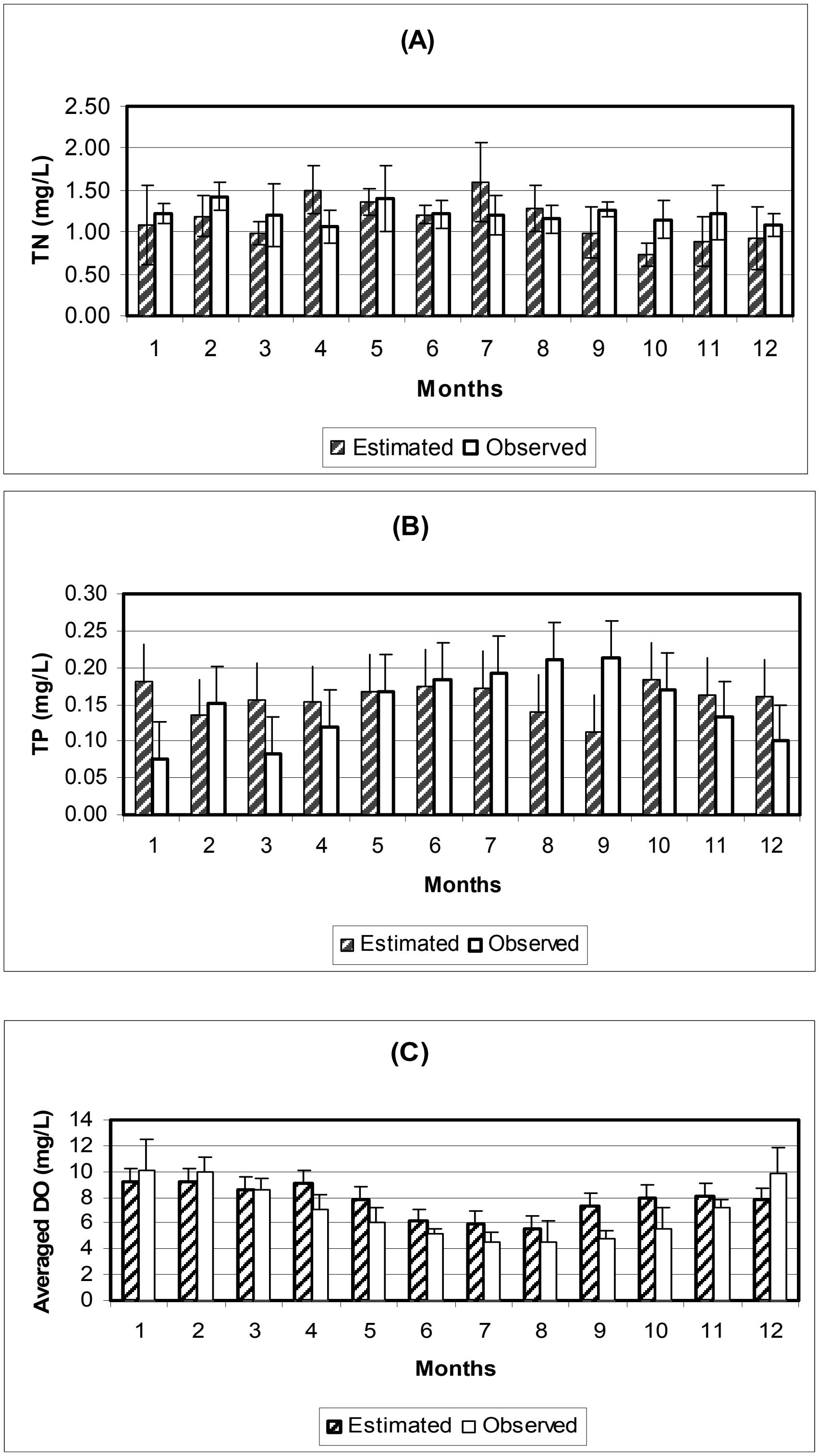


Figure 8. Observed and simulated monthly averaged concentration of (A) total nitrogen, (B) total phosphorus, and (C) dissolved oxygen at the ambient station B9480000.

Model Validation

Validation of the SWAT model is performed by comparing its daily estimated TN, TP, and DO loads with FLUX estimation at the ambient station B9480000. Since FLUX estimates loads from actual monitoring data, both delivered point source and nonpoint source loads are included in the validation.

In order to estimate load, FLUX requires daily flow measurement at the ambient station B9480000. Flow measured at the USGS station 02108566, which is located near the ambient station, is utilized to estimate loads. However, daily flow at the USGS station is available only from September 2003. Therefore, a regression equation is developed to estimate flow for the missing periods, Jan 1999 through August 2003, by regressing daily flow measured at the USGS stations 02108566 and 02108000 (Figure 6). The relationship is expressed by the following equation (4).

Flow at USGS02108566 = $e^{(0.2092 + 1.0275 * \text{Log(flow at USGS 02108000)})}$ ------------------- (4)
R-Square = 0.90.

The high R-Square value indicates strong relationship between the two USGS stations. The relationship is log normal.

Utilizing equation 4, daily flow at the ambient station B9480000 is estimated for the missing periods. The FLUX model is then run to estimate TN, TP, and DO loads at the station. The FLUX estimation provides a coefficient of variation (CV – Standard error divided by mean) that summarizes the quality of fit between predicted and observed loads, where the observed loads are computed from instantaneous concentration times flow. The FULX model and its CVs are summarized in Table 8.

Table 8. Coefficient of variations as estimated by FLUX model.

Constituents	CV
Total Nitrogen Load	0.043
Total Phosphorus Load	0.073
Dissolved Oxygen Load	0.075

The magnitude of the CVs reported in Table 8 is less than 0.1 which suggests that the uncertainty in the loading estimate is significantly low; and hence the FLUX estimate of daily loads are adequate to use for validation purposes.

Comparison of SWAT and FLUX models, 1999 through 2005:

Nearly 70 percent of variation of the FLUX estimation of loads is explained by the SWAT model for TN and TP and 60 percent for DO (Figure 9). The results suggest that the SWAT model provided a good approximation of the FLUX estimates of loads for TN, TP, and DO.

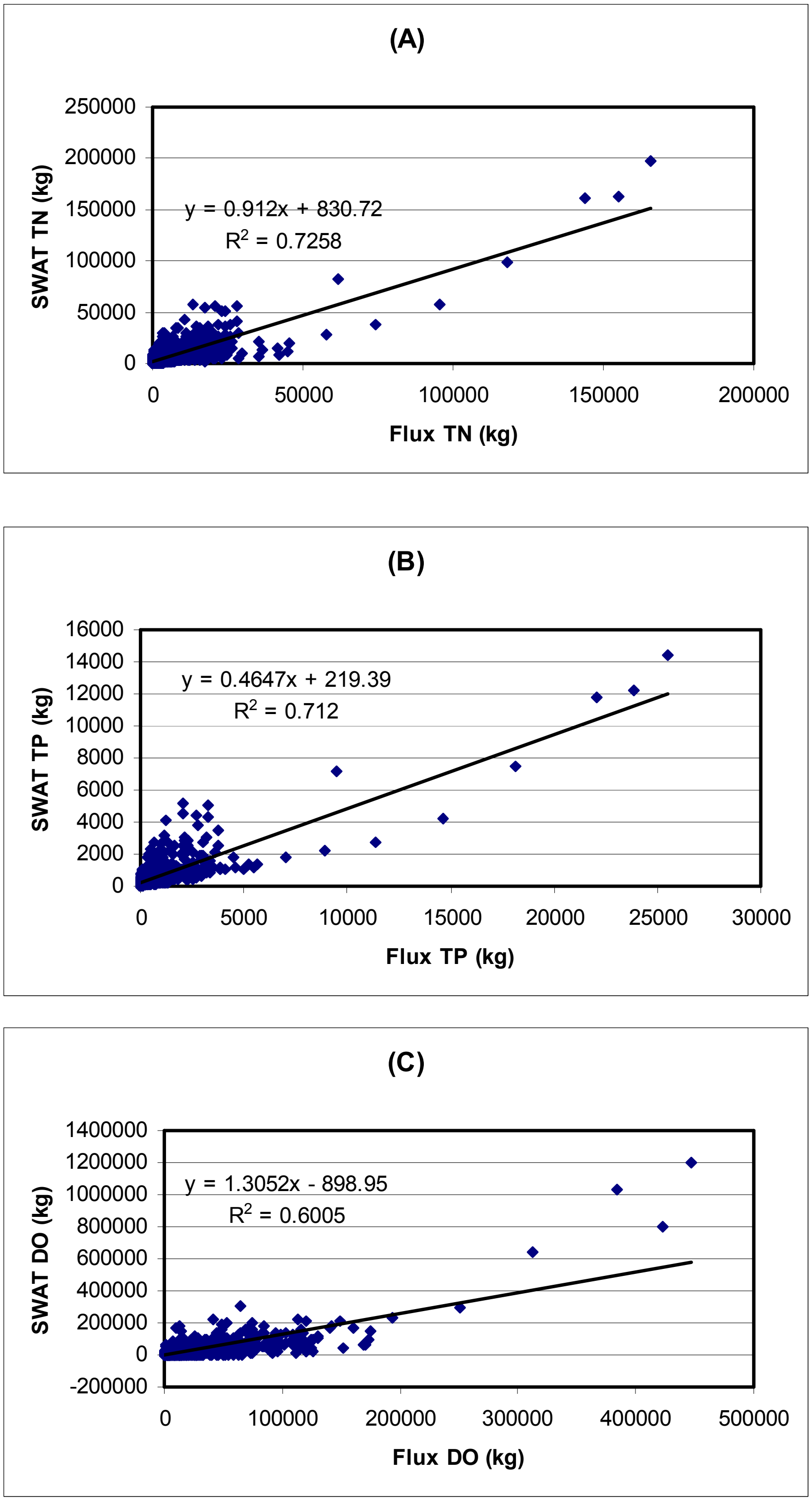


Figure 9. SWAT model comparison to FLUX estimated loads of (A) total nitrogen, (B) total phosphorus, and (C) dissolved oxygen at the ambient station B9480000. Simulation years: 1999 – 2005.

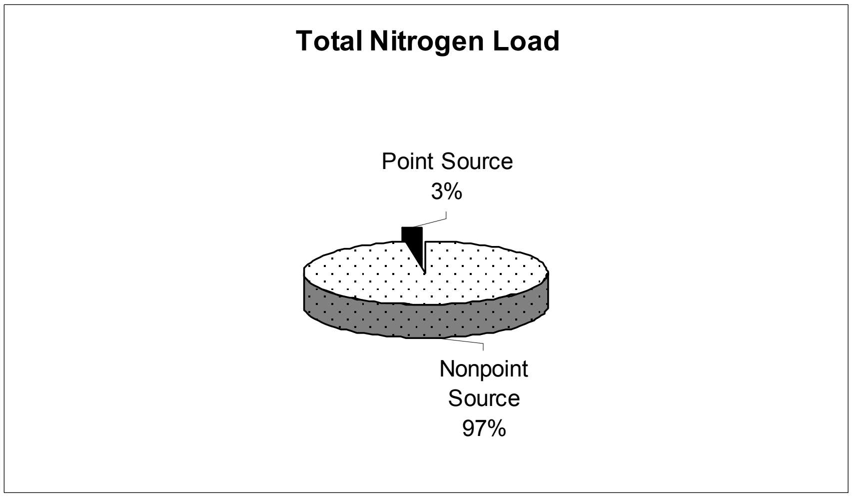
WATERSHED MODEL RESULTS

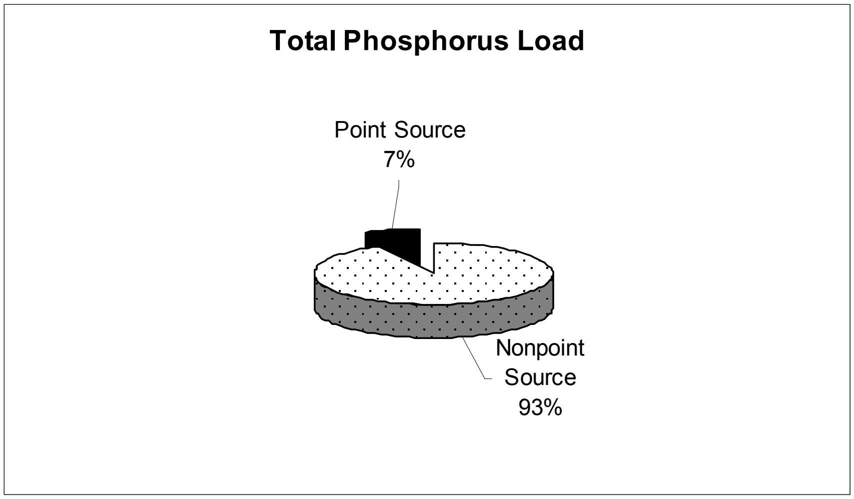
Contribution from Conventional Point Sources

Conventional point sources are typically those regulated under NPDES program and directly discharge domestic and industrial waste in the watershed. A list of the point sources that measure nutrient levels in their effluent at a frequency based on class and waste type in the watershed is given in Table 2. The list does not include MS4 sources.

The SWAT model is run with and without conventional point sources for long term period from 1999 to 2005 to estimate averaged load delivered from point sources. Figure 10 shows the percentage breakdown between point source and nonpoint sources. The percentage contribution from the point sources is estimated considerably low for TN, TP, and DO. Their contributions are 3%, 7%, and 0.4%, respectively.

The nonpoint sources were the major contributors of nitrogen, phosphorus and DO in the Northeast Cape Fear River watershed. The following paragraphs discuss the contribution from non-point sources in detail.





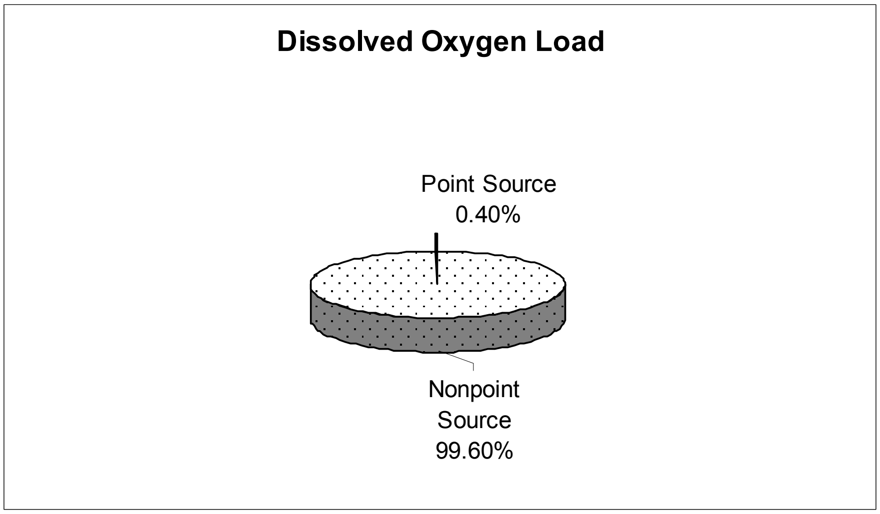
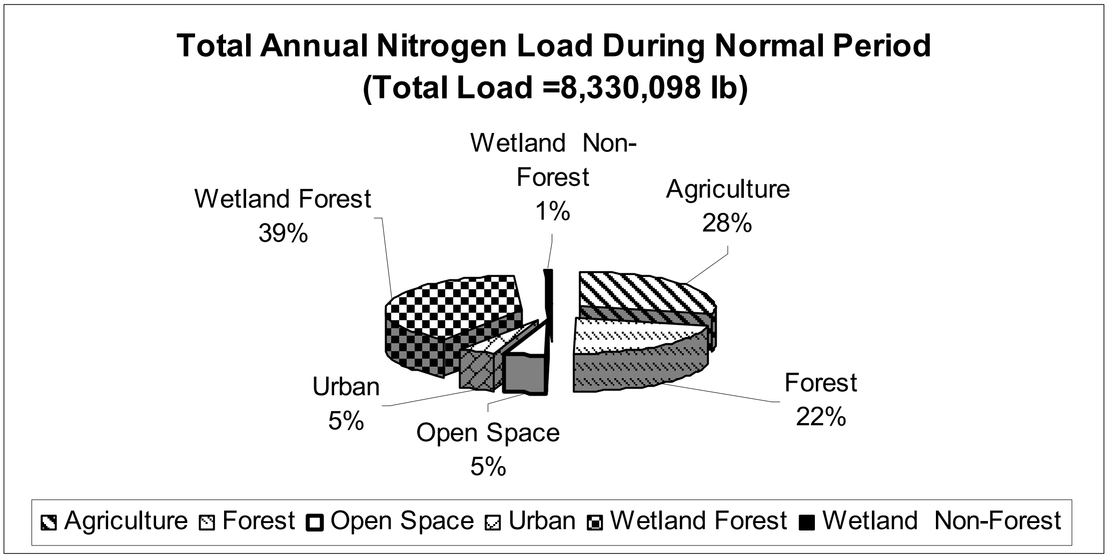


Figure 10. Relative discharge of conventional point and nonpoint source loads to Northeast Cape Fear River.

Contribution from Non-point Sources

The SWAT model is run for long term period, from1999 to 2005, to estimate average loading rates for both normal years and dry years for each land use type. The years, 2001 and 2002, were dry years (Figure 4). Averaged monthly total loading rates by land use (lb per acre) are summarized in Appendix 4. The respective contributing loading rates from each nonpoint source are summarized in Figures 11 through 14.



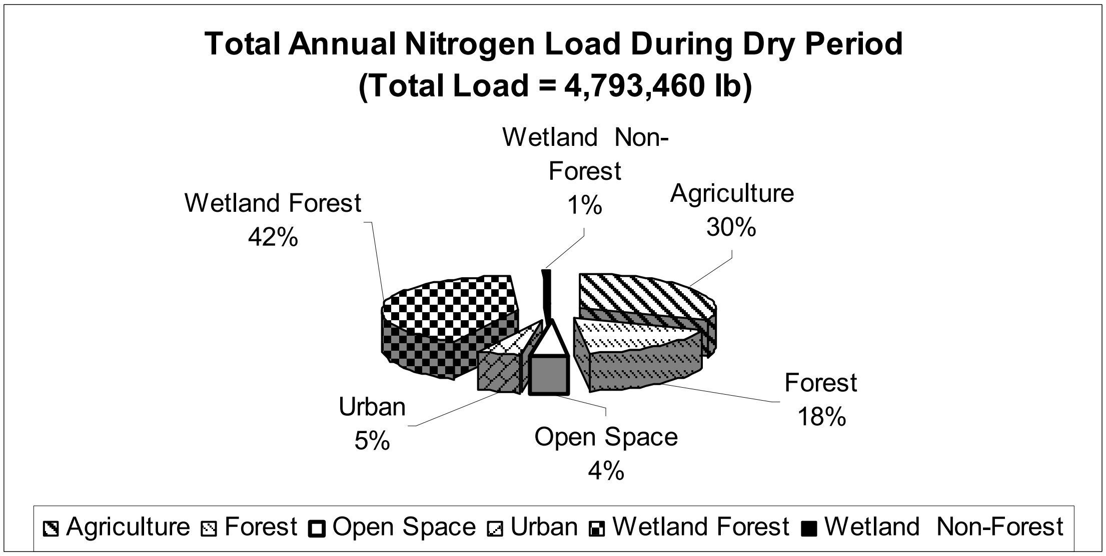


Figure 11. Source attribution of the nonpoint total nitrogen load delivered to Northeast Cape Fear River.

For nitrogen, agriculture and forested wetland contributed a major portion of the load. They respectively contributed approximately 30% and 40% of the total nitrogen load during normal and dry years. Forested wetland covered comparable amount of land area to agricultural and forested lands, but it contributed slightly high TN in the Northeast Cape Fear watershed. The high contribution could be due to the following four reasons:

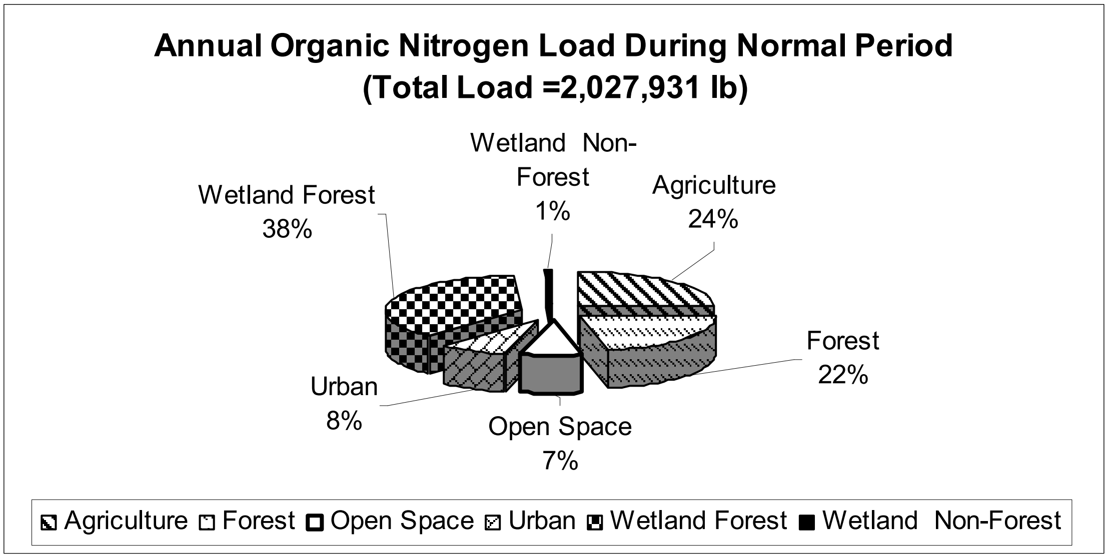
First, the forested wetland in the watershed appears that it was not designed to trap nutrient loads coming from adjoining lands. The wetland functioned in natural environment as a source, where several streams/creeks drain nutrients through it from adjoining lands. Savage and Baker (2007) found that 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. The low filtering capacity could be due to a direct correlation between wetland water quality and surrounding buffer, watershed, and land use.

Second, the forested wetland demonstrated different hydrologic characteristics. Infiltration capacity of the wetland is comparatively low, thereby producing more surface runoff than forested and agricultural lands (Table 9). Since surface runoff is the main carrier of nutrients, the SWAT model predicted more nitrogen transported from wetlands than agricultural land.

Table 9. Related hydrologic and nutrient process under different land use conditions.

Land Use	Runoff	Phosphorus	Nitrogen	Phosphorus	Biomass
		In Soil	Plant Uptake	Plant Uptake	Dry
	(in)	lb	lb	lb	Tons
Urban	21.06	4,328.07	208,006.61	32,102.78	17,892.08
Agriculture	7.09	39,959.36	11,457,938.36	3,098,551.67	2,331,738.71
Open Space	6.61	3,234.44	409,302.64	122,395.66	18,598.86
Deciduous Forest	9.31	141.37	386,130.19	65,403.40	682,136.96
Evergreen Forest	5.97	609.04	3,455,746.42	577,016.28	3,690,116.05
Mixed Forest	6.23	348.74	1,677,532.34	283,784.12	2,983,663.73
Wetland Forest	12.03	8,107.78	3,791,570.96	611,243.60	6,750,007.73
Wetland Non Forest	13.13	192.00	138,899.00	47,607.73	568,580.64

Third, dry biomass accumulation in the forested wetland is substantially higher than in agricultural land (Table 9), suggesting more organic nitrogen pool in the wetland soils. As a result, the forested wetland delivered more organic nitrogen than the agricultural land in the watershed (Figure 12).


Annual Organic Nitrogen Load During Normal Period (Total Load =2,027,931 lb)

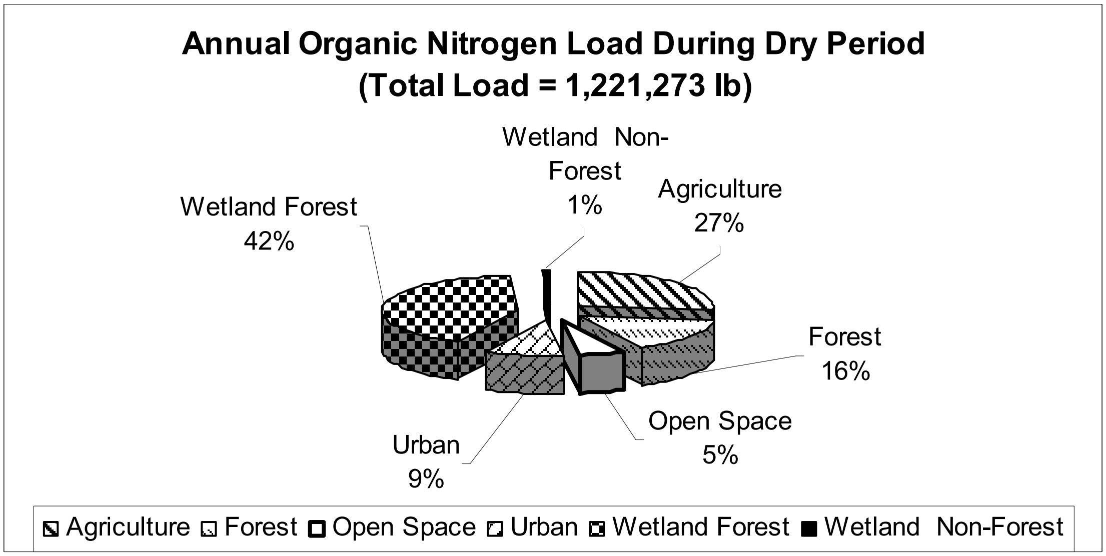
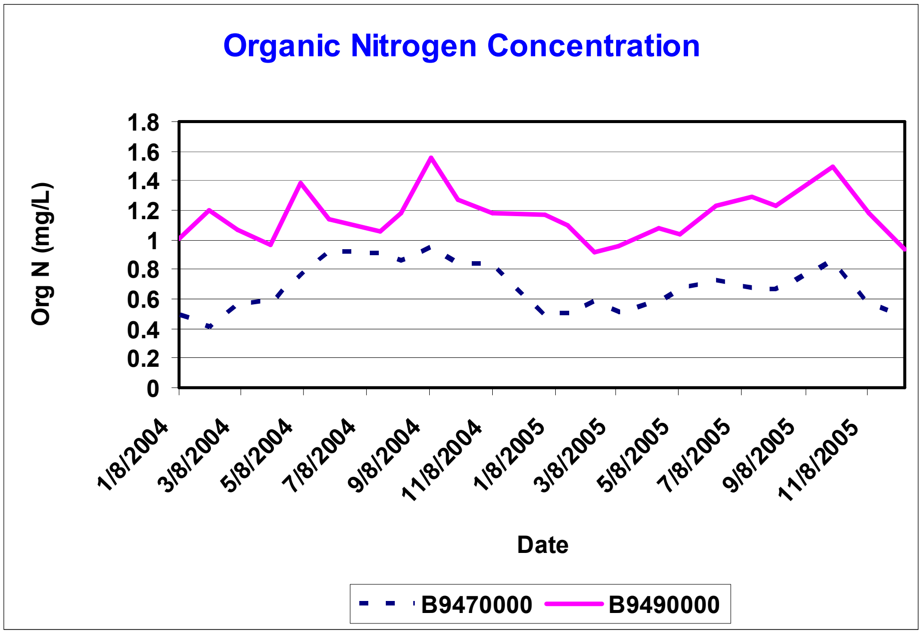

Annual Organic Nitrogen Load During Dry Period (Total Load = 1,221,273 lb)

Figure 12. Source attribution of the nonpoint organic nitrogen load delivered to Northeast Cape Fear River.

The above model prediction is further supported by actual measured nitrogen values during 2004 and 2005 at the ambient stations - B9490000 and B9470000. The station B9490000 is located in Angola Creek which flows through forested wetland, whereas the station B9470000 is located in Rock Fish Creek which flows through mixed land uses where agriculture and forest lands dominate the scenario (Figure 6). Organic nitrogen concentration in Rock Fish Creek remained substantially higher than in Angola Creek throughout the years (Figure 13). The result suggests that forested wetland is comparatively critical to produce organic nitrogen in the Northeast Cape Fear River.



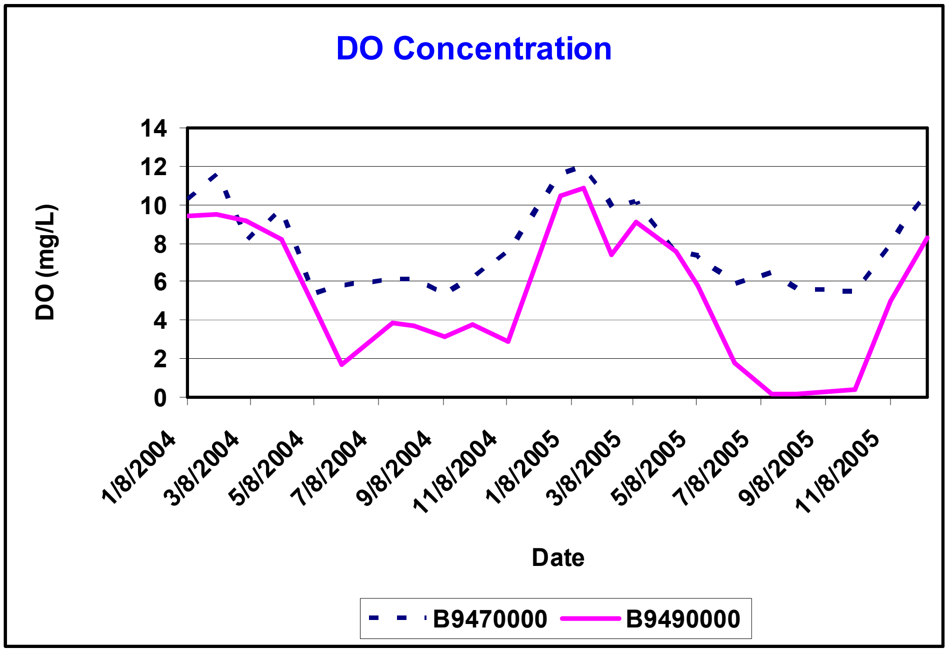


Figure13. Attenuation of nitrogen and dissolved oxygen in streams flowing through forested wetland (B9490000) and mixed land (B9470000).

Forth, plant uptake of nitrogen in the forest wetland was comparatively lower than in agricultural and forested lands (Table 9). As a result, more TN entering the wetland was available for transportation through surface and lateral flow.

Although forested land occupies one third of the watershed area, it contributed only 20% of TN during both dry and normal periods (Figure 11). Cheschier et al. (2003) also found similar result for forested land in the coastal plain of eastern North Carolina (10 km north of Beaufort). They found less than 6.5 kg/ha of annual TN exported from 75% of their forested watershed. In this study, the SWAT model estimated approximately 5 kg/ha, which is close to their measured data. Thus continued conversion of forested land for hog farming land will tend to increase nitrogen loads in the watershed.

Contributions of nitrogen from urban land, open space, and non-forested wetland are small as compared to forested wetland and agricultural land. The small contribution could be due to relatively small portion of land occupied by these land use in the watershed. They occupied only 1.63%, 3.04%, and 0.67% of the watershed, respectively.

For phosphorus, the dominant source of nonpoint load was agricultural land during both dry and normal periods (Figure 14). Unlike nitrogen, accumulative capacity of phosphorus in soil is high (Novotny, 2003). Therefore, a major portion of this load was due to erosion, which accounts for 70% of the total loads (Table 9). This heavy amount of phosphorus load can be reduced through additional adoption of agricultural BMPs.

For dissolved oxygen, the dominant sources of nonpoint load were forested wetland and agricultural land during both dry and normal period. Above analyses suggested that these lands contributed significant amount of nitrogen and phosphorus to the LCFR. If excessive amounts of phosphorus and/or nitrogen are added to the river, there are two possible ways to reduce DO concentration.

First, algae and aquatic plants can grow in large quantities. When these plants die, they are decomposed by bacteria, which use dissolved oxygen. However, significant quantities of algae and aquatic plant growth in LCFR are not yet well documented. In the DWQ's special study report (Lower Cape Fear River/ Estuary TMDL Study, March 14, 2005), it is reported that Chlorophyll *a*, which is a green pigment presented in algae and higher plants, ranged from 1.0μg/L to 35μg/L in the NECFR and LCFR during the summer period of 2004. The Chlorophyll *a* standard is 40 μg/L.

Second, oxidation of ammonia or organic nitrogen can be accelerated in the water body. The oxidation process is known as nitrification. During nitrification, considerable amount of oxygen is utilized to produce nitrate (Novotny, 2003).

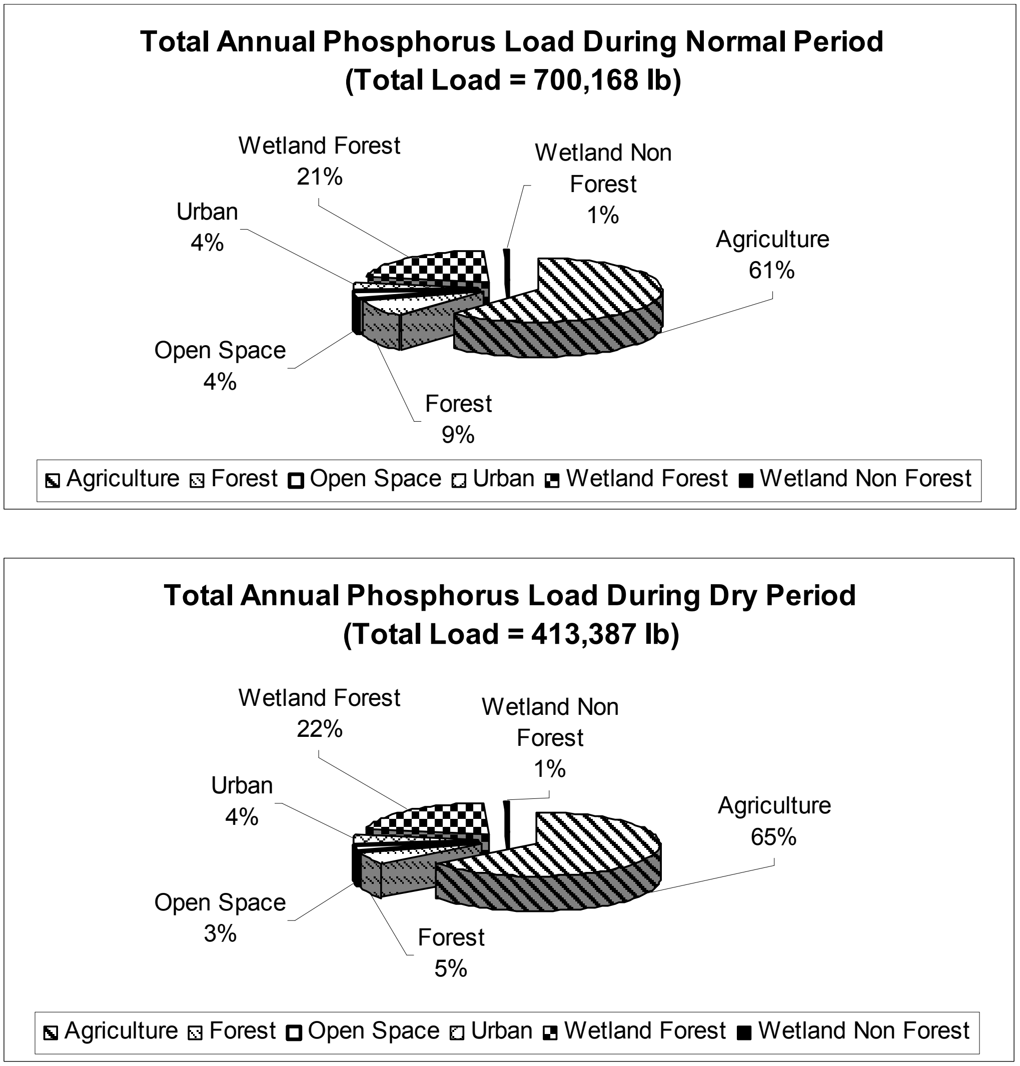
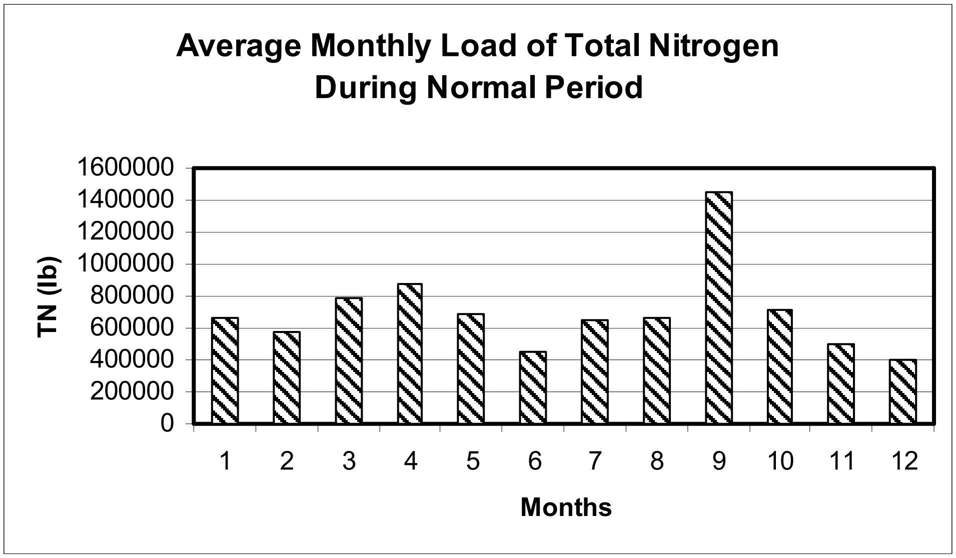


Figure14. Source attribution of the nonpoint total phosphorus load delivered to Northeast Cape Fear River.

Critical Period

A critical period is the period when a maximum amount of nutrient is discharged in a year. Figures 15 and 16 show monthly distribution of TN and TP loads delivered from the NECFR watershed, respectively. The nutrient loads represent the average of the 7-year simulation (1999-2005). It is estimated that significant amounts of TN and TP were delivered to the LCFR in March during dry period and in September during normal period.



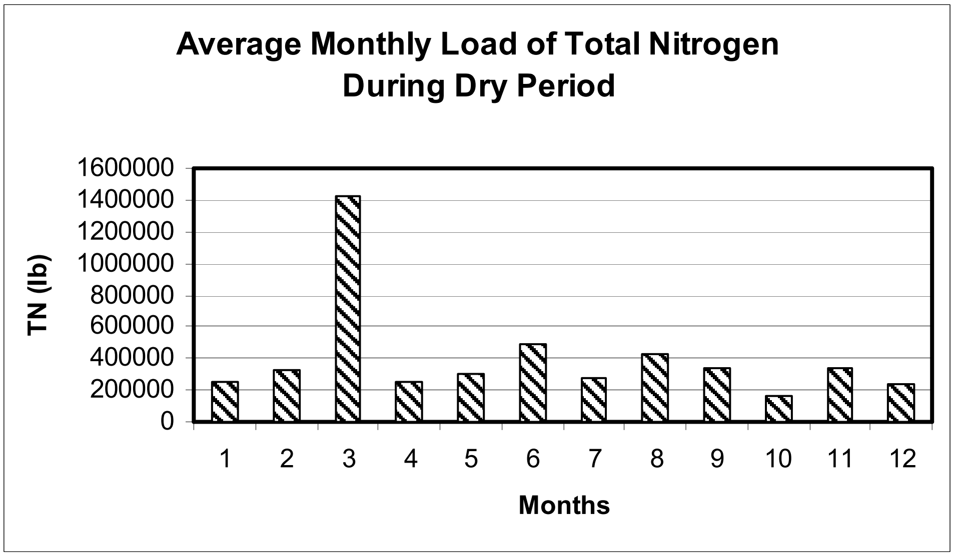
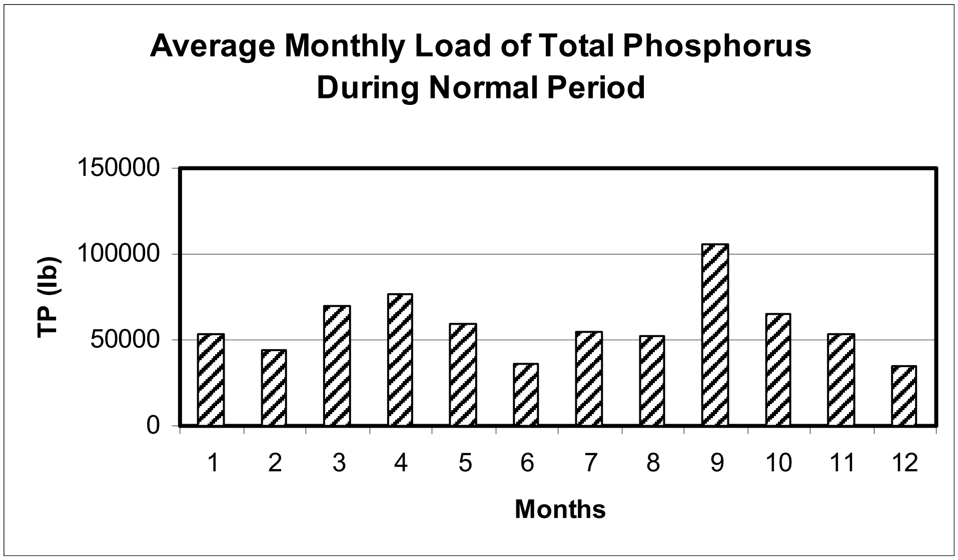


Figure 13. Monthly distribution of delivered total nitrogen load to Northeast Cape Fear River.



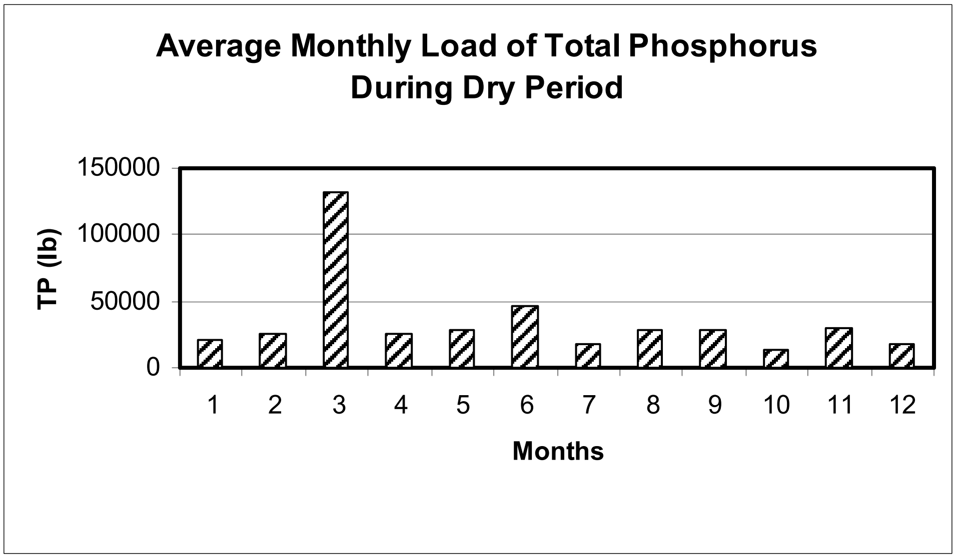


Figure 14. Monthly distribution of delivered total phosphorus load to Northeast Cape Fear River.

CONCLUSION

The State of North Carolina has initiated development of a Total Maximum Daily Load in the Lower Cape Fear River (LCFR) where low dissolved oxygen is a prime concern. Studies have shown that the presence of hog farms and wetland together with industrial and municipal point source discharges in the watersheds could add significant amount of nitrogen and phosphorus to the LCFR.

The ArcView Interfaced Soil and Water Assessment Tool (AVSWAT) model is used to evaluate the Northeast Cape Fear River watershed in order to understand total nitrogen (TN) and total phosphorus (TP) loads from different point and nonpoint sources. The watershed represents blackwater systems in the North Carolina Coastal Plain. It is one of the largest watersheds that drain water to the LCFR. The drainage area of the watershed is approximately 1693 square miles and covers 33% of agricultural land, 31 % of forest land, 30% of Forested Wetland, 1% of Non-forest Wetland, 1.6% of Developed Land, 3% of Open Space, and 0.4% of Water Body.

The model is calibrated for flow, TN, TP, and Dissolved Oxygen (DO). Overall, the difference between simulated and observed flow volume and nutrient concentrations were not significant at 95% confidence level. Error values associated with model prediction were considerably low. Comparing its results with FLUX estimation of daily nutrient loads further validates the model. A reasonable agreement between the two models was observed.

The model results suggested that nonpoint sources contributed more than 90% of the nutrient loads to the Lower Cape Fear River. Among the nonpoint sources, agricultural land and forested wetland contributed a major portion of the load. They respectively contributed approximately 30% and 40% of the total nitrogen load and 60% and 20% of the total phosphorus load during normal and dry years. It is observed that the nutrient load was high during March for dry period and during September for normal period.

It appears the forested wetlands in the NECRF watershed were not designed to trap nutrient loading coming from adjoining lands. The wetlands functioned as a passive source by transporting nutrients into streams in the natural environment. Several streams/creeks drain nutrients from wetlands as well as from adjoining lands. In addition, the wetlands receive pollution input from surrounding uplands, including agricultural land used for hog farming. Adoption of proper BMPs in the watershed would reduce the nutrient loads.

In agricultural land, a significant portion of the phosphorus load was due to erosion. It accounts for 70% of the total load. This heavy amount of load can be reduced through additional adoption of agricultural BMPs.

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Appendix 1. Annual average load from NPDES program

Permit No.	Year	Flow	TN	TP	DO
		(m^3/day)	(kg/day)	(kg/day)	(kg/day)
NC0000817	1999	85.604	0.241	0.028	0.444
NC0000817	2000	54.504	0.082	0.023	0.331
NC0000817	2001	77.076	0.282	0.025	0.525
NC0000817	2002	57.881	0.205	0.012	0.253
NC0000817	2003	58.668	0.126	0.012	0.294
NC0001074	1999	1274.346	10.741	6.870	10.601
NC0001074	2000	1249.649	30.525	16.842	10.482
NC0001074	2001	1268.154	16.115	9.142	10.707
NC0001074	2002	7264.758	10.127	10.572	60.683
NC0001074	2003	1345.875	10.551	9.527	11.390
NC0001074	2004	1480.136	10.621	6.828	12.556
NC0001074	2005	1298.292	10.049	20.327	10.999
NC0001112	1999	9255.492	142.410	86.918	0.000
NC0001112	2000	9132.517	106.002	58.517	0.000
NC0001112	2001	8020.037	66.446	33.068	0.000
NC0001112	2002	7975.043	65.069	38.951	0.000
NC0001112	2003	7679.084	89.797	56.175	0.000
NC0001112	2004	8148.120	45.000	85.732	0.000
NC0001112	2005	11145.792	44.015	85.798	0.000
NC0001228	1999	1861.526	0.000	0.000	0.000
NC0001228	2000	1763.274	0.000	0.000	0.000
NC0001228	2001	1759.720	0.000	0.000	0.000
NC0001228	2002	1749.326	0.000	0.000	0.000
NC0001228	2003	1892.669	0.000	0.000	0.000
NC0001228	2004	1931.326	0.000	0.000	0.000
NC0001228	2005	1987.619	0.000	0.000	0.000
NC0001970	1999	1296.205	25.471	2.522	12.547
NC0001970	2000	1439.877	13.518	1.054	11.711
NC0001970	2001	1218.139	4.941	0.863	10.129
NC0001970	2002	1258.828	8.537	1.219	10.620
NC0001970	2003	1258.828	1.099	0.187	11.105
NC0001970	2004	1085.644	3.978	0.892	8.762
NC0001970	2005	1256.736	9.298	1.869	10.424
NC0002305	1999	2898.415	8.569	18.845	21.005
NC0002305	2000	3133.255	17.041	19.018	22.388
NC0002305	2001	3223.148	26.778	24.800	23.471
NC0002305	2002	3848.301	35.507	25.779	25.157
NC0002305	2003	2998.234	22.687	3.491	21.232
NC0002305	2004	3489.765	62.847	3.102	23.557
NC0002305	2005	3264.007	62.417	3.115	21.946
NC0002763	1999	85.983	0.000	0.000	0.000
NC0002763	2000	27.977	0.000	0.000	0.000
NC0002763	2001	47.313	0.000	0.000	0.000
NC0002763	2002	15.550	0.000	0.000	0.000

Appendix 1: Continued

Permit No.	Year	Flow	TN	TP	DO
		(m^3/day)	(kg/day)	(kg/day)	(kg/day)
NC0002763	2003	35.011	0.000	0.000	0.000
NC0002763	2004	52.265	0.000	0.000	0.000
NC0002763	2005	26.495	0.000	0.000	0.000
NC0002879	1999	3398.615	0.000	0.000	0.000
NC0002879	2000	3658.518	0.000	0.000	0.000
NC0002879	2001	4301.337	0.000	0.000	0.000
NC0002879	2002	2683.463	0.000	0.000	0.000
NC0002879	2003	2760.211	0.000	0.000	0.000
NC0002879	2004	3460.121	0.000	0.000	0.000
NC0002879	2005	1718.102	0.000	0.000	0.000
NC0002933	1999	24.445	0.000	0.000	0.000
NC0002933	2000	24.918	0.000	0.000	0.000
NC0002933	2001	22.868	0.000	0.000	0.000
NC0002933	2002	26.337	0.000	0.000	0.000
NC0002933	2003	25.391	0.000	0.000	0.000
NC0002933	2004	27.126	0.000	0.000	0.000
NC0002933	2005	21.764	0.000	0.000	0.000
NC0003051	2002	77.755	0.000	0.000	0.000
NC0003051	2003	75.700	0.000	0.000	0.000
NC0003051	2004	92.354	0.000	0.000	0.000
NC0003051	2005	80.248	0.000	0.000	0.000
NC0003344	1999	3196.088	72.767	10.806	25.206
NC0003344	2000	3874.547	90.941	16.883	32.216
NC0003344	2001	3928.672	92.629	21.933	34.167
NC0003344	2002	3401.273	85.711	20.261	26.622
NC0003344	2003	2608.880	64.977	16.961	22.463
NC0003344	2004	2774.781	75.253	25.063	22.797
NC0003344	2005	400.968	4.509	0.909	4.319
NC0003450	1999	11.103	0.000	0.000	0.000
NC0003450	2000	0.000	0.000	0.000	0.000
NC0003450	2001	0.000	0.000	0.000	0.000
NC0003450	2002	0.000	0.000	0.000	0.000
NC0003794	1999	451.424	0.000	0.000	0.000
NC0003794	2000	132.759	0.000	0.000	0.000
NC0003794	2001	184.960	0.000	0.000	0.000
NC0003794	2002	354.173	0.000	0.000	0.000
NC0003794	2003	418.463	0.000	0.000	0.000
NC0003794	2004	415.688	0.000	0.000	0.000
NC0003794	2005	406.888	0.000	0.000	0.000
NC0003875	1999	2687.075	18.289	3.309	22.965
NC0003875	2000	2597.299	14.061	0.304	21.753
NC0003875	2001	2481.575	11.407	0.373	20.819
NC0003875	2002	2213.031	13.294	1.350	18.792
NC0003875	2003	2560.297	18.097	0.207	22.028
NC0003875	2004	2629.380	14.275	1.365	22.979

Appendix 1: Continued

Permit No.	Year	Flow (m^3/day)	TN (kg/day)	TP (kg/day)	DO (kg/day)
NC0003875	2005	2529.818	11.367	7.159	22.232
NC0020575	1999	3461.383	23.113	3.933	26.769
NC0020575	2000	3201.385	14.699	2.348	25.766
NC0020575	2001	2525.878	17.711	2.478	20.245
NC0020575	2002	2491.801	14.667	3.177	21.087
NC0020575	2003	3523.679	17.037	8.642	37.843
NC0020575	2004	3001.120	22.456	3.487	25.990
NC0020575	2005	2744.303	22.896	3.660	24.016
NC0020702	1999	2308.503	21.611	5.148	16.492
NC0020702	2000	2645.273	29.613	3.038	22.130
NC0020702	2001	2766.457	31.487	2.565	23.910
NC0020702	2002	2381.799	29.470	3.007	21.019
NC0020702	2003	3296.651	38.404	3.142	29.636
NC0020702	2004	2634.020	32.758	3.826	23.578
NC0020702	2005	2478.063	44.303	2.923	23.442
NC0021113	1999	1547.087	27.259	3.404	13.010
NC0021113	2000	1334.528	19.456	3.532	11.186
NC0021113	2001	1418.519	31.478	3.263	12.305
NC0021113	2002	1380.444	30.112	3.940	11.622
NC0021113	2003	1884.803	34.905	4.958	16.419
NC0021113	2004	1722.201	29.439	4.288	14.723
NC0021113	2005	1937.122	28.168	4.990	17.281
NC0023477	1999	113.550	0.000	0.000	0.000
NC0023477	2000	108.733	0.000	0.000	0.000
NC0023477	2001	110.396	0.000	0.000	0.000
NC0023477	2002	113.550	0.000	0.000	0.000
NC0023477	2003	108.556	0.000	0.000	0.000
NC0023477	2004	103.617	0.000	0.000	0.000
NC0023477	2005	120.449	0.000	0.000	0.000
NC0026018	1999	854.779	10.617	1.407	7.179
NC0026018	2000	727.067	10.908	1.836	6.070
NC0026018	2001	724.102	11.879	1.792	6.363
NC0026018	2002	889.946	8.711	2.164	8.551
NC0026018	2003	1146.667	20.763	1.668	10.112
NC0026018	2004	1016.612	14.265	1.604	9.124
NC0026018	2005	845.842	12.829	1.329	7.656
NC0036668	1999	690.590	11.534	1.679	5.770
NC0036668	2000	706.407	15.133	1.926	5.527
NC0036668	2001	664.508	14.112	1.944	5.296
NC0036668	2002	623.142	8.523	1.523	5.261
NC0036668	2003	808.150	11.089	1.511	7.031
NC0036668	2004	717.404	10.808	1.815	5.956
NC0036668	2005	713.856	15.437	2.106	6.870
NC0039527	1999	295.545	0.000	0.539	1.791
NC0039527	2000	328.349	0.000	0.782	2.068

Appendix 1: Continued

Permit No.	Year	Flow	TN	TP	DO
		(m^3/day)	(kg/day)	(kg/day)	(kg/day)
NC0039527	2001	312.263	0.000	0.879	1.953
NC0039527	2002	285.768	0.000	0.740	1.836
NC0039527	2003	265.265	0.000	0.691	1.675
NC0039527	2004	272.899	0.000	0.865	1.698
NC0039527	2005	246.998	7.284	0.597	1.647
NC0042251	1999	28.640	0.000	0.000	0.259
NC0042251	2000	17.253	0.000	0.000	0.147
NC0042251	2001	12.641	0.000	0.000	0.106
NC0042251	2002	12.396	0.000	0.000	0.107
NC0042251	2003	14.951	0.000	0.000	0.129
NC0042251	2004	17.348	0.000	0.000	0.148
NC0042251	2005	20.843	0.000	0.000	0.181
NC0049743	1999	285.137	59.032	0.057	0.000
NC0049743	2000	134.368	22.931	0.037	0.000
NC0049743	2001	157.393	26.624	0.038	0.000
NC0049743	2002	100.718	8.142	0.012	0.489
NC0049743	2003	138.153	17.171	0.015	0.000
NC0049743	2004	224.382	16.313	0.019	0.000
NC0049743	2005	96.447	7.701	0.008	0.000
NC0051969	1999	29.870	0.000	0.000	0.201
NC0051969	2000	4048.333	0.000	0.000	26.141
NC0051969	2001	27.599	0.000	0.000	0.221
NC0051969	2002	24.571	0.000	0.000	0.175
NC0051969	2003	28.230	0.000	0.000	0.204
NC0051969	2004	25.339	0.000	0.000	0.204
NC0051969	2005	22.836	0.000	0.000	0.210
NC0056863	1999	884.901	11.336	0.977	6.666
NC0056863	2000	804.123	6.713	0.867	6.218
NC0056863	2001	702.541	7.457	0.887	5.758
NC0056863	2002	617.084	7.305	1.122	4.390
NC0056863	2003	971.124	8.684	0.867	7.563
NC0056863	2004	647.946	6.067	0.679	5.589
NC0056863	2005	1008.612	6.980	1.078	7.916
NC0058271	1999	794.850	0.000	0.000	0.000
NC0058271	2000	911.239	0.000	0.000	0.000
NC0058271	2001	1117.206	0.000	0.000	0.000
NC0058271	2002	1182.813	0.000	0.000	0.000
NC0058271	2003	1487.547	0.000	0.000	0.000
NC0058271	2004	1091.342	0.000	0.000	0.000
NC0058271	2005	870.461	0.000	0.000	0.000
NC0058971	1999	4.668	0.000	0.000	0.000
NC0058971	2000	0.252	0.000	0.000	0.000
NC0058971	2001	0.000	0.000	0.000	0.000
NC0065307	1999	15.613	0.000	0.000	0.114
NC0065307	2000	14.541	0.000	0.000	0.097

Appendix 1: Continued

Permit No.	Year	Flow	TN	TP	DO
		(m^3/day)	(kg/day)	(kg/day)	(kg/day)
NC0065307	2001	9.620	0.000	0.000	0.060
NC0065307	2002	8.295	0.000	0.000	0.052
NC0065307	2003	8.453	0.000	0.000	0.053
NC0065307	2004	8.169	0.000	0.000	0.050
NC0065307	2005	8.123	0.000	0.000	0.050
NC0066320	1999	1044.660	0.000	0.000	0.000
NC0066320	2000	1044.660	0.000	0.000	0.000
NC0066320	2001	1044.660	0.000	0.000	0.000
NC0066320	2002	1044.660	0.000	0.000	0.000
NC0066320	2003	1044.660	0.000	0.000	0.000
NC0066320	2004	1042.768	0.000	0.000	0.000
NC0066320	2005	1044.660	0.000	0.000	0.000
NC0085481	1999	48.792	0.000	0.000	0.464
NC0085481	2000	30.154	0.000	0.000	0.263
NC0085481	2001	22.552	0.000	0.000	0.196
NC0085481	2002	15.045	0.000	0.000	0.132
NC0085481	2003	21.322	0.000	0.000	0.194
NC0085481	2004	19.209	0.000	0.000	0.183
NC0085481	2005	20.075	0.000	0.000	0.180
NC0086801	2000	0.000	0.000	0.000	0.000
NC0086801	2001	0.000	0.000	0.000	0.000
NC0086801	2002	86.740	0.000	0.000	0.000
NC0086801	2003	73.808	0.000	0.000	0.000
NC0086801	2004	48.890	0.000	0.000	0.000
NC0086801	2005	30.690	0.000	0.000	0.000

Appendix 2. Observed vs estimated monthly total flow

Year	Month	Observed	SWAT	Year	Month	Observed	SWAT	Year	Month	Observed	SWAT
		(ft)	(ft)			(ft)	(ft)			(ft)	(ft)
1999	Jan	0.328	0.232	2002	Jan	0.099	0.129	2005	Jan	0.087	0.099
1999	Feb	0.156	0.151	2002	Feb	0.088	0.086	2005	Feb	0.078	0.078
1999	Mar	0.107	0.134	2002	Mar	0.196	0.186	2005	Mar	0.118	0.086
1999	Apr	0.068	0.068	2002	Apr	0.111	0.151	2005	Apr	0.119	0.093
1999	May	0.082	0.110	2002	May	0.020	0.039	2005	May	0.089	0.109
1999	Jun	0.029	0.090	2002	Jun	0.009	0.038	2005	Jun	0.037	0.072
1999	Jul	0.056	0.113	2002	Jul	0.009	0.034	2005	Jul	0.046	0.046
1999	Aug	0.031	0.233	2002	Aug	0.011	0.036	2005	Aug	0.030	0.021
1999	Sept	1.155	1.162	2002	Sept	0.029	0.060	2005	Sept	0.013	0.038
1999	Oct	0.527	0.350	2002	Oct	0.011	0.043	2005	Oct	0.189	0.128
1999	Nov	0.150	0.234	2002	Nov	0.063	0.104	2005	Nov	0.081	0.075
1999	Dec	0.091	0.098	2002	Dec	0.080	0.094	2005	Dec	0.190	0.112
2000	Jan	0.183	0.077	2003	Jan	0.065	0.073				
2000	Feb	0.228	0.223	2003	Feb	0.129	0.110				
2000	Mar	0.196	0.215	2003	Mar	0.267	0.223				
2000	Apr	0.145	0.147	2003	Apr	0.269	0.247				
2000	May	0.047	0.060	2003	May	0.157	0.173				
2000	Jun	0.048	0.047	2003	Jun	0.276	0.162				
2000	Jul	0.084	0.075	2003	Jul	0.520	0.615				
2000	Aug	0.064	0.062	2003	Aug	0.223	0.219				
2000	Sept	0.179	0.194	2003	Sept	0.042	0.120				
2000	Oct	0.070	0.097	2003	Oct	0.105	0.143				
2000	Nov	0.041	0.051	2003	Nov	0.179	0.122				
2000	Dec	0.084	0.043	2003	Dec	0.227	0.163				
2001	Jan	0.054	0.013	2004	Jan	0.083	0.092				
2001	Feb	0.078	0.060	2004	Feb	0.150	0.110				
2001	Mar	0.285	0.206	2004	Mar	0.103	0.109				
2001	Apr	0.121	0.125	2004	Apr	0.110	0.131				
2001	May	0.028	0.073	2004	May	0.180	0.205				
2001	Jun	0.103	0.138	2004	Jun	0.075	0.102				
2001	Jul	0.019	0.038	2004	Jul	0.032	0.049				
2001	Aug	0.123	0.101	2004	Aug	0.174	0.136				
2001	Sept	0.038	0.077	2004	Sept	0.143	0.199				
2001	Oct	0.016	0.025	2004	Oct	0.033	0.135				
2001	Nov	0.007	0.010	2004	Nov	0.070	0.141				
2001	Dec	0.016	0.008	2004	Dec	0.089	0.109				

Appendix 3. Observed vs estimated nutrient concentration at B9480000.

Month	Year	EstTN	ObsTN	EstTP	ObsTP	EstDO	ObsDO
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
1	1999	1.13	1.23	0.15	0.05	9.46	11.00
2	1999	1.47	1.23	0.13	0.06	8.81	7.90
3	1999	1.07	0.75	0.17	0.07	10.62	9.70
4	1999	1.55	0.78	0.16	0.11	8.61	6.80
5	1999	1.34	0.87	0.16	0.14	7.35	6.10
6	1999	1.09	0.98	0.27	0.18	6.24	5.40
7	1999	1.01	1.1	0.09	0.21	8.00	5.90
8	1999	1.62	1.05	0.23	0.21	7.82	0.24
8	1999	1.29	1.31	0.09	0.24	1.14	4.40
9	1999	1.01	1.37	0.09	0.21	7.61	4.00
10	1999	0.78	1.42	0.16	0.22	5.81	3.10
11	1999	0.71	1.74	0.14	0.14	9.06	7.20
12	1999	0.67	0.92	0.16	0.12	8.96	10.20
1	2000	0.83	1.27	0.19	0.08	8.69	10.40
2	2000	1.27	1.6	0.13	0.06	8.83	9.80
3	2000	0.79	1.35	0.19	0.11	8.44	8.40
4	2000	1.26	1.11	0.13	0.11	9.08	7.40
5	2000	1.18	1.32	0.15	0.12	8.09	4.80
6	2000	1.37	1.13	0.25	0.15	5.36	5.30
7	2000	1.63	1.08	0.19	0.19	6.03	5.50
8	2000	0.95	0.79	0.21	0.22	7.27	4.90
9	2000	1.16	1.16	0.09	0.2	7.64	5.40
10	2000	0.63	0.82	0.19	0.14	9.44	7.40
11	2000	1.23	0.93	0.20	0.16	8.04	6.90
12	2000	1.43	1.12	0.15	0.07	7.53	10.90
1	2001	1.09	1.05	0.25	0.06	8.75	12.70
2	2001	NA	NA	0.12	0.50	9.52	9.60
4	2001	NA	NA	0.33	0.19	9.31	6.60
5	2001	NA	NA	0.16	0.20	6.94	6.30
6	2001	NA	NA	NA	NA	4.23	4.60
7	2001	1.25	1.45	0.22	0.24	6.51	4.00
8	2001	1.32	1.31	0.12	0.27	6.82	5.70
9	2001	NA	NA	NA	NA	7.77	5.30
10	2001	NA	NA	NA	NA	9.33	6.80
11	2001	NA	NA	NA	NA	5.42	7.70
12	2001	NA	NA	NA	NA	0.47	5.80
1	2002	NA	NA	NA	NA	3.72	5.20
2	2002	NA	NA	NA	NA	9.24	9.90
3	2002	NA	NA	NA	NA	4.95	7.60
4	2002	NA	NA	NA	NA	9.00	7.20
5	2002	NA	NA	NA	NA	7.52	7.00
6	2002	NA	NA	NA	NA	4.31	5.70
7	2002	NA	NA	NA	NA	6.62	3.50
8	2002	NA	NA	NA	NA	2.55	3.90

Appendix 3: Continued

Month	Year	EstTN (mg/L)	ObsTN (mg/L)	EstTP (mg/L)	ObsTP (mg/L)	EstDO (mg/L)	ObsDO (mg/L)
9	2002	NA	NA	NA	NA	6.68	4.70
10	2002	NA	NA	NA	NA	7.42	3.90
12	2002	NA	NA	NA	NA	10.23	11.10
1	2003	NA	NA	NA	NA	10.95	10.90
2	2003	NA	NA	NA	NA	8.75	11.00
3	2003	NA	NA	NA	NA	9.17	7.50
4	2003	NA	NA	NA	NA	9.08	5.20
5	2003	NA	NA	NA	NA	7.92	5.30
6	2003	1.14	1.32	0.16	0.20	6.88	4.80
7	2003	1.10	1.11	0.13	0.16	7.42	3.30
8	2003	0.69	1.29	0.16	0.25	7.78	4.40
9	2003	0.57	1.25	0.18	0.23	7.5	4.30
10	2003	0.64	1.13	0.16	0.12	9.09	7.10
11	2003	1.02	1.36	0.11	0.11	8.01	5.90
12	2003	0.6	1.06	0.18	0.09	9.28	9.30
1	2004	0.53	1.37	0.17	0.08	11.28	9.20
2	2004	1.15	1.53	0.14	0.06	9.85	11.60
3	2004	1.11	1.62	0.11	0.07	8.45	8.70
4	2004	1.3	1.09	0.18	0.12	9.45	8.80
5	2004	1.37	1.74	0.07	0.21	8.13	5.10
6	2004	1.24	1.25	0.13	0.19	7.89	5.10
7	2004	2.04	0.96	0.18	0.16	4.02	4.30
7	2004	1.3	1.02	0.23	0.17	2.84	4.30
7	2004	2.09	1.07	0.24	0.18	4.66	4.60
7	2004	2.61	1.09	0.1	0.18	4.99	4.60
7	2004	1.7	1.25	0.25	0.19	7.16	4.60
7	2004	1.6	1.41	0.17	0.2	5.86	4.70
7	2004	1.69	1.8	0.1	0.23	6.15	5.20
8	2004	1.4	1.12	0.11	0.16	6.5	5.00
8	2004	1.42	1.19	0.08	0.17	7.17	5.40
8	2004	1.35	1.28	0.1	0.2	6.14	6.00
9	2004	1.23	1.29	0.09	0.21	6.86	5.30
10	2004	0.67	1.07	0.16	0.18	8.38	6.00
11	2004	0.99	1.03	0.17	0.16	9.00	7.40
12	2004	1.24	1.28	0.16	0.16	7.86	11.40
1	2005	1.83	1.22	0.15	0.11	11.34	11.30
2	2005	0.88	1.33	0.15	0.08	9.25	10.00
3	2005	0.98	1.08	0.15	0.08	10.13	9.50
4	2005	1.90	1.27	0.14	0.14	8.68	7.60
5	2005	1.57	1.65	0.13	0.18	8.45	7.80
6	2005	1.2	1.41	0.07	0.18	7.95	5.50
7	2005	1.19	1.07	0.16	0.19	6.62	4.90
8	2005	1.47	1.03	0.16	0.18	2.12	5.50
10	2005	0.95	1.31	0.25	0.19	6.19	4.50
11	2005	0.47	1.09	0.19	0.09	8.63	7.80
12	2005	0.70	1.00	0.15	0.06	10.02	10.5

Appendix 4. Monthly average nutrient loads from different land types.

Normal Period												
Nutrient/Land use	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
A. Total Nitrogen (tons)												
Agriculture	75.51	72.42	106.54	119.05	111.47	78.52	108.35	101.91	211.49	94.83	56.09	47.81
Forest	75.69	65.66	78.45	77.51	69.61	44.86	70.01	67.04	180.08	91.88	55.17	52.72
Open Space	16.98	10.06	15.47	13.49	8.75	10.52	18.77	20.06	46.66	22.22	12.17	9.57
Urban	13.96	11.68	15.30	16.52	15.99	13.10	17.89	19.39	30.04	17.51	11.43	9.54
Forested Wetland	144.21	128.77	174.13	205.75	132.49	77.31	105.94	119.58	251.34	124.26	115.22	76.31
Wetland Non-Forest	2.39	1.63	2.40	2.53	2.57	1.99	2.81	3.01	6.45	3.28	1.85	1.50
Total	328.75	290.22	392.30	434.85	340.88	226.30	323.77	330.98	726.06	353.98	251.92	197.45
B. Total Phosphorus (tons)												
Agriculture	13.51	12.17	18.41	19.12	19.06	12.92	19.97	18.67	35.25	22.53	14.96	10.71
Forest	2.68	2.23	3.05	2.87	2.56	1.23	1.73	1.77	4.61	3.49	2.58	2.40
Open Space	1.45	0.51	1.07	0.87	0.44	0.66	1.37	1.34	4.09	1.60	0.72	0.51
Urban	0.96	0.58	0.89	1.12	1.16	0.95	1.41	1.39	2.45	1.07	0.55	0.42
Forested Wetland	8.10	6.34	11.03	14.27	6.08	2.04	2.47	2.79	6.02	3.78	7.65	3.47
Wetland Non-Forest	0.15	0.10	0.14	0.16	0.17	0.12	0.16	0.17	0.34	0.24	0.14	0.12
Total	26.86	21.92	34.60	38.40	29.48	17.92	27.11	26.12	52.76	32.72	26.59	17.64

Appendix 4: Continued

Dry Period												
A. Total Nitrogen (tons)												
Agriculture	41.32	47.12	207.29	37.73	54.37	87.17	44.17	67.36	50.76	23.98	37.47	25.68
Forest	29.13	28.11	126.92	26.63	25.07	41.88	27.59	40.52	30.48	13.10	27.12	22.70
Open Space	6.92	5.88	29.94	6.91	3.02	10.33	7.77	12.67	9.64	4.59	5.82	4.14
Urban	7.65	8.05	23.87	7.33	9.63	13.24	11.03	14.91	10.77	6.09	7.55	6.34
Forested Wetland	37.29	71.39	319.37	45.65	58.29	91.86	49.63	74.15	68.86	30.51	91.08	60.90
Wetland Non-Forest	1.19	1.15	4.47	0.64	1.28	2.29	1.13	2.20	1.59	0.75	1.19	0.72
Total	123.51	161.69	711.87	124.91	151.65	246.77	141.31	211.81	172.10	79.01	170.22	120.49
B. Total Phosphorus (tons)												
Agriculture	7.17	7.73	35.20	7.57	10.48	18.49	6.26	10.49	11.76	5.44	9.01	5.59
Forest	0.76	0.72	3.75	2.35	0.63	0.76	0.35	0.59	0.44	0.24	0.37	0.39
Open Space	0.46	0.27	2.41	0.43	0.11	0.64	0.39	0.72	0.52	0.26	0.25	0.18
Urban	0.59	0.47	2.09	0.24	0.65	1.03	0.77	1.16	0.59	0.27	0.39	0.20
Forested Wetland	1.10	3.72	22.10	2.41	1.99	2.26	0.83	1.32	1.15	0.79	4.99	2.39
Wetland Non-Forest	0.07	0.06	0.25	0.07	0.07	0.12	0.06	0.11	0.08	0.06	0.07	0.05
Total	10.15	12.97	65.80	13.07	13.93	23.30	8.66	14.39	14.56	7.06	15.07	8.81