Total Maximum Daily Loads of Fecal Coliform for the Shellfish Harvesting Areas in the Lockwoods Folly River, Lumber River Basin, Brunswick County, North Carolina

[Waterbody ID 15-25-1-(16)a, Waterbody ID 15-25-1-(16)b, Waterbody ID 15-25-1-(16)c, Waterbody ID 15-25-1-(16)d, Waterbody ID 15-25-1-18-(2), Waterbody ID 15-25-1-19, Waterbody ID 15-25-1-20, Waterbody ID 15-25-1-21]

September 2010

(EPA Approved)

Lumber River Basin

Prepared by:
North Carolina Department of Environment and Natural Resources
Division of Water Quality
1617 Mail Service Center
Raleigh, NC 27699-1617

With support from:
North Carolina Coastal Federation
3609 Highway 24
Newport, NC 28570

Stantec Consulting Services, Inc.
801 Jones Franklin Road
Suite 300
Raleigh, NC 27606

Table of Contents

List of Abbreviations

BMP	Best Management Practice
CFR	Code of Federal Regulations
CWA	Clean Water Act
DEHSS	Division of Environmental Health Shellfish Sanitation
DEM	Digital Elevation Model
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
FA	Future Allocation
GIS	Geographic Information System
GUI	Graphic User Interface
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HUC	Hydrologic Unit Code
ICWW	Intracoastal Waterway
LA	Load Allocation
MF	MF is an abbreviation for the membrane filter procedure for bacteriological analysis
ml	milliliter(s)
MLW	Mean Low Water
MOS	Margin of Safety
MPN	Most Probable Number
NCAC	North Carolina Administrative Code
NCCF	North Carolina Coastal Federation
NCDEH	North Carolina Department of Environmental Health
NCDENR	North Carolina Department of Environment and Natural Resources
NCDOT	North Carolina Department of Transportation
NCDWQ	North Carolina Division of Water Quality
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSSP	National Shellfish Sanitation Program
SA	Class SA waterbody suitable for commercial shellfishing and all other tidal saltwater use
TMDL	Total Maximum Daily Load
TPWQM	Tidal Prism Water Quality Model
USGS	United States Geological Survey
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WRRI	Water Resources Research Institute

List of Tables

List of Figures

Summary Page

1. 303 (d) Listed Waterbody Information

State: North Carolina

County: Brunswick

Major River Basin: Lumber River Basin

Watershed: Lockwoods Folly River (030402070200)

Impaired Waterbody (2008 303(d) List):

Waterbody Name - (ID)	Description	Water Quality Classification	Acres
Lockwoods Folly River - (15-25-1-(16)a)	From Brunswick County SR 1200 to a line crossing Lockwood Folly River 520 meters north of Myrtle Point of the east shore to a point of the west shore 704 meters north of Mullet Creek	SA, HQW	123.6
Lockwoods Folly River - (15-25-1-(16)b)	From a line crossing Lockwood Folly River 520 meters north of Myrtle Point of the east shore to a point of the west shore 704 meters north of Mullet Creek to a line crossing Lockwood Folly River 146 meters north of Genoes Point on the east shore to a point on the west shore 777 meters south of Mullet Creek	SA, HQW	275.6
Lockwoods Folly River - (15-25-1-(16)c)	From a line crossing Lockwood Folly River 146 meters north of Genoes Point on the east shore to a point on the west shore 777 meters south of Mullet Creek to a line crossing Lockwoods Folly River 628 meters south of Genoes point on the east shore	SA, HQW	207.0
Lockwoods Folly River - (15-25-1-(16)d)	From a line crossing Lockwood Folly River 628 meters south of Genoes Point on the east shore to Gores Landing on the east shore to ICWW	SA, HQW	53.1
Mill Creek - (15-25-1-18-(2))	From Brunswick County SR 1112 to Lockwoods Folly River	SA, HQW	2.0
Montgomery Slough - (15-25v)	From ICWW west of Lockwoods Folly Inlet extending eastward (2.4 Miles)	SA, HQW	2.3
Mullet Creek - (15-25-1-19)	From source to Lockwoods Folly River	SA, HQW	5.7
Intracoastal Waterway - (15-25u)	From a line crossing ICWW south of SR 1112 to Cape Fear River Basin	SA, HQW	403.5
Intracoastal Waterway - (15-25t1)	From a line across the ICWW 2030 meters west of NC 130 bridge to a line crossing ICWW south of SR1112	SA, HQW	292.8
Spring Creek - (15-25-1-21)	From source to Lockwoods Folly River	SA, HQW	2.4
Lockwoods Creek - (15-25-1-20)	From source to Lockwoods Folly River	SA, HQW	0.2

Constituent(s) of Concern: Fecal Coliform Bacteria

Designated Uses: aquatic life, shellfish harvesting

Applicable Tidal Salt Water Quality Standards for Class SA Waters:

"Organisms of coliform group: fecal coliform group not to exceed a median MF of 14/100 ml and not more than 10 percent of the samples shall exceed an MF count of 43/100 ml in those areas most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions."

2. TMDL Development

Development Tools (Analysis/Modeling):

The linked watershed and Tidal Prism modeling approach was used to estimate current fecal coliform load from the watershed and to simulate fecal coliform concentrations in the estuary. The long-term model results were used to establish allowable loads for the restricted shellfish harvesting areas. Since long-term model simulation is used to establish TMDLs, it accounts for the seasonal variability and critical conditions, which thereby represents the hydrology, hydrodynamics, and water quality condition of the estuary. The selected watershed model calculated the watershed load to the Lockwoods Folly estuary which includes loads from Mullet Creek, Spring Creek, Mill Creek, Lockwoods Creek, and the Lockwoods Folly River up to Brunswick County SR 1200. Therefore, the load reduction calculated for the estuary is applied to all of the aforementioned segments. A TMDL was not developed for the Intracoastal Waterway (ICWW) and Montgomery Slough because the hydrodynamics are not conducive to using the linked watershed and Tidal Prism modeling approach. The TMDL load reduction does not apply to the ICWW or Montgomery Slough. These areas will instead be addressed in the TMDL implementation strategies.

Critical Conditions:

The 90th percentile concentration is the concentration exceeded only 10% of the time. Since the model simulation period spans five years (2004-2009), the critical condition is implicitly included in the value of the 90th percentile of model results. Given the length of the monitoring record and model simulation and the standard's recognition of unusual and infrequent events, the 90th percentile is used instead of the absolute maximum.

Seasonal Variation:

Seasonal variation in hydrology, climatic conditions, and watershed activities are represented through the use of continuous simulation. In general, high fecal coliform levels occur throughout the year in the estuary. The average monthly concentrations are relatively similar between months. The highest concentrations occur in April while the lowest concentrations occur in February and the late spring months. The model simulation spans five years. As a result, the seasonal variability is directly included in the model simulation.

3. TMDL Allocation Summary

Model results show that the 90th percentile component of the standard, rather than the median component, requires the highest reduction. The allocation is established based on the 90th percentile load.

Waterbody	Pollutant	Existing Load	WLA	LA	MOS	TMDL	Reduction Needed*
Lockwoods Folly River (15-25-1-(16)c) Lockwoods Folly River (15-25-1-(16)a), Lockwoods Folly River (15-25-1-(16)b), Lockwoods Folly River (15-25-1-(16)d), Mill Creek, Mullet Creek, Spring Creek, Lockwoods Creek	Fecal coliform (counts/day)	6.910E+12	2.097E+11	7.855E+11	1.106E+11	1.106E+12	84%

*MOS not included. A reduction of 86% is required when the MOS is taken into account.
WLA = wasteload allocation, LA = load allocation, MOS = margin of safety (10%)
LA = TMDL - WLA - MOS

4. Contributing Municipalities TMDL Allocation Summary: N/A

5. Contributing NPDES Facilities TMDL Allocation Summary: NCDOT stormwater

Pollutant	NCDOT Existing Load	WLA	Reduction Needed
Fecal coliform (counts/day)	4.462E+11	2.097E+11	53%

6. Public Notice Information:

Summary:	A draft of the TMDL was publicly noticed through various means. The TMDL was public noticed in the local newspaper (City of Wilmington Star News) on July 14. The TMDL was also public noticed on July 14, 2010 through the North Carolina Water Resources Research Institute (WRRI) email listserve, to the DWQ mailing list of interested parties, and on the DWQ TMDL website. A press release was sent out on July 13 and an article was published in the Star News on July 21, 2010 (Appendix F). Finally, the TMDL was available on DWQ's website http://h2o.enr.state.nc.us/tmdl/ during the comment period. The public comment period lasted from July 13, 2010 until August 13, 2010.
Did notification contain specific mention of TMDL Proposal?	Yes
Were comments received from the public?	Yes

Was a responsiveness summary prepared?	Yes, see Appendix G of the TMDL report

7. Public Notice Date: July 13, 2010

8. Submittal Date: August 20, 2010

9. Establishment Date: August 07, 2010

10. EPA Lead on TMDL (EPA or blank):

11. DOT a Significant Contribution (Yes or blank):

12. Endangered Species (Yes or blank):

13. MS4s Contributions to Impairment (Yes or blank):

14. TMDL Considers Point Source, Nonpoint Source, or both: Point Source (NCDOT stormwater) and Nonpoint Source

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met.

The Lockwoods Folly River is located in south central Brunswick County, south of Wilmington, NC within the Lumber River Basin (NC subbasin 03-07-59, HUC 030402070200). The River, estuary and their tributaries are located within the A-3 shellfish harvesting area, as designated by the North Carolina Division of Environmental Health (NCDEH). The Lockwoods Folly River and the upriver portion of the estuary are Prohibited for shellfish harvesting due to excessive levels of fecal coliform bacteria. The two downstream portions of the estuary are Conditionally Approved Open and Conditionally Approved Closed. The tributaries of Mill Creek, Mullet Creek, Lockwoods Creek and portions of Montgomery Slough and the Intracoastal Waterway are also Prohibited. Spring Creek is Conditionally Approved Open for shellfish harvesting. All of these segments are listed on the 2008 303(d) list as impaired due to fecal coliform. This document addresses the fecal coliform impairment of these restricted shellfish harvesting areas within the Lockwoods Folly River watershed as listed in the following table.

Waterbody Name - (ID)	Description	Water Quality Classification	Acres
Lockwoods Folly River - (15-25-1-(16)a)	From Brunswick County SR 1200 to a line crossing Lockwood Folly River 520 meters north of Myrtle Point of the east shore to a point of the west shore 704 meters north of Mullet Creek	SA, HQW	123.6
Lockwoods Folly River - (15-25-1-(16)b)	From a line crossing Lockwood Folly River 520 meters north of Myrtle Point of the east shore to a point of the west shore 704 meters north of Mullet Creek to a line crossing Lockwood Folly River 146 meters north of Genoes Point on the east shore to a point on the west shore 777 meters south of Mullet Creek	SA, HQW	275.6
Lockwoods Folly River - (15-25-1-(16)c)	From a line crossing Lockwood Folly River 146 meters north of Genoes Point on the east shore to a point on the west shore 777 meters south of Mullet Creek to a line crossing Lockwoods Folly River 628 meters south of Genoes point on the east shore	SA, HQW	207.0
Lockwoods Folly River - (15-25-1-(16)d)	From a line crossing Lockwood Folly River 628 meters south of Genoes Point on the east shore to Gores Landing on the east shore to ICWW	SA, HQW	53.1
Mill Creek - (15-25-1-18-(2))	From Brunswick County SR 1112 to Lockwoods Folly River	SA, HQW	2.0
Montgomery Slough - (15-25v)	From ICWW west of Lockwoods Folly Inlet extending eastward (2.4 Miles)	SA, HQW	2.3
Mullet Creek - (15-25-1-19)	From source to Lockwoods Folly River	SA, HQW	5.7
Intracoastal Waterway - (15-25u)	From a line crossing ICWW south of SR 1112 to Cape Fear River Basin	SA, HQW	403.5
Intracoastal Waterway - (15-25t1)	From a line across the ICWW 2030 meters west of NC 130 bridge to a line crossing ICWW south of SR1112	SA, HQW	292.8
Spring Creek - (15-25-1-21)	From source to Lockwoods Folly River	SA, HQW	2.4
Lockwoods Creek - (15-25-1-20)	From source to Lockwoods Folly River	SA, HQW	0.2

This document proposes to establish a TMDL for the Lockwoods Folly River and its tributaries. The selected watershed model calculated the watershed load to the Lockwoods Folly estuary which includes loads from Mullet Creek, Spring Creek, Mill Creek, Lockwoods Creek, and the Lockwoods Folly River up to Brunswick County SR 1200. Therefore, the load reduction calculated for the estuary is applied to all of the aforementioned segments. A TMDL was not developed for the Intracoastal Waterway (ICWW) and Montgomery Slough because the hydrodynamics are not conducive to using the linked watershed and Tidal Prism modeling approach. The TMDL load reduction does not apply to the ICWW or Montgomery Slough. These areas will instead be addressed in the TMDL implementation strategies.

Fecal coliform is an indicator organism used in water quality monitoring in shellfish waters to indicate sources of waste from warm-blooded animals. When the water quality standard for fecal coliform in shellfish waters is exceeded, waters are closed for shellfish harvesting to protect human health due to the potential risk from consuming raw molluscan shellfish from contaminated waters. The water quality goal of this TMDL is to reduce high fecal coliform concentrations to levels whereby the designated uses for these waterbodies will be met.

A variety of data at the watershed scale were used to identify potential fecal coliform contributions. This data included land use, soils, septic distribution, shoreline sanitary survey data, and County census data. Much of the potential fecal coliform contributions were analyzed using Geographic Information Systems (GIS) techniques. There are several stormwater permittees in the watershed including the North Carolina Department of Transportation (NCDOT), the Town of Oak Island, and several industrial stormwater permittees. The Town of Oak Island is located along the ICWW and falls outside of the modeled portion of the watershed. As such, its wasteload allocation could not be estimated. The industrial stormwater permittees include sand pits, and concrete and asphalt facilities that are not of concern with regards to fecal coliform. Therefore, NCDOT is the only permitted source included in the WLA and is addressed in this TMDL by separating their land use contribution from other land uses. Taken collectively, the data indicates that the major contributions of fecal coliform loads are nonpoint source runoff, including bacteria from wildlife and pets.

A linked watershed and Tidal Prism modeling approach was utilized to estimate the fecal coliform load from the watershed to the estuary and to simulate fecal coliform concentrations in the estuary from 2004 to 2009. This approach has been used in similar TMDLs in Maryland, Virginia, and North Carolina, though this TMDL uses a more simplified watershed model approach. Long-term model simulation is used to establish the TMDL, thereby accounting for the seasonal variability and critical conditions, which represent the hydrology, hydrodynamics, and water quality condition of the shellfish harvesting areas. The load is then allocated to point and nonpoint sources.

One of the critical tasks for these TMDLs is to determine current loads from all potential sources in the watershed. The procedure needs to account for temporal variability caused by the seasonal variation and the wet-dry hydrological conditions. Long-term model simulation was conducted to simulate fecal coliform concentration in the waterbodies. The long-term daily mean load is estimated for each watershed based on the watershed model results. These results were then used to estimate the current load condition. The allowable loads for the restricted shellfish harvesting areas were then computed using both the median water quality standard for shellfish harvesting of 14 Most Probable Number (MPN)/100ml and the 90^{th} percentile standard of 43 MPN/100ml. An explicit Margin of Safety (MOS) of 10% was incorporated into the analysis to account for uncertainty. The TMDL developed for the Lockwoods Folly River restricted shellfish harvesting areas was estimated to be 1.106×10^{12} counts of fecal coliform per day.

The goal of load allocation is to determine the estimated load for the drainage area while ensuring that the water quality standard can be attained. For restricted shellfish harvesting areas, the 90th percentile criterion requires the greatest reduction. Therefore, the load reduction scenario is estimated based on the 90th percentile water quality standard. The load reduction needed in the watershed of the restricted shellfish harvesting areas to meet the shellfish criteria and the load allocations required to meet the TMDLs is 86%, including the MOS.

Once the EPA has approved a TMDL, and it is known what measures must be taken to reduce pollution levels, the implementation of best management practices (BMPs) is expected to take place. An implementation plan is being developed as a separate document from this TMDL. The North Carolina Department of Environment and Natural Resources (NCDENR) intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality, with consideration given to ease of implementation and cost.

1.0 Introduction

All states are required by Section 303(d) of the 1972 Federal Clean Water Act (CWA) to develop Total Maximum Daily Loads (TMDL) for waterbodies that are impaired and cannot meet their designated use. Designated uses include activities such as swimming, drinking water supply, and shellfish propagation and harvest. Water quality standards have been developed as both narrative statements and numeric values which are designed to protect the designated uses of waterbodies. When water quality standards are not met, TMDLs are developed to calculate the total loading of a pollutant which a waterbody can receive and still achieve their designated use. These TMDLs take into account both seasonal variations and a protective margin of safety (MOS) to account for uncertainty. Water quality criteria may differ among waters with different designated uses.

A common pollutant in waters designated for shellfish propagation and harvesting is fecal coliform. While few fecal coliform are pathogenic, their detection indicates the presence of other bacteriological contaminants such as E. coli. Some waterborne diseases associated with the consumption of raw shellfish include viral and bacterial gastroenteritis and hepatitis A. Fecal coliform are found in the intestinal tract of humans and other warm-blooded animals and are often introduced to waterbodies through point source discharges of wastewater, or via nonpoint source contributions from runoff and failing septic systems.

The Lockwoods Folly River and its tributaries are located in the Lumber River Basin (NC Subbasin 03-07-59, HUC 030402070200). The River, estuary and their tributaries are located within the A-3 shellfish harvesting area, as designated by the North Carolina Division of Environmental Health (NCDEH). The Lockwoods Folly River and the upriver portion of the estuary are Prohibited for shellfish harvesting due to excessive levels of fecal coliform bacteria. The two downstream portions of the estuary are Conditionally Approved Open and Conditionally Approved Closed. The tributaries of Mill Creek, Mullet Creek, Lockwoods Creek and portions of Montgomery Slough and the Intracoastal Waterway are also Prohibited. Spring Creek is Conditionally Approved Open for shellfish harvesting. All of the previously mentioned segments are listed on the 2008 303(d) list as impaired due to fecal coliform.

The water quality goal of this TMDL is to reduce high fecal coliform concentrations in the impaired segments to levels such that the designated use for the restricted shellfish harvesting areas will be met. The selected watershed model calculated the watershed load to the Lockwoods Folly estuary which includes loads from Mullet Creek, Spring Creek, Mill Creek, Lockwoods Creek, and the Lockwoods Folly River up to Brunswick County SR 1200. Therefore, the load reduction calculated for the estuary is applied to all of the aforementioned segments. A TMDL was not developed for the Intracoastal Waterway (ICWW) and Montgomery Slough because the hydrodynamics are not conducive to using the linked watershed and Tidal Prism modeling approach. The TMDL load reduction does not apply to the ICWW or Montgomery Slough. These areas will instead be addressed in the TMDL implementation strategies.

1.1 TMDL Components

The 303(d) process requires that a TMDL be developed for each of the waters appearing in Category 5 of the Surface Water Integrated list. The objective of a TMDL is to estimate allowable pollutant loads and allocate to known sources so that actions may be taken to restore the water to its intended uses (USEPA, 1991). A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving North Carolina's water quality criteria for shellfish waters. Currently, TMDLs are expressed as a "mass per unit time, toxicity, or other appropriate measure" (40 CFR 130.2(i)). It is also important to note that the TMDLs presented herein are not literal daily limits. These loads are based on an averaging period that is defined by the water quality criteria (i.e., 30 samples per station). The averaging period used for development of these TMDLs requires at least 30 samples and uses the most recent 2.5-year (30-month) window of data, assuming one sample per month. Generally, the primary components of a TMDL, as identified by the USEPA (1991) and the Federal Advisory Committee (USEPA, 1998) are as follows:

Target Identification or selection of pollutant(s) and end-point(s) for consideration. The pollutant and end-point are generally associated with measurable water quality related characteristics that indicate compliance with water quality standards. North Carolina indicates known pollutants on the 303(d) list.

Source Assessment. All sources that contribute to the impairment should be identified and loads quantified, where sufficient data exist.

Reduction Target. Estimation or level of pollutant reduction needed to achieve water quality goal. The level of pollution should be characterized for the waterbody, highlighting how current conditions deviate from the target end-point. Generally, this component is identified through water quality modeling.

Allocation of Pollutant Loads. Allocating pollutant control responsibility to the sources of impairment. The wasteload allocation portion of the TMDL accounts for the loads associated with existing and future point sources. Similarly, the load allocation portion of the TMDL accounts for the loads associated with existing and future non-point sources, stormwater, and natural background.

Margin of Safety. The margin of safety addresses uncertainties associated with pollutant loads, modeling techniques, and data collection. The margin of safety may be expressed explicitly as unallocated assimilative capacity or implicitly due to conservative assumptions.

Seasonal Variation. The TMDL should consider seasonal variation in the pollutant loads and end-point. Variability can arise due to stream flows, temperatures, and exceptional events (e.g., droughts, hurricanes).

Critical Conditions. Critical conditions indicate the combination of environmental factors that result in just meeting the water quality criterion and have an acceptably low frequency of occurrence.

Section 303(d) of the CWA requires EPA to review all TMDLs for approval or disapproval. Once

EPA approves a TMDL, then the waterbody may be moved to Category 4a of the Integrated Report. Waterbodies remain on Category 4a of the list until compliance with water quality standards is achieved. Where conditions are not appropriate for the development of a TMDL, management strategies may still result in the restoration of water quality.

A TMDL is comprised of the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. The TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, the TMDL may include a future allocation (FA) when necessary. Conceptually, this definition is denoted by the equation:

TMDL = WLAs + LAs + MOS + (FA, where applicable)

This TMDL does not include future allocations.

1.2 Documentation of Impairment

All surface waters in the state are assigned a primary classification that is appropriate to the best uses of that water. In addition to primary classifications, surface waters may be assigned a supplemental classification to provide special protection. The North Carolina Division of Water Quality (DWQ) Surface Water and Wetlands classification for the restricted shellfish harvesting areas in the watershed is Class SA Waters – Shellfish Harvesting Waters (15A NCAC 02B.0221 Tidal Salt Water Quality Standards for Class SA Waters). A Class SA water is a waterbody that is suitable for commercial shellfishing and all other tidal saltwater use (NCAC 2003). Additionally, these waterbodies have been assigned a supplemental classification of Class HQW – High Quality Waters. All Class SA waters are required to carry a supplemental designation of HQW or ORW (Outstanding Resource Waters) by rule.

Eleven segments in the Lockwoods Folly River watershed have been included on the 2008 North Carolina Integrated Report. These restricted shellfish harvesting areas are identified as areas in this basin that do not meet their designated uses. Waters within this classification, according to 15A NCAC 02B.0021 (Tidal Salt Water Quality Standards for Class SA Waters), must meet the following water quality standard in order to meet their designated use:

“Organisms of coliform group: fecal coliform group not to exceed a median MF of 14/100 ml and not more than 10 percent of the samples shall exceed an MF count of 43/100 ml in those areas most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions.”

For this report, the monitoring data-averaging period was based on monitoring procedures for classifying SA water, i.e. the fecal coliform concentration cannot exceed a median or a geometric mean of an MPN of 14 per 100 ml and the 90th percentile of an MPN of 43 per 100 ml, for six samples per year and 30 samples per station. The averaging period for the monitoring data required at least 30 samples. For this report, the monitoring data analysis period was based on data from 2004 to 2009. The water quality impairment was assessed using the geometric mean, median and 90th percentile concentrations.

1.3 Watershed Description

The Lockwoods Folly River is located in south central Brunswick County, within the Lumber River Basin south of Wilmington, NC (NC subbasin 03-07-59). Although part of the Lumber River Basin, the river originates near the Town of Bolivia, flows westerly and then southwesterly and empties into the Atlantic Ocean through the Lockwoods Folly River Inlet. The barrier islands of Oak Island and Holden Beach protect the inlet, and the Intracoastal Waterway (ICWW) is located landward of the islands. Montgomery Slough partially bisects Oak Island towards the seaward side of the island, and is connected to the ICWW in two locations. The Lockwoods Folly estuary drains to the ICWW before reaching the outlet to the Atlantic Ocean (Figure 1). The ICWW and Montgomery Slough do not drain to the Lockwoods Folly estuary. Given their connection, and the open-ended nature of the ICWW, the hydrodynamics of these two waterbodies are not conducive to using the linked watershed and Tidal Prism modeling approach. These areas will instead be addressed in the TMDL Implementation Plan strategies.

The watershed encompasses five 14-digit HUCS: 03040207020010, 03040207020020, 03040207020030, 03040207020040, and 03040207020050. The drainage area of the watershed is approximately 153 square miles (Figure 1).The Lockwoods Folly Estuary is approximately 3.2 miles in length from the ICWW and moving landward, with an average depth of about 1.2 feet (mean low water). The dominant tide in this region is the lunar semi-diurnal (M2) tide with a tidal period of 12.42 hours. The assumed mean tidal range is 4.1 feet based on the NOAA station located at the Lockwoods Folly Inlet (NOAA 2009).

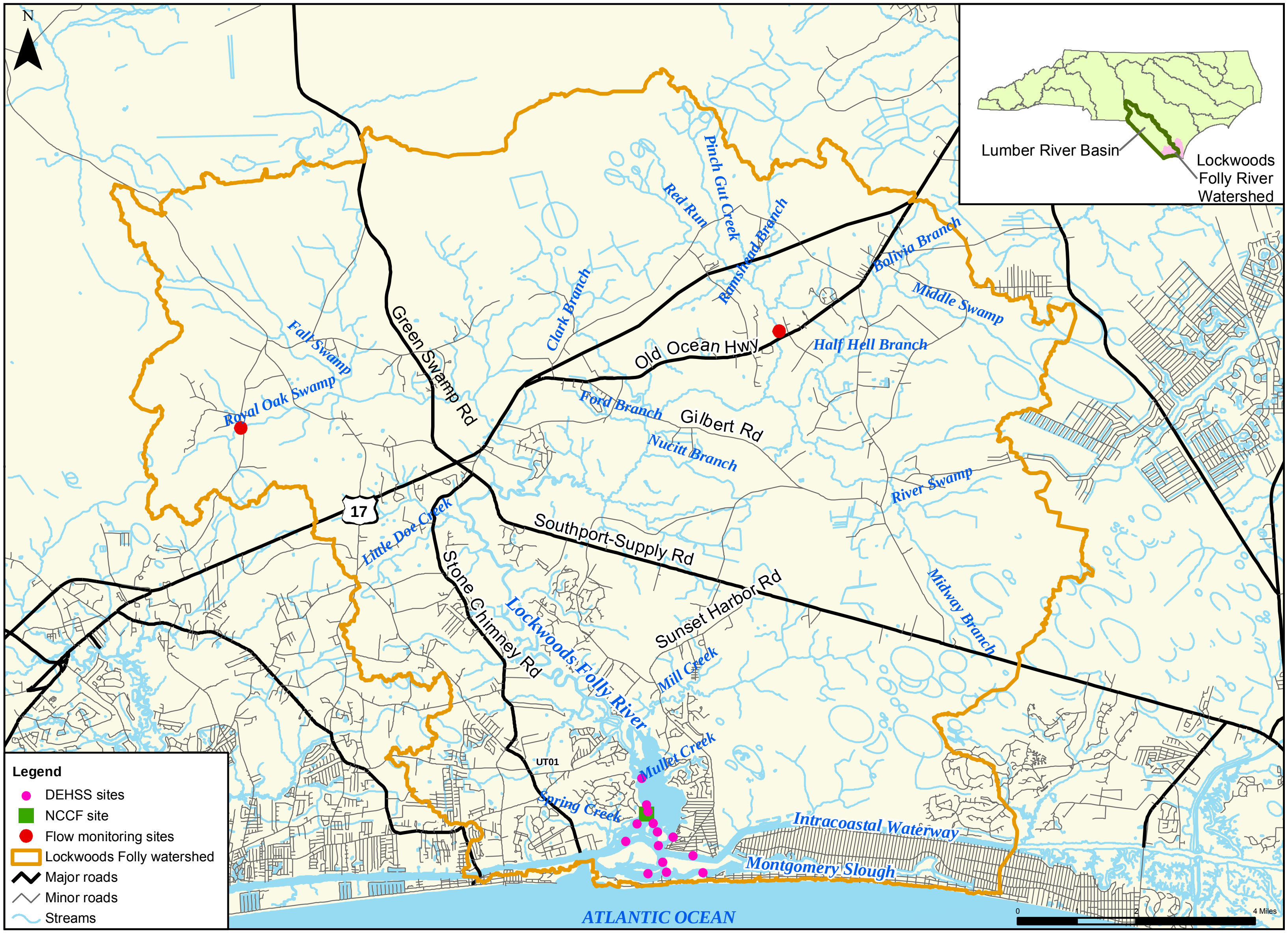


Figure 1. Vicinity and watershed map

1.3.1 Land Use/Land Cover

A land use layer for the watershed was created using the 2004 Brunswick County existing land use map, aerial imagery, and County parcel data. The land uses were assigned to 16 categories as shown in Table 1. NCDOT was separated from other road surfaces in order to track their contribution to fecal coliform loadings separately. At approximately 73%, the watershed is primarily comprised of forest land. Of the forested land, approximately 30% is wooded wetland and 20% is managed pineland. Residential, commercial, industrial, and office land uses combined currently make up about 6% of the watershed. Other major land uses include open space at 7.6%, and row crop at 4.8%. Current land use in the watershed is depicted in Figure 2.

Table 1. Land use distribution in the Lockwoods Folly River watershed

Land Use Category	Area (acres)	Percent
High Density Residential (0.07 - 0.22 acres)	807	0.8%
Medium Density Residential (0.23 - 0.33 acres)	617	0.6%
Low Density Residential (0.34 - 0.99 acres)	1519	1.5%
Very Low Density Residential (1 - 5 acres)	1888	1.9%
Commercial/Heavy Industrial	215	0.2%
Office/Institutional/Light Industrial	596	0.6%
Road (w/ ROW) non-NCDOT	1527	1.6%
Road (w/ ROW) NCDOT	1629	1.7%
Barren Land	220	0.2%
Managed Open Space	7456	7.6%
Golf Course	631	0.6%
Pasture	858	0.9%
Row Crop	4660	4.8%
Forest (includes wooded wetland and managed pineland)	71407	72.9%
Emergent wetland	1860	1.9%
Water	2119	2.2%

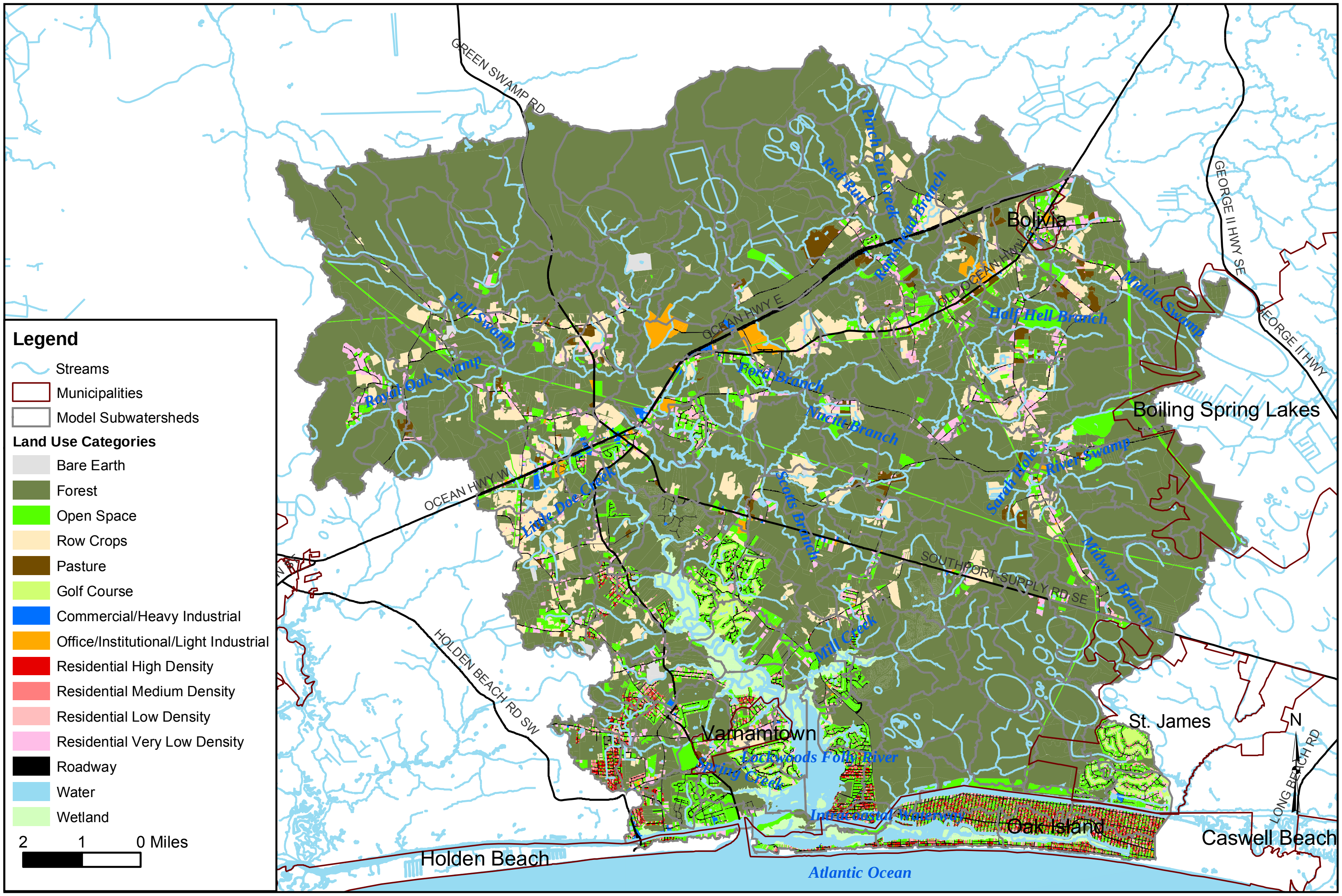


Figure 2. Current land use

1.3.2 Soils

Most of the watershed is located in the Lower Coastal Plain soil region (Daniels et al., 1999). Upland soils adjacent to the floodplain include well drained and moderately well drained soils (hydrologic soil group A or B) such as the loamy Baymeade (SCS 1986). Sandy, excessively drained soils of the Kureb-Wando map units are located within the areas of Varnamtown, Sunset Harbor, and Oak Island. In addition, there are large areas of somewhat poorly to very poorly drained soils such as Leon and Murville, Torhunta, and Croatan. Map units that are completely hydric soils or contain hydric soils make up about 89% of the watershed. Over 92% of the soils in the watershed are rated as very limited in terms of septic suitability.

1.4 Water Quality Characterization

The Shellfish Sanitation and Recreational Water Quality Branch of the NCDEH is responsible for classifying shellfish harvesting waters to ensure oysters and clams are safe for human consumption. NCDEH adheres to the requirements of the National Shellfish Sanitation Program (NSSP), with oversight by the U.S. Food and Drug Administration to conduct shoreline surveys and collect routine bacteria water quality samples in the shellfish-growing areas of North Carolina. The data are used to determine if the water quality criteria are being met. If the water quality criteria are exceeded, the shellfish areas are closed to harvest, at least temporarily, and consequently the designated use is not being achieved. The criteria for the shellfish harvesting areas are based on the 90th percentile, geometric mean, and median of the most recent 30 samples collected at a given site. The criterion for the 90th percentile is not to exceed 43 cts/100mL. The criterion for the geometric mean and median is not to exceed 14 cts/100mL. Shellfish growing areas throughout North Carolina are sampled using the systematic random sampling strategy as outlined in the National Shellfish Sanitation Program's Model Ordinance and guidance document. Routine bacteriological monitoring involves the sampling of shellfish monitoring sites during favorable conditions in which the shellfish beds are open for harvesting to verify that fecal coliform levels are low. In addition to the routine bacteriological monitoring of the areas, at some stations conditional area samples are collected. Conditional samples are collected after an area has been temporarily closed due to rainfall in order to determine whether the shellfish area can be reopened. These samples may be more representative of fecal coliform levels during unfavorable conditions than those collected during routine monitoring. However, it is common to wait a day or two after a rain event before conducting conditional sampling to allow the river to return to more normal conditions.

There are nine monitoring sites sampled by Shellfish Sanitation (DEHSS) which are located within the modeled Lockwoods Folly estuary (Figure 3). As discussed in Section 3.1.3 the estuary was divided into four segments for modeling. All nine monitoring sites lie within the same segment (M0S2).The summary statistics of the most recent 30 samples collected at these sites as of October 2009 are presented in Table 2. Also included in Table 2 are the total number of samples taken at each site between 2004 and 2009, the number of conditional samples in that period, and the date of the latest sample and conditional sample collected at each site.

Table 2. Summary statistics of observation data (2004 to October 2009)

Station	Last 30 Sample Geometric Mean (MPN/100mL)	Last 30 Sample Median (MPN/100mL)	Last 30 Sample 90th Percentile (MPN/100mL)	Date of Last Sample	Date of Last Conditional Sample	No. of Conditional Samples	No. of Total Samples
5A	9	8	29	9/9/2009	11/8/2004	1	49
6A	7	5	41	9/9/2009	4/4/2005	1	37
7	6	4	37	10/7/2009	10/7/2009	94	118
7A	6	4	31	10/7/2009	10/7/2009	93	115
8	7	6	44	9/9/2009	5/1/2006	35	71
10	6	5	36	9/9/2009	4/4/2005	1	38
13	4	4	17	9/9/2009	10/1/2009	21	53
14A	9	8	40	9/9/2009	9/22/2005*	4	54*
14B	6	6	30	9/9/2009	na	na	34

*16 samples collected by NCCF. Last sample collected on 12/12/2008.

The inclusion of conditional samples in developing summary statistics for the monitoring stations is important for assessing water quality in the estuary under all conditions. Sites 7 and 7A have the most complete monitoring record from 2004 to 2009 with 118 and 115, respectively. The majority of those samples at both sites were conditional samples collected consistently throughout the model simulation period. Site 8 follows with 71 samples collected between 2004 and 2009 with 35 of them being conditional. However, the last conditional sample collected at Site 8 occurred in May of 2006. One conditional sample was collected at sites 5A, 6A, and 10, while no conditional samples were collected at 14B. During the model simulation period (2004-2009) only 4 conditional samples were collected at Site 14A. Additionally, the North Carolina Coastal Federation (NCCF) collected 16 samples at Site 14A for the development of the TMDL report. These additional samples were included in the computation of the summary statistics at this station (Table 2).

From the observed data, water quality standards are currently being violated at only one site. Site 8 is violating the 90th percentile standard for fecal coliform with a value of 44 cts/100mL (Table 2). Observed fecal coliform levels at the remaining sites are currently below the water quality standards. However, prior to 2008, five of the monitoring sites were violating the 90th percentile water quality standard, with the highest fecal coliform levels occurring at sites 7 and 7A (Table 3). The drop in the 30-month 90th percentiles at monitoring sites in the estuary began to occur in early 2008, possibly as a result of statewide drought which began in 2007. However, in addition to rainfall, land use, hydrology, and loading from various sources and pathways among other things affect water quality in the estuary. This trend is particularly evident at sites 7 and 7A, where the most conditional samples have been collected of the nine monitoring sites. Graphs of the observed data, 30-month median, and 30-month 90th percentile for each site are included in Appendix A along with tables of the observed data. The graphs show that fecal coliform levels are currently increasing at Sites 7 and 7A as precipitation levels have increased.

Table 3. Summary statistics of observation data (2004 to December 2007)

Station	Last 30 Sample Geometric Mean (MPN/100mL)	Last 30 Sample Median (MPN/100mL)	Last 30 Sample 90th Percentile (MPN/100mL)
5A	10	8	53
6A	na	na	na
7	11	8	85
7A	10	4	125
8	9	5	71
10	7	5	45
13	5	4	30
14A	na	na	na
14B	na	na	na

na = not available, <30 samples collected and summary statistics could not be calculated.

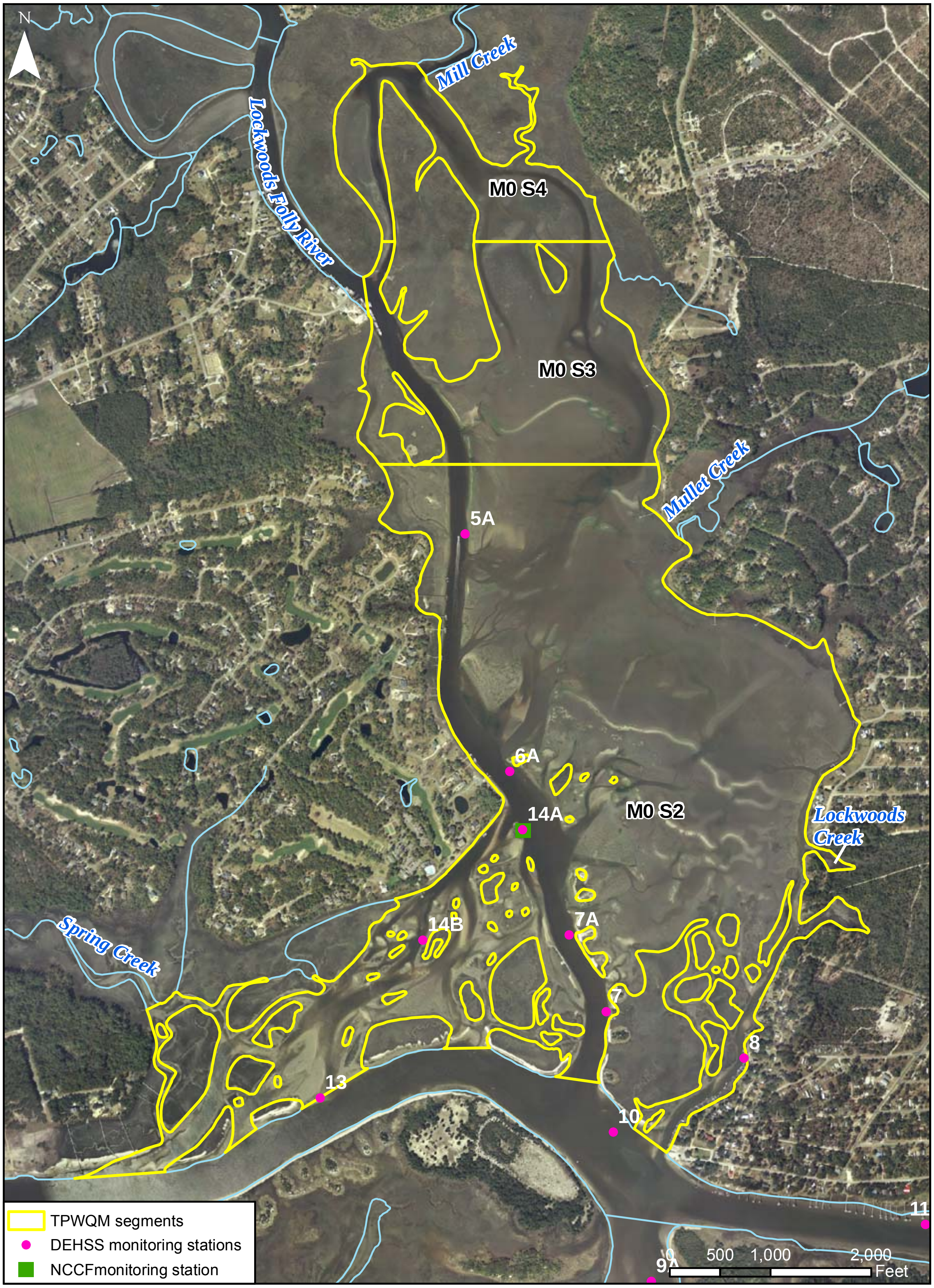


Figure 3. Shellfish Sanitation monitoring station locations and TPWQM model segments

2.0 Source Assessment

2.1 Point Source Assessment

2.1.1 NPDES Wastewater Permits

There are currently no NPDES wastewater permitees in the watershed.

2.1.2 NPDES Stormwater Permits

Stormwater has previously been considered a nonpoint source; however, current EPA guidance and policy requires that NPDES-permitted stormwater sources be included in the wasteload allocation (WLA) of the TMDL as opposed to the load allocation (LA). Many of the roadways in the watershed are maintained by the North Carolina Department of Transportation (NCDOT), including US 17, Old Ocean Highway, Green Swamp Road, and Stone Chimney Road. These NCDOT roads fall under the NCDOT statewide NPDES stormwater permit. NCDOT's contribution to fecal coliform loading in the watershed was tracked separately in the model from other land use types in order to calculate their wasteload allocation and load reduction requirements.

The Town of Oak Island is a Phase II stormwater community. A portion of the Town lies within the Lockwoods Folly River watershed; however, surface runoff from the Town drains to both the Intracoastal Waterway and Montgomery Slough. These two waterbodies do not flow into the Lockwoods Folly estuary. The hydrodynamics of the ICWW and Montgomery Slough are not conducive to using the linked watershed and Tidal Prism modeling approach due to the open boundary of the ICWW and the connectivity of Montgomery Slough. Therefore, a TMDL was not developed for these waterbody segments and the TMDL load reduction does not apply. As such a wasteload allocation could not be calculated separately for the Town of Oak Island. However, the Town will be addressed in the TMDL Implementation Plan. Additionally, the Town's future stormwater permits will incorporate strategies for reductions in fecal coliform loads outlined in the plan. Strategies will include both structural and non-structural best management practices (BMPs) as well as programs to assess the effectiveness of these strategies in reducing fecal coliform loads from the Town.

There are also four active NPDES industrial stormwater permits in the watershed for sand pit, concrete, and asphalt facilities (Table 4). Fecal coliform loading from these types of facilities are not of concern. Therefore, a separate WLA was not calculated for these stormwater permits.

Table 4. Active NPDES industrial stormwater permits in the watershed

Permit No.	Name
NCG020618	Holden Beach Sandpit #2
NCG020630	Tripp's Construction Company LLC
NCG140277	S & W Ready Mix Concrete - Bolivia
NCG160037	Barnhill Contracting Company

2.2 Nonpoint Source Assessment

Nonpoint sources of fecal coliform bacteria do not have one discharge point but occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in the watershed discharging to the restricted shellfish harvesting areas. Fecal coliform bacteria from non-human sources originate from excretions from livestock, wildlife, and pets. Nonpoint source loading typically occurs during rain events when surface runoff transports water carrying fecal coliform over the land surface and discharges it into the stream network. A more direct path to the restricted areas occurs when wildlife defecates in the drainage network, including stream and wetland channels, and stormwater conveyance pipes. Nonpoint source contributions to the bacterial levels from human activities generally arise from malfunctioning or improperly-sited septic systems and their associated drain fields, or illicit connections of sanitary sewage to the stormwater conveyance system. The transport of fecal coliform from the land to the restricted shellfish harvesting area is dictated by the hydrology, soil type, land use, and topography of the watershed.

The purpose of the source assessment was to estimate the populations of pets, livestock, and wildlife and the number of septic systems in the project area. These numbers were derived based on data from various sources including Brunswick County Census data, pet and wildlife statistical data, personal communications with property owners, Shellfish Sanitation Shoreline Survey data, and land use data. A description of these parameters and the development of the nonpoint source assessment are described in detail in Appendix C. The distribution of nonpoint source loads for the watershed is presented in Table 5. These values are direct inputs to the watershed, not the estuary, from various sources and do not take into account decay and transport, on land or in-stream.

Table 5. Estimated distribution of direct fecal coliform nonpoint source loads to the watershed

Source	Fecal coliform (cts/day)	% contribution
Livestock	9.05E+12	15.3%
Wildlife	3.10E+13	52.3%
Pets	1.75E+13	29.6%
Human	1.67E+12	2.8%
Total	5.92E+13	

*The values included in this table are inputs to the watershed, not the estuary (or waterbody), from various sources and do not take into account decay and transport, on land or in-stream.

3.0 Total Maximum Daily Loads and Load Allocation

This section documents fecal coliform TMDL development and allocations for the Lockwoods Folly River watershed. In order to estimate the existing load and allowable load for the watershed, a watershed model was used to simulate fecal coliform loads from the watershed to the estuary. Once the fecal coliform is discharged to the receiving water, it will be transported to the different areas in the estuary due to the interaction of tide and freshwater discharge and decay. Therefore, a tidal model was used to simulate fecal coliform concentrations within the estuary. The required load reduction was determined over the model simulation period (2004 to 2009) based on modeling results. The TMDL is presented as counts per day. The following sections present the detailed TMDL development and load allocations for the project area. The first section describes the watershed and tidal models used for the TMDL study, as well as model set up. The second section presents the model calibration and validation procedures. The third section describes the TMDL calculation. The fourth and fifth sections address the critical period and seasonal variability. The sixth section discusses TMDL loading caps. The seventh and eighth section presents the load allocation and waste load allocation, respectively. The ninth section presents the margin of safety. Finally, the variables of the equation are combined in a summary accounting of the TMDL.

3.1 Modeling Approach

Based on the considerations of the influence of nonpoint sources and tidal-induced transport in the estuary, analysis of the monitoring data, review of the literature, and past pathogens modeling applications, a linked watershed and tidal modeling approach was used to simulate fecal coliform loading from the watershed and fecal coliform concentration in the estuary. A description of the modeling approach is provided in the following section. Detailed documentation of the modeling methods is provided in Stantec, 2010.

3.1.1 <u>Watershed Model Description</u>

A simplified watershed model was developed utilizing HEC-HMS (v. 3.3) to estimate flow for the Lockwoods Folly River watershed given land use, soils, and precipitation data. A fecal coliform loading model from the watershed to the estuary was then developed using literature values for event mean concentrations (EMC) for each land use category in conjunction with the runoff calculated from the various soil-land use combinations in the watershed. HEC-HMS is a Graphical User Interface (GUI) based program designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is able to incorporate storm flow, base flow, and evapotranspiration in a continuous simulation of hydrologic processes.

3.1.2 <u>Tidal Prism Description</u>

The Tidal Prism Water Quality Model was selected as the receiving water quality model. TPWQM simulates tidal transport in terms of the concept of tidal flushing (Ketchum, 1951). The tidal prism, or inter-tidal volume, is the amount of water entering and leaving a coastal basin during each tidal cycle. During flood tide, a large amount of water (i.e., the tidal prism) floods into the coastal basin. This amount of water mixes with the lower tidal water within the basin. A portion of pollutant inside the basin will be transported out of the basin during ebb tide as water is transported out of the basin. The TPWQM can simulate pollutant transport in an estuary both temporally and spatially

(Kuo and Neilson, 1988; Kuo et al., 1998). The input data required to run the model includes tidal range, surface area, and depth of the waterbody. Thus, the tidal prism for the modeling area can be estimated based on the volume of the basins and the tidal range in the area.

3.1.3 Model Setup

The Lockwoods Folly River watershed was delineated into 28 subwatersheds for the watershed loading model using available topography data (DEM grid), aerial photography, and field reconnaissance data. Figure 4 depicts the watershed delineation. It should be noted that the 28th subwatershed drains to the ICWW and was not modeled as contributing flow and fecal coliform load to the Lockwoods Folly estuary. A unique land use layer was developed for the watershed as described in Section 1.3.1.

The project estuary was divided into 4 segments based on the Tidal Prism theory (Kuo and Park 1994), with the first segment being the seaward boundary. The segmentation is depicted in Figure 3. The volume of the estuary was derived using bathymetry data from the US Army Corps of Engineers for the Lockwoods Folly channel through the estuary, in addition to field bathymetry data points collected in November 2009 by the NCCF throughout the estuary. The dominant tide in this region is the semi-diurnal (M2) tide with a tidal range of 4.2 feet based on the NOAA tidal station at the Lockwoods Folly Inlet (NOAA 2009). The surface area of each segment together with tidal range was used to compute the high tide water volume and tidal prisms. Using mean tidal range and mean volume, the model provides the daily mean results, but not the instantaneous condition, which is consistent with the standard. The geometry information of the TPWQM is listed in Appendix B. Given the relatively low level of contribution of land use immediately surrounding the estuary, all flows and loads were modeled as entering the estuary through the Lockwoods Folly River, in the 3rd segment of the TPWQM (M0S3). All monitoring sites are located in Segment M0S2 (Figure 3). Since the TPWQM is on the scale of a tidal cycle (i.e., about 12.42 hours), the load per tidal cycle was calculated by aggregating the hourly loads generated from the watershed loading model. The simulation period of the TPWQM is the same as that of the watershed model.

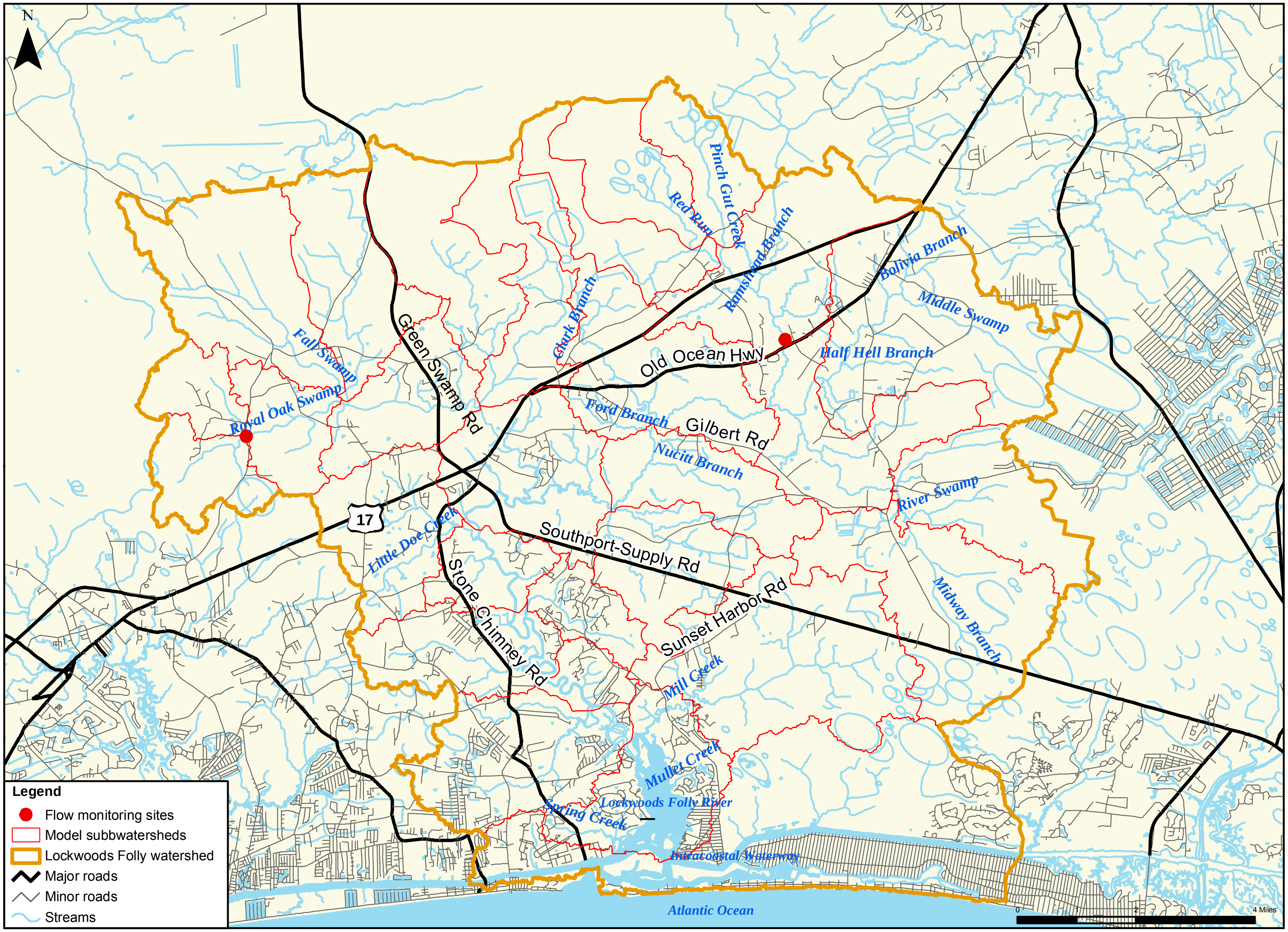


Figure 4. Watershed model subwatersheds

3.1.4 Meteorological Data

One of the major inputs for the watershed hydrology and loading models is precipitation. The nature of rainfall in the Lockwoods Folly River watershed is very non-uniform. As such, precipitation data from three separate precipitation gages was collected in order to model the variability in flow across the watershed.

The first precipitation gage is the Nature Conservancy RAWS station (NNAC), located within the northern portion of the watershed along Green Swamp Road. Comprehensive precipitation records for other rain gages within the watershed were not available. As such, the other two stations from which precipitation data was gathered are located outside of the watershed: Sunny Point RAWS station (NSUN) and Grand Strand Airport Station (NCRE). Data was retrieved for January 1, 2004 until September 30, 2009 from the State Climate Office of North Carolina for the three gages (NC CRONOS 2009). It should be noted that although two of the precipitation gages are not located directly within the watershed, their data demonstrated that the occurrence of rainfall events at these stations matched well with events detected at the NNAC station, i.e. large storms of long duration were found to occur concurrently at all gages. Precipitation data from each station was attributed to the model subwatersheds, based on their proximity. The average monthly precipitation for each gage over the model simulation period is presented in Figure 5.

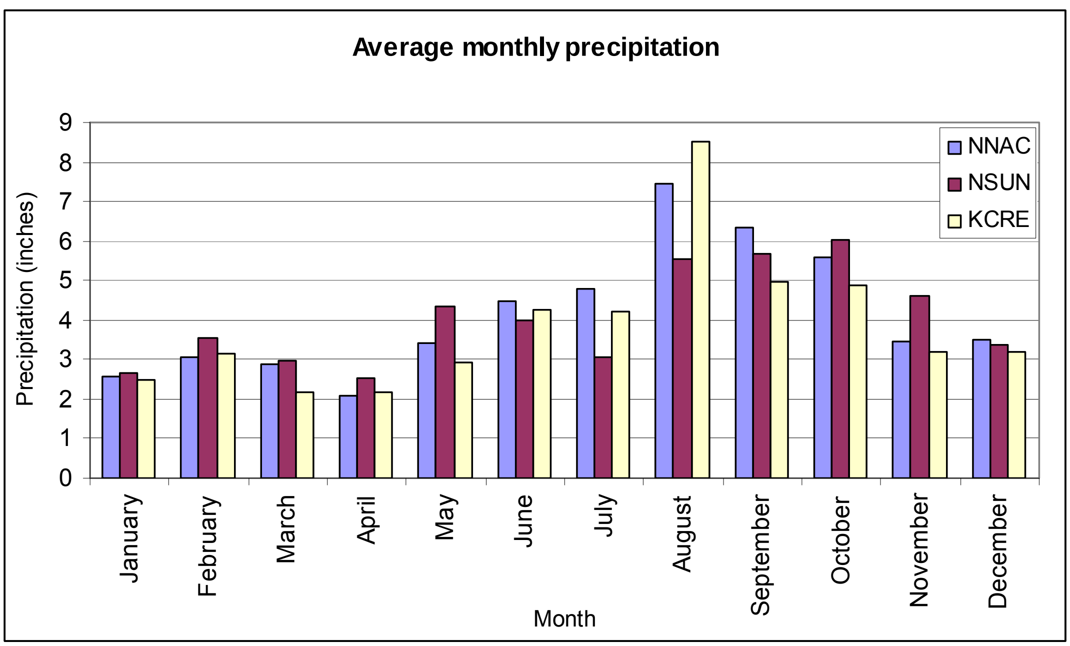


Figure 5. Average monthly precipitation (2004-2009) for the three precipitation gages

3.2 Model Calibration and Validation

Both the watershed and Tidal Prism models were calibrated and verified based on observed data. A description of the model calibration and validation is presented in the following sections.

3.2.1 Watershed Model Calibration

The hydrology of the HEC-HMS watershed model was calibrated and verified for water years 2008 to 2009. There is no long-term USGS gage in the drainage basin; however, a stream gage was installed for the development of the TMDL model. This gage is located on the Lockwoods Folly River off of Old Ocean Highway (Figure 1). The stream gage was installed in August 2008 and recorded data through July 2009. The hydrology calibration involved the adjustment of model parameters such that agreement was achieved between simulated flows and stream flow data measured at the stream gage. The model parameters adjusted included initial deficit, maximum storage, constant loss rate, and initial storage. Calibration of the hydrology model was conducted from October 2008 to February 2009. The model was then verified against stream gage data from February 2009 to July 2009. Graphs of the model calibration and validation are shown in Figures 6 and 7, respectively.

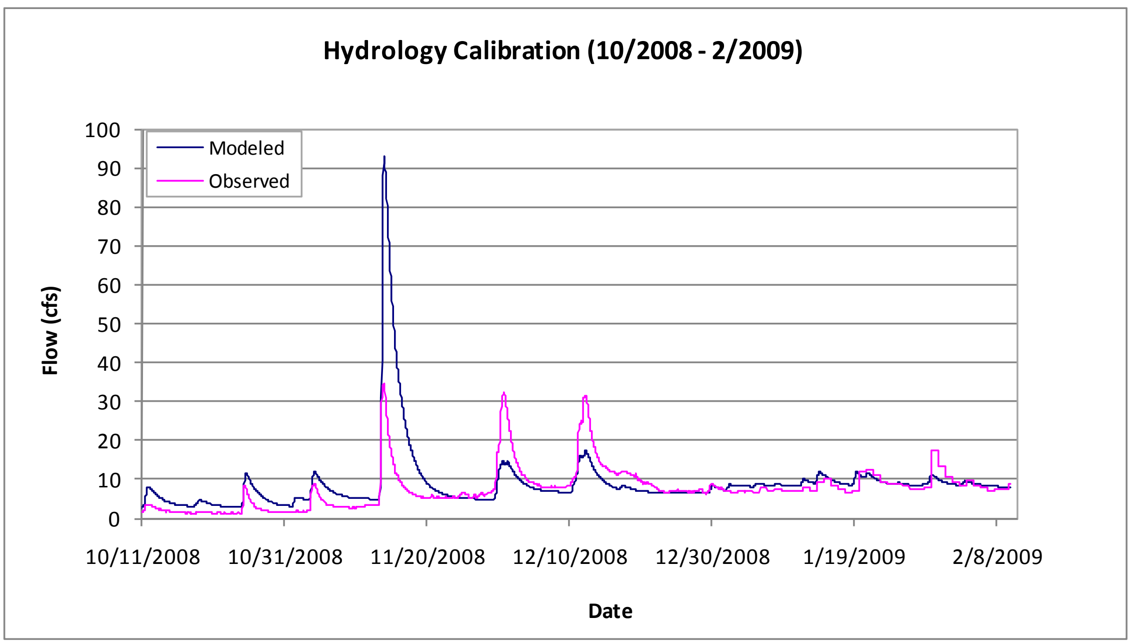


Figure 6. Hydrology model calibration

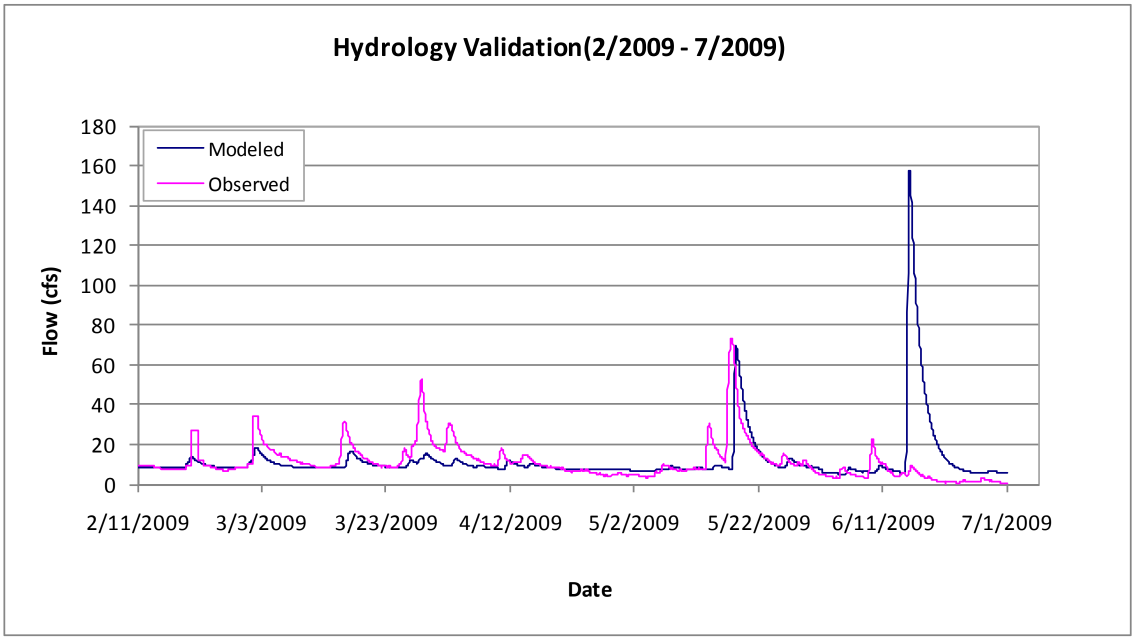


Figure 7. Hydrology model validation

The model was also calibrated such that the quantity of runoff between observed and modeled results were similar. This comparison was made at the seasonal level and for the calibration period as a whole (Table 6). Additionally, model results for total discharge, relative to drainage area, was compared to discharge from a USGS gage to show that model results were within the same range of values. This comparison was made over both the calibration and validation period (Table 7). The USGS gage is located on Hood Creek near Leland, North Carolina (USGS 02105900) with a drainage area of 21.6 square miles.

Table 6. Comparison of observed and modeled runoff

	Modeled Runoff (inches)	Observed Runoff (inches)	Percent Difference
Fall 2008	1.53	1.20	27%
Winter 2008-2009	1.90	2.09	-9%
Spring 2009	2.83	2.50	13%
Total	6.26	5.80	8%

Table 7. Comparison of total seasonal discharge (inches)

	Observed Discharge at USGS Gage Hood Creek (inches)	Model Discharge at Calibration Site (Old Ocean Hwy) (inches)	Modeled Discharge to Lockwoods Folly Estuary (inches)
Fall 2008	2.50	1.69	1.69
Winter 2008-2009	1.95	1.78	1.86
Spring 2009	1.74	2.59	2.24
Total	6.19	6.06	5.79

Percent difference criteria for modeled runoff vary at the annual and seasonal scale. According to Lumb et. al (1994) ±10% is preferred at the annual scale, whereas ±30% is acceptable at the seasonal scale. These criteria have been met by the calibrated hydrology model. There is high variability in rainfall in the watershed which leads to greater differences between observed and modeled runoff than might be observed in watersheds with more uniform rainfall distribution patterns. Additionally, the difference between modeled and observed runoff were enhanced by two instances of extreme peak flows.

During the model calibration/validation periods, the model showed significant differences from the observed data during two events. The first event occurred during the calibration period on November 13, 2008 (Figure 6). The closest precipitation gage (NNAC) to the stream gage was used for the precipitation input to subwatersheds upstream of the stream gage. The NNAC precipitation gage is located approximately 6 miles west of the stream gage. The NNAC gage showed a total rainfall of 1.08 inches on November 13 with 1.05 inches occurring in one hour. The model over predicted flow during this event by approximately 250%. Analysis of this event and the remainder of the record indicate that the model may over predict discharge for high rainfall intensities. However, the model did accurately approximate peak flow values and discharge volume for a storm occurring on May 17, 2009. This storm consisted of 2.28 inches of rainfall with a peak intensity of 0.83 inches in one hour. In general, the model more accurately predicts flows for storms with intensities less than 1 inch per hour. Storm events with intensities greater than 1 inch per hour happen rarely in this area. Reviewing the rainfall record for the watershed, such events occur approximately five times a year.

The second event in which a significant difference between the model and observed data occurred took place during the validation period on June 14, 2009 (Figure 7). The NNAC precipitation gage recorded a total rainfall of 1.51 inches, with 1.46 inches occurring in the first hour of rainfall. With only a slight increase in discharge recorded at the stream gage, this storm event was likely a summer thunderstorm and high intensity rainfall did not occur in the watershed upstream of the stream gage.

After flow rates from each land use type were determined, fecal coliform loads were calculated using EMC (event mean concentration) values from pertinent research (Table 8). A description of EMC selection can be found in Appendix E. These loads were further modified to account for the “first flush” effect by applying a multiplying factor early in storms and a dividing factor as flows decrease. As discharge values were modeled to increase by a certain percentage from the previous time step, the multiplying factor was applied. Otherwise, a dividing factor was applied to the fecal coliform concentration. The percent increase, multiplying, and dividing factors were adjusted during the Tidal Prism Water Quality Model (TPWQM) calibration where fecal coliform loads to the estuary were calibrated against observed data collected by DEHSS (Section 3.2.2).

Table 8. Selected EMC Values (cfu/100ml)

Land Use	EMC Value (cfu/100ml)
Low Density Residential	5150
Medium Density Residential	5150
High Density Residential	5150
Office and Light Industrial	1389
Commercial and Heavy Industrial	2125
Road	1400
Forest	500
Golf and Managed Open Space	500
Pasture	1000
Row Crop	500

3.2.2 Tidal Prism Model Calibration

Calibration point selection

The TPWQM calibration was conducted based on the comparison of model simulated and observed fecal coliform concentrations in the estuary. Several factors were considered in selecting from the monitoring sites for the model calibration. These factors included current water quality violations, past water quality violations, robustness of the data record, and location of the site in the estuary. Site 8 is the only monitoring site currently violating water quality standards (as of October 2009). However, this site is located along the shoreline in the southeastern portion of model segment M0S2 in the estuary and is less influenced by tidal mixing than sites located in the center of the estuary. Sites 7 and 7A are centrally located in model segment M0S2 of the estuary (Figure 3). Both sites have the most complete data records of the monitoring sites, including the most extensive conditional monitoring records. While these sites are not currently violating water quality standards they did demonstrate the highest fecal coliform levels prior to the 2007 drought.

Model results for model segment M0S2 were compared to observed data at sites 7A and 8 during the calibration. Site 7A was selected as a calibration point for the TPWQM due to its central location in the estuary and its extensive data record. Additionally, the calibration was optimized by comparing model results to observed data at Site 8 to ensure that the calibrated model accurately represents both past and current water quality violations.

Calibration

The two parameters that can be adjusted within the TPWQM during calibration are the return ratio and the fecal coliform decay rate. The return ratio is the fraction of water leaving the estuary during the ebb tide that will be transported back to the estuary during the next flood tide. The return ratio ranges from 0 to 1. Past studies of the TPWQM have demonstrated that the calculated salinity is relatively insensitive to the value of return ratio between 0.1 to 0.5 and the value of 0.3 works well for small creeks in Virginia (Kuo, et al. 1998). Return ratio was adjusted during model calibration for the Lockwoods Folly estuary. It was found that the Lockwoods Folly estuary is also insensitive to adjustments in return ratio. The final return ratio selected for the Lockwoods Folly TPWQM was 0.3. The first order decay is used in the model to represent the fecal coliform die-off due to temperature, salinity, solar radiation, and loss due to settling and other factors. A system with a higher decay rate has a higher assimilative capacity than a system with a lower decay rate. The value of decay rate varies from 0.7 to 3.0 per day in salt water (Mancini 1978; Thomann and Mueller 1987). A decay rate of 0.7 per day was used for the Lockwoods Folly estuary as a conservative estimate in the TMDL model.

Fecal coliform loads to the estuary were also adjusted during the TPWQM model calibration. The calibration procedure involved adjusting the multiplier and divisor values described in Section 3.2.1 which adjust the fecal coliform concentrations in runoff over a storm event. The final values for the multiplying and dividing factors were selected such that the modeled fecal coliform concentrations in Segment M0S2 of the estuary fell within the range of observed values at Site 7A and Site 8 during the model simulation period. Additionally, it was verified that the model results approximated the observed 30-sample 90th percentile over the 5-year model simulation period. The 90th percentile is a criterion used by DEHSS as a standard for shellfish use ratings. Model results and observed values for Site 7A are presented in Figure 8. The comparison of the model 30-month 90th percentile and Site 7A observed 90th percentile are presented in Figure 9. Note that in Figure 9, each point represents the 90th percentile of the previous 30 months. Therefore, from 2004 to 2009 the first modeled point appears in July of 2006. Figure 10 depicts the comparison of model results to observed fecal coliform levels at Site 8. The comparison of the modeled and Site 8 observed 30-month 90th percentiles is presented in Figure 11.

The observed measurements show the lowest concentration is always 1.7 MPN/100ml. This is due to the laboratory methods used for determining the fecal coliform counts. The model was not able to consistently capture these low concentration events. The model may not have captured these lower baseline values due to the length and shallow geometry of the estuary and an inability to model sufficient tidal flushing. However, the high concentration is more critical for determining the bacteria capacity of the estuary. The 5-year model simulation period demonstrated seasonal variability and captured peak fecal coliform concentrations compared to observed data. Given the long-term simulation results, the overall model performance is satisfactory.

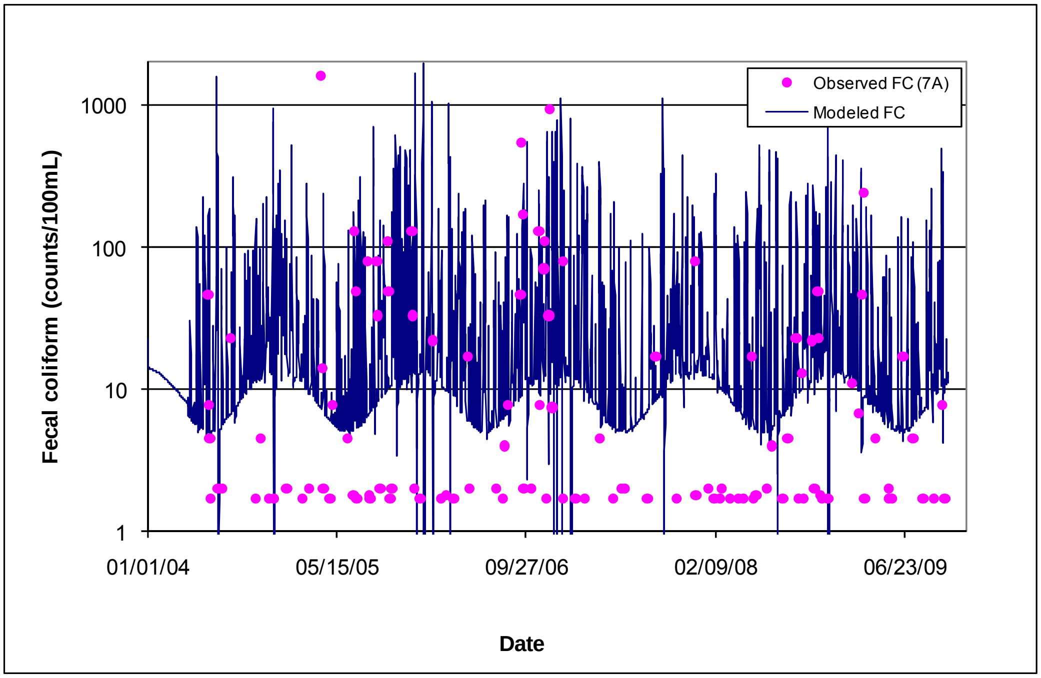


Figure 8. Modeled fecal coliform concentration for model segment M0S2 and observed fecal coliform concentration at Site 7A

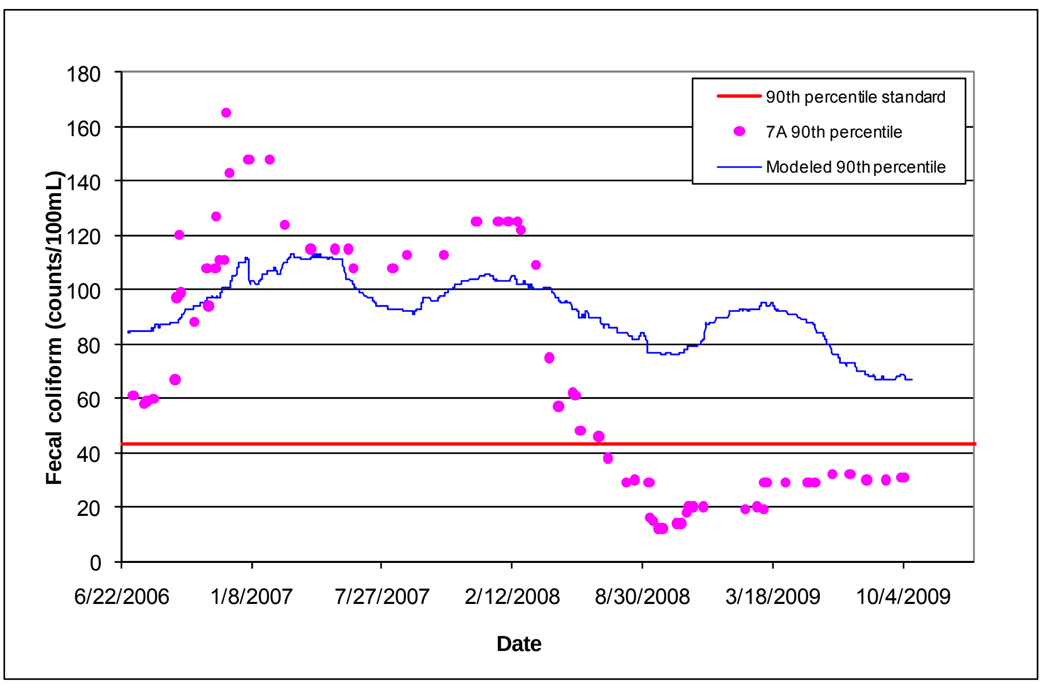


Figure 9. Modeled 90th percentile fecal coliform concentration for model segment M0S2 and observed 90th percentile fecal coliform concentration at Site 7A

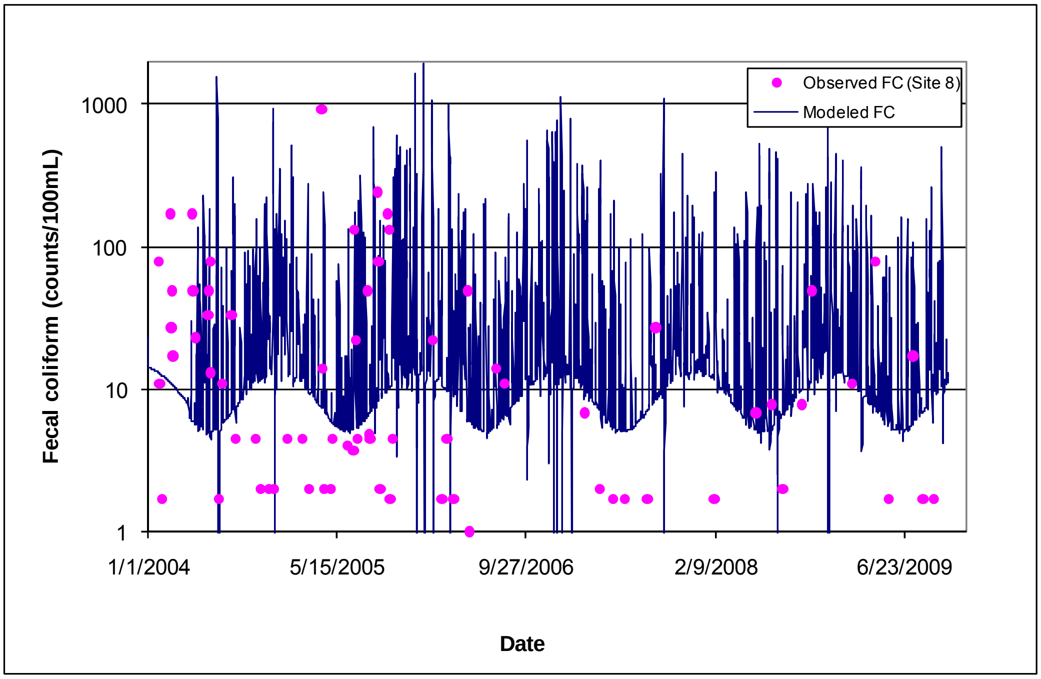


Figure 10. Modeled fecal coliform concentration for model segment M0S2 and observed fecal coliform concentration at Site 8

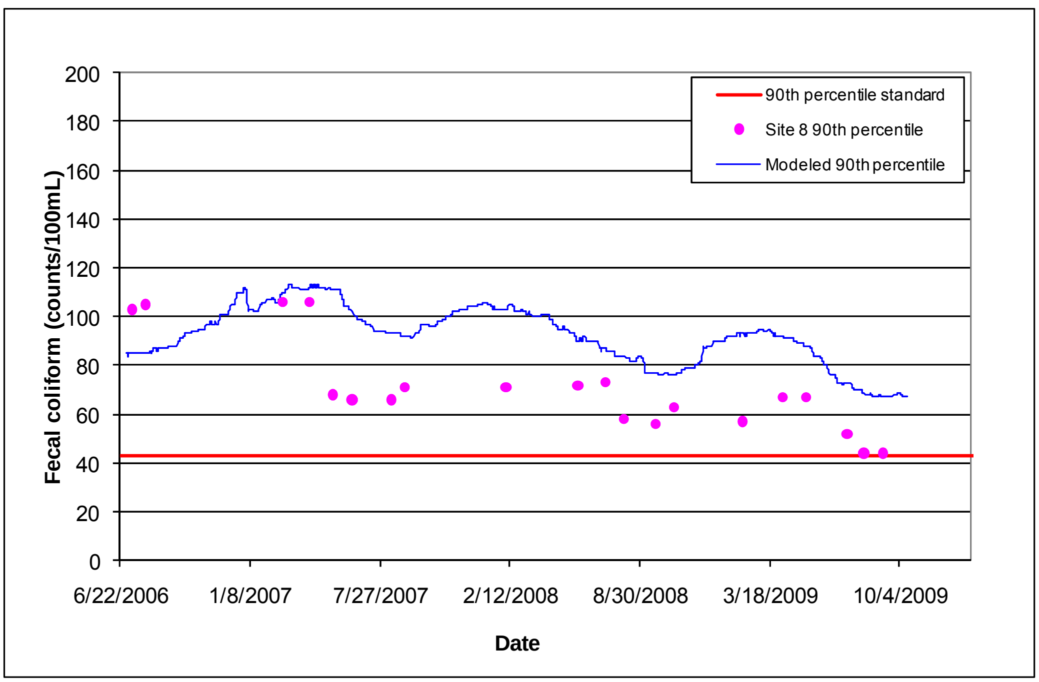


Figure 11. Modeled 90th percentile fecal coliform concentration for model segment M0S2 and observed 90th percentile fecal coliform concentration at Site 8

3.3 TMDL Calculation

The existing load (or current condition) is estimated as the sum of all the loads from subwatersheds discharging into the estuary. The loading is expressed as counts per day. The TMDL calculation is based on the water quality criteria; in this case it is the median and 90th percentile for the most recent 30 samples. Since the samples are taken on an approximately monthly basis (i.e., samples can be taken in any month), the running 30-month median and 30-month 90th percentile were calculated for the model segment containing the TPWQM calibration points (Segment M0S2). The watershed loading was reduced until both water quality standards were met in Segment M0S2 at all times during the TMDL period. This segment contains all water quality monitoring stations in the estuary therefore load reductions determined for the segment are applicable to all stations.

The final load is the maximum allowed daily load, or TMDL. The load reduction is calculated as the difference between the current condition and the TMDL loading. A summary of existing load and TMDL loading is presented in Table 9. The model time series plots of both the running 30-month median and 90th percentile for Segment M0S2 of the estuary under existing conditions and with the TMDL loading are presented in Appendix D.

Table 9. TMDL summary

Waterbody	Pollutant	Existing Load	WLA	LA	MOS	TMDL	Reduction Needed*
Lockwoods Folly River (15-25-1-(16)c) Lockwoods Folly River (15-25-1-(16)a), Lockwoods Folly River (15-25-1-(16)b), Lockwoods Folly River (15-25-1-(16)d), Mill Creek, Mullet Creek, Spring Creek, Lockwoods Creek	Fecal coliform (counts/day)	6.910E+12	2.097E+11	7.855E+11	1.106E+11	1.106E+12	84%

WLA = wasteload allocation; LA = load allocation, MOS = margin of safety
*When the MOS is included, the total required reduction is 86%

3.4 Critical Condition

The EPA Code of Federal Regulations (40 CFR 130.7 (c) (1)) requires TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The critical condition accounts for the hydrologic variation in the watershed over many sampling years whereas the critical period is the condition under which a waterbody is the most likely to violate the water quality standard(s).

The 90th percentile concentration is the concentration exceeded only 10% of the time. Since the model simulation period spans 5 years, the critical condition is implicitly included in the value of the 90th percentile of model results. Given the length of the monitoring record and model simulation and the standard's recognition of unusual and infrequent events, the 90th percentile is used instead of the absolute maximum.

3.5 Seasonality

Fecal coliform distributions often show high seasonal variability, which is required to be considered in TMDL determinations. The seasonal fecal coliform distributions of observed data at Sites 7A and 8 are presented in Figures 12 and 13. The results show that high fecal coliform levels occur throughout the year in the estuary. The average monthly concentrations are relatively similar between months at both sites, though Site 7A shows slightly more variation. The highest concentrations occur in April at both monitoring sites. The lowest concentrations occur in February and the late spring months.

The largest standard deviation corresponds to the highest concentration for each station. These high concentrations result in a high 90th percentile concentration. Given the length of the model simulation, the seasonal variability is directly included in the model simulation.

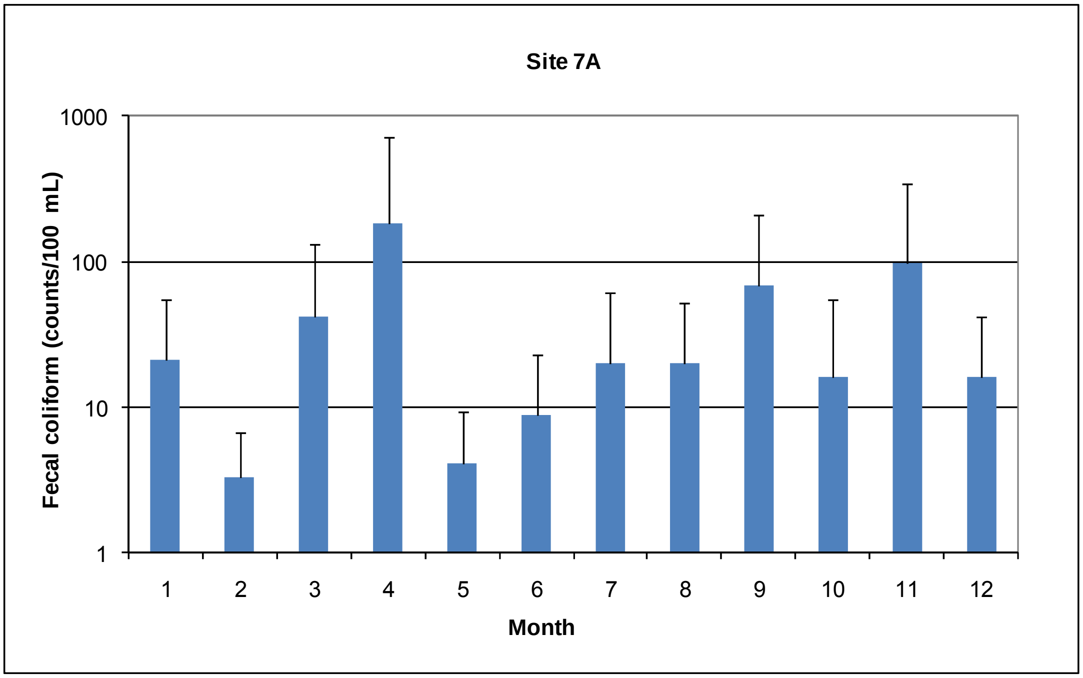


Figure 12. Distribution of monthly average fecal coliform concentration at Site 7A (log scale)

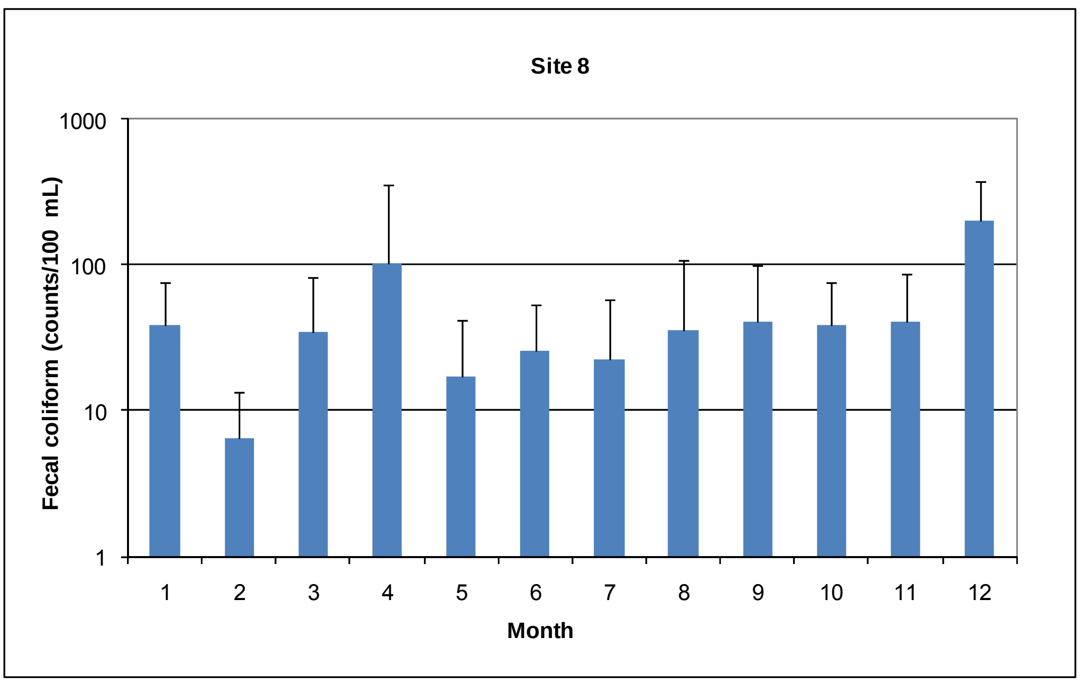


Figure 13. Distribution of monthly average fecal coliform concentration at Site 8 (log scale)

3.6 TMDL Loading Cap

This section presents the TMDL for the median and 90th percentile conditions for the Lockwoods Folly estuary and tidal creeks. The TMDL was calculated based on the model simulation results. The TMDL for the estuary was calculated to be 1.106 x 10^{12}, with the TMDL calculation period from 7/1/2004 to 1/1/2007. The greater reduction required when comparing the median and the 90th percentile results was used for the TMDL. Based on model results, the 90th percentile is the stricter standard which requires the greatest reduction.

The TMDL calculation period is the 30 months preceding the last daily prediction to meet the standard. Thus, the averaging period for the development of the TMDL used daily predictions from the TMDL model runs for the 30 months preceding the highest 90th percentile concentration over the model simulation period. Over this calculation period, daily bacteria loading predictions were taken from each model subwatershed and subsequently summed across the watershed. The daily average load was then calculated over the 30-month period. As seen in Figure D1 (Appendix D) the highest 90th percentile during the model simulation period occurred on 1/1/2007. Thus, the TMDL was calculated for the 30 months from 7/1/2004 to 1/1/2007.

Load reductions required to meet the TMDL are 84% (excluding the MOS). The reduction established based on the 90th percentile criterion indicates that the waterbody will meet the water quality standard requiring not more than 10% of the samples to exceed an MF count of 43/100 ml. Using the 90th percentile in this manner is consistent with the procedure used by DEHSS on their sample data for determining whether shellfish areas should be open, conditionally prohibited, or closed.

3.7 Wasteload Allocation

As described in Section 2.1.2, NCDOT is the only NPDES-permitted discharge in the watershed included in the WLA. Bacteria loading coming from NCDOT land was isolated from other sources using the delineated land use and calibrated model as a base. The model was rerun setting the EMC on NCDOT land to zero. The difference between the calibrated model run and the model run without NCDOT represents NCDOT's existing fecal coliform load to the Lockwoods Folly estuary. The existing NCDOT load was calculated over the same time period as the TMDL calculation (7/1/2004 – 1/1/2007) (Section 3.6), with a result of 4.46 x 10^{11} counts per day (Table 10). NCDOT's contribution is 6% of the total fecal coliform load from the watershed to the estuary. The required reduction from NCDOT land was calculated to be 53% of their existing load. This reduction is based on NCDOTs relative contribution to fecal loads using its EMC values compared to a developed land area weighted EMC value that was calculated using land use area (Table 1) and corresponding EMC values (Table 8). The resulting WLA is 2.097 x 10^{11} counts per day. This value and the margin of safety (Section 3.9) were then subtracted from the TMDL loading cap to determine the final LA (Section 3.8).

Table 10. Wasteload allocation summary

Pollutant	NCDOT Existing Load	WLA	Reduction Needed
Fecal coliform (counts/day)	4.462E+11	2.097E+11	53%

3.8 Load Allocation

The load allocations were determined using the same period as the TMDL calculation (Section 3.6). Thus, the averaging period for the development of the TMDLs used daily predictions from the TMDL model runs for the 30 months preceding the highest 90^{th} percentile concentration. Over this period, daily bacteria loading predictions were taken from each model subwatershed and subsequently summed across the watershed. The daily average was then calculated which serves as the basis for the load allocation. The wasteload allocation (WLA) and the margin of safety (MOS) were subtracted from the TMDL to determine the final load allocation (LA).

3.9 Margin of Safety

A Margin of Safety (MOS) is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

For TMDL development, the MOS needs to be incorporated to account for uncertainty due to model parameter selection. Based on previous model sensitivity analysis, it has been determined that the most sensitive parameter is the decay rate. The value of the decay rate varies from 0.7 to 3.0 per day in salt water (Mancini, 1978; Thomann and Mueller, 1987, EPA 1985). A decay rate of 0.7 per day in the estuary was used as a conservative estimate in the TMDL model. An explicit MOS was also included in the TMDL calculation as a conservative estimate. The explicit MOS was achieved by applying a 10% load reduction from the calculated TMDL.

3.10 Summary of Total Maximum Daily Load

As explained in the previous sections, the TMDL was calculated based on model runs that had a maximum 30-month 90^{th} percentile concentration of 43 MPN/100 ml. The load reductions calculated for the TMDL addresses the reduction required for all monitoring stations in the estuary. Additionally an explicit margin of safety of 10% was applied to the TMDL load.

NCDOT is the only NPDES-permitted source included in the WLA column. The Town of Oak Island is a Phase II stormwater community. However, it lies in a portion of the watershed that could not be modeled due to the hydrodynamics of the ICWW on Montgomery Slough and a WLA could not be determined for the Town (Section 2.1.2). The Town will be addressed in the TMDL Implementation Plan. Additionally, the Town’s future stormwater permits will incorporate strategies for reductions in fecal coliform loads outlined in the Implementation Plan. Strategies will include both structural and non-structural best management practices (BMPs) as well as programs to assess the effectiveness of these strategies in reducing fecal coliform loads from the Town. Four active industrial stormwater permittees are also present in the watershed; however, these are sand pit, concrete, and asphalt facilities and fecal coliform loading from these facilities are not of concern. Therefore, a separate WLA was not calculated for these stormwater permits.

The TMDL calculated based on the 30 months preceding the last highest 90th percentile concentration during the 5-year model simulation period is summarized as follows:

Waterbody	Pollutant	Existing Load	WLA	LA	MOS	TMDL	Reduction Needed*
Lockwoods Folly River (15-25-1-(16)c) Lockwoods Folly River (15-25-1-(16)a), Lockwoods Folly River (15-25-1-(16)b), Lockwoods Folly River (15-25-1-(16)d), Mill Creek, Mullet Creek, Spring Creek, Lockwoods Creek	Fecal coliform (counts/day)	6.910E+12	2.097E+11	7.855E+11	1.106E+11	1.106E+12	84%

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
MOS = Margin of Safety
*When the MOS is included, the total required reduction is 86%

4.0 TMDL Implementation Plan

The TMDL analysis was performed using the best data available to specify the fecal coliform reductions necessary to achieve water quality criteria. The intent of meeting the criteria is to support the designated use classifications in the watershed. A TMDL Implementation Plan will be developed as a separate document to this TMDL report. The Plan will be developed based on this TMDL, strategies put forth by the Lockwoods Folly Roundtable project, and with input from the North Carolina Coastal Federation, the North Carolina Division of Water Quality and other stakeholders. While the TMDL load reduction does not apply to the ICWW or Montgomery Slough, these waters will be included in the implementation plan. Potential funding sources for implementation include Section 319 funds and 205(j) funds, as well as the Clean Water Management Trust Fund, EPA Environmental Education Grants and EPA Water Quality Agreement Grants, among others.

At a minimum the Implementation Plan will follow the Nine Key Elements for implementing watershed plans outlined by the EPA. These nine elements include:

1. Identify the cause of impairment and pollutant sources.
2. Estimate the load reductions expected from management measures.
3. Describe the nonpoint source management measures that will need to be implemented to achieve the load reductions in 2 and the critical areas in which those measures will be needed to implement this plan.
4. Estimate the amount of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.

5. Include an information and educational component to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the nonpoint source management measure that will be implemented.
6. Provide a schedule for implementing the nonpoint source management measures identified in this plan that is reasonably expeditious.
7. Describe the interim milestones for determining whether nonpoint source management measures or other control actions are being implemented.
8. Provide a set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards.
9. Monitor to evaluate the effectiveness of the implementation efforts over time, measured against criteria established under item 8 above.

5.0 Stream Monitoring

The Shellfish Sanitation Section of DEH should continue the systematic random sampling strategy in the TMDL waters, even if the waters are eventually permanently closed to shellfish harvesting. This system is well-suited for monitoring and classifying shellfish waters and it can serve to track the effectiveness of TMDL implementation and water quality improvements. DEHSS will continue to close the areas if levels of fecal coliform indicate that harvesting shellfish from those waters could cause a public health risk. Additionally, there will be a program to assess fecal coliform load reductions from the Town of Oak Island, a Phase II stormwater community, in its future stormwater permits.

6.0 Future Efforts

The North Carolina Coastal Federation will take the primary lead in developing the TMDL Implementation Plan. Actual TMDL implementation will be dependent upon funding sources. The NCCF has completed several projects to date which will contribute to reducing fecal coliform loads in the watershed, including education and outreach programs and the installation of stormwater BMPs. Possible grant funding sources for TMDL implementation strategies include the Section 319 fund administered by DWQ and the Clean Water Management Trust Fund among others.

7.0 Public Participation

A draft of the TMDL was publicly noticed through various means. The TMDL was public noticed in the local newspaper (City of Wilmington Star News) on July 14. The TMDL was also public noticed on July 14, 2010 through the North Carolina Water Resources Research Institute (WRRI) email listserve, the DWQ mailing list of interested parties, and on the DWQ TMDL website. In addition a press release was given by NCCF on July 13. An article entitled “Pollution report first step in reclaiming Lockwood Folly” was also published in the City of Wilmington StarNews Online newspaper on July 21, 2010 (Appendix F). Finally, the TMDL was available on DWQ’s website http://h2o.enr.state.nc.us/tmdl/ during the comment period. The public comment period lasted from July 13, 2010 until August 13, 2010.

The DWQ received written Comments during the comment period. Summaries of the comments and DWQ’s response are presented in Appendix G.

A stakeholder process has been conducted as a part of this project. To date, four presentations have been made to the County Commission and its planning board, as well as citizens. Public education and outreach has also been conducted, including a media campaign, public education brochures, a tabloid summarizing the Lockwood Folly Roundtable Strategies, and local volunteer involvement in water quality monitoring. Examples of materials used for public education and outreach are included in Appendix H. Additionally a technical working group consisting of project partners, local decision makers, and representatives of the various interest groups and agencies has provided guidance and oversight of the project. This group has met four times to date to review progress of the TMDL development and Implementation Plan strategies.

8.0 Further Information

Further information concerning North Carolina's TMDL program can be found on the Internet at the Division of Water Quality website: http://portal.ncdenr.org/web/wq/ps/mtu.

Technical questions regarding this TMDL should be directed to the following members of the DWQ Modeling/TMDL Unit:

Adugna Kebede, Modeler

e-mail: adugna.kebede@ncdenr.gov

Kathy Stecker

e-mail: kathy.stecker@ncdenr.gov

References

ASAE 1998. *ASAE Standards, 45th edition: Standards, Engineering Practices, Data*. American Society of Agricultural Engineers. St. Joseph, MI.

AVMA 2007. US Pet Ownership Market Research Statistics. American Veterinary Medical Association. http://avma.org/reference/marketstats/ownership.asp Accessed November 2007.

Caraco, D. 2001. The Watershed Treatment Model. Center for Watershed Protection. Ellicott City, Maryland.

Clemmons, Dale 2009. Personal communication. Owner of livestock operation in Bolivia, North Carolina.

Daniels, RB, SW Buol, HJ Kleiss, and CA Ditzler 1999. Soil Systems in North Carolina. Technical Bulletin 314. North Carolina State University Soil Science Department.

Holman, Robert 2007. NCDOT. Pet Waste – A Hidden Source of Contamination. WRRI 10th Annual Conference: Managing Public Water Supplies. Raleigh, NC.

Horsely and Whitten, Inc. 1999. Identification and evaluation of nutrient and bacterial loadings to Maquoit Bay, New Brunswick and Freeport, Maine. Final Report

Kator, H. and MW Rhodes 1996. Identification of pollutant sources contributing to degraded sanitary water quality in Taskinas Creek National Estuarine Research Reserve, Virginia. Special Report in Applied Marine Science and Ocean Engineering No. 336.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr. 1994. User's manual for an expert system (HSPEXP) for calibration of the Hydrologic Simulation Program-FORTRAN. U.S. Geological Survey Water-Resources Investigations Report 94-4168. U.S. Geological Survey.

MD DNR 2003. 2002-2003 Game Program Annual Report. Maryland Department of Natural Resources, Wildlife and Heritage Service. http://www.dnr.state.md.us/wildlife/.

MDE 2005. Total Maximum Daily Loads of Fecal Coliform for the Restricted Shellfish Harvesting Area in Back Creek of the Honga River Basin in Dorchester County, Maryland. Maryland Department of the Environment. July, 2005.

NCAC 2003. North Carolina Administrative Code.

NC CRONOS 2009. NC CRONOS Database. The State Climate Office of North Carolina. http://www.nc-climate.ncsu.edu/cronos/.

NC DEH 2000. Report on the Proper Maintenance of Septic Tank Systems in Accordance with Section 13.5 of HB 1160. Submitted by the NC Commission for Health Services to the Environmental Review Commission. North Carolina Division of Environmental Health.

NC DENR 2007a. Total Maximum Daily Loads for Fecal Coliform for Jarrett Bay and Its Embayment, North Carolina. North Carolina Department of Environment and Natural Resources.

NC DENR 2007b. Report of Sanitary Survey April 2002 through February 2007. Division of Environmental Health, Shellfish Sanitation and Recreational Water Quality. North Carolina Department of Environment and Natural Resources.

NC WRC 2008. Wildlife Species and Conservation. North Carolina Wildlife Resources Commission. http://www.ncwildlife.org/fs_index_07_conservation.htm

NOAA 2009. Tidal Station Locations and Ranges. National Oceanic and Atmospheric Administration. http://tidesandcurrents.noaa.gov/tides07/tab2ec3a.html

SCS 1988. Soil Survey of Brunswick County, North Carolina. Soil Conservation Service. US Department of Agriculture.

Simmons, Otto 2010. Personal communication. Adjunct Assistant Professor, Biological and Agricultural Engineering Department, North Carolina State University.

Stantec 2007. Lockwoods Folly River Local Watershed Plan, Detailed Assessment and Targeting of Management Report. Prepared by Stantec for the North Carolina Ecosystem Enhancement Program.

Stantec 2010. Lockwoods Folly River TMDL Model Documentation. Prepared by Stantec for the North Carolina Department of Environment and Natural Resources Division of Water Quality.

Uebler, RL, SJ Steinbeck, and JD Crowder 1984. Septic system failure on a Leon (hardpan) soil and feasibility of drainage to improve system performance. Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems. ASAE. New Orleans, LA.

USACE 2008. Hydrologic Modeling System HEC-HMS User’s Manual Version 3.3. US Army Corps of Engineers. Hydrologic Engineering Center. Davis, California.

USEPA 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. EPA 440/4-91-001. United States Environmental Protection Agency. Washington, DC.

USEPA 1998. Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program. EPA 100-R-98-006. United States Environmental Protection Agency. Washington, DC.

USEPA 2000. Bacteria Indicator Tool User's Guide. EPA823B01003. United States Environmental Protection Agency. Washington, DC.

VA DEQ 2002. Fecal Coliform TMDL for Dodd Creek Watershed, Virginia, June 2002.

VIMS, 2004: Technical Memorandum for Fecal Coliform TMDL of Shellfish Harvesting areas.

Appendix A. Observed Time Series Plots and Water Quality Data

The most recent fecal coliform observation data (2004-2009) for all monitoring sites within the Lockwoods Folly estuary along with their 30-month median and 90th percentiles are presented in Figure A1 to Figure A9. Table A1 following the graphs presents the observed fecal coliform data for samples collected at the nine sites from 2004 to 2009.

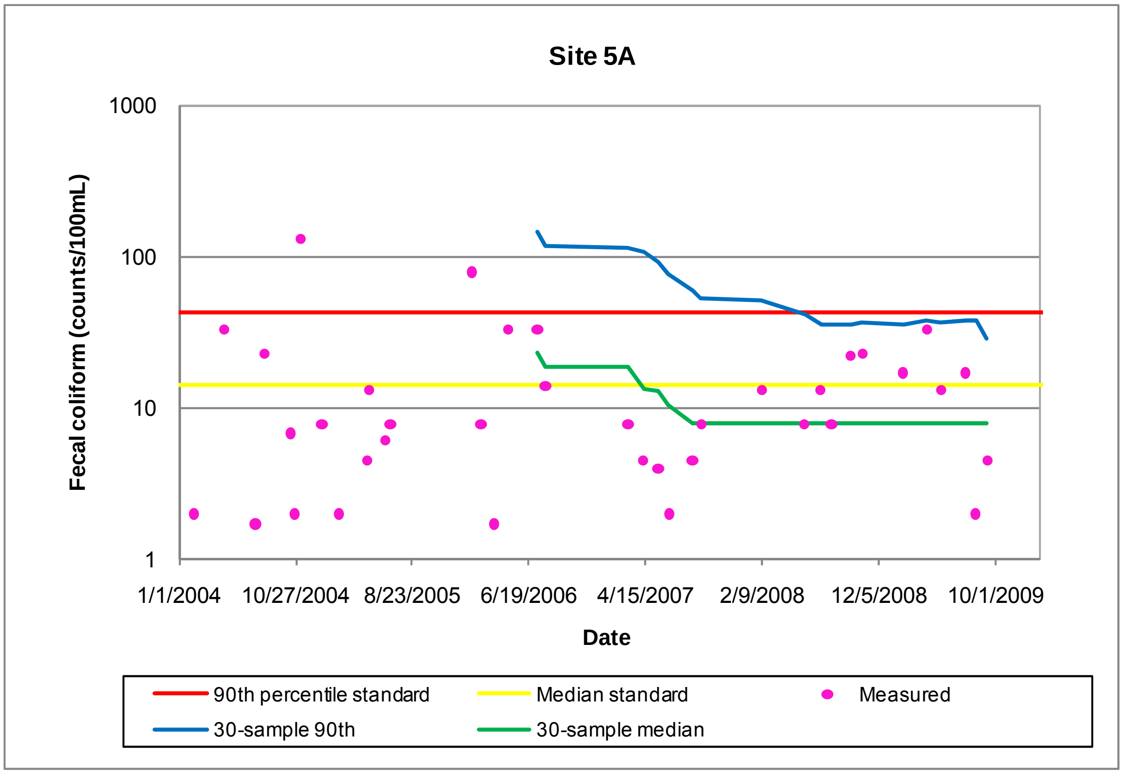


Figure A1. Time series plot of fecal coliform observations at Site 5A

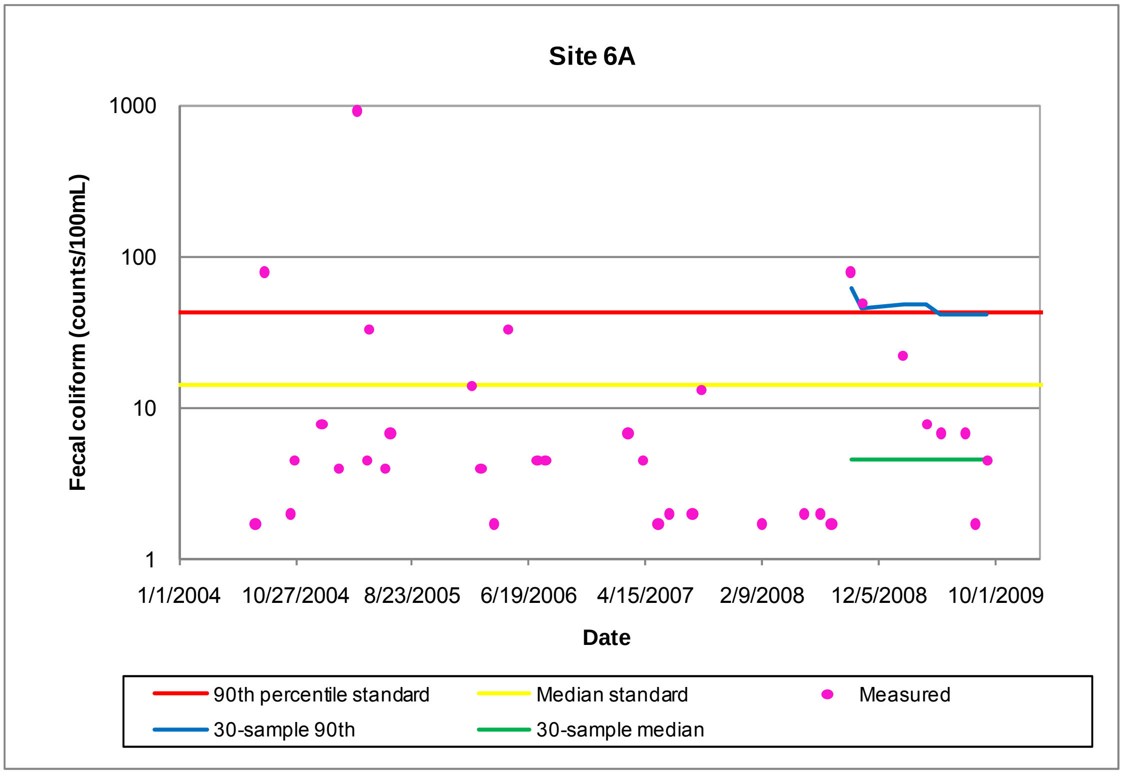


Figure A2. Time series plot of fecal coliform observations at Site 6A

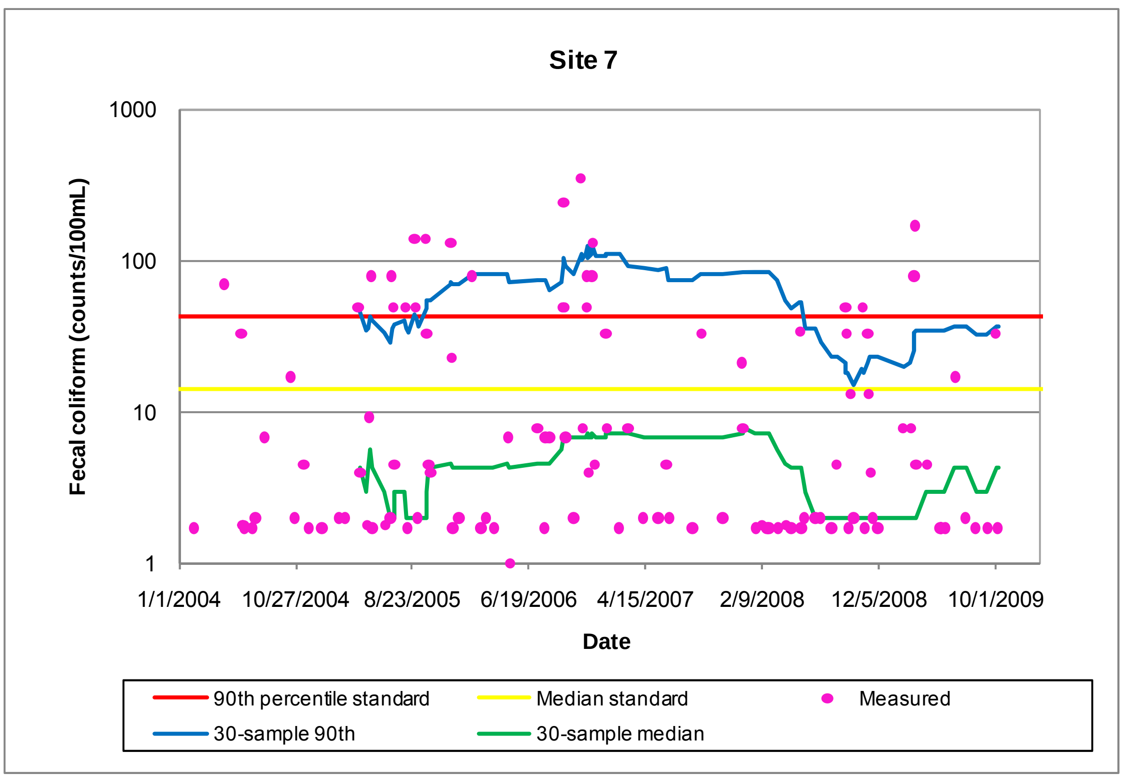


Figure A3. Time series plot of fecal coliform observations at Site 7

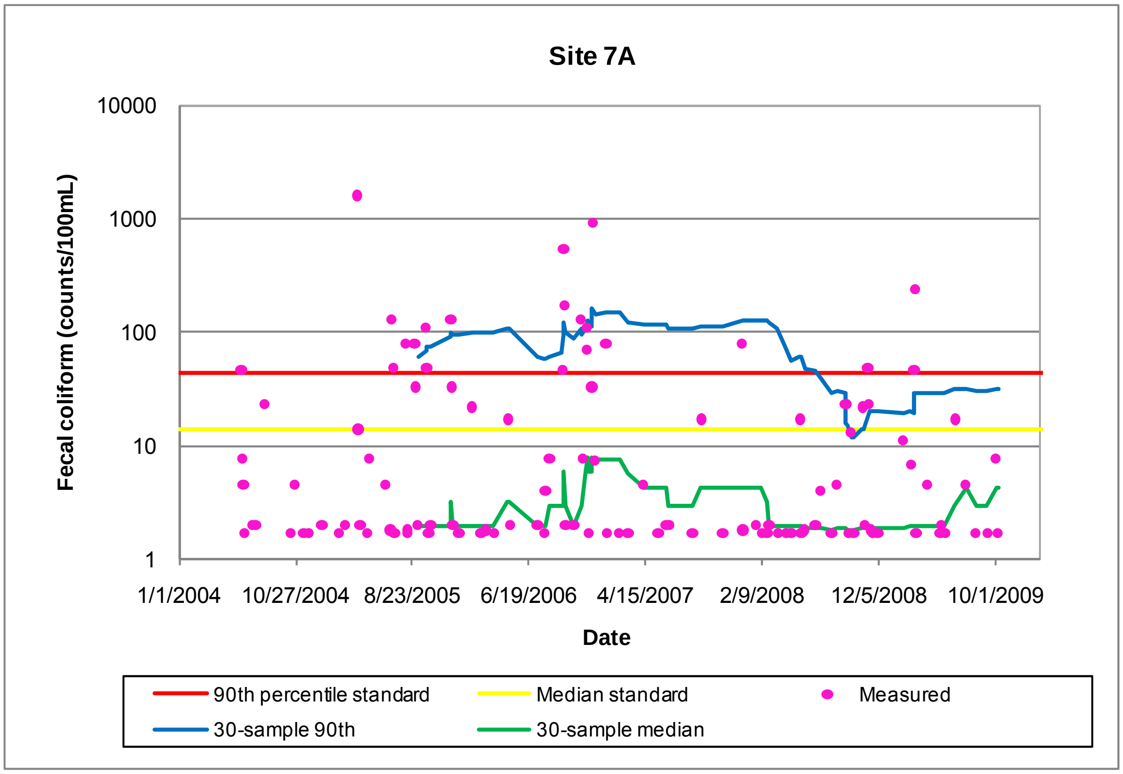


Figure A4. Time series plot of fecal coliform observations at Site 7A

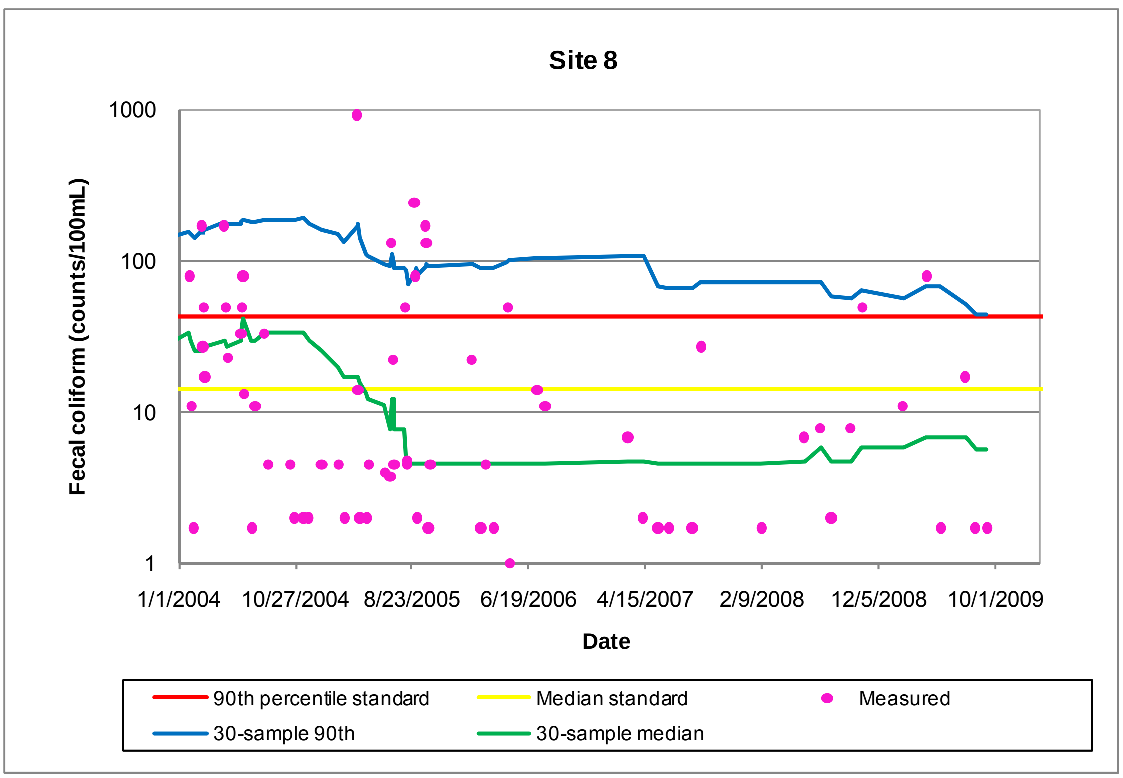


Figure A5. Time series plot of fecal coliform observations at Site 8

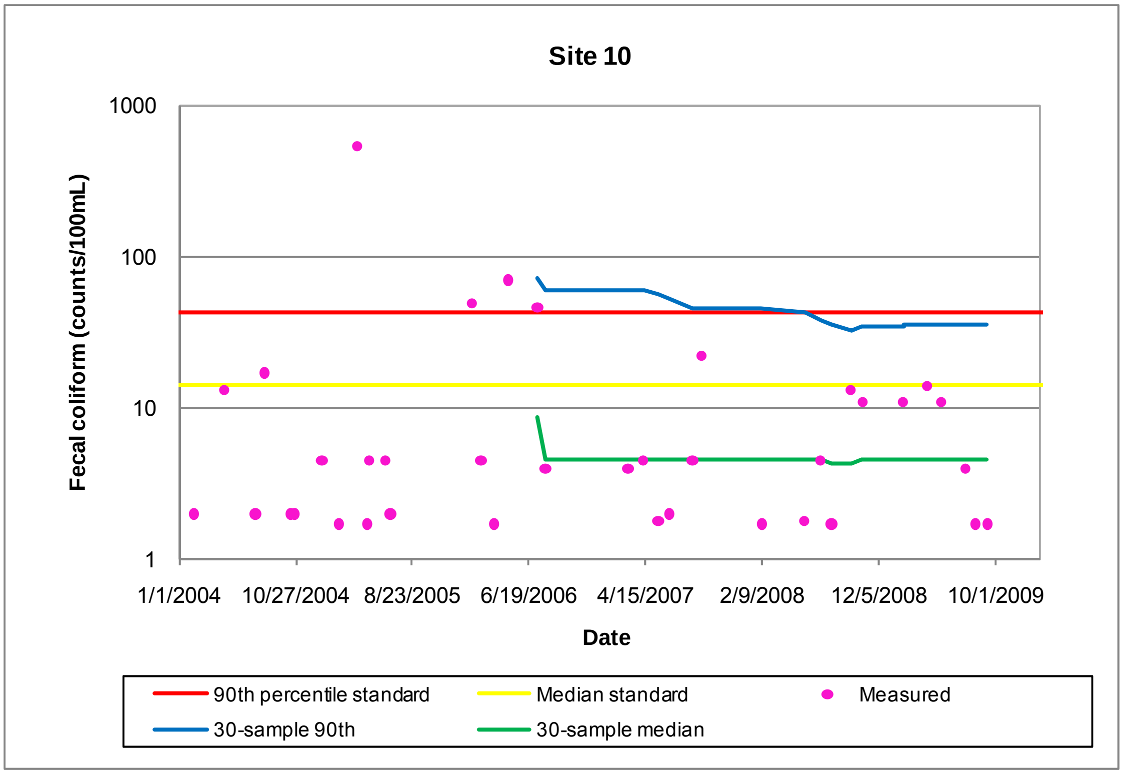


Figure A6. Time series plot of fecal coliform observations at Site 10

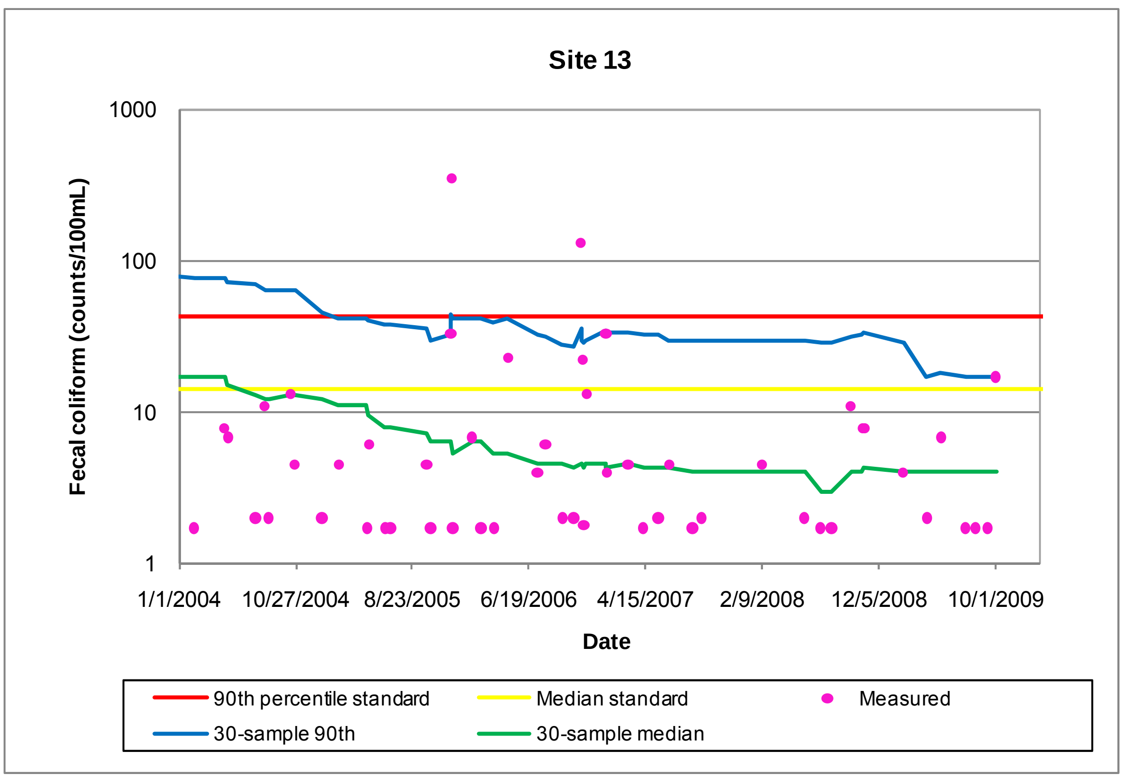


Figure A7. Time series plot of fecal coliform observations at Site 13

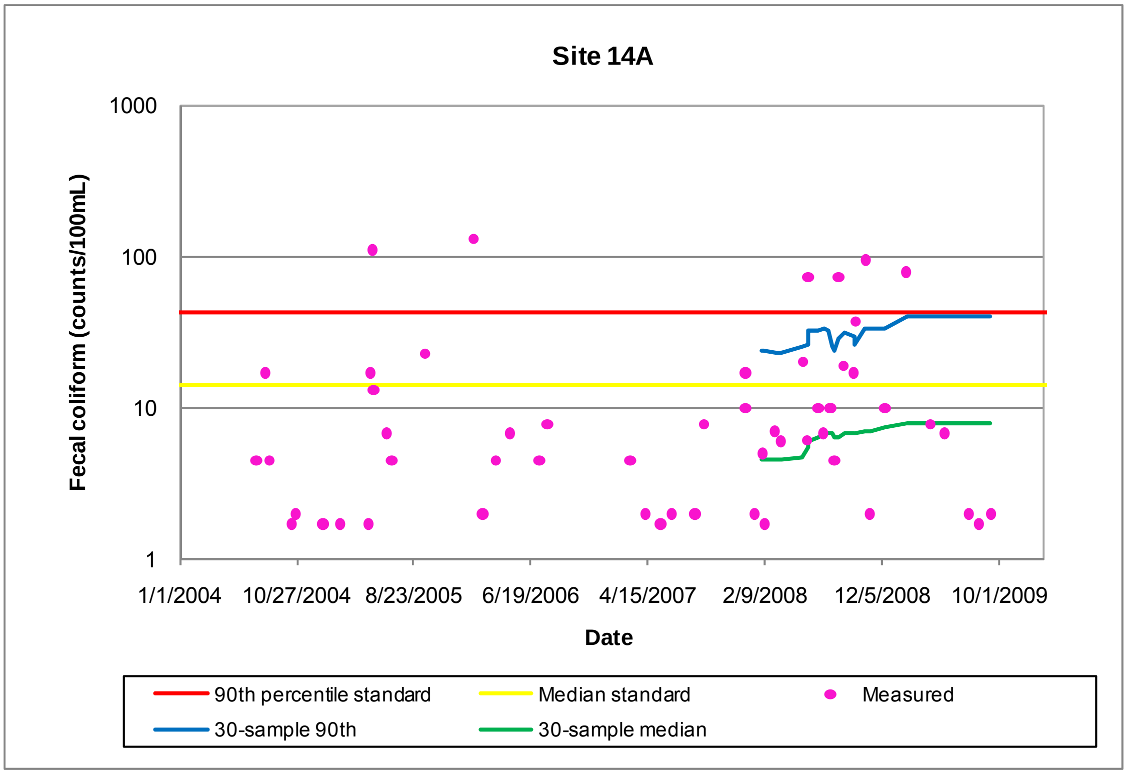


Figure A8. Time series plot of fecal coliform observations at Site 14A

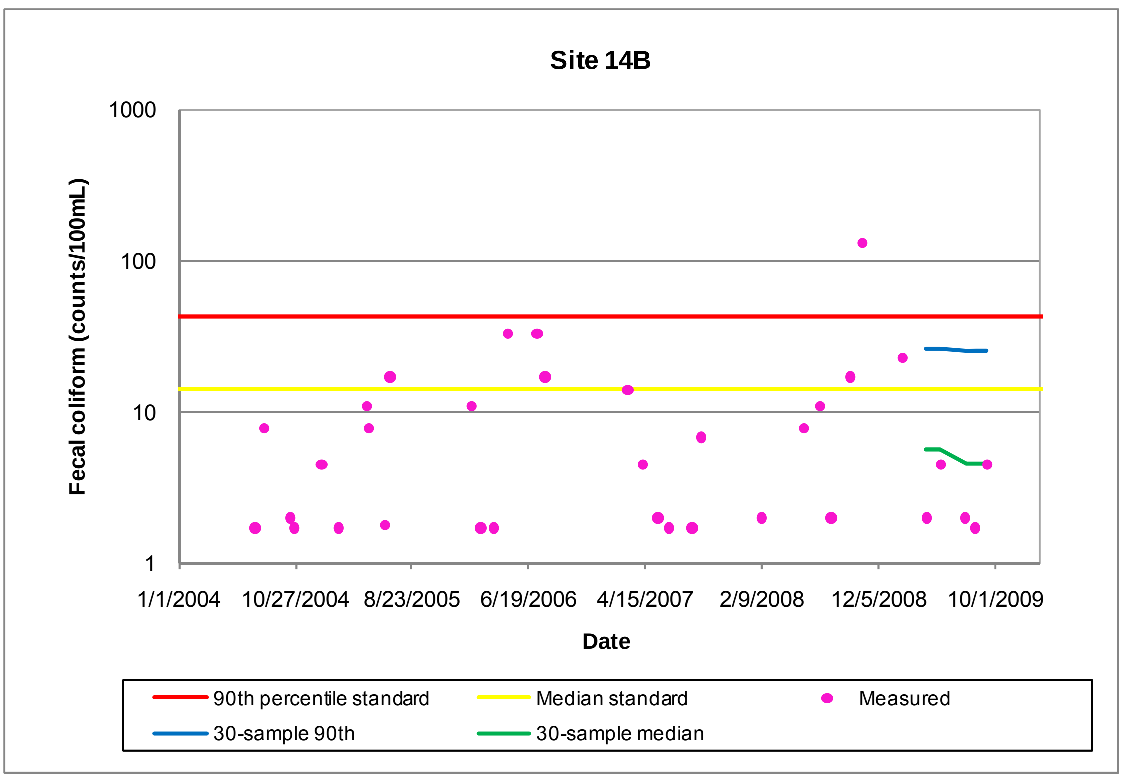


Figure A9. Time series plot of fecal coliform observations at Site 14B

Table A1. Observed data at all monitoring stations in the Lockwoods Folly estuary (2004-2009)

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
1/7/2002	5A	Early FLD	31	350.0
4/2/2002	5A	1/3 EBB	35	1.7
6/17/2002	5A	1/2 FLD	BROKEN	49.0
7/18/2002	5A	Late EBB	32	130.0
9/19/2002	5A	1/2 EBB	26	130.0
10/30/2002	5A	1/3 FLD	21	240.0
1/7/2003	5A	1/2 FLD	36	49.0
2/26/2003	5A	2/3 EBB	28	33.0
5/5/2003	5A	2/3 FLD	29	110.0
7/8/2003	5A	Early FLD	20	79.0
8/19/2003	5A	1/3 FLD	15	13.0
10/22/2003	5A	1/2 EBB	32	23.0
2/9/2004	5A	Early EBB	34	2.0
4/27/2004	5A	Late EBB>Early FLD	28	33.0
7/16/2004	5A	1/3 EBB	35	1.7
8/9/2004	5A	1/4 FLD	22	23.0
10/13/2004	5A	1/4 EBB	32	6.8
10/26/2004	5A	1/3 EBB	35	2.0
11/8/2004	5A			130.0
1/3/2005	5A	1/2 FLD	31	7.8
2/14/2005	5A	2/3 FLD	32	2.0
4/28/2005	5A	2/3 FLD	33	4.5
5/3/2005	5A	Late EBB	31	13.0
6/13/2005	5A	1/3 FLD	30	6.1
6/28/2005	5A	1/3 FLD	35	7.8
1/23/2006	5A	1/3 FLD	30	79.0
2/16/2006	5A	1/3 EBB	32	7.8
3/20/2006	5A	2/3 FLD	35	1.7
4/25/2006	5A	2/3 EBB	35	33.0
7/10/2006	5A	1/2 EBB	35	33.0
7/31/2006	5A	1/3 FLD	35	14.0
2/28/2007	5A	1/2 EBB	30	7.8
4/9/2007	5A	1/2 FLD	34	4.5
5/16/2007	5A	1/3 EBB	35	4.0
6/14/2007	5A	1/3 EBB	36	2.0
8/13/2007	5A	LATE FLOOD	36	4.5
9/4/2007	5A	1/4 FLOOD	35	7.8
2/6/2008	5A	1/2 ebb	35	13.0
5/27/2008	5A	1/4 flood	35	7.8
7/8/2008	5A	1/4 FLOOD	37	13.0
8/5/2008	5A	3/4 flood	36	7.8
9/24/2008	5A	late ebb	34	22.0
10/22/2008	5A	late ebb	32	23.0
2/5/2009	5A	late ebb	24	17.0
4/7/2009	5A	1/4 EBB	31	33.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
5/13/2009	5A	3/4 EBB	35	13.0
7/15/2009	5A	EARLY FLD	34	17.0
8/10/2009	5A	3/4 FLD	36	2.0
9/9/2009	5A	LATE FLD	35	4.5
3/14/2002	6A			540.0
3/18/2002	6A			6.8
7/16/2004	6A	1/3 EBB	35	1.7
8/9/2004	6A	1/4 FLD	26	79.0
10/13/2004	6A	1/4 EBB	32	2.0
10/26/2004	6A	1/3 EBB	35	4.5
1/3/2005	6A	1/2 FLD	32	7.8
2/14/2005	6A	2/3 FLD	34	4.0
4/4/2005	6A			920.0
4/28/2005	6A	2/3 FLD	34	4.5
5/3/2005	6A	Late EBB	32	33.0
6/13/2005	6A	1/3 FLD	32	4.0
6/28/2005	6A	1/3 FLD	35	6.8
1/23/2006	6A	1/3 FLD	32	14.0
2/16/2006	6A	1/3 EBB	35	4.0
3/20/2006	6A	2/3 FLD	35	1.7
4/25/2006	6A	2/3 EBB	34	33.0
7/10/2006	6A	1/2 EBB	35	4.5
7/31/2006	6A	1/3 FLD	35	4.5
2/28/2007	6A	1/2 EBB	32	6.8
4/9/2007	6A	1/2 FLD	34	4.5
5/16/2007	6A	1/3 EBB	36	1.7
6/14/2007	6A	1/3 EBB	36	2.0
8/13/2007	6A	LATE FLOOD	36	2.0
9/4/2007	6A	1/4 FLOOD	36	13.0
2/6/2008	6A	1/2 ebb	35	1.7
5/27/2008	6A	1/4 flood	35	2.0
7/8/2008	6A	1/4 FLOOD	38	2.0
8/5/2008	6A	3/4 flood	36	1.7
9/24/2008	6A	late ebb	34	79.0
10/22/2008	6A	late ebb	34	49.0
2/5/2009	6A	late ebb	28	22.0
4/7/2009	6A	1/4 EBB	33	7.8
5/13/2009	6A	3/4 EBB	35	6.8
7/15/2009	6A	EARLY FLD	35	6.8
8/10/2009	6A	3/4 FLD	36	1.7
9/9/2009	6A	LATE FLD	36	4.5
6/9/2004	7A			46.0
6/11/2004	7A			7.8
6/14/2004	7A			4.5
6/16/2004	7A			1.7
7/6/2004	7A			2.0
7/16/2004	7A	1/3 EBB	35	2.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
8/9/2004	7A	1/4 FLD	28	23.0
10/13/2004	7A	1/4 EBB	32	1.7
10/26/2004	7A	1/3 EBB	35	4.5
11/16/2004	7A			1.7
11/30/2004	7A			1.7
1/3/2005	7A	1/2 FLD	33	2.0
2/14/2005	7A	2/3 FLD	34	1.7
3/2/2005	7A			2.0
4/4/2005	7A			1600.0
4/6/2005	7A			14.0
4/10/2005	7A			2.0
4/28/2005	7A	2/3 FLD	34	1.7
5/3/2005	7A	Late EBB	32	7.8
6/13/2005	7A	1/3 FLD	33	4.5
6/28/2005	7A	1/3 FLD	35	1.8
7/1/2005	7A			130.0
7/5/2005	7A			49.0
7/7/2005	7A			1.7
8/4/2005	7A			79.0
8/9/2005	7A			1.8
8/11/2005	7A			1.7
8/29/2005	7A			79.0
9/1/2005	7A			33.0
9/6/2005	7A			2.0
9/26/2005	7A			110.0
9/29/2005	7A			49.0
10/3/2005	7A			1.7
10/8/2005	7A			2.0
11/29/2005	7A			130.0
12/1/2005	7A			33.0
12/5/2005	7A			2.0
12/21/2005	7A			1.7
1/23/2006	7A	1/3 FLD	33	22.0
2/16/2006	7A	1/3 EBB	35	1.7
3/1/2006	7A			1.8
3/20/2006	7A	2/3 FLD	35	1.7
4/25/2006	7A	2/3 EBB	34	17.0
5/1/2006	7A			2.0
7/10/2006	7A	1/2 EBB	36	2.0
7/27/2006	7A			1.7
7/31/2006	7A	1/3 FLD	35	4.0
8/10/2006	7A			7.8
9/12/2006	7A			46.0
9/15/2006	7A			540.0
9/18/2006	7A			170.0
9/21/2006	7A			2.0
10/12/2006	7A			2.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
10/31/2006	7A			130.0
11/3/2006	7A			7.8
11/13/2006	7A			70.0
11/15/2006	7A			110.0
11/19/2006	7A			1.7
11/27/2006	7A			33.0
11/29/2006	7A			920.0
12/5/2006	7A			7.5
1/2/2007	7A			79.0
1/4/2007	7A			1.7
2/5/2007	7A			1.7
2/28/2007	7A	1/2 EBB	32	1.7
4/9/2007	7A	1/2 FLD	35	4.5
5/16/2007	7A	1/3 EBB	35	1.7
6/6/2007	7A			2.0
6/14/2007	7A	1/3 EBB	36	2.0
8/13/2007	7A	LATE FLOOD	36	1.7
9/4/2007	7A	1/4 FLOOD	37	17.0
10/30/2007	7A			1.7
12/18/2007	7A			79.0
12/20/2007	7A			1.8
1/22/2008	7A			2.0
2/6/2008	7A	1/2 ebb	35	1.7
2/21/2008	7A			1.7
2/25/2008	7A			2.0
3/19/2008	7A			1.7
4/9/2008	7A			1.7
4/23/2008	7A			1.7
5/15/2008	7A			17.0
5/19/2008	7A			1.7
5/27/2008	7A	1/4 flood	35	1.8
6/24/2008	7A			2.0
7/8/2008	7A	1/4 FLOOD	38	4.0
8/5/2008	7A	3/4 flood	36	1.7
8/18/2008	7A			4.5
9/9/2008	7A			23.0
9/11/2008	7A			23.0
9/16/2008	7A			1.7
9/24/2008	7A	late ebb	34	13.0
9/30/2008	7A			1.7
10/22/2008	7A	late ebb	34	22.0
10/28/2008	7A			2.0
11/6/2008	7A			49.0
11/9/2008	7A			23.0
11/12/2008	7A			1.8
11/17/2008	7A			1.7
12/2/2008	7A			1.7

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
2/5/2009	7A	late ebb	30	11.0
2/23/2009	7A			6.8
3/4/2009	7A			46.0
3/6/2009	7A			240.0
3/9/2009	7A			1.7
4/7/2009	7A	1/4 EBB	32	4.5
5/11/2009	7A			1.7
5/13/2009	7A	3/4 EBB	35	2.0
5/22/2009	7A			1.7
6/18/2009	7A			17.0
7/15/2009	7A	EARLY FLD	35	4.5
8/10/2009	7A	3/4 FLD	36	1.7
9/9/2009	7A	LATE FLD	36	1.7
10/1/2009	7A			7.8
10/7/2009	7A			1.7
1/7/2002	7	Early FLD	37	170.0
4/2/2002	7	1/3 EBB	37	1.7
6/17/2002	7	1/2 FLD	BROKEN	2.0
7/18/2002	7	Late EBB	35	23.0
9/19/2002	7	1/2 EBB	31	70.0
10/30/2002	7	1/3 FLD	32	33.0
1/7/2003	7	1/2 FLD	36	7.8
2/26/2003	7	2/3 EBB	32	17.0
5/5/2003	7	2/3 FLD	34	1.7
7/8/2003	7	Early FLD	30	33.0
8/19/2003	7	1/3 FLD	25	23.0
10/22/2003	7	1/2 EBB	35	22.0
2/9/2004	7	Early EBB	36	1.7
4/27/2004	7	Late EBB>Early FLD	30	70.0
6/9/2004	7			33.0
6/11/2004	7			1.8
6/14/2004	7			1.8
6/16/2004	7			1.7
7/6/2004	7			1.7
7/16/2004	7	1/3 EBB	35	2.0
8/9/2004	7	1/4 FLD	30	6.8
10/13/2004	7	1/4 EBB	32	17.0
10/26/2004	7	1/3 EBB	35	2.0
11/16/2004	7			4.5
11/30/2004	7			1.7
1/3/2005	7	1/2 FLD	32	1.7
2/14/2005	7	2/3 FLD	34	2.0
3/2/2005	7			2.0
4/6/2005	7			49.0
4/10/2005	7			4.0
4/28/2005	7	2/3 FLD	34	1.8

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
5/3/2005	7	Late EBB	32	9.2
5/9/2005	7			79.0
5/11/2005	7			1.7
6/13/2005	7	1/3 FLD	33	1.8
6/28/2005	7	1/3 FLD	35	2.0
7/1/2005	7			79.0
7/5/2005	7			49.0
7/7/2005	7			4.5
8/4/2005	7			49.0
8/9/2005	7			1.7
8/11/2005	7			1.7
8/29/2005	7			140.0
9/1/2005	7			49.0
9/6/2005	7			2.0
9/26/2005	7			140.0
9/29/2005	7			33.0
10/3/2005	7			4.5
10/8/2005	7			4.0
11/29/2005	7			130.0
12/1/2005	7			23.0
12/5/2005	7			1.7
12/21/2005	7			2.0
1/23/2006	7	1/3 FLD	33	79.0
2/16/2006	7	1/3 EBB	35	1.7
3/1/2006	7			2.0
3/20/2006	7	2/3 FLD	35	1.7
4/25/2006	7	2/3 EBB	35	6.8
5/1/2006	7			1.0
7/10/2006	7	1/2 EBB	35	7.8
7/27/2006	7			1.7
7/31/2006	7	1/3 FLD	35	6.8
8/10/2006	7			6.8
9/12/2006	7			49.0
9/15/2006	7			240.0
9/18/2006	7			49.0
9/21/2006	7			6.8
10/12/2006	7			2.0
10/31/2006	7			350.0
11/3/2006	7			7.8
11/13/2006	7			49.0
11/15/2006	7			79.0
11/19/2006	7			4.0
11/27/2006	7			79.0
11/29/2006	7			130.0
12/5/2006	7			4.5
1/2/2007	7			33.0
1/4/2007	7			7.8

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
2/5/2007	7			1.7
2/28/2007	7	1/2 EBB	30	7.8
4/9/2007	7	1/2 FLD	35	2.0
5/16/2007	7	1/3 EBB	35	2.0
6/6/2007	7			4.5
6/14/2007	7	1/3 EBB	36	2.0
8/13/2007	7	LATE FLOOD	36	1.7
9/4/2007	7	1/4 FLOOD	36	33.0
10/30/2007	7			2.0
12/18/2007	7			21.0
12/20/2007	7			7.8
1/22/2008	7			1.7
2/6/2008	7	1/2 ebb	35	1.8
2/21/2008	7			1.7
2/25/2008	7			1.7
3/19/2008	7			1.7
4/9/2008	7			1.8
4/23/2008	7			1.7
5/15/2008	7			34.0
5/19/2008	7			1.7
5/27/2008	7	1/4 flood	35	2.0
6/24/2008	7			2.0
7/8/2008	7	1/4 FLOOD	38	2.0
8/5/2008	7	3/4 flood	36	1.7
8/18/2008	7			4.5
9/9/2008	7			49.0
9/11/2008	7			33.0
9/16/2008	7			1.7
9/24/2008	7	late ebb	34	13.0
9/30/2008	7			2.0
10/22/2008	7	late ebb	35	49.0
10/28/2008	7			1.7
11/6/2008	7			33.0
11/9/2008	7			13.0
11/12/2008	7			4.0
11/17/2008	7			2.0
12/2/2008	7			1.7
2/5/2009	7	late ebb	30	7.8
2/23/2009	7			7.8
3/4/2009	7			79.0
3/6/2009	7			170.0
3/9/2009	7			4.5
4/7/2009	7	1/4 EBB	34	4.5
5/11/2009	7			1.7
5/13/2009	7	3/4 EBB	35	1.7
5/22/2009	7			1.7
6/18/2009	7			17.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
7/15/2009	7	EARLY FLD	38	2.0
8/10/2009	7	3/4 FLD	36	1.7
9/9/2009	7	LATE FLD	36	1.7
10/1/2009	7			33.0
10/7/2009	7			1.7
1/7/2002	8	Early FLD	37	79.0
2/13/2002	8			2.0
3/14/2002	8			33.0
3/18/2002	8			2.0
4/2/2002	8	1/3 EBB	37	1.7
6/17/2002	8	1/2 FLD	BROKEN	23.0
7/18/2002	8	Late EBB	37	17.0
9/19/2002	8	1/2 EBB	37	22.0
9/26/2002	8			4.5
10/14/2002	8			49.0
10/17/2002	8			79.0
10/21/2002	8			33.0
10/30/2002	8	1/3 FLD	33	46.0
1/7/2003	8	1/2 FLD	36	7.8
2/19/2003	8			1.7
2/26/2003	8	2/3 EBB	34	23.0
3/26/2003	8			33.0
3/28/2003	8			46.0
4/1/2003	8			1.8
4/15/2003	8			23.0
4/16/2003	8			33.0
5/5/2003	8	2/3 FLD	33	11.0
5/28/2003	8			79.0
5/30/2003	8			27.0
7/8/2003	8	Early FLD	36	11.0
8/19/2003	8	1/3 FLD	24	13.0
9/22/2003	8			7.8
9/25/2003	8			1.7
10/14/2003	8			7.8
10/22/2003	8	1/2 EBB	35	110.0
10/31/2003	8			79.0
11/3/2003	8			49.0
11/4/2003	8			110.0
11/7/2003	8			79.0
11/10/2003	8			2.0
12/16/2003	8			240.0
12/18/2003	8			350.0
12/21/2003	8			17.0
1/29/2004	8			79.0
2/2/2004	8			11.0
2/9/2004	8	Early EBB	36	1.7
3/1/2004	8			170.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
3/3/2004	8			27.0
3/5/2004	8			49.0
3/8/2004	8			17.0
4/27/2004	8	Late EBB>Early FLD	30	170.0
4/30/2004	8			49.0
5/6/2004	8			23.0
6/9/2004	8			33.0
6/11/2004	8			49.0
6/14/2004	8			79.0
6/16/2004	8			13.0
7/6/2004	8			1.7
7/16/2004	8	1/3 EBB	36	11.0
8/9/2004	8	1/4 FLD	35	33.0
8/19/2004	8			4.5
10/13/2004	8	1/4 EBB	32	4.5
10/26/2004	8	1/3 EBB	32	2.0
11/16/2004	8			2.0
11/30/2004	8			2.0
1/3/2005	8	1/2 FLD	31	4.5
2/14/2005	8	2/3 FLD	33	4.5
3/2/2005	8			2.0
4/4/2005	8			920.0
4/6/2005	8			14.0
4/10/2005	8			2.0
4/28/2005	8	2/3 FLD	34	2.0
5/3/2005	8	Late EBB	34	4.5
6/13/2005	8	1/3 FLD	29	4.0
6/28/2005	8	1/3 FLD	35	3.7
7/1/2005	8			130.0
7/5/2005	8			22.0
7/7/2005	8			4.5
8/4/2005	8			49.0
8/9/2005	8			4.8
8/11/2005	8			4.5
8/29/2005	8			240.0
9/1/2005	8			79.0
9/6/2005	8			2.0
9/26/2005	8			170.0
9/29/2005	8			130.0
10/3/2005	8			1.7
10/8/2005	8			4.5
1/23/2006	8	1/3 FLD	32	22.0
2/16/2006	8	1/3 EBB	35	1.7
3/1/2006	8			4.5
3/20/2006	8	2/3 FLD	35	1.7
4/25/2006	8	2/3 EBB	34	49.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
5/1/2006	8			1.0
7/10/2006	8	1/2 EBB	35	14.0
7/31/2006	8	1/3 FLD	34	11.0
2/28/2007	8	1/2 EBB	32	6.8
4/9/2007	8	1/2 FLD	35	2.0
5/16/2007	8	1/3 EBB	35	1.7
6/14/2007	8	1/3 EBB	36	1.7
8/13/2007	8	LATE FLOOD	36	1.7
9/4/2007	8	1/4 FLOOD	36	27.0
2/6/2008	8	1/2 ebb	35	1.7
5/27/2008	8	1/4 flood	35	6.8
7/8/2008	8	1/4 FLOOD	37	7.8
8/5/2008	8	3/4 flood	36	2.0
9/24/2008	8	late ebb	35	7.8
10/22/2008	8	late ebb	35	49.0
2/5/2009	8	late ebb	32	11.0
4/7/2009	8	1/4 EBB	35	79.0
5/13/2009	8	3/4 EBB	36	1.7
7/15/2009	8	EARLY FLD	35	17.0
8/10/2009	8	3/4 FLD	38	1.7
9/9/2009	8	LATE FLD	38	1.7
1/7/2002	10	Early FLD	37	130.0
4/2/2002	10	1/3 EBB	37	4.5
6/17/2002	10	1/2 FLD	BROKEN	2.0
7/18/2002	10	Late EBB	36	17.0
9/19/2002	10	1/2 EBB	34	23.0
10/30/2002	10	1/3 FLD	33	49.0
1/7/2003	10	1/2 FLD	35	33.0
2/26/2003	10	2/3 EBB	30	4.5
5/5/2003	10	2/3 FLD	33	13.0
7/8/2003	10	Early FLD	30	33.0
8/19/2003	10	1/3 FLD	23	17.0
10/22/2003	10	1/2 EBB	35	46.0
2/9/2004	10	Early EBB	36	2.0
4/27/2004	10	Late EBB>Early FLD	30	13.0
7/16/2004	10	1/3 EBB	35	2.0
8/9/2004	10	1/4 FLD	30	17.0
10/13/2004	10	1/4 EBB	32	2.0
10/26/2004	10	1/3 EBB	35	2.0
1/3/2005	10	1/2 FLD	34	4.5
2/14/2005	10	2/3 FLD	34	1.7
4/4/2005	10			540.0
4/28/2005	10	2/3 FLD	33	1.7
5/3/2005	10	Late EBB	34	4.5
6/13/2005	10	1/3 FLD	33	4.5
6/28/2005	10	1/3 FLD	35	2.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
1/23/2006	10	1/3 FLD	32	49.0
2/16/2006	10	1/3 EBB	35	4.5
3/20/2006	10	2/3 FLD	34	1.7
4/25/2006	10	2/3 EBB	34	70.0
7/10/2006	10	1/2 EBB	35	46.0
7/31/2006	10	1/3 FLD	35	4.0
2/28/2007	10	1/2 EBB	26	4.0
4/9/2007	10	1/2 FLD	35	4.5
5/16/2007	10	1/3 EBB	35	1.8
6/14/2007	10	1/3 EBB	36	2.0
8/13/2007	10	LATE FLOOD	36	4.5
9/4/2007	10	1/4 FLOOD	36	22.0
2/6/2008	10	1/2 ebb	35	1.7
5/27/2008	10	1/4 flood	35	1.8
7/8/2008	10	1/4 FLOOD	38	4.5
8/5/2008	10	3/4 flood	36	1.7
9/24/2008	10	late ebb	34	13.0
10/22/2008	10	late ebb	35	11.0
2/5/2009	10	late ebb	31	11.0
2/5/2009	10	LATE EBB	31	11.0
4/7/2009	10	1/4 EBB	32	14.0
5/13/2009	10	3/4 EBB	35	11.0
7/15/2009	10	EARLY FLD	37	4.0
8/10/2009	10	3/4 FLD	37	1.7
9/9/2009	10	LATE FLD	37	1.7
1/7/2002	13	Early FLD	37	49.0
4/2/2002	13	1/3 EBB	37	1.7
6/17/2002	13	1/2 FLD	BROKEN	4.5
7/18/2002	13	Late EBB	36	79.0
9/4/2002	13			13.0
9/19/2002	13	1/2 EBB	35	17.0
9/26/2002	13			2.0
10/14/2002	13			33.0
10/17/2002	13			23.0
10/30/2002	13	1/3 FLD	35	49.0
1/7/2003	13	1/2 FLD	36	2.0
2/19/2003	13			2.0
2/26/2003	13	2/3 EBB	31	11.0
3/26/2003	13			350.0
3/28/2003	13			23.0
4/1/2003	13			2.0
4/15/2003	13			23.0
4/16/2003	13			17.0
5/5/2003	13	2/3 FLD	34	2.0
5/28/2003	13			33.0
5/30/2003	13			46.0
7/8/2003	13	Early FLD	34	17.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
8/19/2003	13	1/3 FLD	27	22.0
9/22/2003	13			17.0
9/25/2003	13			2.0
10/14/2003	13			2.0
10/22/2003	13	1/2 EBB	35	21.0
10/31/2003	13			11.0
11/3/2003	13			110.0
11/4/2003	13			13.0
11/7/2003	13			26.0
11/10/2003	13			7.8
12/16/2003	13			2.0
12/18/2003	13			110.0
12/21/2003	13			13.0
2/9/2004	13	Early EBB	36	1.7
4/27/2004	13	Late EBB>Early FLD	30	7.8
5/6/2004	13			6.8
7/16/2004	13	1/3 EBB	35	2.0
8/9/2004	13	1/4 FLD	32	11.0
8/19/2004	13			2.0
10/13/2004	13	1/4 EBB	32	13.0
10/26/2004	13	1/3 EBB	34	4.5
1/3/2005	13	1/2 FLD	32	2.0
2/14/2005	13	2/3 FLD	32	4.5
4/28/2005	13	2/3 FLD	33	1.7
5/3/2005	13	Late EBB	32	6.1
6/13/2005	13	1/3 FLD	34	1.7
6/28/2005	13	1/3 FLD	35	1.7
9/29/2005	13			4.5
10/8/2005	13			1.7
11/29/2005	13			33.0
12/1/2005	13			350.0
12/5/2005	13			1.7
1/23/2006	13	1/3 FLD	35	6.8
2/16/2006	13	1/3 EBB	35	1.7
3/20/2006	13	2/3 FLD	35	1.7
4/25/2006	13	2/3 EBB	35	23.0
7/10/2006	13	1/2 EBB	36	4.0
7/31/2006	13	1/3 FLD	35	6.1
9/12/2006	13			2.0
10/12/2006	13			2.0
10/31/2006	13			130.0
11/3/2006	13			22.0
11/6/2006	13			1.8
11/13/2006	13			13.0
1/2/2007	13			33.0
1/4/2007	13			4.0

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
2/28/2007	13	1/2 EBB	32	4.5
4/9/2007	13	1/2 FLD	34	1.7
5/16/2007	13	1/3 EBB	35	2.0
6/14/2007	13	1/3 EBB	36	4.5
8/13/2007	13	LATE FLOOD	36	1.7
9/4/2007	13	1/4 FLOOD	35	2.0
2/6/2008	13	1/2 ebb	35	4.5
5/27/2008	13	1/4 flood	35	2.0
7/8/2008	13	1/4 FLOOD	38	1.7
8/5/2008	13	3/4 flood	36	1.7
9/24/2008	13	late ebb	34	11.0
10/22/2008	13	late ebb	34	7.8
10/28/2008	13			7.8
2/5/2009	13	late ebb	32	4.0
4/7/2009	13	1/4 EBB	33	2.0
5/13/2009	13	3/4 EBB	34	6.8
7/15/2009	13	EARLY FLD	35	1.7
8/10/2009	13	3/4 FLD	37	1.7
9/9/2009	13	LATE FLD	35	1.7
10/1/2009	13			17.0
7/16/2004	14A	1/3 EBB	35	4.5
8/9/2004	14A	1/4 FLD	26	17.0
8/19/2004	14A			4.5
10/13/2004	14A	1/4 EBB	32	1.7
10/26/2004	14A	1/3 EBB	35	2.0
1/3/2005	14A	1/2 FLD	32	1.7
2/14/2005	14A	2/3 FLD	34	1.7
4/28/2005	14A	2/3 FLD	34	1.7
5/3/2005	14A	Late EBB	32	17.0
5/9/2005	14A			110.0
5/11/2005	14A			13.0
6/13/2005	14A	1/3 FLD	32	6.8
6/28/2005	14A	1/3 FLD	35	4.5
9/22/2005	14A			23.0
1/23/2006	14A	1/3 FLD	32	130.0
2/16/2006	14A	1/3 EBB	35	2.0
3/20/2006	14A	2/3 FLD	35	4.5
4/25/2006	14A	2/3 EBB	35	6.8
7/10/2006	14A	1/2 EBB	36	4.5
7/31/2006	14A	1/3 FLD	35	7.8
2/28/2007	14A	1/2 EBB	32	4.5
4/9/2007	14A	1/2 FLD	35	2.0
5/16/2007	14A	1/3 EBB	35	1.7
6/14/2007	14A	1/3 EBB	36	2.0
8/13/2007	14A	LATE FLOOD	36	2.0
9/4/2007	14A	1/4 FLOOD	36	7.8
12/20/2007	14A			17

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
12/21/2007	14A			10
1/14/2008	14A			2
2/1/2008	14A			5
2/6/2008	14A	1/2 ebb	35	1.7
3/5/2008	14A			7
3/20/2008	14A			6
5/15/2008	14A			20
5/27/2008	14A	1/4 flood	35	6.1
5/29/2008	14A			73
6/24/2008	14A			10
7/8/2008	14A	1/4 FLOOD	38	6.8
7/21/2008	14A			10
7/29/2008	14A			10
8/5/2008	14A	3/4 flood	36	4.5
8/14/2008	14A			73
8/28/2008	14A			19
9/24/2008	14A	late ebb	34	17.0
9/26/2008	14A			37
10/22/2008	14A	late ebb	35	95.0
11/4/2008	14A			2
12/12/2008	14A			10
2/5/2009	14A	late ebb	28	79.0
4/7/2009	14A	1/4 EBB	34	7.8
5/13/2009	14A	3/4 EBB	35	6.8
7/15/2009	14A	EARLY FLD	35	2.0
8/10/2009	14A	3/4 FLD	37	1.7
9/9/2009	14A	LATE FLD	37	2.0
7/16/2004	14B	1/3 EBB	35	1.7
8/9/2004	14B	1/4 FLD	30	7.8
10/13/2004	14B	1/4 EBB	32	2.0
10/26/2004	14B	1/3 EBB	34	1.7
1/3/2005	14B	1/2 FLD	31	4.5
2/14/2005	14B	2/3 FLD	32	1.7
4/28/2005	14B	2/3 FLD	33	11.0
5/3/2005	14B	Late EBB	32	7.8
6/13/2005	14B	1/3 FLD	31	1.8
6/28/2005	14B	1/3 FLD	35	17.0
1/23/2006	14B	1/3 FLD	35	11.0
2/16/2006	14B	1/3 EBB	35	1.7
3/20/2006	14B	2/3 FLD	35	1.7
4/25/2006	14B	2/3 EBB	34	33.0
7/10/2006	14B	1/2 EBB	35	33.0
7/31/2006	14B	1/3 FLD	35	17.0
2/28/2007	14B	1/2 EBB	31	14.0
4/9/2007	14B	1/2 FLD	35	4.5
5/16/2007	14B	1/3 EBB	35	2.0
6/14/2007	14B	1/3 EBB	36	1.7

DATE	Station no.	TIDE	Salinity (ppt)	FC (cts/100mL)
8/13/2007	14B	LATE FLOOD	36	1.7
9/4/2007	14B	1/4 FLOOD	35	6.8
2/6/2008	14B	1/2 ebb	35	2.0
5/27/2008	14B	1/4 flood	35	7.8
7/8/2008	14B	1/4 FLOOD	38	11.0
8/5/2008	14B	3/4 flood	36	2.0
9/24/2008	14B	late ebb	34	17.0
10/22/2008	14B	late ebb	33	130.0
2/5/2009	14B	late ebb	31	23.0
4/7/2009	14B	1/4 EBB	34	2.0
5/13/2009	14B	3/4 EBB	35	4.5
7/15/2009	14B	EARLY FLD	34	2.0
8/10/2009	14B	3/4 FLD	36	1.7
9/9/2009	14B	LATE FLD	36	4.5

Appendix B. Tidal Prism Model Segmentation

Table B1. Geometry information of the Lockwoods Folly Estuary used for the TPWQM

Segment	Distance from mouth (km)	High water volume (m^3 x 10^6)	Tidal prism (m^3 x 10^6)	Depth (m)
M0_1	0.000	0.000	3.171	0.000
M0_2	1.830	3.179	0.783	1.062
M0_3	2.490	0.774	0.239	1.188
M0_4	3.100	0.271	0.000	0.828

Appendix C. Nonpoint Source Assessment

Nonpoint sources of fecal coliform bacteria do not have one discharge point but occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in watersheds discharging to the restricted shellfish harvesting areas. The possible introductions of fecal coliform bacteria to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. As the runoff occurs during rain events, surface runoff transports water and fecal coliform over the land surface and discharges to the restricted shellfish harvesting area. The deposition of nonhuman fecal coliform directly to the restricted shellfish area occurs when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions to the bacterial levels from human activities generally arise from failing septic systems and their associated drain fields. The transport of fecal coliform from land surface to the restricted shellfish harvesting area is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to determine the sources of fecal coliform contribution and reduction needed to achieve water quality criteria, and to allocate fecal coliform load among these sources, it is necessary to identify all existing sources. The nonpoint source assessment was conducted using available data collected in the watershed. Multiple data sources were used to determine the potential sources of the fecal coliform load from the watershed. The data used for the source assessment are:

Land use data developed for the Lockwoods Folly LWP Detailed Assessment (2007)
U.S. Census Data for Brunswick County
Shoreline sanitary survey data
Wildlife population data
Household pet statistics
Literature data on septic failure rates
Stream coverage

Due to insufficient data sources, the source assessment method does not account for boat discharge, resuspension from bottom sediment, and the potential for regrowth of fecal coliform in the estuary. It should be noted that the source loads calculated for this source assessment are an estimation of the fecal coliform loads available for runoff in the watershed, and do not estimate direct loading from each source type to the Lockwoods Folly estuary.

Wildlife Contributions

It is generally assumed that wildlife in the watershed include the following: beaver, deer, birds and ducks, muskrat, raccoons, and wild turkey. Fecal coliform loading from wildlife occurs from either excretion on land and subsequent runoff, or through direct deposition into waterbodies. Wildlife densities in the watershed were estimated based on data from sources such as the North Carolina Wildlife Resources Commission, the North Carolina Department of Environment and Natural Resources, the Virginia Department of Environmental Quality, and the Maryland Department of Natural Resources. Population densities and habitat requirements are summarized by species in Table C1. These densities were applied to available habitat in the Lockwoods Folly watershed in order to estimate wildlife populations present. Habitat for each wildlife type in the watershed was determined utilizing available land use data and GIS analysis techniques. Fecal coliform contributions were then estimated based on the number of wildlife and fecal coliform production rates, listed in Table C2. The analysis resulted in a total wildlife fecal coliform contribution of 3.10 x

10^{13} counts per day.

Table C1. Wildlife habitat and densities

Wildlife Type	Population Density	Habitat Requirements
Beaver[1]	4.8 animals/mile of stream	Tidal and non-tidal regions
Deer[3]	0.035 animals/acre	Entire watershed
Birds[4]	0.07 animals/acre	Entire watershed
Duck[2]	0.039 animals/acre	Entire watershed
Muskrat[1]	2.75 animals/acre	Within 66 feet of streams and ponds
Raccoon[1]	0.07 animals/acre	Within 600 feet of streams and ponds
Wild Turkey[3]	0.005 animals/acre	Entire watershed excluding farmsteads and urban

[1]VA DEQ 2002, [2]MD DNR 2003, [3]NC WRC 2008, [4]NC DENR 2007a

Table C2. Wildlife fecal coliform production rates

Source	Fecal Coliform Production (cts/animal/day)
Beaver[1]	2.50E+08
Deer[1]	5.00E+08
Birds[1]	2.43E+09
Duck[1]	2.43E+09
Muskrat[2]	3.40E+07
Raccoon[2]	1.00E+09
Wild Turkey[3]	9.30E+07

[1]EPA 2000, [2]Kator & Rhodes 1996, [3]ASAE 1998

Livestock Contributions

Fecal coliform contributions from livestock occur through manure spreading processes and direct deposition during grazing. One larger livestock establishment is present in the watershed. This farm, located on Galloway Road, currently houses approximately 100 head of beef cattle, 7200 hogs, and 6 donkeys (personal communication, Dale Clemmons). There are also several other small farms scattered throughout the watershed with a small number of cattle, horses, and poultry. In the Shoreline Survey conducted by NCDEH Shellfish Sanitation, these smaller farms were reported to house approximately 25 horses, 25 hens, and 20 head of cattle total (NC DENR 2007b).

The hog farm in the watershed is a state-permitted facility and, as such, is not required to be included in the wasteload allocation of the TMDL. The waste from the facility is pre-treated in two anaerobic waste lagoons and is subsequently treated using land application. According to the permits and the nutrient management plans for this farm, it is a no-discharge facility and the waste is required to be applied at agronomic rates without direct runoff to streams. The facility has had no violations in its history. Given the permit requirements and nutrient management plans, this facility is likely not a significant source of fecal coliform. The fecal coliform loads calculated for this facility, and all sources, in this nonpoint source assessment are an estimate of the fecal coliform available for runoff in the watershed and are not a representation of direct loading to streams.

In order to calculate available loads from livestock to the watershed, literature values were collected for fecal coliform production rates of livestock, the confinement of livestock, and the percent of manure available for runoff. Fecal coliform production rates for various types of livestock are listed in Table C3. The amount of manure available for runoff is based on the confinement of the livestock and also on the stockpiling of the manure that is produced and distributed to agricultural land (MDE 2005). It was assumed that 100% of the direct deposit contribution was available for runoff. The estimated percentage of manure application available for wash off is about 40% (VIMS 2004). For poultry, however, about 10% is available for wash off (MDE 2005) (Table C4). Therefore, fecal coliform decay is considered in the estimation of fecal coliform loading. Characteristics of the operation were also taken into account. In large permitted hog farms, the waste from the hogs is stored in lagoons for anaerobic treatment and applied to agricultural fields according to strict regulation. The availability of fecal coliform for runoff is highly variable between sites and depends upon factors such as soils, vegetated buffer condition, slope, and setbacks. The estimated percentage of manure application from hogs available for runoff may be less than 10% (personal communication, Otto Simmons). A conservative estimate of 10% was assumed for this source assessment.

Table C3. Livestock fecal coliform production rates

Source	FC Production (counts/animal/day)
Dairy	1.01E+11
Beef	1.20E+10
Horses	4.20E+08
Sheep	1.20E+10
Broilers	1.36E+08
Turkeys	9.30E+07
Chickens	1.36E+08
Layers	1.36E+08
Hogs	1.08E+10

Source: VIMS 2004

Table C4. Livestock percent confinement and manure runoff

Livestock	Percent of Time Confined	Percent Manure Available for Runoff
Dairy	80%	40%
Beef	20%	40%
Horses	50%	40%
Sheep	50%	40%
Broilers	85%	10%
Turkeys	85%	10%
Chickens	85%	10%
Layers	85%	10%
Hogs[1]	100%	10%

[1]Hogs are confined 100% of the time in large permitted hog farms

Based on the number and type of livestock in the watershed, their fecal coliform production rates, and percent of manure available for runoff, it was calculated that the daily load of fecal coliform from livestock is 9.05 x 10^{12} counts per day.

Pet Contribution

Pet contributions to fecal coliform loading usually occur through runoff from urban and residential areas. In order to quantify the density of domestic animals in the Lockwoods Folly watershed, the number of household pets was calculated based on market research statistics from the American Veterinary Medical Association (AVMA, 2007). It was assumed that dogs would be the only household pet contributing to fecal coliform loading. National statistics show that 36.1% of households own dogs with an average of 1.6 dogs per household. The number of households in the watershed was calculated from tax parcel data, resulting in approximately 11,240 households and 6490 dogs.

No current data exists on the pet waste disposal habits of the residents of the Lockwoods Folly watershed. However, an extensive citizen survey, which included data on pet waste removal, was conducted across the state in 2005 by the North Carolina Department of the Environment and Natural Resources. The results showed that 47% of urban pet walkers, 49% of suburban pet walkers, and 59% of rural pet walkers 'rarely' or 'never' picked up pet waste (Holman 2007). EPA studies estimate that the fecal coliform production rate of dogs can amount to 5 x 10^{9} counts/dog/day (EPA 2000). Based on these statistics, and the assumption that pet waste habits would lie somewhere between the suburban and rural habits, a total fecal coliform loading rate from pets was calculated to be 1.75 x 10^{13} counts per day over the entire watershed using the following equation:

Loading = NR_1PR_{dog}

Where:

N = the number of dogs in the area

R_1 = percentage of dogs contributing fecal matter (54%)

PR_{dog} = average fecal coliform production rate for dogs

Human Contributions

Human contributions to fecal coliform loading can occur due to wastewater facility discharges, the failure of septic systems, or through the pollution of recreational vehicles discharging directly into waterbodies in the watershed. There is limited sewer service provided by the West Brunswick Wastewater Treatment Facility. This is a no-discharge facility which provides a high level of pretreatment before utilizing land application as a final treatment. Effluent limits for fecal coliform are a monthly geometric mean of 14 counts/100mL. The main land application site in the watershed is located on a forested parcel on Smith Road. Given the level of pretreatment, the slow application rates, the vegetative cover at the site, and the well established vegetative buffers of streams on site, this is not a likely source of fecal coliform in the watershed. Instead, due to limited sewer service in the area, the failing of septic systems is the main contributor of fecal coliform sources from humans.

The number of septic systems in the watershed was calculated using GIS techniques and available tax parcel and sewer system spatial data. All developed parcels in the watershed without sewer were assumed to have septic systems. The analysis resulted in an estimated 11,060 septic systems in the watershed, with 5,890 septics in the watershed area draining to the estuary (the remainder are within areas that drain to the ICWW). The calculation for estimating the daily loading of fecal coliform from septic systems involves the number of septic systems, the average number of persons per septic system (or household), septic failure rates, and an average pollutant loading value associated with each person.

Septic systems exhibit variable failure rates depending on the type of system, maintenance regime, and environmental factors such as soil type and groundwater level. In a study of septic systems in Brunswick County, Uebler et al. (1983) found that systems on poorly drained Leon soils had a 13% higher rate of failure (20.5% versus 7.5%) compared to other systems. A statewide survey conducted in 1982 and cited in NCDEH (2000) found an average 11.4% failure rate. Data collected by Brunswick County shows 1,091 unique repairs in the watershed based on data from 1980 to mid-2006. Staff with the County Department of Health suggested that the tracking system has evolved over time and that this number may not be representative of an exact accounting of the number of repairs conducted. In addition, there may be some systems with failure that were never reported. Using GIS analysis, it was calculated that approximately 30% of soils within developed parcels with septic fall into the following drainage classes: excessively drained, poorly drained, or very poorly drained. Some of the remaining soils have limited suitability for septic tanks as well. The failure rate used for this study is based on a weighted average of data from Uebler et al. (1983) and county soils data. A final failure rate of 12% was estimated. This rate is inclusive of a variety of failure types.

The pollutant loading per person was calculated based on an estimated wastewater production of 70 gallons/person/day (Horsely & Whitten 1996) and an average fecal coliform concentration of 2 x 10^5 MPN/100 ml (EPA 2002). US 2006 Census data for Brunswick County shows an average of 2.38 persons per household. Given these statistics and the estimated septic system failure rate, fecal coliform loading due to human contributions in the watershed area draining to the estuary was calculated to be 8.91 x 10^{11} counts per day using the following equation:

Load = PSF_rCQC_v

Where

P = number of people per septic system (or household)

S = number of septic systems

F_r = septic failure rate

C = fecal coliform concentration in wastewater

Q = wastewater production per person

C_v = conversion factor (37.854)

Appendix D. Model Results of Median and 90th Percentile

The 30-month median and 90th percentile were calculated for the model segment M0S2 of the TPWQM in which the calibration points Site 7A and Site 8 are located. The time series plot for the TMDL period of the existing condition and load reduction scenario for the 90th percentile and median are presented in Figures D1 and D2. Given that each point represents a statistic of the previous 30 months, the first point appears in July of 2006.

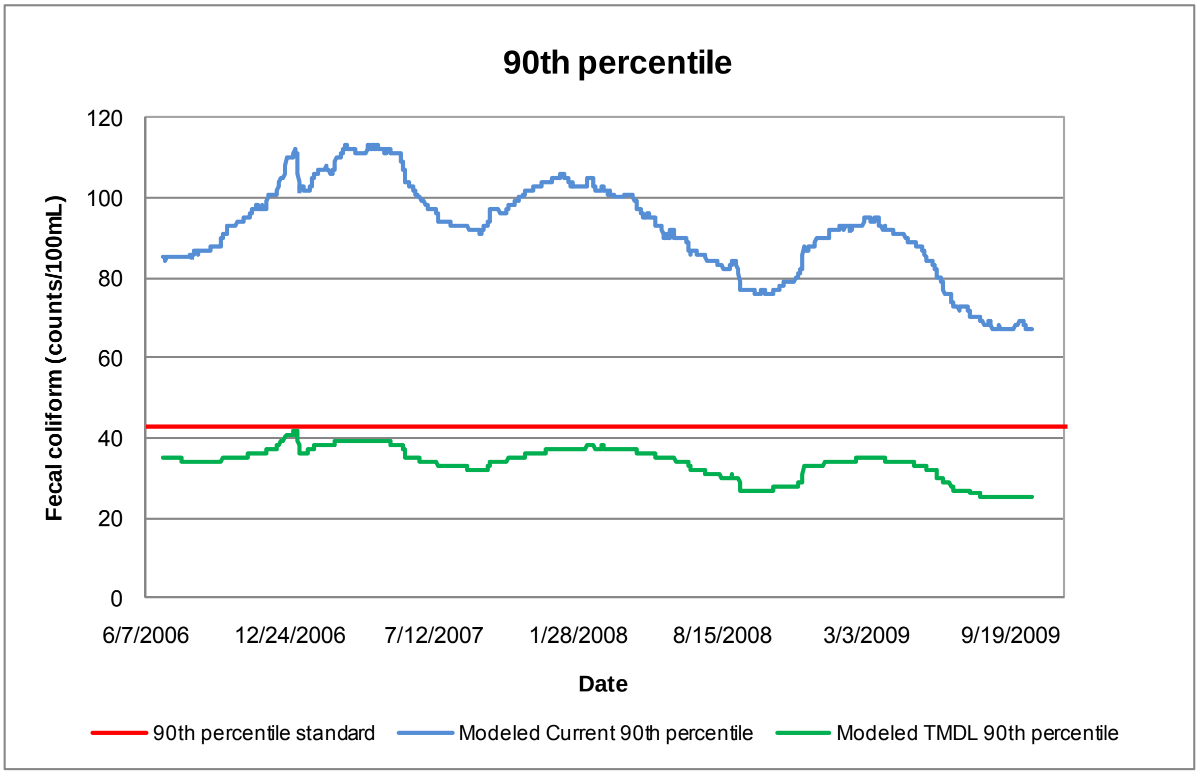


Figure D1. Modeled current and TMDL 90th percentile

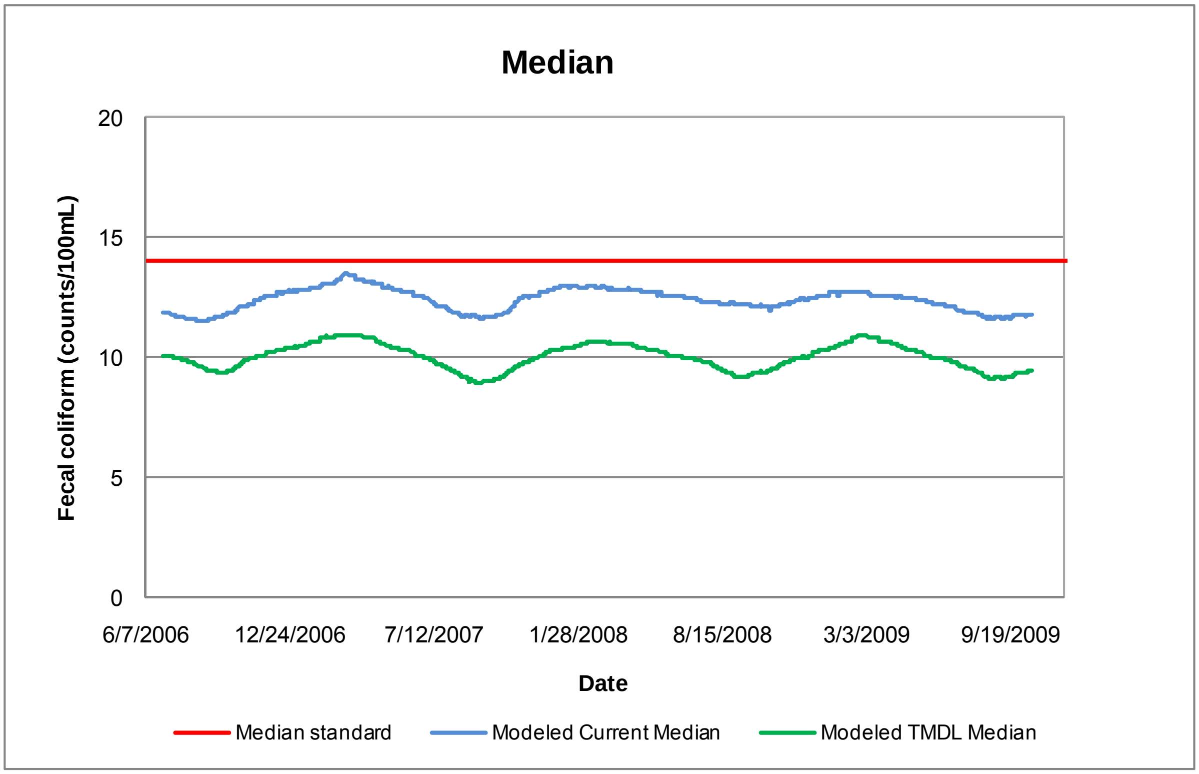


Figure D2. Modeled current and TMDL median

Appendix E
Lockwoods Folly River TMDL
Model Documentation

Prepared for the

North Carolina Division of Water Quality

August 2010

Prepared by

Stantec Consulting Services Inc.
801 Jones Franklin Road
Raleigh, North Carolina 27606
Ph: 919/ 865-6866
Fax: 919/ 851-7024

www.stantec.com

Stantec Project No.: 171300183

1.0 Introduction

A linked watershed and tidal modeling approach was used to simulate fecal coliform loading from the Lockwoods Folly River watershed and fecal coliform concentration in the Lockwoods Folly estuary. Freshwater flows for the watershed were estimated through simplified hydrologic modeling and pathogen loads were generated through the application of event mean concentrations. The Tidal Prism Water Quality Model (TPWQM) was used as the receiving-water quality model to predict fecal coliform concentrations in the estuary. A description of the watershed, the modeling approach for the watershed loading model, and the receiving-water quality model are provided in the following sections.

The water quality goal of this TMDL is to reduce high fecal coliform concentrations in the impaired segments to levels such that the designated use for the restricted shellfish harvesting areas will be met. The selected watershed model calculated the watershed load to the Lockwoods Folly estuary which includes loads from Mullet Creek, Spring Creek, Mill Creek, Lockwoods Creek, and the Lockwoods Folly River up to Brunswick County SR 1200. Therefore, the load reduction calculated for the estuary is applied to all of the aforementioned segments. A TMDL was not developed for the Intracoastal Waterway (ICWW) and Montgomery Slough because the hydrodynamics are not conducive to using the linked watershed and Tidal Prism modeling approach. These areas will instead be addressed in the TMDL implementation strategies.

2.0 Watershed Description

2.1.1 <u>Hydrology</u>

The Lockwoods Folly River study area is situated in south central Brunswick County and covers approximately 153 square miles. Although Lockwoods Folly River is part of the Lumber River Basin, it originates near the Town of Bolivia, flows westerly and then southwesterly, and empties into the Atlantic Ocean through the Lockwoods Folly River Inlet. The barrier islands of Oak Island and Holden Beach protect the river inlet. The Atlantic Intracoastal Waterway (ICWW), constructed in the 1930’s, is located landward of the islands connecting to a small estuary formed by the river near the Town of Varnamtown (Figure 1). In addition to the ICWW and the inlet, the Lockwoods Folly River from the ocean to the Highway 211 bridge (~12.5 miles) is maintained for navigation by the US Army Corps of Engineers (Corps). Montgomery Slough partially bisects Oak Island towards the seaward side of the island, and is connected to the ICWW in two locations. The Lockwoods Folly estuary drains to the ICWW before reaching the outlet to the Atlantic Ocean (Figure 1). The ICWW and Montgomery Slough do not drain to the Lockwoods Folly estuary. Given their connection, and the open-ended nature of the ICWW, the hydrodynamics of these two waterbodies are not conducive to using the linked watershed and Tidal Prism modeling approach. These areas will instead be addressed in the TMDL implementation plan strategies.

While it does not drain to the Lumber River, the Lockwoods Folly River watershed is considered to be within the Lumber River Basin, which is composed of four separate river systems. The Lockwoods Folly River is located within the basin’s Coastal Area Watershed, which also includes the Shallotte River to the west. The study area, which includes portions draining directly to the ICWW, encompasses five 14-digit hydrologic units: 03040207020010, 03040207020020, 03040207020030, 03040207020040, and

03040207020050. Major tributaries to the Lockwoods Folly River are River Swamp, Royal Oak Swamp, and Mill Creek. The ICWW and Mongtomery Slough do not drain to the Lockwoods Folly estuary (Figure 1).

The watershed contains two hydrologic areas as identified by the US Geological Survey (Giese and Mason, 1993): HA2 (sandy soils) and HA1 (clayey soils). Local relief is commonly 1 to 2 feet per mile and the median 7Q10 (the lowest stream flow for seven consecutive days that would be expected to occur once in ten years) approaches zero. Average annual precipitation in Southport, Brunswick County based on 49 years of record is 56.6 inches (Fine and Cunningham, 2001). There are no USGS stream gages located within the watershed. Stream gages in nearby watersheds are at Hood Creek near Leland (USGS 02105900) and Waccamaw River at Freeland (USGS 02109500), located in the northeast and northwest Brunswick County, respectively.

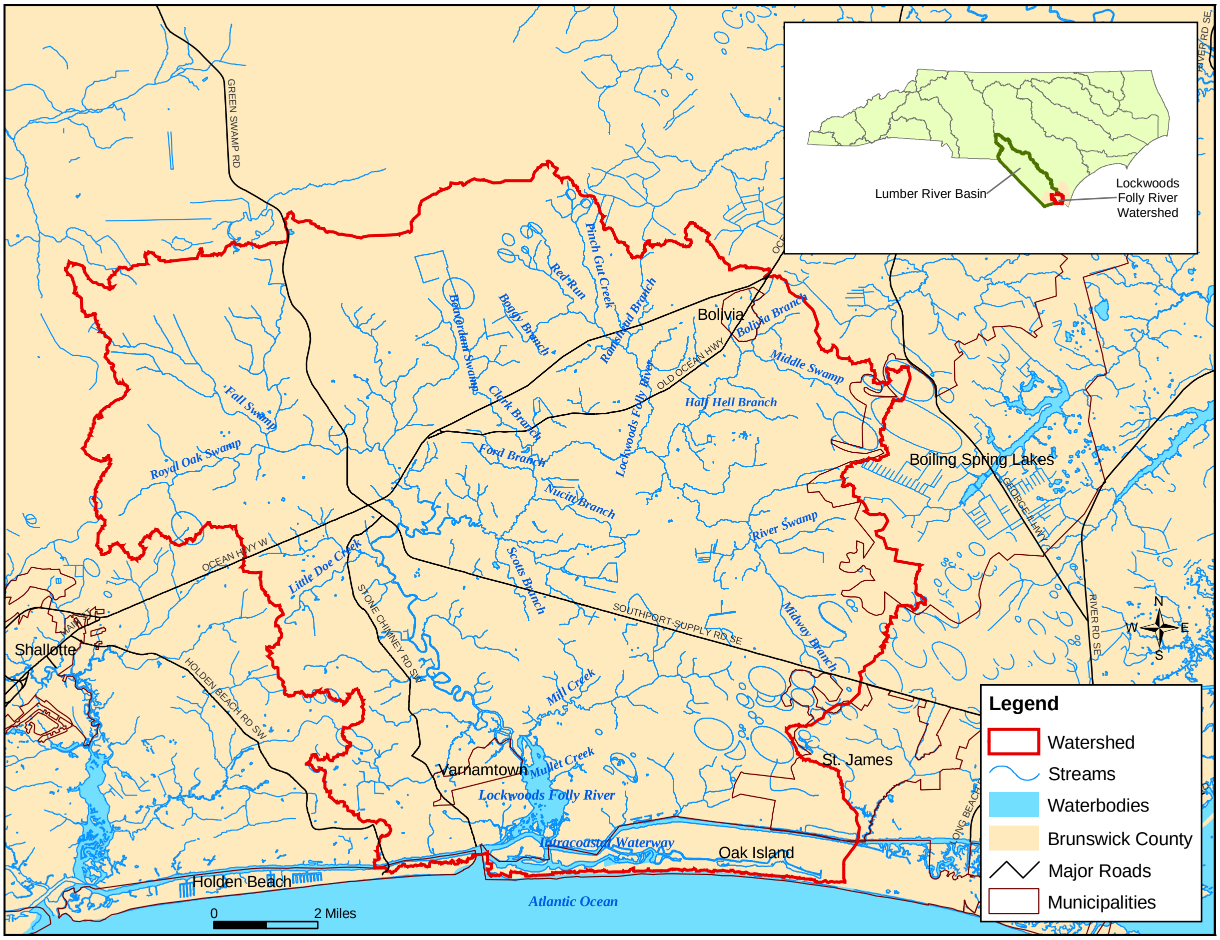


Figure 1. Location map

2.1.2 Geology and Soils

Topography of the study area is mostly characterized by gently undulating to nearly flat plains. Natural subsurface drainage is sluggish except near streams. Elevation ranges from 83 feet down to sea level. The mean elevation for the watershed study area is approximately 36 feet above sea level.

The dominant geologic formation of the Lockwoods Folly River watershed is the tertiary Waccamaw Formation, characterized by fossiliferoas sand with silt and clay. Brunswick County is underlain by more than 1,300 ft of mostly unconsolidated sediments, consisting of surficial deposits, and the Castle Hayne (in the southeastern part of the County), Peedee, Black Creek, Middendorf, and Cape Fear Formations (Fine and Cunningham, 2001).

Most of the watershed is located in the Lower Coastal Plain soil region (Daniels et al., 1999). Upland soils adjacent to the floodplain include well drained and moderately well drained soils (hydrologic soil group A or B) such as the loamy Baymeade (SCS 1986). Sandy, excessively drained soils of the Kureb-Wando map units are located within the areas of Varnamtown, Sunset Harbor, and Oak Island. In addition, there are large areas of somewhat poorly to very poorly drained soils such as Leon and Murville, Torhunta, and Croatan. Map units that are completely hydric soils or contain hydric soils make up about 89% of the watershed. Over 92% of the soils in the watershed are rated as very limited in terms of septic suitability.

2.1.3 Land Use and Land Cover

An existing land use/land cover map was created for modeling purposes using the 2004 Brunswick County existing land use map and aerial photography. The resulting map is comprised of 16 different land use classes including Office/Institutional, Commercial/Heavy Industrial, Golf Course, Roads, Pasture, Row Crop, Water, Wetland, Bare Earth, Forest, Open Space, and four residential land uses of various densities. North Carolina Department of Transportation (NCDOT) roads were separated from non-NCDOT roads in order to track their individual contribution of fecal coliform loads to the watershed. The density of residential land use was assigned based on lot size (Table 1).

Table 1. Residential land use categories

Lot Size (acres)	Residential Category	Residential Category Code
0.07 – 0.2249	Residential high density	RHD
0.2250 – 0.3349	Residential medium density	RMD
0.3350 – 0.9950	Residential low density	RLD
0.995 – 5.0	Residential very low density	RVL

All residential parcels over five acres were reviewed using 2004 aerial imagery (obtained from Brunswick County) and were then assigned a land use of Forest, Row Crop, Pasture, Bare Earth or Open Space based on land cover. The land cover is the dominant land use in these situations as a house on these large parcels does not contribute a significant amount of impervious surface. All other categories were assigned based on the 2004 Brunswick County existing land use map.

The resulting land use distribution in the Lockwoods Folly River watershed is included in Table 2 and depicted in Figure 2. At approximately 73%, the watershed is primarily comprised of forest land. Of the forested land, approximately 30% is wooded wetland and 20% is managed pineland. Residential, commercial, industrial, and office land uses combined currently make up about 6% of the watershed. Other major land uses include Open Space at 7.6% and Row Crop at 4.8%.

Table 2. Land use distribution in the Lockwoods Folly River watershed

Land Use Category	Area (acres)	Percent
High Density Residential (0.07 - 0.22 acres)	807	0.8%
Medium Density Residential (0.23 - 0.33 acres)	617	0.6%
Low Density Residential (0.34 - 0.99 acres)	1519	1.5%
Very Low Density Residential (1 - 5 acres)	1888	1.9%
Commercial/Heavy Industrial	215	0.2%
Office/Institutional/Light Industrial	596	0.6%
Road (w/ ROW) non-NCDOT	1527	1.6%
Road (w/ ROW) NCDOT	1629	1.7%
Bare Earth	220	0.2%
Open Space	7456	7.6%
Golf Course	631	0.6%
Pasture	858	0.9%
Row Crop	4660	4.8%
Forest (includes wooded wetland and managed pineland)	71407	72.9%
Emergent wetland	1860	1.9%
Water	2119	2.2%

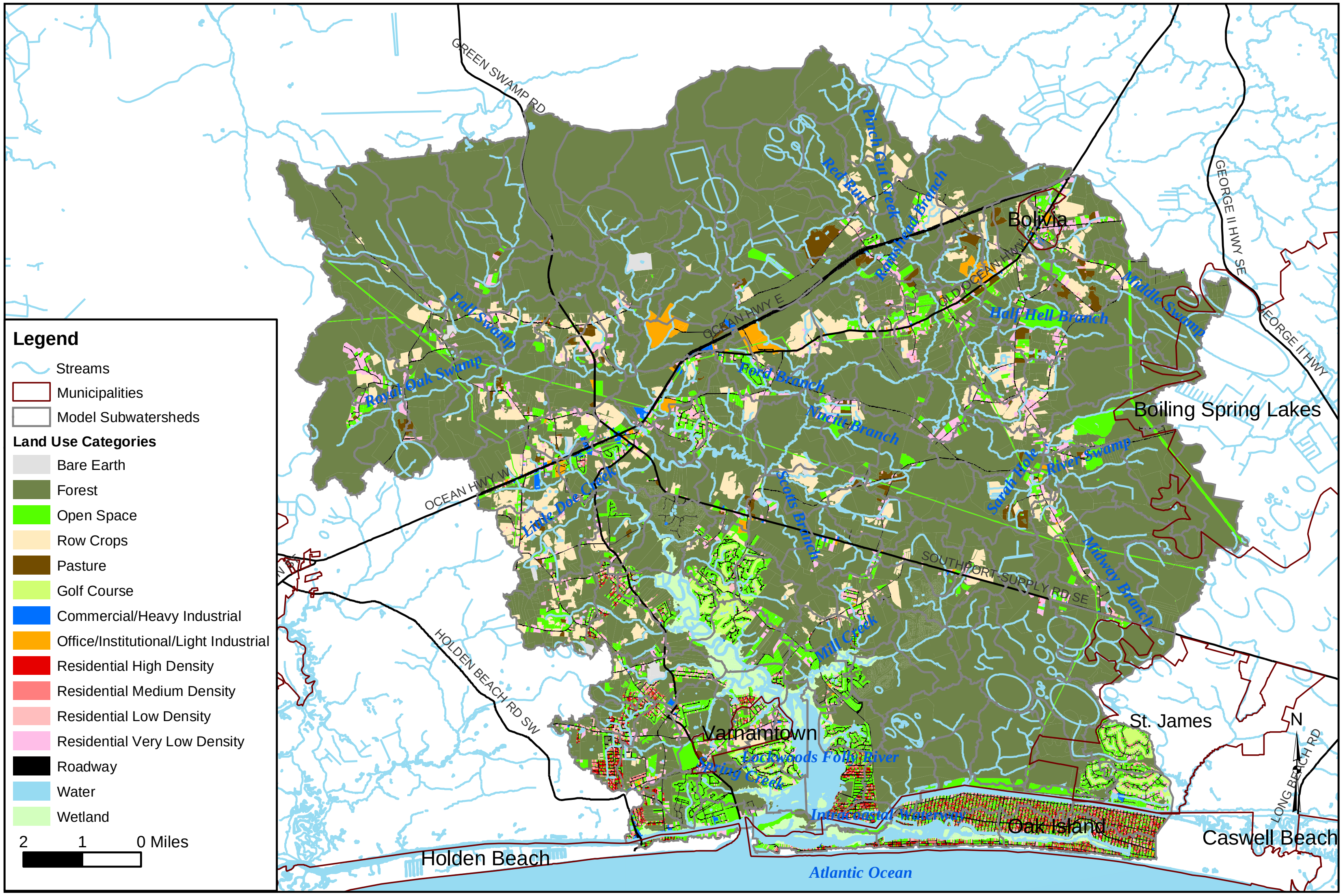


Figure 2. Current land use

3.0 Watershed Model

A simplified watershed model was developed utilizing HEC-HMS (v. 3.3) to estimate flow for the Lockwoods Folly River watershed given land use, soils, and precipitation data. The fecal coliform loading model was developed using literature values for event mean concentrations (EMC) in conjunction with the runoff calculated from the various soil-land use combinations in the watershed. The fecal coliform loading model was generated using a series of Excel spreadsheets. Instructions for using and navigating these spreadsheets are included in Appendix A.

3.1 Watershed Hydrology Model

HEC-HMS is a GUI based program designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is able to incorporate storm flow, base flow, and evapotranspiration in a continuous simulation of hydrologic processes. Data collection requirements for HEC-HMS are less intensive than more complex models like HSPF.

3.1.1 Subbasin Delineation

The Lockwoods Folly River watershed was delineated into 27 subbasins contributing flow to the Lockwoods Folly estuary (Figure 3). It should be noted that contribution of flow and fecal coliform loading from a 28th subbasin was not included in this model. The 28th basin drains to the Intracoastal Waterway and Montgomery Slough, and not to the Lockwoods Folly estuary. Subbasin delineation was performed using ArcGIS tools and was based on elevation data. The delineation was further refined based on roadways, field reconnaissance, and the location of monitoring stations.

Weighted curve numbers (CN) for each subbasin were developed using guidance published by the Soil Conservation Service (SCS 1975) based on the relative areas of land use and soil combinations in each subbasin. The curve numbers were used to assign values for various input parameters in the watershed hydrology model as described in Section 3.1.2.

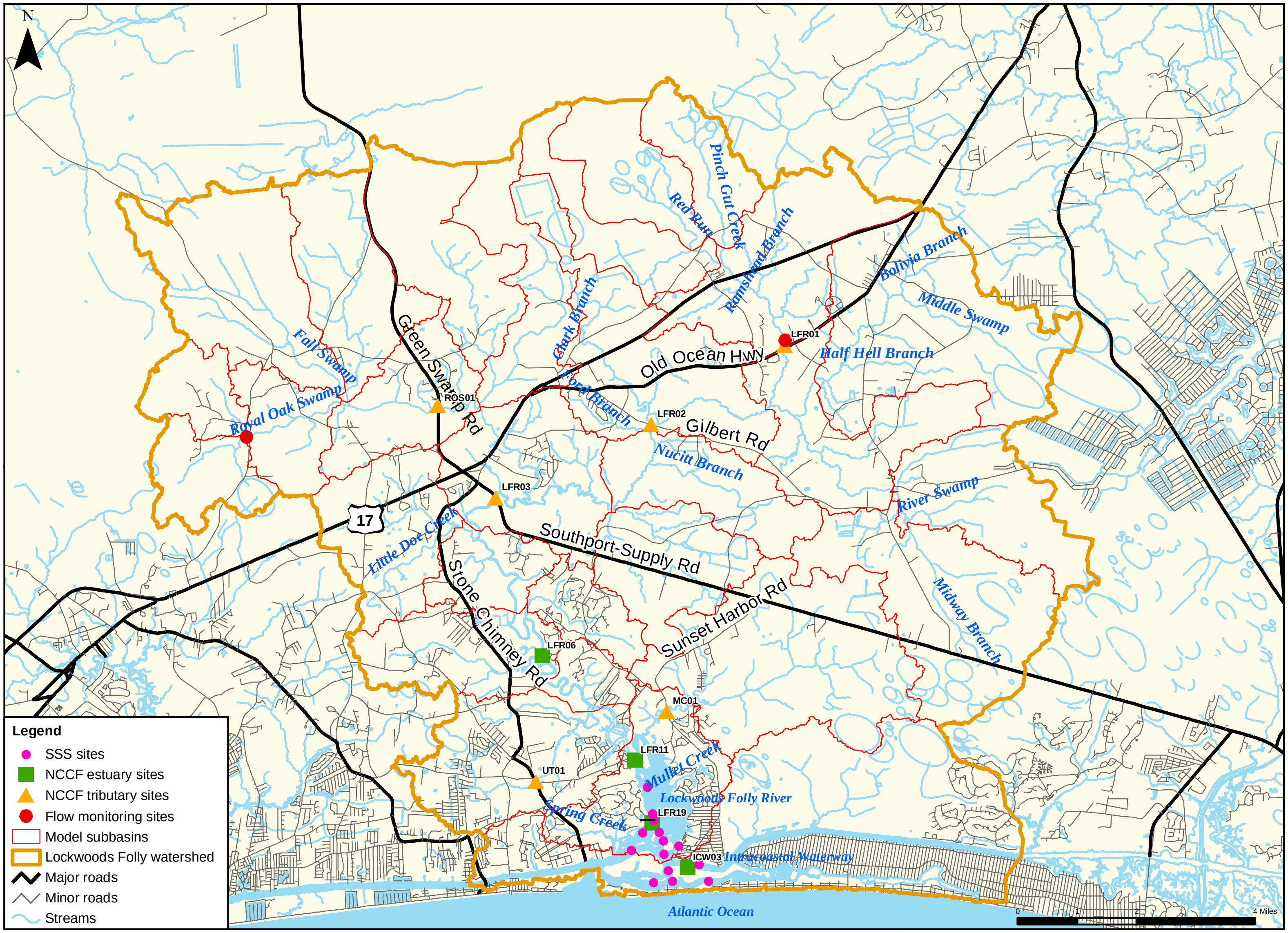


Figure 3. Watershed model subbasins and flow and water quality monitoring stations

3.1.2 HEC-HMS Model Subroutines

HEC-HMS uses a series of subroutines to model flow in a dendritic system. These subroutines include the Loss Model, Transform Model, and Baseflow Model. Values derived for the input parameters of these subroutines are summarized in Table 3 and Table 4. Results from these subroutines were used in final discharge calculations to the estuary as described in Section 3.1.3. The model was developed using an hourly time step. A more detailed description of the HEC-HMS model is provided in the user's manual (USACE 2008).

Loss Model

The Deficit and Constant Loss Model was selected to model runoff quantity from the 27 delineated subbasins. This model was selected because it allows for the drying of soil via evapotranspiration, and is therefore more suitable for running a long-term, continuous simulation of runoff. Inputs for this subroutine include initial deficit (in), maximum storage (in), constant rate (in/hr), and percent imperviousness. Percent imperviousness for each subbasin was derived from land use data and literature values for imperviousness using GIS techniques. Initial deficit, maximum storage, and constant rate were derived based on curve number for each subbasin as follows. Weighted curve numbers were assigned to each subbasin as described in Section 3.1.1, providing a range of curve numbers across the entire watershed. A range of values was then established for each input variable (i.e. maximum storage or constant rate). A value of each input variable was assigned to each subbasin based on the relative position of their curve number along the watershed-wide curve number range (e.g. if a subbasin's curve number was in the 10^{th} percentile of the curve number range, a value for the input variable was assigned such that it was the 10^{th} percentile value of the variable's range). The range of each input variable was adjusted for the calibration of the flow model described in Section 3.1.5.

Assumptions for the Loss Model include the following:

- Depth to groundwater is sufficient such that it does not influence infiltration rates.
- Input variable values remain constant for storm events of different magnitudes.

The governing equations of the Loss Model relate to the underlying concept that the maximum potential rate of precipitation loss, f_c, is constant throughout an event. Thus, if p_t is the average precipitation depth during a time interval to t+dt, the excess, pe_t, during the interval is given by:

$$pe_t \equiv \left\{ \begin{matrix} p_t - f_c \ \ if \ \ p_t \geq f_c \\ 0 \qquad otherwise \end{matrix} \right\}$$

An initial loss, I_a, is added to the model to represent interception and depression storage. Interception storage is a consequence of absorption by surface cover. Depression storage is a result of depressions in the watershed; water in these depressions is stored and eventually infiltrates or evaporates. This loss occurs prior to the onset of runoff.

Until the accumulated precipitation amount on the pervious area exceeds the initial loss volume, no runoff occurs. Thus the excess is given by:

$$pe_t \equiv \begin{Bmatrix} 0 & if \sum p_i \le Ia \\ p_t - f_c & if \sum p_i \ge Ia \text{ and } p_t \ge f_c \\ 0 & if \sum p_i \ge Ia \text{ and } p_t \le f_c \end{Bmatrix}$$

Transform Model

The transform model generates the discharge at a given point in the watershed based on the runoff calculated in the Loss Model. The Clark Unit Hydrograph was selected for this subroutine. Input parameters for this model include time of concentration (hours) and a storage coefficient (hours). Time of concentration within each subbasin was calculated using topographic data and stream length data. The storage coefficient represents the time over which the discharge is distributed for a given point in the watershed. The initial storage coefficient value was assigned based on research which demonstrated that a constant ratio relationship between storage coefficient and time of concentration exists at regional levels (USGS 2000). This ratio was altered during the calibration process as described in Section 3.1.5. A single ratio (R) of storage coefficient to time of concentration value was used for the entire watershed. Governing equations include the following, where R is the ratio, S is the storage coefficient, and T_c is the time of concentration:

$$R \equiv \frac{S}{T_c + S}$$

Assumptions for the Transform model include the following:

- The ratio between storage coefficient and time of concentration is constant across a region.
- The Lockwoods Folly River watershed is a single region.

For the governing equations, the Clark method requires three parameters to calculate a unit hydrograph: T^c, the time of concentration for the basin, R, a storage coefficient, and a time-area curve. A time-area curve defines the cumulative area of the watershed contributing runoff to the subbasin outlet as a function of time (expressed as a proportion of T^c).

The dimensionless time area curve is derived by:

AI =	1.414 *T* ^1.5	for 0 <= *T* < 0.5
1 – *AI* =	1.414 (1 – *T*) ^1.5	for 0.5 < *T* <1

where:

A*I* = cumulative area as a fraction of total subbasin area and

T = fraction of time of concentration.

The ordinates of the time-area curve are converted to volume of runoff per second for unit excess and interpolated to the given time interval. The resulting translation hydrograph is then routed through a linear reservoir to simulate the storage effects of the basin; and the resulting unit hydrograph for instantaneous excess is averaged to produce the hydrograph for unit excess occurring in the given time interval.

The linear reservoir routing is accomplished using the general equation:

$Q(2) = CA \times I \times CB \times Q(1)$

The routing coefficients are calculated from:

$CA = \mathit{Delta}\ T / (R + 0.5 \times \mathit{Delta}\ T)$

$CB = 1 - CA$

$Qungr = 0.5\ [Q(1) + Q(2)]$

where:

$Q(2)$ = instantaneous flow at end of period,

$Q(1)$ = instantaneous flow at the beginning of period,

I = ordinate of the translation hydrograph,

Delta T = computation time interval in hours (also duration of unit excess),

R = basin storage factor in hours, and

Qungr = the unit hydrograph ordinate at end of computation interval.

The computation of unit hydrograph ordinates is terminated when its volume exceeds 0.995 inch (mm) or 150 ordinates, whichever occurs first.

Baseflow

There are several possible methods for modeling baseflow within HEC-HMS. For this watershed model, a constant monthly baseflow was estimated based on observed data from discharge gages installed in the watershed (Section 3.1.5) versus relative drainage areas. Monthly baseflow values for each subbasin are presented in Table 4. Assumptions for the Baseflow Model include the following:

- Baseflow remains constant throughout a given month.
- Baseflow is related to drainage area for any given point in the watershed.
- Baseflow is relatively constant from year to year.

3.1.3 Final Discharge Calculation (the Routing Model)

To calculate the discharge from the entire watershed entering into the estuary, flow from each subbasin was extracted from the HEC-HMS model and brought into Excel. Routing from each subbasin to the estuary was then derived based on flood wave velocity and lag time. Average flood wave velocities for each subbasin were estimated using field reconnaissance and data from the discharge gage. Flood wave velocities were subsequently used to calculate lag time for each subbasin. The final discharge to the estuary was then calculated as a function of each subbasin's lag time and modeled discharge at any given time step.

Assumptions for the Final Discharge Calculation (Routing Model) include the following:

- Lag time remains constant for a given subbasin across various discharge magnitudes.
- Flood wave velocity is not influenced by tidal effects.

Governing equations include the following:

$$Lagtime \equiv \frac{StreamLength}{Velocity}$$

Table 3. Watershed hydrology input parameters by subbasin

Subbasin	Loss Model				Transform Model		Lag Time Subbasin to Estuary (hr)
	Initial Deficit (in)	Maximum Storage (in)	Constant Rate (in/hr)	Impervious %	Time of Concentration (hr)	Storage Coefficient (hr)	
Subbasin-1	0.248	0.4950	0.671	2.7	12.22	51.9	47
Subbasin-2	0.31	0.6200	0.813	2.9	9.56	40.6	47
Subbasin-3	0.353	0.7060	0.896	3.5	6.65	28.3	59
Subbasin-4	0.349	0.6980	0.889	3.3	5.86	24.9	53
Subbasin-5	0.404	0.8090	0.985	4.4	8.24	35.0	39
Subbasin-6	0.289	0.5780	0.768	3.6	13.31	56.5	40
Subbasin-7	0.286	0.5730	0.762	6.6	12.29	52.2	40
Subbasin-8	0.274	0.5480	0.734	7.6	5.77	24.5	30
Subbasin-9	0.248	0.4960	0.672	8.0	6.98	29.7	23
Subbasin-10	0.333	0.6660	0.859	7.0	7.43	31.6	12
Subbasin-11	0.363	0.7260	0.915	4.8	2.03	8.6	20
Subbasin-12	0.337	0.6730	0.866	9.8	5.13	21.8	15
Subbasin-13	0.479	0.9580	1.095	7.1	3.31	14.0	4
Subbasin-14	0.315	0.6300	0.823	11.2	8.99	38.2	4
Subbasin-15	0.386	0.7710	0.954	3.3	10.67	45.3	5
Subbasin-16	0.319	0.6380	0.831	4.1	5.54	23.5	38
Subbasin-17	0.25	0.5010	0.678	3.1	7.34	31.2	41
Subbasin-18	0.327	0.6530	0.846	3.3	10.26	43.6	61
Subbasin-19	0.39	0.7790	0.961	3.5	9.39	39.9	61
Subbasin-20	0.256	0.5130	0.693	4.5	10.33	43.9	51
Subbasin-21	0.216	0.4320	0.589	5.3	14.06	59.7	51
Subbasin-22	0.26	0.5200	0.701	5.9	11.23	47.7	44
Subbasin-23	0.213	0.4250	0.579	2.5	15.71	66.7	61
Subbasin-24	0.217	0.4340	0.591	2.0	9.32	39.6	61
Subbasin-25	0.236	0.4710	0.641	2.2	7.15	30.3	61
Subbasin-26	0.249	0.4970	0.674	6.3	11.22	47.6	55
Subbasin-27	0.309	0.6190	0.811	9.3	2.55	10.8	0

Table 4. Estimated constant monthly baseflows (cfs) by subbasin

	January	February	March	April	May	June	July	August	September	October	November	December
Subbasin-1	3.6588	3.6588	3.8051	3.4392	3.0734	2.3416	1.9757	1.6099	1.3172	1.244	2.1953	2.927
Subbasin-2	2.5364	2.5364	2.6379	2.3842	2.1306	1.6233	1.3697	1.116	0.91311	0.86238	1.5219	2.0291
Subbasin-3	2.2499	2.2499	2.3399	2.1149	1.8899	1.4399	1.215	0.98996	0.80997	0.76497	1.35	1.7999
Subbasin-4	1.3528	1.3528	1.4069	1.2716	1.1363	0.86579	0.73051	0.59523	0.48701	0.45995	0.81168	1.0822
Subbasin-5	2.0137	2.0137	2.0943	1.8929	1.6915	1.2888	1.0874	0.88603	0.72494	0.68466	1.2082	1.611
Subbasin-6	2.7078	2.7078	2.8161	2.5453	2.2745	1.733	1.4622	1.1914	0.97481	0.92065	1.6247	2.1662
Subbasin-7	2.0671	2.0671	2.1498	1.9431	1.7364	1.323	1.1162	0.90954	0.74417	0.70282	1.2403	1.6537
Subbasin-8	2.9533	2.9533	3.0714	2.7761	2.4808	1.8901	1.5948	1.2995	1.0632	1.0041	1.772	2.3626
Subbasin-9	2.424	2.424	2.521	2.2786	2.0362	1.5514	1.309	1.0666	0.87265	0.82417	1.4544	1.9392
Subbasin-10	2.1557	2.1557	2.2419	2.0263	1.8108	1.3796	1.1641	0.9485	0.77605	0.73293	1.2934	1.7245
Subbasin-11	1.1646	1.1646	1.2112	1.0947	0.97827	0.74535	0.62889	0.51243	0.41926	0.39596	0.69876	0.93168
Subbasin-12	0.99158	0.99158	1.0312	0.93209	0.83293	0.63461	0.53546	0.4363	0.35697	0.33714	0.59495	0.79327
Subbasin-13	0.64082	0.64082	0.66645	0.60237	0.53829	0.41012	0.34604	0.28196	0.23069	0.21788	0.38449	0.51265
Subbasin-14	3.1402	3.1402	3.2658	2.9518	2.6378	2.0097	1.6957	1.3817	1.1305	1.0677	1.8841	2.5122
Subbasin-15	5.1004	5.1004	5.3044	4.7944	4.2844	3.2643	2.7542	2.2442	1.8362	1.7341	3.0603	4.0803
Subbasin-16	2.2205	2.2205	2.3093	2.0872	1.8652	1.4211	1.1991	0.97701	0.79937	0.75496	1.3323	1.7764
Subbasin-17	2.107	2.107	2.1913	1.9806	1.7699	1.3485	1.1378	0.9271	0.75853	0.71639	1.2642	1.6856
Subbasin-18	4.2214	4.2214	4.3902	3.9681	3.546	2.7017	2.2795	1.8574	1.5197	1.4353	2.5328	3.3771
Subbasin-19	2.5036	2.5036	2.6038	2.3534	2.103	1.6023	1.352	1.1016	0.9013	0.85123	1.5022	2.0029
Subbasin-20	2.9189	2.9189	3.0357	2.7438	2.4519	1.8681	1.5762	1.2843	1.0508	0.99244	1.7514	2.3352
Subbasin-21	5.0782	5.0782	5.2813	4.7735	4.2657	3.25	2.7422	2.2344	1.8281	1.7266	3.0469	4.0626
Subbasin-22	3.9708	3.9708	4.1297	3.7326	3.3355	2.5413	2.1443	1.7472	1.4295	1.3501	2.3825	3.1767
Subbasin-23	1.556	1.556	1.6183	1.4627	1.3071	0.99587	0.84026	0.68466	0.56018	0.52906	0.93363	1.2448
Subbasin-24	1.8168	1.8168	1.8894	1.7078	1.5261	1.1627	0.98105	0.79938	0.65403	0.6177	1.0901	1.4534
Subbasin-25	1.3483	1.3483	1.4022	1.2674	1.1325	0.86288	0.72806	0.59323	0.48537	0.45841	0.80895	1.0786
Subbasin-26	3.2708	3.2708	3.4016	3.0745	2.7475	2.0933	1.7662	1.4391	1.1775	1.1121	1.9625	2.6166
Subbasin-27	2.6124	2.6124	2.7169	2.4556	2.1944	1.6719	1.4107	1.1495	0.94046	0.88821	1.5674	2.0899

3.1.4 Precipitation Data

One of the major inputs for the hydrology model is precipitation. The nature of rainfall in the Lockwoods Folly Watershed is highly non-uniform. As such, rainfall data from three separate precipitation gages was collected in order to model the variability in flow across the watershed.

The first precipitation gage is the Nature Conservancy RAWS station (NNAC), located within the northern portion of the watershed, along Green Swamp Road. Comprehensive precipitation records for other rain gages within the watershed were not available. As such, the other two stations from which precipitation data was gathered are located outside of the watershed. The Sunny Point RAWS station (NSUN) is located in Kure Beach, NC while the Grand Strand Airport Station (KCRE) is located in North Myrtle Beach, SC. Precipitation data from January 1, 2004 until September 30, 2009 was retrieved from the State Climate Office of North Carolina for the three gages (NC CRONOS 2009). It should be noted that although two of the precipitation gages are not located directly within the watershed, their data demonstrated that occurrence of rainfall events at these stations matched well with events detected at the NNAC station, i.e. large storms of long duration were found to occur concurrently at all three gages. Average monthly precipitation during the modeling period for the three gages is presented in Figure 4.

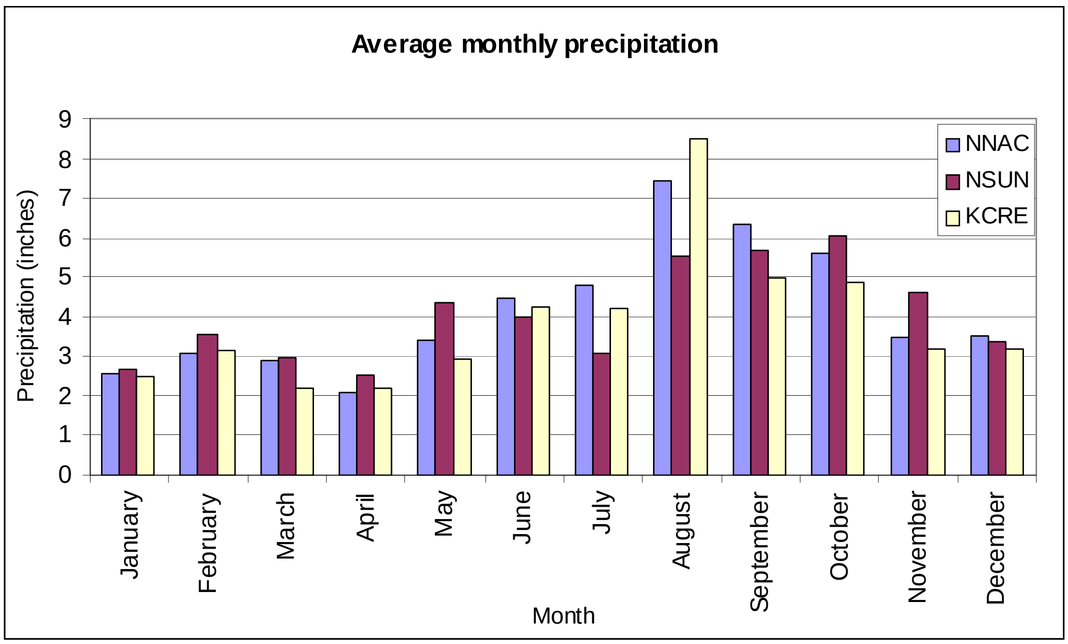


Figure 4. Average monthly precipitation (2004-2009) for the three precipitation gages

3.1.5 Hydrology Model Calibration

Stream height gages were installed in the watershed specifically for this TMDL project in order to calibrate the hydrology model. The most complete record was collected at the gage installed off of Old Ocean Hwy at monitoring station LFR01 (see Figure 3) from August 2008 to July 2009. Stream height was translated into a discharge record based on the rating curve calculated for the site from data collected on cross-sectional area and flow. The rating curve for the gage is presented in Figure 5. The resulting discharge record was used to calibrate and validate the hydrology model.

The hydrology model was calibrated by adjusting the range of values used for the variables within the Deficit and Constant Rate Model. As described in Section 3.1.2, a value of each input variable was assigned to each subbasin based on the relative position of their curve number along the watershed curve number range (e.g. if a subbasin's curve number was in the 10th percentile of the curve number range across the watershed, a value for the input variable was assigned such that it was the 10th percentile value of the variable's range). The range of values for each input variable was adjusted during the calibration procedure to calibrate stormflow volumes. Additionally, the storage coefficient was adjusted during the calibration procedure. Essentially the 'regional' relationship/ratio between storage coefficient and time of concentration (see the Transform Model in Section 3.1.2) was derived by altering the storage coefficient until the shape of the unit hydrograph for modeled data reasonably approximated the observed unit hydrograph at the watershed stream gage.

Calibration criteria for the hydrology model involved reasonable matching between the modeled discharge and observed discharge at the stream height gage. 'Reasonable' matching was considered to consist of accurately approximating peak discharges as well as the total volume of water passing through the measurement point across the calibration period. Calibration was conducted from October 10, 2008 to February 10, 2009. The calibrated model was then validated against observed discharge data from February 11 to July 1, 2009. Figures 6 & 7 plot modeled and observed discharge at LFR01 where the stream gage was located, for the calibration and validation periods. The model was also calibrated such that the quantity of runoff between observed and modeled results were similar. This comparison was made at the seasonal level and for the calibration period as a whole (Table 5). Additionally, simulated total discharge, adjusted using the drainage area ratio method, was compared to discharge from a USGS gage at a nearby watershed to demonstrate that model results were within the same range of values. This comparison was made over both the calibration and validation period (Table 6). The USGS gage is located on Hood Creek near Leland, North Carolina, with a drainage area of 21.6 sq mi (USGS 02105900). The drainage area upstream of the stream gage on the Lockwoods Folly River is 16.0 sq mi.

Table 5. Comparison of observed and modeled runoff

	Modeled Runoff (inches)	Observed Runoff (inches)	Percent Difference
Fall 2008	1.53	1.20	27%
Winter 2008-2009	1.90	2.09	-9%
Spring 2009	2.83	2.50	13%
Total	6.26	5.80	8%

Table 6. Comparison of total seasonal discharge relative to drainage area

	USGS Gage Hood Creek (inches)	Model Calibration Site (Old Ocean Hwy) (inches)	Discharge to Lockwoods Folly Estuary (inches)
Fall 2008	2.50	1.69	1.69
Winter 2008-2009	1.95	1.78	1.86
Spring 2009	1.74	2.59	2.24
Total	6.19	6.06	5.79

*Values in table are total seasonal discharge (cubic feet) divided by drainage area (square feet) and converted from feet to inches.

Percent difference criteria varies between the seasonal and annual scale. The criteria according to Lumb et. al (1994) are presented in Table 7. These criteria have been met by the calibrated hydrology model. There is high variability in rainfall in the watershed which leads to greater differences between observed and modeled runoff than might be observed in watershed with more uniform rainfall distribution patterns. Additionally, the differences between modeled and observed runoff were enhanced by two instances of extreme peak flows, which are described below.

Table 7. Percent difference criteria for modeled and observed discharge

Prediction Error	Percent Difference Criteria
Error in total volume	±10%
Error in volume of 50% lowest flows	±10%
Error in volume of 10% highest flows	±15%
Seasonal volume error	±30%

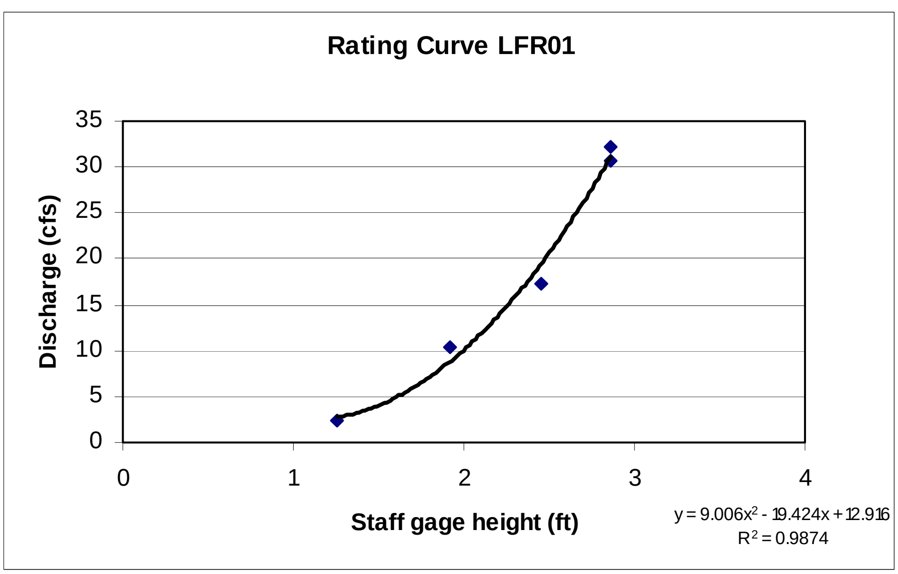


Figure 5. Rating curve for stream discharge at LFR01

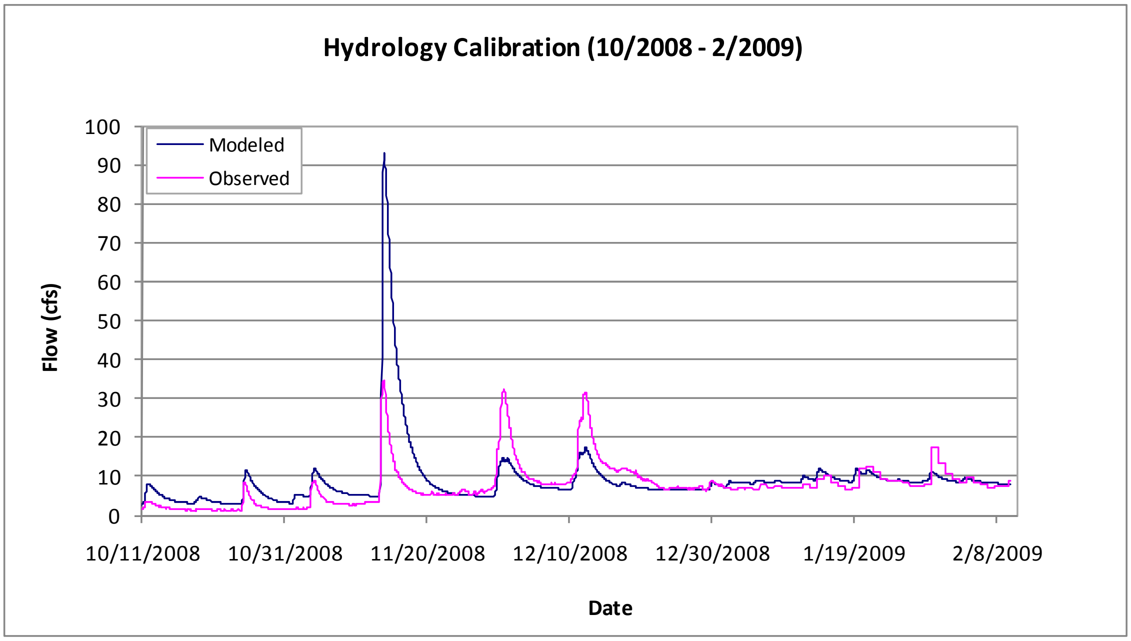


Figure 6. Watershed hydrology model calibration (October 2008 to February 2009)

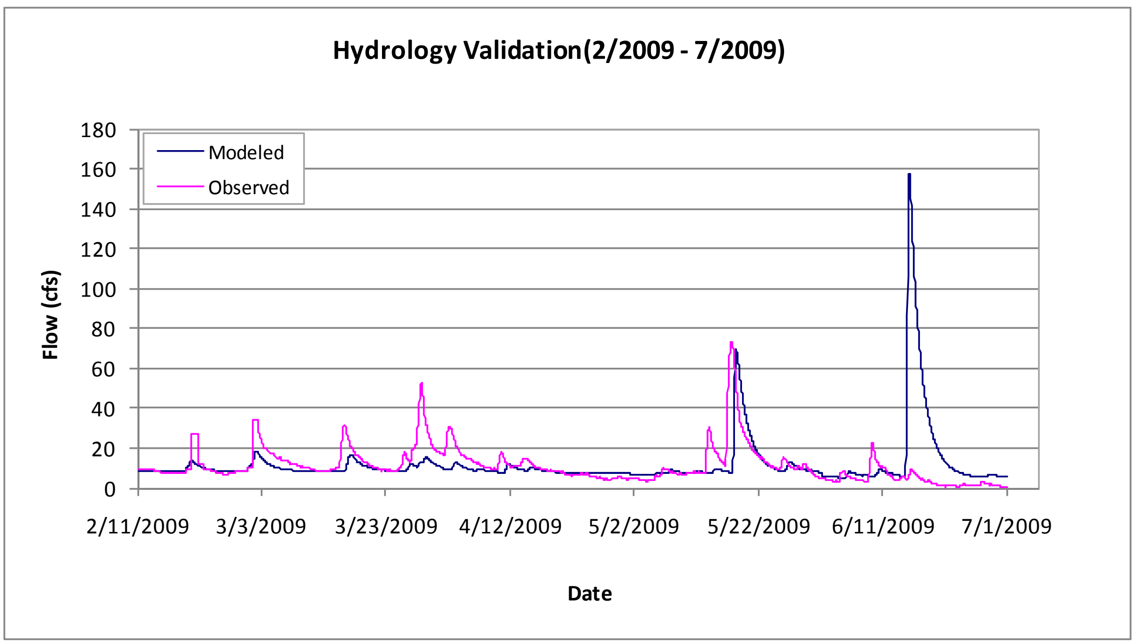


Figure 7. Watershed hydrology model validation (February 2009 to July 2009).

During the model calibration/validation periods, the model showed significant differences from the observed data during two events. The first event occurred during the calibration period on November 13, 2008. The closest precipitation gage (NNAC) to the stream gage was used for the precipitation input to subbasins upstream of the stream gage. The NNAC precipitation gage is located approximately 6 miles west of the stream gage. The NNAC gage showed a total rainfall of 1.08 inches on November 13 with 1.05 inches occurring in one hour. The model over predicted flow during this event by approximately 250%. Analysis of this event and the remainder of the record indicate that the model may over predict discharge for high rainfall intensities. However, the model did accurately approximate peak flow values and discharge volume for a storm occurring on May 17, 2009. This storm consisted of 2.28 inches of rainfall with a peak intensity of 0.83 inches in one hour. In general, the model more accurately predicts flows for storms with intensities less than 1 inch per hour. Storm events with intensities greater than 1 inch per hour happen rarely in this area. Reviewing the rainfall record for the watershed, such events occur approximately five times a year.

The second event in which a significant difference between the model and observed data occurred took place during the validation period on June 14, 2009. The NNAC precipitation gage recorded a total rainfall of 1.51 inches, with 1.46 inches occurring in the first hour of rainfall. With only a slight increase in discharge recorded at the stream gage, this storm event was likely a summer thunderstorm and high intensity rainfall did not occur in the watershed upstream of the stream gage.

3.2 Watershed Loading Model

In order to calculate fecal coliform loads from the watershed to the estuary, the Rational Method was used to compute the fraction of stormflow coming from each land use type within each subbasin. The governing equation for the Rational Method is:

$$Q_{LU} \equiv \frac{Q_{tot} C_{LU} A_{LU}}{\sum C_{LUi} A_{LUi}}$$

Where, Q_{LU} is discharge (cfs) from each land use within the subbasin, Q_{tot} is the total discharge from the subbasin, C_{LU} is the rational method runoff coefficient for each land use type, A_{LU} is the area of each land use type. A constant monthly baseflow for each subbasin was assumed, as described in Section 3.1.2. The baseflow associated with each land use within each subbasin was calculated based on the following:

$$Q_b \equiv \frac{Q_{tot}\left(\frac{A_{LU}}{C_{LU}}\right)}{\left(\frac{A_{tot}}{C_{avg}}\right)}$$

Where, Q_b is the baseflow discharge, Q_{tot} is the total discharge from the subbasin, A_{LU} and C_{LU} are the same as above, A_{tot} is the total subbasin area, and C_{avg} is the average rational method runoff coefficient for the subbasin.

After flow rates from each land use type were determined in Excel, fecal coliform loads were calculated using EMC (event mean concentration) values for each land use category from pertinent research. These loads were further modified to account for the "first flush" effect by applying a multiplying factor early in storms and a dividing factor as flows decrease. As discharge values were modeled to increase by a certain percentage from the previous time step, the multiplying factor was applied. Otherwise, a dividing factor was applied to the fecal coliform concentration. The percent increase, multiplying, and dividing factors were adjusted during the Tidal Prism Water Quality Model (TPWQM) calibration (Section 4.3). The flows and fecal coliform loads from each land use type in the subbasin were summed and routed to the estuary on the basis of the lag time (routing) method (Section 3.1.3).

A decay rate of fecal coliform was also incorporated into the watershed loading model. Fecal coliform decay rate is a highly variable parameter affected by salinity, temperature, turbidity, and light exposure. Decay rates in freshwater are noted to be significantly lower in freshwater than saltwater (Eleria 2005). In freshwater, the effective die-off of fecal coliform has been shown to vary from 40 to 70% per day (Elshorbagy & Ormsbee 2005, Yagow et al. 2001). A system with a higher decay rate has a higher assimilative capacity than a system with a lower decay rate. A decay rate of 30% per day was selected for the watershed model as a conservative estimate. The lag times for the subbasins in the watershed vary from 0.17 to 2.5 days.

3.2.1 EMC Value Selection

EMCs represent the average concentration of a pollutant in stormwater runoff and are usually reported in mass per unit volume (mg/l). Many factors may affect EMC values including land use, annual rainfall, percent imperviousness, season, watershed size, and storm event size. Regional differences in EMCs are largely determined by the amount and frequency of rainfall. Pitt et al. (2005) reporting on findings from the National Stormwater Quality Database (NSQD) found that residential areas located in the wettest parts of the country such as the Southeast appear to have lower EMCs for many stormwater pollutants. The result most likely stems from the reduced time between rainfall events allowing for less accumulation of pollutants on impervious surfaces which then become available for washoff during the next storm event. Regression analyses by Driver (1988) and Maestre and Pitt (2005) have supported similar conclusions. Driver (1988) found that annual rainfall depth was the best overall predictor of stormwater EMCs.

The relative impact of land use and imperviousness is less clear. The National Urban Runoff Program (NURP) findings showed no significant differences in urban runoff concentrations as a function of common urban land uses (USEPA, 1983). Maestre and Pitt (2005) conducted a statistical analysis of data from the NSQD focusing on EPA Rain Zone 2, which includes North Carolina, Virginia, Maryland, Tennessee, Kentucky, and West Virginia. No significant regression relationship (negative) was found for fecal coliform with percent imperviousness in residential land use categories. A lack of data in the study prevented a full analysis for commercial and industrial land uses.

Several studies have suggested a positive linear relationship between fecal coliform concentrations and impervious cover (Young and Thackston, 1999; Mallin et al., 2000, Tufford and Marshall, 2002). Schueler suggested an indirect relationship between bacteria and imperviousness (CWP 2003). Pitt found that median concentrations of fecal coliform were higher in residential and open space categories compared to commercial and industrial land uses (Pitt et al., 2005). The study also found that the first flush phenomenon is more prevalent in high impervious land uses of commercial development.

The stormflow EMC values selected for the watershed loading model are derived based on a number of literature sources (Table 8). Final fecal coliform EMC values for the model were based on Zone 2 data in Pitt et al. (2005) and EPA (2001).

Table 8. Literature review of fecal coliform EMC values (cfu/100ml)

Source	Location	Low Density Residential	Medium Density Residential	High Density Residential	Office and Light Industrial	Commercial and Heavy Industrial	Road	Forest	Golf and Managed Open Space	Pasture	Row Crop
Pitt et al. (2005)	US	8345	8345	8345	2500	4300					
USEPA - NURP (1983)	US	101	101	101		21000					
Pitt et al. (2005)	EPA Rain Zone 2	1600	1600	1600	1377	2400					
Pitt et al. (2005)	EPA Rain Zone 3	2800	2800	2800	210	2000					
Tetra Tech (2004)[1]	NC					1540	1540	252	100	12500	414
Young and Thackston (1999)[2, 3]	TN	12182									
USEPA (2001)[1]	GA	8700	8700	8700	1400	1850	1400	500	500		
Newell et al. (1992)[1]	TX	22000	22000	22000	22000	22000		1600	2500	2500	2500
Baird et al. (1996)	TX	20000	20000	20000	9700	6900	53000				
Bales et al. (1999)	NC		29000		27500	14600					
Selected Value		**5150**	**5150**	**5150**	**1389**	**2125**	**1400**	**500**	**500**	**1000**	**500**

All values are medians unless otherwise noted.
[1] Literature review
[2] Mean value
[3] Average of winter and summer storms

3.2.2 Watershed Loading Model Calibration

Fecal coliform loads to the estuary were calibrated against observed data collected by the North Carolina Shellfish Sanitation Program (DEHSS). The calibration was performed by applying a multiplier and divisors to the EMC values outlined in Table 8. Bacteria is a highly variable stormwater pollutant, with concentrations varying by factors of 10 to 100 during a single storm event (Zariello et al. 2002; CWP 1999). In order to account for the varying concentration of fecal coliform over individual storm events in the watershed loading model, the series of factors were applied to the EMC values for fecal coliform. A multiplier was applied at the beginning of storm to account for the 'first flush' effect, followed by two subsequent divisors applied toward the end of the storm to account for decreasing concentrations at the end of storm events. The multiplier and divisors were adjusted during the calibration of the receiving-water TPWQM in order to adjust loads to the estuary such that modeled fecal coliform concentrations were representative of observed fecal coliform concentrations in the estuary. A final multiplier of 82 and final divisors of 100 and 20000 were selected during the calibration. The factors were applied in the following manner:

If $Q_t > 1.07 * Q_{t-1}$	$FC_{count} *82$
If $Q_t < [AVG(Q_{t-1} \rightarrow Q_{t-12})]*1.04$	$FC_{count} /20000$
If $Q_t > [AVG(Q_{t-1} \rightarrow Q_{t-12})]*1.04$ AND $Q_t < 1.07 * Q_{t-1}$	$FC_{count} /100$

A schematic of a unit hydrograph and the relative time-frame over which these factors were applied is depicted in Figure 8.

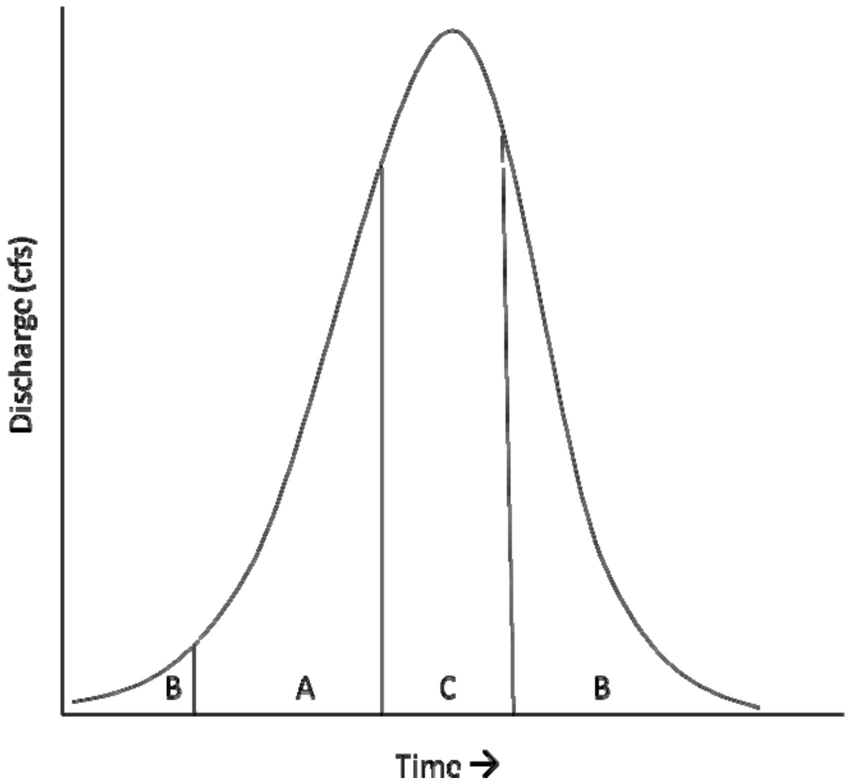


Figure 8. Schematic of a unit hydrograph and the relative time period of multiplier and divisor application to EMC values in the watershed loading model.

The intent was to show increased loading at the beginning of a storm using the multiplier, then transition to the divisor of 100 after the first flush, and towards the end of the storm transition to the second divisor of 20000, which would further decrease loads. Multiple calibration runs were performed varying these timestep, multiplying, and dividing factors. It should be noted that the application of the divisor in Line B (20000) was applied at the tail end of storms and during baseflow to simulate an effective concentration of nearly 0 for fecal coliform during these conditions. The relative time over which each of the multiplier or divisors were applied was dependent upon the intensity of rainfall during the preceding 12 hours.

To verify that the loads generated by the application of these factors was reasonable, the existing daily load to the Lockwoods Folly estuary was compared to fecal coliform loads calculated for other coastal watersheds in North Carolina, relative to area. The existing load for the Lockwoods Folly estuary was calculated to be 6.91E+12 counts per day. Relative to area, the load is 5.04E+10 counts per day per square mile. Loads into Jarret Bay, NC were calculated to be 7.82E+10 counts per day per square mile (NCDENR 2007) and loads in the White Oak embayment were calculated to be 4.2E+11 counts per day per square mile (NCDENR 2009). It should be noted that the White Oak embayment watershed is more developed than the Lockwoods, accounting for a greater loading per square mile.

3.2.3 Watershed Loading Model Assumptions

Several assumptions were made for the watershed fecal coliform loading model and include the following:

- The septic contribution to the watershed is captured in the baseflow and stormflow EMC values.
- Assumed a decay rate of 30% per day in freshwater.

3.3 Watershed Model Limitations and Sources of Uncertainty

As with any model, this modeling approach is subject to limitations and sources of uncertainty. One limitation of the model pertains to the time step. The model was performed on an hourly time step, and as such it is not sensitive to changes in rainfall intensities over time steps of less than an hour. Another limitation of the model is its inability to account for increased fecal coliform accumulation on land surfaces with increased durations between rainfall events. A third limitation is the model's inability to account for antecedent soil moisture conditions. However, over a five-year modeling period, the effect of antecedent conditions is negligible.

There are also several sources of uncertainty in the model. The most significant source of uncertainty is the precipitation data. Precipitation data gathered by volunteers for the NCCF demonstrate the variability in rainfall intensity across the watershed. For example, values were found to range from 1 to 3.5 inches for a single storm on September 26, 2008. Only one complete data record was available for a precipitation gage within the watershed, and data from 2 gages outside of the watershed were included in order to account for this variability in precipitation across the watershed. Additionally, the lack of a precipitation gage near the stream gage presents a source of uncertainty. With no precipitation gage nearby, model results predict stormflows where the gage shows none and vice versa. For example, as seen in Figure 7 the model predicted a large storm event on June 14, 2009, though none was observed at the stream gage, and similarly on November 2008 as seen in Figure 6. Over 1.5 inches of precipitation was recorded at the NNAC gage on that date (an input to the model), but given the variability of precipitation in the watershed, it is possible that a storm event did not occur in the drainage area of the stream gage. The resulting discrepancies between modeled and observed flow are discussed previously in Section 3.1.5.

4.0 Tidal Prisms Water Quality Model

The receiving-water quality model used was the Tidal Prism Water Quality Model (TPWQM) developed by Kuo and Park (1994). The tidal prism model simulates physical transport processes in terms of the concept of tidal flushing. Detailed documentation of the model theory and input files is provided in *A PC-Based Tidal Prism Water Quality Model for Small Coastal Basins and Tidal Creeks* (Kuo & Park 1994). Steps in developing the TPWQM for the Lockwoods Folly River included segmenting the estuary, creating a linkage between the watershed loading model and the estuary receiving-water quality model through VBA scripting, calibrating the model to water quality data, and calculating the TMDL.

4.1 Segmentation

The TPWQM segmentation scheme requires data on the geometry and tidal range of the estuary. Bathymetry data for the Lockwoods Folly channel through the estuary was obtained from the US Army Corps of Engineers. In addition, field bathymetry data points were collected by the NC Coastal Federation throughout the estuary. An inverse-distance-weighted interpolation of the bathymetry data points was generated in GIS to represent a Mean Tide Level depth surface for the estuary. Tidal range data was collected from the NOAA Tide monitoring station at the Lockwoods Folly Inlet. The mean tidal range was reported to be 4.2 feet (NOAA, 2009). GIS techniques were used to calculate low tide volume and intertidal volume at any given point along the estuary from the interpolated depth and tidal range data. These volumes along with freshwater flows were used to develop the model segmentation as described below.

The first transect of the segmentation is situated across the mouth of the estuary. The location of the second transect is selected such that a water particle will move from the first to the second transect over the flood tide. Therefore, the intertidal volume (i.e. the tidal prism) upriver of the second transect must be large enough to accommodate the low tide volume in the second segment and the volume of freshwater flows upriver of the second segment over flood tide. The theory and equations of this segmentation scheme are described in detail in Kuo & Park (1994).

A segmentation program (Geo-TPM) was developed by the Virginia Institute of Marine Science for a separate tidal prism model developed for permitting purposes. This program does not incorporate the contribution of freshwater flows to an estuary. The freshwater volume to the Lockwoods Folly estuary was found to be negligible in comparison to the tidal volume. Therefore, the Geo-TPM program was used in conjunction with the tidal volume data to calculate the segments of the estuary. The segmentation resulted in four segments with the first segment being the seaward boundary. The second, third, and fourth segments move upriver into the estuary. In the TPWQM, all freshwater flows and fecal coliform loads are modeled as entering into the third segment (M0S3) of the estuary via the Lockwoods Folly River. The TPWQM calibration point (Site 7A) is located in Segment M0S2 (Figure 9). The segmentation data is also used to develop the geometry input file of the TPWQM (Appendix B – GEO-HYD.IN).

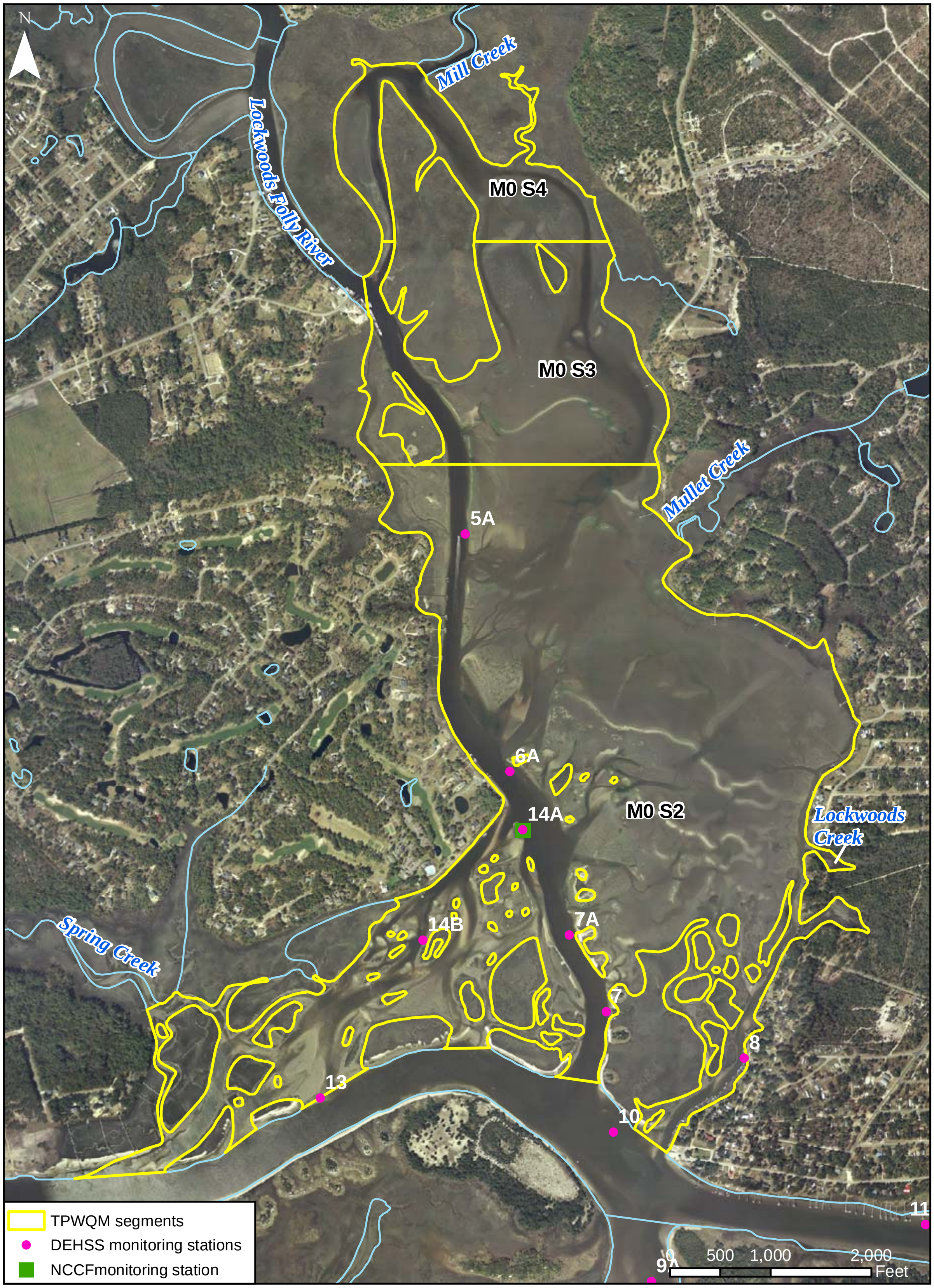


Figure 9. Estuary model segmentation

4.2 Watershed Loading Model – TPWQM Linkage

The TPWQM model utilizes a series of text files which are pulled in by an executable file for the model. Only three text input files were manipulated in modeling fecal coliform in the Lockwoods Folly River with the TPWQM: 1) test_lb.in (the toggle file which indicates which parameters and conditions are utilized); 2) GEO-HYD.IN (includes geometry parameters and the return ratio for each model segment); and 3) CAL-NPS.IN (the file which houses the spatially and temporally varying flow and load values generated from the watershed model). Final files of the test_lb.in and GEO-HYD.in, and an excerpt from the CAL-NPS.IN file are included in Appendix B.

While the first two files can be manipulated easily and directly in a simple text reader program, the CAL-NPS.IN file had to contain four years of flow and fecal coliform load data on a time step of tidal cycles. Therefore, a Visual Basic Script was created to generate an appropriately formatted text file from the final flow and fecal coliform loading generated from the watershed model (Section 3.2 and Appendix A). The VBA script includes three subroutines. The three subroutine scripts are included in Appendix C. The VBA script aggregates hourly flow and loads generated by the watershed loading model up to the tidal cycle for input into the TPWQM.

4.3 TPWQM Model Calibration

Calibration point selection

The TPWQM calibration was conducted based on the comparison of model simulated and observed fecal coliform concentrations in the estuary. Several factors were considered in selecting monitoring sites for the model calibration. These factors included current water quality violations, past water quality violations, robustness of the data record, and location of the site in the estuary. Site 8 is the only monitoring site currently violating water quality standards (as of October 2009). However, this site is located along the shoreline in the southeastern portion of model segment M0S2 in the estuary and is less influenced by tidal mixing than sites located in the center of the estuary. Sites 7 and 7A are centrally located in model segment M0S2 of the estuary (Figure 9). Both sites have the most complete data records of the monitoring sites, including the most extensive conditional monitoring records. While these sites are not currently violating water quality standards they did demonstrate the highest fecal coliform levels prior to the 2007 drought.

Model results for model segment M0S2 were compared to observed data at sites 7A and 8 during the calibration. Site 7A was selected as a calibration point for the TPWQM due to its central location in the estuary and its extensive data record. Additionally, the calibration was optimized by comparing model results to observed data at Site 8 to ensure that the calibrated model accurately represents both past and current water quality violations.

Calibration

The two parameters that can be adjusted within the TPWQM during calibration are the return ratio and the fecal coliform decay rate. The return ratio is the fraction of water leaving the estuary during the ebb tide that will be transported back to the estuary during the next flood tide. The return ratio ranges from 0 to 1. Past studies of the TPWQM have demonstrated that the calculated salinity is relatively insensitive to the value of return ratio between 0.1 to 0.5 and the value of 0.3 works well for small creeks in Virginia (Kuo, et al. 1998). Return ratio was adjusted during model calibration for the Lockwoods Folly estuary. It was found that the Lockwoods Folly estuary is also insensitive to adjustments in return ratio. The final return ratio selected for the Lockwoods Folly TPWQM was 0.3. The first order decay is used in the model to represent the fecal coliform die-off due to temperature, salinity, solar radiation, and loss due to settling and other factors. A system with a higher decay rate has a higher assimilative capacity than a system with a lower decay rate. The value of decay rate varies from 0.7 to 3.0 per day in salt water (Mancini 1978; Thomann and Mueller 1987). A decay rate of 0.7 per day was used for the Lockwoods Folly estuary as a conservative estimate in the TMDL model.

Fecal coliform loads to the estuary were also adjusted during the TPWQM model calibration. The calibration procedure involved adjusting the multiplier and divisor values described in Section 3.2.1 which adjust the fecal coliform concentrations in runoff over a storm event. The final values for the multiplying and dividing factors were selected such that the modeled fecal coliform concentrations in Segment M0S2 of the estuary fell within the range of observed values at Site 7A and Site 8 during the model simulation period. Additionally, it was verified that the model results approximated the observed 30-sample 90th percentile over the 5-year model simulation period . The 90th percentile is a criterion used by DEHSS as a standard for shellfish use ratings. Model results and observed values for Site 7A are presented in Figure 10. The comparison of the model 30-month 90th percentile and Site 7A observed 90th percentile are presented in Figure 11. Note that in Figure 11, each point represents the 90th percentile of the previous 30 months. Therefore, from 2004 to 2009 the first modeled point appears in July of 2006. Figure 12 depicts the comparison of model results to observed fecal coliform levels at Site 8. The comparison of the modeled and Site 8 observed 30-month 90th percentiles is presented in Figure 13.

The observed measurements show the lowest concentration is always 1.7 MPN/100ml. This is due to the laboratory methods used for determining the fecal coliform counts. The model was not able to consistently capture these low concentration events. The model may not have captured these lower baseline values due to the length and shallow geometry of the estuary and an inability to model sufficient tidal flushing. However, the high concentration is more critical for determining the bacteria capacity of the estuary. The 5-year model simulation period demonstrated seasonal variability and captured peak fecal coliform concentrations compared to observed data. Given the long-term simulation results, the overall model performance is satisfactory.

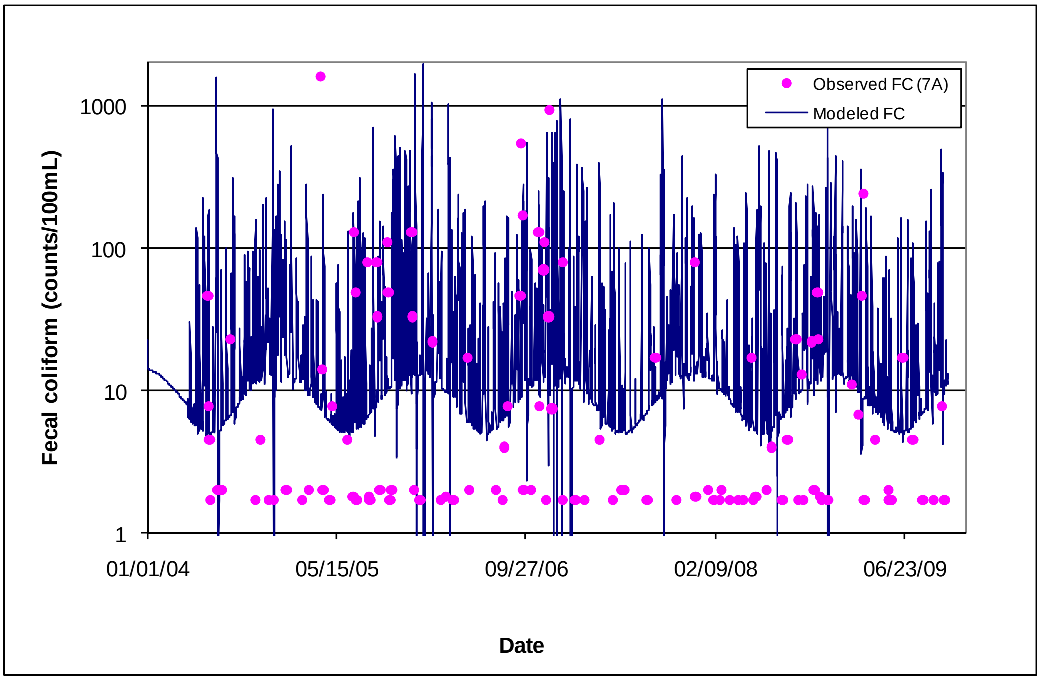


Figure 10. Modeled fecal coliform concentration for model segment M0S2 and observed fecal coliform concentration at Site 7A

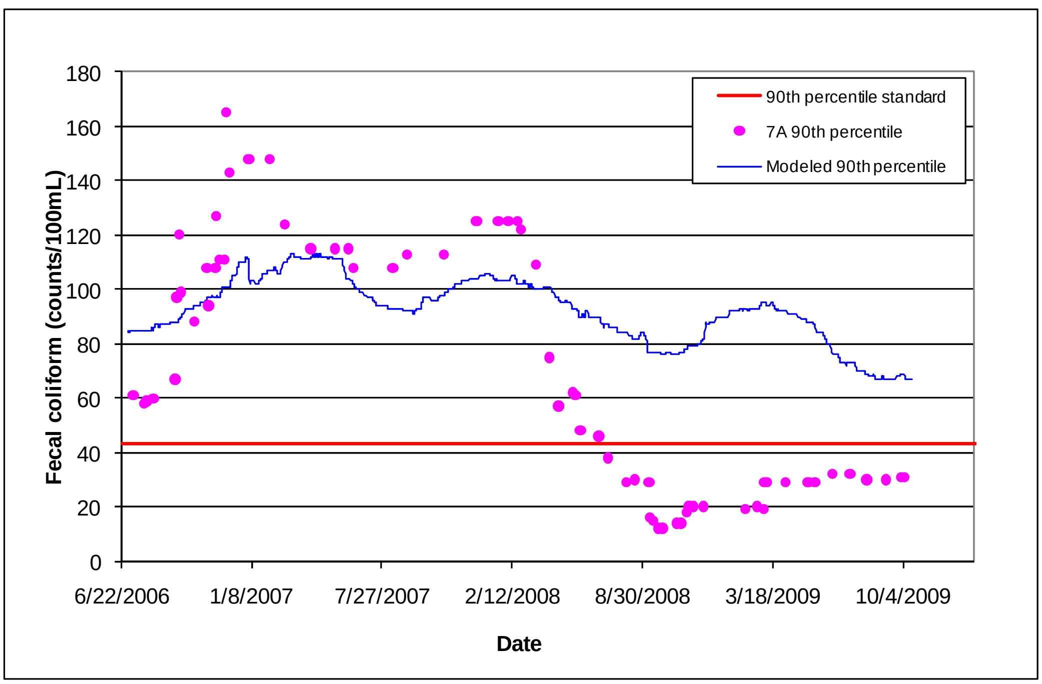


Figure 11. Modeled 90th percentile fecal coliform concentration for model segment M0S2 and observed 90th percentile fecal coliform concentration at Site 7A

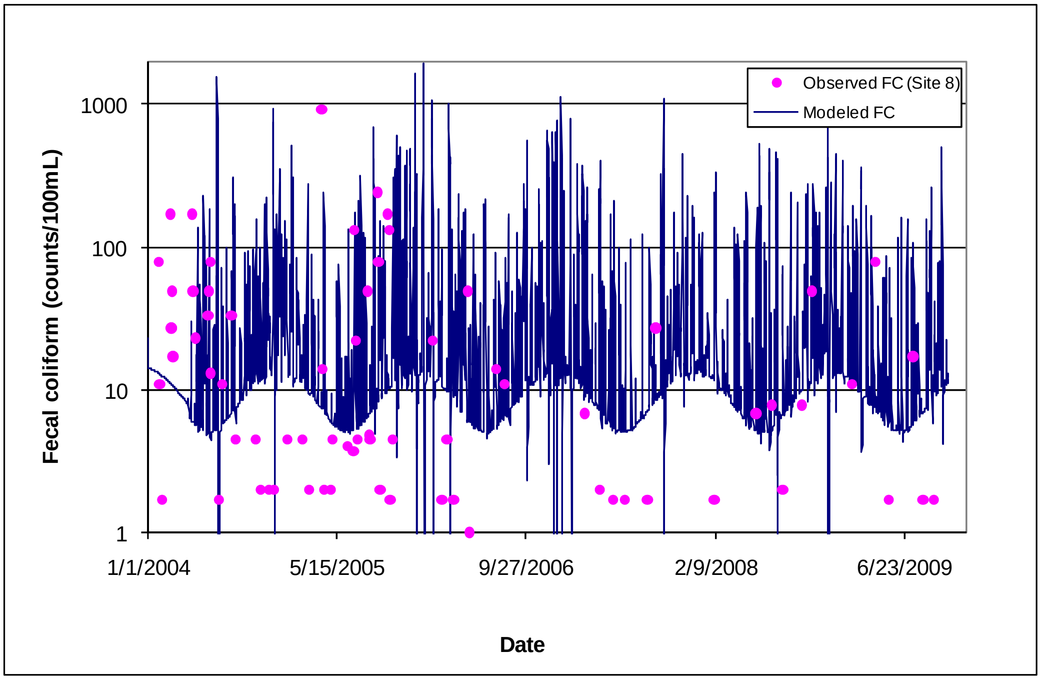


Figure 12. Modeled fecal coliform concentration for model segment M0S2 and observed fecal coliform concentration at Site 8

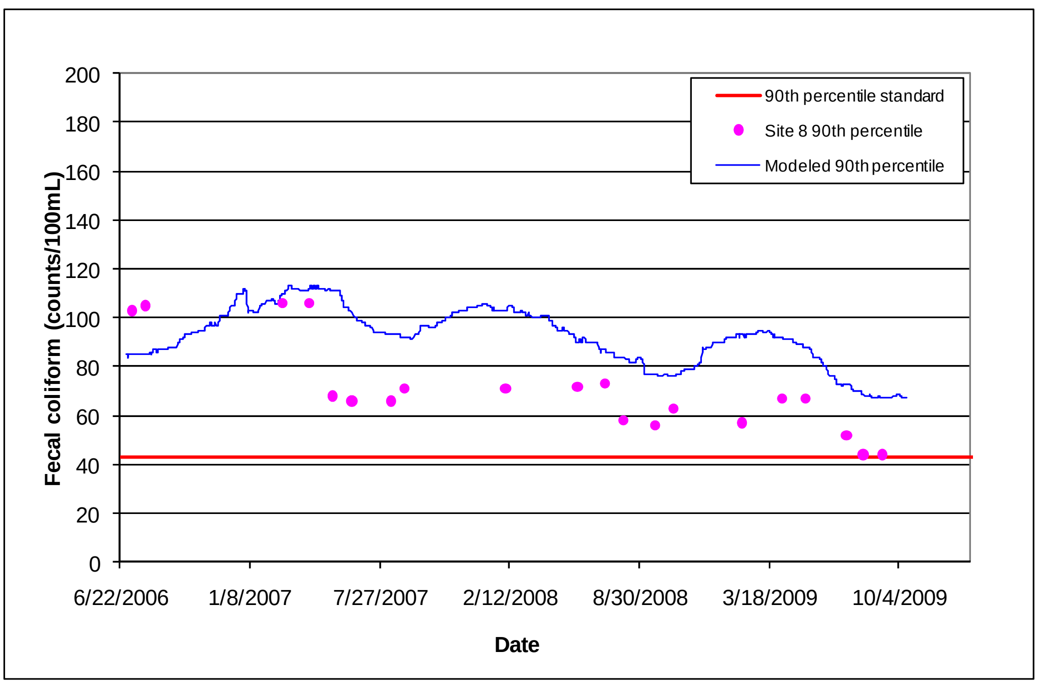


Figure 13. Modeled 90th percentile fecal coliform concentration for model segment M0S2 and observed 90th percentile fecal coliform concentration at Site 8

4.4 TPWQM Model Assumptions

Several assumptions were made in running the tidal prism model and include the following:

- Downstream (seaward) boundary conditions remain constant. The TPWQM requires input data regarding of boundary conditions regarding pollutant concentration. A constant boundary condition for fecal coliform was set to 0. This is a conservative assumption which thereby models all fecal coliform loads as coming from the estuary and not from outside the mouth of the estuary.
- The contribution of septic systems to fecal coliform loading is included in the baseflow loads of the watershed model. A separate input to the estuary for septic loads was not modeled.
- There are no point sources contributing fecal coliform loads to the estuary.
- A daily record of temperature was not available at different points in the estuary. Therefore, a constant temperature of 20 °C was utilized. Temporally varying temperatures can be simulated; however, the use of constant temperature was selected in order to improve modeled baseline concentration results.

4.5 TPWQM Model Limitations and Sources of Uncertainty

The TPWQM is subject to limitations and sources of uncertainty. One limitation pertains to segmentation. Segmentation is performed on the basis of the geometry of the estuary. Several monitoring sites are present across an individual model segment in the Lockwoods Folly estuary. While variability exists between these monitoring sites, the model is not able to capture variability within a model segment.

The TPWQM is a receiving-water quality model and the results therein are affected by the uncertainties associated with the loading model. These uncertainties are discussed in Section 3.3. The most sensitive calibration parameter in the TPWQM is the decay rate of fecal coliform. Decay is a variable parameter affected by temperature and salinity. A conservative value of 0.7 was selected for the decay rate in order to minimize the possibility of under predicting fecal coliform concentrations in the estuary. Due to the high variability of the nature of fecal coliform, it is understandable that the model may fail to simulate some isolated events.

4.6 TMDL Calculation

The existing load (or current condition) is estimated as the sum of all the loads from subwatersheds discharging into the estuary. The loading is expressed as counts per day. The TMDL calculation is based on the water quality criteria; in this case it is the median and 90th percentile for the most recent 30 samples. Since the samples are taken on an approximately monthly basis (i.e., samples can be taken in any month), the running 30-month median and 30-month 90th percentile were calculated for the model segment containing the TPWQM calibration point (Segment M0S2). The watershed loading was reduced until both water quality standards were met at all times during the model simulation period. The final load is the maximum allowed daily load, or TMDL. The load reduction is calculated as the difference between the current condition and the TMDL loading. A summary of existing load and TMDL loading is presented in Table 9. The model time series plots of both the running 30-month median and 90th percentile for Segment M0S2 of the estuary under existing conditions and with the TMDL loading are presented in Appendix D.

Table 9. TMDL summary

Waterbody	Pollutant	Existing Load	WLA	LA	MOS	TMDL	Reduction Needed
Lockwoods Folly River (15-25-1-(16)c) Lockwoods Folly River (15-25-1-(16)a), Lockwoods Folly River (15-25-1-(16)b), Lockwoods Folly River (15-25-1-(16)d), Mill Creek, Mullet Creek, Spring Creek, Lockwoods Creek	Fecal coliform (counts/day)	6.910E+12	2.097E+11	7.855E+11	1.106E+11	1.106E+12	84%

WLA = wasteload allocation; LA = load allocation, MOS = margin of safety

4.7 Critical Condition

The EPA Code of Federal Regulations (40 CFR 130.7 (c)(1)) requires TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The critical condition accounts for the hydrologic variation in the watershed over many sampling years whereas the critical period is the condition under which a waterbody is the most likely to violate the water quality standard(s).

The 90th percentile concentration is the concentration exceeded only 10% of the time. Since the model simulation period spans 5 years, the critical condition is implicitly included in the value of the 90th percentile of model results. Given the length of the monitoring record and model simulation and the standard's recognition of unusual and infrequent events, the 90th percentile is used instead of the absolute maximum.

4.8 Seasonality

Fecal coliform distributions often show high seasonal variability, which is required to be considered in TMDL determinations. The seasonal fecal coliform distributions of observed data at Sites 7A and 8 are presented in Figures 14 and 15. The results show that high fecal coliform levels occur throughout the year in the estuary. The average monthly concentrations are relatively similar between months at both sites, though Site 7A shows slightly more variation. The highest concentrations occur in April at both monitoring sites. The lowest concentrations occur in February and the late spring months.

The largest standard deviation corresponds to the highest concentration for each station. These high concentrations result in a high 90th percentile concentration. Given the length of the model simulation, the seasonal variability is directly included in the model simulation.

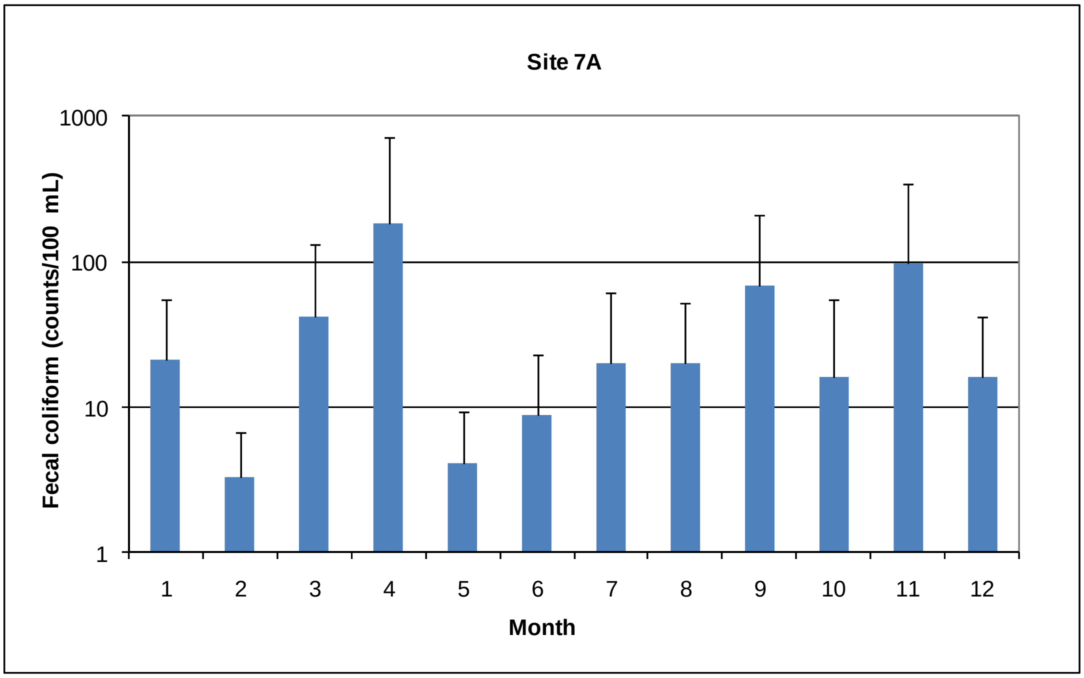


Figure 14. Seasonal distribution of fecal coliform concentration at Site 7A (log scale)

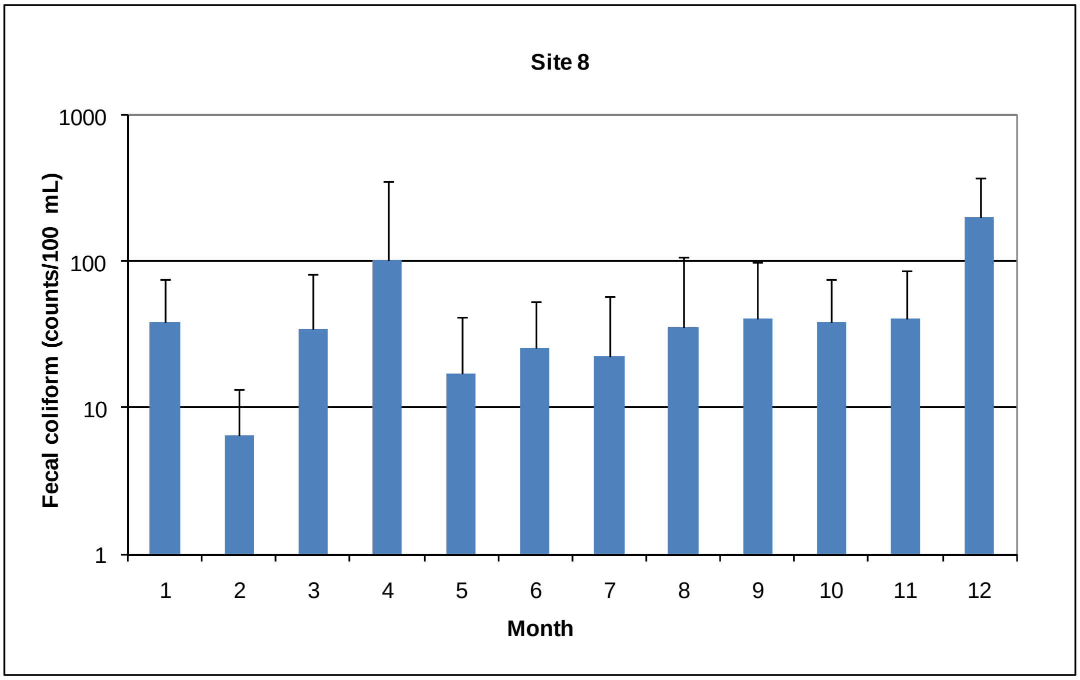


Figure 15. Seasonal distribution of fecal coliform concentration at Site 8 (log scale)

4.9 TMDL Loading Cap

This section presents the TMDL for the median and 90th percentile conditions for the

Lockwoods Folly estuary and tidal creeks. The TMDL was calculated based on the model simulation results. The TMDL for the estuary was calculated to be 1.106 x 10^{12}, with the TMDL calculation period from 7/1/2004 to 1/1/2007. The greater reduction required when comparing the median and the 90^{th} percentile results was used for the TMDL. Based on model results, the 90^{th} percentile is the stricter standard which requires the greatest reduction.

The TMDL calculation period is the 30 months preceding the last daily prediction to meet the standard. Thus, the averaging period for the development of the TMDL used daily predictions from the TMDL model runs for the 30 months preceding the highest 90^{th} percentile concentration over the model simulation period. Over this calculation period, daily bacteria loading predictions were taken from each model subwatershed and subsequently summed across the watershed. The daily average load was then calculated over the 30-month period. As seen in Figure D1 (Appendix D) the highest 90^{th} percentile during the model simulation period occurred on 1/1/2007. Thus, the TMDL was calculated for the 30 months from 7/1/2004 to 1/1/2007.

Load reductions required to meet the TMDL are 84% (excluding the MOS). The reduction established based on the 90^{th} percentile criterion indicates that the waterbody will meet the water quality standard requiring not more than 10% of the samples to exceed an MF count of 43/100 ml. Using the 90^{th} percentile in this manner is consistent with the procedure used by DEHSS on their sample data for determining whether shellfish areas should be open, conditionally prohibited, or closed.

4.10 Wasteload Allocation

The wasteload allocation pertains to NPDES-permitted point sources. There are no wastewater discharges in the watershed. There are two main NPDES stormwater permitees in the watershed: NCDOT and the Town of Oak Island, a Phase II community. Surface and ground water from the Town of Oak Island drains to the ICWW and Mongtomery Slough. As mentioned in Section 2.1.1, these two waterbodies do not drain to the Lockwoods Folly estuary and the hydrodynamics of these waterways are not conducive to using the linked watershed and Tidal Prism modeling approach. Therefore, a WLA could not be calculated for the Town. The Town will be addressed in the TMDL Implementation Plan as well as future stormwater permits. There are also four industrial stormwater permittees which include sand pits, and concrete and asphalt facilities which are not of concern with regards to fecal coliform. Therefore, NCDOT is the only bacteria source accounted for in the WLA.

Bacteria loading coming from NCDOT land was isolated from other sources using the delineated land use and calibrated model as a base. The model was rerun setting the EMC on NCDOT land to zero. The difference between the calibrated model run and the model run without NCDOT represents NCDOT's existing fecal coliform load to the Lockwoods Folly estuary. The existing NCDOT load was calculated over the same time period as the TMDL calculation (7/1/2004 – 1/1/2007), with a result of 4.46 x 10^{11} counts per day. NCDOT's contribution is 6% of the total fecal coliform load from the watershed to the estuary. The required reduction from NCDOT land was calculated to be 53% % of their existing load. This reduction is based on NCDOTs relative contribution to fecal loads using its EMC values compared to a developed land area weighted EMC value that was calculated using land use area (Table 2) and corresponding EMC values (Table 8). The resulting WLA is 2.097 x 10^{11} counts per day. This value and the margin of safety are subtracted from the TMDL loading cap to determine the final LA.

4.11 Load Allocation

The load allocations were determined using the same period as the TMDL calculation. Thus, the averaging period for the development of the TMDLs used daily predictions from the TMDL model runs for the 30 months preceding the highest 90th percentile concentration over the TMDL period. Over this period, daily bacteria loading predictions were taken from each model subwatershed and subsequently summed across the watershed. The daily average load was then calculated which serves as the basis for the load allocation. The wasteload allocation (WLA) and the margin of safety (MOS) were subtracted from the TMDL to determine the final load allocation (LA).

4.12 Margin of Safety

A Margin of Safety (MOS) is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

For TMDL development, the MOS needs to be incorporated to account for uncertainty due to model parameter selection. Based on previous model sensitivity analysis, it has been determined that the most sensitive parameter is the decay rate. The value of the decay rate varies from 0.7 to 3.0 per day in salt water (Mancini, 1978; Thomann and Mueller, 1987, EPA 1985). A decay rate of 0.7 per day in the estuary was used as a conservative estimate in the TMDL model. An explicit MOS was also included in the TMDL calculation as a conservative estimate. The explicit MOS was achieved by applying a 10% load reduction from the calculated TMDL.

With the MOS included, the total required reduction in load is 86%.

4.13 Summary of Total Maximum Daily Loads

As explained in the previous sections, the TMDL was calculated based on model runs that had a maximum 30-month 90th percentile concentration of 43 MPN/100 ml. Additionally an explicit margin of safety of 10% was applied to the TMDL load. NCDOT is the only NPDES-permitted source in the area so its allocation is in the WLA column. The TMDL is calculated based on the 30 months preceding the last highest 90th percentile concentration in the TMDL model runs and is summarized as follows:

Waterbody	Pollutant	Existing Load	WLA	LA	MOS	TMDL	Reduction Needed*
Lockwoods Folly River (15-25-1-(16)c) Lockwoods Folly River (15-25-1-(16)a), Lockwoods Folly River (15-25-1-(16)b), Lockwoods Folly River (15-25-1-(16)d), Mill Creek, Mullet Creek, Spring Creek, Lockwoods Creek	Fecal coliform (counts/day)	6.910E+12	2.097E+11	7.855E+11	1.106E+11	1.106E+12	84%

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
MOS = Margin of Safety
*When the MOS is included, the total required reduction is 86%

5.0 References

Baird, C.F., Dybala, T.J., Jennings, Marshall, and Ockerman, D.J., 1996, Characterization of nonpoint sources and loadings to the Corpus Christi Bay National Estuary Program study area: Corpus Christi Bay National Estuary Program, CCBNEP–05, 226 p

Bales, J.D., J.C. Weaver, and J.B. Robinson. 1999. Relation of land use to streamflow and water quality at selected sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993-1998. USGS Water Resources Investigations Report 99-4180. Raleigh, NC.

Center for Watershed Protection (CWP) 2003. Impacts of impervious cover on aquatic systems. Watershed Protection Research Monograph No. 1.

CWP 1999. Microbes and Urban Watersheds – Concentrations, Sources and Pathways. Watershed Protection Techniques 3(1): 554 – 565. Center for Watershed Protection.

Daniels, RB, SW Buol, HJ Kleiss, and CA Ditzler 1999. Soil systems in North Carolina. Technical Bulletin 314. North Carolina State University Soil Science Department.

Driver, N 1988. National summary and regression models of storm-runoff loads and volumes in urban watersheds in the United States. Thesis. Colorado School of Mines. Golden, Colorado

Eleria, A. and R.M. Vogel 2005. Predicting fecal coliform bacteria levels in the Charles River, Massachusetts, USA. *Journal of the American Water Resources Association* 41 (5):1195-1209.

Elshorbagy A., L. Ormsbee (2005). Object-oriented modeling approach to surface water quality management. *Environmental Modelling & Software* 21 (2006): 689-698.

Fine, J.M. and W.L. Cunningham. 2001. Compilation of water-resources data and hydrogeologic setting for Brunswick County, North Carolina, 1933–2000. U.S. Geological Survey Open-File Report 01–240.

Kuo, A.Y., K. Park 1994. A PC-based Tidal Prism Water Quality Model for small coastal basins and tidal creeks. Special Report No. 324. Virginia Institute of Marine Science, The College of William and Mary. Gloucester Point, VA.

Kuo, A.Y., A. Butt, S. Kim, and J. Ling (1998). Application of a Tidal Prism water quality model to Virginia Small Coastal Basins. SRAMSOE No. 348.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr. 1994. User's manual for an expert system (HSPEXP) for calibration of the Hydrologic Simulation Program-FORTRAN. U.S. Geological Surve Water-Resources Investigations Report 94-4168. U.S. Geological Survey.

Mallin, M.A., K.E. Williams, E.C. Esham, and R.P. Lowe 2000. Effect of human development on bacteriological water quality in coastal watersheds. *Ecological Applications* 10(4): 1047-1056.

Maestre, A. and R. Pitt 2005. Identification of significant factors affecting stormwater quality using the NSQD. Computational Hydraulics International (CHI) Draft Monograph.

Mancini, J. L. (1978). Numerical estimates of coliform mortality rates under various conditions. *Journal Water Pollution Control Federation* 50(11): 2477-2484.

NC CRONOS 2009. NC CRONOS Database. The State Climate Office of North Carolina. http://www.nc-climate.ncsu.edu/cronos/.

NCDENR 2007. Total Maximum Daily Loads for Fecal Coliform for Jarrett Bay and Its Embayment, North Carolina. North Carolina Department of Environment and Natural Resources, Division of Water Quality.

NCDENR 2009. Total Maximum Daily Loads for Fecal Coliform for Embayments in Southeast White Oak River, North Carolina. North Carolina Department of Environment and Natural Resources, Division of Water Quality.

Newell, C.J., H.S. Rifai, P.B. Bedient (1992). Characterization of non-point sources and loadings to Galveston Bay. *GBNEP-15.* Prepared for the Northern Virginia Regional Commission.

NOAA 2009. Tidal Station Locations and Ranges. National Oceanic and Atmospheric Administration. http://tidesandcurrents.noaa.gov/tides07/tab2ec3a.html

Pitt, R., A. Maestre, and R. Morquecho 2005. The National Stormwater Quality Database (NSQD, version 1.1). 3/04/2005 http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

SCS 1975. Urban hydrology for small watersheds, Technical Release No. 55. Soil Conservation Service. United States Department of Agriculture. Washington, D.C.

SCS 1988. Soil Survey of Brunswick County, North Carolina. Soil Conservation Service. US Department of Agriculture.

Tetra Tech. 2004. Technical Memorandum – Task 1: Impact Analysis Town Center Stormwater. Management Plan. Prepared for the Town of Cary.

Thomann, R. V. and J. Mueller (1987). Principles of surface water quality modeling and control. Harper Collins Publishers.

Tufford, D.L. and W.D. Marshall 2002. Fecal coliform source assessment in a small, mixed land use watershed. *Journal of the America Water Resources Association* 38(6): 1625-1635.

USACE 2008. Hydrologic Modeling System HEC-HMS User's Manual Version 3.3. US Army Corps of Engineers. Hydrologic Engineering Center. Davis, California.

USEPA 1983. Nationwide Urban Runoff Program. United States Environmental Protection Agency, Washington, D.C. December 1983.

USEPA 2001. PLOAD version 3.0, An ArcView GIS tool to calculate nonpoint sources of pollution in watershed and stormwater projects. United States Environmental Protection Agency, Washington, D.C. January 2001.

USGS 2000. Equations for estimating Clark unit-hydrograph parameters for small rural watersheds in Illinois. Water Resources Investigations Report 00-4184. United States Geological Survey. Urbana, Illinois.

Yagow, G., T. Dillaha, S. Mostaghimi, K. Brannan, C. Heatwole, M.L. Wolfe 2001. TMDL modeling of fecal coliform bacteria with HSPF. Written for presentation at the 2001 ASAE Annual International Meeting. Sacramento, California.

Young, K.D. and E.L. Thackston. 1999. Housing density and bacterial loading to urban streams. *Journal of Environmental Engineering* 125(12): 1177-1180.

Zarriello, PJ, LK Barlow, and US EPA, and Massachussetts Department of Environmntal Protection and US Geological Survey 2002. Measured and simulated runoff to the lower Charles River, Massachussetts.

Appendix A. Instructions for Navigating the Watershed Loading Excel Spreadsheets and Generating the TPWQM Input File CAL-NPS.IN

1. Run HEC-HMS model.
2. Select the results tab.
3. Select Subbasin-1, then Time-Series Table. Copy columns labeled Direct Flow and Baseflow. Paste these columns into the MS Excel file “Subbasin_1.xls” in column “BX” (highlighted yellow) at the proper row corresponding to the lag time between this Subbasin-1 and the Estuary. (Lag times are included in MS Excel File “Lag Time per subbasin to Estuary.xls”). For convenience, the lag time has been highlighted in column “BT”. Column “BT” is labeled for hourly offsets.
4. Repeat step three (3) for each of the 27 subbasins, in their respective MS Excel files.
5. Copy columns “C” and “D” from Subbasin_1.xls.
6. Paste the columns into “Lockwoods Final Watershed Results_multistep-loading_with_losses.xls” MS Excel file in the worksheet named “by_subbasin”, under the appropriate subbasin heading, Subbasin-1 at columns “BG” and “BH”.
7. Repeat steps 5 and 6 for each of the 27 subbasin files, pasting data in the appropriate columns, beginning at “BG” and “BH” for Subbasin-1 and ending at columns “DG” and “DH” for Subbasin-27. (Note: This may require an intermediate spreadsheet due to demands on RAM).
8. After all subbasin data is entered in the “Lockwoods Final Watershed Results_multistep-loading_with_losses.xls”, in the “by_subbasin” worksheet, calibration of fecal coliform loading can be conducted. Calibration parameters are located in cells “D1” (% increase to trigger flushing effect), “F1” (multiplier for first flush), “J1” and “H1” (divisors for post-flush). They change the proportional adjustment of bacterial load for the first flush and afterwards, as well as determining the increase in flow required to trigger “first flush” conditions.
9. The “Watershed_total” worksheet automatically calculates total Q and counts entering the estuary on an hourly basis, for the duration of the simulation. In this sheet, Column G shows the concentration of fecal coliform in the flow entering the estuary. As a note, the simulation is not fully accurate until the beginning of day 6 when the entire watershed is represented.
10. Copy Columns A through D in the “Watershed_total” worksheet. Paste them into Columns A through D in the “Lockwoods Final Watershed Results MACRO.xls” MS Excel file in worksheet “Sheet 1”. (Note, click ‘Enable Macros’ when opening this MS Excel File). Follow instructions in the worksheet to generate the CAL_NPS.IN loading file for the tidal prisms model.

To Change Event Mean Concentrations (EMC)

1. EMC values may be changed in the MS Excel file “Lockwoods Output.xls” in the worksheet titled “Load Factor Data Sheet”. Columns A through P in Row 5 list base EMC values used which apply to direct runoff. They may be adjusted directly in this file. Columns R through AG list EMC values attributed to baseflow. The current model assumed baseflow EMC’s to be 25% of runoff EMC’s as a starting point. This may be adjusted, for each land use type, by changing the decimal value in Row 1. Recall that divisors were applied to these values as described in Section 4.3 of the model documentation.
2. After changing the values in “Lockwoods Output.xls”, each subbasin sheet must be reopened to allow it to calculate new loadings using the altered data. Pasting

data from HEC-HMS may be omitted as flow values have not changed. (Resume from step 5 above.)

Appendix B. TPWQM Input Files

GEO-HYD.IN

```
LOCKWOODS FOLLY
: updated geometry - 20100311
: Hydrodynamics and geometry input

   4    0  Lockwoods Folly Estuary
   0

$$$ geometry and hydrodynamic input $$$
       (km)       (10^6 m^3)           (m)
CH   S# DIST    VH      P       AL      HA
M 0  1  0.000   0.0     3.171   0.3     0.000
M 0  2  1.830   3.179   0.783   0.3     1.062
M 0  3  2.490   0.774   0.239   0.3     1.188
M 0  4  3.100   0.271   0.000   0.3     0.828
```

Test_lb.IN

```
LOCKWOODS FOLLY TMDL:
: control input file
: for control parameters and constant WQ parameters

$$$ I/O control variables $$$
iPLT   iWQV   iTMP   iBEN   iSi    iTSS   iSRP   iFCB
0      1      0      0      0      0      0      1
iUKin  iBcS   iZK    iNR    iNC
1      0      1      1      1
Lsal   LBc    LBd    Lpo4   Lnh4   Lno3   Lsa    Lo2    Ltmp
1      0      0      0      0      0      0      0      1
iICI   iAGR   iSTL   iSUN   iPSL   iNPL
0      0      0      0      0      1
iBCS   iBCB   iBCCO  iBCPO  iBCPI  iBCNO  iBCNI  iBCSUP  iBCSA
0      0      0      0      0      0      0      0       0
iBCCOD iBCO2  iBCTSS iBCTAM iBCFCB iBCT
0      0      0      0      0      0
Tstrt  COV
2.0000 1.0E-6
iTmax  Nprn   iTimeS iSTS   iETS
4087   4      1      0      4087
iTSCH  iTSSEG
0      2
Tout(j)
2  3  7  8

$$$ constant parameters for ALGAE (see Table 3-1) $$$
KHNc   KHNd   KHNg   KHPc   KHPd   KHPg   KHS    STOX
0.01   0.01   0.01   0.001  0.001  0.001  0.05   1.0
KeTSS  KeChl  CChlc  CChld  CChlg  DOPTc  DOPTd  DOPTg
0.018  0.060  0.06   0.06   0.06   0.1    0.1    0.1
I0     IsMIN  FD     CIa    CIb    CIc
400.0  40.0   0.5    0.7    0.2    0.1
TMc    TMd    TMg    KTG1c  KTG2c  KTG1d  KTG2d  KTG1g  KTG2g
20.0   20.0   25.0   0.005  0.005  0.004  0.006  0.008  0.010
TRc    TRd    TRg    KTBc   KTBd   KTBg
20.0   20.0   20.0   0.069  0.069  0.069

$$$ constant parameters for CARBON (see Table 3-2) $$$
FCRP   FCLP   FCDP   FCDc   FCDd   FCDg   KHRc   KHRd   KHRg
0.35   0.55   0.10   0.0    0.0    0.0    0.5    0.5    0.5
KRC    KLC    KDC    KRCalg KLCalg KDCalg
0.005  0.075  0.01   0.0    0.0    0.0
TRHDR  TRMNL  KTHDR  KTMNL  KHORDO KHDNN  AANOX
20.0   20.0   0.069  0.069  0.5    0.1    0.5

$$$ constant parameters for PHOSPHORUS (see Table 3-3) $$$
FPRP   FPLP   FPDP   FPIP   FPRc   FPRd   FPRg   FPLc   FPLd   FPLg
0.1    0.2    0.5    0.2    0.0    0.0    0.0    0.0    0.0    0.0
```

```
FPDc   FPDd   FPDg   FPIc   FPId   FPIg   KPO4p
1.0    1.0    1.0    0.0    0.0    0.0    0.066
KRP    KLP    KDP    KRPalg  KLPalg  KDPalg  CPprm1  CPprm2  CPprm3
0.005  0.075  0.1    0.0    0.0    0.2    41.1   40.0   200.0

$$$ constant parameters for NITROGEN (see Table 3-4) $$$
FNRP   FNLP   FNDP   FNIP   FNRc   FNRd   FNRg   FNLc   FNLd   FNLg
0.35   0.55   0.10   0.0    0.0    0.0    0.0    0.0    0.0    0.0
FNDc   FNDd   FNDg   FNIc   FNId   FNIg   ANCc   ANCd   ANCg
1.0    1.0    1.0    0.0    0.0    0.0    0.167  0.167  0.167
ANDC   rNitM  KHNitDO KHNitN  TNit   KNit1  KNit2
0.933  0.07   1.0    1.0    27.0   0.0045  0.0045
KRN    KLN    KDN    KRNalg  KLNalg  KDNalg
0.005  0.075  0.015  0.0    0.0    0.0

$$$ constant parameters for SILICA (see Table 3-5) $$$
FSPP   FSIP   FSPd   FSId   ASCd   KSAp   KSU    TRSUA  KTSUA
1.0    0.0    1.0    0.0    0.5    6.0    0.03   20.0   0.092

$$$ constant parameters for COD & DO (see Table 3-6) $$$
AOCR   AONT   KRO    KTR    KHCOD  KCD    TRCOD  KTCOD
2.67   4.33   3.933  1.024  1.5    20.0   20.0   0.041

$$$ constant parameters for TSS, TAM, FCB & TEMPERATURE (see Table 3-7) $$$
RDTSS  KHbmf  BFTAM  Ttam   Ktam   TAMdmx  Kdotam  KFCB   TFCB
5.00   0.5    0.01   20.0   0.2    0.015  1.0    -0.7   1.07
TmpMax  TmpMin  DTmax  Cp     Rho    KT     Te
28.3   8.89   197.0  4186.0  1000.0  17.6   32.5

$$$ spatially/temporally constant INITIAL CONDITIONS $$$
Sal    Bc     Bd     Bg     RPOC   LPOC   DOC    APCi
24.95  0.75   0.00   0.00   0.1469  0.2937  1.0280  0.024
RPOP   LPOP   DOP    PO4t   RPON   LPON   DON    NH4    NO3
0.0084  0.0168  0.0590  0.0282  0.0573  0.1145  0.4009  0.0630  0.0100
SU     SA     COD    DO     TSS    TAM    FCB    T
0.5    0.5    0.00   6.20   10.0   10.0   22.91  20.00

$$$ spatially/temporally constant ALGAL PARAMETERS (/d except Keb in /m) $$$
PMc    PMd    PMg    BMRc   BMRd   BMRg   PRRc   PRRd   PRRg   Keb
2.0    0.0    0.0    0.06   0.0    0.0    0.1    0.0    0.0    0.735

$$$ spatially/temporally constant SETTLING VELOCITIES (m/d) $$$
WSc    WSd    WSg    WSrp   WSlp   WSs    WStss
0.10   0.0    0.0    0.1    0.1    1.00   0.10

$$$ const/sin. varying DBC(g/m^3): S(ppt),TAM(mol/m^3),FCB(MPN/100mL),T(oC) $$$
c0S    c1S    c2S    c0T    c1T    c2T    APCd
21.4352 -4.56044-.25682714.452  -4.79258-8.666240.024
c0Bc   c1Bc   c2Bc   c0Bd   c1Bd   c2Bd   c0Bg   c1Bg   c2Bg
0.58925 0.11442 0.28081 0.0    0.0    0.0    0.0    0.0    0.0
c0C1   c1C1   c2C1   c0C2   c1C2   c2C2   c0C3   c1C3   c2C3
```

```
0.58972 0.07577 -0.017341.17943 0.15155 -0.121354.12802 0.53041 -0.12135
c0P1    c1P1    c2P1    c0P2    c1P2    c2P2    c0P3    c1P3    c2P3
0.0044  0.0     0.0     0.088   0.0     0.0     0.0308  0.0     0.0
c0PO4t  c1PO4t  c2PO4t
0.016   0.0     0.0
c0N1    c1N1    c2N1    c0N2    c1N2    c2N2    c0N3    c1N3    c2N3
0.0347  0.0     0.0     0.0693  0.0     0.0     0.2426  0.0     0.0
c0NH4   c1NH4   c2NH4   c0NO3   c1NO3   c2NO3
0.06    0.0     0.0     0.0187  0.0     0.0
c0SU    c1SU    c2SU    c0SA    c1SA    c2SA
0.0     0.0     0.0     0.0     0.0     0.0
c0COD   c1COD   c2COD   c0O2    c1O2    c2O2
0.0     0.0     0.0     8.94949 1.54105 1.4146
c0TSS   c1TSS   c2TSS   c0TAM   c1TAM   c2TAM   c0FCB   c1FCB   c2FCB
0.0     0.0     0.0     0.0     0.0     0.0     15.3671 -2.128435.79289

$$$ constant benthic flux (g/m^2/d) $$$
PO4     NH4     NO3     SA      COD     DO
0.006   0.012   0.005   0.00    0.00    -1.8

$$$ const PS(kg/TC):
PSQ(m^3/s),S(ppt),DO(g/m^3),TAM(kmol/TC),FCB(MPN/100mL),T(C) $$$
MC      0
BR      0
ST      0
CH   S# PSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
     RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
     SU      SA      COD     DO      TSS     TAM     FCB     T

$$$ const NPS(kg/TC):
DSQ(m^3/s),S(ppt),DO(g/m^3),TAM(kmol/TC),FCB(10^9MPN/TC),T(C) $$$
DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
0.0000  0.00    0.00    0.00    0.00    0.000   0.000   0.000
RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
SU      SA      COD     DO      TSS     TAM     FCB     T
0.00    0.00    0.00    0.00    0.00    0.00    0.0     0.00

$$$ File names for spatially/temporally varying parameters: lower case only $$$
Input file for initial conditions        = none
Input file for algal growth, resp, pred  = none
Input file for settling vel of algae, part= none
Input file for Io, FD, KT, Te            = none
Input file for downstream boundary condi. = none
Input file for benthic fluxes            = none
Input file for temperature               = none
Input file for point source input        = none
Input file for NPS input inc/ atm input  = cal-nps.in
Input file for sediment model input coeff = none
Diagnostic file-zero K(inetics)          = cal-k.log
Diagnostic file-negative R(esiduals)     = cal-r.log
```

Diagnostic file-negative concentration = cal-nc.log
Diagnostic file-salinity = cal-sal.log
Diagnostic file-cyanobacteris = none
Diagnostic file-diatoms = none
Diagnostic file-PO4 = none
Diagnostic file-NH4 = none
Diagnostic file-NO3 = none
Diagnostic file-SA = none
Diagnostic file-O2 = none
Diagnostic file-temperature = none
Output file for longitudinal distribution = mld.dat
Output file for 1st time series output = mts-m0s2.out
Output file for 2nd time series output = none

CAL-NPS.IN (Excerpt – Tide Cycles 1 to 4)

```
C LOCKWOODS FOLLY
C Run 16a
C Hydrodynamics and geometry input

CH   S# DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
M 0  2   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     19.46   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
M 0  2     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# SU      SA      COD     DO      TSS     TAM     FCB     T
M 0  2     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
M 0  3     0.000   0.000   0.000   0.000    0.00   0.000   76.84   0.000
M 0  4     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
   202 CON  :  4/ 1/ 1  12.42

CH   S# DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
M 0  2   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     19.71   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
M 0  2     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# SU      SA      COD     DO      TSS     TAM     FCB     T
M 0  2     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
M 0  3     0.000   0.000   0.000   0.000    0.00   0.000   87.92   0.000
M 0  4     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
   203 CON  :  4/ 1/ 1   0.84

CH   S# DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
M 0  2   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     20.08   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
M 0  2     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# SU      SA      COD     DO      TSS     TAM     FCB     T
M 0  2     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
M 0  3     0.000   0.000   0.000   0.000    0.00   0.000   39.99   0.000
M 0  4     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
   204 CON  :  4/ 1/ 2  13.26

CH   S# DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC
M 0  2   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     20.89   0.000   0.000   0.000   0.000   0.000   0.000   0.000
```

```
M 0  4   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4     NO3
M 0  2     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  3     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
M 0  4     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
CH   S# SU      SA      COD     DO      TSS     TAM     FCB     T
M 0  2     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
M 0  3     0.000   0.000   0.000   0.000    0.00   0.000  144.99   0.000
M 0  4     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000
   205 CON  :  4/ 1/ 2   1.68
```

Appendix C. Watershed-TPWQM Linkage VBA Scripts

Subroutine 1

```
Sub RUN_ME_FIRST_TidalData_Summation()
'routine to display daily time in hours with decimal hours
'Clear Range that is written to
  Columns("E:M").Select
  Selection.ClearContents
    Range("M1").Select
'End of Clear Range

Dim StartTime As Double
Dim hrsCounter As Double
Dim Counter As Double
Dim gonzoOld As Double
Dim StartRowFrac As Double 'variable used to count fraction of first row in rolling
calculations
StartRowFrac = 1
Dim FinishRowFrac As Double 'variable used to count fraction of last row in rolling
calculations
Dim TidalStepSize As Double 'time step in hours - set constant
TidalStepSize = 12.42 'hrs
Dim StartRowFracOld As Double
Dim FinishRowFracOld As Double
Cells(1, 11) = "FRF"
Cells(1, 10) = "SRF"
Cells(1, 13) = "Finish Row"
StartTime = 0
hrsCounter = 24
blabla = 2
gonzoOld = 1
Counter = 1
Cells(2, 10) = StartRowFrac
For i = 2 To 5000
'CELLS WRITING TO CONTINUOUS
      Cells(Counter + 1, 12) = StartTime
      'following line added
      startRownum = Int(StartTime + 1)
      Cells(Counter + 1, 13) = startRownum
      'MsgBox ("SRF = " & Round(StartRowFrac, 6))
'END OF CONTINUOUS WRITING CELLS
'INSERTED ROUTINE TO CALC LOAD AND FLOW

'END OF INSERTED ROUTINE
Cells(1, 5) = "StartHr"
Cells(Int(StartTime + blabla), 5) = Int(StartTime + 1) '- 1 'elapsed hr of start
Cells(Int(StartTime + blabla), 6) = StartTime 'elapsed hrs decimal
Cells(Int(StartTime + blabla), 7) = (0.5175 * hrsCounter * Counter) - Int((0.5175 *
hrsCounter * Counter) / 24) * 24
```

```
Cells(Int(StartTime + blabla), 8) = Cells(Int(StartTime + 2), 1) - Cells(2, 1) 'elapsed days
Cells(Int(StartTime + blabla), 9) = (Cells(Int(StartTime + 2), 1) - Cells(2, 1)) * 24 'elapsed
days in hrs

FinishRowFrac = ((0.5175 * hrsCounter * Counter) - Int((0.5175 * hrsCounter * Counter) /
24) * 24) - Int((0.5175 * hrsCounter * Counter) - Int((0.5175 * hrsCounter * Counter) / 24)
* 24)
Cells(Int(StartTime + blabla), 11) = FinishRowFrac
   'MsgBox ("FRF = " & Round(FinishRowFrac, 6))

StartTime = (0.5175 * hrsCounter * Counter)
StartRowFrac = 1 - FinishRowFrac
Cells(Int(StartTime + blabla), 10) = StartRowFrac
Counter = Counter + 1
'INSERTED ROUTINE TO CALC LOAD AND FLOW
'StartRowFracOld = StartRowFrac
'FinishRowFracOld = FinishRowFrac
'MsgBox ("FRF= " & Round(FinishRowFrac, 4))

'END OF INSERTED ROUTINE
Next i
End Sub
```

Subroutine 2

```
Sub RUN_ME_SECOND_sumtidal_data()
'subroutine to sum 1-hr tide step data over 12.24 hr cycle

'Clear Range that is written to
  Columns("O:R").Select
  Selection.ClearContents
  Range("M1").Select
'End of Clear Range

Dim firstDataRow As Long
Dim startRownum As Long
Dim endRowNum As Long
Dim counter2 As Long
Dim sumQ As Double
Dim sumLoad As Double
Dim FRF As Double
Dim SRF As Double
firstDataRow = 1
counter2 = 1

Cells(1, 15) = "Date"
Cells(1, 16) = "Time"
Cells(1, 17) = "Flow"
Cells(1, 18) = "Load"

For i = 1 To 4000
'initialize sum variables
sumQ = 0
sumLoad = 0

startRownum = Cells(counter2 + firstDataRow, 13) + firstDataRow
endRowNum = Cells(counter2 + firstDataRow + 1, 13) + firstDataRow
SRF = Cells(startRownum, 10)
FRF = Cells(startRownum, 11)
sumQ = SRF * Cells(startRownum, 3) + FRF * Cells(endRowNum, 3)
sumLoad = SRF * Cells(startRownum, 4) + FRF * Cells(endRowNum, 4)
   For j = (startRownum + 1) To (endRowNum - 1)
      sumQ = sumQ + Cells(j, 3)
      sumLoad = sumLoad + Cells(j, 4)
   Next j
Cells(counter2 + 1, 15) = Cells(startRownum, 1)
Cells(counter2 + 1, 16) = Cells(startRownum, 7)
Cells(counter2 + 1, 17) = Round(sumQ, 2)
Cells(counter2 + 1, 18) = Round(sumLoad, 2)
counter2 = counter2 + 1

Next i
End Sub
```

Subroutine 3

```
Sub RUN_ME_THIRD_TPWQM_WriteCAL_NPS_InputFile()
'first set a string which contains the path to the file you want to create.
'this example creates one and stores it in the root directory
Dim botRow As Single
botRow = InputBox("Input the row number for the last row of data in Column O")
Dim Qtemp As Double
Dim QOut As String
Dim FCBtemp As Double
Dim FCBOut As String
Dim taggerOut As String
Dim taggerVal As String
'*******
Dim StartDate As Variant
Dim yy2 As String
Dim mm2 As String
Dim dd2 As String
Dim StartTimer As Single
Dim StartTimerOut As String
'*******
'Time Step Increment Formatting
Dim tStepInc As Integer
Dim tStepOut As String
'*************THE VALUE BELOW (SET BY MRC AT 202) IS THE START OF THE TIME
STAMP - USE NOT DOCUMENTS
'*************VALUE CAN BE EDITED
tStepInc = 202
'*************END OF COMMENT
tStepOut = Format(tStepInc, "@@@@@@@")
taggerVal = "0.000"
taggerOut = Format(taggerVal, "@@@@@@@@")
'*****EDIT THE LINE BELOW TO REDIRECT LOCATION AND NAME OF FILE.
SAMPLE LINE INCLUDED AFTER - REMOVE LEADING
'*****SINGLE " ' " TO ACTIVATE LINE AND PUT ONE IN FRONT OF THE LINE
BELOW
MyFile = "c:\TPWQM\" & "RENAME ME CAL-NPS.IN.txt"
'*****SAMPLE
'MyFile = "c:\TPWQM\" & "KRISTENS CALNIPS FILE.IN"
'set and open file for output

MsgBox "Writing RENAME ME CAL-NPS.IN.txt file to C:\TPWQM\"
fnum = FreeFile()
Open MyFile For Output As fnum
'***********
'This section writes file header
Print #fnum, "C LOCKWOODS FOLLY" '************EDIT TEXT IN QUOTES HERE FOR
FIRST LINE OF TITLE
Print #fnum, "C Test Run"   '***************EDIT TEXT IN QUOTES HERE FOR RUN
DESCRIPTION
Print #fnum, "C Hydrodynamics and geometry input"
```

```
Print #fnum,
'Start Looping Procedure
'***********KRISTEN - EDIT THE SECOND VALUE IN THE LOOP BELOW TO
INCREASE OR DECREASE LENGTH OF WRITTEN FILE
'***********SUGGESTED VALUE IS ROW NUMBER OF LAST LINE OF DATA IN
COLUMN "O" AS IN OLIVER IN THE SPREADSHEET
For i = 2 To botRow ' ******CHANGE SECTION VALUE HERE TO CHANGE HOW
MANY LINES ARE READ**********
'*************
'This section reads from the spreadsheet
    '*****READ AND FORMAT FLOW AND LOAD DATA
    Qtemp = Cells(i, 17)
    QOut = Format(Qtemp, "@@@@@@@@")
    FCBtemp = Cells(i, 18)
    FCBOut = Format(FCBtemp, "@@@@@@@@")
    '*****READ AND FORMAT DATE AND TIME DATA
    StartDate = Cells(i, 15)
    'YEAR DATA
        yr2 = Format(StartDate, "yy")
        If Left(yr2, 1) = "0" Then
        yr2 = " " & Right(yr2, 1)
        End If
    'MONTH DATA
        mm2 = Format(StartDate, "mm")
        If Left(mm2, 1) = "0" Then
        mm2 = " " & Right(mm2, 1)
        End If
    'DAY DATA
        dd2 = Format(StartDate, "dd")
        If Left(dd2, 1) = "0" Then
        dd2 = " " & Right(dd2, 1)
        End If
    'TIME DATA
        StartTimer = Cells(i, 16)
        StartTimerOut = Round(StartTimer, 5)
        StartTimerOut = Format(StartTimer, "@@@@@@")

'write project info and then a blank line
Print #fnum, "CH   S# DSQ     Sal     Bc      Bd      Bg      RPOC    LPOC    DOC"
Print #fnum, "M 0  2   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000"
Print #fnum, "M 0  3  "; QOut; "   0.000   0.000   0.000   0.000   0.000   0.000   0.000"
Print #fnum, "M 0  4   0.00000   0.000   0.000   0.000   0.000   0.000   0.000   0.000"

Print #fnum, "CH   S# RPOP    LPOP    DOP     PO4t    RPON    LPON    DON     NH4
NO3"
Print #fnum, "M 0  2     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.000"
Print #fnum, "M 0  3     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.000"
Print #fnum, "M 0  4     0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.000"
```

```
Print #fnum, "CH   S# SU      SA      COD     DO      TSS     TAM     FCB     T"
Print #fnum, "M 0  2     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000"
Print #fnum, "M 0  3     0.000   0.000   0.000   0.000    0.00   0.000"; FCBOut; taggerOut
Print #fnum, "M 0  4     0.000   0.000   0.000   0.000    0.00   0.000     0.0   0.000"

Print #fnum, tStepOut; " CON  : "; yr2 & "/"; mm2 & "/" & dd2 & " " & StartTimerOut
'************* END OF DATE TEXT
Print #fnum,
tStepInc = 1 + tStepInc
tStepOut = Format(tStepInc, "@@@@@@@")

Next i
Print #fnum,
Close #fnum
MsgBox "RENAME ME CAL-NPS.IN.txt file written to C:\TPWQM\"
End Sub
```

Appendix D. Model Results of Median and 90th Percentile

The 30-month median and 90th percentile were calculated for the model segment M0S2 of the TPWQM in which the calibration points Site 7A and Site 8 are located. The time series plot for the TMDL period of the existing condition and load reduction scenario for the 90th percentile and median are presented in Figures D1 and D2. Given that each point represents a statistic of the previous 30 months, the first point appears in July of 2006.

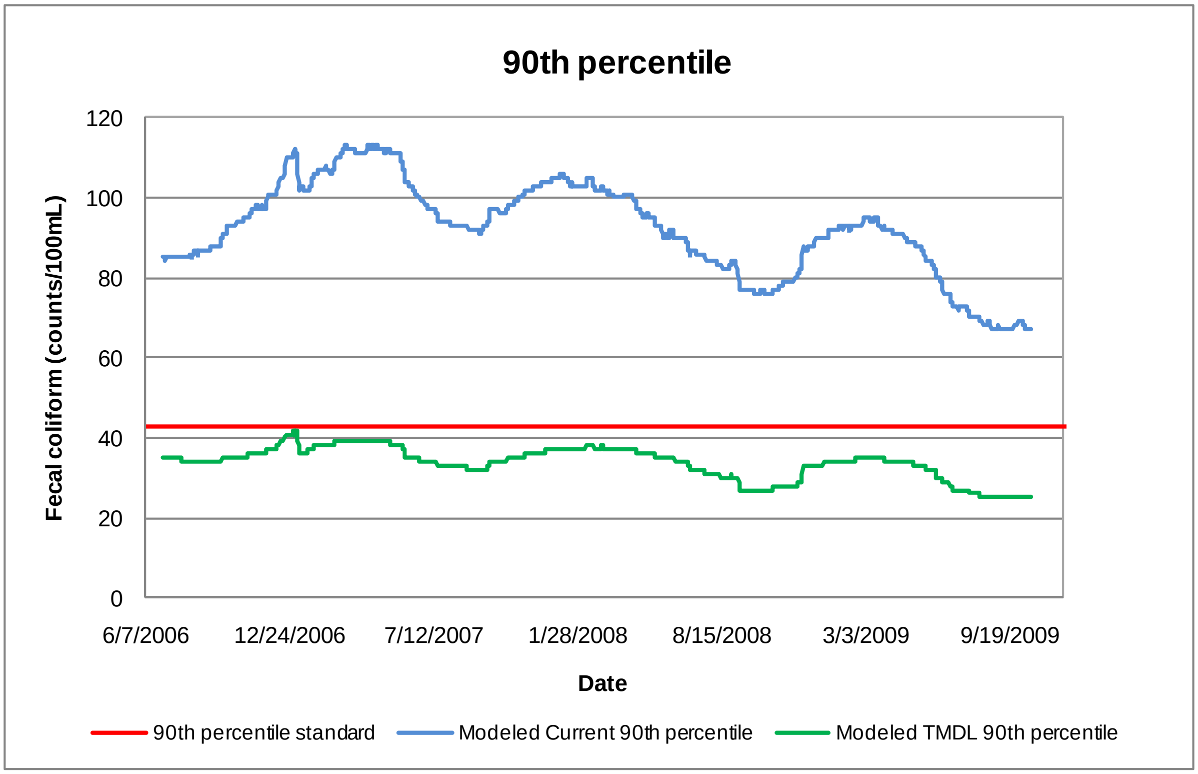


Figure D1. Modeled current and TMDL 90th percentile

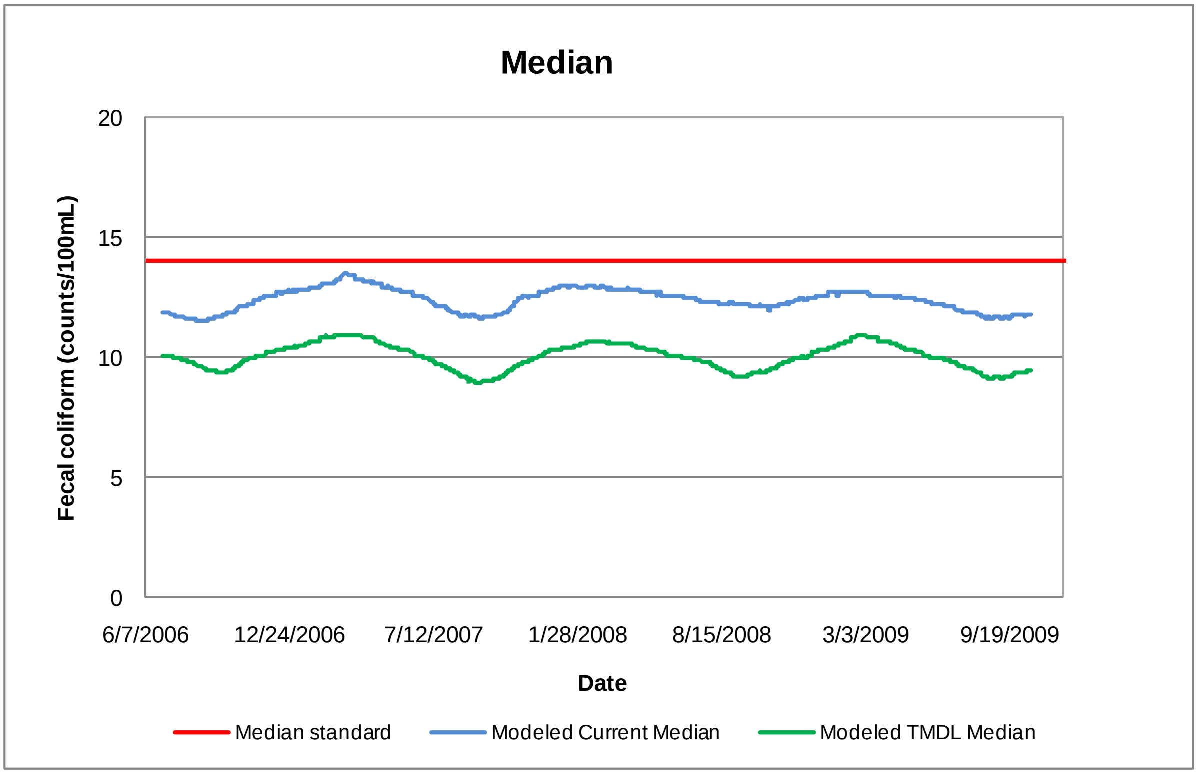


Figure D2. Modeled current and TMDL median

Appendix F. Public Notice

A public notice was posted to the DWQ TMDL website and notice was sent to a mailing list of interested parties and the WRRI listserv.

Notice was also posted in the City of Wilmington STAR-NEWS newspaper. In addition a press release was given by NCCF. An article entitled “Pollution report first step in reclaiming Lockwood Folly” was also published in the City of Wilmington StarNews Online newspaper.

Attachments:

1. Affidavit of Publication of the legal notice from the City of Wilmington STAR-NEWS newspaper.

2. Public announcement document for the draft Total Maximum Daily Loads for the Shellfish Harvesting Areas in the Lockwoods Folly River.

3. Press Release

4. StarNews Online article (“Pollution report first step in reclaiming Lockwood Folly”)

AFFIDAVIT OF PUBLICATION

STATE OF NORTH CAROLINA
COUNTY OF NEW HANOVER

PUBLIC NOTICE
State of North Carolina
Division of Water Quality
Draft Total Maximum Daily Load for Fecal Coliform Report for the Shellfish Harvesting Areas in the Lockwoods Folly River, Lumber River Basin, Brunswick County, North Carolina: To review, visit http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls or call 919-807-6305. Written comments will be accepted until August 13, 2010. Send comments to adugna.kebede@ncdenr.gov or NCDWQ Planning Section, Attn: Adugna Kebede, 1617 Mail Service Center, Raleigh NC 27699.

Before the undersigned, a Notary Public of Said County and State,

Keith Raffone

Who, being duly sworn or affirmed, according to the law, says that he/she is

Controller

of THE STAR-NEWS, a corporation organized and doing business under the Laws of the State of North Carolina, and publishing a newspaper known as STAR-NEWS in the City of Wilmington

PUBLIC NOTICE State of North Carolina Division of Water Quality Draft Total Maximum Daily Load for Fecal Coliform Report for the Shellfish Harvesting Areas in the Lockwoods Folly River, Lumber River Basin, Brunswick County, North Carolina. To review, visi

was inserted in the aforesaid newspaper in space, and on dates as follows:

7/14 1x

And at the time of such publication Star-News was a newspaper meeting all the requirements and qualifications prescribed by Sec. No. 1-597 G.S. of N.C.

Title: **Controller**

Sworn or affirmed to, and subscribed before me this 20th day of July, A.D., 2010

In Testimony Whereof, I have hereunto set my hand and affixed my official seal, the day and year aforesaid.

Jerrie L O'Conner
Notary Public

TERRIE L O'CONNER NOTARY PUBLIC NEW HANOVER COUNTY, N.C.

My commission expires 12th day of Sep., 2012

Upon reading the aforegoing affidavit with the advertisement thereto annexed it is adjudged by the Court that the said publication was duly and properly made and that the summons has been duly and legally served on the defendant(s).

This ____________ day of ________________, ____

____
Clerk of Superior Court

MAIL TO:

North Carolina Department of Environment and Natural Resources
Division of Water Quality

Beverly Eaves Perdue
Governor

Coleen H. Sullins
Director

Dee Freeman
Secretary

DRAFT Total Maximum Daily Loads for the Shellfish Harvesting Areas in the Lockwoods Folly River, Lumber River Basin, Brunswick County, North Carolina

July 2010
North Carolina Department of Environment and Natural Resources
Division of Water Quality

Now Available for Public Comment

This draft TMDL report was prepared as a requirement of the Federal Water Pollution Control Act, Section 303(d). Interested parties are invited to comment on the draft TMDL report by August 13, 2010. Comments concerning the report should be directed to Adugna Kebede at adugna.kebede@ncdenr.gov or write to:

Adugna Kebede
NC Division of Water Quality
Planning Section
1617 Mail Service Center
Raleigh, NC 27699

If you wish to obtain a hard copy of the TMDL, please contact Linda Chavis at (919) 807-6305 or email at linda.chavis@ncdenr.gov

The draft TMDL can also be downloaded from the following website:
http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls

1617 Mail Service Center, Raleigh, North Carolina 27699-1617
Location: 512 N. Salisbury St. Raleigh, North Carolina 27604
Phone: 919-807-6300 \ FAX: 919-807-6492 \ Customer Service: 1-877-623-6748
Internet: www.ncwaterquality.org

North Carolina Coastal Federation
CITIZENS WORKING TOGETHER FOR A HEALTHY COAST

FOR IMMEDIATE RELEASE **July 13, 2010**

Contact: Mike Giles
Phone: 910.509.2838
Email: mikeg@nccoast.org

Stormwater Polluting Lockwoods Folly River

WILMINGTON – Polluted runoff is closing shellfish beds in the Lockwoods Folly River in Brunswick County, according to new study done by the N.C. Coastal Federation, the state and others. The report finds that bacteria entering the river with each rain must be reduced as much as 84 percent if the river is to once again meet state water standards for shellfishing.

The study addresses the causes of bacterial contamination of the river and the continued closures of shellfish beds in what was once an important commercial oyster fishery. More than 55 percent of the river is now closed permanently or temporarily to shellfishing because of high bacteria levels. That represents a three-fold increase since 1980. Runoff after rainfalls accounts for most of the bacteria entering the river, the study found

The federation joined Brunswick County, the N.C. Division of Water Quality, the N.C. Ecosystem Enhancement Program and the N.C. Department of Transportation on the three-year study of the river. A grant from the U.S. Environmental Protection Agency paid for the study.

The N.C. Division of Water Quality has posted the study report on its Web site to allow for public comment and input. To review the study and make comments visit http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls or call 919-807-6305. Written comments will be accepted until Aug. 13. Send comments to Adugna Kebede at adugna.kebede@ncdenr.gov or by mail to him at NCDWQ Planning Section, 1617 Mail Service Center, Raleigh 27699.

For more than two years volunteers collected water samples, measured stream flow and water heights both in the lower river and in the swampy streams and creeks of this 88,000-acre watershed. That information was fed into a computer model, which identified the

N.C. Coastal Federation Southeast Regional Office | 530 Causeway Dr., Suit F1| Wilmington, NC 28480
Phone: 910.509.2838 | Email: nccf@nccoast.org | Web: www.nccoast.org

sources of the bacteria and the ways they were entering the river. The model also established a limit to the amount of bacteria that can enter the river without polluting shellfish beds.

For further information on the project and how to make comments please contact Mike Giles at 910-509-2838 or mikeg@nccoast.org. Information on the project is also available on the federation Web site at www.nccoast.org. Click on the SE page link and follow the link to the advocacy page.

N.C. Coastal Federation Southeast Regional Office | 131 Racine Dr., Suite 101| Wilmington, NC 28403
Phone: 910.790.3275 | Email: nccf@nccoast.org | Web: www.nccoast.org

Pollution report first step in reclaiming Lockwood Folly

By Shelby Sebens
Shelby.Sebens@StarNewsOnline.com

Published: Wednesday, July 21, 2010 at 5:37 p.m.

Photo by Matt Born

A boater heads past the fishing boats docked in Varnamtown along the Lockwood Folly River on July 21, 2010. The river is contaminated with excessive levels of fecal coliform bacteria.

Among the marshes and scenic landscape of the Lockwood Folly River, pipes and small trickles of water carry pollutants that has impaired the Brunswick County waterway to the point that more than half of the river and tributaries are often closed to shellfishing.

And bringing that water back to state standards will take an 84 percent reduction in the bacteria entering the river when it rains, according to a recent study of the Brunswick County watershed.

The three-year study, funded by the Environmental Protection Agency, found that the source of the pollution is fecal coliform, a waste source from warm-blooded animals.

Public comments on the study are being accepted through Aug. 13 before it goes to the Environmental Protection Agency for final approval.

After spending two years collecting data in the hot sun, rain and muddy waters, volunteers and members of the N.C. Coastal Federationhope this is the first step toward a cleaner river.

"If we screw this one up, shame on us," Coastal Federation volunteer Rich Peruggi said.

Peruggi started volunteering for the advocacy group four years ago after the federation advertised a call for citizens' help. Living in Winding River Plantation, Peruggi knows first hand the beauty of the river and the effects of the pollution.

And he's already taking matters into his own hands. After learning that the parking lot near a marina in his neighborhood was contributing to runoff pollution in the river, he spearheaded a rain garden project to head off some of it.

Peruggi joined two other volunteers and Mike Giles, the Cape Fear Coastkeeper with the N.C. Coastal Federation, on a media tour of the river Wednesday.

"The shellfish are the canaries in the coal mine, so to speak," Peruggi said, pointing to yellow signs along the way that prohibit shellfishing.

Once fecal coliform levels exceed state standards, it becomes hazardous to human health to eat the shellfish living there.

Data collected by Peruggi and other volunteers found levels of fecal coliform ranging from more than 200 colonies per 100 milliliters to an excess of 1,000. The state standard for shellfish waters is 14 colonies.

The data has been compiled into a mathematical computer model that shows how much pollution needs to be reduced to restore the river and meet water quality standards.

Some areas had levels so high it was hazardous for people to swim, Giles said.

Once the EPA approves the study, Giles said, the plan is to implement best management practices to reduce the pollution entering the river.

He said the N.C. Coastal Federation, along with its partners – Brunswick County, N.C. Division of Water Quality, N.C. Ecosystem Enhancement Program and the N.C. Department of Transportation – plan to work with developers and individual property owners on ways to reduce stormwater runoff.

For example, a property owner could stop using fertilizer or clean up after pets, Giles said.

He is also hoping that new developers will follow the county's low-impact development ordinance, and that current developments can retrofit boat ramps, bulkheads and parking lots to reduce their environmental impact.

Peruggi said the group looks at New Hanover County's creeks as the poster child of what not to do. The creeks are closed to shellfishing because of high pollution, Giles said.

Shelby Sebens: 343-2076

On Twitter.com: @ShelbySebens

Appendix G: Public Comment

The public comment period extended from July 13, 2010 through August 13, 2010. Comments were received from North Carolina Coastal Federetion (NCCF) and North Carolina Department of Transportation. These comments with the NC Division of Water Quality responses are provided in the Responsiveness Summary presented below.

Lockwood Folly River Fecal Coliform Bacteria TMDL Responsiveness Summary

August 2010

1) One comment stated that the Lockwood's Folly River TMDL report is an excellent example of a comprehensive collaborative effort involving partnerships with a wide variety of agency personnel, a diverse group of citizen volunteers to achieve a common goal. The project is also a result of extensive data and research over a five year period that provided an intensive review of the water quality issues and impacts on the watershed in order to fully evaluate the impacts upon the watershed and the requirements for the TMDL. The report represents extensive work both within the watershed and an exhaustive review of information collected from a variety of sources which has been incorporated into the TMDL report which is very well written and concise. The comment highlighted the collaborative process and listed the partners who participated in this project. The commenter appreciated the DWQ and EPA for their efforts in encouraging the collaborative work to impaired waterbodies in coastal areas.

   Response: Thank you for your support and for being part of the collaborative process that resulted in the development of this TMDL. As stated in your comment, this TMDL is the result of a joint effort by NC Division of Water Quality, NC Shellfish Sanitation, Brunswick County, the Lockwood Folly Roundtable, the NC Coastal Federation and over 100 volunteers in a variety of capacities. DWQ encourages a collaborative approach and works with local governments and stakeholders to improve water quality in North Carolina.

2) One comment stated that the Lockwoods Folly TMDL model documentation provides valuable information related to the bacteria modeling performed for the TMDLs and requested that the model documentation be included in the Appendix to the TMDL report, as opposed to being maintained as a separate document.

   Response: The DWQ agrees that the model report provides valuable information on the Lockwoods Folly TMDL modeling framework. The model documentation is included as Appendix E in the revised TMDL report.

3) One comment stated that on page 9 the TMDL report speculates that improvement in water quality is attributed to the statewide drought that began in 2007. The commenter suggested that if data exists to support this claim figures be added to the report illustrating the relationship between the rainfall deficit and the improving trend in water quality. The comment also stated that it is notable in Figure 9 that the model-predicted 90th percentile fecal coliform value does not drop off beginning in 2008 as the observed values do for Site 7A. Figure 11 also doesn't suggest a precipitation driven improvement in water quality.

Rather, the figures suggest that factors other than rainfall deficit may be affecting water quality. It is important to understand these relationships in order to support the effective implementation plan.

Response: In Section 1.4 'Water Quality Characterization' of the TMDL report, the 2007 state wide drought was suggested as one possible factor for the low levels of observed fecal coliform concentrations in the estuary. The main focus of this discussion is description of the monitoring data in the estuary. There is no site-specific rainfall data to conduct a detailed analysis of the rainfall-water quality relationship in the area. While low rainfall levels were suggested as a reason for low levels of fecal coliform after 2007, we understand that a number of factors including rainfall, land use, hydrology, loading from various sources and pathways, and etc. affect water quality in the estuary. The text is revised to reflect this point (Section 1.4). The TMDL analysis includes a detailed assessment of the major sources of fecal coliform loading in the watershed which will be targeted in the implementation plan. Figures 9 and 11 show model-predicted 90th percentile fecal coliform values. While these values are calculated from daily predictions of the model over a thirty-month period, the observed 90th percentile is calculated from only thirty samples over a thirty month period. This could be one of the main reasons for the discrepancy between the model-predicted 90th percentile values and the observed 90th percentile values. The model predictions take into account the daily variation in fecal coliform levels whereas the monitored data included water quality measurements taken every month or every other month.

4) One comment stated that portions of the Intercoastal Waterway and Montgomery Slough are listed on the cover page and page iv of the TMDL document which strongly implies that the TMDL reductions apply to these waters. Since the TMDL is not developed for these waterbodies the commenter recommends removing references to these waterbodies from the TMDL document. The commenter supports the inclusion of fecal coliform reducing recommendation in the implementation plan for the ICWW and Montgomery Slough, but it needs to be clear that the TMDL does not apply to these waterbodies.

   Response: The Intercoastal Waterway and the Montgomery Slough are part of the Lockwood Folly River watershed and these areas will be addressed in the TMDL implementation strategy. The TMDL document clearly states that a TMDL is not developed for the Intercoastal Waterway and the Montgomery Slough and these areas will be addressed in the TMDL implementation strategy which the commenter fully supports. The text is revised to clearly indicate that the TMDL load reduction will not apply to these two waterbodies (pages vi, ix, 1, 12, and 30).

5) One comment stated that Section 3.7 of the TMDL report describes the approach used to quantify existing and allowable bacteria loads from NCDOT areas. This section states that *"The required load reduction from NCDOT land was calculated to be 53% of their existing load based on area and its relative contribution to fecal coliform loads compared to other developed land use types, using EMC as a proxy."* Based on this general description, we have not been able to duplicate the results presented in the TMDL because insufficient detail is provided. The commenter requested to include a detailed description of the method along with supporting information used in the calculation, such as EMC values and a description of

the land use categories categorized as ‘developed.”

Response: The NCDOT load was calculated using the model as described in Section 3.7 of the TMDL report and Section 4.9 of the model documentation which is attached as Appendix E. In addition, the model documentation presents a detailed description of the EMC value selection in section 3.2.1 and Table 8. A table summarizing the EMC values used for the different land use types is included in the TMDL report (See Section 3.2.1, Table 8 of the revised TMDL document). The text is revised to include more details on the approach used to quantify bacteria loading from DOT areas (Section 3.7). The models used for the TMDL calculations are available to interested parties.

6) One comment stated that Section 3.2.1 of the TMDL report states that the EMC values used were adjusted during model calibration to account for a “first flush” effect by applying a multiplying factor early during a storm event and a dividing factor as flows decrease during and after a storm event. Section 3.2.2 of the “Lockwoods Folly River TMDL Model Documentation” draft report, states the multiplying factor to be eighty-two and dividing factor to be twenty-thousand and one-hundred, depending on flow. The multiplier value is very important because it sets the maximum or peak concentration simulated during a storm and thus it defines the existing condition by which the 90th percentiles concentration and required percent reduction in the TMDL are determined. Given the importance of this variable, additional explanation on the selection of these values should be provided in the text along with a supporting analysis that demonstrates that an adjusted EMC approach, when compared to the use of a single EMC value, will result in a similar total bacteria load delivered or exported for a given land use type and storm event.

   Response: Appendix E Sections 3.2.1 and 3.2.2 of the Lockwoods Folly River TMDL model documentation present a detailed description of EMC value selection and the watershed model calibration with particular emphasis on the selection of the multiplying and dividing factors used in the model. These factors are used as calibration parameters and are adjusted based on flow and observed fecal coliform levels in the estuary. Ranges of literature EMC values are given in Table 8 of Appendix E.

7)
   A. One comment stated that Figures 9 and 11 in the report present calculated 30-month, 90th percentile values based on water quality observations and model results at Sites 7A and 8, respectively. Based on these figures, the model appears to be simulating a very similar trend in bacteria concentration at both locations even though water quality measurements indicate that more localized factors are driving water quality conditions.

      Response: It should be noted that both Sites 7A and 8 are located in the same model segment and as such the predicted concentrations are the same for both sites. Given the complex hydrology and model limitations, care was taken to balance adjustment of model parameters to represent both sites during calibration. As stated in the TMDL document site 7 and 7A are located in the center of the estuary while Site 8 is located along the shoreline in the southeastern portion of the model segment MOS2 and is less influenced by tidal mixing. For this reason, the water quality measurements at these sites are different.

B. The comment further stated that the model also appears to over-predict during 2006-2009 period and remain high when measurements drop well below the 43 cfu/100 ml threshold at Site 7A. Model over-prediction is of concern because the water quality measurements at these locations are already biased high due to the nature of Shellfish Sanitation's Conditional Sampling Program. Over two-thirds of the bacteria measurements at Site 7A and 8 are conditional samples. Since conditional samples are more representative of fecal coliform levels during unfavorable conditions, we would expect them to be higher than conditions present under routine ambient monitoring. These factors, in combination with a very low bacteria decay rate for saline waters may suggest that the model is either too conservative or is not capturing the events that lead to lower bacteria concentrations. Additional figures showing cumulative flows and loads over time (observed and simulated) and monthly flow volumes and loads (observed and simulated) may be useful in order to better understand potential uncertainty and biases in the modeling and confirm that the existing calibration is adequately representing conditions present in the waterbody.

   Response: As shown in Figure 9, the model generally under-predicts high levels of fecal coliform and over-predicts low levels of fecal coliform. In Figure 11, while the model predicts high levels of fecal coliform well, it over-predicts low levels of fecal coliform. It should be noted that Figures 9 and 11 show model-predicted 90th percentile fecal coliform values. While these values are calculated from daily predictions of the model over a thirty-month period, the observed 90th percentile is calculated from only thirty samples over a thirty month period. This could be one of the main reasons for the discrepancy between the model-predicted 90th percentile values and the observed 90th percentile values. In most case the variability in fecal coliform levels is very high. The model predictions take into account the daily variation in fecal coliform levels whereas the monitored data include fecal coliform data measured every month or every other month. In addition, similar to other watershed and water quality models, the Lockwoods Folly River TMDL modeling framework has limitations. We acknowledge that there are data limitations, inherent model limitations, and uncertainty associated with these factors. It is expected to have such limitations and uncertainty when dealing with complex systems such as the Lockwoods Folly River watershed. Conservative assumptions were made in the model to account for uncertainty and to provide margin of safety. The models were calibrated based on the best available data for the given period and the model results should be interpreted in light of the model limitations. The watershed and water quality model limitations and sources of uncertainty are discussed in Section 3.3 and Section 4.5 of Appendix E, respectively.

   The purpose of conditional sampling is to take samples after an area has been temporarily closed in an attempt to show that the river has returned to normal and that it can be reopened to shellfish harvest. As such, Shellfish Sanitation staff may wait a day or two after a rain event before conducting conditional sampling in order to increase the likelihood of reopening the waters. Therefore these samples are not always more representative of unfavorable conditions. The text in is revised to reflect this point (Section 1.4).

8) One comment appreciates the cooperative efforts to find fair, reasonable and cost effective solutions to the bacteria contamination problems within NC's shellfish harvesting waters.

Response: Thank you for being part of the collaborative process in developing this TMDL. This TMDL is the result of a joint effort by NC Division of Water Quality, NC Shellfish Sanitation, Brunswick County, the Lockwood Folly Roundtable, the NC Coastal Federation and over 100 volunteers in a variety of capacities. DWQ encourages a collaborative approach and works with local governments and stakeholders to improve water quality in North Carolina.

Appendix H. Public Education and Outreach Materials

1. Brunswick County Lockwood Folly Boat Tour

2. Press Release: The Lockwood Folly River Needs a Few Good People

3. Press Release: Volunteers Needed to Pinpoint Problems on the Lockwood Folly

4. Lockwood Folly River Study Fact Sheet

5. Press Release: Study Aims to Find Solutions

6. Press Release: Development Planners Keep Environment in Mind

7. Press Release: Coastal Federation, Brunswick County, NCDOT to Examine Low Impact Development for Road Projects

8. Press Release: Runoff a Likely Culprit for Lockwood Folly Bacterial Woes

9. Press Release: Community Wetland Planting and Clean Water Event

10. Press Release: Water Quality Projects to Restore the Lockwood Folly River Installed at the Brunswick County Government Center

11. Tabloid: Lockwood Folly River Water Quality Strategy

Brunswick County Lockwood Folly Boat Tour
Wednesday, March 14, 2007

Agenda

8:30 am	Board bus at Wilmington Hilton (Facing the river, bus will be parked on the right side of the hotel)
8:45 am	Bus Departs Hotel
9:45 am	Bus Arrives at Holden Beach Marina, just before the bridge to Holden Beach on the left. (exit road to the right of bridge, park under bridge and meet at the front of marina at docks.)
9:45 am	Welcome and Tour Introduction
10:15 am	Board Boat
10:30 am	Boat departs for River Cruise Presentations and guided tour
Noon	lunch break/ free discussion on the boat
12:30 pm	Presentations and guided tour continues
2:00 pm	Boat docks at Holden Beach Marina
2:15 pm	Bus departs Marina
3:00 pm	Bus arrives at Wilmington Hilton

This is an enclosed boat (with an open air top deck) but we suggest you bring foul weather gear and appropriate clothing for inclement and/or cold/cool weather. Please do not forget your camera! Space is limited and requires advanced registration.
Questions? Call Lauren Kolodij (910) 262-5178 or Mike Giles (910) 231-6687.

North Carolina Coastal Federation
North Carolina Coastal Federation l 131 Racine Drive Suite 101 l Wilmington, NC 28403
Phone: 910-790-3275 l Fax: 910-790-9013 l Email: nccf@nccoast.org l Web: http://www.nccoast.org

Press Release

FOR IMMEDIATE RELEASE
September 20, 2007

Contact: Mike Giles, Cape Fear COASTKEEPER®
Phone: (910)790-3275: 910-231-6687 (cell)
Email: capefearcoastkeeper@nccoast.org

The Lockwood Folly River Needs a Few Good People

Wilmington, NC- In 2005 the N. C. Coastal Federation joined Brunswick County, the Environmental Protection Agency and the State Ecosystem Enhancement Program in a multi-year project to identify sources of pollution on the Lockwood Folly River. This study will assist the agencies in development of an overall watershed management plan for the river. The plan is intended as a model to properly guide growth and development to halt the current trend of increasingly polluted and impaired water. Since 1980 the percent of the river closed to shell fishing has more that tripled from 15% to over 55% and all indications are that downward trend will continue, unless citizens work together to stem the negative effects of increasing storm water and pollution sources along the river.

But the partners cannot do it alone. They are recruiting volunteers who will collect water samples and other information at over 11 locations for over a year beginning this November. The water sample information will be used for the development of strategies to reduce the sources of pollution and identify the maximum pollution load the river can sustain without degrading the water quality.

In 2005 the N. C. Division of Water Quality, the N.C. Department of Transportation, the N.C. Ecosystem Enhancement program, and Brunswick County joined the Federation to study the Lockwood Folly River watershed from the intra coastal waterway to the headwaters of the River. Grants from the U.S. Environmental Protection Agency have paid for the study with guidance from the State Division of Water Quality. Residents only have to look north to New Hanover County, where all but one of the tidal creeks are permanently closed to shellfishing, to see what unchecked growth can do to water quality. In 2005 the county established, with the Coastal Federation and other partners, the Lockwood Folly Roundtable, an eight member group who, over the course of the past two years, developed a set of 10 proposed strategies to help cure the problems on the ailing river. These strategies are meant not to hinder growth and development but to compliment growth and protection of the resources as an overall goal.

Storm water runoff is the number one source of pollution in our coastal rivers, streams, creeks and wetlands and the effects of that pollution continues to grow. The surging development within the 150-square-mile watershed has had a severe effect on the health of the river. "The main goal of the water sampling project, called a TMDL study, is to find out what is causing the pollution in the river," explained Mike Giles, the federation's Cape Fear COASTKEEPER® and the project leader. "We want to identify the sources of the bacteria coming down the river, and then develop a model, developed by Stantec consulting, to control and eventually reduce the bacterial pollution by implementing the roundtable land use strategies".

While Stantec and its computer specialists will do the analytical work, volunteers will assist in the field work by sampling the river at selected sites and under selected conditions to providing the baseline data for the model development. The samples, taken after heavy rain events, will be tested for bacteria by a certified Laboratory in Wilmington.

"We are looking for folks in Varnamtown, Sunset Harbor and communities like Winding River, who are willing to get their hands and feet wet and want to make a difference in the future of the river" Giles said. "These community minded people will be helping not only a river but a way of life and culture that is fast disappearing along our coast".

Boats aren't required since most of the samples can be taken from land or a dock. The volunteers will be trained in early November and sampling will begin later that month. **Anyone interested in volunteering should call Mike Giles @ (910)790-3275 or email him @capefearcoastkeeper@nccoast.org.**

There will be other opportunities for people to get involved as fisherman, landowners, business people and others who call the river home will be invited to join a small stakeholders' group that will offer advice and guidance to the volunteer team**. Interested persons are invited to the first meeting on Monday, October 22, 2007 at the Varnamtown Hall at 6:30 PM. The public is invited to attend the meeting to learn more about the project. Other opportunities will include: a public presentation to the Brunswick County Board of Commissioners on Monday November 5, 2007.** Giles said he invites any interested party or person to come to one of the meetings and follow the progress of the sampling project and the Lockwood Folly strategies.

Reporters/Media note: Boat tours of the project area and interviews of the project team and volunteer samplers can be arranged after November 1 by calling Mike Giles at (910)790-3275

###

About the North Carolina Coastal Federation: "Citizens Working Together for a Healthy Coast"

The North Carolina Coastal Federation (NCCF) is the state's largest nonprofit organization Working to restore and protect the coast. NCCF headquarters are located at 3609 Highway 24 in Ocean between Morehead City and Swansboro and are open Monday through Friday from 8:30 am to 5 pm.

The NCCF also operates field offices in Wilmington and Manteo. For more information call 252-393-8185 or check out NCCF's website at www.nccoast.org

North Carolina Coastal Federation
North Carolina Coastal Federation l 131 Racine Drive Suite 101 l Wilmington, NC 28403
Phone: 910-790-3275 l Fax: 910-790-9013 l Email: nccf@nccoast.org l Web: http://www.nccoast.org

Press Release

FOR IMMEDIATE RELEASE

September 25, 2007

Contact: Mike Giles, Cape Fear COASTKEEPER®
Phone: (910)790-3275: 910-231-6687 (cell) Email: capefearcoastkeeper@nccoast.org

Volunteers needed to pinpoint problems on the Lockwood Folly

Wilmington, N.C.-The North Carolina Coastal Federation is looking for a few good men and women.

The Federation needs help to tackle pollution problems on the Lockwood Folly River and is calling for willing and able volunteers. The effort is part of an ongoing partnership that includes Brunswick County and state and federal agencies and seeks to identify and fix the sources of pollution entering and degrading the river's water quality. The partnership formed in 2005 to work on these issues, and this new work represents a follow-up on the successful Lockwood Folly Roundtable project.

Storm water runoff is the number one source of pollution in our coastal rivers, streams, creeks and wetlands and the effects of that pollution continue to grow with the area's surging development.

"The main goal of the water sampling project is to find out what's causing the pollution in the river," explained Mike Giles, the Federation's Cape Fear COASTKEEPER® and the project leader. "We want to identify the sources of the bacteria coming down the river, and then develop ways to control and eventually reduce the bacterial pollution".

The volunteers will collect water samples and other information at locations on the Lockwood Folly River, beginning in November. The water sample information will be used find ways to reduce the sources of pollution and to identify the maximum amount of pollution the river can handle without degrading the water quality.

"We are looking for folks in Varnamtown, Sunset Harbor and communities like Winding River who are willing to get their hands and feet wet and want to make a difference in the future of the river," Giles said. "These community-minded people will be helping not only a river but a way of life and culture that is fast disappearing along our coast".

Results from the initial project and those generated by the volunteers samples will be used to guide growth and development and to prioritize retrofit opportunities to fix existing pollution problems.

Boats aren't required since most of the samples can be taken from land or a dock. The volunteers will be trained in early November and sampling will begin later that month. Prospective volunteers are invited to attend a kickoff public meeting on Monday, October 22 at the Varnamtown Town Hall at 6:30 p.m. **Those interested in volunteering should call Mike Giles @ (910)790-3275 or email him at capefearcoastkeeper@nccoast.org.**

###

The North Carolina Coastal Federation: "Citizens Working Together for a Healthy Coast"

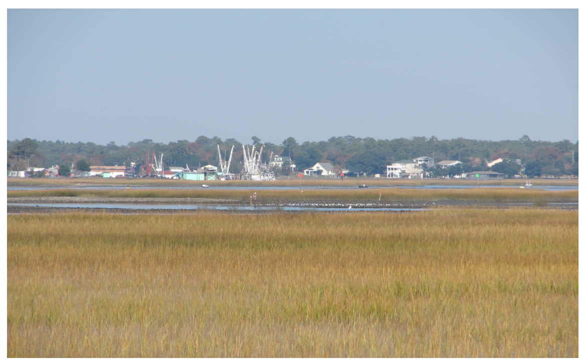
The North Carolina Coastal Federation (NCCF) is the state's only non-profit organization focused exclusively on protecting and restoring the coast of North Carolina through education, advocacy and habitat restoration and preservation. For more information call 252-393-8185 or check out NCCF's website at www.nccoast.org

Lockwood Folly River Study
Fact Sheet

The Partners

The N.C. Coastal Federation, Brunswick County, the N.C. Division of Water Quality, NC Ecosystem Enhancement Program, and the N.C. Department of Transportation

More than 55% of the waters in the Lockwood Folly River are closed either permanently or temporarily to shellfishing because of bacterial pollution. Stormwater runoff, wildlife and failing septic tanks are thought to be the sources of the bacteria. Under the federal Clean Water Act, these waters are considered "impaired" because they can't meet their intended use for harvesting clams and oysters. North Carolina is obligated under the law to clean up these waters.



The Study

Using money from the U.S. Environmental Protection Agency, the partners will study the river from the Intracoastal water way up through the estuaries and tributaries. Volunteers will collect more than 300 water samples from 11 locations in the river. The samples will be tested for bacteria and the results used in computer models that will determine the likely sources of pollution. The study, which will end in 2010, will devise plans for the watershed to control the bacteria, suggest remedies and management strategies.

How You Can Help

- Consider volunteering to take water samples. No boat is required, and volunteers will be trained.
- Attend public meetings about the project. They will be help periodically while the study is ongoing, usually at Varmumtown Hall or the Brunswick County Fishing Club in Sunset Harbor. The dates will be publicized well in advance.

To learn more or to volunteer, call Mike Giles at (910)790-3275 or email him at capefearcoastkeeper@nccoast.org.

3-20-08 Star News Article
Lockwood Folly River

StarNewsOnline.com

Study aims to find solutions

By Shannan Bowen,
Staff Writer
Published: Saturday, March 22, 2008 at 6:01 a.m.

Mike Giles, N.C. Coastal Federation , collects water samples from the Lockwood Folly River Thursday, March 20, 2008. The N.C. Coastal Federation and its volunteers are collecting the samples to determine sources of pollution in the river. Staff Photo By Mike Spencer/STAR-NEWS

Sunset Harbor | Thursday morning, just after a light rain, was prime time to collect samples of polluted water in the Lockwood Folly River.

Mike Giles, Cape Fear Coastkeeper for the N.C. Coastal Federation, and a group of volunteers set out about twice a month on the river to collect samples that are tested to ferret out the sources of the pollution.

So far, tests have found high levels of fecal coliform bacteria, which can come from sewage, animal feces and fertilizer.

The sampling should be completed in October. A consultant will then gather the test results and use a computerized model to show likely sources of the pollution.

The sources can include stormwater runoff from developments along the river, wildlife and failing septic tanks, said Tracy Skrabal, a coastal restoration specialist for the N.C. Coastal Federation, who helped Giles collect samples Thursday.

More than 55 percent of the Lockwood Folly River is closed either permanently or temporarily to shellfishing because of bacterial pollution.

The river once was a popular spot for oyster harvesting.

This has prompted years of studies and roundtable meetings by Brunswick County officials and environmental agencies who hope to find ways to reduce the river's pollution and restore its shellfishing areas.

Giles' study, which began in fall of last year and is expected to be completed in 2009, will suggest remedies and strategies for controlling the bacteria.

One strategy, called low-impact development, is the topic of discussion for a committee of county officials, builders and environmentalists.

The committee, which will meet sometime in the next few weeks, will review a resolution and manual that gives builders alternatives to conventional curb-and-gutter stormwater runoff techniques.

A low-impact development design captures stormwater runoff, treats it and uses it in the landscape.

Rain gardens, for example, include plants that soak up the runoff water and its nutrients.

Giles said the biggest issue with stormwater is the way developers and county officials allow it to reach bodies of water like the Lockwood Folly River.

"If we don't do something, we're going to lose our shellfish waters," he said.

"It's going to take a lot of willpower and working together."

A volunteer's job

Volunteers for the N.C. Coastal Federation's study have met since October. They collect samples mostly after a rainy night, but the lack of rain this year has made that challenging.

Phyllis Evans is one volunteer who collects water samples from a creek that flows into the Lockwood Folly River.

To collect the samples, she first lowers a bucket into the river. After pouring the water into two plastic test bottles, she places them into a cooler and then measures the water's temperature and salinity.

Other details, such as the time of the day, weather and noticeable conditions in the river are recorded.

Evans lives in River Run Plantation, one of the developments touching the river, and volunteered because she wanted to be part of a project that will change the river.

"I want this river cleaned up," she said.

Shannan Bowen: 755-6307

shannan.bowen@starnewsonline.com

Lockwood Folly River News

Development planners keep environment in mind

By Shannan Bowen
Staff Writer

Published: Wednesday, October 1, 2008 at 6:52 p.m.
Last Modified: Wednesday, October 1, 2008 at 7:01 p.m.

Supply | Even before the county's new guidelines are in place, a residential development planned near Holden Beach is being designed with the environment in mind.

Staff Photo | Paul Stephen
Senior planner Stephen Carpenter (from left) and Heather Burkert, president of H. Burkert & Co. landscape architecture firm, talk with landowner Michael Hobbs about waterfront homes that will be built along the banks of an old mine site lake at the Lakeside at Holden Beach development site Wednesday Oct.1, 2008. The development is the first in Brunswick County to abide by new low-impact development rules.

Lakeside at Holden Beach will be built on 100 acres once used as a sand and marl mine, and the developers say a 16-acre lake on the property and Lockwood Folly River tributaries will be protected from runoff pollution by using low-impact development techniques.

The stormwater controls, such as rain gardens instead of traditional curbs and gutters, are at the heart of a push to encourage building that's more environmentally friendly. .

The Lockwood Folly River has been the focus of more than a year's worth of studies and roundtables where representatives from county departments, the state's Division of Water Quality and the N.C. Coastal Federation gathered to discuss ways to retrofit development and restore the river's health through low-impact development and other guidelines that will be outlined in a county resolution.

The city of Wilmington recently passed a similar resolution, and New Hanover County will consider one Monday night.

Brunswick County officials are tweaking a draft of the resolution, and Assistant County Commissioner Steve Stone said it might be on the county commissioners' Oct. 20 agenda.

Officials say the Lockwood Folly River is polluted because of the way developers have allowed stormwater to flow into the river after collecting chemicals and waste from the land.

A low-impact development stormwater design would capture runoff, treat it and use it in the landscape. Rain gardens, for example, include native plants that soak up the runoff water and use it for nutrients.

Members of the committee that studied the river and discussed the low-impact development resolution hope the proposed resolution's guidelines, though voluntary, will encourage developers to think of new ways to maintain stormwater runoff.

Heather Burkert, the landscape architect for Lakeside at Holden Beach, said low-impact development designs will be incorporated by using covenants and deed restrictions to require each house to use elements such as cisterns, or devices that capture rain and feed the lot's irrigation system.

Each of the planned 221 homesites in the community will have rain gardens to collect stormwater runoff and cisterns to collect roof water.

In addition, most streets will allow stormwater runoff to flow into vegetative swales that will transport stormwater to infiltration areas to remove pollutants.

"We became cognizant by studying what the land was already doing and trying to respect that and work with the land instead of trying to control it," Burkert said.

The master plan for Lakeside has been approved by the county, and the community's developer, Stone Chimney Development LLC, plans to break ground on the site sometime next year.

Burkert said she believed the developer would be the first to turn in a stormwater permit application using low-impact development techniques outlined in the county's proposed resolution.

“We have been interested in this a long time, and now they’re allowing us to do it,” she said.

Shannan Bowen: 264-8345

shannan.bowen@starnewsonline.com

3609 Highway 24 (Ocean) Newport NC 28570

North Carolina Coastal Federation I 3609 Hwy 24 (Ocean) I Newport, NC 28570
Phone: 252-393-8185 I Fax: 252-393-7508 I Email: nccf@nccoast.org I Web: http://www.nccoast.org

Press Release

November 25, 2008
NCCF contact: Lauren Kolodij
Phone: 252-393-8185 **Cell:** 910-262-5178
E-mail: laurenk@nccoast.org
N.C. DOT contact: Lisa Craley
Phone: 919-733-2522

Coastal Federation, Brunswick County, N.C. DOT to examine low impact development for road projects

Wilmington, N.C.—Thanks to the N.C. Clean Water Management Trust Fund (CWMTF), a non-profit, a local government and a state agency will be able to collaborate on ways to incorporate low impact development (LID) practices into state highway and development construction by reducing stormwater flows. And reducing polluted stormwater will help clean up local waters.

The North Carolina Coastal Federation (NCCF) has received a $75,650 grant from the CWMTF to initiate a cooperative LID planning process with Brunswick County and the N.C. Department of Transportation's Highway Stormwater Program (NCDOT). The project will identify cost-effective options for the use of LID design practices into highway infrastructure projects that may help protect and restore the water quality in the Lockwood Folly River watershed. It will also provide LID tools to developers working in the area as part of a holistic approach to tackling water quality problems.

Stormwater is rain water that falls upon hardened, or impervious, surfaces, picking up pollutants on the ground and flushing them into our creeks, rivers and sounds. LID practices seek to use planning, design features and other techniques to capture and treat polluted stormwater and protect water quality.

In the project, NCDOT, LID experts and engineers from the Maryland and Florida DOTs will examine LID practices as cost-saving measures in real-world highway and road projects. The discussion will provide information for NCDOT engineers as they move forward with planning other road projects.

Dave Henderson, NCDOT's State Hydraulics Engineer, said, "The project comes at an opportune time for our interagency planning process. The information we develop will have long-term implications for future DOT practices."

The project expands upon previous work and the momentum generated by ongoing efforts to protect and restore valuable shellfishing and recreational waters of the Lockwood Folly River. NCCF and the county brought together major stakeholders in a group called the Lockwood Folly Roundtable. In 2007, this group recommended a blueprint of nine actions to protect and restore water quality in the Lockwood Folly River. Brunswick County commissioners subsequently accepted the blueprint, and this project represents another step in implementing three of the recommendations: (1) promoting better coordination of the dozens of federal, state and local government programs and agencies involved in environmental management; (2) promoting widespread use of LID practices in new land developments and (3) encouraging projects that reduce existing levels of stormwater pollution by facilitating the identification, design, construction and maintenance of retrofit projects.

NCDOT owns and operates the county's largest stormwater drainage system, and the agency wants to see how LID might be used to improve the county's water quality issues in a cost-effective way.

The CWMTF was established 1996 to help finance projects that enhance or restore degraded waters, protect unpolluted waters, and/or contribute toward a network of riparian buffers and greenways for environmental, educational and recreational benefits.

###

The North Carolina Coastal Federation is the state's only non-profit organization focused exclusively on protecting and restoring the coast of North Carolina through education, advocacy and habitat restoration and preservation. Its headquarters and central regional office are located at 3609 Highway 24 in Ocean between Morehead City and Swansboro. The Federation also has a northeast regional office in Manteo and a southeast regional office in Wilmington. For more information call 252-393-8185 or check out NCCF's website at www.nccoast.org

Runoff a likely culprit for Lockwood Folly bacterial woes

Staff photo | Shannan Bowen
Consultant Jason Doll (left) and Mike Giles of the N.C. Coastal Federation discuss a project that attempts to pin-point sources of pollution in the Lockwood Folly River.

By Shannan Bowen
Staff Writer

Published: Sunday, April 12, 2009 at 5:50 p.m.
Last Modified: Sunday, April 12, 2009 at 5:50 p.m.

Sunset Harbor | Rainfall and stormwater runoff are most likely to blame for the Lockwood Folly River's troubled waters.

A preliminary analysis of water samples, taken from the Brunswick County river over the course of a year, showed the highest levels of bacteria and other pollutants flowed to the river with stormwater runoff from paved surfaces and other areas, said Mike Giles, the Cape Fear Coastkeeper with the N.C. Coastal Federation.

Many landscapes, developed or not, allow rain to run off into the river, carrying bacteria from animal waste, chemicals from vehicles and fertilizers from yards, for example, into the water.

More than half of the river is already closed to shellfishing because of bacterial pollution long suspected from stormwater runoff, failed septic tanks and other causes.

This prompted years of study by county officials and environmental agencies in search of ways to reduce the river's pollution and restore its shellfishing areas.

Collecting samples from the river was the first step in a project funded by the U.S. Environmental Protection Agency to attempt to pinpoint pollution sources in the river.

More than a dozen volunteers helped Giles collect water samples over the past year, which were then sent to a lab and tested for fecal coliform and other bacteria.

Jason Doll, a consultant for Stantec Consulting in Raleigh, will take the sample results and create a mathematical computer model showing how much pollution needs to be reduced to restore the river and meet water quality standards.

Giles said test results averaged 350 to more than 1,000 fecal coliform colonies per 100 milliliters of water. The state's water quality standards for safe consumption of shellfish is just 14 colonies per 100 milliliters of water, he said.

Doll said it wasn't surprising that the highest contamination levels were found after rainfall, but where they found those high levels was interesting.

Doll said he thought water samples showing the highest levels of fecal coliform bacteria would be taken from areas in the river near developed land.

"But people have developed near the estuary, where there is more saltwater," he said, adding that saltwater kills some of that harmful bacteria.

Doll said most of the higher levels of pollution were found in tributaries, where there was less salinity and flushing of the river.

But many people are starting to purchase and develop land along the river's tributaries since most of the land along the estuary has already been purchased and developed, Giles said.

"It will just increase the problem if we don't develop it correctly," he said. "More and more people want to be on the river."

Doll, Giles and the team of volunteers gathered at an oyster roast April 3 to celebrate the completion of the sampling project.

Doll said he hoped to have the computer model completed by late summer.

A list of strategies to keep the river clean, including low-impact development techniques and retrofitting drainage systems, will then be created and presented to county officials for implementation.

Shannan Bowen: 343-2016

shannan.bowen@starnewsonline.com

North Carolina Coastal Federation

North Carolina Coastal Federation | 3609 Hwy 24 (Ocean) | Newport, NC 28570
Phone: 252-393-8185 | Fax: 252-393-7508 | Email: nccf@nccoast.org | Web: http://www.nccoast.org

Press Release

FOR IMMEDIATE RELEASE

June 2, 2009

Contact: Tracy Skrabal
Phone: 910-790-3275x201
Email: tracys@nccoast.org

Community Wetland Planting and Clean Water Event Scheduled in Bolivia, June 9

Wilmington, N.C. – The partnership of the North Carolina Coastal Federation, Brunswick County, the N.C. Cooperative Extension Service and the Brunswick Soil and Water Conservation District invite all area residents and visitors to a community wetland planting and clean water educational event. The event will take place at the Brunswick County Government Complex Cooperative Extension Offices (Building N) in Bolivia on Tuesday, June 9, from 10:00 a.m. to 12:30 p.m.

Participants will learn about the health of their local creeks and simple things they can do in their back yards to protect area water quality. Information on back yard rain gardens and rain barrels and other steps people can take to reduce stormwater runoff and nuisance flooding will be available. Visitors can visit a backyard rain-garden and a stormwater treatment wetland.

For those who want to get their hands dirty, there will be a volunteer wetland planting on-site at the Government Complex. Once complete, this created wetland will capture and treat polluted rainwater before it has a chance to become polluted runoff. It is the first of many stormwater retrofits that N.C. Coastal Federation, Brunswick County and Stantec Engineering will be constructing within the Lockwood Folly watershed as part of a water quality demonstration project. This project is an important component of the Lockwood Folly Watershed Strategy and builds upon the work of many volunteer hours spent monitoring the river.

Volunteer planters are welcome and needed, and the public is invited to attend the clean water event, and/or help to plant the wetland. Those interested in planting should contact Tracy Skrabal at the N.C. Coastal Federation at 910-790-3275 for more information and to sign up to plant.

###

The N.C. Coastal Federation is the state's only non-profit organization focused exclusively on protecting and restoring the coast of North Carolina through education, advocacy and habitat restoration and preservation. Its headquarters and central regional office are at 3609 N.C. 24 in Ocean between Morehead City and Swansboro. The federation also has a Northeast Regional Office in Manteo and a Southeast Regional Office in Wilmington. For more information or to join call 252-393-8185 or visit the federation's website at www.nccoast.org

North Carolina Coastal Federation | 3609 Hwy 24 (Ocean) | Newport, NC 28570
Phone: 252-393-8185 | Fax: 252-393-7508 | Email: nccf@nccoast.org | Web: http://www.nccoast.org

Press Release

FOR IMMEDIATE RELEASE
September 18, 2009

Contact: Ted Wilgis
Phone: 910-790-3275 x 202
Email: tedw@nccoast.org

Water Quality Projects to Restore the Lockwood Folly River Installed at the Brunswick County Government Center—Tour Available Sept. 24

Bolivia, N.C. – The partnership of the North Carolina Coastal Federation (NCCF), Brunswick County, the N.C. Cooperative Extension Service, Brunswick Soil and Water Conservation District, with engineering support from Stantec Consulting, has completed the installation of a rain garden and stormwater wetland at the Brunswick County Government Center in Bolivia. NCCF will give a tour of the stormwater wetland and rain garden to the public and media on Thursday, September 24 at 12:30 pm.

NCCF and the project partners are installing a series of measures at the government complex to capture and treat polluted stormwater from the site before it enters local creeks and the Lockwood Folly. Earlier this summer, volunteers and staff from project partners spent two days installing over 1,500 wetland plants in the wetland and rain garden.

The stormwater project not only improves water quality in the Lockwood Folly River but also educates and encourages others to implement low-impact development (LID) measures in the watershed. LID's goal is to use a natural landscape to absorb and treat stormwater close to its source before it can degrade water quality in local creeks and rivers.

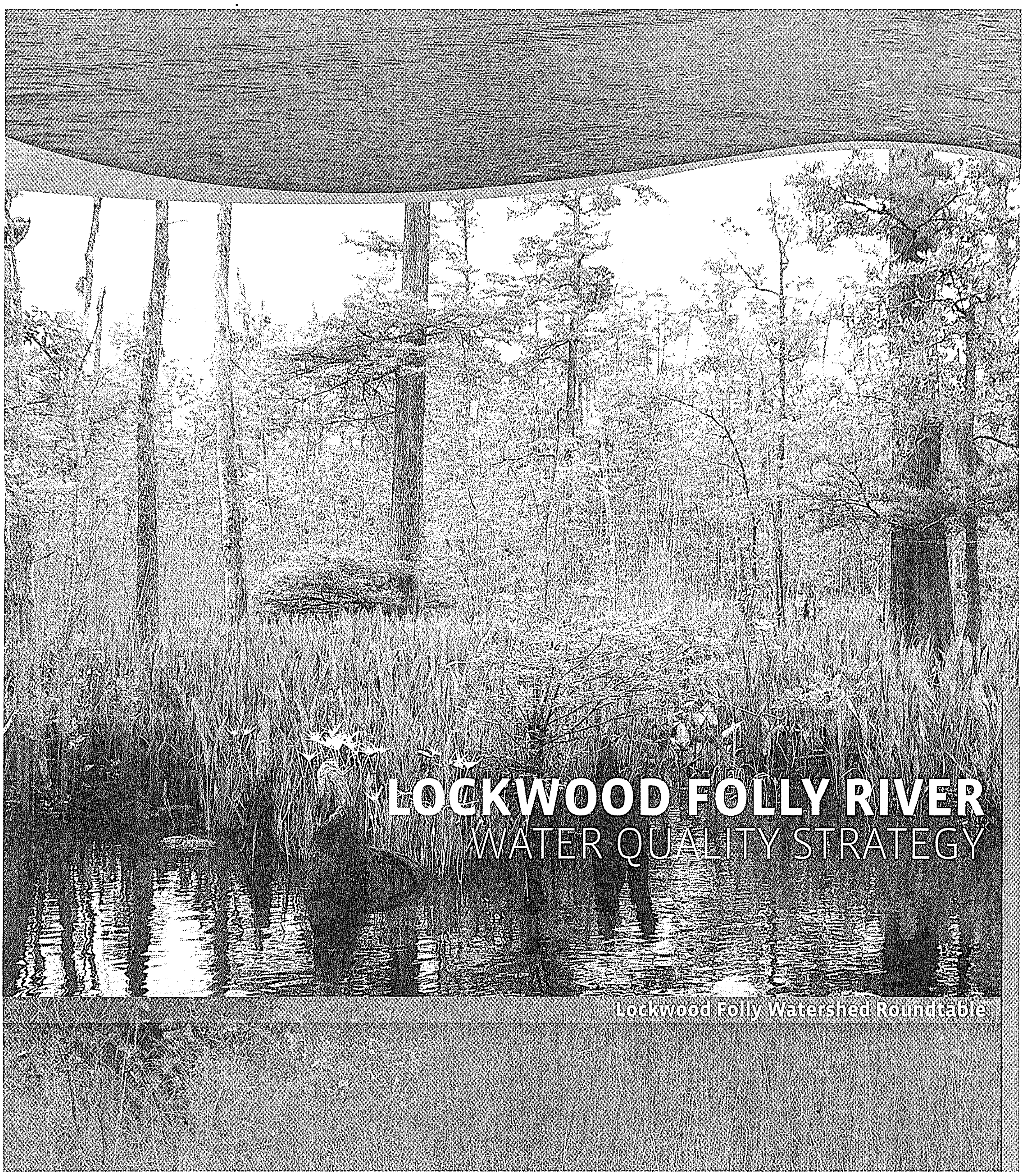
Stormwater runoff, the primary source of surface water pollution, is water from rain or irrigation that flows over land and into local creeks, streams and waterways. Runoff carries pollutants such as pet waste, auto fluids, fertilizers, pesticides and litter through the drainage system and directly into our waterways.

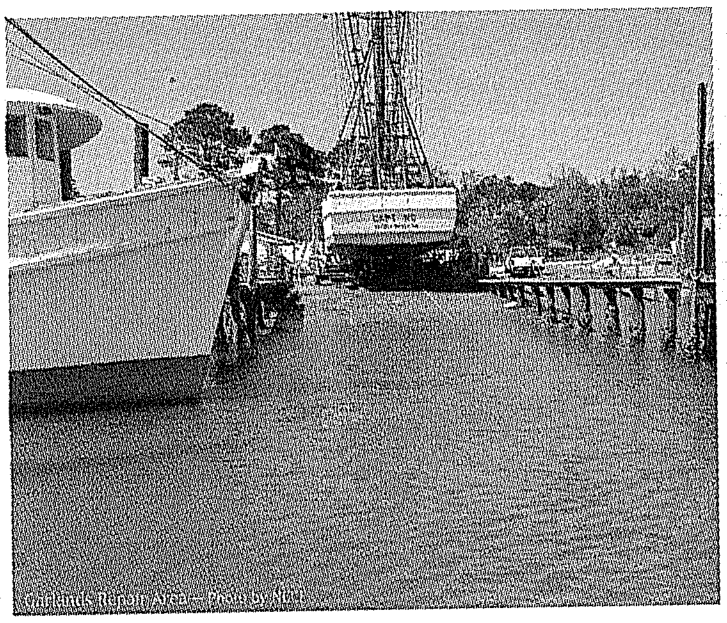
The N.C. Attorney General's Environmental Enhancement Grant Program funded the project. This project site was identified as an ideal candidate for a water quality demonstration and education project during a two-year watershed planning and monitoring project for the Lockwood Folly watershed and is part of the Lockwood Folly Watershed Strategy. The project is also a component of the Cape Fear Arch Conservation Collaboration, which consists of a diverse group of organizations, including NCCF, interested in conserving natural resources and enhancing water quality in Brunswick, Columbus, New Hanover, Sampson, Pender and Bladen Counties in North Carolina and Horry and Georgetown Counties, South Carolina.

The tour will start at the Brunswick County Government Complex Cooperative Extension Offices (Building N) in Bolivia. Those interested in the tour should contact Ted Wilgis at the N.C. Coastal Federation at 910-790-3275 or tedw@nccoast.org for more information.

###

The N.C. Coastal Federation is the state's only non-profit organization focused exclusively on protecting and restoring the coast of North Carolina through education, advocacy and habitat restoration and preservation. Its headquarters and central regional office are at 3609 N.C. 24 in Ocean between Morehead City and Swansboro. The federation also has a Northeast Regional Office in Manteo and a Southeast Regional Office in Wilmington. For more information or to join call 252-393-8185 or visit the federation's website at www.nccoast.org.


LOCKWOOD FOLLY RIVER
WATER QUALITY STRATEGY
Lockwood Folly Watershed Roundtable



Garlands Repair Area – Photo by NCC

Docks – Photo by NCC

"We thank the roundtable for its dedicated work in crafting these strategies"
–DAVID SANDIFER: CHAIR, BRUNSWICK CO. BOARD OF COMMISSIONERS

Growth: A Balancing Act

Brunswick County isn't a hidden treasure anymore. Since 1980 the county's population has tripled to more than 93,000, and another 35,000 residents are expected to arrive by 2020.

The tremendous influx of people earned Brunswick the title of 55th fastest growing county in the country between April 2000 and July 2006.

But the pressures of absorbing that much growth that quickly are being felt throughout the county, from crowded schools to clogged roads.

The environment is no exception.

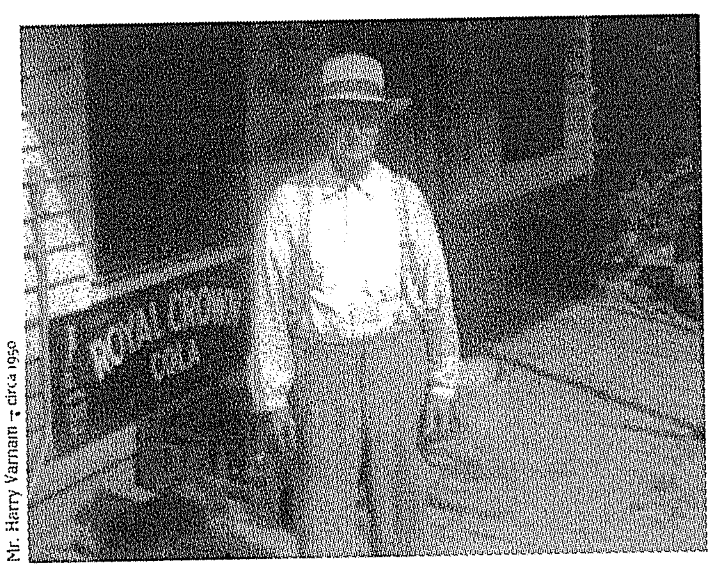
For generations, locals have enjoyed the bounty of Lockwood Folly, a river and estuarine system between Holden Beach and Oak Island famed for its rich shellfish beds.

But the surging development within the 150-square-mile watershed has had a severe effect on the health of the river.

The portion of the river closed to shellfishing has more than tripled from 18 percent in 1980 to 55 percent today.

Residents have just to look over the Cape Fear River to New Hanover County, where all but one of the county's tidal creeks are permanently closed to shellfishing, to see what unbridled growth can do to water quality.

Worried about the river's health and the continued viability of the local fishing industry the Brunswick County Board of Commissioners two years ago teamed up with the N.C. Coastal Federation, the U.S. Environmental Protection Agency and the state Ecosystem Enhancement Program to establish the Lockwood Folly Watershed Roundtable.



Mr. Harry Varnam – circa 1950

The eight-member group, which included participants from a range of backgrounds, was tasked with developing strategies to balance development with the needs of the environment. The resulting proposal creates a blueprint for "green" growth. The Board of Commissioners voted to accept the strategies in February and will convene work sessions in the coming months to plan implementation.

The strategies range from educating the public about the importance of protecting water quality to changing land-development policies to protect vulnerable water quality.

Together, they offer Brunswick County a roadmap to a future where development doesn't have to come at the expense of the environment.

"We thank the roundtable for its dedicated work in crafting these strategies," said David Sandifer, chairman of the county commission. "It will take a combination of these techniques and sustained effort from everyone for our county to grow wisely while protecting our natural environment."

Stormwater and Low Impact Development

Stormwater runoff is the top polluter of North Carolina's coastal waters.

The idea of low impact development, or LID, is to catch and treat runoff from roofs, driveways, streets and other impervious surfaces on site before it reaches a stream, channel or culvert – and eventually the Lockwood Folly River.

LID does not limit a site's development potential but instead calls for developing more thoughtfully by using the landscape and small-scaled engineering techniques to keep water where it falls.

An economic study by N.C. State University demonstrated that using LID practices instead of conventional development methods can reduce the costs of expensive stormwater ponds, resulting in substantial savings for the developer.

Along with gaining favored status in stormwater planning, LID also would be integrated into development policies for the watershed.

Another Roundtable strategy calls for extending sewer service to portions of the watershed where there's a history of failing septic systems, another major source of pollution in the river.

The Roundtable recommendations also include promoting increased coordination between federal, state and local agencies to streamline and better focus the regulatory oversight within the watershed.

But the citizen group wasn't interested in just passive ways to stabilize the river's health, they also wanted to actively protect water quality and jumpstart the recovery process.

That includes seeking partners, from both the public and private sectors, to help acquire from willing sellers land critical to protecting water quality.

Programs to retrofit existing properties, since runoff from them is the cause of many of the river's current woes, also are proposed along with new initiatives to stabilize eroding shorelines.

In all, the strategies recommended by the Roundtable are intended to complement, not hinder development in the Lockwood Folly watershed.

By working with developers and reaching out to residents, the foundation for a healthier Lockwood Folly watershed where development and the environment can coexist becomes an attainable goal.

We welcome your help as we work to keep the Lockwood Folly River a resource we all can continue to enjoy.

Strategies FOR THE LOCKWOOD FOLLY RIVER:

Prevention, Planning and Strategic Restoration

The following is a brief outline of the strategies accepted by the Brunswick County Commission. The County will be conducting work sessions in upcoming months to explore ways of prioritizing and implementing the strategies to protect and restore the river. For more the full Roundtable report and notices about the work sessions, visit the county's website at www.brunsco.net.

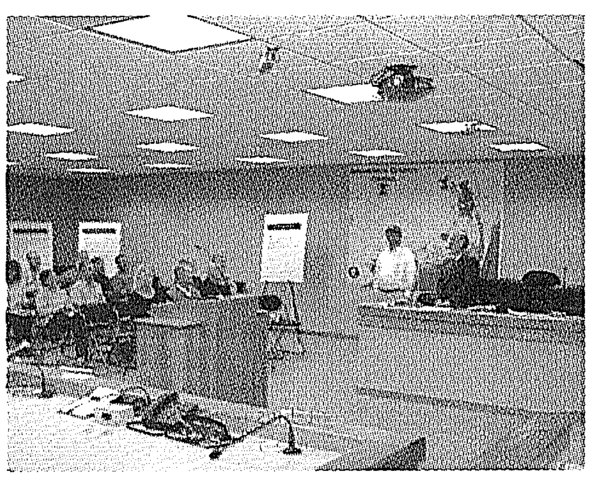
These strategies are designed to guide future growth and development in the watershed and set priorities to preserve fragile habitat and restore degraded water quality. All of the experts and Roundtable members emphasize that no single strategy is a 'silver bullet'. Lasting, significant changes in the downward trend of water quality in the Lockwood Folly River will take coordinated implementation of all of these strategies.

(1)

A) Assess water quality risk according to natural systems in the watershed and develop future land use policies and ordinances that fit land use density and landscape design to the level of water quality risk.

B) Sewer extension policies that: 1) give priority services to communities with malfunctioning septic tanks, and 2) ensure that land use and development policies in wastewater service areas are consistent with risks to water quality.

These strategies would look at hydrologic features and assign water quality risk factors and use them to determine the appropriate type and density of development. Possible implementation options include using cluster housing neighborhood design for a given amount of development and limiting built-upon surfaces in the most vulnerable areas.



Public Meeting-Photo by, NCCF

(2) Incorporate low impact development (LID) technology into county site design and development policies. The strategy will include methods to integrate this tool into the county's existing development management program as an option for developers. LID is a comprehensive land planning and engineering design approach that seeks to maintain and improve the pre-development hydrology of a developing watershed. LID uses the natural capacity of land to soak up rainfall and prevent contaminated stormwater runoff from entering water bodies. These techniques were the basis for a national conference held in Wilmington in March, which featured Brunswick County's work on the Lockwood Folly as a case study. For more information about LID, visit www.lowimpactdevelopment.org.

(3) Coordinate state, local and federal regulatory programs with Brunswick County taking the lead enforcement role and fostering inter-local cooperation. This strategy suggests policy changes and a financial plan to implement it.

(4) Create an action plan to acquire strategic sites and properties to protect and restore water quality. Sites would be targeted according to a comprehensive selection method, and would be acquired from willing property owners by partnerships with the nonprofit community and state and federal agencies.

(5)

A) Develop a public education, information and outreach program. Involve the public so that protecting and restoring water quality in the Lockwood Folly River becomes an important local priority.

B) Recognize the environmental and cultural significance of the Lockwood Folly River through federal Wild and Scenic River designation. This non-regulatory designation will underscore the special nature of the river as development in the area continues to increase.

(6) Protect stream edges in the watershed by implementing a 'living shorelines' program. A living shoreline is an innovative alternative to bulkheads for shoreline stabilization, erosion control and stormwater buffer and wildlife habitat restoration. This strategy involves possibly creating a cost-share program for living shoreline restoration projects and incorporating language supporting living shorelines into the county's CAMA land use plan.

(7) Identify sites for water quality 'retrofit' to reduce or eliminate unwanted runoff. The county should work with state agencies such as the NC Ecosystem Enhancement Program and non-profit organizations to secure funding to address targeted sites for retrofit identified by the Roundtable.

(8) Develop a financial incentive program that encourages developers to take alternative approaches that support water quality objectives. Development practices, such as LID, conservation easements and preservation of wetlands, which are protective of water quality, would be rewarded with mechanisms such as a streamlined review process, favorable ad valorem tax treatment, and tax-advantaged donations.

(9) Develop a working waterfront program that assists in the preservation of traditional waterfront businesses, such as fish houses and commercial marinas, and public access sites, such as boat ramps and fishing piers.

The full report on the Roundtable's findings and strategy implementation options and the first tabloid are available on the county's website at www.brunsco.net. Check the website for notice of the work sessions that the county will hold to plan to how to put the strategies into action.

LEARN MORE ABOUT WATER QUALITY:

Brunswick County
www.brunsco.net

NC Ecosystem Enhancement Program (EEP)
www.nceep.net

NC Stormwater Program
www.ncstormwater.org

US EPA 303(d) list of impaired water bodies
h2o.enr.state.nc.us/tmdl/General_303d.htm#Downloads

NC Division of Water Quality (DWQ)
h2o.enr.state.nc.us

NC Division of Coastal Management (DCM)
dcm2.enr.state.nc.us

NC Division of Environmental Health, Shellfish Sanitation and Recreational Water Quality Section (DEH)
www.deh.enr.state.nc.us/shellfish/index.html

North Carolina Coastal Federation
www.nccoast.org

Help Protect the River

Check the county's website to see the full draft report and to find out about the upcoming work sessions.

BRUNSWICK COUNTY
NORTH CAROLINA

Forty thousand copies of this tabloid were printed at a cost of $2002.49, at a cost of .05 per copy. This document was produced with funding from the US Environmental Protection Agency.