LOWER CAPE FEAR RIVER PROGRAM
CENTER FOR MARINE SCIENCE

THE UNIVERSITY OF NORTH CAROLINA WILMINGTON
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March 5, 2014

Mr. Tom Reeder
Director, Division of Water Resources
NC Department of Environment and Natural Resources
1611 Mail Service Center
Raleigh, NC 27699-1611

Subject: Request for Reclassification of a Portion of the Lower Cape Fear River with the Supplemental Swamp Classification

Dear Mr. Reeder:

The purpose of this letter is to formally request that the Division of Water Resources (DWR) recommend to the Environmental Management Commission (EMC) that portions of the Lower Cape Fear River Estuary (LCFRE) that are currently classified as Class SC Waters be reclassified to include the supplemental Swamp (Sw) classification. This would recognize the influence of natural drainage from riverine wetland and salt marsh systems that are ubiquitous throughout the Lower Cape Fear River, Northeast Cape Fear River and Black River watersheds on water quality conditions in the river. This would be consistent with the classifications of immediate upstream segment of the Cape Fear River and the tributaries which all currently carry the supplemental Sw classification.

Information typically requested by DWR for reclassification requests is included in Table 1 and a map showing the area being requested for consideration for the Sw supplemental classification is included as Figure 1. An additional map based on the US Geological Survey 7.5 minute topographic maps will be included in the hard copy of this letter and attachments.

Information typically requested by DWR for reclassification requests is included in Table 1 and a map showing the area being requested for consideration for the Sw supplemental classification is included as Figure 1. An additional map based on the US Geological Survey 7.5 minute topographic maps will be included in the hard copy of this letter and attachments.

This letter provides additional background on the Lower Cape Fear River Program (LCFRP) and this specific request and a summary of supporting technical papers that have been prepared.

Background on LCFRP and LCFRE

The Lower Cape Fear River Program is an integrative effort which brings together a coalition of citizens groups, industry, business, local, regional, and state government, and the university community. The Lower Cape Fear River Program (LCFRP) was formed in May, 1994 to develop an understanding of the fundamental scientific processes shaping and controlling the Cape Fear River Estuary and provide a mechanism for information exchange and public education. It is administered in cooperation with the University of North Carolina Wilmington's Center for Marine Science.

Since the group was formed, comprehensive data to assess ecological conditions in the river has been collected. The LCFRP was one of the first coalition monitoring groups established through a memorandum of agreement (MOA) with NC Department of Environment and Natural Resources (DENR) that relieves NPDES permit holders of individual requirements to perform instream monitoring and replaces that with a comprehensive and coordinated monitoring program. Currently, there are 17 NPDES permit holders that are party to the MOA, but many other advisory board members from throughout the lower basin as listed on the border on the first page of this letter. All of the monitoring data is submitted to DENR in accordance with the MOA. The program also has an interactive data base available on the internet where the LCFRP data can be accessed. This site also includes data from the Middle and Upper Cape Fear River Basin coalition groups for a comprehensive tool to review water quality conditions for the entire river basin.

Beginning in 1998, the section of the LCFRE from upstream of Toomers Creek to a line across the river between Lilliput Creek and Snows Cut has been listed on the State of North Carolina's 303d List as impaired for DO. In 2006, DENR added pH as impaired for this segment, and in 2008, DENR added copper and turbidity to the listing, as well. The draft 2014 303d List maintains these impairments despite some changes to the listing methodology (DENR, 2014).

Until recently, DENR had been pursuing development of a total maximum daily load (TMDL) to establish what were originally believed to be reduction needs for oxygen-demanding pollutants, including biochemical oxygen demand (BOD) and ammonia nitrogen (NH_3-N). An extensive effort had gone into developing a three-dimensional hydrodynamic and water quality model (using the Environmental Fluid Dynamics Code, or EFDC, model) between 2000 and 2009. This model provides an excellent tool for evaluating water quality conditions in the LCFRE. Based on the modeling analysis, the DENR determined that developing a TMDL using the existing standard for the Class SC portion of the LCFRE of 5 milligrams per liter (mg/L) (at all times) would not be appropriate because the modeling results indicate that point-source discharges have a relatively minor impact on DO levels, and that even significant reductions in background (both natural and nonpoint source) loads would not result in attainment of the current standard for considerable periods of time during the summer. Recently, DENR indicated that changes to the classification of the LCFRE might be appropriate to recognize the influence of natural drainage from riverine and saltwater marsh systems in the watershed on DO concentrations. A reclassification with the supplemental Sw classification would allow the water quality standards for DO and pH to be interpreted with narrative portion of the standard [from 15A NCAC 2B .0220 (3)]:

> *(b) Dissolved oxygen: not less than 5.0 mg/l, except that swamp waters, poorly flushed tidally influenced streams or embayments, or estuarine bottom waters may have lower values if caused by natural conditions;*
>
> *(g) pH: shall be normal for the waters in the area, which generally shall range between 6.8 and 8.5 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;*

It is recognized that with this classification change, DWR will still require the development of implementation procedures for determining allowable waste load allocations for point source discharges.

Supporting Information

There is a wealth of research and technical assessment studies that have been conducted on the LCFRE since the formation of the LCFRP in 1995, as well as during the 40 years prior to that time. In discussing this reclassification request with DWR staff, it was suggested that a summary of information be prepared to support the reclassification request. Four Technical Memoranda (TM) have been prepared in support of this reclassification request and are included as Attachments to this letter. The following is a brief summary of each TM.

TM 1 - Summary of Background Information and Previous Studies for the Lower Cape Fear River

This TM served to review available background information for the LCFRE dating back to original studies in the 1950s where water quality and pollutions sources were assessed and initial recommendations on stream classifications were made. Key studies and assessments up to the present time were also reviewed and a bibliography or studies and research papers was also included. A several of the key points from this TM include:

- Swamp influences were identified even during the early studies and the entire LCFRE and tributaries were recommended and subsequently classified with the supplemental Sw classification

- The supplemental Sw classification was removed from the Class SC portion of the Cape Fear River in 1981 without extensive evaluation for the basis of this change

- LCFRP monitoring in the mid to late 1990s documented the impact of swamp drainage following hurricanes, similar to what was documented during the 1990s

- The EFDC hydrodynamic and water quality model completed in 2009 demonstrated that the point sources had a minor contribution to the DO deficit and that even with 30 to 70 percent reductions in loadings of oxygen demanding materials from tributaries and wetlands/marsh systems (a combination of anthropogenic and natural sources), the DO standard of 5 mg/L could not be achieved between 20 and 30 percent of the time.

TM 2 - Updated Trend Analysis of DO Conditions and Pollutant Loading from Point Sources

This TM was an update of an analysis done in 2003. The previous DO trend analysis found no statistically significant trend for DO for the period of 1984 through 2002 for DO conditions at several stations within or immediately adjacent to the 303(d) listed portion of the LCFRE. The same conclusion was drawn for the period of 1991 through 2002, despite a statistically significant reduction in major point source ultimate biochemical oxygen demand (BODu) load of approximately 25 percent for that period. The updated analysis used monitoring data and information on point source loading from 1994 through 2013. The updated point source analysis focused on International Paper and Cape Fear Public Utilities Authority (CFPUA) Northside and Southside discharges since these facilities comprise over 90 percent of the point source loading to the local watershed. This analysis also showed no significant trend in DO levels in the LCFRE over the 20 year period while the loading of BODu from these three facilities declined by 23 percent over the same time period. This analysis confirms model results indicating that point sources are having a minor impact on DO levels in the LCFRE.

TM 3 - Analysis of Long-term Data near the Limits of the Tidal Influence for the Cape Fear River, Black River, and NE Cape Fear River

This TM presents an analysis of water quality parameters at the sampling stations representative of inflows to the system, with the purpose of examining issues related to a supplemental Sw classification for the estuary. Data was examined for several key parameters, including nutrients, pH, and DO, that are related to the occurrence of low DO in the Cape Fear River. The evaluation of water quality data at the boundary conditions supports the concept that inflows from the swamp areas have a significant impact on water quality in the Cape Fear River. The levels of nutrients, DO, and pH are consistently different between the station at Lock & Dam 1 (L&D1) on the main stem of the Cape Fear River, and in the major blackwater tributaries – the Black River and the NE Cape Fear River. A distinct response from these inflows can be seen in the levels for these parameters in the portion of the Cape Fear River near Navassa, providing additional supporting evidence that water quality in the Cape Fear River is significantly influenced by the conditions found in the swamp areas tributary to the river downstream of L&D1.

TM 4 - An Analysis of Model Results to Assess the Relative Impact of Riparian Wetlands and Salt Marshes versus other Tributary Loadings

This TM used the results of the two modeling efforts with the EFDC model in the 2000s to examine the technical basis for a supplemental Sw classification for the LCFRE. The two modeling studies included the initial EFDC model developments by Tetra Tech on behalf of the City of Wilmington and New Hanover County and the follow up work by the University of North Carolina – Charlotte on behalf of NC DENR. Both modeling efforts demonstrated that the impact from point source loads in the LCFRE contributes to less than 10 percent of the DO deficit in the LCFRE. The 2001 modeling effort demonstrated that an accurate calibration could not be achieved without representing the wetting and drying of adjacent low elevation wetland and salt marsh areas. That modeling estimated that wetland/marsh and sediment oxygen demand (SOD) sources accounted for between 75 and 80 percent of all oxygen demand in the LCFRE. The 2009 modeling effort validated and expanded the influence of adjacent marshland based on more detailed analysis. Further, application of the 2009 model that simulated up to 70 percent of nonpoint source load reduction demonstrated that even with such large pollutant loading reductions, DO concentrations would be expected to be below 5 mg/L approximately 20 percent of the time in the LCFRE during the summer. Therefore, the 2001 and 2009 modeling analyses provide further weight of evidence collectively that flow and oxygen-demanding loads from wetlands/marsh systems SOD are driving low DO during the summer period and suggest that reinstitution of the supplemental Sw designation for the LCFRE should be considered by DENR and the EMC.

Summary

It is clear from the data collection, modeling and technical analyses that the DO standard of 5 mg/L for the LCFRE is not appropriate since it is not achieved a significant portion of the time as a result of natural drainage from riverine wetlands and salt marshes. From a regulatory standpoint, a straightforward way to deal with this issue is to reclassify the area with the supplemental Sw classification. The information summarized in this letter and the attached TMs support this classification action.

Our organization appreciates DENR and the EMC's consideration of this request. We are also willing to provide further information and analysis related to this request as needed.

Sincerely,

Chris May
Chair Lower Cape Fear River Program Advisory Board and
Executive Director, Cape Fear River Council of Governments

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c: LCFRP Advisory Board and Technical Committee Members
Bill Kreutzberger/CH2M HILL
Trevor Clements/Tetra Tech

Table 1.
DWR Requested Information in Support of Reclassification Requests

Date of Request	March 6, 2014
Requested by	Lower Cape Fear River Program
River Basin and Counties	Cape Fear River Basin New Hanover and Brunswick Counties
Water bodies requested for Reclassification	Water Body: *Cape Fear River* Description: *From a point upstream Toomers creek to a line across the river from Snows Point (through Snows Marsh) to Federal Point* Index No.: *18-(71)* Current Classification: *SC* Requested Classification: *SC Sw*
Map	See Figure 1 from 7.5 minute USGS GIS Information
Rationale for Request	See text of letter and attached Technical Memoranda
Local Champions for Request	Lower Cape Fear River Program Members

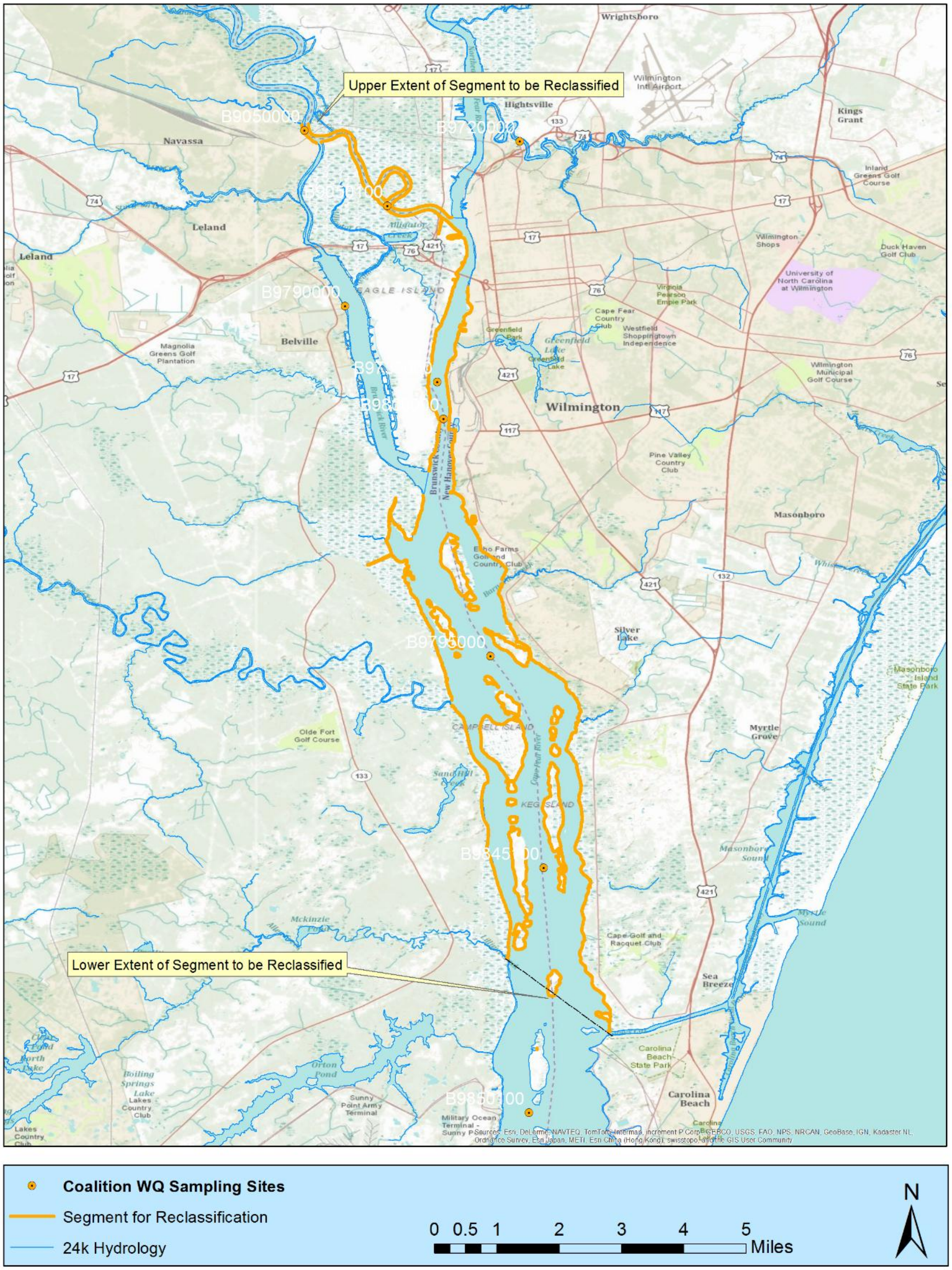

Figure 1.

Requested portion of Lower Cape Fear River Estuary for Consideration for Supplemental Swamp Classification

Attachments

TM 1 - Summary of Background Information and Previous Studies for the Lower Cape Fear River

TM 2 - Updated Trend Analysis of DO Conditions and Pollutant Loading from Point Sources

TM 3 - Analysis of Long-term Data near the Limits of the Tidal Influence for the Cape Fear River, Black River, and NE Cape Fear River

TM 4 - An Analysis of Model Results to Assess the Relative Impact of Riparian Wetlands and Salt Marshes versus other Tributary Loadings

Technical Memo:
Task 1 – Summary of Background Information and Previous Studies for the Lower Cape Fear River

Prepared for

Lower Cape Fear River Program

Prepared by

CH2MHILL®

February 25, 2014

1 Introduction

The purpose of this technical memorandum (TM) is to identify available data and studies pertaining to the Lower Cape Fear River Estuary (LCFRE), and highlight key information pertaining to the influence of natural drainage from riverine and saltwater marsh systems in the watershed on dissolved oxygen (DO) conditions. This information is being summarized at a high level, for further consideration as the North Carolina Department of Environment and Natural Resources (DENR) and Environmental Management Commission consider appropriate stream classification and associated water quality criteria for the Cape Fear River.

1.1 BACKGROUND

The Lower Cape Fear River Program (LCFRP) was established in 1995 as a collaborative effort by public, private, and academic interests to collect data and research information on the LCFRE and its coastal watershed. Since the group was formed, comprehensive data to assess environmental conditions in the river has been collected.

Beginning in 1998, the section of the LCFRE from upstream of Toomers Creek to a line across the river between Lilliput Creek and Snows Cut has been listed on the State of North Carolina's 303d List as impaired for DO. In 2006, DENR added pH as impaired for this segment, and in 2008, DENR added copper and turbidity to the listing, as well. The draft 2014 303d List maintains these impairments despite some changes to the listing methodology (DENR, 2014).

Until recently, DENR had been pursuing development of a total maximum daily load (TMDL) to establish what were originally believed to be reduction needs for oxygen-demanding pollutants, including biochemical oxygen demand (BOD) and ammonia nitrogen (NH_3-N). However, the DENR has recently determined that, based on the technical information compiled and assessed to date, developing a TMDL using the existing standard for the LCFRE of 5 milligrams per liter (mg/L) (at all times) would not be appropriate because the modeling results indicate that point-source discharges have a relatively minor impact on DO levels, and that even significant reductions in background (both natural and nonpoint source) loads would not result in attainment of the current standard for considerable periods of time during the summer. Recently, DENR indicated that changes to the classification of the LCFRE might be appropriate to recognize the influence of natural drainage from riverine and saltwater marsh systems in the watershed on DO concentrations.

There is a wealth of research and technical assessment studies that have been conducted on the LCFRE since the formation of the LCFRP in 1995, as well as during the 40 years prior to that time. Over the years, many technical studies of the LCFRE have been conducted by the LCFRP, DENR, other agencies and academic researchers, and consultants. As a result, an extensive technical foundation of knowledge on the LCFRE has been created, including information on physical, chemical, and biological features and processes.

1.2 SUMMARY OF AVAILABLE INFORMATION

A comprehensive listing of studies and research related to the LCFR has been included in the Attachment to this TM. In reviewing this information, it was decided to start with the early study of the river used to determine the stream classification and water quality standards and then move forward to the present. The following is a summary of this available information related to understanding the LCFRE, especially as it relates to assessing DO concentrations..

1.2.1 Original North Carolina State Board of Health Studies

Beginning in the mid-1950s and continuing until the early 1960s, the Division of Water Pollution Control of the State Board of Health conducted sanitary surveys of all the river basins in North Carolina, and made recommendations for stream classifications to be included in state water quality standards. The Cape Fear River Basin was sampled in 1955 and 1956, and the study report was published in 1957 (State Stream Sanitation Committee, 1957). This report includes analytical results from stream sampling and documented pollution loads from major sources of pollution.

The setting at the time of this study was that many towns and cities did not have any treatment, and industries varied from having no treatment to primary treatment facilities. There were no major impoundments in the Cape Fear Basin, so the basin experienced extreme ranges in flow conditions, depending on precipitation and hurricane conditions, which were apparent during 1955 when three hurricanes impacted eastern North Carolina.

In the lower river, there were two principal sources of pollution identified, the Riegel Paper Corporation (Riegel) and the City of Wilmington, plus numerous other smaller communities and industrial facilities. The following table summarizes the treatment and loads from the primary facilities.

Table 1. Primary Facility Treatment and Load Summary

Facility	Type of Treatment	Estimated Load (PE)
Riegel	Primary (13% efficient)	330,000
City of Wilmington	None	44,700
Timmie Manufacturing	Lagoon (20% efficient)	1,144
Wilmington Packing	Grease removal (20% efficient)	3,850
Wanet Sausage Co.	Grease removal (20% efficient)	3,200

Note:

PE - population equivalent

These loads cannot be directly transferred to the way oxygen-demanding loads are measured today. However, assuming 0.17 pounds per day (lb/d) of $CBOD_5$ per PE, this translates to about 65,000 lb/d of $CBOD_5$ discharged as highly reactive raw or primary treated waste. No information was presented in the study to estimate the nitrogenous (organic nitrogen and ammonia) oxygen demand load. This is estimated to be about 10 times greater than the current loading of $CBOD_5$ based on comparison with current discharger monitoring data. The water quality data demonstrated impacts on DO conditions in the river. Summertime DO levels from downstream of Riegel to downstream of Wilmington typically ranged from 2 to 3 mg/L, with some values considerably less than that. The highly reactive wastewater resulted in a double DO sag beginning just a few miles below the Riegel discharge to downstream of Wilmington.

Despite the significant impacts from untreated and poorly treated wastewater under low to moderate flow conditions in the river, two different situations influencing DO condition were also described in the report:

1. High flows from the Black and NE Cape Fear Rivers, and moderate flow from the Cape Fear River (data from August 30, 1955):
   - Low DO (1.3 to 2 mg/L) and low pH (5 to 6) coming from NE Cape Fear and Black Rivers
   - Resulting in low DO (1.3 to 2.2 mg/L) and low pH (5.8 to 6) in the typically brackish area below Wilmington
2. High flows from the Cape Fear River, and moderate flows from the NE Cape Fear and Black Rivers (data from July 23-24, 1956):
   - DO (2.8 to 4.9 mg/L and pH 6.8 to 7.2) conditions in lower river were moderate

They concluded that under some situations, swamp drainage conditions could significantly influence DO and pH conditions in the river, and recommended that the freshwater portion of the Lower Cape Fear River (LCFR) be Class C-Swamp (C-Sw) from the Riegel water intake to Toomers Creek, and Class SC-Swamp (SC-Sw) from Toomers Creek to the mouth of the Cape Fear River. These recommendation were adopted in 1962.

1.2.2 Reclassification in 1981

In 1981, a rule-making proceeding was initiated to remove the "Swamp" designation from waters classified as Class SA (for shellfishing). The record includes little basis for the removal of the Swamp designation from tidal saltwater classes other than statements that the designation is inconsistent with a shellfishing designation. There was little other discussion of the changes and nothing specific to Class SC waters. Based on the lack of objection, the Swamp designation was removed from a substantial portion of all tidal saltwaters in North Carolina in 1981 in conjunction with some other stream/coastal water classification changes (DEM, 1981). This action changed the classification of the Cape Fear River from “upstream of the mouth of Toomers creek to Atlantic Ocean” from Class SC Sw to Class SC. However, the Sw designation was not removed from the Class SC portion of the NE Cape Fear River by this action. As a result of this reclassification, the DO standard of not less than 5 mg/L at all times and pH standard not less than 6.8 became effective for the Class SC portion of the Cape Fear River, with no recognition of the potential influence of natural conditions.

1.2.3 Initial Water Quality Modeling

Despite significant improvement in wastewater treatment throughout the basin since the initial studies in the 1950s, there was a recognition that water quality conditions in the Cape Fear River might limit future industrial and urban growth. In addition, hydrological conditions in the basin had changed with the filling of Jordan Lake in 1981. This lake has a watershed of approximately 1,700 square miles (mi^2), and has authorized purposes of flood damage reduction, water supply, water quality control, fish and wildlife conservation, and outdoor recreation. With this changed hydrology, and significant urban and industrial growth in the Wilmington area, the Division of Environmental Management (DEM) initiated the development of a water quality model using a program called the Georgia Estuary Model (DEM, 1984). The U.S. Environmental Protection Agency (USEPA) and Georgia Environmental Protection Division had been promoting the model as a useful tool for coastal river/estuary systems and were in the process of applying the model to the Lower Savannah River along the Georgia-South Carolina border. Although the report was finalized in 1984, the model was not apparently used for any major permitting decisions for the river.

1.2.4 Federal Paperboard Co. Studies

In 1990, Federal Paperboard Co., the current owner of the facility formerly called the Riegel Paper Corporation, conducted a series of studies in order to resolve a long-time permit dispute. While the facility had greatly expanded treatment with the installation of an aerated stabilization basin (ASB) system, the facility and DEM could not agree on appropriate permit limits for the facility. This included development of a water quality model for the LCFR (Hydroscience, 1990) and extensive biological surveys on the LCFRE, as well as lower portions of the Black River and NE Cape Fear River (CH2M HILL, 1992).

The water quality model was developed as a slack-tide calibrated QUAL 2E model, recognizing that this was a conservative approach for modeling the impacts of the Federal Paperboard Co. discharge, since it did not consider dilution provided by tidal exchange. The DEM developed a similar model of the river, and both models indicated that there was only a small DO sag resulting from the Federal Paperboard Co. discharge under this conservative modeling approach (Kreutzberger and Wakild, 1993).

Biological investigations of the river, including habitat characteristics, benthic macroinvertebrates, and fisheries, indicated that the aquatic life uses of the river were not impaired as a result of wastewater discharges. Habitat characteristics of the Cape Fear River related to basin hydrology and historical dredging were determined to be primary factors affecting variability in biological characteristics in the river (CH2M HILL, 1992; Kreutzberger and Wakild, 1993; Sacco et al., 1993).

Information provided by these studies allowed the National Pollutant Discharge Elimination System (NPDES) permit issues for Federal Paperboard Co. to be resolved with a permit issued and a Special Order by Consent (SOC) to achieve those limits by 1999. International Paper purchased the mill in 1996 and continues to operate this facility today.

1.2.5 1996 Cape Fear River Basinwide Water Quality Management Plan

In the mid-1990s, the DENR began development of basinwide water quality management plans for each of the river basins in the state, with plans to update them every 5 years. They also rearranged permit expiration schedules so that these plans could then guide all of the permitting in each basin. In the 1996 Plan, the LCFRE was not considered impaired, and there was no specific water quality management strategy presented. However, because portions of the estuary were designated as Primary Nursery Areas (PNA) by the Division of Marine Fisheries, this area was subject to High Quality Waters (HQW) requirements according to the plan.

This actually includes significant portions of the currently impaired areas. Based on this requirement, all new and expanding dischargers were required to meet advanced treatment requirements for oxygen-consuming wastes for which the specific limitations have evolved over the years (DENR, 1996).

1.2.6 Lower Cape Fear River Program Studies

As noted in the background, the LCFRP was established in 1995 and has been providing excellent data on ambient conditions in the river, as well as a wide variety of targeted research efforts. The annual and special reports, as well as published research papers, are listed in the attachment. A comprehensive review of the efforts is beyond the scope of this TM. The following provides a brief overview of the consistent findings over the years and a few highlighted observations that seem pertinent to consideration of the appropriate classification for the LCFRE.

In reviewing annual reports over the nearly 20 years of monitoring, the characterization of the LCFRE and tributaries has been fairly consistent. The LCFR has been characterized as experiencing periodically high turbidity with moderate to high levels of inorganic nutrients. The estuary also has two major blackwater tributaries (the Black and Northeast Cape Fear Rivers) that generally exhibit low levels of turbidity, lower levels of inorganic nutrients, and high levels of color. Despite the high levels of nutrients, algal blooms are typically limited in the rivers due to a combination of limited light as a result of turbidity and flushing in the Cape Fear River, or limited light because of the highly colored waters in the tributaries. During periods of low flow, discussed later in this section, chlorophyll a levels increase because water clarity increases and flushing decreases, allowing more time for algal populations to develop. Some major algal blooms have been observed in tributaries where point-source influences have been noted. Blackwater swamps and agricultural areas have been characterized as periodically having high pollutant levels (Mallin et al., 2013).

In addition to the overall summary of conditions, the LCFRP has documented water quality conditions following major hurricanes and during two extreme droughts. The following summarizes some observations during these periods.

The early years of the monitoring effort allowed for extensive documentation of hurricane effects similar to those observed during the initial water quality surveys in 1955. In the summer of 1996, eastern North Carolina experienced the effects of Hurricane Bertha (July 1996) and Hurricane Fran (September 1996). The ongoing LCFRP was able to document the water quality response from Hurricane Fran in particular, where hurricane-induced flooding resulted in significant inputs from riparian wetlands, especially in the NE Cape Fear River. The DO in the NE Cape Fear River fell to about zero for approximately 3 weeks, and there were also documented fish kills. The DO levels in the mainstem of the Cape Fear River were as low as 2 mg/L but recovered faster due to flushing from flows originating from the upper part of the watershed. It is important to note that while inputs from riparian wetlands were significant contributors to the tremendous loads of oxygen-demanding materials, there were also significant inputs of raw and partially treated sewage as a result of power failures, as well as significant inputs of swine waste from breached lagoon storage systems. Therefore, the natural inputs from wetlands could not be separated from anthropogenically derived inputs, which were concluded to be especially significant in the NE Cape Fear River system based on monitoring results for BOD and ammonia (Mallin et al., 1997).

Much of North Carolina and the Cape Fear River basin, in particular, experienced a severe drought in 2001 and 2002 that ended in 2003. The LCFRP documented higher salinity levels and extended low DO conditions in the main river during the summer of 2002. Several tributaries, Angola Creek, the upper portion of the NE Cape Fear River, and the upper South River were noted to have extremely low DO levels. Turbidity levels were lower than the mean conditions for the period of record in the Cape Fear River and the upper estuary, but algal blooms were not documented in the major rivers but were observed in some small streams (Mallin et al., 2003).

Another severe drought occurred during 2007. Observations were similar for the 2001-2002 drought in terms of low DO levels and lower than typical levels of turbidity in the Cape Fear River. While algal blooms were not observed in the Cape Fear River, some severe blooms were observed in many small tributaries where turbidity levels were also significantly lower than the long-term trend (Mallin et al., 2008).

This is just a brief summary of the extensive assessment efforts conducted by the LCFRP. There has also been a wide variety of published papers. The assessment reports and other publications are listed in the Attachment A.

1.2.7 City of Wilmington/New Hanover County Studies

In the period between 2000 and 2001, efforts were made on behalf of the City of Wilmington and New Hanover County to develop an initial application of a three-dimensional hydrodynamic model (the Environmental Fluid Dynamics Code, or EFDC, model), with the intention of meeting several objectives deemed important at the time (Tetra Tech, 2001). This model was an important step in developing an assessment tool for the river. However, DENR and stakeholders determined that more data for development and calibration were required to support development of a model that could be used to determine a TMDL for the impaired portions of the river. This effort is discussed in this section relative to the University of North Carolina (UNC)-Charlotte Water Quality Model.

In addition to the initial EFDC model development, a trend analysis was also conducted of available data to determine whether there was any significant change in DO levels in the impaired portion of the river during a period when significant reductions in point-source loadings of oxygen-consuming wastes occurred (Doll and Clements, 2003). The previous DO trend analysis found no statistically significant trend for DO for the period of 1984 through 2002. The same conclusion was drawn for the period of 1991 through 2002, despite a statistically significant reduction in major point-source ultimate biochemical oxygen demand (BODu) load of approximately 25 percent for that period. This analysis has been updated with recent data and is presented in TM A-2 (Tetra Tech, 2014).

1.2.8 UNC-Charlotte Water Quality Model

As an extension of the effort started by consultants to the City of Wilmington and New Hanover County (Tetra Tech, 2001), DENR contracted with UNC-Charlotte to further develop the hydrodynamic model and water quality model using EFDC (Bowen et al., 2009). The objective of the study was to develop a water quality model of the LCFRE that would be suitable for use in developing a TMDL to address DO impairment. This model generally covers the tidally influenced areas of the Cape Fear River, Black River, and NE Cape Fear River, and extends to the mouth of the Cape Fear River with the Atlantic Ocean. The final report documents the details of the model development and calibration.

Analyses were conducted upon completion of model development, and calibration including the following eight scenarios:

1. Eliminating wastewater point-source loadings
2. Reducing river, creek, and wetland loadings
3. Changing wastewater loadings for various values of sediment oxygen demand
4. Reducing river, creek, and wetland loadings, and sediment oxygen demand
5. Eliminating ammonia inputs from wastewater point sources
6. Increasing wastewater inputs to maximum permitted values
7. Deepening of the navigation channel
8. Changing Brunswick County wastewater loadings

The following are a few highlights of major observations for some scenarios based on a simulation period to include April through October during a relatively low flow year – 2004.

1.2.8.1 Eliminating Wastewater Point-source Loadings

The sensitivity of the system to point sources was performed by running the model under different point-source conditions, including one with all point sources removed. Results from this analysis are shown in Figure 1 for the impaired portion of the Cape Fear River as a cumulative frequency diagram illustrating the percentage of the time the DO was above a certain level. Key findings include:

- During the period of lowest DO (selected as the 10th percentile), turning off all point-source discharges resulted in an increase in the DO from about 4.3 to 4.6 mg/L.

- DO levels were less than the standard of 5 mg/L approximately 32 percent of the time with the point-source discharges, and 27 percent of the time when these loadings were turned off.

1.2.8.2 Reducing River, Creek, and Wetland Loadings

Nonpoint-source reduction scenarios were also run by reducing the loading of oxygen-demanding pollutants for the tributaries and wetland cells by 30, 50, and 70 percent. These results indicate the following:

- During the period of lowest DO (selected as the 10th percentile), the difference between the base case with all calibrated pollutant loading and a 70 percent reduction in tributary/wetland loading resulted in an increase in DO of about 4.3 to 4.7 mg/L.
- DO levels were less than the standard of 5 mg/L approximately 32 percent of the time for the base case, 24 percent of the time with a 30 percent reduction in tributary/wetland loads, 20 percent of the time with a 50 percent reduction in tributary/wetland loads, and 18 percent of the time with a 70 percent reduction of tributary wetland loads.

1.2.8.3 Eliminating Ammonia Inputs from Wastewater Point Sources

The model results indicated that elimination of ammonia from point sources resulted in an approximate 0.1 mg/L increase in DO for periods when the DO was less than 5 mg/L.

Based on the results of the UNC-Charlotte modeling study, DENR determined that it could not move forward with development of a TMDL because it was apparent that point sources contributed a relatively small portion of the observed DO impairment based on the DO standard of 5 mg/L. DENR also concluded that although natural sources appeared to be a significant contributor to the low DO conditions, they could not differentiate what portion of the DO deficit was due to natural sources versus anthropogenic sources.

April through October Simulated Dissolved Oxygen Concentrations in the Impaired Area, Lower Cape Fear River Estuary

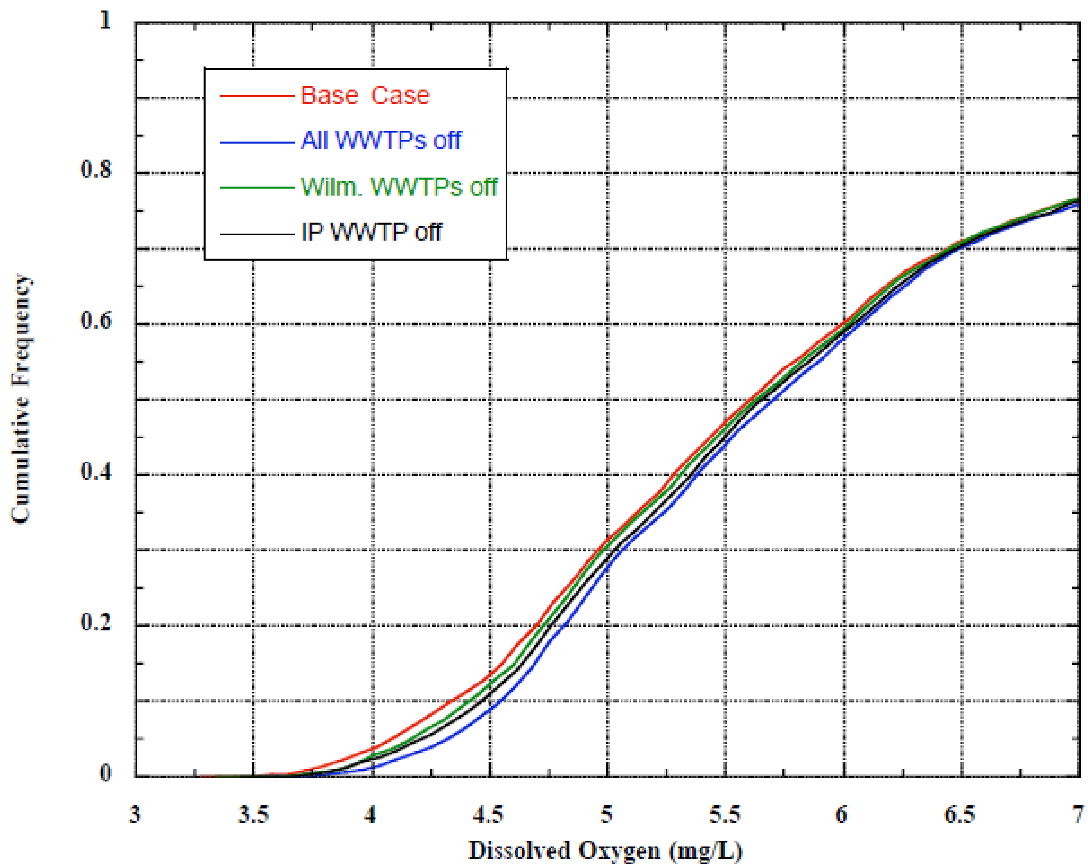

Figure 1. Cumulative frequency of model-predicted DO concentrations (April through October 2004) in the impaired portion of the LCFRE for the base case and three reduction scenarios for WWTP loads (reproduced from Bowen et al., 2009)

The three analyses highlighted above demonstrate the LCFRE lack of sensitivity to changes in point source loads. It should also be pointed out that the modeling also showed a significant impact of further channel dredging on DO conditions in the river.

2 Summary

There is a vast amount of data, research, technical analysis, and modeling for the LCFRE. While discharges from point sources and nonpoint sources appear to have some contribution to the DO deficit, it is also clear that natural drainage from riparian wetlands, salt marshes, and blackwater tributaries are more significant contributors to DO conditions not meeting the assigned standard of 5 mg/L and the pH minimum of 6.8 at all times for Class SC waters (see TM 4 for additional technical details on relative impact of sources on DO deficit) (Tetra Tech, 2014). The supplemental "Swamp" classification appears appropriate for these areas to recognize the natural source contributions to deviations in these parameters.

Other TMs prepared in conjunction with this summary address other aspects of these issues, including:

- TM 2 - Updated trend analysis of DO conditions and pollutant loading from point sources
- TM 3 - Analysis of long-term data near the limits of the tidal influence for the Cape Fear River, Black River, and NE Cape Fear River, which are approximate boundaries in the EFDC model
- TM 4 - An analysis of model results to assess the relative impact of riparian wetlands and salt marshes versus other tributary loadings

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Technical Memo: Dissolved Oxygen Trend Analysis for the Lower Cape Fear River Estuary

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The Lower Cape Fear River Program

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February 21, 2014

1 Introduction

The Lower Cape Fear River Program (LCFRP) is a large-scale water quality and environmental assessment program covering the Cape Fear River Estuary and a large portion of the lower Cape Fear River watershed. The LCFRP represents a collaboration of academia, government, industry, and the public, which has been coordinating with the North Carolina Department of Environment and Natural Resources (DENR) since 1995. The purpose of this memo is to update a previous (Tetra Tech, 2003) statistical trend analysis performed on dissolved oxygen (DO) data collected in the Lower Cape Fear River Estuary (LCFRE) portion of the basin. The current memo was prepared as part of a joint LCFRP-DENR effort to summarize the existing body of technical evidence for submission to the North Carolina Environmental Management Commission (EMC) requesting reclassification of portions of the LCFRE into a supplemental “Swamp” designation— a designation which had been applied to the LCFRE from the late 1950’s until the early 1980’s.

The previous DO trend analysis found no statistically significant trend for DO for the period of 1984 through 2002. The same conclusion was drawn for the period of 1991 through 2002, despite a statistically significant reduction in major point source ultimate biochemical oxygen demand (BODu) load of approximately 25 percent for that period. For this updated review, advanced statistical analyses were performed to determine if ambient DO data or major point source BODu loads exhibit significant trends over an extended period of time in the LCFRE (i.e., extending the data reviewed out to 2013). Monitoring data compilation, preparation, and analysis methods and results are summarized below.

2 Monitoring Data

The first step for the extended trend analysis involved obtaining ambient DO data and major point source data relevant for the LCFRE. The following subsections describe what data were compiled and how the data were processed to address outliers and fill gaps in preparation for the statistical tests.

2.1 Dissolved Oxygen

DO data were obtained from STORET (EPA’s online data storage and retrieval resource) for five monitoring stations in the Cape Fear Estuary (Table 1 and Figure 1). These stations were chosen for the analysis because they offered the longest available period of monitoring records and because they are each located either directly within or immediately adjacent to the 303(d) listed portion of the Cape Fear Estuary. Note that the names of the last two stations in the table have changed since the first trend analysis memo was produced in 2003, due apparently to renumbering of the channel markers. The station IDs, and thus the locations, are identical.

Table 1. Ambient Monitoring Stations Used in the DO Trend Analysis

Station ID	Station Name	Selected Period of Record
B902000	Cape Fear River downstream Hale Point Landing near Phoenix	January 1992 – April 2013
B905000	Cape Fear River at Navassa	May 1984 – April 2013
B974000	Northeast Cape Fear River at NC 133 at Wilmington	January 1981 – April 2013
B980000	Cape Fear River at Channel Marker 61 at Wilmington	January 1985 – April 2013
B982000	Cape Fear River at Channel Marker 56 near Wilmington	January 1981 – April 2013

Figure 1. Locations of Ambient Monitoring Stations Used in the DO Trend Analysis

Only DO measurements within one foot the water surface were evaluated, because historical depth stratified monitoring data has consistently indicated strong mixing with little vertical stratification in the estuary. As was done with the previous analysis, one outlier was removed from the dataset; 0.4 mg/l from February 1998 at the Northeast Cape Fear River station. Observations associated with major hurricane events that affected the Cape Fear Estuary were also removed. Following Hurricane Bertha on July 12, 1996 and Hurricane Fran on September 5, 1996, prolonged periods of depressed instream dissolved oxygen levels in the Cape Fear Estuary followed each storm (Mallin et al., 1997). The Mallin report indicated conditions approached anoxia at several monitoring locations after Fran, likely due to significant undocumented “point sources” including pump station and WWTP failures as well as hog lagoon breaches. After each storm, dissolved oxygen levels did not return to normal until about two months following each event. Two other hurricanes were identified that struck in the vicinity of the Cape Fear Estuary – Hurricane Bonnie on August 27, 1998 and Hurricane Floyd on September 16, 1999. Based on the recovery period reported by Mallin et al., observations were removed from each of the datasets for a period of two months following each of the four hurricanes. Figure 2 through Figure 6 show the dissolved oxygen observations for the five stations. The hurricane event observations that were omitted from the analysis are shown in red; the impact of the hurricanes on DO is visible in many cases.

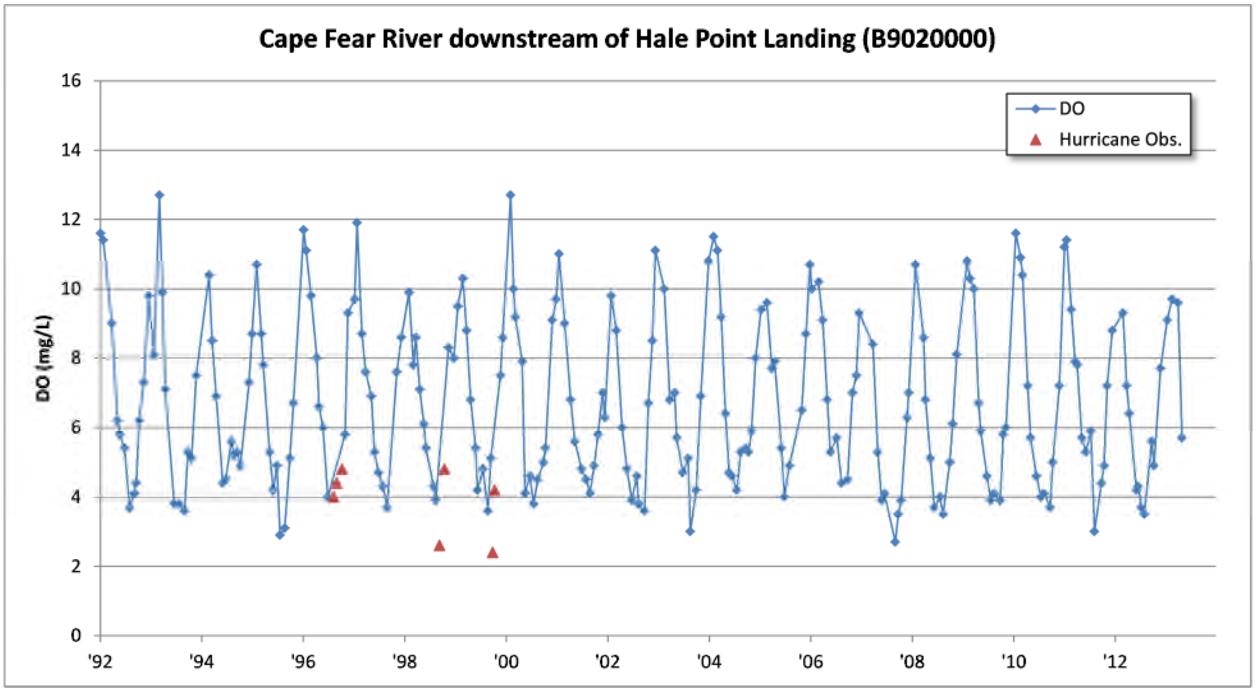

Figure 2. Dissolved Oxygen at B9020000, Cape Fear River Downstream of Hale Point Landing

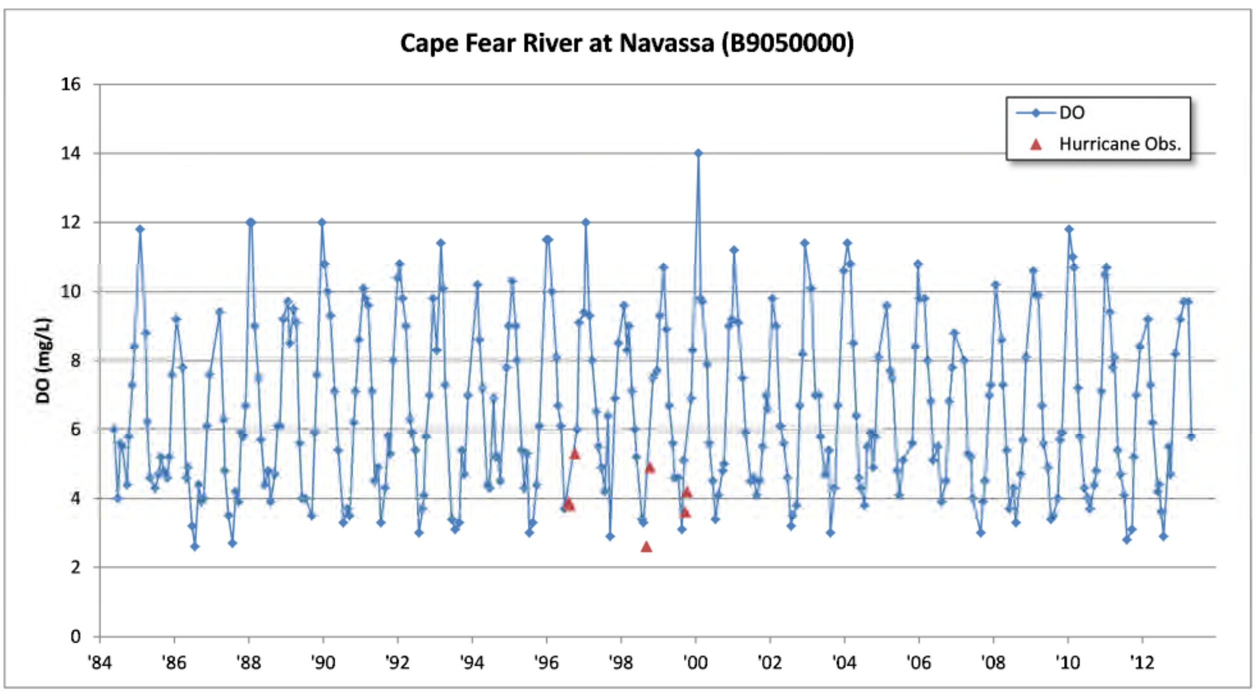

Figure 3. Dissolved Oxygen at B9050000, Cape Fear River at Navassa

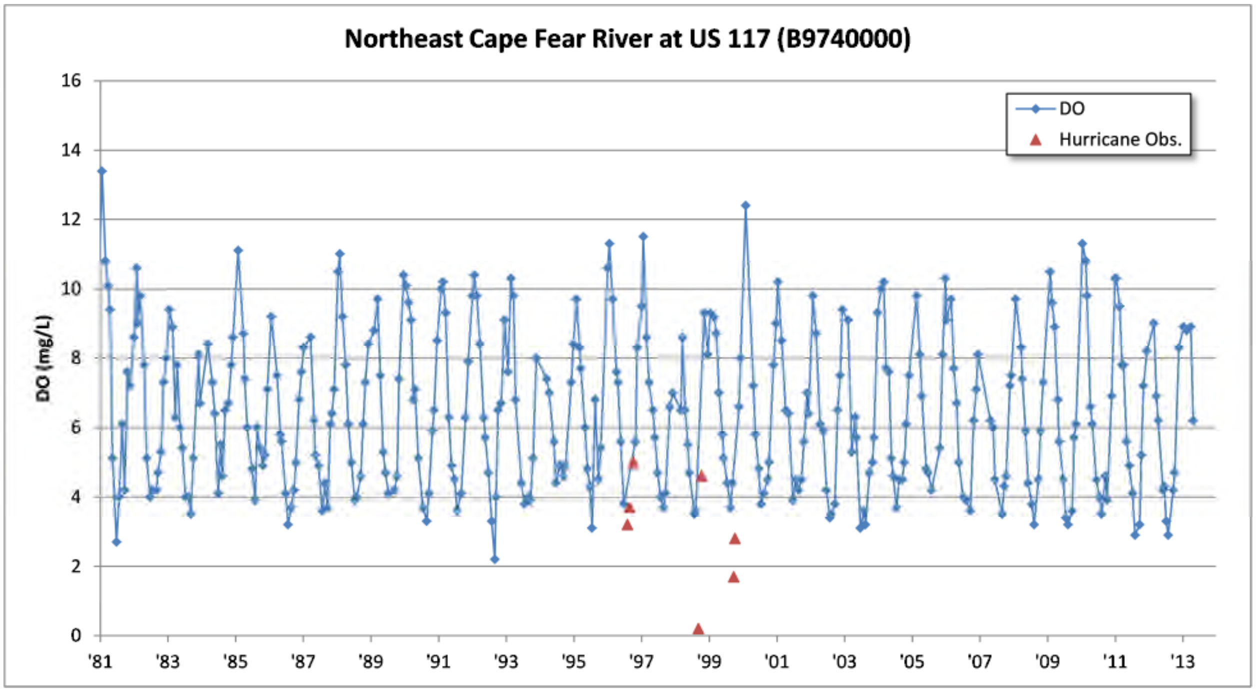

Figure 4. Dissolved Oxygen at B9740000, Northeast Cape Fear River at US 117

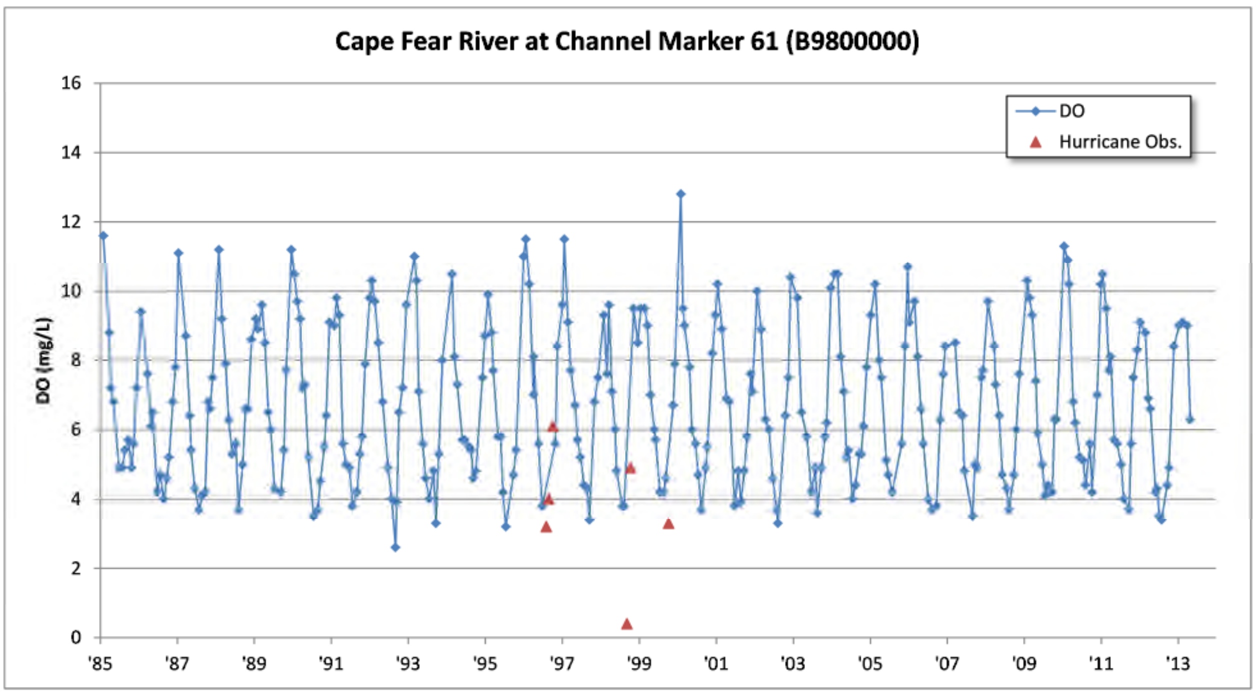

Figure 5. Dissolved Oxygen at B9800000, Cape Fear River at Channel Marker 61

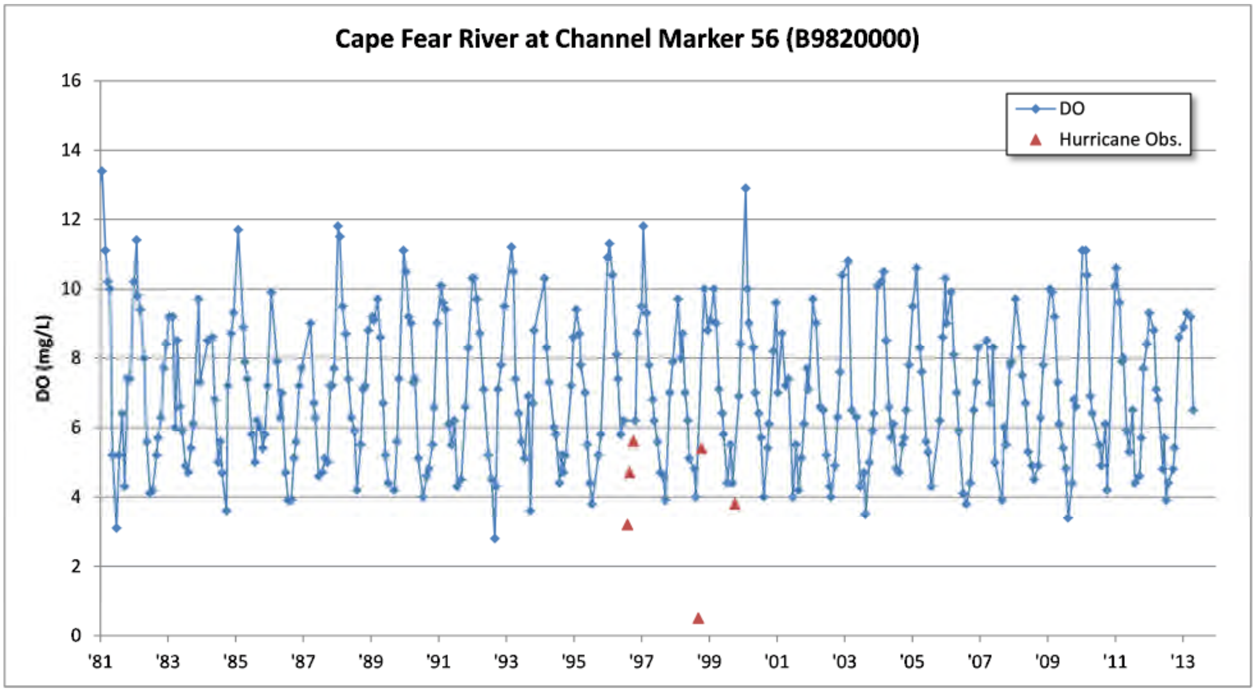

Figure 6. Dissolved Oxygen at B9820000, Cape Fear River at Channel Marker 56

2.2 Point Source Data

Data were obtained from DENR for major facilities discharging oxygen demanding waste from January of 1994 through November of 2013. Previous point source pollutant loading assessments by DENR (1999) have shown that, based on actual summer effluent data from 1998 and 1999, 90% of the total point source based oxygen demanding pollutant load to the estuary comes from three facilities – International Paper (NPDES NC0003298), Wilmington Northside WWTP (NPDES NC0003298), and Wilmington Southside WWTPs (NPDES NC0003298). Brief correspondence with the DENR NPDES Permitting Unit indicated that these facilities remain the bulk of total discharge in the LCFRE. For that reason, the analysis is focused on those three point sources.

For each of the facilities, monthly loads of BOD5 and ammonia were estimated using monitoring data. In most cases, BOD5 and ammonia were reported as a daily concentration. Daily load was calculated on days where both daily concentration and daily flow data existed. The one exception was BOD5 from International Paper, which was already reported as a daily load. These daily loads were then averaged on a monthly basis, and multiplied by the number of days in the month to obtain the monthly load. There were a few cases where monthly loads had to be estimated differently:

- Daily discharge data for BOD5 and ammonia were not available from DENR for the Wilmington Southside facility during 1999. As a result, City of Wilmington monthly discharge data were used for this period. The 1999 monthly loads were estimated for the previous 2003 trend analysis memo, and were used in this analysis as well.
- Ammonia data were not reported on a routine basis between January 1994 and January 1997 at International Paper; rather, three monthly values were available during each of the three years spanning 1994 – 1996. Yearly averages were calculated from the available months, and missing values were set equal to the average from the same year; January 1997 was set equal to the average for 1996. A total of 28 values were estimated using these methods.

- Data were not available to estimate BOD5 during November 2001 at International Paper and May 2005 at Wilmington Southside. There was also an apparent reporting error for January 1997 at International Paper, with average BOD5 reported about two orders of magnitude lower than typical values. In each case, values were estimated by taking the average of the value for the previous month and the subsequent month.

Monthly BOD5 loads were converted to CBODu using multipliers inferred from graphs provided in Bowen et al. (2009). A multiplier of 5.65 was used for International Paper based on the combined average from two long term BOD studies. The multiplier for the Wilmington Southside facility long term BOD measurement was estimated as 3.0. The near detection low level of long term BOD measurement for the Wilmington Northside facility prevented estimating a multiplier from the graph with sufficient confidence, so 3.0 was used to be consistent with the Southside value. Monthly ammonia loads were converted to NBODu using a multiplier of 4.5 (the stoichiometric ratio for the amount of DO required for the oxidation of ammonia). The estimated monthly CBODu loads for each of the three facilities are shown in Figure 7 through Figure 9, and monthly NBODu loads are shown in Figure 10 through Figure 12.

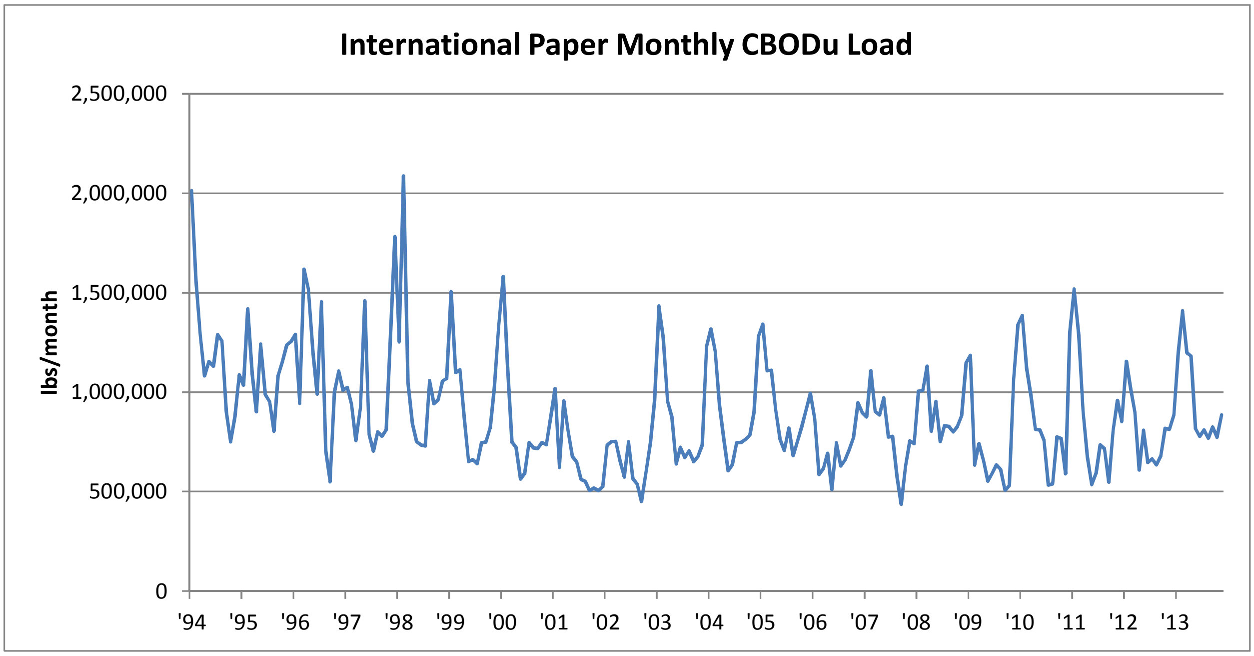

Figure 7. Estimated Monthly CBODu for International Paper

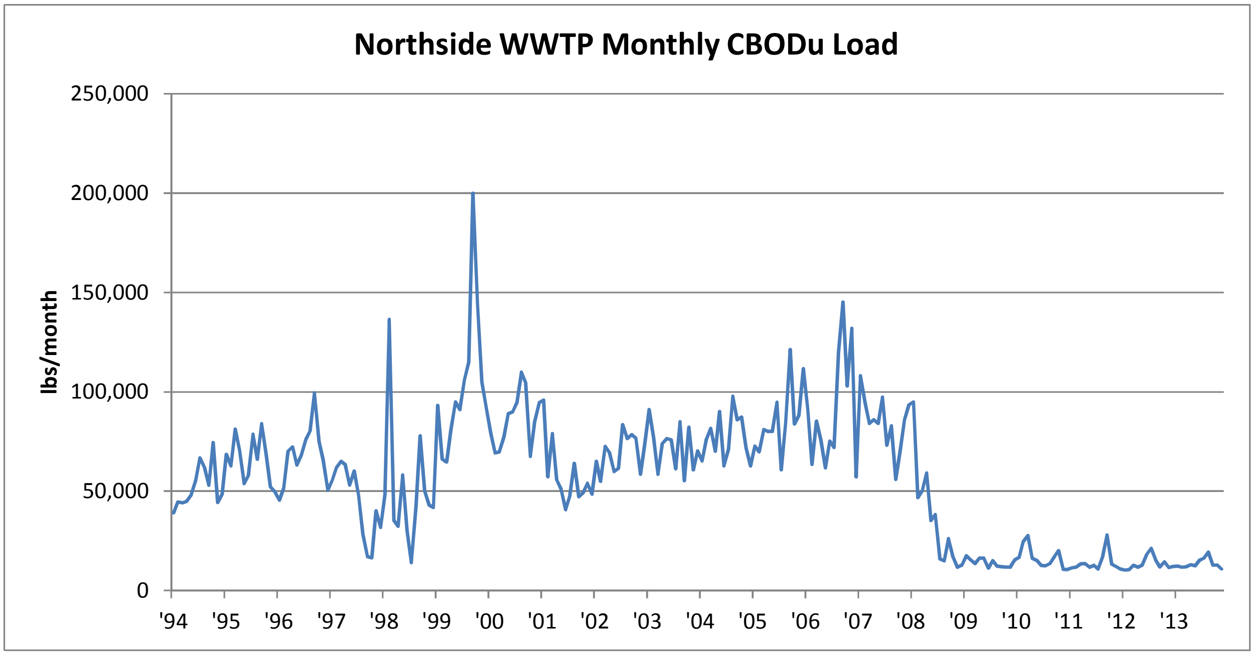

Figure 8. Estimated Monthly CBODu for Northside WWTP

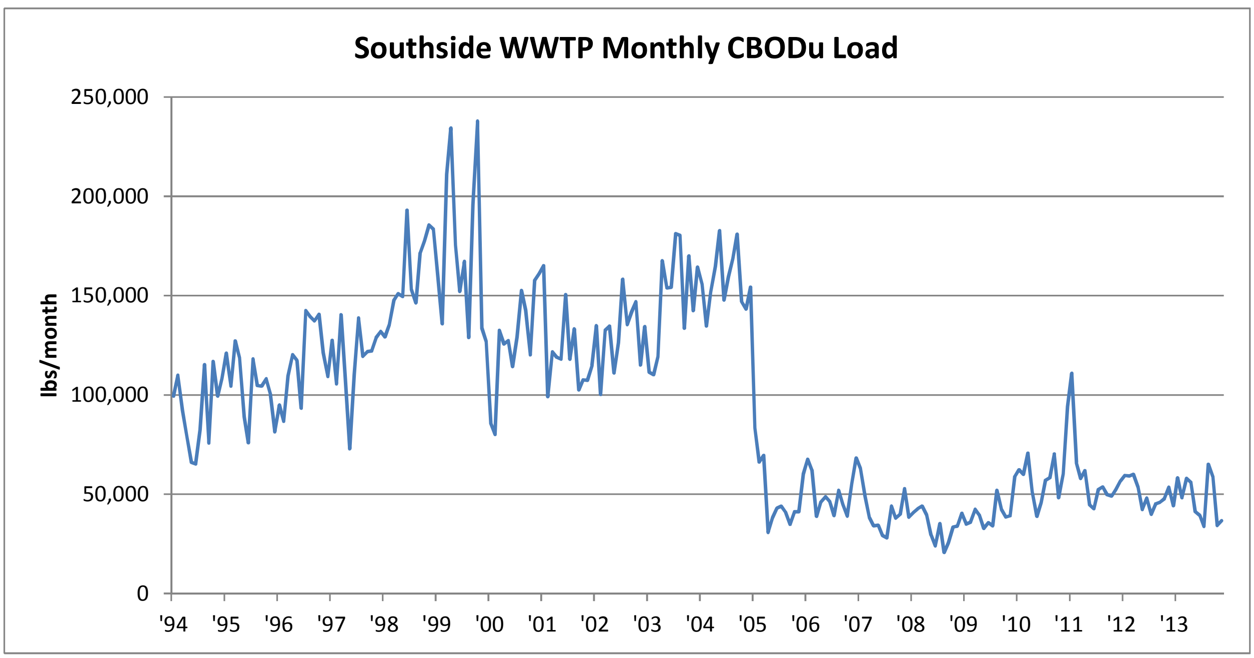

Figure 9. Estimated Monthly CBODu for Southside WWTP

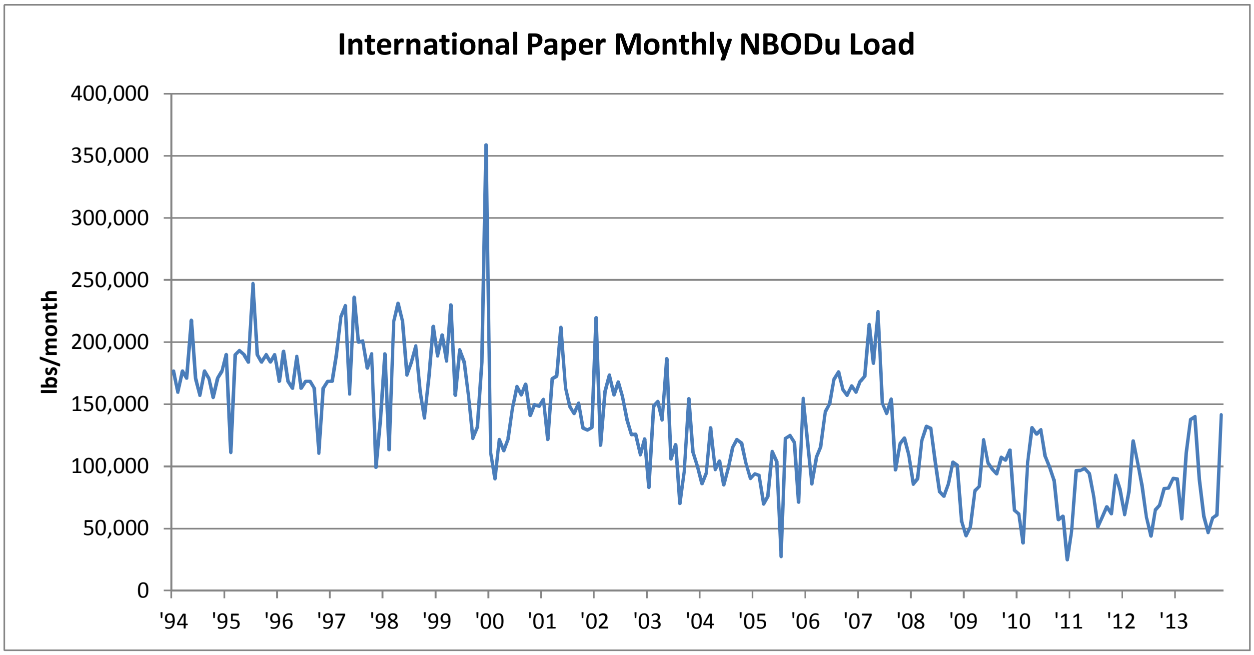

Figure 10. Estimated Monthly NBODu for International Paper

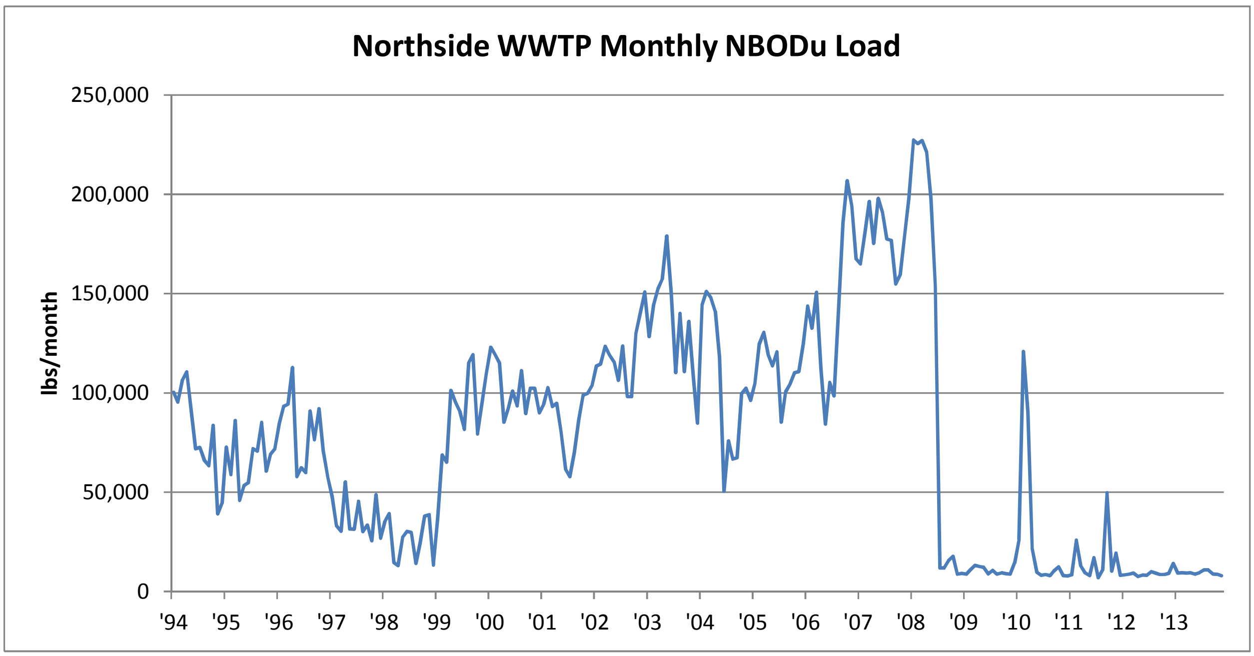

Figure 11. Estimated Monthly NBODu for Northside WWTP

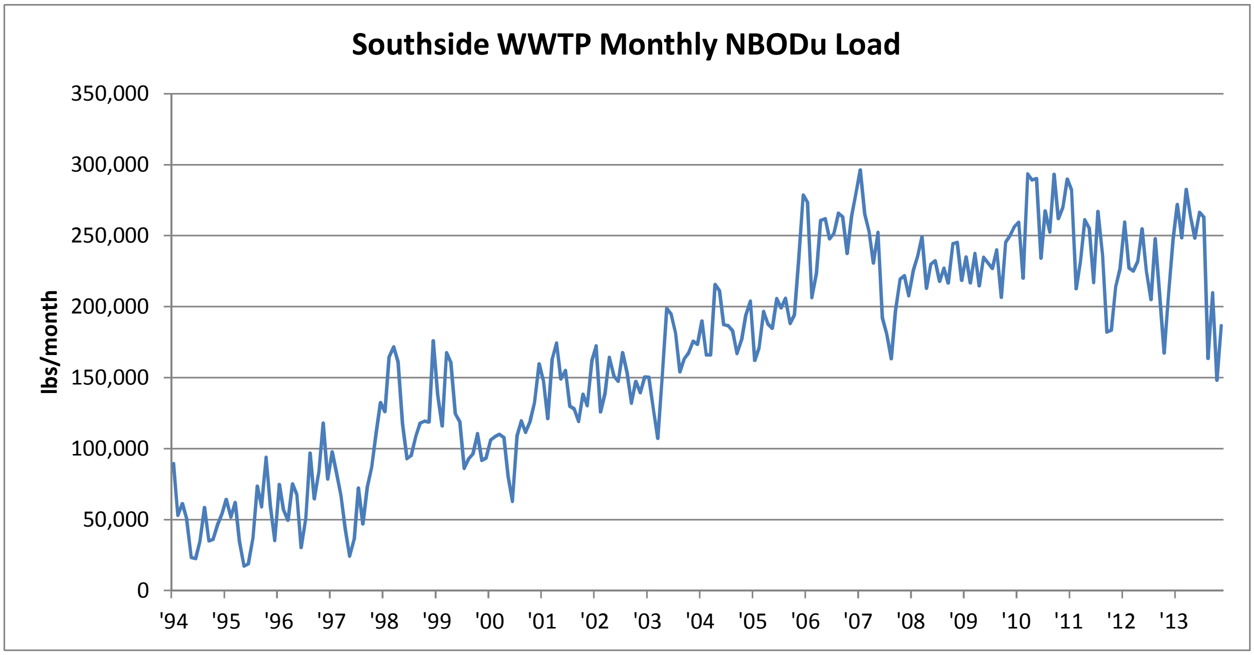

Figure 12. Estimated Monthly NBODu for Southside WWTP

3 Trend Analysis

3.1 Statistical Tests

The USGS Kendall Program (Helsel et al., 2006) was used to perform the statistical trend analysis on the DO and BODu monitoring data. Specifically, the Seasonal Kendall test was selected within the USGS Kendall Program for the trend analysis because seasonality is present in the both the ambient DO and BODu data, and the Seasonal Kendall test accounts for autocorrelation across seasons. Also, the Seasonal Kendall test allows for missing values and does not require complete years of data (i.e., bias in not introduced). Additional background on the statistical methods applied is provided in Attachment A. DO is known to show a seasonal pattern, but seasonality in BOD should be confirmed prior to conducting the test. CBODu and NBODu were summed across the three point sources to develop an overall point source estimated BODu time series. Average monthly BODu was then calculated across the monitoring period of 1994 – 2013. As seen in Figure 13, there is clearly a seasonal pattern in BODu loads to the Cape Fear Estuary.

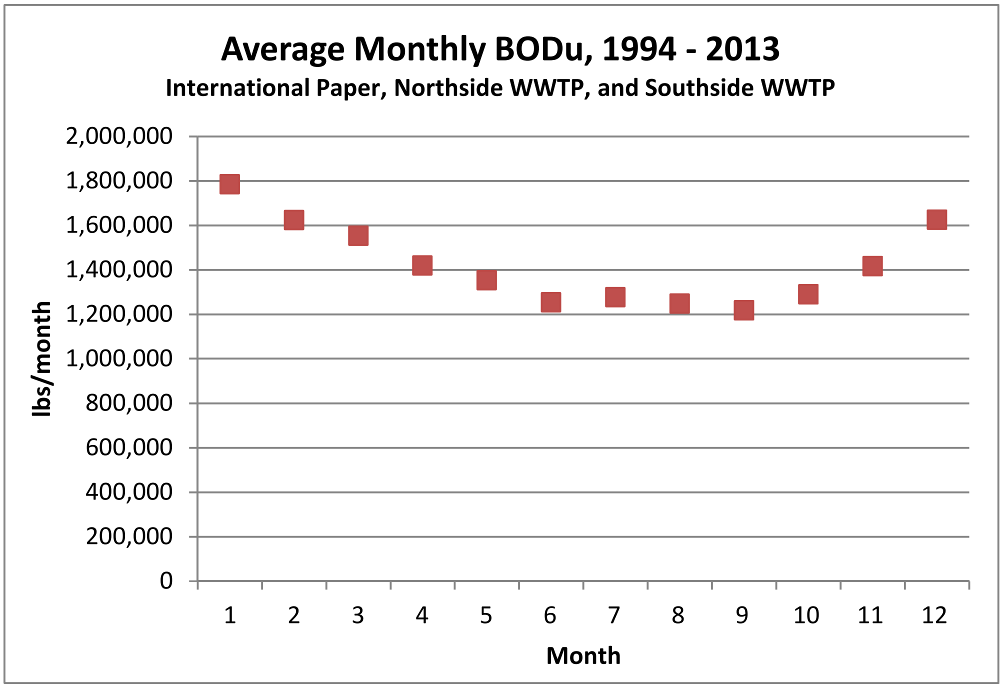

Figure 13. Estimated Average Total Monthly BODu to Cape Fear Estuary, 1999 - 2013

The Seasonal Kendall test was performed on the total BODu time series, using "seasons" defined by months. Monthly seasons are typically used for the Seasonal Kendall test; while seasons of a different duration can be used (e.g., bi-weekly, quarterly), the Seasonal Kendall test was developed using monthly data, and much of the guidance on minimum period of record and adjusting for autocorrelation is focused on using monthly data (Hirsch et al., 1981). In the previous trend analysis, quarterly data were used to reduce seasonal autocorrelation associated with monthly data. However, the USGS Kendall program calculates a modified version of the test statistic that accounts for the autocorrelation, so the data did not require any adjustment for the analyses conducted for this memorandum.

For total BODu, the Seasonal Kendall test indicated a trend of strong statistical significance, with a *p*-value adjusted for autocorrelation of 0.0034; any *p*-value less than 0.05 is considered significant with 95 percent confidence. The trend calculated using Sen's slope estimator (Sen, 1968) was -18,340 lbs/month; in other words an overall annual reduction of 220,080 lbs/yr. A plot of estimated total BODu with the trend superimposed is shown in Figure 14. An additional test was conducted using BODu for a reduced time period (2003 – 2013) to check whether the trend has continued since publication of the previous trend analysis. The adjusted *p*-value was 0.0143, indicating a highly significant trend for the reduced time period, and the magnitude was actually higher at -32,730 lbs/month.

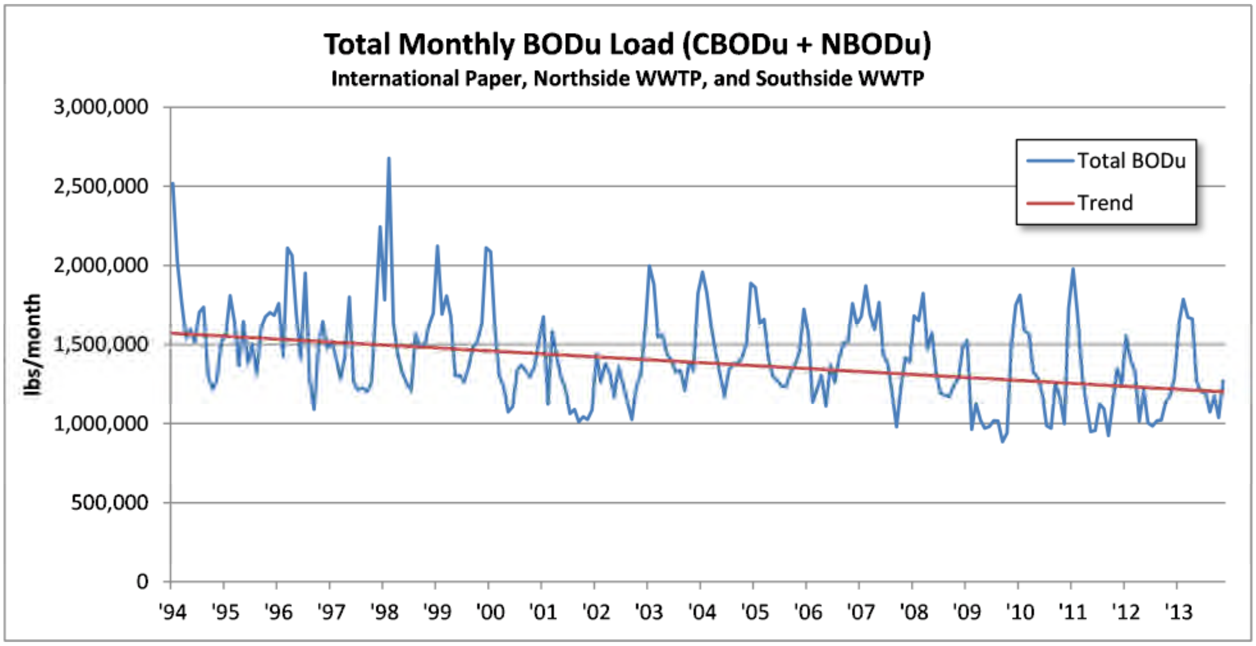

Figure 14. Estimated Total Monthly BODu to Cape Fear Estuary, with Reported Trend

Seasonal Kendall tests were then performed for DO at each of the five stations for the periods of record shown in Table 1. In all cases, the null hypothesis of no trend could not be rejected – in other words, a finding of no trend. The *p*-values adjusted for autocorrelation did not indicate anything close to statistical significance (Table 2). The tests were repeated for reduced time periods of 2003 – 2013 to test for any trend following publication of the previous trend analysis. Again, no trends were found and all the adjusted *p*-values did not show any statistical significance.

Table 2. Results of DO Trend Analysis Showing No Trend of Significance

Station ID	*p*-value, full period of record	*p*-value, 2003 – 2013
B9020000	0.5026	0.9238
B9050000	0.6853	0.4310
B9740000	0.1532	0.9334
B9800000	0.4823	0.9159
B9820000	0.1342	0.8636

3.2 Conclusions

This memorandum supports the same finding as the previous analysis conducted in 2003. A significant downward trend was detected in the total oxygen demanding pollutant loads from the three facilities that comprise roughly 90 percent of all point source loads to the LCFRE, while no corresponding trend was found in DO monitoring data at five separate LCFRE stations. During the 20 years of point source load monitoring included in this analysis, the total estimated BODu load from the three facilities has declined about 23 percent as indicated by the trend estimate.

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Bowen, J.D., S. Negusse, J.M. Goodman, B. Duclaud, M. Robin, and J. Williams. 2009. *Development and Use of a Three-Dimensional Water Quality Model to Predict Dissolved Oxygen Concentrations in the Lower Cape Fear River Estuary, North Carolina*. Department of Civil and Environmental Engineering, University of North Carolina at Charlotte.

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Attachment A – Background on Statistical Methods

The Seasonal Kendall test (Hirsch et al., 1982) and Sen's nonparametric slope estimator (Sen, 1968) were used to test for the presence of a statistically significant trend. Background information outlining the technical basis for the selection of these methods is provided below.

The nonparametric Mann-Kendall test for trend (Mann, 1945; Kendall, 1975) forms the basis of a method that is frequently used for trend analyses performed on water quality monitoring data – the Seasonal Kendall Test. The method was developed and popularized by USGS researchers throughout the 1980s (Hirsch et al., 1991), and USGS published computer code supporting its use.

Mann-Kendall is especially useful for detecting trends in environmental variables for several reasons:

- The test is nonparametric, and the data do not need to be normally distributed.
- Missing values are allowed; gaps are simply ignored.
- Data reported at the detection limit can be used without censoring, so long as the values are set lower than the smallest observation.

This is all possible because Mann-Kendall looks only at the relative magnitudes of sequential data, so the type of distribution, gaps, and the assumptions used for non-detects become irrelevant. The test does, however, assume that the data are not serially correlated, an assumption frequently violated by environmental monitoring data. Serial correlation (also called autocorrelation) occurs when data points are not independent from each other. Monitoring data tend to show positive serial correlation, meaning that positive errors (about the mean) in one time period are associated with positive errors in adjacent time periods (and negative errors are associated with adjacent negative errors).

The Seasonal Kendall test is a generalization of the Mann-Kendall test, developed by Hirsch et al. (1982). In its original application, data were divided into 12 "seasons", with each month representing a season. Missing values are allowed (as is the case with the Mann-Kendall test), and complete years of all 12 seasons are not required. The Mann-Kendall test statistic and its variance are calculated separately on each season. The statistics are summed and a Z statistic computed, which is compared to the standard normal tables. The null hypothesis HO is there is no trend, while the alternative hypothesis HA is either an upland or downward trend (a two-tailed test). Serial correlation among values within a season can be addressed by a modification of the test statistic (Hirsch and Slack, 1984). The modification is recommended in cases where there are 10 or more observations per season (i.e., 10 years of data if seasons are defined monthly) due to difficulties accurately determining covariance for fewer data.

A slope can be calculated as well for the Seasonal Kendall test. The slope is based on Sen's nonparametric slope estimator (Sen, 1968). The method estimates a series of slopes between values from the same season. The Seasonal Kendall slope is the median of this series of slopes.

The USGS Kendall Program (Helsel et al., 2006) was developed to address a gap in publically available software for estimating trends using the Seasonal Kendall test and other Kendall tests. In the 1980s USGS popularized Kendall methods, and USGS published computer code supporting its use in popular statistical packages. However, in later years as statistical analysis moved to desktop computing, the code became difficult to execute without purchase of commercial statistical software. As a result, USGS repackaged the code into an executable program which can be used on computers supporting DOS or DOS emulation. The USGS Kendall program is freely available from a USGS website.

Helsel, D.R., D.K. Mueller, and J.R. Slack. 2006. *Computer Program for the Kendall Family of Trend Tests.* Scientific Investigations Report 2005-5275. U.S. Geological Survey. Reston, VA.

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Technical Memo:
Task 3 - Analysis of Water Quality Data at Cape River Estuary Model Boundaries

Prepared for

Lower Cape Fear River Program

Prepared by

CH2MHILL®

February 25, 2014

1 Introduction

Since 1998, the section of the Lower Cape Fear River Estuary (LCFRE) from upstream of Toomers Creek to a line across the river between Lilliput Creek and Snows Cut has been listed on the State of North Carolina’s 303d List as impaired for dissolved oxygen (DO). Since the original listing for DO, many technical studies of the LCFRE have been conducted by the North Carolina Department of Environment and Natural Resources (DENR), the Lower Cape Fear River Program (LCFRP), other agencies and academic researchers, and consultants. As a result, an extensive technical foundation of knowledge on the LCFRE has been created, including information on physical, chemical, and biological features and processes. Monitoring programs have provided insight regarding ambient conditions over many years on water quality, benthos, and fish. Additionally, sophisticated three-dimensional (3D), hydrodynamic modeling tools have been developed for the entire estuary and the portion of the river beginning at Lock and Dam #1 (L&D1) (Tetra Tech, 2001; Bowen et al., 2009).

The modeling results indicate that point-source discharges have little impact on DO levels, and that even significant reductions in background (both natural and nonpoint source) loads would not result in attainment of the current standard at all times. DENR has also agreed with representatives of the LCFRP that a more thorough understanding of natural and anthropogenic sources of oxygen deficit is needed.

This technical memorandum (TM) presents an analysis of water quality parameters at the points representative of inflows to the system, with the purpose of examining issues related to a supplemental DENR “Swamp” classification for the estuary. This TM examines data related to key parameters, including nutrients, pH, and DO, that are related to the occurrence of low DO in the Cape Fear River.

1.1 Data Sources and Processing

The LCFRP has conducted monitoring in coordination with DENR since 1995, and a considerable amount of data is available prior to that. There has also been extensive data collected by the Middle Cape Fear Basin Association (MCFBA) upstream of L&D1 since mid-1998 and the Upper Cape Fear Basin Association (UCFBA) since about 2000. Data for this evaluation were downloaded from the Cape Fear River Basin Monitoring Coalitions Water Quality Data website (accessible at http://www.cormp.org/CFP/CFP_map.php) and the U.S. Environmental Protection Agency’s (USEPA’s) STOrage and RETrieval (STORET) Data Warehouse (2012accessible at http://www.epa.gov/storet/). The primary stations of interest for this evaluation were:

- B8360000 Cape Fear River at NC 11 near East Arcadia (downstream of L&D1)
- B9670000 Northeast (NE) Cape Fear River near Wrightsboro
- B9000000 Black River at NC 210 at Still Bluff
- B9050000 Cape Fear River at Navassa

These stations (shown in Figure 1) represent the water quality conditions at the main inflows to the system: the Middle Cape Fear River, the Black River, and the NE Cape Fear River, and coincide with the boundary conditions of the 3D hydrodynamic model developed for the system. The station at L&D1 represents water quality in the Cape Fear River as water leaves the Sandhills and enters the coastal area. The NE Cape Fear and Black River stations measure water quality as water leaves areas currently classified as swamps. The Cape Fear monitoring station at Navassa is included in the analysis, as it reflects the changes in water quality as a result of the confluence of the middle Cape Fear River and Black River. While data is available at a number of other stations, such as B980000 (Cape Fear River at Channel Marker 61), they were not used for this analysis. The data would also capture the changes as a result of the inflow of the NE Cape Fear River, but would also more directly reflect the influence of tidal flows.

Figure 1. Location of Stations used for Evaluation of Boundary Conditions

The data were downloaded from the Cape Fear River Basin Monitoring Coalition's Water Quality Data and USEPA's STORET websites in February 2014. Data downloaded included all data available for these sites at that time. Parameters evaluated for this analysis include DO, nitrate-nitrite (NO_2-NO_3), total Kjeldahl nitrogen (TKN), pH, total phosphorus (TP), and ammonia (NH_3). Data were processed to identify measurements collected during the summer period (April through October) to focus on critical DO periods. The dataset was also processed to only evaluate surface grab samples. Depth-stratified monitoring showed little vertical stratification, and inclusion of all data would have skewed results toward deeper locations with more samples per event. Finally, data were averaged on a monthly basis to simplify the comparison and reduce the effects of any outliers.

1.2 RESULTS

The water quality monitoring data was evaluated using basic statistics, as well as time series plots. The statistics provide a long-term evaluation of water quality; whereas, the time series plots allow for identification of key periods and the relative difference in water quality between stations in more detail. Table 1 provides a summary of the basic monthly summer (April through October) statistics for the stations of interest.

Review of the data shows distinct differences in water quality between the Cape Fear River at L&D1 and the major tributaries, the Black River, and NE Cape Fear River. The average summer (April through October) monthly DO level at L&D1 is greater than 7 mg/L; whereas, as the DO levels in the Black River are nearly 2 mg/L lower at 5.19 mg/L and more than 2 mg/L less in the NE Cape Fear River at 4.96 mg/L. This primarily reflects the low DO found in these swamp areas but it is important to note that the DO below L&D 1 maybe somewhat influenced by reaeration from the dam.

The influence of the Black River and the NE Cape Fear River on the Cape Fear River mainstem can also be seen in the summer (April through October) monthly average NO_2-NO_3 and TP values. Concentrations of both of these constituents are higher at L&D1 when compared to the other stations. The addition of the flows from the tributaries significantly reduces the concentrations, as is seen at Navassa.

A number of time series plots were generated to assess changes in these constituents over time and to also provide a method to compare stations in a more detailed fashion. The plots for each constituent and a brief discussion is provided in Figures 2 through 7.

The DO time series (Figure 2) shows that summer (April through October) DO levels at L&D1 are greater than 5 mg/L the majority of the time. Only one event fell below 4 mg/L, which corresponded to Hurricane Fran. Summer (April through October) DO levels in the NE Cape Fear River are significantly lower at all times. The lowest observed DO in the NE Cape Fear River coincides with Hurricane Fran in 1996, Hurricane Bonnie in 1998, and Hurricane Floyd in 1999. While DO levels at L&D1 show some decrease during these events, a more significant effect is seen at the tributary stations and at Navassa. In general, the NE Cape Fear River shows the lowest DO levels, with levels at Navassa being second lowest. This suggests that inflow from the NE Cape Fear River and the swamps it drains has a significant impact on DO levels in the Cape Fear River mainstem. DO in the Black River tends to be more moderate, typically being less than concentrations at L&D1 but not as low as in the NE Cape Fear River. Inflow from the Black River is likely to have an impact but of a lesser magnitude. DO does not appear to show a negative or positive trend if the excursions related to hurricanes in the late 1990s are excluded.

Summer (April through October) nitrate-nitrite levels (Figure 3) are the highest at L&D1, receiving nitrate loading from upstream sources and atmospheric deposition. Nitrate is readily utilized in anoxic systems, such as swamps, as an oxygen source and can often fall below 0.1 mg/L. This is reflected in the low values seen in the Black River and the NE Cape Fear River. The levels at Navassa reflect the inflow from these low nitrate areas, with levels in the Cape Fear River dropping from those seen at L&D1. Nitrate-nitrite concentrations appear to show a slight positive trend in recent years at L&D1 and Navassa.

Table 1. Summary of Monthly Water Quality Statistics for Summer Periods (April through October)

	Cape Fear River at L&D1	Black River at NC 210 at Still Bluff	Cape Fear River at Navassa	NE Cape Fear River near Wrightsboro
DO				
Minimum (mg/L)	3.60	1.20	0.85	0.10
Maximum (mg/L)	10.10	8.00	9.20	8.50
Average (mg/L)	7.14	5.19	5.10	4.96
NO_2+NO_3-N				
Minimum (mg/L)	0.01	0.01	0.00	0.01
Maximum (mg/L)	1.58	0.52	1.14	0.51
Average (mg/L)	0.64	0.14	0.42	0.23
TKN-N				
Minimum (mg/L)	0.10	0.20	0.10	0.10
Maximum (mg/L)	2.00	2.00	1.50	2.10
Average (mg/L)	0.69	0.81	0.72	0.78
pH				
Minimum (mg/L)	5.30	4.80	5.60	5.00
Maximum (mg/L)	7.35	7.80	7.90	7.30
Average (mg/L)	6.61	6.13	6.87	6.63
TP				
Minimum (mg/L)	0.08	0.04	0.04	0.05
Maximum (mg/L)	0.61	0.36	0.31	0.36
Average (mg/L)	0.18	0.10	0.14	0.12
NH_3-N				
Minimum (mg/L)	0.01	0.01	0.01	0.01
Maximum (mg/L)	0.22	0.20	0.20	0.30
Average (mg/L)	0.07	0.05	0.07	0.05

Note:

mg/L - milligram per liter

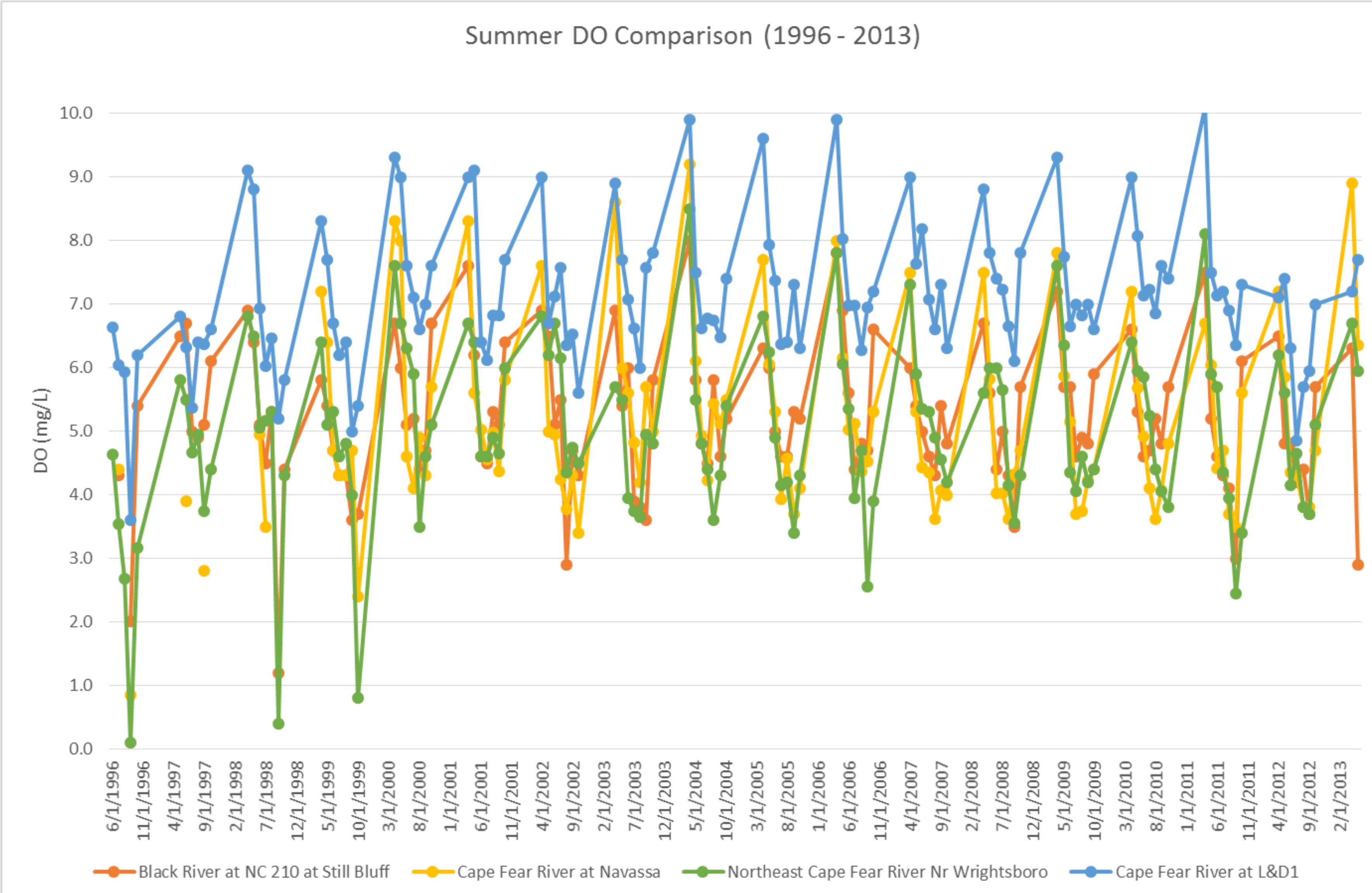

Figure 2. Dissolved Oxygen in the LCFRE (April through October Data Only)

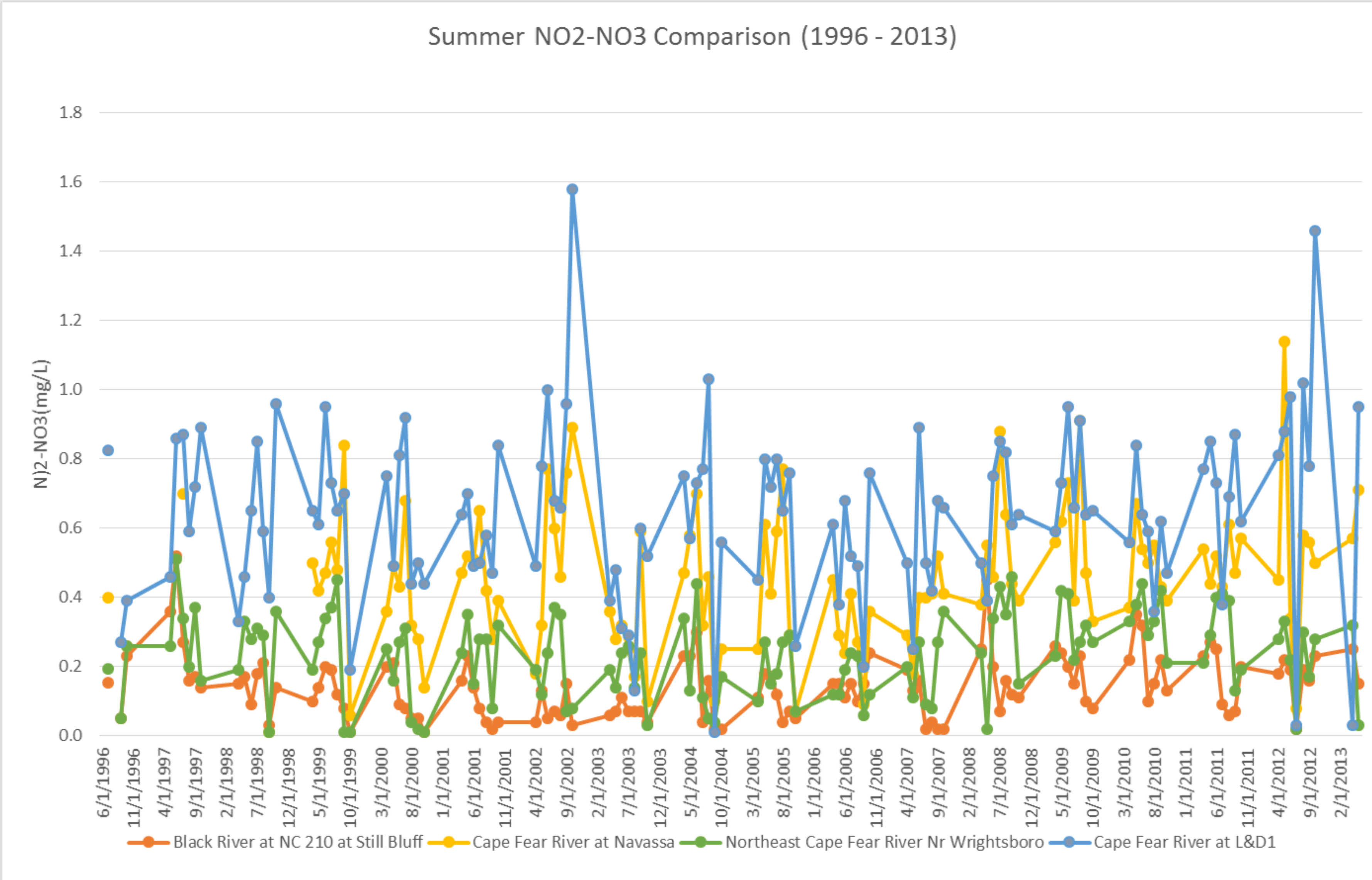

Figure 3. Nitrate-Nitrite in the LCFRE (April through October Data Only)

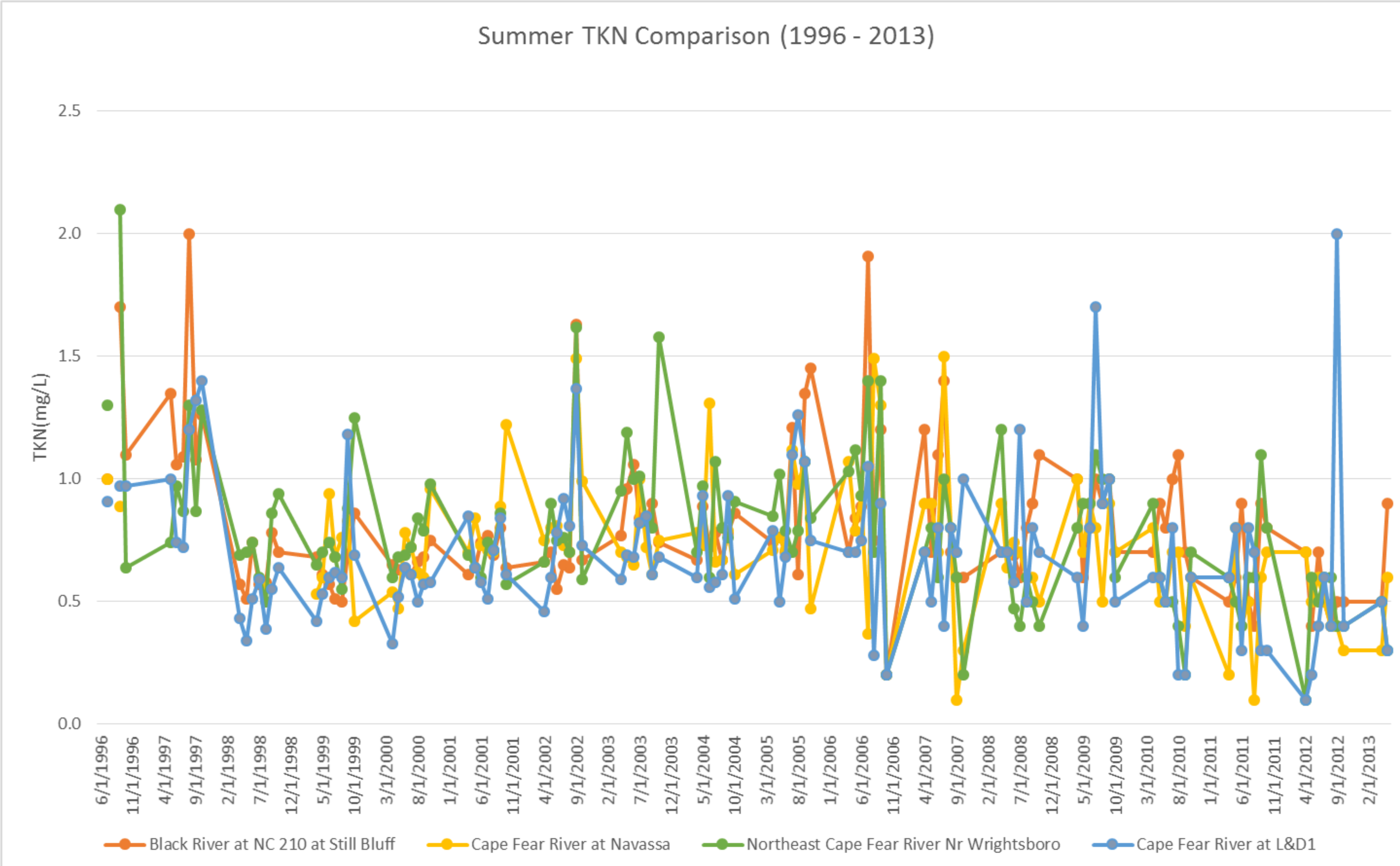

Figure 4. Total Kjeldahl Nitrogen in the LCFRE (April through October Data Only)

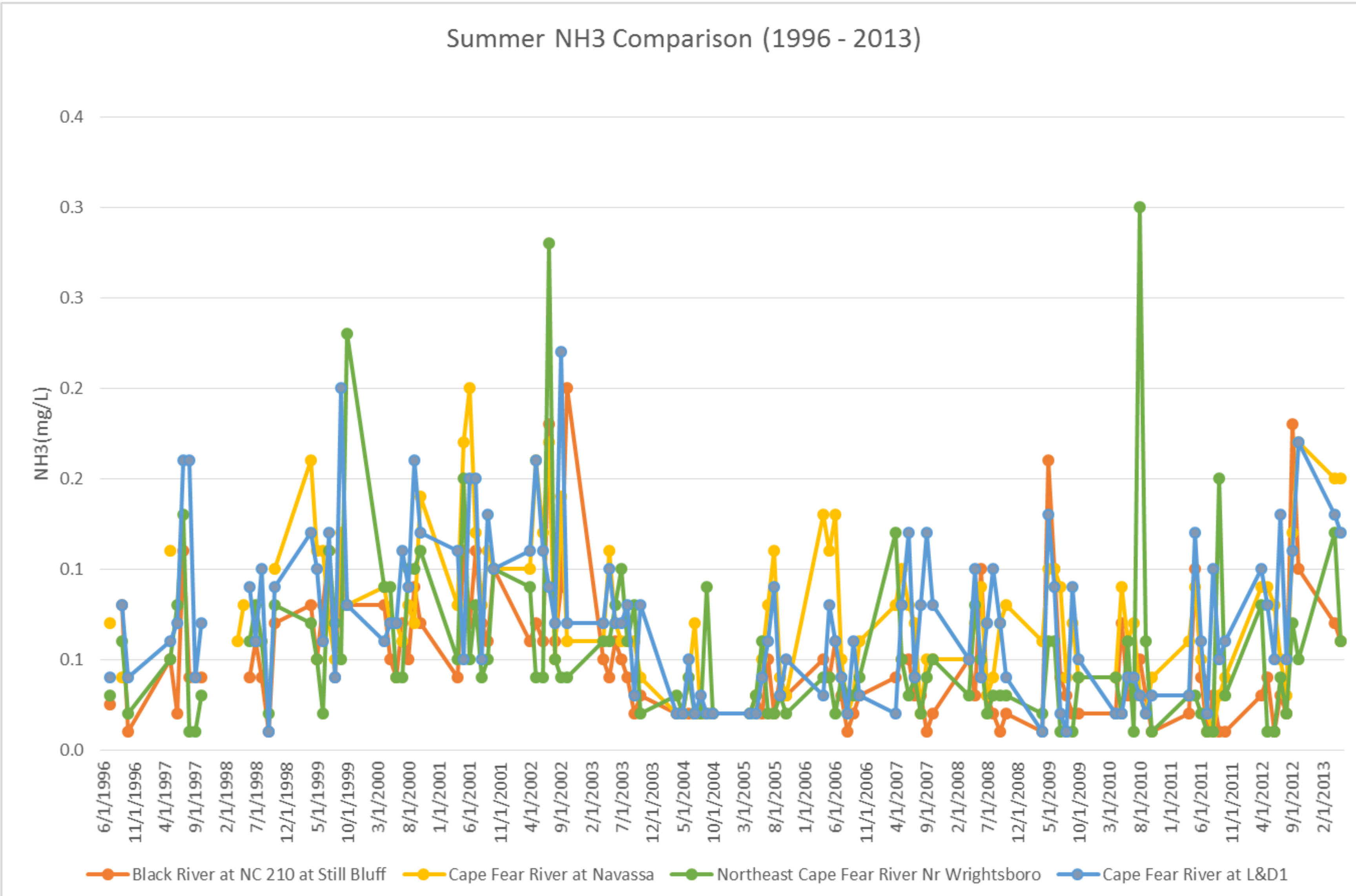

Figure 5. Ammonia in the LCFRE (April through October Data Only)

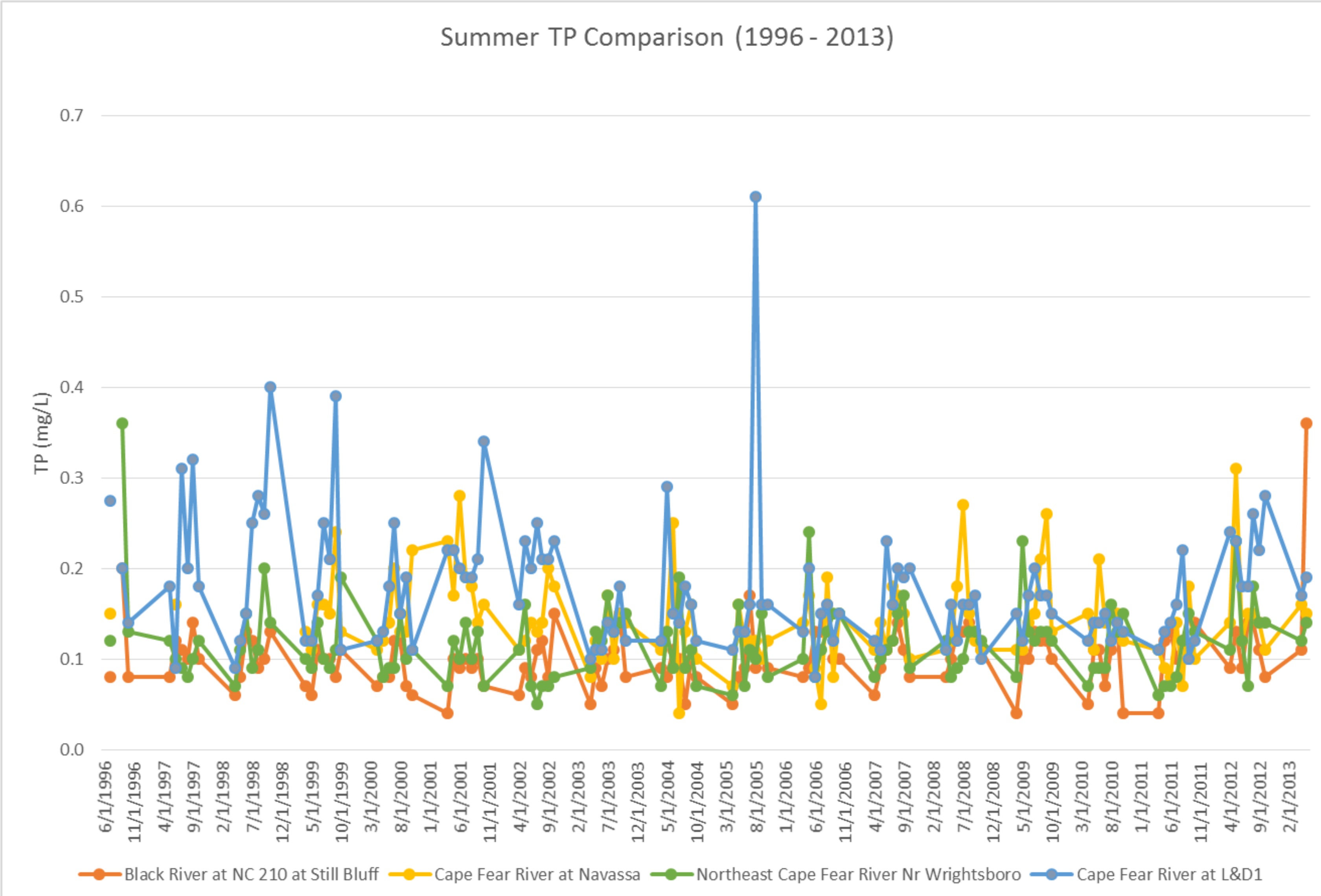

Figure 6. Total Phosphorus in the LCFRE (April through October Data Only)

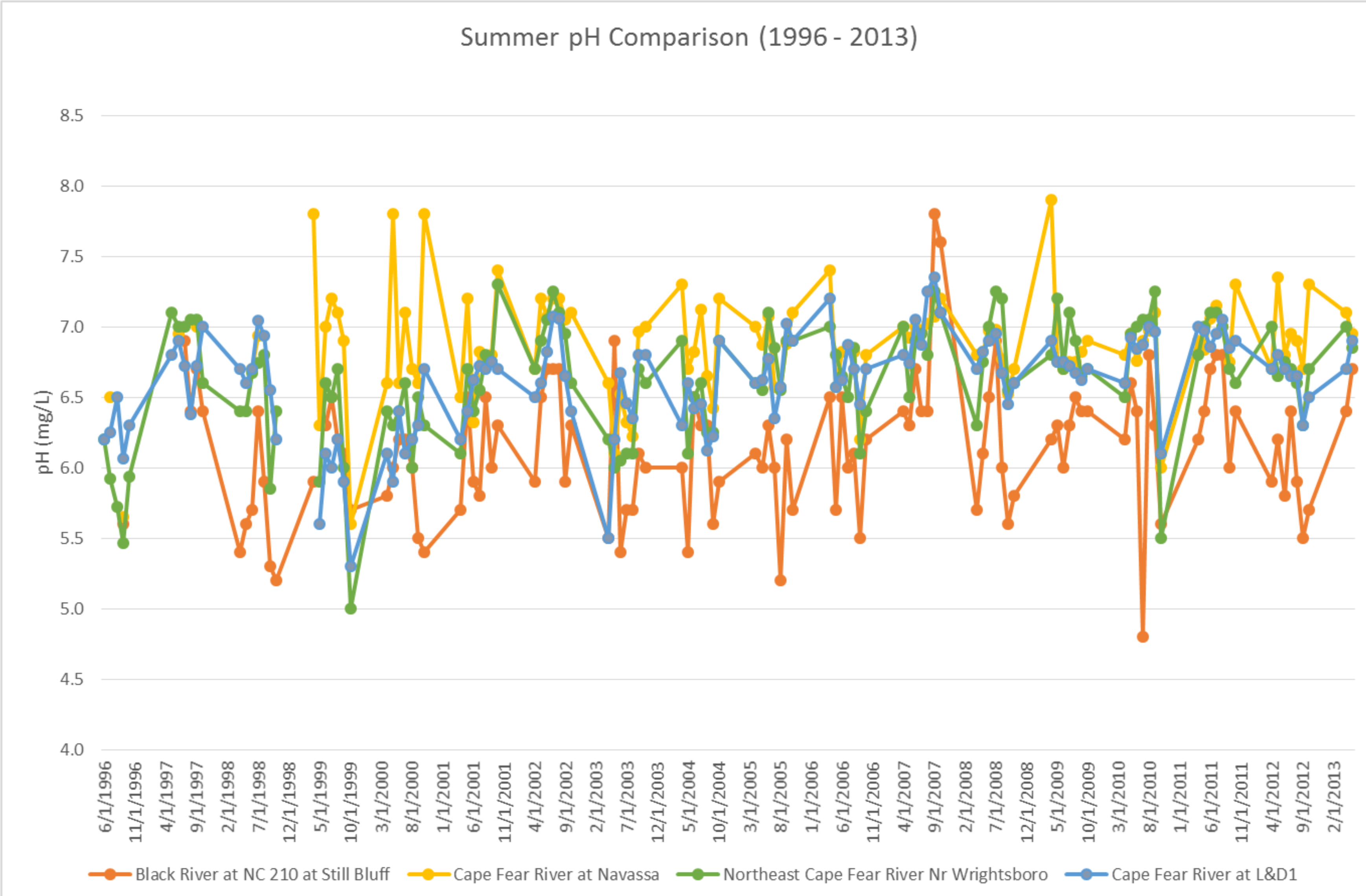

Figure 7. pH in the LCFRE (April through October Data Only)

The highest levels of summer (April through October) TKN (Figure 4) are typically seen in the Black River and reflect the organic load generated by the high biological productivity of the adjacent marsh areas. Levels at L&D1 are consistently the lowest, although a few high values do occur at this station. TKN levels appear to be trending lower in recent years.

Summer (April through October) ammonia levels (Figure 5) at all stations were relatively similar and typically less than 0.1 mg/L. Ammonia is readily utilized for primary production, so ammonia loads are quickly transformed into organic matter. Ammonia levels appear to have dropped since 2002, with a slight increase in 2012.

Summer (April through October) phosphorus levels (Figure 6) at all stations were relatively similar and typically less than 0.2 mg/L. Phosphorus is utilized for primary production but is not the limiting nutrient in estuarine systems. Phosphorus levels in the Cape Fear River appear to have dropped since 2002, with a slight increase in 2012.

The sum er summer (April through October) pH levels (Figure 7) at the boundary stations show an interesting pattern. The lowest levels are consistently seen in the Black River with levels often less than 6 standard units. This is typical for swamp areas where decomposition of organic matter results in the occurrence of high levels of humic acids. Levels in the NE Cape Fear River are higher than in the Black River, suggesting that the vegetation and substrate is different between the two drainages. The highest levels are at Navassa. The pH at L&D1 and NE Cape Fear are fairly similar, with the L&D1 values being approximately 0.5 standard units higher. The Cape Fear River is listed for pH impairment. A review of Figure 7 shows that the low pH excursions may be naturally occurring. Levels in the Black River are typically less than 6.5 standard pH units, and frequently fall below 6.0 standard units. A coinciding drop of pH at Navassa is seen during these periods, supporting the conclusion that low pH in the Cape Fear is driven by an influx of low pH waters from adjacent swamp areas.

2 Conclusions

The evaluation of water quality data at the boundary conditions supports the concept that inflows from the swamp areas have a significant impact on water quality in the Cape Fear River. The levels of nutrients, DO, and pH are consistently different between the station at L&D1, and in the Black River and the NE Cape Fear River. A distinct response from these inflows can be seen in the levels at Navassa for these parameters, supporting the idea that water quality in the Cape Fear River is dominated by the conditions found in the swamp areas below L&D1.

3 Works Cited

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Technical Memo:
The Relationship of Adjacent Wetlands and Salt Marsh to Dissolved Oxygen in the Lower Cape Fear River Estuary

Prepared for

The Lower Cape Fear River Program

Prepared by

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February 21, 2014

1 Introduction

The Lower Cape Fear River Program (LCFRP) is a large-scale water quality and environmental assessment program covering the Cape Fear River Estuary and a large portion of the lower Cape Fear River watershed. The LCFRP represents a collaboration of academia, government, industry, and the public, which has been coordinating with the North Carolina Department of Environment and Natural Resources (DENR) since 1995. The purpose of this memo is to summarize previous water quality modeling performed to analyze the impact that adjacent wetlands and salt marsh areas in the Lower Cape Fear River Estuary (LCFRE) portion of the basin have on dissolved oxygen (DO) concentrations in that region. The memo was prepared as part of a joint LCFRP-DENR effort to summarize the existing body of technical evidence for submission to the North Carolina Environmental Management Commission (EMC) requesting reclassification of portions of the LCFRE into a supplemental “Swamp” designation— a designation which had been applied to the LCFRE from the late 1950’s until the early 1980’s.

Contents of the memo focus on two relatively extensive modeling studies. The first was completed in 2001 by Tetra Tech on behalf of the City of Wilmington and New Hanover County, prior to the formation of the Cape Fear Public Utility Authority (CFPUA). In that study, the physical link between wetlands, salt marshes, the main channel, water movement, and contributions to dissolved oxygen (DO) deficit was established (Tetra Tech, 2001). Follow up work by the University of North Carolina – Charlotte on behalf of NC DENR both confirmed and expanded on the link (Bowen, et. Al., 2009). The results of these modeling studies are summarized here to provide a significant part of the technical basis for reclassifying the portions of the LCFR with the supplemental “Swamp” designation.

2 Preliminary Modeling Effort (2001)

In the period between 2000 and 2001, efforts were made on behalf of the City of Wilmington and New Hanover County to develop an initial application of a three-dimensional hydrodynamic model (the Environmental Fluid Dynamics Code, or EFDC, model) with the intention of meeting several objectives deemed important at the time (Tetra Tech, 2001):

- Simulation of the mixing and transport of the existing and proposed future Wilmington Northside and Wilmington Southside wastewater treatment plant effluents.
- Simulation of the impact of existing and proposed future Northside and Southside facility pollutant loads for oxygen-demanding substances.
- Evaluation of multiple sources and cumulative loads of oxygen-demanding substances to the lower Cape Fear River estuary.
- Analysis of the various processes affecting dissolved oxygen and their relative contribution to ambient dissolved oxygen deficit levels.

EFDC was selected because it is versatile, peer reviewed, accepted and endorsed by the USEPA, available in the public domain, and could be used for 1, 2, or 3-dimensional (3-D) simulation of rivers, lakes, estuaries, coastal regions and wetlands. The 2001 model development was considered a scoping level effort with an end goal of providing model results to guide further, more expansive model development supporting long term water quality management of the LCFRE. Specifically, an important question at the time was whether a 3-D model or 2-D model would be needed for the anticipated Total Maximum Daily Load (TMDL) development planned for the estuary because of its inclusion on the State’s 303(d) list of impaired waters for low dissolved oxygen in 1998 with low pH added in 2006.

2.1.1 Preliminary Model Approach

A vast amount of data characterizing the LCFRE system available from numerous agencies and organizations was drawn upon to set up, calibrate, and validate the initial 3-D EFDC model. An overview of the data used in the preliminary model setup and calibration listed by sources and associated types is provided below:

- National Oceanic and Atmospheric Administration – digital bathymetry, land surface elevations, and tide data.
- US EPA– Reach File 1.0 cross-sectional data; Reach File 3.0 river shoreline data.
- National Weather Service – atmospheric data including observations of wind speed, wind direction, barometric pressure, air temperature, rainfall and cloud cover.
- US Army Corps of Engineers – electronic navigational survey data; water level, current, temperature, and salinity data collected during extensive 3 month intensive survey in 1993.
- US Geological Survey – daily river flow data; dye dispersion study.
- LCFRP – ambient water quality data.
- NC DENR – ambient water quality data; NPDES discharge data; Long-term BOD analyses; Sediment Oxygen Demand (SOD) in-situ measurements.

Additionally, two extensive dye studies were conducted in December 1999 (Tetra Tech, 2001). Approximately 1,300 samples were collected for dye, salinity, and temperature throughout the estuary during the two studies. A fixed station was also monitored for water level, salinity, and temperature at 15-minute intervals for 10 days. In addition to providing data to support calibration of the hydrodynamic portion of the model, the dye studies provided a basis for examining near field mixing and far field transport of the existing effluents. During these initial field studies, movement of water into adjacent wetlands and salt marshes during flood portions of the tide, and drainage of these areas during the ebb portion of tides, was observed.

In the course of the subsequent EFDC model calibration, the previously set up model grid was enhanced through the addition of several areas of swamp grid cells to better represent the wetting and drying of floodplain wetlands and their effect on in-stream dissolved oxygen levels (Figure 1). Out of the revised total of 950 cells, 146 (~15%) were “marsh” cells with the remaining 804 modeled as “channel” cells. To evaluate the sensitivity of the model to the presence of the swamp areas, the model was run without the additional grid cells. Although there were not specific model calibration points in swamp only areas, the main model calibration points showed substantial improvement of model performance with the added representation of the marsh cells.

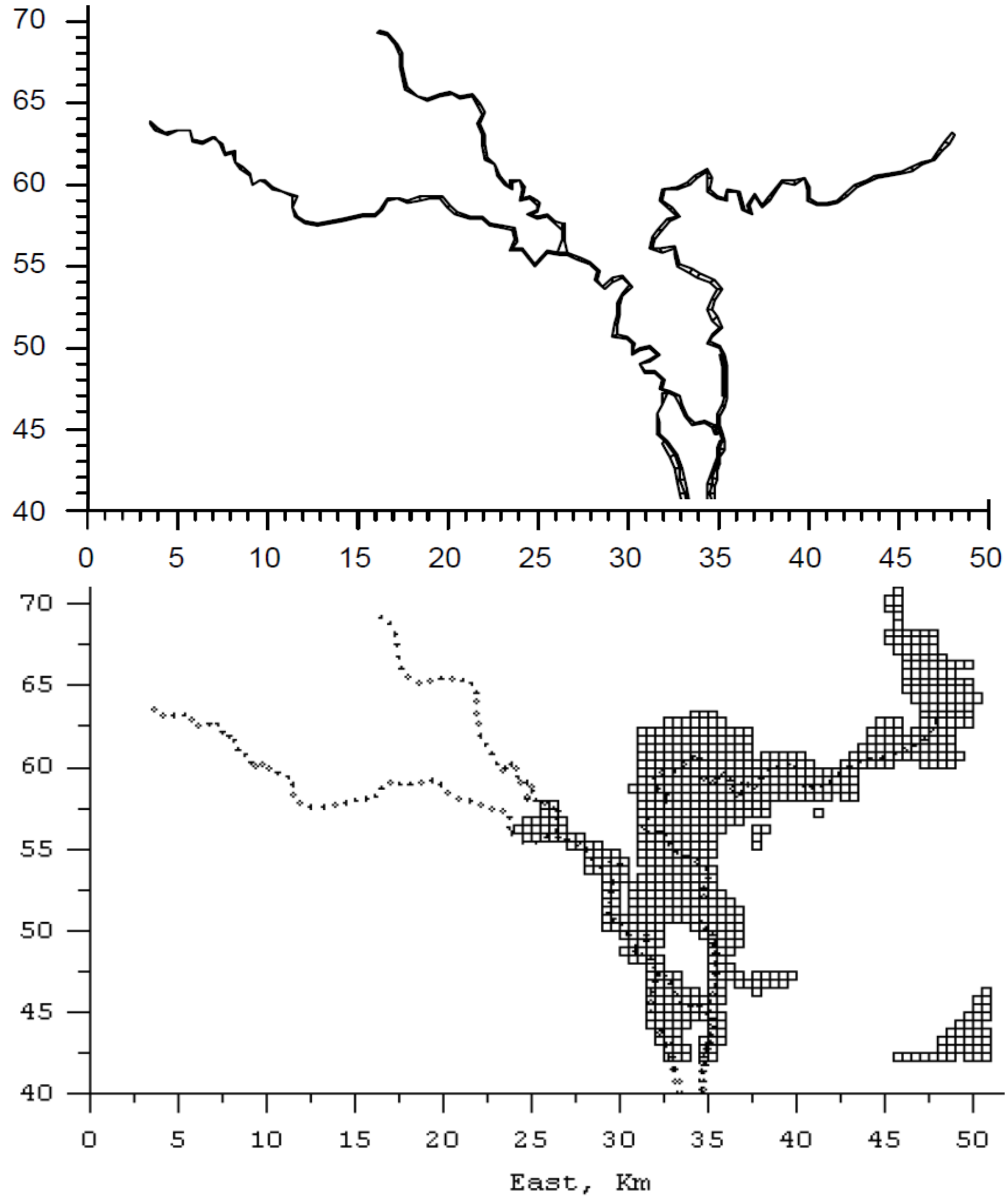

Figure 1. Upper Section of 2001 EFDC Model Grid Without, and With, Swamp Areas Delineated on the Basis of Elevation from the NOAA Coastal Relief Database

2.1.2 Preliminary Model Results

Results of multiple sensitivity analyses performed with the 2001 EFDC model for the LCFRE provided for a type of DO deficit component analysis. Results for July 19, 1998 were graphed in the study, and are shown below in Figure 2. July 19, 1998 was selected because it represented the day of lowest predicted DO for the baseline analysis prior to the effect of Hurricane Bonnie (i.e., a summer critical condition day). Each bar graph displays the model-predicted relative effect of each source of oxygen demand at five separate stations in the LCFRE for the simulated day of July 19. The bar graphs for the Navassa and Northeast Cape Fear River mouth stations (where observed DO concentrations are often the lowest during summer critical periods) show that SOD and swamp oxygen demand are predicted to account for between 73 and 84 percent of the total oxygen demand at those stations. SOD and swamp oxygen demand also comprised the majority of the total oxygen demands at other stations showing the importance of these sources. Overall, the combined effect of SOD and swamp oxygen demand was predicted to be between 3 and 4 times greater than the combined impact of loading from point source and tributary BOD loads during a summer critical condition day. This was one of the first demonstrations that the low DO occurring in the LCFRE was driven by exchange with the bottom sediment and naturally occurring low DO from adjacent marsh/swamp lands and not from loads from point source discharges and major tributaries including the mainstem above Lock and Dam No. 1.

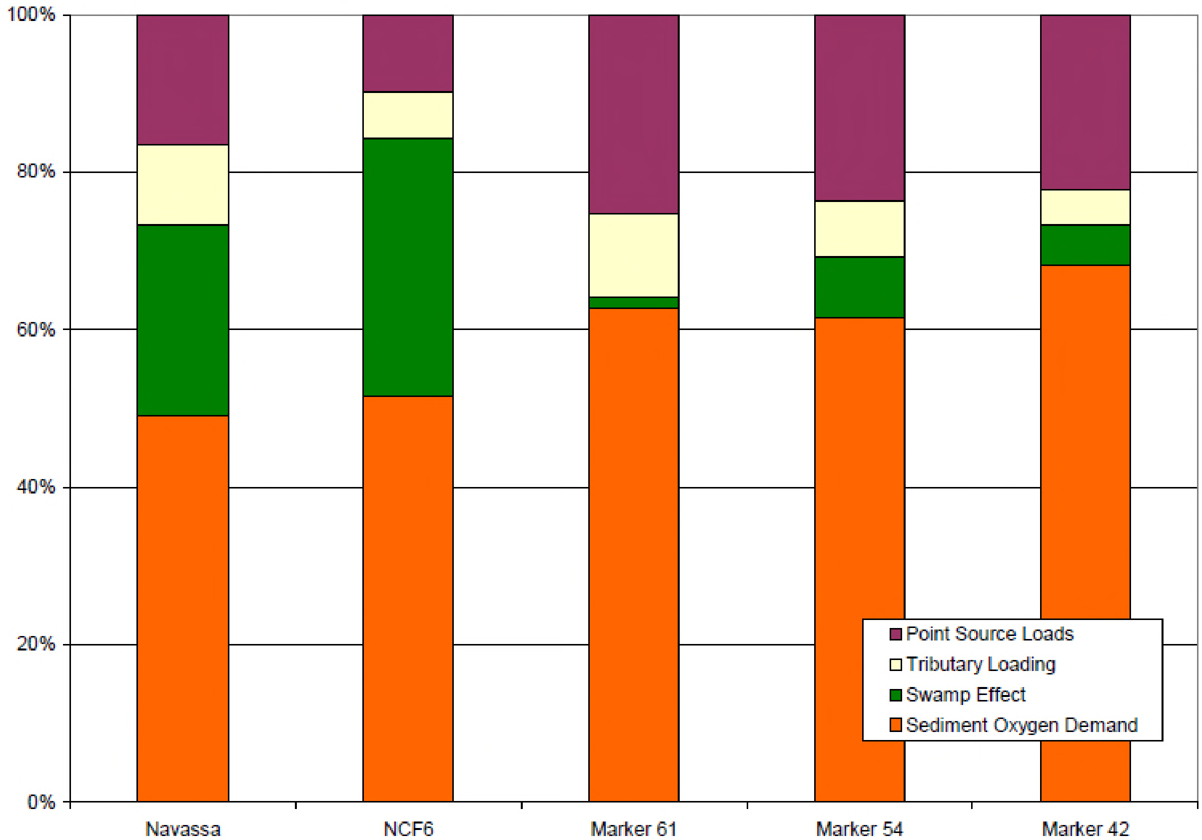

Figure 2. Predicted Relative Impact of Sources of Oxygen Demand in the Estuary (July 19, 1998)

Although the 2001 EFDC modeling demonstrated that a significant portion of the DO deficit near Navassa and down through Channel Marker 61 could be attributed to the combined effects of instream SOD and the oxygen demand from adjacent decaying marsh and swamp vegetation, it was acknowledged that uncertainty remained regarding the precise allocation to the two different oxygen demanding sources because of limited field data on each. The 2001 study recommended that additional study be performed on the LCFRE system to help delineate marsh impacts from instream SOD, which could help further refine the modeling assumptions for these parameters.

3 Subsequent Modeling Effort (2009)

To support the State's regulatory program for dissolved oxygen management in the LCFRE, a detailed monitoring and modeling program was conducted in the mid-2000s culminating with an updated EFDC modeling study (Bowen, et. al., 2009). As with the 2001 modeling effort, existing pertinent data were gathered to support model development, calibration, and validation. Two recommendations from the earlier 2001 modeling effort—that additional information be gathered on the bathymetry within the estuary, and that additional work be done to quantify the effect of the riparian wetlands within the estuary—were undertaken during the updated hydrodynamic model calibration.

Twenty-one river cross-sections were surveyed by NC DENR and the additional bathymetric information was incorporated into the updated specification of the model grid. Additional grid work was also performed to specify the location and size of “wetland” cells that adjoin the main river channel. The overall strategy in determining wetland surface area was to use the information on the attenuation of the tidal amplitude to determine the distribution and overall area of the fringing marshes while considering the wetland delineations performed by the NC Division of Coastal Management in1999. As a result, the 2009 EFDC model included 100 additional model grid cells, of which 95 were “marsh” cells (Figure 3). This modification brought the number of marsh cells up to 241, approximately 23 percent of the model’s total cell count of 1050 (up from 15 percent of 2001 model’s total cell count).

Figure 3. 2009 EFDC Model Grid Showing Location and Size of Marsh Cells; (map image extracted from Bowen, et al., 2009)

Results from the 2009 modeling effort showing average DO concentrations and deficit sources predicted for the model summer period (April through October) are displayed in Figure **4**. Unlike the 2001 effort, the swamp and tributary loading predictions were lumped into one category, "Riv Load Def." as labeled in Figure **4**. The 2009 modeling results, similar to the 2001 results, show that the portion of the DO deficit attributed to SOD and river loadings of organic matter is significantly greater than that attributed to point source loads (i.e., Waste Water Treatment Plant, or WWTP, effluent). Additionally, while the 2001 model considered wetlands to be a sink of DO but did not model these areas as sources of organic matter (OM) loadings, the 2009 model considered tidal creeks and wetlands as both sinks of DO and a source of OM and freshwater back to the channel cells. Note that since the 2009 results are for average summer conditions; we would expect the contributions at critical low flow conditions within the summer to show even more dominance by wetlands since the filling and draining of adjacent marshland would continue due to tidal cycle while the amount of tributary loading would decrease with freshwater flow decreases during the critical period.

Although the 2009 model results combine riverine and wetland loads, the updated model configuration physically links even more area to wetland and salt marsh sources than the 2001 model (23 percent as opposed to 15 percent previously). Since the 2001 model results already showed greater impact on DO deficit from wetlands than riverine loadings at key locations such as Navassa and the mouth of the Northeast Cape Fear River (refer back to Figure 2), one might reasonably infer that with even greater physical attribution to wetlands and salt marsh in the 2009 model that the swamp impact is greater than the river load regarding deficit in the LCFRE hot spots. Additionally, the 2009 modeling confirmed that DO deficit associated with the total point source load in the LCFRE (noted by "WWTP deficit" in Figure **4**) is less than 10 percent of the total DO deficit.

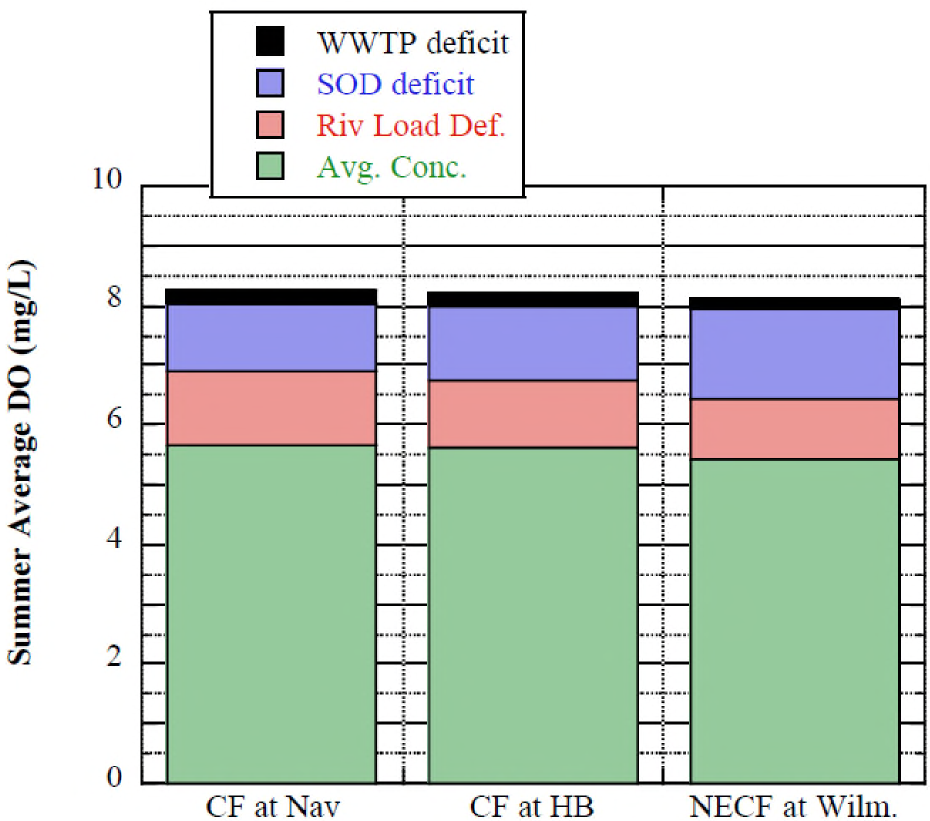

Figure 4. Summer Season (Apr-Oct) Time-Averaged Model Predicted DO Concentrations (image from Bowen, et al., 2009)

Additional scenario testing performed by Bowen et. al. (2009) simulated conditions in the LCFRE with up to 70 percent of the riverine (nonpoint source) oxygen demanding load being removed. The results indicated that even with such a large nonpoint source load reduction, DO concentrations are predicted to be less than the current water quality standard of 5 mg/L roughly 20 percent of the time during summer conditions. The 2009 modeling study therefore added further weight of evidence that other local, naturally occurring sources of oxygen demand (i.e., marshland and SOD) are driving low DO during the summer period.

4 Summary

At the time of the initial 1998 303(d) listing of the LCFRE as impaired due to low dissolved oxygen, NC DENR used a DO standard of 5 mg/L to make its assessment and the reason for impairment was thought to be a combination of point source discharge and nonpoint source pollutant loadings. The setup, calibration, validation, and independent application of two EFDC hydrodynamic water quality models for the LCFRE (Tetra Tech, 2001, and Bowen et.al., 2009) provide a strong scientific basis for isolating primary influences on DO concentrations in the LCFRE. Both modeling efforts demonstrated that the impact from point source loads in the LCFRE contributes to less than 10 percent of the DO deficit in the LCFRE. The 2001 modeling effort demonstrated that an accurate calibration could not be achieved without representing the wetting and drying of adjacent low elevation wetland and salt marsh areas. That modeling estimated that wetland/marsh and SOD sources accounted for between three quarters and four fifths of all oxygen demand in the LCFRE. The 2009 modeling effort validated and expanded the influence of adjacent marshland based on more detailed analysis. Further, application of the 2009 model that simulated up to 70 percent of nonpoint source load reduction demonstrated that even with such large pollutant loading reductions, DO concentrations would be expected to be below 5 mg/L 20 percent of the time in the LCFRE during the summer. Therefore, the 2001 and 2009 modeling analyses provide further weight of evidence collectively that other local, naturally occurring sources of oxygen demand (i.e., marshland and SOD) are driving low DO during the summer period and suggest that reinstitution of the supplemental “Swamp” designation for the LCFRE should be considered by NC DENR and the Environmental Management Commission.

References

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