Dissolved Oxygen Total Maximum Daily Load for the Brown Creek Watershed, Anson County, North Carolina (Water Body ID: 13-20b)

Final Report

(EPA Approved: September 14, 2011)

Yadkin-Pee Dee River Basin

Prepared by:

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Summary of TMDL Submittal

303(d) List Information

State North Carolina

Basin Yadkin-Pee Dee River Basin

303(d) Listed Waters

Name of Stream	Description	Class	AU#	8 Digit HU	Miles
Brown Creek	From mouth of Lick Creek to Yadkin-Pee Dee River	C	13-20b	03040104	28.5

WQ Standard Violated Dissolved Oxygen

Pollutant of Concern Total Ultimate Biological Oxygen Demand (TBODu)

Sources of Impairment Nonpoint sources from upland watershed

Public Notice Date: July 12, 2011

Submittal Date: To be determined

Establishment Date: To be determined

EPA Lead on TMDL (EPA or blank):

DOT a Significant Contribution (Yes or Blank):

Endangered Species (yes or blank):

MS4s Contributions to Impairment (Yes or Blank):

TMDL Considers Point Source, Nonpoint Source, or both: Nonpoint Source

TMDL Information

Critical condition	Summer.
Seasonality	Evaluated the DWQ's ambient data from 1998-2007 to examine seasonal variation in dissolved oxygen concentration.
Development tools	River and stream water quality model, QUAL2K.

Loading allowed at critical condition:

Waste Load Allocation (WLA):	0 lb TBODu per day.
Load Allocation (LA):	19.31 TBODu lbs per day.
Margin of Safety (MOS):	2.15 TBODu lbs per day.
TMDL (WLA+LA+MOS):	21.46 TBODu lbs per day.

Total Maximum Daily Load (TMDL)	Sources	TBODu Loading Reduction
Waste Load Allocation (WLA)	WWTP	0%
Load Allocation (LA)	Potential non-point sources include stormwater runoff, illegal disposal, malfunctioning septic systems, illicit discharges of domestic waste, and applications of chemical fertilizer, poultry litter, and bio-solid.	31%

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1 Introduction

The North Carolina Division of Water Quality (DWQ) has identified a 28.5 mile segment of Brown Creek in the Yadkin-Pee Dee River Basin as impaired by low Dissolved Oxygen (DO) since 1998. It is reported on the 2010 303(d) Report of Impaired Waters due to violations of the North Carolina water quality standard (NCDENR 2010). The impaired segment is located from the mouth of Lick Creek, near Mineral Spring Road, to Pee Dee River (Figure 1). This section of the creek is located in sub-basin 03040104 and designated as Class C water[1]. According to Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations, the State is required to develop a Total Maximum Daily Load (TMDL) for the impaired segment in the creek. The TMDL process establishes the allowable pollutant loadings or other quantifiable parameters for the creek based on the relationship between pollutant sources and in-stream water quality conditions. This allows water quality-based controls to be developed to reduce pollution and to restore and maintain water quality in the creek.

Section 303(d) of the CWA requires EPA to review all TMDLs for approval or disapproval. Once EPA approves a TMDL, then the water body may be moved to Category 4 of the 303(d) list. Water bodies remain on Category 4 of the list until compliance with water quality standards is achieved.

This report represents a DO TMDL for Brown Creek in the Yadkin-Pee Dee River Basin. Although an implementation plan for Total Ultimate Biological Oxygen Demand (TBODu) is not included as a part of this TMDL, reduction strategies are needed. Involvement of local governments and agencies will be necessary in order to develop implementation plans and reduction strategies.

[1] Class C waters are freshwaters that are protected for secondary recreation such as fishing, wildlife, fish consumption, aquatic life including propagation, survival and maintenance of biological integrity, and agriculture. Secondary recreation includes wading, boating, and other uses involving human body contact with water where such activities take place in an infrequent, unorganized, or incidental manner.

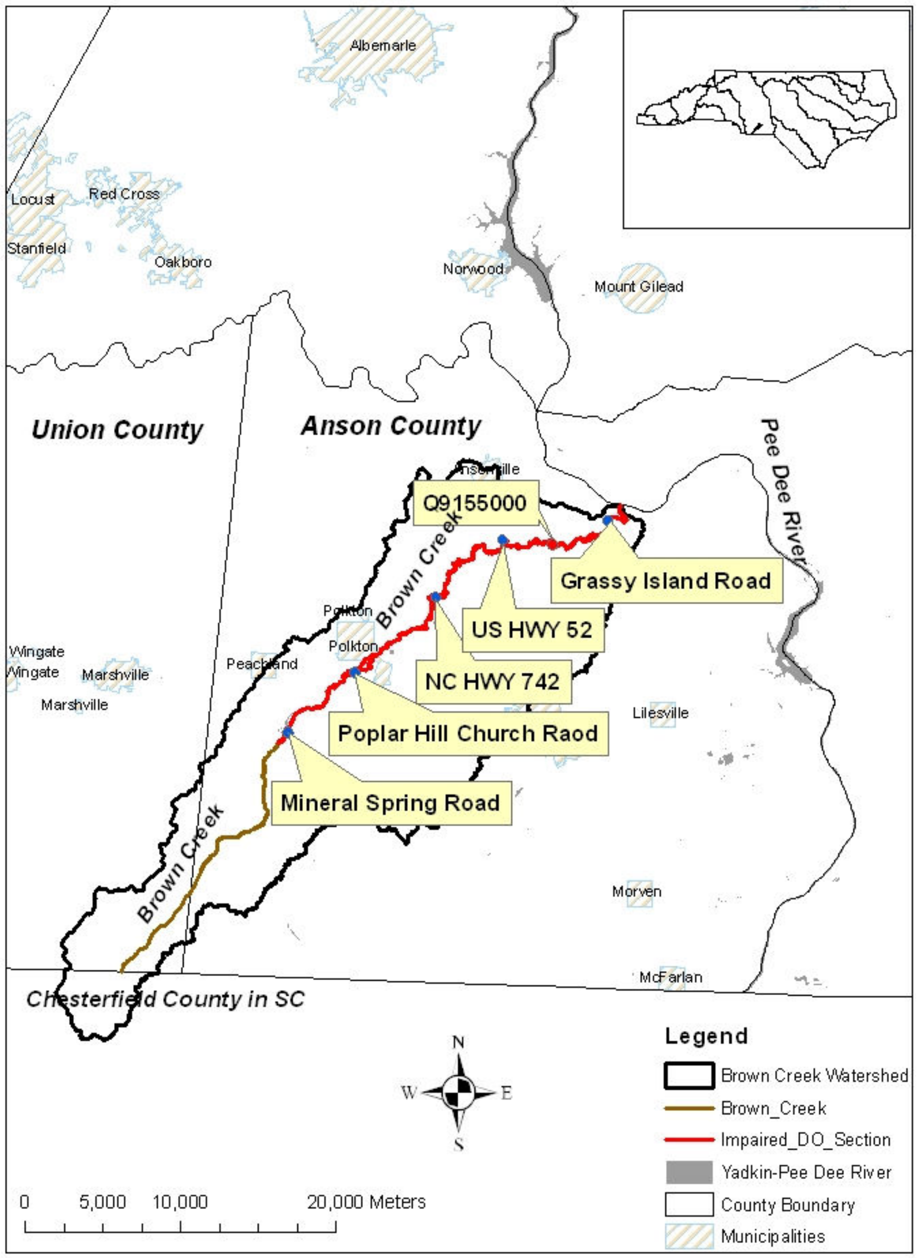

Figure 1. Brown Creek Watershed showing water quality monitoring sites and dissolved oxygen impaired segment of the Creek (red color line)

1.1 Watershed Description

Brown Creek starts from South Carolina (SC) State near the borderline between Chesterfield County and Union County in North Carolina (NC) and ends at the Pee Dee River in NC (Figure 1). The impaired segment of the creek runs through Anson County in NC.

The Brown Creek watershed has an area of approximately 197.23 square miles, comprising predominantly forested land (66.2%) and agricultural land (22.0%) (Source: The 2006 National Land Cover Data). The forested land includes 25.5% deciduous forest, 33.7% evergreen forest, 4.2% mix forest, and 2.7% shrub/scrub. The agricultural area includes 13.0% Pasture/hay lands, 7.6% grasslands/Herbaceous lands, and 1.5% cultivated crops. Other uses are comprised of 5.6% urban lands, including residential area, 5.6% woody wetlands, 0.25% barren land, 0.03% non-forest wetland and 0.2% water.

The Brown Creek watershed is within the Triassic Hydrologic area and is composed of sedimentary rocks, including shale, sandstone, and arkose (a mixture of quartz and clay minerals). Permeability is low in the watershed due to presence of clay material underneath surface soil. Therefore, usually base flow remains low in this watershed. As a result tributaries receive less water, and sometimes no water, especially during summer period when precipitation stays sporadic (See Appendix C, Figure C5). The 7Q10 flow is estimated to be zero for the creek (Giese and Mason, 1993).

1.2 Water Quality Target: North Carolina Water Quality Standard

The North Carolina fresh water quality standard for Class C waters for DO (15A NCAC: 02B.0211) states:

Dissolved Oxygen: not less than 6.0 mg/L for trout water; for non-trout waters, not less than a daily average of 5.0 mg/L with a minimum instantaneous value of not less than 4.0 mg/L; swamp water, lake coves or backwaters, and lake bottom waters may have lower values if caused by natural conditions.

The in-stream numeric target, or endpoint, is the restoration objective that is expected to be reached by implementing the specified load reductions in the TMDL. The target allows for the evaluation of progress towards the goal of reaching water quality standards for the impaired stream by comparing the in-stream data to the target. In the Brown Creek watershed, the water quality target for DO is the daily average of 5mg/L.

1.3 Water Quality Assessment

The DWQ monitors a suite of water quality parameters, including DO, at ambient stations throughout the state on a monthly basis. There is one DWQ ambient station (Q9155000) in Brown Creek at Pinkston RIV Rd (Figure 1). DO levels at the station are responsible for the 303(d) listing of a portion of the creek. Table 1 summarizes nutrient concentrations at the station from 1998 to 2007.

Table 1. Monthly average water quality in Brown Creek at the ambient station, Q9155000 (1998-2007).

Month	DO mg/L	Temperature Degree C	TKN mg/L	NOx mg/L	TN mg/L	TP mg/L	pH
1	9.89	6.99	0.62	0.12	0.74	0.12	6.42
2	10.64	6.97	0.30	0.07	0.37	0.07	6.66
3	9.39	12.04	0.43	0.07	0.50	0.11	6.81
4	8.06	16.13	0.40	0.12	0.52	0.10	6.86
5	5.81	17.95	0.58	0.19	0.77	0.09	6.75
6	3.92	22.21	0.47	0.13	0.60	0.07	6.80
7	3.01	25.13	0.82	0.09	0.91	0.11	6.75
8	3.57	24.39	0.65	0.08	0.73	0.12	6.70
9	3.67	21.41	0.48	0.08	0.55	0.12	6.69
10	4.39	17.60	0.50	0.03	0.53	0.14	6.79
11	4.78	12.57	0.50	0.04	0.54	0.12	6.67
12	8.88	7.37	0.73	0.05	0.77	0.11	6.96

On average, DO concentrations were below the State’s standard, 5 mg/L, during summer and fall (June through November) in Brown Creek. Therefore, a question is raised about possible sources that reduced DO concentration. To answer the question, the DWQ conducted a bi-weekly special study during summer period, April through October 2010, at the following five different locations along the impaired segment of the creek: Mineral Spring Road, Poplar Hill Church Road, NC HWY 742, US HWY 52, and Grassy Island Road (Figure 1). The objectives of the special study were to analyze TN, TP, and organic matter at the five different locations; to compare the results to the USGS national background averages; and to estimate their relative contribution from background sources. The national background averages are 1.0 mg/L for TN and 0.1 mg/L for TP (http://pubs.usgs.gov/circ/circ1225/index.html). The averaged values were estimated from nutrient concentrations in streams from undeveloped areas in the USA. A detailed study plan is well documented by Rajbhandari, 2010 and the observed data are presented in Appendix A.

Quartile distributions of DO, TN, TP, and BOD5 concentrations that were observed during the special study period in Brown Creek are presented in Figures 2 to 5. Summaries of the observed concentrations are presented in Table 2. During the study period, only a few observations (7% to 14%) met the DO standard in the creek (Figure 2). On average, DO concentration was lowest (1.8 mg/L) at Mineral Spring Road (Table 2). The concentration gradually increased to 3.4 mg/L downstream. Overall, the concentrations were below 5 mg/L throughout the study locations.

Table 2. Averaged physical and chemical concentrations observed during the special study period, April through October, 2010, in Brown Creek.

Locations	No. of Obs.	BOD5 (mg/L)	TOC (mg/L)	TKN (mg/L)	NOx (mg/L)	TN (mg/L)	TP (mg/L)	Cond[1]. (µS)	pH	Temp[2] (deg C)	DO (mg/L)
Mineral Spring Road	14	12.05	23.79	3.08	0.03	3.11	0.65	175.00	6.82	21	1.81
Poplar Hill Church Road	13	8.94	14.46	1.74	0.02	1.75	0.25	128.92	6.78	22	2.78
NC HWY 742	14	3.50	13.44	1.04	0.07	1.11	0.16	123.43	6.89	21	3.01
US HWY 52	14	5.86	14.42	1.73	0.13	1.86	0.27	135.36	6.96	22	3.44
Grassy Island Road	14	1.70	13.74	0.95	0.39	1.34	0.19	128.21	6.92	22	3.44

1. Cond. = Conductivity
2. Temp. = Water Temperature.

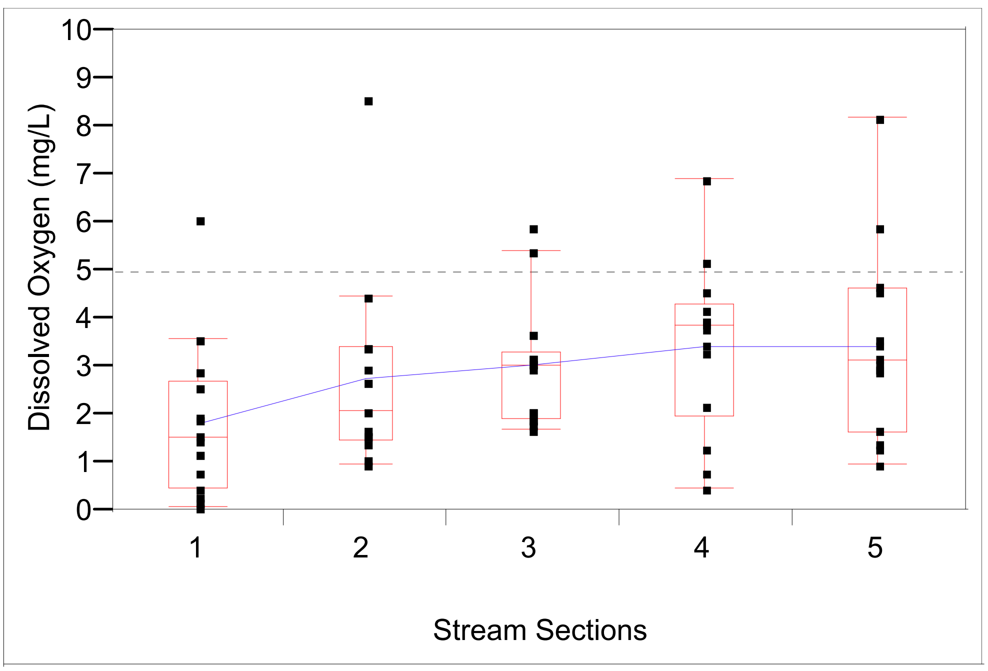

Figure 2. Quartile distribution of Dissolved Oxygen (DO) at (1) Mineral Spring Road, (2) Poplar Hill Church Road, (3) NC HWY 742, (4) US HWY 52, and (5) Grassy Island Road, April through October 2010.

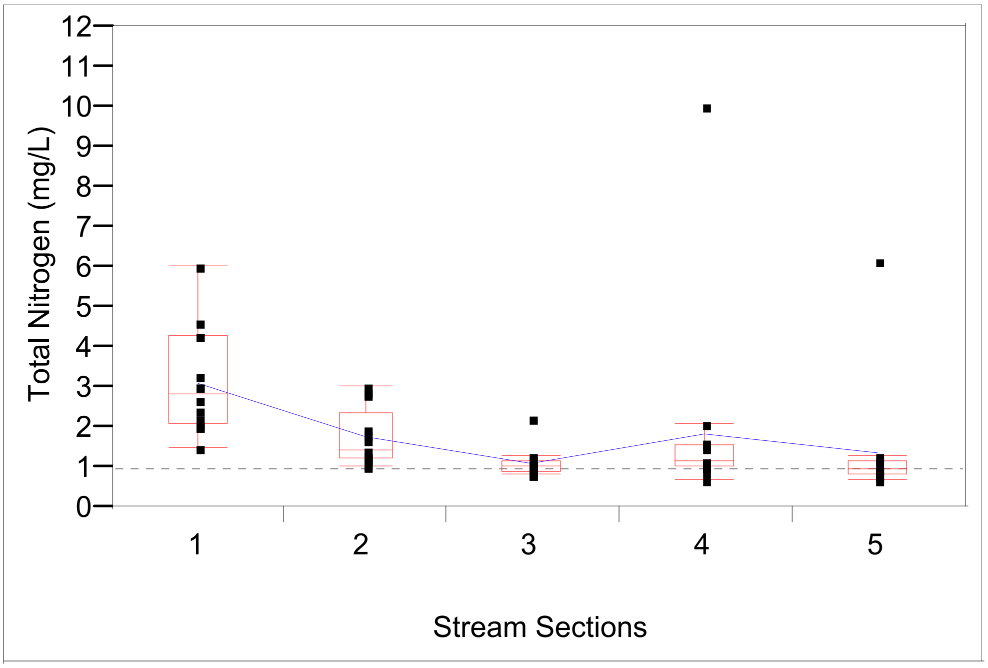

Figure 3. Quartile distribution of Total Nitrogen (TN) at (1) Mineral Spring Road, (2) Poplar Hill Church Road, (3) NC HWY 742, (4) US HWY 52, and (5) Grassy Island Road, April through October 2010.

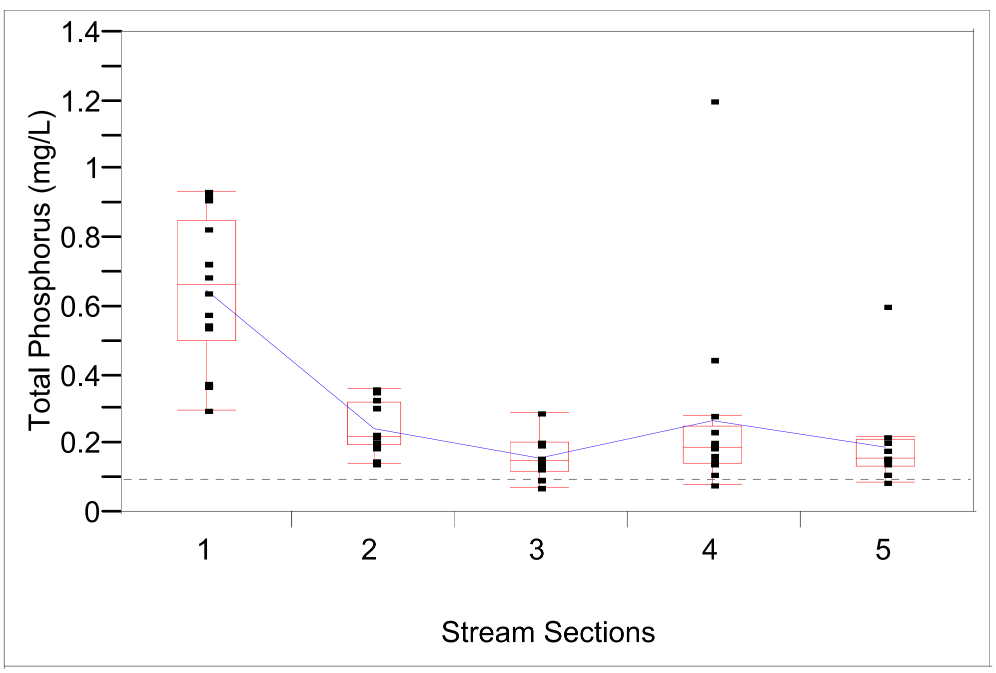

Figure 4. Quartile distribution of Total Phosphorus (TP) at (1) Mineral Spring Road, (2) Poplar Hill Church Road, (3) NC HWY 742, (4) US HWY 52, and (5) Grassy Island Road, April through October 2010.

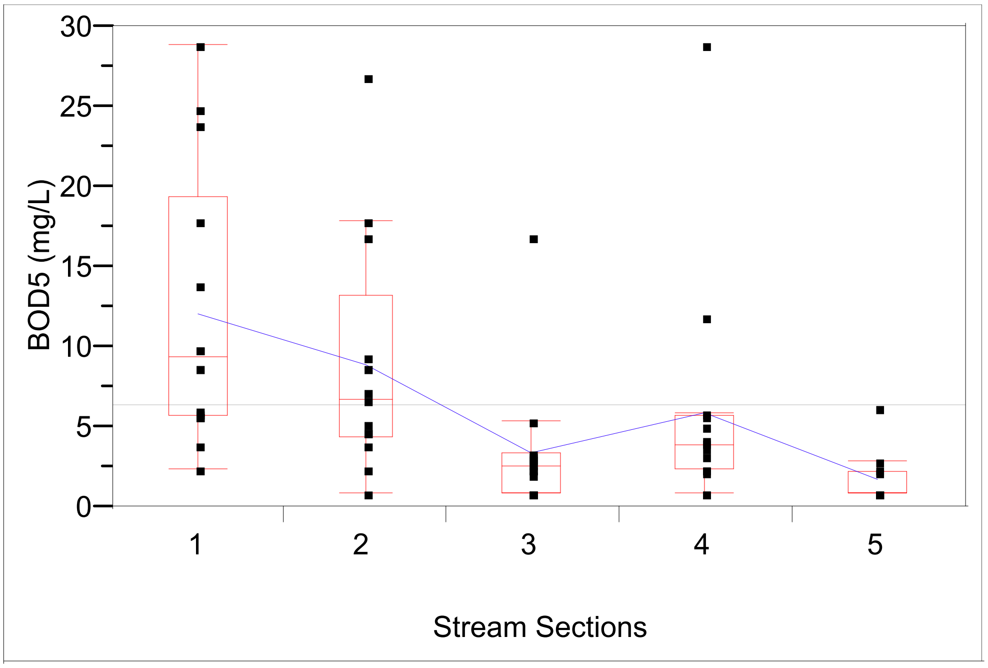

Figure 5. Quartile distribution of measured Five-day Biochemical Oxygen Demand (BOD5) at (1) Mineral Spring Road, (2) Poplar Hill Church Road, (3) NC HWY 742, (4) US HWY 52, and (5) Grassy Island Road, April through October 2010.

Figures 3 and 4 clearly reveal that the low DO concentrations in Brown Creek were due to anthropogenic activities in upland watershed and around near Peachland City and Polkton City. Almost all concentrations of TN and TP exceeded the USGS national background averages (1 mg/L for TN and 0.1 mg/L for TP) at upstream locations, Mineral Spring Road and Poplar Hill Church Road. Only a few observations exceeded the USGS national background averages at the downstream locations, NC 742 to Grassy Island Road. These results suggest that the low DO concentration in Brown Creek was due to some potential sources in the watershed that also contributed N and P. Usually N is found in human waste discharges, animal droppings, and fertilizer runoff. P is found in fertilizer and some detergents.

Figure 5 further demonstrates that organic matter was concentrated at the upstream watershed near Peachland City and Polkton City. Averaged BOD5 concentrations were greater in Brown Creek at Mineral Spring Road and Poplar Hill Church Road. Usually organic matter (e.g., vegetation and human and animal waste) increases BOD5 in a water body. Since the creek runs through Triassic land where infiltrability is very low, it is expected that any accumulated nutrients and organic matter in the lands would transport to the creek through surface runoff after a rainfall event. A detailed assessment of the probable sources is discussed in source assessment, below.

1.4 Flow Assessment

There was no USGS gauge station in Brown Creek. Considering accessibility the DWQ staff selected a location in Brown Creek at NC HWY 742 for undertaking flow measurement (velocity, depth, and discharge rate) while collecting water samples from the creek. The flow data is presented in Table 3 and a cross sectional diagram of the location is presented in Figure 6.

Table 3. Hydrologic responses in Brown Creek at NC HWY 742 during water sampling periods.

Date	Precipitation[1] (in)	Discharge (cfs)	Velocity (ft/sec)	Depth ft
4/14/2010	0	4.57	0.12	1.04
4/21/2010	0	2.37	0.08	0.77
5/12/2010	0	0.64	0.03	0.53
5/17/2010	1.3	10.33	0.23	1.21
5/27/2010	0	2.16	0.08	0.74
6/16/2010	0	0.76	0.03	0.61
6/22/2010	0	0.26	0.01	0.49
7/13/2010	0.29	0.78	0.03	0.62
7/27/2010	0.59	5.84	0.13	1.15
8/10/2010	0	0.16	0.01	0.47
8/24/2010	0.02	0.70	0.03	0.55
10/14/2010	0.01	0.32	0.02	0.45

1. Precipitation source: Anson County Airport.

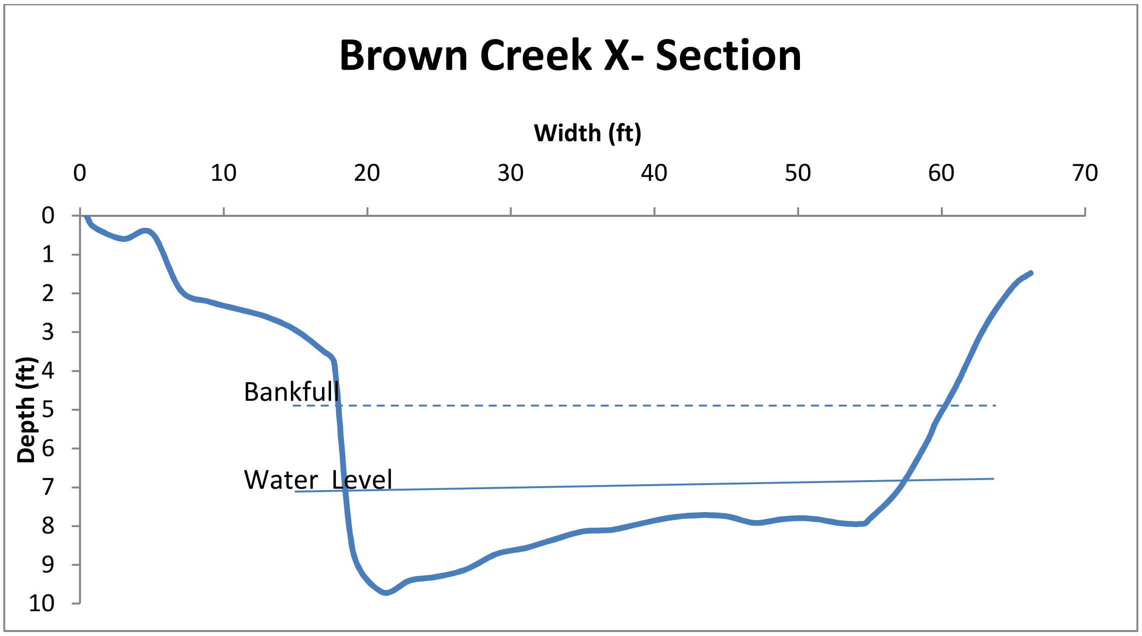

Figure 6. Cross sectional view of Brown Creek at NC Hwy 742.

Brown Creek at NC Hwy 742 was approximately 66 ft wide with maximum water depth of 1.6 ft. Approximately, water level starts at 19ft and ends at 57 ft from the bank. Discharge while collecting water samples ranged from 0.16 cfs to 10.33 cfs. The highest discharge was observed during the storm event of 1.3 inches on May 17, 2010. There was a total storm event of approximately 13.56 inches during the study period (April through October, 2010). The relationships among the flow, discharge, and depth are expressed by the following equations:

$$V = 0.04\, Q^{0.76} \quad R\text{-}Square = 0.98\text{--------------------}(1)$$

$$D = 0.56\, Q^{0.26} \quad R\text{-}Square = 0.94\text{--------------------}(2)$$

Where, V = Velocity in ft/sec, D = Water depth in ft, and Q = Discharge in cfs.

2 Source Assessment

The source assessment characterizes the known and suspected sources of a pollutant to the impaired water body. Generally, sources of TN, TP, and organic matter may be point or non-point in nature. Point sources are typically those regulated under the NPDES system, permitted discharges for which the DWQ has significant information. There were two NPDES industrial stormwater dischargers to Brown Creek: the Anson Waste Management Facility (NCG120064) and Southeastern PET Resin Recyclers (NCG030225). Both facilities were under a general stormwater permit that requires semi-annual discharge monitoring to guide stormwater pollution prevention efforts. These facilities were considered to be contributing almost negligible loads to the creek.

Non-point sources are diffuse sources that typically cannot be identified as entering a water body at a single location. In order to characterize possible non-point sources in Brown Creek, the water quality parameters - BOD5, TOC, and tannin and lignin - that were collected during the special study period were examined. The observed BOD5 concentrations were further converted into Labile (biologically active and unstable) Organic Carbon (LOC) and Refractory (poorly biodegradable) Organic Carbon (ROC) by using equations 3 and 4 to examine whether the sources were anthropogenic eutrophication or not. The equations were derived by Hendrickson et al., 2007, considering that LOC and ROC decompose simultaneously, albeit at different rates. Their first-order decay rates were 0.075 day $^{-1}$ and 0.001 day $^{-1}$, respectively.

$$LOC\ (mg/L) = (BOD5*74.906 - TOC)/61.54 \text{ --------------------- } (3)$$
$$ROC\ (mg/L) = TOC\text{-}LOC \text{ --- } (4)$$

The above equations represent the St. Johns River, which is one of the largest blackwater rivers of the southeast U.S., draining a 24,765 km^2 area in Atlantic coastal plain river estuary in northeast Florida. The river is slow moving and receives nutrients from adjoining swamp water. Although there are some differences in physiological characteristics compared to Brown Creek, it could be assumed that any information drawn from the river would be applicable to this study, because the creek is slow moving and receives organic matter from adjoining forested, agricultural, and urban watersheds. Table 4 displays average values of LOC, ROC, and Tannin and Lignin in Brown creek during the study period.

Table 4. Average values of different organic matters in Brown Creek during the study period, April – October, 2010.

Location	LOC[1] (mg/L)	ROC[2] (mg/L)	Tannin and Lignin[3] (mg/L)
Mineral Spring Road	14.28	9.51	2.7
Poplar Hill Church Road	10.64	3.82	1.9
NC HWY 742	4.04	9.40	1.7
US HWY 52	6.90	7.52	1.5
Grassy Island Road	1.85	11.89	1.5

1. LOC = Labile organic carbon. It was estimated using equation 3.
2. ROC = Refractory organic carbon. It was estimated using equation 4.
3. Measured organic compounds.

Hendrickson et al., 2007, found highest concentration of LOC and lowest concentration of ROC in domestic waste. In addition they found highest concentration of ROC in dairy, row crop, and undeveloped watershed runoff and lowest in urban runoff. In this study, LOC concentrations upstream, near Mineral Spring Road and Poplar Hill Church Road, were higher than ROC concentrations (Table 3). Therefore, it is assumed that some anthropogenic sources such as malfunctioning septic system, chemical fertilizer application, poultry litter application, stormwater runoff (unfiltered water flowing across impervious surfaces due to urbanization) from Peachland City and Polkton City, Illicit discharges of domestic waste (direct pipeline) and bio-solid application would have been contributing organic matters to the creek. For examples, approximately 1.4 miles upstream of Mineral Spring Road, there was a parcel of cultivated land that was in the middle of the stream floodway. It was extensively ditched. This parcel would be a possible source of N and P input into the creek. Further down the road, approximately 4 miles, there was a permitted land application of bio-solids (WQ0000057), which would also be a possible source of BOD input into the creek (Source: Personal communication with Art Barnhardt, Fayetteville Regional Office, Aquifer Protection).

The above assumption that the low DO status in Brown Creek was due to anthropogenic sources is further supported by the low values of tannin and lignin concentrations in the creek (Table 4). The low values suggest that decaying organic matters from plant materials, mainly from background sources, were insignificant. Therefore, it is assumed that organic matter contributions from background sources were negligible in the creek.

3 Modeling Approach

Based on Federal TMDL guidance and requirements, development of the DO TMDL for Brown Creek was conducted for a critical low flow condition using a modeling program called QUAL2K (Q2K), Version 2.11 (Chapra et.al, 2008). The model is a river water quality model that is intended to represent a modernized version of the QUAL2E model (Brown and Barnwell 1987). The model is one dimensional; therefore it assumes that the channel is well-mixed vertically and laterally. The model employs steady state hydraulics. It uses a diel heat budget, computes diel water-quality kinetics, and simulates point and non-point loads and abstractions.

The Q2K model is implemented within the Microsoft Windows environment. Fortran language is used for numerical computations. Excel is used as the graphical user interface. All interface operations are programmed in the Microsoft Office macro languages. Details of the model applications are well documented in Chapra et al., 2008.

3.1 Modeling Setup

The Q2K model requires a water body to be divided into different sections so that each section will have roughly uniform hydraulic characteristics. For this study, Brown Creek was divided into five sections at Mineral Spring Road, Poplar Hill Church Road, NC HWY 742, US HWY 52, and Grassy Island Road. These sections were then populated with following input parameters. The corresponding input values for each section are presented in Appendix B.

- Geographic Characteristics: An internet GIS program called Google Earth (Earth Viewer 3D) was utilized to generate the geographic information such as longitude and latitude, time zone, and elevation.
- Meteorological characteristics: The meteorological data such as air temperature, dew point temperature, wind speed, and cloud cover were acquired from the State Climate Office of North Carolina, North Carolina State University (NCSU). Besides these parameters, the model also requires a percent shading coverage. Based on the DWQ staff's field observation it was estimated to be 35% on average.
- Physical, chemical and biological parameters: The key water quality parameters like ammonia, Total Kjeldahl Nitrogen (TKN), TN, TP, BOD5, TOC, pH, Conductivity, and water temperature were collected during the special study period (April – October, 2010).
- Hydraulic characteristics: The model either uses Manning's n or flow rating coefficients to estimate travel time for routing water constituents. For this study, Manning's n was used. Based on the DWQ staff's field observation, values for Manning's n ranges from 0.075 to 0.15 for Brown Creek where bottom garbles, weedy reaches, timber stands, and underbrush were common (See Appendix C, Figure C1).

3.2 Model Calibration

Model calibration was performed for a low flow stage that was observed on August 10, 2010 in Brown Creek. On that day discharge was recorded at 0.16 cfs (velocity = 0.01 ft/sec and depth = 0.47 ft) (Table 3). Calibration was then completed by adjusting a number of key coefficients so that the model reproduced the following observed water quality parameters: Water Temperature, pH, TKN, TN, and TP, and DO. The adjusted coefficients are presented in Appendix B and observed and simulated graphs are presented in Figures 7 to 12. The model seems to be predicting slightly higher TKN and TP concentrations towards downstream (Figures 9 and 11). It could be due to model limitation when examining the contribution of nonpoint sources of pollutants to river water quality degradation. The model is not set up to account for contributions from nonpoint sources in the watershed. Therefore, a variation may deviate from the model assumptions (Shanahan et al. 1998). Considering the data and information available the model is considered reasonably calibrated. Overall, the model simulated pollutants of interest within the range shown by the observed data and reproduced the general water quality trends reasonably well.

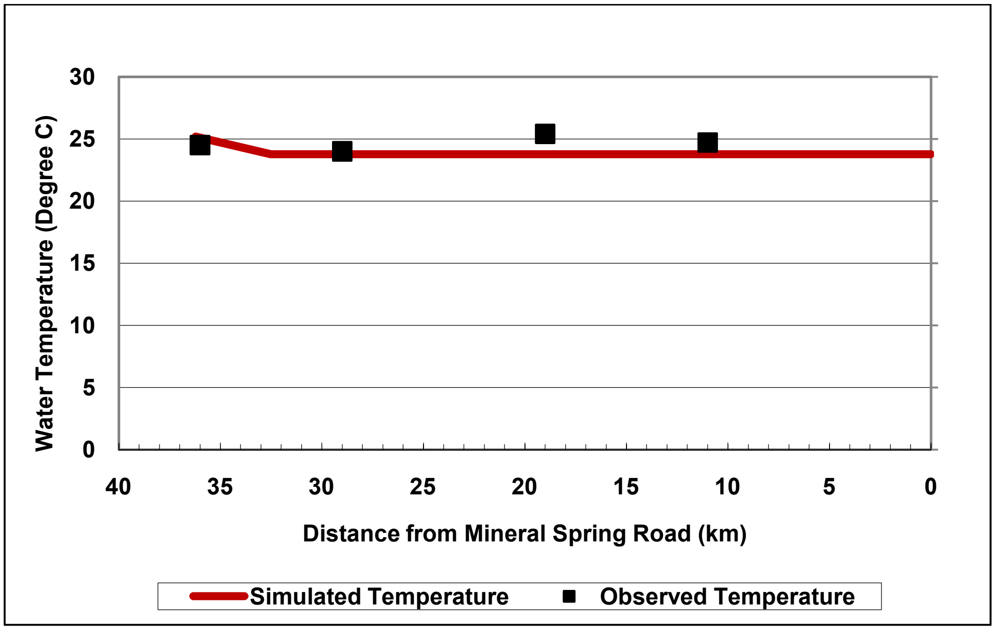

Figure 7. Observed versus simulated water temperature in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

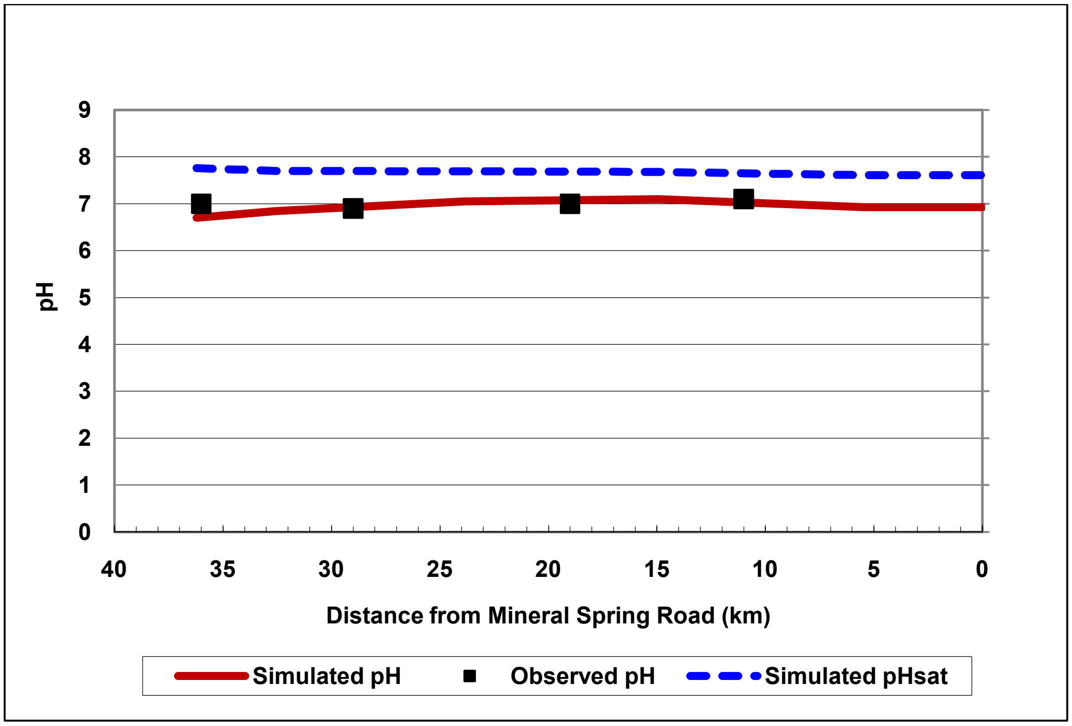

Figure 8. Observed versus simulated pH in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

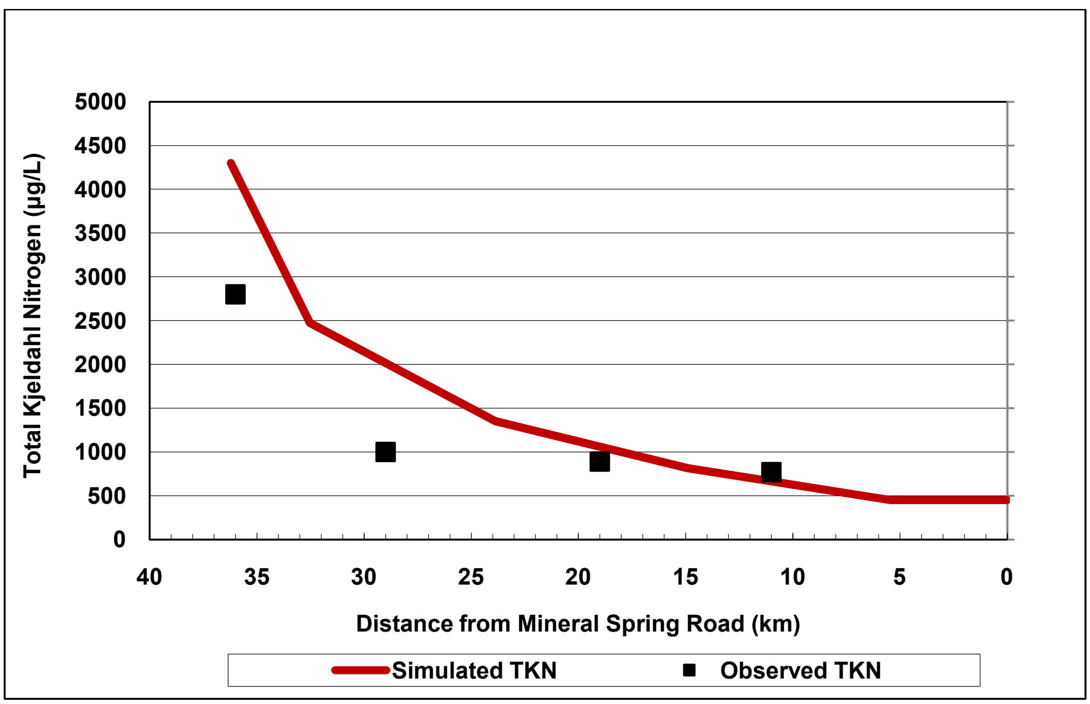

Figure 9. Observed versus simulated Total Kjeldahl Nitrogen (mg/L) in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

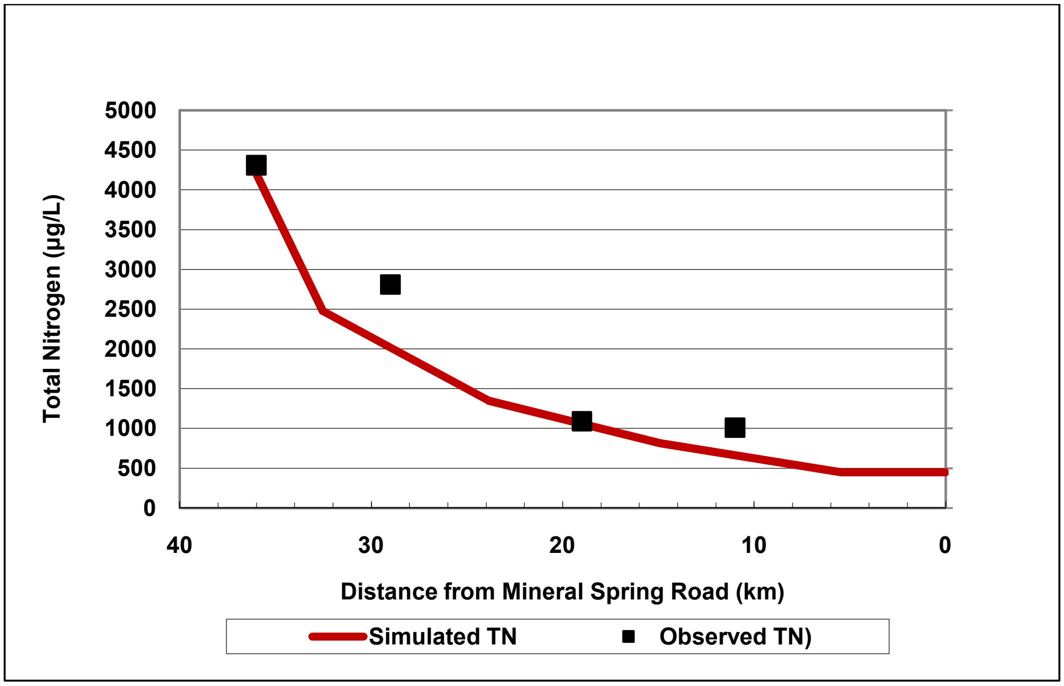

Figure 10. Observed versus simulated Total Nitrogen (mg/L) in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

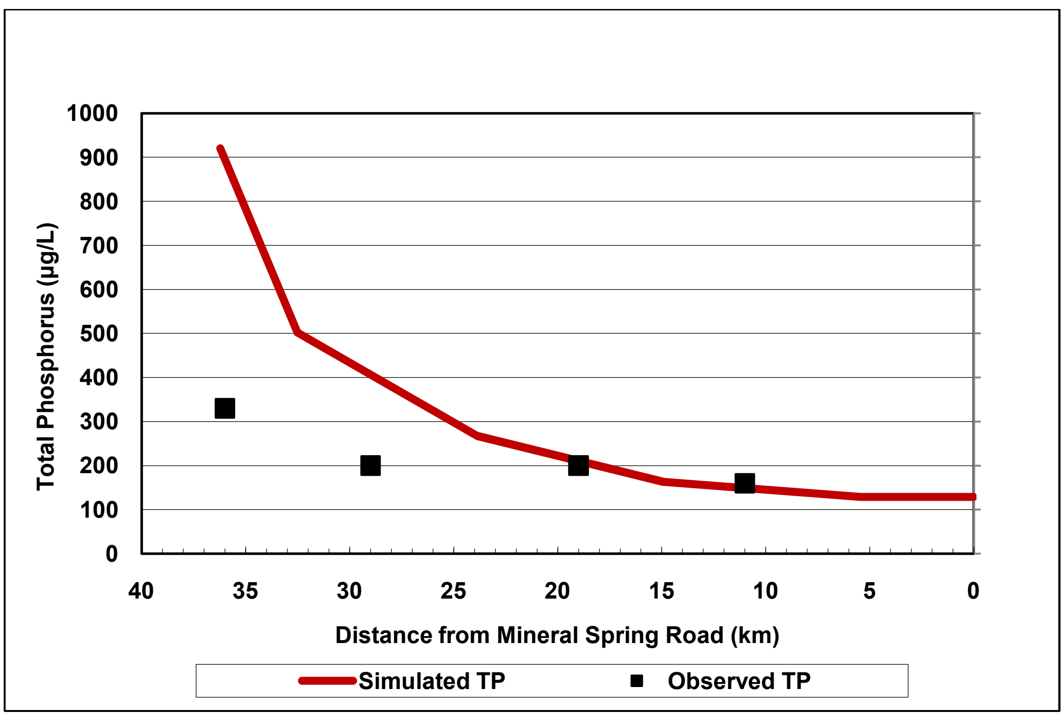

Figure 11. Observed versus simulated Total Phosphorus (mg/L) in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

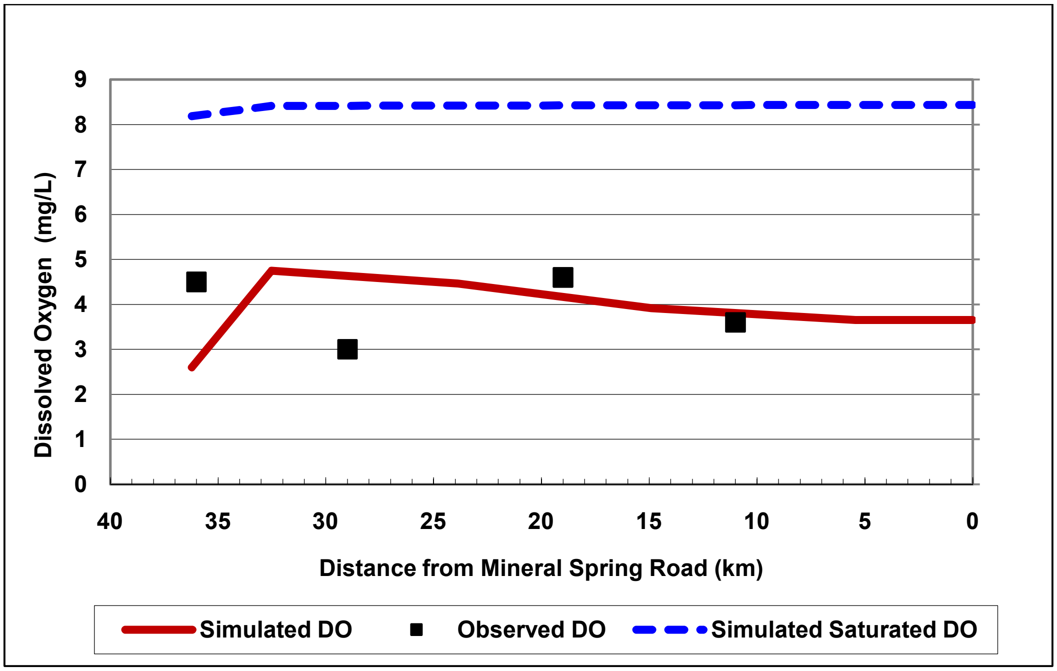

Figure 12. Observed versus simulated Dissolved Oxygen (mg/L) in Brown Creek at Mineral Spring Road to the confluence of the Pee Dee River.

3.3 Pollutant of Concern

Based on the Q2K modeling, the pollutant of concern for DO is ultimate total biological oxygen demand (TBODu), which includes both carbonaceous (CBODu) and nitrogenous (NBODu). The equations below show the relationships:

$$TBODu = CBODu + NBODu \text{ ----------------------- } (5)$$

$$NBODu = TKN * r_{on} \text{ ----------------------------------- } (6)$$

Where r_{on} is a nitrification ratio which is estimated to be 4.57 on average (Chapra et. al, 2008).

During summer period Brown Creek receives almost negligible amount of flow from its tributaries (Appendix C: Picture C5), thereby diminishing tributary nutrient loads and enhancing sediment oxygen demand (SOD). Therefore, bottom sediments in the creek play substantial roles to reduce oxygen during summer period when warm temperature enhances biological processes which consumes oxygen through oxidation of organic carbon (CBOD) and nitrification of ammonia (NBOD). As per equation 5, sum of oxidation and nitrification equates a value to TBODu. For this study, a value for TBODu is estimated as follows.

Figure 13 represents the calibration or baseline model run for DO in Brown Creek. This DO curve, calculated by the Q2K model, corresponds to an input value of 4.3 mg/L for TKN and 9.6 for CBODu. The TKN concentration represents a measured value whereas the CBODu concentration represents an estimated value. The CBODu concentration was estimated by dividing the measured BOD concentration by a constant 2.5 (Thomas and Mueller, 1987). Using equations 5 and 6, TBODu was then estimated to be 29.25 mg/L (TBODu = 9.6 + 4.3*4.57).

4 Total Maximum Daily Load

Total maximum daily load (TMDL) can be defined as the total amount of pollutant that can be assimilated by the receiving water body while achieving water quality standards. A TMDL can be expressed as the sum of all point source loads (WLAs), non-point source loads (LAs), and an appropriate margin of safety (MOS), which takes into account any uncertainty. This definition can be expressed by equation 7:

$$TMDL = \sum WLAs + \sum LAs + MOS \text{ ---------------(7)}$$

The objective of the TMDL is to estimate allowable pollutant loads and to allocate the loads to the known pollutant sources in the watershed so that the appropriate control measures can be implemented and the water quality standard can be achieved. The Code of Federal Regulations (40 CFR § 130.2 (1)) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For this study, TMDL is expressed as mass per day (Daily Load) to represent the maximum daily load of TBODu that can be assimilated by Brown Creek while maintaining the DO water quality standard of 5 mg/L.

4.1 Seasonal Variation

DO concentrations in Brown Creek tend to be lowest during summer period and highest during winter period (Table 1). Conditions of low temperature and high flow during winter and early spring (cold weather months) generally increase DO concentration. High nutrient loads during colder weather months tend to be flushed through the creek rapidly, making nutrients unavailable for eventual DO consumption. Considering this natural phenomenon, this study focuses on TBODu loadings during summer period (warm weather month) only. It is assumed that basing the TMDL on warm weather months would protect the creek during cold weather months as well.

4.2 Model Uncertainty

The Q2K model is not adept at characterizing prediction uncertainty. Because of the lack of certain site specific information, professional judgment and literature values were used to calculate the DO loading. Therefore, the model results should be interpreted in light of the model limitations and prediction uncertainty.

4.3 Estimation of Existing Load

An existing load for the pollutant, TBODu, was calculated based on a critical flow, the existing TBODu concentration, and a conversion factor (190.50). Equation 8 is used to estimate the existing load and the results are given in Table 5.

*Load (lbs/day) = Critical Flow (m^3/s) * TBODu (mg/L) * 190.50* ------------------------- *(8)*

Table 5. Calculation of existing load for TBODu

Location	Flow[1] (m^3/s)	TBODu (mg/L)	Conversion Factor	Existing Load (lbs/day)
Brown Creek at Mineral Spring Road	0.005	29.25	190.50	27.86

Note: 1. Flow is based on field measurement at NC 742 on 8/10/2010

4.4 Estimation of Target Load

The calibrated Q2K model was run by gradually decreasing the TKN value, an ingredient of TBODu (Equations 5 and 6), while keeping the rest of the calibrated parameters the same, to bring the modeled in-stream DO concentration at or above the North Carolina fresh water quality standard, 5 mg/L. Figure 13 represents the DO concentration above the water quality standard when the optimum value for TKN was set to 2.83 mg/L. The optimum value for TBODu was then used to estimate a target load using Equations 5, 6, and 8. The results are given in Table 6, below.

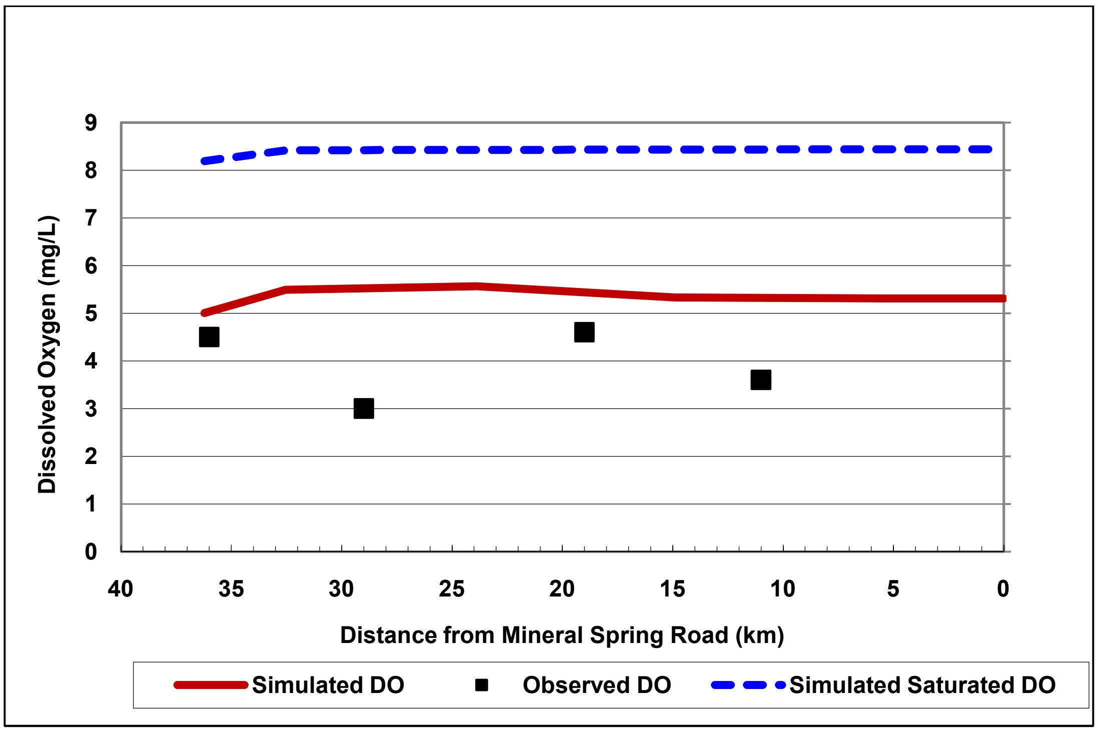

Figure 13. Model simulated Dissolved Oxygen (DO) concentrations for the TMDL scenario to determine a load of total ultimate Biological Oxygen Demand (TBODu) that would not violate water quality standard for DO in Brown Creek.

Table 6. Calculation of target load for TBODu

Location	Flow[1] (m^3/s)	TBODu (mg/L)	Conversion Factor	Target Load (lbs/day)
Brown Creek at Mineral Spring road	0.005	22.53	190.50	21.46

Note: 1. Flow is based on field measurement at NC 742 on 8/10/2010

4.5 Estimation of Margin of Safety (MOS)

TMDL should reflect a MOS based on uncertainty in the modeling analysis, data collection, and point and non-point load estimates. MOS may be incorporated into a TMDL either implicitly, through the use of conservative assumptions to develop allocations, or explicitly through a reduction in the TMDL target. For this study, an explicit MOS was incorporated in the analysis by setting the TMDL target at 10% lower than the estimated water quality target of 21.46 lb/day for TBODu. The MOS was thus estimated to be 2.15 lb/day.

4.6 Estimation of Waste Load Allocation (WLA)

There were no waste water treatment plants in the Brown Creek Watershed. However, there were two NPDES industrial stormwater dischargers: Anson Waste Management Facility (NCG120064) and Southeastern PET Resin Recyclers (NCG030225). Both facilities were under a general stormwater permit that requires semi-annual discharge monitoring to guide stormwater pollution prevention efforts. These facilities were considered to be contributing almost negligible loads to the creek. Therefore, the WLA was set to zero for this study.

4.7 Estimation of Load Allocation (LA)

Using Equation 7, above, LA was estimated by subtracting the targeted load capacity (TMDL) from WLA and MOS. The results are presented in Table 7.

Table 7.Calculation of TMDL for TBODu

Location	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	TMDL (lb/day)
Brown Creek at Mineral Spring Road	0	19.31	2.15	21.46

4.8 Load Reduction

The total load reduction required for TBODu in order to maintain the water quality standard of 5 mg/L for DO in Brown Creek was estimated by subtracting the existing load from LA. The results are presented in Table 8.

Table 8.Estimation of load reduction for TBODu

Location	Existing Load (lb/day)	LA (lb/day)	Load Reduction (lb/day)	Load Reduction (%)
Brown Creek at Mineral Spring Road	27.86	19.31	8.55	31%

The 31% load reduction is required from non-point sources from the upstream watershed and around Peachland City and Polkton City. The reduction does not include background sources, because the organic matters such as ROC and Tannin and Lignin concentrations were substantially low in the creek (Table 4). It is, therefore, assumed that nutrient contributions from background sources are negligible in the creek.

5 Summary and Future Considerations

Brown Creek in Yadkin-Pee Dee River basin was listed as impaired since 1998 on North Carolina's 303(d) Report of Impaired Waters due to violations of the North Carolina water quality standard for DO. According to the Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations, the State is required to develop a Total Maximum Daily Load (TMDL) for the impaired segment in the creek.

In the process of developing this TMDL, the DWQ conducted a special study from April through October 2010. The staff observed that the impaired segment of the creek (AU# 13-20b), 28.5 miles, appeared to exhibit anthropogenic impact from upland watershed near Peachland City and Polkton City. The Q2K model was used to simulate instream DO concentrations and to allocate TBODu load to various non-point sources. There were no point sources. However, there were two NPDES industrial stormwater dischargers, which were considered to be contributing almost negligible loads to the creek.

In order for the water quality target to be met, the final allocation of the load requires the non-point sources to reduce TBODu loading by approximately 31%. Most importantly, it appears to reduce the loading from anthropogenic activities in upland watershed and around the Cities of Peachland and Polkton. These activities include stormwater runoff, malfunctioning septic systems, illicit discharges of domestic waste, chemical fertilizer application, poultry litter application, and bio-solid application.

5.1 Future Monitoring

It is recommended to continue DO monitoring on a monthly interval at the ambient site. The continued monitoring will allow the DWQ to evaluate progress towards the goal of reaching water quality standards by comparing the instream DO load to the TMDL target. If future monitoring for DO indicates the standard has been met, the monitoring data may be used to support delisting the Brown Creek from the 303(d) list. If reductions are achieved but the standard is still not met, the TMDL may be revised.

5.2 Implementation Plan

This TMDL was developed using the best data available to specify TBODu load reduction necessary to achieve water quality criteria for DO in Brown Creek. The intent of meeting the criteria is to support the designated use classifications in the watershed.

Implementation plans are not a required component of a TMDL. The involvement of local governments and agencies will be needed in order to develop meaningful implementation plans. While developing the plan it should be noted that the TMDL requires a 31 % reduction of TBODu from non-point sources, mainly at around the cities of Peachland and Polkton. In addition to the reduction, future growth in urban landuses should also be accompanied by nutrient and organic matter control measures.

North Carolina State University, Soil Science Department, is currently implementing an extension program to educate stakeholders in the Brown Creek Watershed about poultry litter BMPs and subsurface application technology. The program aims at reducing N and P contributions from the poultry litter application in farmlands to the creek. The extension programs will help to meet some of this TMDL's target. Therefore, the DWQ staff should coordinate with the university staff to layout a concrete action plan in order to make sure that the activities would be advantageous to meet the goal of reaching water quality standard for DO in the creek.

5.3 Public Participation

A draft of the TMDL was publicly noticed through various means. NCDWQ electronically distributed the draft TMDL and public comment information to known interested parties through Water Resources Research Institute (WRRI) of The University of North Carolina web site at http://www.ncsu.edu/wrri. The announcement is provided in Appendix D. The TMDL was also available from the NCDWQ website at (http://portal.ncdenr.org/web/wq/ps/mtu) during the comment period. The public comment period lasted from July 12, 2011 – August 18, 2011. NCDWQ received one comment, noting a typo in a facility name. This was corrected. Several internal comments were also received, suggesting clarifying languages. No substantive changes were made.

5.4 Additional 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/tmdl/tmdls. Technical questions regarding this TMDL should be directed to the following members of the DWQ Modeling/TMDL Unit: Narayan Rajbhandari, Senior Environmental Specialist, narayan.rajbhandari@ncdenr.gov and Kathy Stecker, Supervisor, Kathy.stecker@ncdenr.gov.

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7 Appendix A. Special Study Data

Table A1. Physical and chemical data collected during the special study periods, April 2010 through August 2010, to assess low dissolved oxygen condition in Brown Creek.

Sample Sites	Date	BOD5	TOC	NH_3	TKN	NOx	TN	Total P	Temp.	Cond.	pH	D.O.
	mm/dd/yyyy	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	˚C	µS		mg/L
Mineral Spring Rd.	3/10/2010	NA	8.20	0.01	0.52	0.01	0.53	0.08	11.00	91.00	6.60	8.30
Mineral Spring Rd.	4/14/2010	2.60	19.00	0.22	NA	0.01	NA	0.30	16.70	154.00	6.70	2.00
Mineral Spring Rd.	4/21/2010	2.40	17.00	0.21	1.50	0.01	1.51	0.30	14.80	155.00	6.70	1.90
Mineral Spring Rd.	5/12/2010	5.80	18.00	0.50	2.00	0.01	2.01	0.54	16.30	189.00	6.90	0.22
Mineral Spring Rd.	5/17/2010	6.10	17.00	0.46	2.00	0.03	2.03	0.38	20.70	180.00	6.90	1.50
Mineral Spring Rd.	5/27/2010	3.90	17.00	0.44	1.80	0.28	2.08	0.37	19.60	168.00	6.70	3.60
Mineral Spring Rd.	6/16/2010	5.70	30.00	0.46	2.40	0.01	2.41	0.55	23.60	175.00	6.70	0.30
Mineral Spring Rd.	6/22/2010	10.00	36.00	0.66	3.00	0.01	3.01	0.94	24.30	201.00	6.80	0.50
Mineral Spring Rd.	7/13/2010	8.80	19.00	0.71	2.70	0.01	2.71	0.58	23.80	155.00	6.80	0.80
Mineral Spring Rd.	7/27/2010	6.00	34.00	0.35	2.20	0.01	2.21	0.64	25.80	171.00	6.60	0.11
Mineral Spring Rd.	8/10/2010	24.00	24.00	0.33	4.30	0.01	4.31	0.92	24.80	175.00	6.70	2.60
Mineral Spring Rd.	8/24/2010	25.00	17.00	0.42	4.30	0.01	4.31	0.83	24.60	180.00	6.80	2.90
Mineral Spring Rd.	9/9/2010	29.00	38.00	0.52	6.00	0.01	6.01	0.91	21.80	186.00	6.90	1.60
Mineral Spring Rd.	9/22/2010	18.00	25.00	0.71	4.60	0.01	4.61	0.73	21.80	181.00	7.00	6.10
Mineral Spring Rd.	10/14/2010	10.00	17.00	1.00	3.00	0.01	3.01	0.73	16.90	164.00	7.00	2.00
Mineral Spring Rd.	10/27/2010	14.00	24.00	0.44	3.30	0.01	3.31	0.69	16.70	170.00	7.00	1.20
Poplar Hill Church Rd.	3/10/2010	NA	8.40	0.01	0.52	0.01	0.53	0.07	10.70	82.00	6.70	9.50
Poplar Hill Church Rd.	4/14/2010	2.60	15.00	0.06	NA	0.01	NA	0.16	15.90	131.00	6.90	4.00
Poplar Hill Church Rd.	4/21/2010	1.00	13.00	0.09	1.10	0.01	1.11	0.14	15.70	129.00	6.80	3.40
Poplar Hill Church Rd.	5/12/2010	4.00	13.00	0.27	1.30	0.01	1.31	0.20	17.50	141.00	6.90	2.70
Poplar Hill Church Rd.	5/17/2010	5.30	13.00	0.19	1.30	0.03	1.33	0.23	20.60	124.00	6.60	1.10
Poplar Hill Church Rd.	5/27/2010	2.40	14.00	0.34	1.20	0.04	1.24	0.21	20.60	131.00	6.70	3.00
Poplar Hill Church Rd.	6/16/2010	7.20	15.00	0.17	1.80	0.01	1.81	0.31	24.70	138.00	6.60	1.70

Table A1 continued

Sample Sites	Date	BOD5	TOC	NH_3	TKN	NOx	TN	Total P	Temp.	Cond.	pH	D.O.
	mm/dd/yyyy	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	˚C	µS		mg/L
Poplar Hill Church Rd.	6/22/2010	4.70	15.00	0.15	1.20	0.01	1.21	0.22	25.20	145.00	6.90	1.60
Poplar Hill Church Rd.	7/13/2010	9.40	15.00	0.13	1.90	0.04	1.94	0.19	24.50	140.00	7.00	2.10
Poplar Hill Church Rd.	7/27/2010	18.00	16.00	0.02	3.00	0.01	3.01	0.35	27.00	136.00	6.80	1.60
Poplar Hill Church Rd.	8/10/2010	27.00	18.00	0.02	2.80	0.01	2.81	0.33	25.90	131.00	7.00	4.50
Poplar Hill Church Rd.	8/24/2010	4.70	13.00	0.11	1.00	0.01	1.01	0.15	25.10	98.00	6.60	1.00
Poplar Hill Church Rd.	9/9/2010	6.70	14.00	0.11	1.40	0.01	1.41	0.20	21.40	127.00	6.70	8.60
Poplar Hill Church Rd.	9/22/2010	17.00	15.00	0.09	2.90	0.01	2.91	0.36	21.30	134.00	6.80	1.40
Poplar Hill Church Rd.	10/14/2010	8.80	14.00	0.09	1.70	0.01	1.71	0.31	16.40	102.00	6.80	3.40
Poplar Hill Church Rd.	10/27/2010	4.90	13.00	0.01	1.10	NA	NA	0.17	18.00	108.00	6.80	3.00
N.C. HWY.742	3/10/2010	NA	8.30	0.01	0.44	0.01	0.45	0.06	10.70	83.00	7.00	10.80
N.C. HWY.742	4/14/2010	1.00	14.00	0.06	NA	0.07	NA	0.33	16.00	127.00	7.00	6.20
N.C. HWY.742	4/21/2010	1.00	11.00	0.05	0.74	0.10	0.84	0.10	15.20	125.00	6.90	5.90
N.C. HWY.742	5/12/2010	2.40	11.00	0.09	0.82	0.05	0.87	0.07	16.80	143.00	7.00	3.10
N.C. HWY.742	5/17/2010	3.50	11.00	0.11	0.84	0.06	0.90	0.13	20.20	137.00	7.00	3.10
N.C. HWY.742	5/27/2010	1.00	12.00	0.08	0.79	0.19	0.98	0.15	20.20	119.00	6.90	3.70
N.C. HWY.742	6/16/2010	1.00	23.00	0.09	1.20	0.09	1.29	0.14	24.80	147.00	6.80	1.90
N.C. HWY.742	6/22/2010	2.70	16.00	0.05	1.20	0.03	1.23	0.16	24.80	161.00	7.00	2.10
N.C. HWY.742	7/13/2010	2.50	17.00	0.05	1.10	0.02	1.12	0.10	24.00	165.00	7.00	1.80
N.C. HWY.742	7/27/2010	3.10	12.00	0.07	0.91	0.11	1.02	0.21	25.70	96.00	6.80	3.20
N.C. HWY.742	8/10/2010	1.00	13.00	0.14	1.00	0.09	1.09	0.20	25.40	109.00	6.90	3.00
N.C. HWY.742	8/24/2010	2.10	9.20	0.12	0.92	0.18	1.10	0.21	24.90	91.00	6.70	1.90
N.C. HWY.742	9/9/2010	5.40	13.00	0.02	1.10	0.01	1.11	0.20	21.50	111.00	6.80	5.40
N.C. HWY.742	9/22/2010	17.00	13.00	0.01	2.20	0.01	2.21	0.29	21.60	118.00	7.00	3.20
N.C. HWY.742	10/14/2010	3.00	13.00	0.04	0.80	0.01	0.81	0.15	16.60	98.00	6.80	2.10
N.C. HWY.742	10/27/2010	3.30	14.00	0.01	0.89	0.01	0.90	0.16	16.70	108.00	6.80	1.70
U.S. HWY. 52	3/10/2010	NA	7.60	0.01	0.41	0.01	0.42	0.06	10.30	88.00	7.00	11.10

Table A1 continued

Sample Sites	Date	BOD5	TOC	NH_3	TKN	NOx	TN	Total P	Temp.	Cond.	pH	D.O.
	mm/dd/yyyy	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	˚C	µS		mg/L
U.S. HWY. 52	4/14/2010	1.00	13.00	0.01	NA	0.04	NA	0.10	15.30	134.00	7.00	6.90
U.S. HWY. 52	4/21/2010	1.00	9.90	0.01	0.61	0.06	0.67	0.08	15.10	138.00	7.10	6.90
U.S. HWY. 52	5/12/2010	2.40	10.00	0.10	0.95	0.08	1.03	0.11	18.30	154.00	7.10	4.20
U.S. HWY. 52	5/17/2010	3.20	11.00	0.09	0.82	0.08	0.90	0.14	21.30	135.00	6.90	3.80
U.S. HWY. 52	5/27/2010	1.00	12.00	0.08	0.80	0.35	1.15	0.14	20.80	131.00	7.00	5.20
U.S. HWY. 52	6/16/2010	3.70	21.00	0.16	1.40	0.11	1.51	0.21	25.60	146.00	6.80	1.30
U.S. HWY. 52	6/22/2010	5.90	17.00	0.25	1.50	0.05	1.55	0.28	27.10	166.00	7.00	0.80
U.S. HWY. 52	7/13/2010	29.00	28.00	4.90	10.00	0.01	10.01	1.20	25.40	228.00	7.20	0.50
U.S. HWY. 52	7/27/2010	5.10	20.00	0.13	1.40	0.67	2.07	0.45	25.80	127.00	6.90	3.50
U.S. HWY. 52	8/10/2010	2.20	13.00	0.07	0.89	0.12	1.01	0.20	26.00	108.00	7.00	4.60
U.S. HWY. 52	8/24/2010	2.40	10.00	0.10	0.97	0.23	1.20	0.17	25.30	88.00	6.70	3.90
U.S. HWY. 52	9/9/2010	4.30	12.00	0.16	1.10	0.01	1.11	0.19	23.00	118.00	6.90	2.20
U.S. HWY. 52	9/22/2010	4.10	11.00	0.04	1.10	0.01	1.11	0.15	22.70	125.00	7.00	4.00
U.S. HWY. 52	10/14/2010	5.80	13.00	0.11	1.10	0.07	1.17	0.19	16.40	110.00	6.90	4.00
U.S. HWY. 52	10/27/2010	12.00	14.00	0.01	1.60	0.01	1.61	0.24	16.50	121.00	6.90	3.30
Grassy Island Rd.	3/10/2010	NA	8.20	0.01	0.44	0.01	0.45	0.06	9.90	89.00	7.10	11.40
Grassy Island Rd.	4/14/2010	1.00	13.00	0.03	NA	0.05	NA	0.10	16.40	130.00	7.00	6.40
Grassy Island Rd.	4/21/2010	1.00	10.00	0.03	0.63	0.08	0.71	0.09	15.50	135.00	7.00	5.90
Grassy Island Rd.	5/12/2010	1.00	10.00	0.17	0.78	0.05	0.83	0.11	17.40	153.00	6.90	8.20
Grassy Island Rd.	5/17/2010	1.00	10.00	0.07	0.66	0.07	0.73	0.11	22.60	148.00	7.00	3.10
Grassy Island Rd.	5/27/2010	1.00	16.00	0.05	0.79	0.52	1.31	0.14	21.10	123.00	6.80	4.70
Grassy Island Rd.	6/16/2010	1.00	22.00	0.10	1.10	0.11	1.21	0.22	26.00	146.00	6.90	1.40
Grassy Island Rd.	6/22/2010	1.00	15.00	0.11	1.10	0.08	1.18	0.21	27.00	162.00	6.90	1.70
Grassy Island Rd.	7/13/2010	2.20	14.00	0.11	0.98	0.01	0.99	0.22	24.70	179.00	7.10	1.00
Grassy Island Rd.	7/27/2010	6.30	29.00	0.28	2.40	3.80	6.20	0.60	25.00	83.00	6.20	4.60
Grassy Island Rd.	8/10/2010	1.00	10.00	0.10	0.77	0.23	1.00	0.16	26.40	120.00	7.10	3.60

Table A1 continued

Sample Sites	Date	BOD5	TOC	NH_3	TKN	NOx	TN	Total P	Temp.	Cond.	pH	D.O.
	mm/dd/yyyy	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	˚C	µS		mg/L
Grassy Island Rd.	8/24/2010	1.00	9.30	0.06	0.82	0.26	1.08	0.16	25.60	80.00	6.70	3.50
Grassy Island Rd.	9/9/2010	1.00	11.00	0.10	0.92	0.07	0.99	0.18	23.70	117.00	7.40	2.90
Grassy Island Rd.	9/22/2010	2.90	10.00	0.01	0.78	0.01	0.79	0.18	22.70	135.00	6.90	1.30
Grassy Island Rd.	10/14/2010	1.00	14.00	0.04	0.81	0.10	0.91	0.15	17.10	100.00	6.70	3.20
Grassy Island Rd.	10/27/2010	2.40	12.00	0.01	0.82	0.01	0.83	0.16	17.40	114.00	6.90	3.00

8 Appendix B. QUAL2K Input Tables

Table B1. Headwater Data Inputs

Headwater Parameters	Units	Input Values	Source
Headwater Flow	cum/s	0.01	Field Measurement at NC742
Temperature	C	24.80	Field Measurement
Conductivity	umhos	175.00	Field Measurement
Inorganic Solids	mgD/L	6.00	Averaged TSS data for 2007 summer period at DWQ ambient site, Q9155000
Dissolved Oxygen	mg/L	2.60	Field Measurement
CBODslow	mgO2/L	0.00	Assumed negligible slow CBOD in the water body
CBODfast	mgO2/L	9.60	Estimated from f-ratio (measured BOD/CBOD = 2.5) (Thomann and Mueller, 1987)
Organic Nitrogen	ugN/L	3970.00	Estimate from measured TKN and NH4 (TKN = Org N + NH4)
NH4-Nitrogen	ugN/L	330.00	Field Measurement (Assumed NH4 ≈ NH3)
NO3-Nitrogen	ugN/L	10.00	Field Measurement (Assumed NOx ≈ NO3)
Organic Phosphorus	ugP/L	460.00	Assumed 50% of measured TP
Inorganic Phosphorus (SRP)	ugP/L	460.00	Assumed 50% of measured TP
Phytoplankton	ugA/L	NA	
Internal Nitrogen (INP)	ugN/L	NA	
Internal Phosphorus (IPP)	ugP/L	NA	
Detritus (POM)	mgD/L	2.00	Based on calibration of the model
Pathogen	cfu/100 mL	NA	
Alkalinity	mgCaCO3/L	18.00	Based on calibration of the model
Constituent i		NA	
Constituent ii		NA	
Constituent iii		NA	
pH	s.u.	6.70	Field Meaurement

NA = Not available

Table B2. Reach Data Inputs

Reach parameters Units	Mineral Spring Rd to Popular Hill Ch Rd	Popular Hill Ch Rd to NC742	NC742 to US52	US52 to Grassy Island Rd	Sources
Reach Number	1	2	3	4	
Reach length (km)	7.39	9.89	8.06	10.88	GIS Coverages
Downstream					
Latitude	34.99	35.04	35.07	35.08	GIS Coverages
Longitude	79.80	79.85	79.90	79.97	GIS Coverages
Location					
Upstream (km)	36.22	28.83	18.94	10.88	GIS Coverage
Downstream (km)	28.83	18.94	10.88	0.00	GIS Coverage
Elevation					
Upstream (m)	83.00	76.00	70.00	64.00	GIS Coverage
Downstream (m)	76.00	70.00	64.00	57.00	GIS Coverage
Rating Curves					
Channel Slope	0.0009	0.0006	0.0007	0.0006	GIS Coverage
Manning's n	0.14	0.14	0.14	0.14	Professional judgment
Bottom Width m	12.00	12.00	12.00	12.00	X-section measurement at NC 742
Side Slope	0.00	0.00	0.00	0.00	Professional judgment
Side Slope	0.00	0.00	0.00	0.00	Professional judgment
Weir Height (m)	NA	NA	NA	NA	No data available
Prescribed Reaeration (/d)	1.00	0.15	0.07	0.07	Professional judgment
Prescribed Dispersion (m2/s)	NA	NA	NA	NA	No data available
Bottom Algae Coverage	1.00	1.00	1.00	1.00	Field observation
Bottom SOD Coverage	1.00	1.00	1.00	1.00	Field observation
Prescribed SOD gO2/m2/d	NA	NA	NA	NA	No data available
Prescribed CH4 flux gO2/m2/d	NA	NA	NA	NA	No data available
Prescribed NH4 flux (mgN/m2/d)	NA	NA	NA	NA	No data available
Prescribed Inorg P flux (mgP/m2/d)	NA	NA	NA	NA	No data available

NA = Not available

Table B3. Meteorological Data Inputs

Time	Air Temperature (Degree C)	Dew Point (Degree C)	Wind Speed (m/s)	Cloud Cover (%)	Shade (%)
12:00 AM	22.72	22.72	1.56	45.0%	35.0%
1:00 AM	22.78	22.78	0.00	45.0%	35.0%
2:00 AM	22.28	22.28	0.00	45.0%	35.0%
3:00 AM	22.61	22.61	0.00	45.0%	35.0%
4:00 AM	22.89	22.89	1.56	45.0%	35.0%
5:00 AM	22.78	22.78	0.00	45.0%	35.0%
6:00 AM	23.22	23.22	1.56	45.0%	35.0%
7:00 AM	24.00	23.78	0.00	45.0%	35.0%
8:00 AM	24.50	23.89	1.56	45.0%	35.0%
9:00 AM	25.50	23.00	1.56	45.0%	35.0%
10:00 AM	27.00	22.61	1.56	45.0%	35.0%
11:00 AM	28.78	23.22	2.06	45.0%	35.0%
12:00 PM	30.50	23.00	2.59	45.0%	35.0%
1:00 PM	31.61	23.72	0.00	45.0%	35.0%
2:00 PM	31.89	23.39	2.06	45.0%	35.0%
3:00 PM	32.61	23.61	3.08	45.0%	35.0%
4:00 PM	31.61	23.28	4.11	45.0%	35.0%
5:00 PM	30.50	24.00	3.62	45.0%	35.0%
6:00 PM	27.28	25.61	3.08	45.0%	35.0%
7:00 PM	23.72	23.61	0.00	45.0%	35.0%
8:00 PM	22.72	22.61	3.62	45.0%	35.0%
9:00 PM	23.28	20.61	0.00	45.0%	35.0%
10:00 PM	23.00	22.11	2.59	45.0%	35.0%
11:00 PM	23.50	22.61	0.00	45.0%	35.0%

Table B4. Water Column Rate Inputs

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	3	gA	gA
Inorganic suspended solids:			
Settling velocity	1.304	m/d	v_i
Oxygen:			
Reaeration model	User specified		
User reaeration coefficient α			α
User reaeration coefficient β			β
User reaeration coefficient γ			γ
Temp correction	1.024		q_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	2	/d	k_{hc}
Temp correction	1.047		q_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		q_{dcs}
Fast CBOD:			
Oxidation rate	5	/d	k_{dc}
Temp correction	1.047		q_{dc}
Organic N:			
Hydrolysis	0	/d	k_{hn}

Table B4 continued			
Parameter	Value	Units	Symbol
Temp correction	1.07		q_{hn}
Settling velocity	0.003	m/d	v_{on}
Ammonium:			
Nitrification	3	/d	k_{na}
Temp correction	1.07		q_{na}
Nitrate:			
Denitrification	1	/d	k_{dn}
Temp correction	1.07		q_{dn}
Sed denitrification transfer coeff	10	m/d	v_{di}
Temp correction	1.07		q_{di}
Organic P:			
Hydrolysis	0	/d	k_{hp}
Temp correction	1.07		q_{hp}
Settling velocity	0.004	m/d	v_{op}
Inorganic P:			
Settling velocity	0.004	m/d	v_{ip}
Inorganic P sorption coefficient	0.073	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	1.831	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		q_{gp}
Respiration rate	0.1	/d	k_{rp}
Temp correction	1.07		q_{rp}
Excretion rate	0	/d	k_{ep}
Temp correction	1.07		q_{dp}
Death rate	0	/d	k_{dp}
Temp correction	1		q_{dp}
External Nitrogen half sat constant	15	ugN/L	k_{sPp}
External Phosphorus half sat constant	2	ugP/L	k_{sNp}
Inorganic carbon half sat constant	2.00E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	57.6	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Subsistence quota for nitrogen	0	mgN/mgA	q_{0Np}
Subsistence quota for phosphorus	0	mgP/mgA	q_{0Pp}
Maximum uptake rate for nitrogen	0	mgN/mgA/d	r_{mNp}

Table B4 continued			
Parameter	Value	Units	Symbol
Maximum uptake rate for phosphorus	0	mgP/mgA/d	r_{mPp}
Internal nitrogen half sat constant	0	mgN/mgA	K_{qNp}
Internal phosphorus half sat constant	0	mgP/mgA	K_{qPp}
Settling velocity	0.15	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	999.991	mgA/m^2/d or /d	C_{gb}
Temp correction	1.07		q_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	1	/d	k_{rb}
Temp correction	1.07		q_{rb}
Excretion rate	0.5	/d	k_{eb}
Temp correction	1.05		q_{db}
Death rate	0.09	/d	k_{db}
Temp correction	1.07		q_{db}
External nitrogen half sat constant	0.052	ugN/L	k_{sPb}
External phosphorus half sat constant	96.379	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.00E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	76.319	langleys/d	K_{Lb}
Ammonia preference	99.982	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	2.524	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.002	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	149	mgN/mgA/d	r_{mN}
Maximum uptake rate for phosphorus	5.009	mgP/mgA/d	r_{mP}
Internal nitrogen half sat constant	0.384	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.102	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	7.179	/d	k_{dt}
Temp correction	1.07		q_{dt}
Fraction of dissolution to fast CBOD	0.00		F_f
Settling velocity	2	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		q_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		a_{path}

Table B4 continued			
Parameter	Value	Units	Symbol
pH:			
Partial pressure of carbon dioxide	360	ppm	p_{CO2}
Constituent i			
First-order reaction rate	0	/d	
Temp correction	1		q_{dx}
Settling velocity	0	m/d	v_{dt}
Constituent ii			
First-order reaction rate	0	/d	
Temp correction	1		q_{dx}
Settling velocity	0	m/d	v_{dt}
Constituent iii			
First-order reaction rate	0	/d	
Temp correction	1		q_{dx}
Settling velocity	0	m/d	v_{dt}

Table B5. Light and Heat Inputs

Parameter	Value	Unit	Symbol
Photo-synthetically Available Radiation	0.47		
Background light extinction	0.3	/m	k_{eb}
Linear chlorophyll light extinction	0.0088	1/m-(ugA/L)	a_p
Nonlinear chlorophyll light extinction	0.054	1/m-(ugA/L)2/3	a_{pn}
ISS light extinction	0.052	1/m-(mgD/L)	a_i
Detritus light extinction	0.174	1/m-(mgD/L)	a_o
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	5		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.7		a_{tc}
Down welling atmospheric long wave IR radiation			
atmospheric long wave emissivity model	Brunt		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer		
Sediment heat parameters			
Sediment thermal thickness	10	cm	H_s
Sediment thermal diffusivity	0.005	cm^2/s	a_s
Sediment density	1.6	g/cm^3	r_s
Water density	1	g/cm^3	r_w
Sediment heat capacity	0.4	cal/(g ^oC)	C_{ps}
Water heat capacity	1	cal/(g ^oC)	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	Yes		

Table B6. Water Quality Data Inputs

Reach Numbers	1	2	3	4	Sources
Distance from headwater(km)	36.00	29.00	19.00	11.00	Gis Coverage
Cond (umhos)	131.00	109.00	108.00	120.00	Field Measurement
ISS (mgD/L)	NA	NA	NA	NA	Data not available
DO (mgO2/L)	4.50	3.00	4.60	3.60	Field Measurement
CBODs (mgO2/L)	0.00	0.00	0.00	0.00	Assumed negligible slow CBOD in the water body
CBODf (mgO2/L)	10.80	0.40	0.88	0.40	Estimated from f-ratio (measured BOD/CBOD = 2.5) (Thomann and Mueller, 1987)
Norg (ugN/L)	2780.00	860.00	820.00	670.00	Estimate from measured TKN and NH4 (TKN = Org N + NH4)
NH4 (ugN/L)	20.00	140.00	70.00	100.00	Field Measurement (Assumed NH4 ≈ NH3)
NO3 (ugN/L)	10.00	90.00	120.00	10.00	Field Measurement (Assumed NOx ≈ NO3)
Porg (ugN/L)	165.00	100.00	100.00	80.00	Assumed 50% of measured TP
Inorg P (ugP/L)	165.00	100.00	100.00	80.00	Assumed 50% of measured TP
Phyto (ugA/L)	NA	NA	NA	NA	Data not available
Detr (mgD/L)	NA	NA	NA	NA	Data not available
Pathogens (cfu/100 mL)	NA	NA	NA	NA	Data not available
Alk (mgCaCO3/L)	NA	NA	NA	NA	Data not available
Constituent i	NA	NA	NA	NA	Data not available
Constituent ii	NA	NA	NA	NA	Data not available
Constituent iii	NA	NA	NA	NA	Data not available
pH	7.00	6.90	7.00	7.10	Field Measurement
Bot Alg (mgA/m^2)	NA	NA	NA	NA	Data not available
TN (ugN/L)	4310.00	2810.00	1090.00	1010.00	Field Measurement
TP (ugP/L)	330.00	200.00	200.00	160.00	Field Measurement
TSS (mgD/L)	NA	NA	NA	NA	Data not available
NH3 (ugN/L)	20.00	140.00	70.00	100.00	Field Measurement
CBODu (mgO2/L)	10.80	0.40	0.88	0.40	Estimated from f-ratio (measured BOD/CBOD = 2.5) (Thomann and Mueller, 1987)
TOC (mgC/L)	18.00	13.00	13.00	10.00	Field Measurement
TKN (ugN/L)	2800.00	1000.00	890.00	770.00	Field Measurement

9 Appendix C. Brown Creek Pictures

Figure C1. Brown Creek at the DWQ's ambient station, Q9155000 (7/12/2009).

Figure C2. The DWQ staffs (Sam Whitaker on left and Jim Fisher on right) were collecting a bathymetric data and flow velocity at the crossing of Brown Creek and NC Hwy 742 on 10/27/2010.

Figure C3. The DWQ staffs (Sam Whitaker and Heather Patt) were collecting water samples at the crossing of Brown Creek and Poplar Hill Church Road on 7/12/2009.

Figure C4. A substantial algae growth in Brown Creek at Poplar Hill Church Road on 7/27/2010.

Figure C5. Lick Creek at the confluence of Brown Creek at Mineral Spring Road, showing no flow condition on 7/12/2009.

10 Appendix D. Public Announcement

The WRRI Daily Digest
Volume 1 : Issue 780 : "text" Format

Messages in this Issue:
201107/2 : DRAFT Total Maximum Daily Load for Dissolved Oxygen for Brown Creek, Anson County, Yadkin-Pee Dee River Basin, North Carolina
"Rajbhandari, Narayan" <narayan.rajbhandari@ncdenr.gov>
201107/3 : Invitation: USGS North Carolina Lecturship Presentation - Pavement Sealcoat, PAHs and the Environment
Holly S Weyers <hsweyers@usgs.gov>

Date: Wed, 13 Jul 2011 15:09:02 -0400
From: "Rajbhandari, Narayan" <narayan.rajbhandari@ncdenr.gov>
To: "wrri-news@lists.ncsu.edu" <wrri-news@lists.ncsu.edu>
Cc: "Rajbhandari, Narayan" <narayan.rajbhandari@ncdenr.gov>,"Patt, Heather" <heather.patt@ncdenr.gov>,"Schneier, Joan" <joan.schneier@ncdenr.gov>, "Barnhardt, Art" <art.barnhardt@ncdenr.gov>,"Hill, Thomas A" <Thomas.Hill@ncdenr.gov>, "Georgoulias, Bethany"<bethany.georgoulias@ncdenr.gov>

Subject: DRAFT Total Maximum Daily Load for Dissolved Oxygen for Brown Creek, Anson County, Yadkin-Pee Dee River Basin, North Carolina
Message-ID: <EE7F3F790126B542902F8DB67800B5D53B6C832D47@NCWITMXMBEV39.ad.ncmail>

Now Available for Public Comment

DRAFT Total Maximum Daily Load for Dissolved Oxygen for Brown Creek, Anson County, Yadkin-Pee Dee River Basin, North Carolina

July 14, 2011
North Carolina Department of Environment and Natural Resources, Division of Water Quality

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 18, 2011. Comments concerning the report should be directed to Narayan Rajbhandari at narayan.rajbhandari@ncdenr.gov or write to:

Narayan Rajbhandari
NC Division of Water Quality
Planning Section
1617 Mail Service Center
Raleigh, NC 27699

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