Total Maximum Daily Load (TMDL) Analysis for the Chesapeake and Delaware Canal and Lums Pond Sub-Watershed, Delaware

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EXECUTIVE SUMMARY

Section 303 (d) of the Clean Water Act, as amended by the Water Quality Act of 1987, requires States to identify impaired waters on April 1 of every even-numbered year and to develop Total Maximum Daily Loads (TMDLs) for pollutants of concern. During the 2002 reporting cycle, the Delaware Department of Natural Resources and Environmental Control (DNREC) identified the Chesapeake and Delaware Canal (C&D Canal, segment DE090-001) and Lums Pond, a sub-watershed of the C & D Canal (segment DE090-L01), to be impaired for nutrients. In addition, Lums Pond was listed for bacteria impairment during the 2002 reporting cycle; however, it was delisted in 2004 for bacteria impairment.

Regarding the listing of Delaware waters for nutrients, it must be noted that, except for tidal waters of Delaware's Inland Bays, the State of Delaware does not have water quality criteria for nutrients. Instead, in order to ensure that nutrients are not causing water quality impairments such as low dissolved oxygen, starting in 1992, DNREC started using a very conservative assessment methodology which resulted in listing almost all surface waters of the State on the 303(d) List for nutrients. Delaware took this conservative approach so that it could comprehensively study nutrient conditions for all of its surface waters and to determine the level of nutrients that may cause water quality impacts. Following this strategy, and after performing extensive hydrologic and water quality monitoring, modeling, and TMDL analyses for almost all watersheds in the State, Delaware has recently updated concentration levels of nitrogen and phosphorus such that the levels consider impacts to dissolved oxygen. These updated concentration levels will be used for all current and future assessments of water quality impacts of nutrients.

To assess water quality conditions of the listed segments of the C&D Canal and Lums Pond, and to develop TMDLs for impacted waters, water quality monitoring was conducted from July 2009 through June 2011. For this monitoring effort, several new monitoring stations were added to the long-term monitoring network to assist with the modeling effort. The results of this 2 years of monitoring, as well as monitoring efforts conducted since the early 2000's, has shown that nutrient levels in the C&D Canal are below the levels that Delaware now considers to cause dissolved oxygen impacts. This conclusion is confirmed by monitoring results for dissolved oxygen, which shows no violation of the dissolved oxygen standard in the C&D Canal. Considering this, it was decided that TMDLs were not needed for dissolved oxygen nor nutrients for the C&D Canal. Delaware's 2012 303(d) List indicates that the C&D Canal is no longer impaired.

However, the 2-year intensive monitoring showed that the dissolved oxygen standard is violated during the summer low-flow periods in a small tributary southeast of the Lums Pond that connects the Pond to a marina on the C&D Canal (Summit Marina). This tributary, technically unnamed, will be referred to as "Southeast Creek" for the purposes of this report. This small tributary also receives discharge from a small wastewater treatment plant (WWTP) that serves the Lums Pond State Park. The Lums Pond State

Park WWTP is owned and operated by DNREC's Division of Park and Recreation. Effluent from this plant is discharged in a batch fashion over the course of 3 to 9 days every month or every other month.

Considering the violation of the applicable water quality standard with regard to dissolved oxygen in this stream, the U.S. EPA's Enhanced Stream Water Quality Model (Qual2K) was used as an assessment tool to determine factors causing low dissolved oxygen and to develop a TMDL for point and nonpoint sources for the entire of Lums Pond Sub-Watershed. The results of the QUAL2K modeling analysis showed that in order to attain the water quality standard with regard to dissolved oxygen, the nonpoint source loads of biological oxygen demand (BOD) and nutrients to the Pond need to be reduced by 40% from 2009 – 2011 baselines. Since New Castle County in its entirety has been issued a Municipal Separate Storm Sewer System (MS4) permit (NPDES Permit # DE 0051071), the nonpoint source TMDL loads are assigned waste load allocations instead of load allocations. In addition, the Lums Pond State Park WWTP needs to reduce its permitted discharge loads of BOD and nutrients to the stream. The proposed Load Allocation (LA) and Waste Load Allocation (WLA) for the Lums Pond Sub-Watershed are as follows:

Situation	**CBOD5**	**TN**	**TP**
unit	lb/day	lb/day	lb/day
LA	0	0	0
WLA for MS4	88	30	1
WLA for WWTP	13	9	2
TMDL	101	39	3

It should be noted that the proposed WLA for the Lums Pond State Park WWTP is one of many potential loading scenarios that would result in meeting applicable water quality criteria. DNREC plans to conduct further analysis of the performance of the State Park WWTP to see if there are other loading scenarios that would achieve the same water quality results in the most cost-effective manner. Upon finding such a loading scenario, DNREC may decide to revise the NPDES Permit limits for some of the parameters for the Lums Pond State Park WWTP while still maintaining all applicable water quality standards.

1.0 Introduction

Section 303 (d) of the Clean Water Act, as amended by the Water Quality Act of 1987, requires States to identify impaired waters on April 1 of every even-numbered year and develop Total Maximum Daily Loads (TMDLs) for pollutants of concern. During the 2002 reporting cycle, the Delaware Department of Natural Resources and Environmental Control (DNREC) identified the Delaware portion of the Chesapeake and Delaware Canal (C&D Canal), and the Lums Pond, a sub-watershed of the C & D Canal, as impaired for nutrients. The C&D Canal and Lums Pond have been placed on the State of Delaware's 303 (d) List since 2002 (1) and thus has been targeted for further analysis and TMDL development. Figure 1-1 shows the C&D Canal Watershed and Figure 1-2 shows the Lums Pond Sub-Watershed in more detail. Table 1-1 is an excerpt from the 2010 303 (d) List showing impaired segments of the C&D Canal and Lums Pond (2).

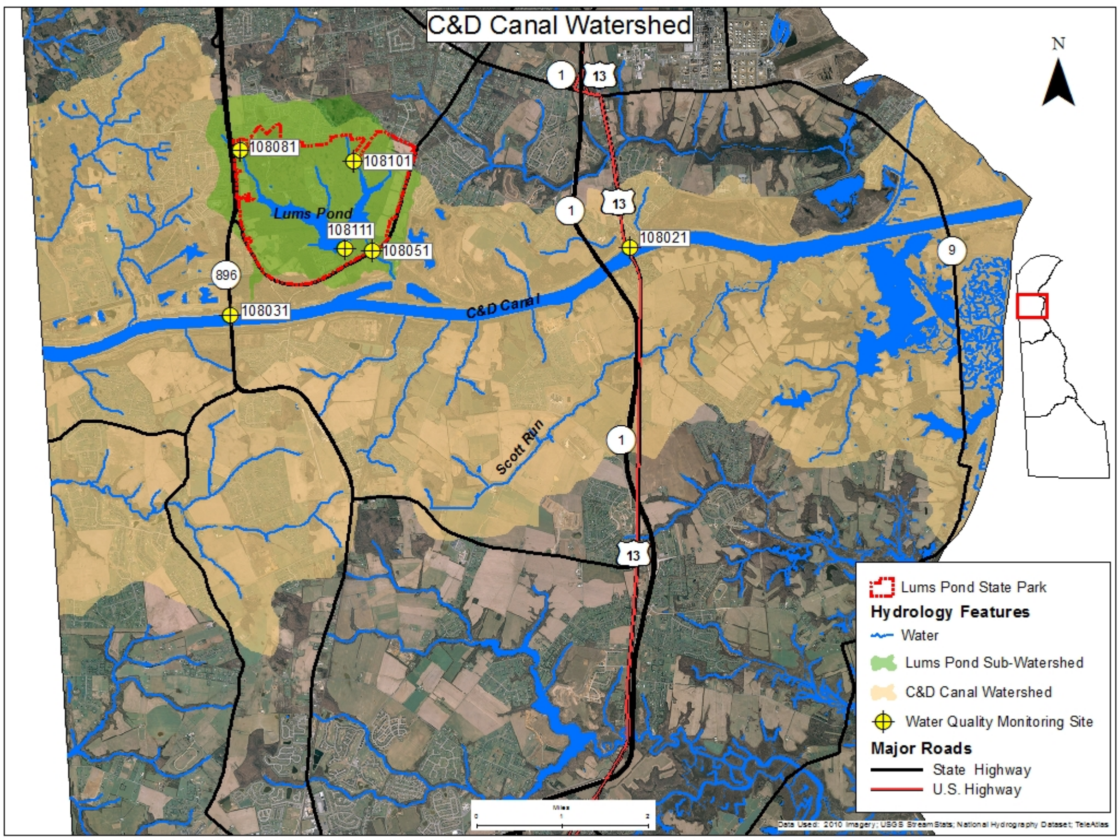

Figure 1–1 C&D Canal Watershed Map

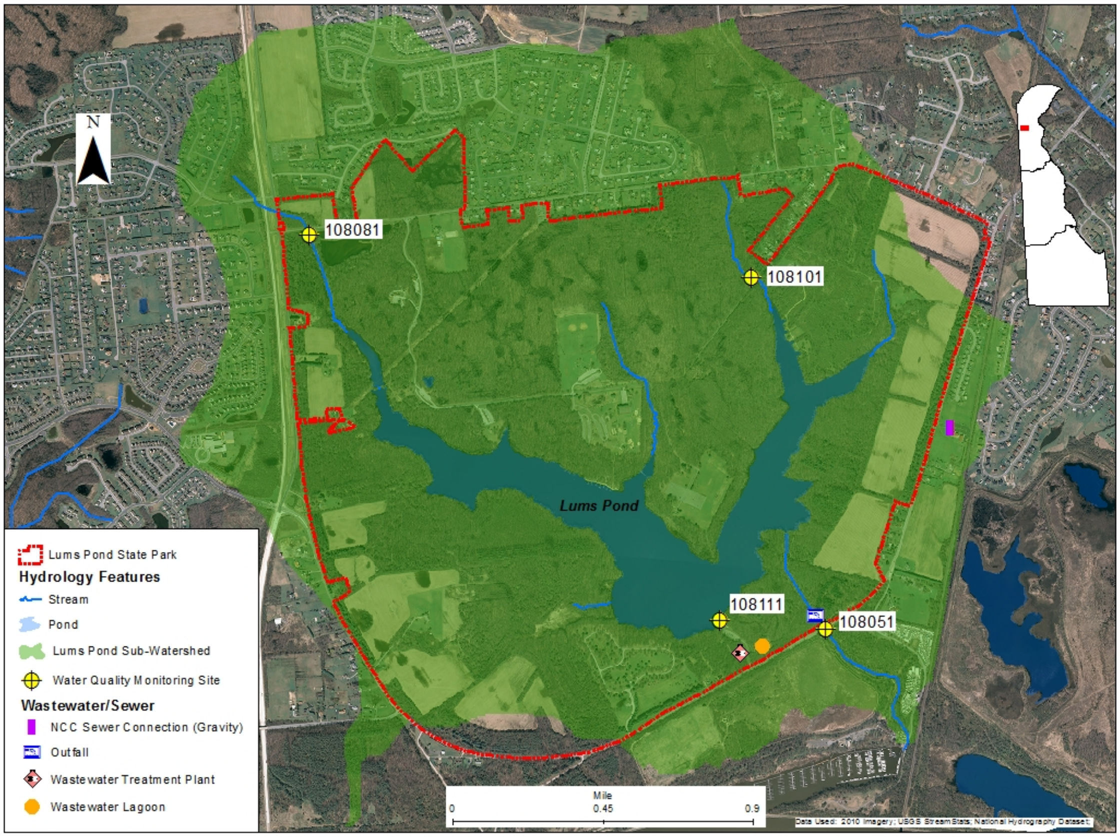

Figure 1–2 Lums Pond Sub-Watershed Map

Table 1-1 Excerpts from the 2010 303(d) List for Impaired Segments of C&D Canal and Lums Pond (2)

SEGMENT	DESCRIPTION	SIZE	POLLUTANT OR STRESSOR	PROBABLE SOURCE(S)	YEAR LISTED	TARGET DATE FOR TMDL	TMDL DATE	Pollutant CALM Code
C&D Canal	C&D Canal from the Maryland line to Delaware River	15.0 M	Nutrients	NPS	2002	2011		5
Lums Pond	Pond south of Newark	189.3 acres	Nutrients	NPS	2002		2011	5

1.1 Chesapeake and Delaware Canal and Lums Pond Sub-Watershed

The Chesapeake and Delaware Canal (C&D Canal) cuts through the northern part of the Delmarva Peninsula and connects Chesapeake Bay on west side of the peninsula with Delaware River and Bay on the east side of the peninsula. The canal is 450 feet wide and 35 feet deep. The portion of the canal across the State of Delaware is about 12 miles long from Reedy Point on the Delaware River to the Delaware-Maryland state line. Flow of the canal is tidally influenced from its two ends. Lums Pond and several other small streams drain to C&D Canal and the watershed within Delaware has a total drainage area of 64 square miles.

Lums Pond is on the north side of the C&D Canal and on the east side of Delaware Route 896 near Summit Bridge in New Castle County. The pond has a surface area of approximately 190 acres and is surrounded mainly by forest. It receives water from four small headwater streams on the north end of the pond and releases its water to a marina on the C&D Canal at the pond's southeast corner through a small tributary as shown in Figure 1-2. This tributary, technically unnamed, will be referred to as "Southeast Creek" for the purposes of this report. The Lums Pond Sub-Watershed has a drainage area of 4.3 square miles, 65% of which is within the Lums Pond State Park, managed by DNREC's Division of Parks and Recreation.

1.2 Designated Uses

The purpose of establishing TMDLs is to reduce pollutants to levels that would result in meeting applicable water quality standards and support designated uses of streams. Section 3 of the State of Delaware Surface Water Quality Standards, as amended, June 11, 2011 (3), specifies the following designated uses for the waters of the C & D Canal including the Lums Pond Sub-Watershed:

- Primary Contact Recreation
- Secondary Contact Recreation
- Fish, Aquatic Life, and Wildlife
- Industrial Water Supply

1.3 Applicable Water Quality Standards and Nutrient Guidelines

To protect designated uses, the following two sections of the State of Delaware Surface Water Quality Standards provide specific narrative and numeric criteria with regard to dissolved oxygen and nutrients:

a. Section 4, Criteria to Protect Designated Uses, and
b. Section 5, Anti-degradation and ERES Waters Policies,

Dissolved Oxygen (D.O.):

- Daily average shall not be less than 5.5 mg/l
- 4.0 mg/l instantaneous minimum

Nutrients:

- It shall be the policy of this Department to minimize nutrient input to surface waters from point and human induced non-point sources. The types of, and need for, nutrient controls shall be established on a site-specific basis.

The above standards are State Regulation and the basis for preparing 305(b) Reports, compiling 303(d) Lists, and establishing TMDLs.

For waters that do not have numeric nutrient criteria, DNREC has used threshold limits of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus as indicators of excessive nutrient levels in surface waters. During the past 15 years, DNREC has collected a significant amount of physical, chemical, and biological data for all waters of the State. One of the objectives of this data collection effort has been to support the development of numeric nutrient criteria for the State's surface waters including lakes, streams, and estuaries. Furthermore, DNREC, with financial support from U.S. EPA Region 3, has conducted several nutrient criteria related data analysis and field studies to establish scientifically-defensible relationships between nutrient concentrations and biological and environmental impacts. However, unfortunately, none of these efforts and research studies has produced the desirable results. The latest effort in this regard was a data analysis effort by an EPA contractor (Tetra Tech) in October 2010 to develop stressor-response relationships between nutrients and biological impacts. The study, which relied on many years of physical, chemical, and biological data, concluded that observed correlations between nutrient levels and environmental responses are "imprecise."

Considering the above limitations, Delaware decided to address nutrient over-enrichment of its surface waters by reducing nutrient concentrations to levels that will not cause water quality impacts with regard to dissolved oxygen. Delaware considered upper threshold limits of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus and used water quality models to ensure that these levels will not cause violations of water quality standards with regard to dissolved oxygen or algal blooms. Extensive water quality modeling and TMDL analyses performed for almost all waters of the State has shown that as long as these upper targets are not exceeded, nutrient levels will not cause violations of water quality standards with regard to dissolved oxygen or excessive algal growth.

Delaware is prepared to revise these target values in the event future research studies show that alternative values are more appropriate. Should future data or research determine that the values currently being applied are not protective for this waterbody in meeting water quality criteria and designated uses, the TMDL will be amended to incorporate the new more protective target values.

1.4 Water Quality Conditions of C&D Canal and Lums Pond Sub-Watershed

To assess water quality conditions of the C&D Canal and Lums Pond, DNREC has collected water quality samples at three long-term monitoring stations – two stations in the C&D Canal (108021 and 108031) and one in Lums Pond (108111), as listed in Table 1-2. Sampling frequency of these three stations follows the annual surface water quality monitoring plans and is monthly or bimonthly. In preparation for conducting additional water quality analyses and TMDL development for these waters, DNREC added three monitoring stations in the Lums Pond Sub-Watershed and conducted monthly sampling from July 2009 through June 2011. Two of the three new stations are in headwater streams of the pond and one in a tributary southeast of the pond, called "Southeast Creek," that connects the pond to a marina on the C&D Canal. These six stations are listed in Table 1-2 and showed in Figure 1-1.

Table 1-2 Water Quality Monitoring Sites in the Chesapeake and Delaware Canal and Lums Pond Sub-Watershed

Station ID	Station Location	Period of Data Record
108021	C & D Canal at St. Georges Bridge (Rt. 13)	1999 - 2011
108031	C & D Canal at Summit Bridge Rd. (Rt.896)	1999 - 2008
108111	Lums Pond at Boat Ramp	1999 - 2011
108081	Lums Pond West Tributary below Howell School Rd. (Rd 54)	2009 - 2011
108101	Lums Pond East Tributary above bridge at Buck Jersey Rd. (Rd 403)	2009 - 2011
108051	Southeast Creek at trail bridge upstream of Red Lion Rd. (Rt. 71)	2009 - 2011

Statistical analysis of the monitoring data collected from the C&D Canal and Lums Pond during the period 1999 – 2011 was performed and the results are presented here in Table 1-3 and Figure 1-3. Table 1-3 reports minimum, maximum, average, and 10^{th} and 90^{th} percentiles for dissolved oxygen, total phosphorus, and total nitrogen measurements at each of the three stations. The same information is shown in Figure 1-3. In this figure, the red dot and top and bottom short bars represent average, maximum and minimum values of the samples, respectively, and the top and bottom lines of the blue box represent the 90th and 10th percentile values of the samples at each monitoring station. The average value and the 10th percentile and 90th percentile values are assessed to follow the State of Delaware's 305(b) and 303(d) Assessment and Listing Methodology (2). For surface waters, if the 10th percentile of dissolved oxygen concentrations is greater than the water quality criteria, the waterbody is considered to be attaining its water quality criteria with regard to dissolved oxygen. For nutrients, the average value must be below the threshold values of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus.

Table 1-3 Statistical Summary of Water Quality Data Collected from the C&D Canal and Lums Pond during 1999-2011

Site	Location	Statistics	DO (mg/l)	TN (mg/l)	TP (mg/l)
108021	C&D Canal at Rt. 13 Bridge	Minimum	5.77	0.90	0.024
		10th percentile	6.25	1.27	0.059
		Average	9.21	1.87	0.141
		90th percentile	13.31	2.45	0.238
		Maximum	16.50	3.51	0.371
108031	C&D Canal at Summit Bridge (Rt.896)	Minimum	5.81	0.69	0.027
		10th percentile	6.34	1.09	0.057
		Average	9.63	1.72	0.117
		90th percentile	13.32	2.55	0.199
		Maximum	17.23	2.82	0.253
108111	Lums Pond at Boat Ramp	Minimum	6.02	1.02	0.013
		10th percentile	7.20	1.13	0.036
		Average	10.06	1.63	0.061
		90th percentile	13.15	2.00	0.095
		Maximum	18.38	3.32	0.230

From a review of the values reported in Table 1-3 and Figure 1-3, it can be seen that the 10th percentile value of dissolved oxygen levels at both stations in the C&D Canal are above the DO standard of 5.5 mg/l; therefore, the waters of the C&D Canal are not impaired with regard to dissolved oxygen. Similarly, for nutrients, the average concentrations of total nitrogen and total phosphorus are below the threshold values of 3 mg/l and 0.2 mg/l, respectively; therefore, the waters of the C &D Canal are not impaired because of nutrients. Hence, it is concluded that TMDL analyses for neither dissolved oxygen nor nutrients are needed for the C & D Canal. Delaware's 2012 303(d) List will indicate that the C&D Canal is no longer impaired.

Similarly, data collected from the four stations in the Lums Pond Sub-Watershed for the period of July 2009 – June 2011 are summarized and the results presented in Table 1-4 and Figure 1-4. In addition to dissolved oxygen, total nitrogen, and total phosphorus, Figure 1-4 also includes other concentrations for exploring potential cause-effect relationships. These measurements include carbonaceous biological oxygen demand, ammonia nitrogen, nitrate and nitrite nitrogen, orthophosphate phosphorus, and chlorophyll-a. Again, the average value and the 10th percentile and 90th percentile values are assessed in consistent with the State of Delaware's 305(b) and 303(d) Assessment and Listing Methodology (2). For surface waters, if the 10th percentile of dissolved oxygen concentrations is greater than the water quality criteria, the waterbody is considered to be attaining its water quality criteria with regard to dissolved oxygen. For nutrients, the average value must be below the threshold values of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus.

Reviewing the values reported in Table 1-3 and Table 1-4 and Figure 1-3 and Figure 1-4, it can be seen that the 10^{th} percentile values of dissolved oxygen levels in headwater streams and the pond are above DO standard of 5.5 mg/l; therefore, waters of the headwater streams and the pond are not impaired with regard to dissolved oxygen. However, the 10^{th} percentile value at the Southeast Creek Station 108051 - 3.4 mg/l - is below the standard of 5.5 mg/l; hence, this segment is impaired because of low dissolved oxygen. Therefore, further detailed TMDL analysis was conducted for Southeast Creek.

Southeast Creek connects Lums Pond to a marina on the C&D Canal and is less than one mile long. It receives Lums Pond overflow at the pond's southeast corner. In addition, a small wastewater treatment plant - the Lums Pond State Park WWTP (NPDES Permit No. 0050083) - discharges into this stream near the Route 71 Bridge. Discharge is in a batch style and typically occurs over a 3 to 9–day period every month or every other month. Additional information about the WWTP is presented in Section 1.5.

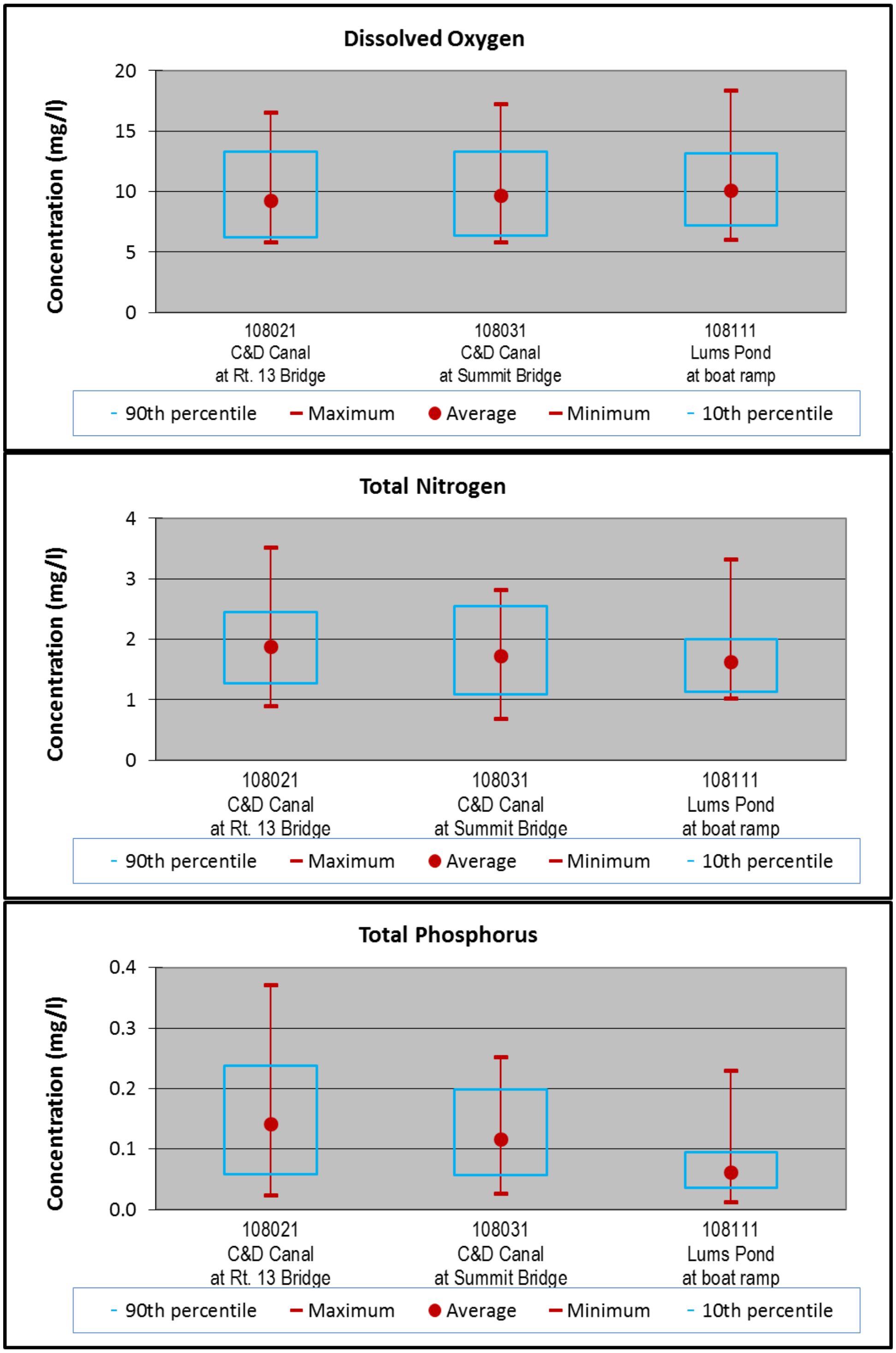

Figure 1-3 Statistical Summaries of Water Quality Data Collected from the C&D Canal and Lums Pond during 1999 - 2011

During the period July 2009 thru June 2011, monthly samples were collected from the stream at the Park's trail crossing that is about 100 yards north of the Route 71 Bridge. Time series of the monitoring data for several parameters are presented in Figure 1-5, represented by red dots. For comparison, data collected at Station 108111 at Lums Pond for the same period is presented in the same graph represented by blue dots. It is apparent that dissolved oxygen concentrations at both sites were lower in the summer months than during the winter months. Furthermore, instream dissolved oxygen levels near Route 71 went even lower than dissolved oxygen at the pond, and were below the applicable water quality standard of 5.5 mg/l during the summer months. It is noted that, in Delaware, during the summer season, stream flow tends to be at its lowest compared to other seasons.

Table 1-4 Summary Statistics for Water Quality Data Collected from the Lums Pond Sub-Watershed during the Period 2009-2011

Site	Location	Statistics	DO (mg/l)	TN (mg/l)	TP (mg/l)
108081	Lums Pond, West Tributary below Howell School Rd. (Rd 54)	minimum	5.16	0.83	0.04
		10th percentile	6.07	0.91	0.05
		average	7.95	1.26	0.11
		90th percentile	10.97	1.72	0.25
		maximum	12.05	1.99	0.30
108101	Lums Pond East Trib. Above Bridge at Buck Jersey Rd. (Rd 403)	minimum	7.83	0.94	0.02
		10th percentile	7.88	1.03	0.03
		average	10.15	1.73	0.06
		90th percentile	12.46	2.42	0.09
		Maximum	12.48	2.94	0.09
108111	Lums Pond at Boat Ramp	Minimum	6.02	1.09	0.04
		10th percentile	6.55	1.18	0.04
		Average	8.98	1.56	0.06
		90th percentile	11.56	2.02	0.10
		Maximum	12.22	2.30	0.11
108051	Southeast Creek at the Park trail bridge upstream of Red Lion Rd. (Rt. 71)	Minimum	2.56	0.94	0.03
		10th percentile	3.74	1.18	0.04
		Average	8.15	1.64	0.08
		90th percentile	12.20	2.04	0.10
		Maximum	12.36	3.08	0.46

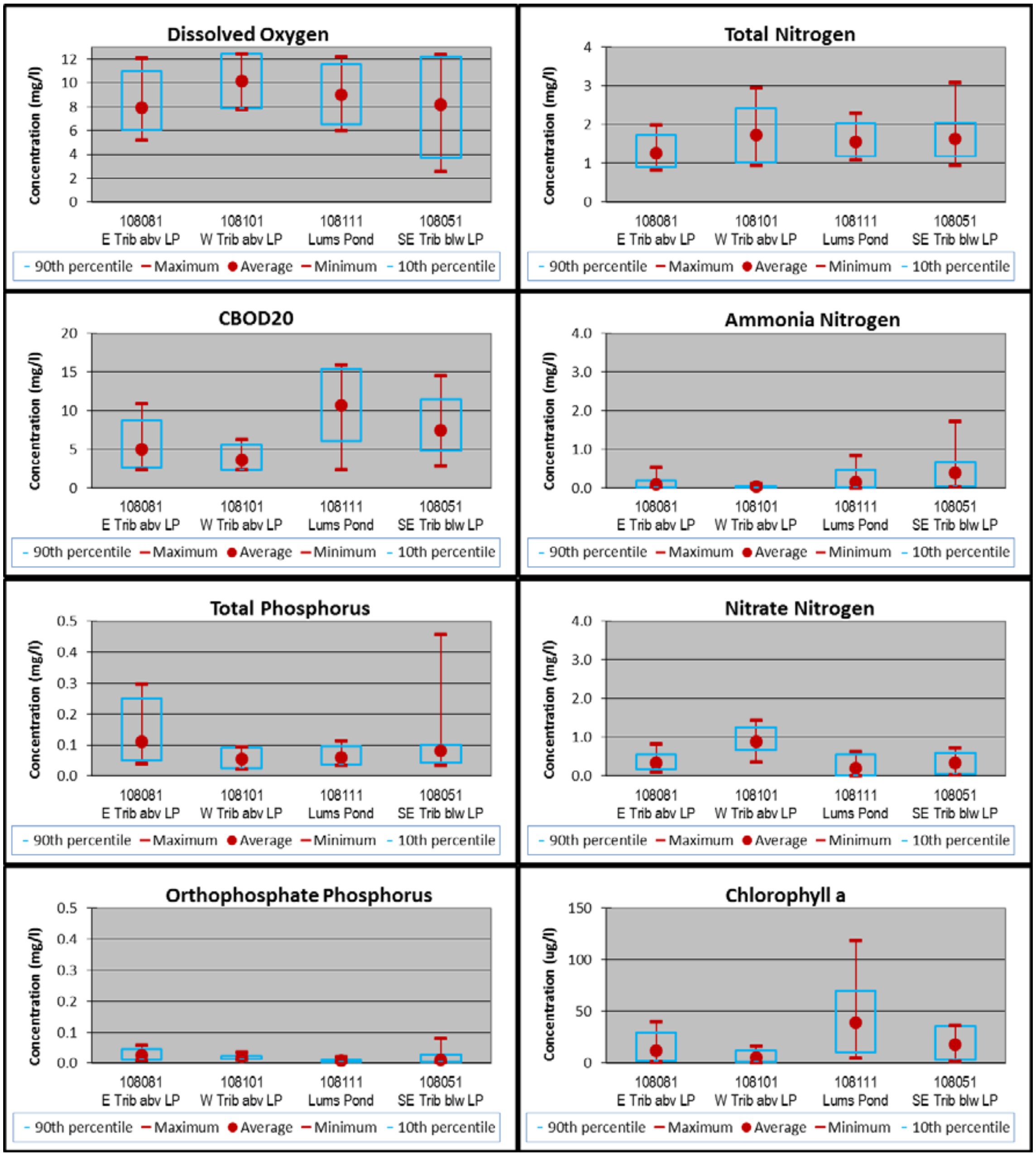

Figure 1-4 Statistic Summaries for Water Quality Data Collected at Four Monitoring Sites in the Lums Pond Sub-Watershed during 2009-2011

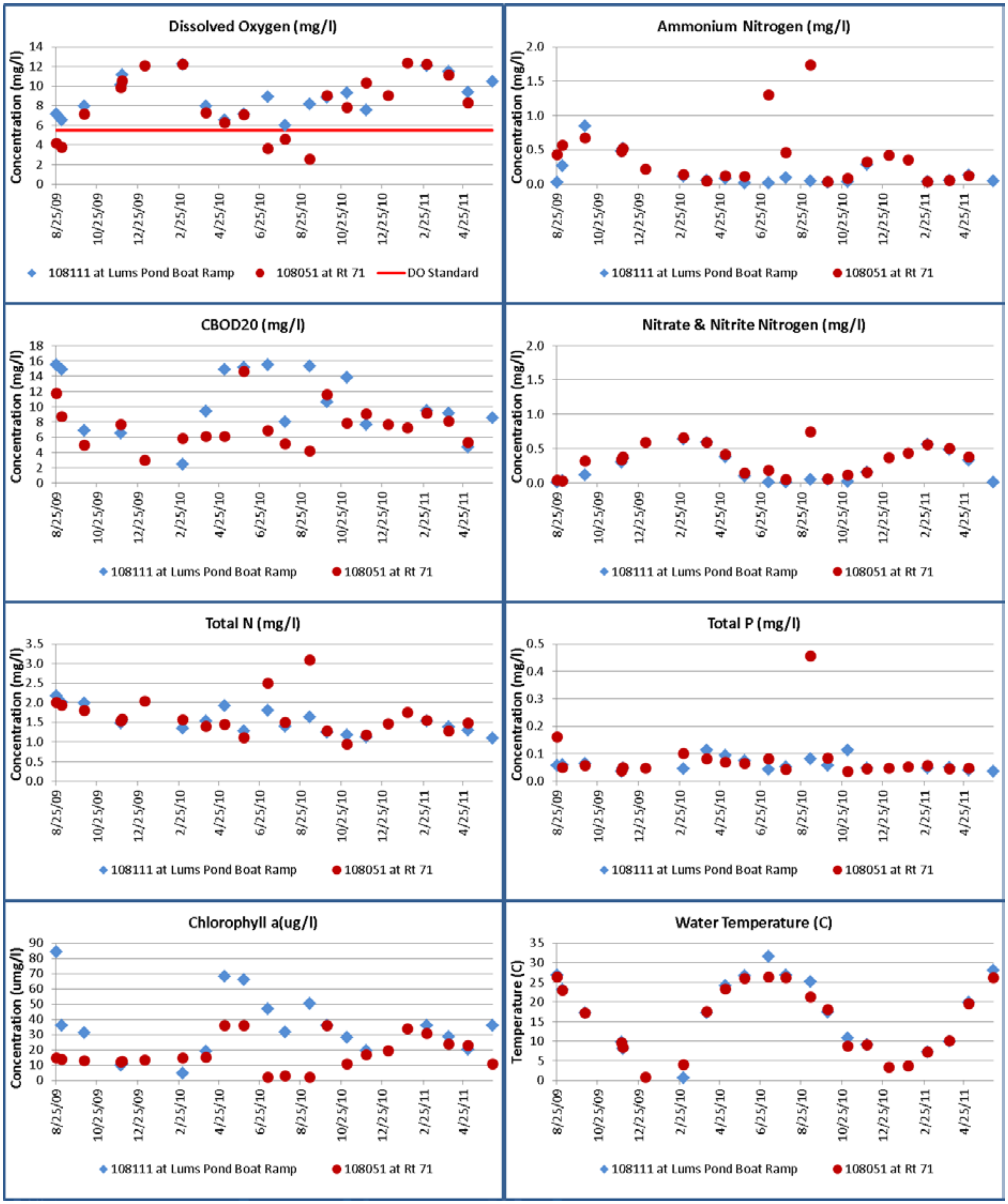

Figure 1-5 Time Series for Water Quality Data Collected at Station 108111 in Lums Pond and at Station 108051 in Southeast Creek

1.5 Sources of Pollution

As discussed earlier and shown in Figure 1-2, one NPDES facility is located in the Lums Pond Sub-Watershed. It is a WWTP owned and operated by DNREC's Division of Parks and Recreation. The facility is a secondary treatment plant that serves the Lums Pond State Park. It discharges treated wastewater to Southeast Creek in a batch fashion. The outfall of the discharge is north of Route 71 road crossing and the discharge schedule and flows during the period 2009-2011 were provided by DNREC's Surface Water Discharges Section (9) and are included in Appendix A. The NPDES Discharge Permit for this facility (NPDES Permit No. 0050083) was reissued in 2009 for a five-year term and will expire in 2014. Table 1-5, an excerpt from the NPDES Permit, summarizes the permit limits and effluent monitoring frequency requirements (10). Effluent monitoring data for this facility were retrieved from EPA's Permit Compliance System (PCS) database and provided by the Surface Water Discharges Section (11). Table 1-6 presents the summary of discharge monitoring data for the period of July 2009 through February 2011. The point source discharge data will be considered in the TMDL model scenario analysis.

Table 1-5 NPDES Permit Effluent Limitations and Monitoring Requirements (10)

Parameter	Effluent Limitations							Monitoring Requirements	
	Load			Concentration				Measure-ment Frequency	Sample Type
	Daily Average	Daily Maximum	Units	Daily Average	Daily Maximum	Maximum Instantaneous	Units		
Flow*			mgd					Continuous	Record/ Totalize
BOD5	26	40	lbs/day	30	45		mg/L	Once per week	Comp.
Total Suspended Solid (TSS)	26	40	lbs/day	30	45		mg/L	Once per week	Comp.
Enterococcus				45		104	col/100mL	Once per week	Grab
Total Residual Chlorine				1 mg/l < Total Residual Chlorine < 4 mg/l				Daily	Grab
pH				6.0 S.U. < pH < 9.0 S.U.			S.U.	Daily	Grab
The discharge shall be free from floating solids, sludge deposits, debris, oil and scum.									

*Hydraulic design flow 0.105 mgd

Table 1-6 Summary of Effluent Monitoring Records for July 2009 through February 2011

Parameter	Unit	Average	Maximum	Minimum
Flow	mgd	0.10	0.21	0.07
BOD5 Conc.	mg/l	6.83	18.55	3.22
BOD5 Load	lb/d	8.31	32.49	3.65
TSS Conc.	mg/l	3.00	7.50	1.00
TSS Load	lb/d	3.61	9.25	1.00
pH	SU	7.16	8.60	6.85

Potential nonpoint sources affecting Southeast Creek include surface runoff and groundwater loads from surrounding land. Dominated land uses within the Lums Pond Sub-Watershed are forestland and residential areas, which take up 36 and 31 percent of the sub-watershed area, respectively. The detailed geographic distribution of land use for this sub-watershed according to the 2007 Delaware Office of State Planning Coordination land cover data (5) is shown in Figure 1-6. A summary of the relative distribution of land use coverage is presented by a pie chart in Figure 1-7. Contribution of nonpoint source load is considered in the water quality model through data input and model calibration to site-specific monitoring data.

Note that the Lums Pond Sub-Watershed resides in a Municipal Separate Storm Sewer System (MS4) permitted region –the entire New Castle County with NPDES Permit # DE 0051071. EPA guidelines require that nonpoint source loads for MS4 permitted areas be considered as WLAs instead of LAs.

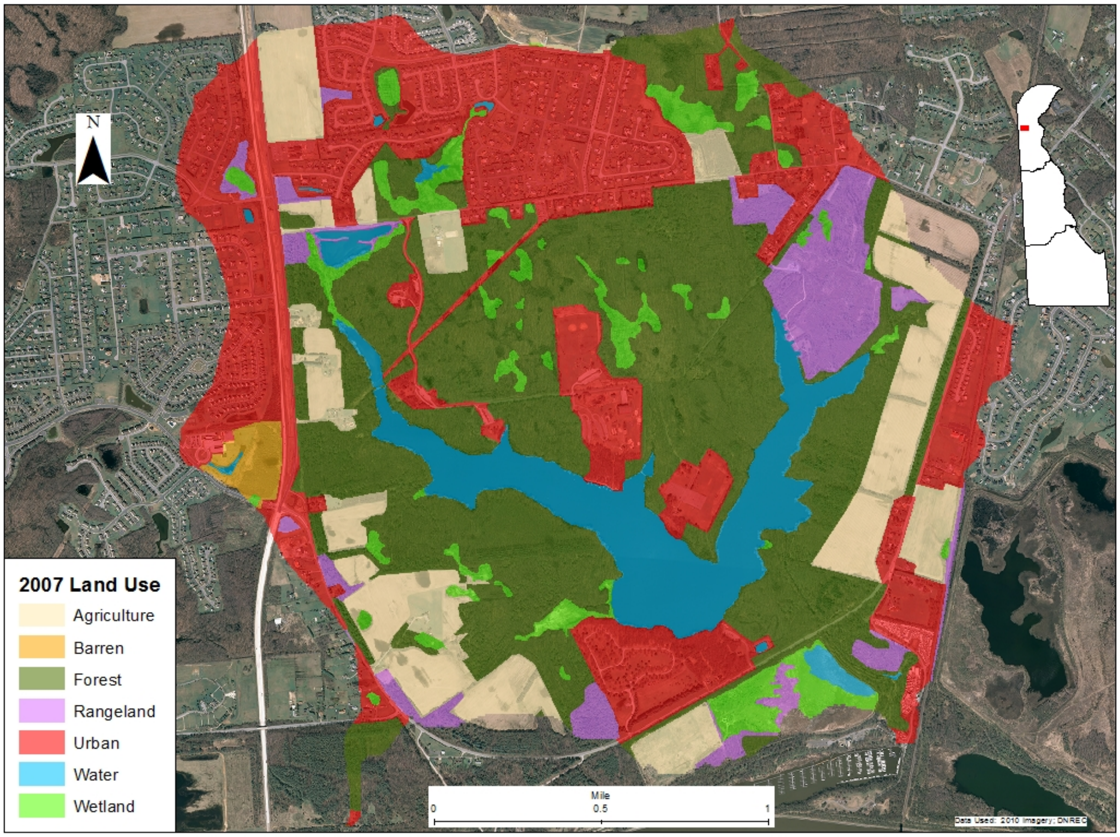

Figure 1-6 2007 Land Use in the Lums Pond Sub-Watershed

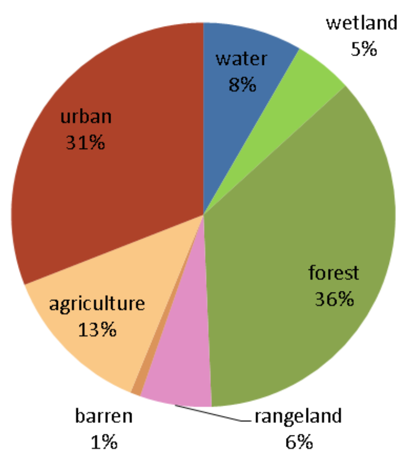

Figure 1-7 2007 Land Use Percentages in the Lums Pond Sub-Watershed

1.6 Objective and Scope of the Lums Pond Sub-Watershed TMDL Analysis

The objective of the TMDL analysis for the Lums Pond Sub-Watershed is to estimate the maximum amount of dissolved oxygen consuming compounds and nutrients that the Sub-Watershed can receive without violating applicable water quality standards. As discussed previously, water quality violations of the dissolved oxygen standard have been observed during the 2009-2011 time period in the downstream segment of Lums Pond – the Southeast Creek; therefore, the focus of this TMDL analysis is on the Southeast Creek and its drainage area – the Lums Pond Sub-Watershed.

To achieve the above objective, DNREC has:

- Developed a water quality model for Southeast Creek using U.S. EPA's Qual2K Model as a framework;
- Calibrated the model to the summer average condition observed during the 2009-2011 time period;
- Applied load reduction scenarios using the calibrated model; and
- Proposed load reductions from point and nonpoint sources.

Chapter 2 of this report provides a brief review of the Southeast Creek Qual2K model. The results of the model run for the calibration and load reductions under critical summer average conditions are discussed in Chapter 3. An estimation of the Lums Pond Sub-Watershed TMDLs and the allocations to point and nonpoint sources are discussed in Chapter 4.

2.0 Southeast Creek Water Quality Model

2.1 The Stream Water Quality Model (Qual2K)

The Stream Water Quality Model (Qual2K) was chosen as the framework for Southeast Creek model development and TMDL analysis. Qual2K is a simple one-dimensional model that addresses basic stream transport and mixing processes. The kinetic processes employed in Qual2K address nutrient cycles, algal growth, and dissolved oxygen dynamics (6). The Qual2K model is suitable for simulating hydrologic and water quality conditions for a small free-flowing stream such as Southeast Creek. Considering the available data and the problem at hand, and considering the limitations of other available models, Qual2K was selected as the tool for developing the Southeast Creek water quality model and conducting the TMDL analysis.

Qual2K, a modernized version of Qual2E that has been widely used for studying the impact of conventional pollutants on streams, is operated as a Microsoft Excel program. It is supported and distributed by the U.S. EPA. The model used for this study was downloaded from the US EPA website (URL:http://www.epa.gov/athens/wwqtsc/html/qual2k.html).

2.2 Major Components of the Southeast Creek Qual2K Model

The Southeast Creek Qual2K model is set up as a one-dimensional, steady-state model. It simulates instream water quality conditions including dissolved oxygen, BOD, algae as chlorophyll-*a*, as well as various species of nitrogen and phosphorus. The major components of the Southeast Creek Qual2K model are discussed below.

Model Segmentation

The Southeast Creek Qual2K model consists of six reaches and covers a 1.3-kilometer stretch starting from the Lums Pond outlet to the marina on the C&D Canal. The model's headwater is the pond and model's last segment is an underground channel that connects the stream to the marina. No natural tributaries enter this 1.3-km stretch. The point source discharge from the Lums Pond State Park WWTP enters this stream at Reach 2, about 0.3 km downstream from the pond. The monitoring station 108051 is within reach 2 near the discharge outfall. Figure 2-1 displays the Southeast Creek Qual2K Model segment diagram. A description of the modeled segments and their characteristics are presented in Table 2-1.

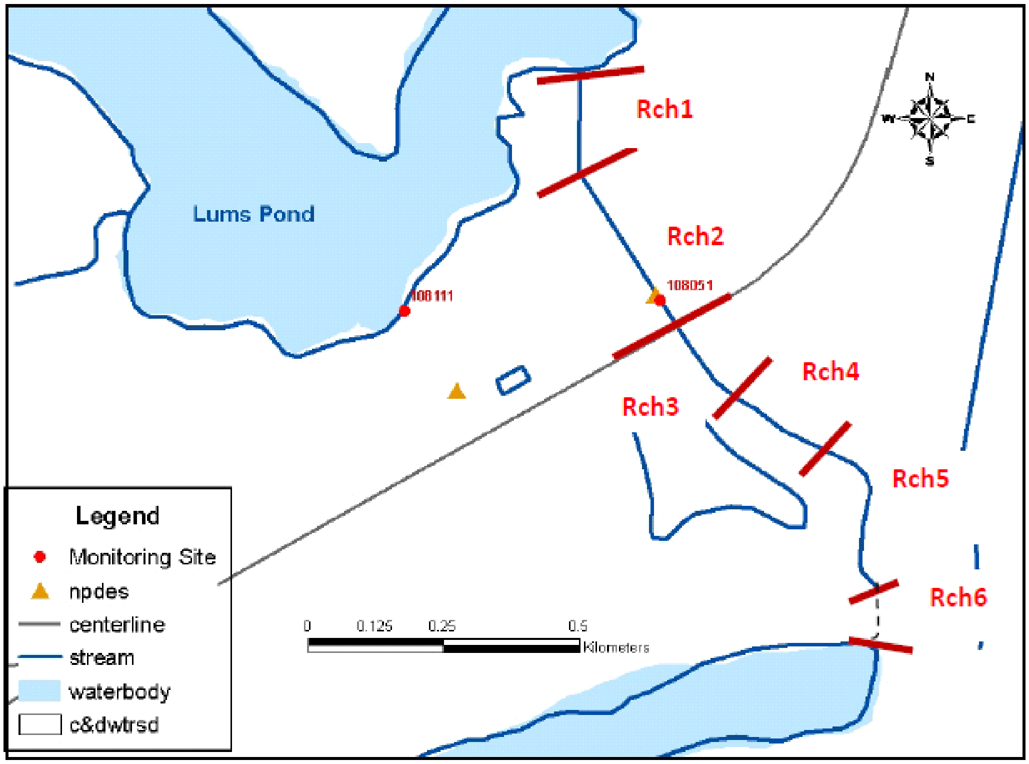

Figure 2-1 Southeast Creek Qual2K Reaches

Table 2-1 Southeast Creek Qual2K Reaches

Reach #	Length (km)	Description	Bottom Width (m)	Channel Slope	Side Slope (both sides)	Manning n
1	**0.201**	It is the most upstream segment, starting from the pond's outlet.	1.5	0.0005	0.5	0.1
2	**0.302**	This segment is upstream of Rt 71 and receives WWTP discharge. Monitoring station 108051 is located at trail crossing inside the Park.	1.5	0.0005	0.5	0.1
3	**0.201**	This segment is downstream of Rt 71.	1.5	0.0005	0.5	0.1
4	**0.201**		1.5	0.0008	0.5	0.1
5	**0.302**		1.5	0.0010	0.5	0.1
6	**0.101**	This segment is an underground channel connecting the stream to the marina.	1.5	0.0015	0.5	0.1

Hydraulic Characteristics

The Southeast Creek Qual2K model uses the Manning equation to describe stream hydraulic characteristics and assumes that the stream has a trapezoidal channel cross-section.

Estimates were made for the width and depth of flow in the stream based on a field visit conducted on July 6, 2011. The width ranges from 1.5 to 2.5 meter and depth ranges from 0.1 to 0.2 meters. The bottom slope of the stream was estimated based on USGS topographic maps. The hydraulic characteristics of model segments are provided in Table 2-1.

Stream Flow and Point Source Discharge

Since low dissolved oxygen concentrations are observed during the summer months, summer (June – September) average flow during July 2009 - June 2011 was considered in model calibration and load reduction evaluations.

The Lums Pond Sub-Watershed has no stream gauging station. Daily stream flow at USGS gauging station 01478000 at Cooch's Bridge on Christina River (7) was used to estimate daily flows for Southeast Creek. Figure 2-2 shows the summer average flow relative to daily flow and average daily flow for the period of July 2009 – June 2011 at Cooch's Bridge. The summer average flow of 11 cubic feet per second, shown by the red line, is a low flow period compared to the average daily mean of 30.47 cubic feet per second, shown by the green line. Flow at Southeast Creek was calculated by multiplying the flow at Cooch's Bridge by a factor representing the ratio of the drainage area of Lums Pond above Southeast Creek to the drainage area of the Christina River above Cooch's Bridge. Table 2-2 presents the drainage areas and estimated summer average flows compared to flows during other seasons estimated for Southeast Creek.

The WWTP discharges its treated wastewater into Southeast Creek in a batch fashion, typically over a 3 to 9-day period every month or every other month. The average flow of observed batch discharges for the period July 2009 through June 2011 was 0.11 MGD (0.2 cubic feet per second). The discharge schedule and flow for this two-year period are included in Appendix A. A comparison of discharge dates to water quality sampling dates shows that they were not concurrent. Therefore, observed water quality impairment of Southeast Creek with regard to dissolved oxygen cannot be attributed to the point source discharge.

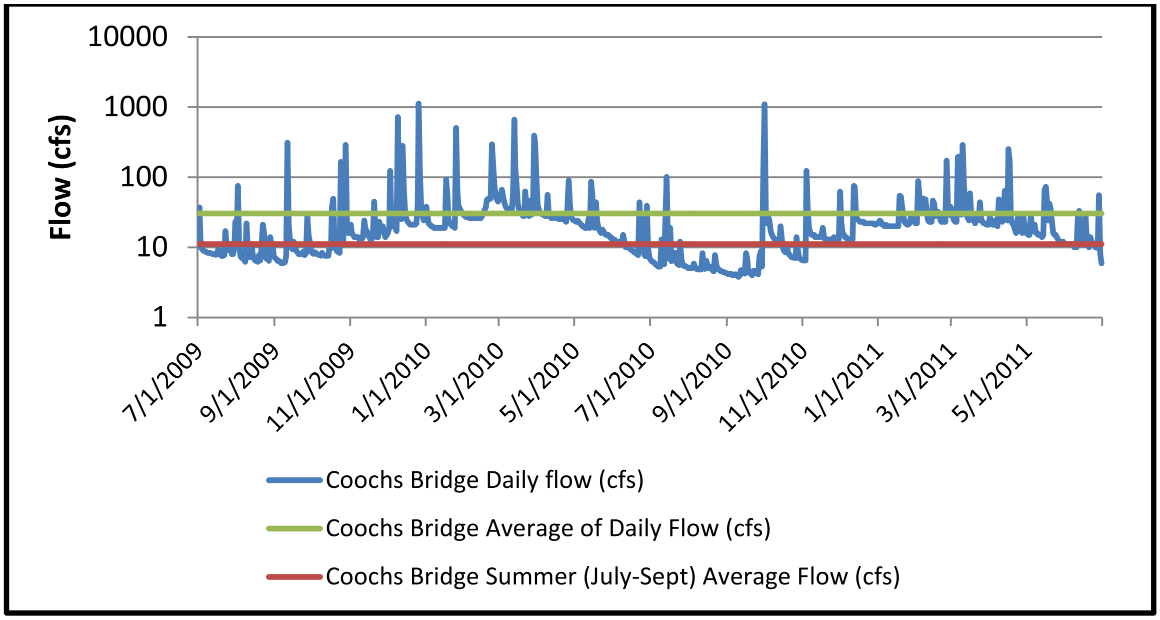

Figure 2-2 Summer Averaged Flow Compared to Average Daily Flow at Cooch's Bridge of Christina River

Table 2-2 Estimated Drainage Area, Summer Average Flow for Southeast Creek and Average Flow of the WWTP

Period	Cooch's Bridge	Lums Pond Outlet
Drainage Area (mi2)	20.50	3.98
% of Gaged Area	100%	19%
Long-term Daily Average (1943 - 2011) (cfs)	29.00	5.63
Daily Average during July 2009 - June 2011 (cfs)	30.47	5.92
Long-term Summer Average (July-Sept during 1943 -2011) (cfs)	18.83	3.66
Summer (June-Sept) Average during July 2009 - June 2011 (cfs)	11.28	2.19
WWTP (design flow 0.105 mgd discharging to reach #2 in cfs)	--------	0.16

Boundary Water Quality Conditions

The Qual2K model uses specific data groups to define model boundary conditions – headwater, downstream boundary, tributary streams, point sources, and diffuse sources. It uses the headwater data group to define the most upstream boundary condition of a model domain. The downstream boundary condition can be defined by users or computed internally. The point source data group defines the conditions of point source discharges from facilities or tributaries that enter simulated stream segments. The diffuse sources data group defines the conditions of uniformly distributed flow over the entire length of the model reach. The uniformly distributed flow could be groundwater inflow and/or distributed surface runoff that is assumed to be constant over time.

The headwater conditions for the Southeast Creek Qual2K Model were characterized by using monitoring data collected at Station 108111 in the pond. The average concentrations of various water quality parameters at Station 108111 over the summer months (June – September) during July 2009 – June 2011 were used as model headwater inputs. Headwater input details are included in Appendix B.

The option of internally calculating downstream boundary conditions was selected for development of the Southeast Creek Qual2K Model.

The point source input of the model was characterized by using the Lums Pond State Park's WWTP discharge monitoring data, permit limits, as well as assumed values based on secondary treatment plant expected performance values for parameters that are not monitored at the plant. Point source input details are included in Appendix B.

Diffuse source conditions were estimated using runoff concentrations for each land use type according to percentages of different land use types in an area that drains directly to a model segment. In developing a water quality model for the Murderkill River Watershed of Delaware, HydroQual, Inc. compiled runoff concentrations of seven different land uses from literature values as well as land use studies in Delaware. Since the area adjacent to the Southeast Creek is mostly forested, runoff concentrations of forestland used in the Murderkill River water quality model were used to define the diffuse source concentrations for the Southeast Creek Qual2K Model (8). Diffuse source input details are included in Appendix B.

System Parameters

The physical, chemical, and biological processes simulated by the Qual2K Model are represented by a set of equations containing several groups of parameters. Detailed descriptions of these parameters and their associated processes are available in the Qual2K Model user's manual. Parameters representing global rate constants used in model calibration of average summer conditions are listed in Appendix C.

3.0 Model Calibration and Scenario Analysis

3.1 Model Calibration

Because low dissolved oxygen level is the concern for this analysis, the Southeast Creek Qual2K Model was calibrated to the summer (June – September) average flow and water quality conditions observed during the period July 2009-June 2011. The model calibration did not include the point source discharge since, as discussed in Section 2-2, the water quality sampling dates were not concurrent with the dates of the batch discharge of the Lums Pond State Park's WWTP. The input and output data for the Southeast Creek Qual2K Model calibration is presented in Appendix B.

Figure 3-1 displays model output for stream channel flow, velocity, water depth, and bottom width under summer average condition during July 2009 – June 2011. Figure 3-2 presents calibration results for water temperature, dissolved oxygen, BOD, chlorophyll-a, and various species of nutrients. In these figures, model simulation results are displayed as a solid line from left to right representing stream conditions from the headwaters at the Lums Pond outlet to the downstream segment at the Summit Marina. Observed data from Station 108111 at the pond and Station 108051 at the Park trail bridge crossing north of Route 71 are shown by symbols representing mean, maximum, and minimum values.

The calibration results show that dissolved oxygen, BOD, nitrogen, and phosphorus are calibrated reasonably well to observed data. In addition, the results show that oxygen demanding pollutants from the pond are causing instream dissolved oxygen concentrations to fall below the water quality standard of 5.5 mg/l under summer average conditions.

3.2 Load Reduction Scenarios

Based on the calibrated model, a 40% load reduction scenario was performed. This scenario simulated the instream conditions when 40% reductions of BOD and nutrients were applied to its headwater and diffuse sources. The simulation results are presented in Figure 3-3 and show that, with 40% load reduction, instream dissolved oxygen concentrations meet water quality standard of 5.5 mg/l under summer average condition. For nutrients, instream total nitrogen and total phosphorus concentrations are below the threshold values of 3 mg/l and 0.2 mg/l respectively. The load reduction from headwater and diffuse sources represent the reduction from nonpoint sources; hence, this scenario is considered as the basis for calculating the TMDL load from nonpoint sources.

As Southeast Creek also receives batch discharges from the Lums Pond State Park WWTP, it is necessary to make sure that dissolved oxygen is attained when a batch discharge is occurring during summer critical conditions. Therefore, a scenario considering the point source discharge under average summer conditions was also performed. This scenario was based on the 40% nonpoint source reduction scenario as discussed above and considered adding the WWTP discharge to the system. The levels of BOD and nutrients loads discharged from the WWTP to the stream were bounded and limited by the receiving instream water quality condition. Table 3-1 lists the allowable discharge levels resulting from the model simulation and the current permitted discharge levels. Note that, in this scenario, the discharge effluent flow was kept at the facility's hydraulic design level. The effluent concentration of BOD was reduced from the current permitted level at 30 mg/l to the level at 15 mg/l at which the instream DO standard of 5.5 mg/l was attained. Since the facility is not currently monitoring nutrient levels, typical concentrations for a secondary treatment level were assumed for this analysis. The results of this scenario run are presented in Figure 3-4 and show that instream dissolved oxygen concentrations are kept at or above 5.5 mg/l along the entire length of the stream. For nutrients, instream total nitrogen and total phosphorus concentrations are below the threshold values of 3 mg/l and 0.2 mg/l respectively. Therefore, this scenario was considered as the basis for calculating the TMDL waste load allocation for the WWTP.

Table 3-1 Allowable Discharge Levels from Model Simulation Compared to Currently Permitted Discharge Levels for the Lums Pond State Park WWTP

WWTP Discharge	Flow	DO	CBOD5	TN	TP
unit	mgd	mg/l	mg/l	mg/l	mg/l
Currently Permitted Levels	0.11		30		
Allowable Levels	0.11	5.5	15	10	2

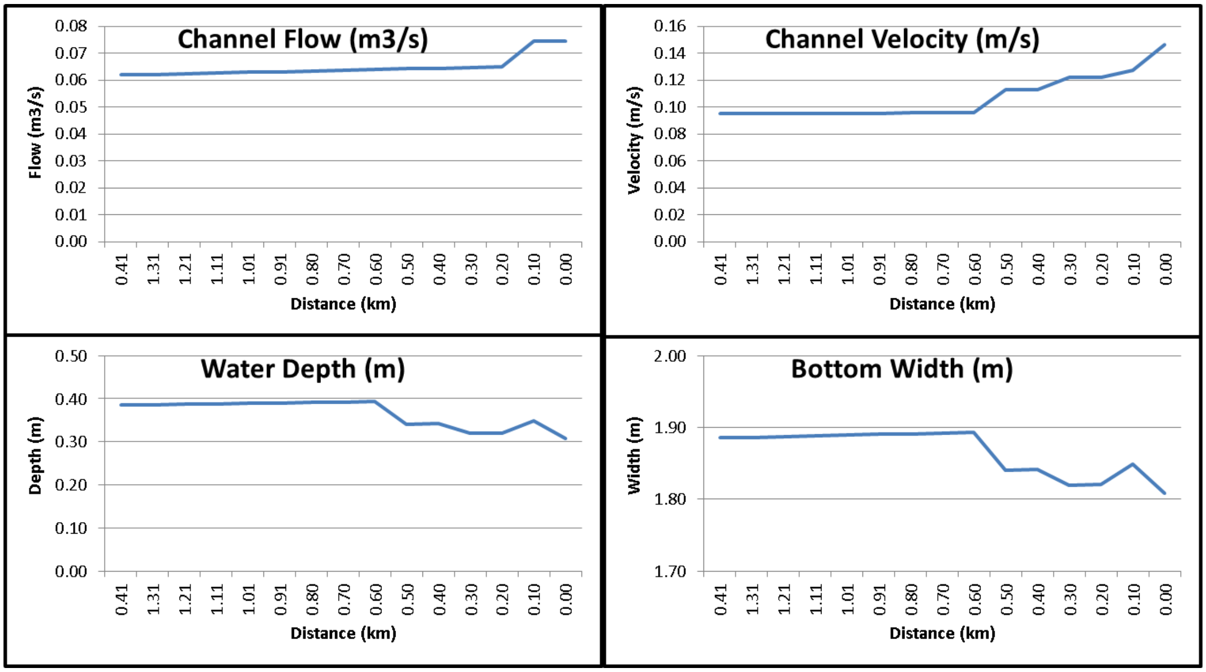

Figure 3-1 Hydraulic Conditions of Calibration Run for the Southeast Creek Qual2K Model

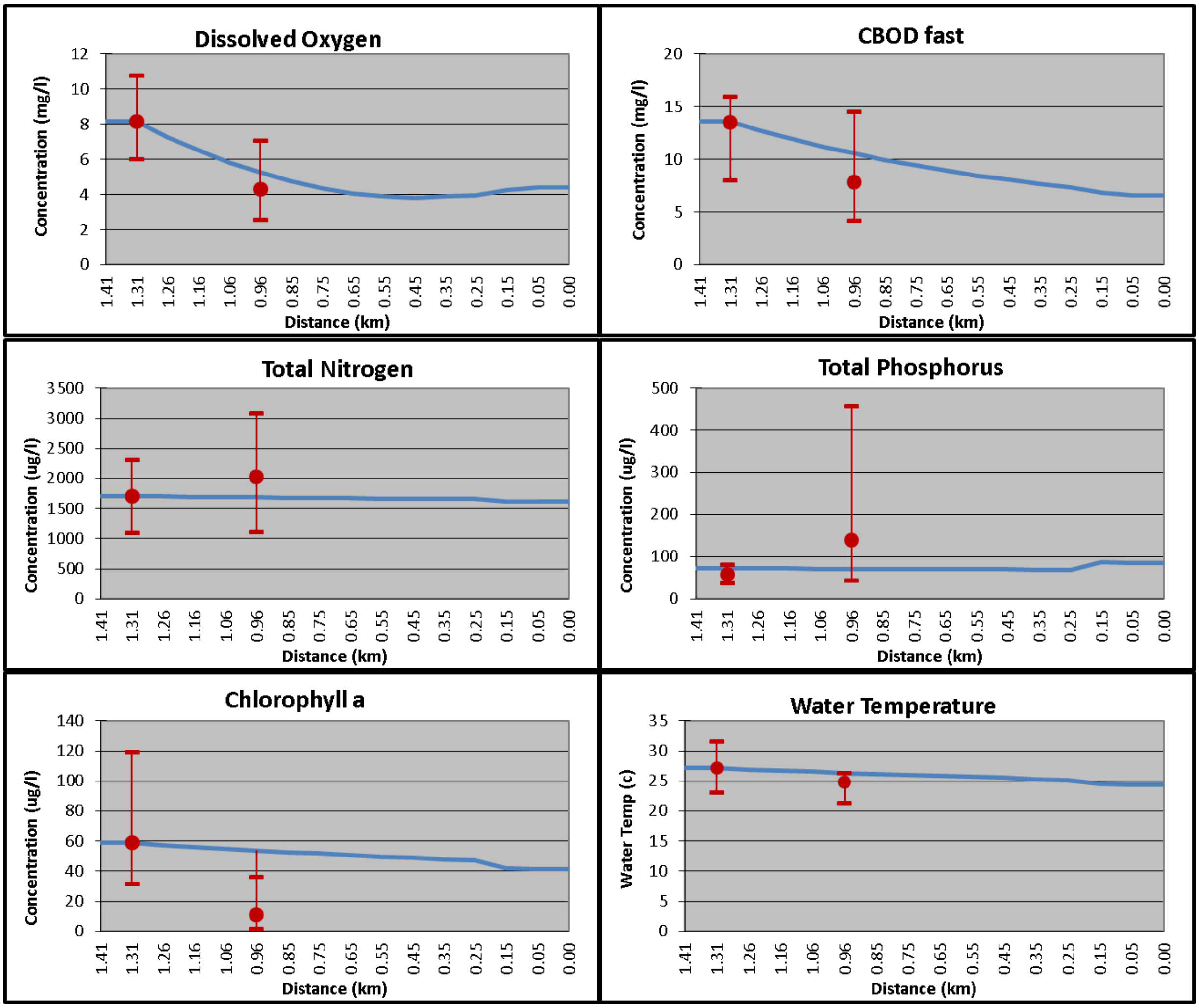

Figure 3-2 Calibration Results of the Southeast Creek Qual2K Model

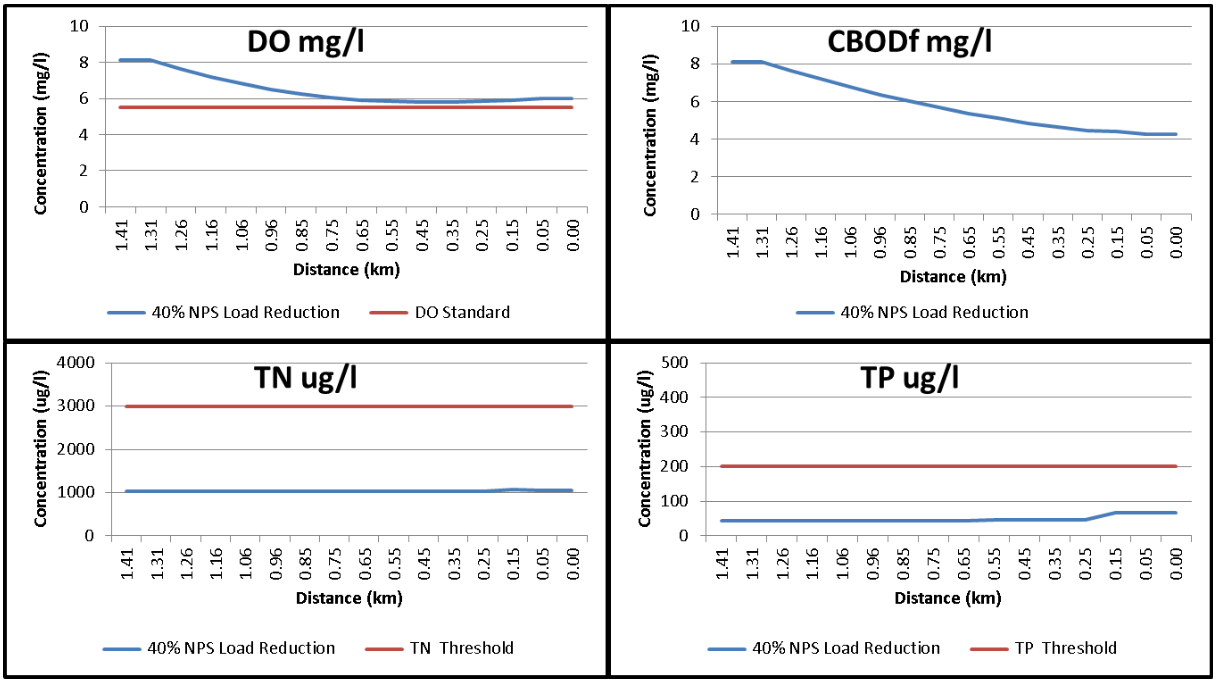

Figure 3-3 Results of the 40% Nonpoint Source Load Reduction Scenario

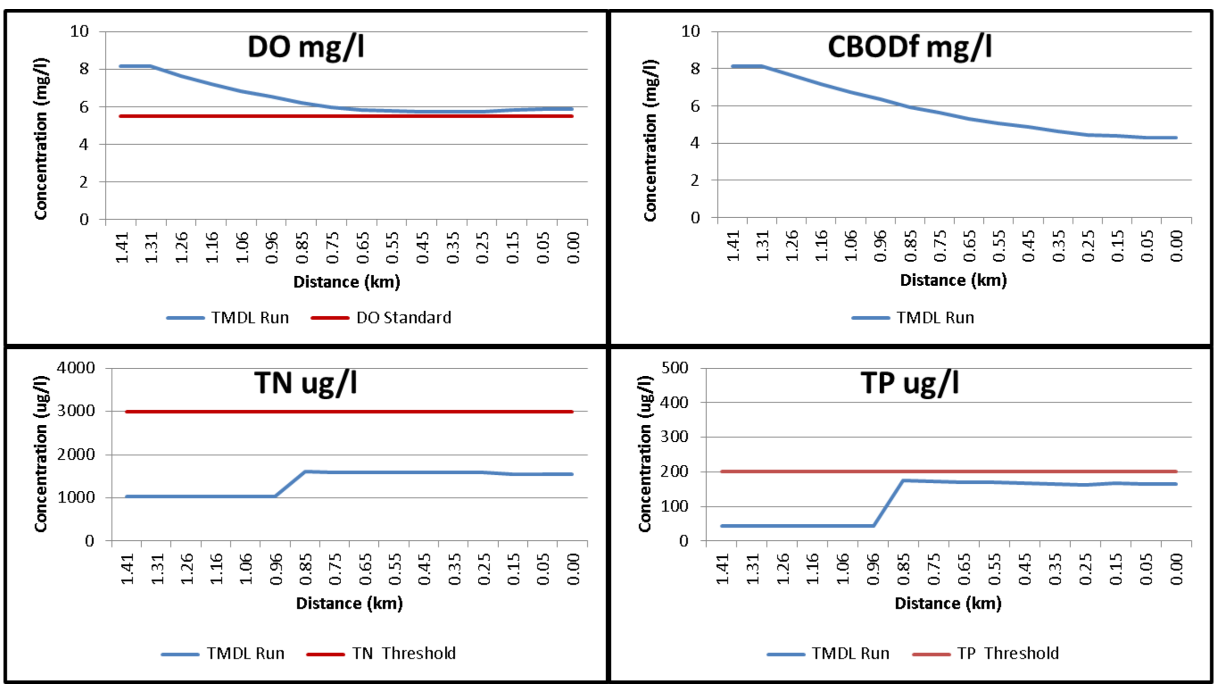

Figure 3-4 Results of Adding Point Source Loads in Addition to a 40% Nonpoint Source Load Reduction Scenario

4.0 Establishment of Dissolved Oxygen and Nutrient TMDLs for the Lums Pond Sub-Watershed

As it was discussed in Chapter 1 of this report, the applicable water quality standard for the Lums Pond Sub-Watershed is dissolved oxygen of 5.5 mg/l and nutrient threshold limits of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus. Examining water quality data collected during July 2009 – June 2011 shows that water quality conditions in the sub-watershed meet the dissolved oxygen standard and nutrient threshold values everywhere except for Southeast Creek. Violations of the dissolved oxygen standard were observed in Southeast Creek during the summer months.

Southeast Creek receives pollutants from Lums Pond, groundwater, surface runoff, and batch discharges from the Lums Pond State Park WWTP. As the observed summer low DO was not concurrent with WWTP discharges, the Southeast Creek Qual2K Model was calibrated to summer average conditions without including loads from the WWTP discharge. As discussed in Chapter 3, with a 40% reduction from nonpoint source loads, based on the calibrated model, the instream dissolved oxygen concentrations will meet water quality standards under critical summer average conditions. Governed by the model calibration and its 40% reduction scenario, the baseline load and TMDL load from nonpoint sources were calculated; the baseline load was calculated by multiplying annual mean flow and annual average concentrations for the period of July 2009 – June 2011 and TMDL load by 40% reduction from baseline load. However, the Lums Pond Sub-Watershed resides in a Municipal Separate Storm Sewer System (MS4) permitted region – the entire New Castle County (NPDES Permit # DE 0051071). EPA guidelines require that nonpoint source loads generated from MS4 permitted areas are treated as point source loads for TMDL purpose and therefore are assigned to waste load allocations (WLAs) instead of load allocations (LAs). Hence, all nonpoint source loads generated from this sub-watershed are assigned to MS4 point sources with WLAs and no loads allocated to nonpoint sources as LAs. The results of baseline load calculation and assigned TMDL WLA and LA are presented in Table 4-1.

Built on top of the 40% load reduction scenario, another scenario was developed considering the addition of pollutant loads discharged from the WWTP to the system. As discussed in Chapter 3, the simulation results show that instream water quality conditions meet the DO criteria and nutrient threshold limits under critical summer average condition. Therefore, this scenario was used as the basis for calculating the TMDL waste load allocation for the WWTP. The TMDL waste load allocation was calculated by multiplying the facility's design flow to the pollutant concentration suggested by this scenario, while baseline load was calculated by multiplying the design flow to the currently permitted discharge concentration. The resulting Waste Load Allocation (WLA) for the Lums Pond State Park WWTP is presented in Table 4-1.

Table 4-1 Lums Pond Sub-Watershed Baseline Loading Levels for MS4 and WWTP and Proposed TMDL Waste Load Allocations and Load Allocations

Situation	CBOD5	TN	TP
unit	lb/day	lb/day	lb/day
MS4 Baseline as of 7/2009 – 6/2011	146	50	2
TMDL for NPS (LA)	0	0	0
TMDL for MS4 (WLA)	88	30	1
WWTP Baseline	26		
TMDL for WWTP (WLA)	13	9	2
TMDL	**101**	**39**	**3**

It should be noted that the proposed WLA for the Lums Pond State Park WWTP is one of many potential loading scenarios that would result in meeting applicable water quality criteria. DNREC plans to conduct further analysis of the performance of the State Park WWTP to see if there are other loading scenarios that would achieve the same water quality results in the most cost-effective way. Upon finding such a loading scenario, DNREC may decide to revise the NPDES Permit limits for some of the parameters of the Lums Pond State Park WWTP while still maintaining all applicable water quality standards.

5.0 Discussion of Regulatory Requirements for TMDLs

Federal regulations at 40 CFR Section 130 require that TMDLs must meet the following eight minimum regulatory requirements:

1. The TMDLs must be designed to achieve applicable water quality standards.
2. The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.
3. The TMDLs must consider the impact of background pollutants.
4. The TMDLs must consider critical environmental conditions.
5. The TMDLs must consider seasonal variations.
6. The TMDLs must include a margin of safety.
7. The TMDLs must have been subject to public participation.
8. There should be a reasonable assurance that the TMDLs can be met.

As the following discussion will indicate, the Southeast Creek TMDL meets these eight minimum regulatory requirements.

1. The TMDLs must be designed to achieve applicable water quality standards.

Section 1.3 describes the water quality standards for dissolved oxygen and nutrient guidelines for total nitrogen and total phosphorus in the Lums Pond Sub-Watershed. The applicable criteria for dissolved oxygen for freshwater streams are 5.5 mg/l as a daily average and 4.0 mg/l as a minimum at any time. The nutrient threshold levels are 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus. The results of the TMDL scenario analysis demonstrate that the proposed load reductions from the point source and nonpoint sources will result in meeting these criteria and threshold values under the critical summer conditions. Therefore, it can be concluded that the proposed TMDL is designed to meet the applicable water quality criteria and TMDL threshold values.

2. The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.

The total allowable loads of the proposed TMDLs have been calculated based on the model results and presented in Table 4-1. The proposed total allowable loads for nutrients and BOD include waste load allocations for the Lums Pond State Park WWTP and MS4 point sources of the Sub-Watershed.

3. The TMDLs must consider the impact of background pollutants.

The Lums Pond Sub-Watershed TMDL analysis was based on a calibrated Qual2K water quality model. The model was developed using water quality monitoring data to represent model inputs from headwater, tributary inflow, diffuse inflow, and point sources. Since the monitoring data was reflective of background pollutant conditions, it can be concluded that the impact of background pollutants was accounted for in the model.

4. The TMDLs must consider critical environmental conditions.

Low stream flows during summer months coupled with high water temperatures are critical conditions for Southeast Creek. The Southeast Creek Qual2K Model was calibrated to the summer average flow and water quality conditions. The TMDL analysis of load reductions from point sources and nonpoint sources was conducted for critical summer conditions. Therefore, the critical environmental condition for the Lums Pond Sub-Watershed was considered in this analysis.

5. The TMDLs must consider seasonal variations.

Seasonal variation was considered in the development of the Southeast Creek Qual2K Model. The Southeast Creek Q2K Model was calibrated to critical summer average conditions; hence, seasonal variation was considered in this TMDL analysis. In addition, all data collected during the 2009-2011 time period, in which included data from different months and seasons, were used to build the model and calculate annual nutrient loads. Therefore, seasonal variations were considered in the analysis.

6. The TMDLs must consider a margin of safety.

EPA’s technical guidance allows consideration of a margin of safety as implicit or as explicit. An implicit margin of safety relies on consideration of conservative assumptions in model development and TMDL establishment. An explicit margin of safety is considered when a specified percentage of assimilative capacity is reserved and unassigned to account for uncertainties, lack of sufficient data, or future growth.

An implicit margin of safety has been considered for this analysis. The Southeast Creek Qual2K Model was calibrated using conservative assumptions regarding reaction rates, pollutant loads, and simultaneous occurrence of critical environmental conditions and batch discharges from the point source. Use of these conservative assumptions support the existence of an implicit margin of safety.

7. The TMDLs must have been subject to public participation.

A public hearing will be held to present the Lums Pond Sub-Watershed TMDL to the public and to receive comments prior to formal adoption of the TMDL Regulation. Notice of the public hearing will be published in at least two newspapers of statewide circulation, in the Delaware Register of Regulations, and will be posted on DNREC's website. Comments may be submitted in writing or orally at the public hearing. A Court Reporter will prepare a transcript of the hearing and a Hearing Officer's Report and Secretary's Order will be developed. These documents will be posted on DNREC's website and will be made available to anyone who requests them.

8. There should be a reasonable assurance that the TMDLs can be met.

Delaware adopts all its TMDLs as State Regulation following a robust public participation process. Adoption of the TMDLs as State Regulation will provide reasonable assurance that the requirements of the TMDLs will be implemented. The Lums Pond Sub-Watershed TMDL requires a 40% load reduction from nonpoint sources and reduced loads from a point source managed by the Division of Parks and Recreation, DNREC. When point and nonpoint source load reductions called for by this TMDL are implemented, water quality standards with regard to dissolved oxygen will be met in all segments of the Lums Pond Sub-Watershed. DNREC will work with local citizen groups and Lums Pond State Park Managers to develop a strategy to implement the nonpoint source reduction requirements. In addition, staff from three divisions within DNREC will ensure that the renewed permit for the State Park WWTP complies with the requirements of this TMDL and that WWTP performance meets limits prescribed by the permit.

References

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Appendix A. Lums Pond State Park WWTP Discharge Schedule and Flow (9)

Date	WWTP Discharge Flow (mgd)	Date	WWTP Discharge Flow (mgd)	Date	WWTP Discharge Flow (mgd)
6/22/2009	0.0820	2/21/2010	0.0800	2/18/2011	0.0150
6/23/2009	0.1250	2/22/2010	0.1000	2/19/2011	0.0080
6/24/2009	0.1380	2/23/2010	0.1000	2/20/2011	0.2100
6/25/2009	0.0680	2/24/2010	0.1300	2/21/2011	0.2050
6/26/2009	0.1330	2/25/2010	0.1300	2/22/2011	0.1940
6/27/2009	0.0008	2/26/2010	0.1100	2/23/2011	0.1890
8/25/2009	0.0540	2/27/2010	0.0016	2/24/2011	0.1370
8/26/2009	0.1280	4/10/2010	0.1470	2/25/2011	0.0300
8/27/2009	0.1160	4/11/2010	0.1350	4/17/2011	0.1230
8/28/2009	0.1480	4/12/2010	0.1480	4/18/2011	0.0770
8/29/2009	0.1110	4/13/2010	0.1380	4/19/2011	0.0500
8/30/2009	0.0008	4/14/2010	0.0760	4/20/2011	0.1500
10/29/2009	0.0740	4/15/2010	0.0230	4/21/2011	0.1330
10/30/2009	0.1440	4/16/2010	0.0006	4/22/2011	0.1200
10/31/2009	0.0020	6/24/2010	0.1730	4/23/2011	0.1080
11/12/2009	0.1150	6/25/2010	0.1210	4/24/2011	0.0200
11/13/2009	0.1120	6/26/2010	0.1210	4/25/2011	0.0019
11/14/2009	0.1060	6/27/2010	0.1170	4/26/2011	0.0000
11/15/2009	0.0800	6/28/2010	0.1450	7/1/2011	0.1180
11/16/2009	0.0590	6/29/2010	0.0017	7/2/2011	0.1170
11/17/2009	0.0008	8/21/2010	0.1400	7/3/2011	0.1030
12/26/2009	0.1210	8/22/2010	0.1090	7/4/2011	0.1020
12/27/2009	0.1210	8/23/2010	0.1600	7/5/2011	0.1150
12/28/2009	0.1480	8/24/2010	0.1160	7/6/2011	0.1200
12/29/2009	0.1150	8/25/2010	0.0120		
12/30/2009	0.1190	11/5/2010	0.0040		
12/31/2009	0.0015	11/6/2010	0.1700		
		11/7/2010	0.1360		
		11/8/2010	0.1540		
		11/9/2010	0.0600		
		11/10/2010	0.0580		
		11/11/2010	0.0530		
		11/12/2010	0.0450		
		11/13/2010	0.0030		

Appendix B. Input and Output Data for the Southeast Creek Qual2K Model Calibration

Input Data:

Headwater label	*Reach No*	*Flow*
		Rate
		(m^3/s)
Headwater (LP Outlet)	1	0.0620
Water Quality Constituents	*Units*	*0.0000*
Temperature	C	27.1400
Conductivity	umhos	180.3800
Inorganic Solids	mgD/L	11.9000
Dissolved Oxygen	mg/L	8.1388
CBODslow	mgO2/L	
CBODfast	mgO2/L	13.5600
Organic Nitrogen	ugN/L	1198.9700
NH4-Nitrogen	ugN/L	67.1300
NO3-Nitrogen	ugN/L	22.8800
Organic Phosphorus	ugP/L	5.0900
Inorganic Phosphorus (SRP)	ugP/L	8.8800
Phytoplankton	ugA/L	58.6500
Internal Nitrogen (INP)	ugN/L	
Internal Phosphorus (IPP)	ugP/L	
Detritus (POM)	mgD/L	
Pathogen	cfu/100 mL	
Alkalinity	mgCaCO3/L	24.4300
Constituent i		
Constituent ii		
Constituent iii		
pH	s.u.	7.7900

PS input for Calibration Run				*Point*		*Temperature*			*Specific Conductance*			*Inorganic Suspended Solids*		
	Tributary	*leadwate*	*Location*	*bstractior*	*Inflow*	*mean*	*range/2*	*time of*	*mean*	*range/2*	*time of*	*mean*	*range/2*	*time of*
Name	*No.*	*Label*	*km*	*m3/s*	*m3/s*	*°C*	*°C*	*max*	*umhos*	*umhos*	*max*	*mg/L*	*mg/L*	*max*
Lums Pond Park STP	0	Headw a	0.86	0.0000	0.0000	26.67	0.00	12:00 AM	350.00	0.00	12:00 AM	12.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	0.0000	0.0093	21.484	0.000	0.000	141.600	0.000	0.000	48.720	0.000	0.000

PS input for Calibration Run				Dissolved Oxygen			Slow CBOD			Fast CBOD		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km	mg/L	mg/L	max	mgO2/L	mgO2/L	max	mgO2/L	mgO2/L	max
Lums Pond Park STP	0	Headw a	0.86	3.00	0.00	12:00 AM	0.00	0.00	12:00 AM	30.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	6.322	0.000	0.000	0.000	0.000	0.000	5.552	0.000	0.000

Conti.

PS input for Calibration Run				Organic N			Ammonia N			Nitrate + Nitrite N		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km	ugN/L	ugN/L	max	ugN/L	ugN/L	max	ugN/L	ugN/L	max
Lums Pond Park STP	0	Headw a	0.86	3500.00	0.00	12:00 AM	8000.00	0.00	12:00 AM	0.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	886.203	0.000	0.000	127.800	0.000	0.000	256.000	0.000	0.000

Conti.

PS input for Calibration Run				Organic P			Inorganic P			Phytoplankton		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km	ugP/L	ugP/L	max	ugP/L	ugP/L	max	ugA/L	ugA/L	max
Lums Pond Park STP	0	Headw a	0.86	900.00	0.00	12:00 AM	200.00	0.00	12:00 AM	0.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	163.200	0.000	0.000	39.000	0.000	0.000	11.944	0.000	0.000

Conti.

PS input for Calibration Run				Internal Nitrogen			Internal Phosphorus			Detritus		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km	ugN/L	ugN/L	max	ugP/L	ugP/L	max	mgD/L	mgD/L	max
Lums Pond Park STP	0	Headw a	0.86	0.00	0.00	12:00 AM	0.00	0.00	12:00 AM	0.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Conti.

PS input for Calibration Run				Pathogen Indicator Bacteria			Alkalinity			Constituent i		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km	cfu/100ml	cfu/100r	max	ngCaCO3/	mgCaCO3/l	max			max
Lums Pond Park STP	0	Headw a	0.86	0.00	0.00	12:00 AM	100.00	0.00	12:00 AM	0.00	0.00	12:00 AM
Small trib entering Reach5	0		0.20	0.000	0.000	0.000	35.280	0.000	0.000	0.000	0.000	0.000

Conti.

PS input for Calibration Run				Constituent ii			Constituent iii			pH		
	Tributary	leadw ate	Location	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of
Name	No.	Label	km			max			max	s.u.	s.u.	max
Lums Pond Park STP	0	Headw a	0.86	0.00	0.00	12:00 AM	0.00	0.00	12:00 AM	7.15	0.00	12:00 AM
Small trib entering Reach5	0		0.20	0.000	0.000	0.000	0.000	0.000	0.000	7.102	0.000	0.000

Output Data:

wq0001	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Reach Label	Headwater (LPO	from Lums Pond	from Lums Pond	receiving PS	receiving PS	receiving PS	Monitoring Site	Monitoring Site	Turning Channel	Turning Channel	Steep Channel	Steep Channel	Steep Channel	Underground Cha	Terminus
	x(km)	1.31	1.26	1.16	1.06	0.96	0.85	0.75	0.65	0.55	0.45	0.35	0.25	0.15	0.05	0.00
	cond (umho	180.38	180.44	180.50	180.55	180.61	180.67	180.72	180.78	180.83	180.89	180.94	180.99	176.10	176.10	176.10
	ISS (mgD/l	11.90	11.33	10.78	10.27	9.78	9.31	8.87	8.46	8.07	7.70	7.35	7.03	11.78	11.36	11.36
	DO(mgO2/	8.14	7.25	6.50	5.81	5.23	4.75	4.35	4.03	3.90	3.81	3.88	3.95	4.26	4.39	4.39
	CBODs (mgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CBODf (mgO	13.56	12.71	11.93	11.22	10.56	9.95	9.39	8.88	8.46	8.06	7.70	7.35	6.83	6.59	6.59
	No(ugN/L	1198.97	1183.64	1168.67	1154.06	1139.78	1125.83	1112.21	1098.89	1086.70	1074.77	1063.43	1052.32	1021.91	1012.60	1012.60
	NH4(ugN/l	67.13	80.40	92.90	104.71	115.87	126.45	136.50	146.05	154.98	163.47	171.49	179.09	178.74	184.81	184.81
	NO3(ugN/l	22.88	27.81	33.06	38.59	44.35	50.30	56.39	62.60	68.21	73.93	79.48	85.16	111.76	115.58	115.58
	Po (ugP/L	5.09	5.55	6.00	6.44	6.87	7.29	7.70	8.10	8.50	8.89	9.28	9.66	29.00	28.69	28.69
	Inorg P (ugP	8.88	9.21	9.54	9.87	10.19	10.51	10.83	11.15	11.46	11.77	12.08	12.39	15.94	15.73	15.73
	Phyto (ugA/	58.65	57.38	56.16	54.98	53.84	52.74	51.67	50.65	49.73	48.83	47.98	47.16	42.06	41.60	41.60
	qNp(ugN/mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	qPp (ugP/mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Detritus (mgD	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02
	Pathogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alk	24.43	24.43	24.43	24.42	24.41	24.40	24.39	24.38	24.37	24.35	24.34	24.32	25.68	25.66	25.66
onstituen	i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
onstituen	ii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
onstituen	iii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	pH	7.79	7.38	7.19	7.08	7.00	6.95	6.91	6.88	6.87	6.86	6.86	6.87	6.90	6.91	6.91
Bot Algae	mgA/m2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QNb	ugN/mgA	0.00	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN
QPb	ugP/mgA	0.00	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN	laN
	TOC	7.39	7.02	6.69	6.37	6.08	5.82	5.57	5.34	5.14	4.96	4.79	4.63	4.23	4.13	4.13
	TN	1711.26	1705.01	1698.99	1693.20	1687.64	1682.29	1677.15	1672.19	1667.91	1663.74	1659.87	1656.08	1615.27	1612.52	1612.52
	TP	72.62	72.15	71.70	71.28	70.89	70.53	70.20	69.89	69.69	69.50	69.35	69.21	87.01	86.02	86.02
	TKN	1688.38	1677.20	1665.93	1654.61	1643.28	1631.99	1620.76	1609.60	1599.70	1589.81	1580.39	1570.92	1503.51	1496.94	1496.94
TSS	(mgD/L)	17.77	17.07	16.41	15.78	15.18	14.61	14.06	13.54	13.07	12.61	12.18	11.77	16.01	15.55	15.55
	CBODu	19.87	18.89	17.99	17.15	16.37	15.65	14.98	14.35	13.83	13.34	12.89	12.46	11.38	11.10	11.10
	NH3	2.62	1.24	0.92	0.79	0.72	0.69	0.67	0.66	0.68	0.70	0.73	0.75	0.78	0.81	0.81
	DO sat	7.93	7.96	7.99	8.02	8.05	8.08	8.10	8.13	8.16	8.19	8.21	8.23	8.33	8.35	8.35
	pHsat	7.92	7.92	7.92	7.92	7.92	7.91	7.91	7.91	7.91	7.91	7.91	7.91	7.93	7.93	7.93

Appendix C. Rate Constants Used for the Southeast Creek Qual2K Model

Parameter	*Value*	*Units*	*Symbol*
Stoichiometry:			
Carbon	40.000	gC	gC
Nitrogen	7.200	gN	gN
Phosphorus	1.000	gP	gP
Dry weight	100.000	gD	gD
Chlorophyll	1.000	gA	gA
Inorganic suspended solids:			
Settling velocity	1.304	m/d	v_i
Oxygen:			
Reaeration model	Internal		
User reaeration coefficient α	0.000		α
User reaeration coefficient β	0.000		β
User reaeration coefficient γ	0.000		γ
Temp correction	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.690	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.570	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.600	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.600	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.600	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.600	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.600	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	2.000	/d	k_{hc}
Temp correction	1.047		θ_{hc}
Oxidation rate	0.000	/d	k_{dcs}
Temp correction	1.050		θ_{dcs}
Fast CBOD:			
Oxidation rate	3.000	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	0.200	/d	k_{hn}
Temp correction	1.070		θ_{hn}
Settling velocity	0.250	m/d	v_{on}
Ammonium:			

Nitrification	2.000	/d	k_{na}
Temp correction	1.070		θ_{na}
Nitrate:			
Denitrification	0.300	/d	k_{dn}
Temp correction	1.070		θ_{dn}
Sed denitrification transfer coeff	0.000	m/d	v_{di}
Temp correction	1.070		θ_{di}
Organic P:			
Hydrolysis	0.350	/d	k_{hp}
Temp correction	1.070		θ_{hp}
Settling velocity	0.250	m/d	v_{op}
Inorganic P:			
Settling velocity	0.150	m/d	v_{ip}
Inorganic P sorption coefficient	0.073	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.050	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	1.000	/d	k_{gp}
Temp correction	1.070		θ_{gp}
Respiration rate	0.500	/d	k_{rp}
Temp correction	1.070		θ_{rp}
Excretion rate	0.000	/d	k_{ep}
Temp correction	1.070		θ_{dp}
Death rate	0.050	/d	k_{dp}
Temp correction	1.050		θ_{dp}
External Nitrogen half sat constant	15.000	ugN/L	k_{sPp}
External Phosphorus half sat constant	2.000	ugP/L	k_{sNp}
Inorganic carbon half sat constant	0.000	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	60.000	langleys/d	K_{Lp}
Ammonia preference	25.000	ugN/L	k_{hnxp}
Subsistence quota for nitrogen	0.000	mgN/mgA	q_{0Np}
Subsistence quota for phosphorus	0.000	mgP/mgA	q_{0Pp}
Maximum uptake rate for nitrogen	0.000	mgN/mgA/d	ρ_{mNp}
Maximum uptake rate for phosphorus	0.000	mgP/mgA/d	ρ_{mPp}
Internal nitrogen half sat constant	0.000	mgN/mgA	K_{qNp}
Internal phosphorus half sat constant	0.000	mgP/mgA	K_{qPp}
Settling velocity	0.200	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		

Max Growth rate	60.000	mgA/m²/d or /d	C_{gb}
Temp correction	1.070		θ_{gb}
First-order model carrying capacity	100.000	mgA/m²	$a_{b,max}$
Respiration rate	1.000	/d	k_{rb}
Temp correction	1.070		θ_{rb}
Excretion rate	0.500	/d	k_{eb}
Temp correction	1.050		θ_{db}
Death rate	0.250	/d	k_{db}
Temp correction	1.070		θ_{db}
External nitrogen half sat constant	300.000	ugN/L	k_{sPb}
External phosphorus half sat constant	100.000	ugP/L	k_{sNb}
Inorganic carbon half sat constant	0.000	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	50.000	langleys/d	K_{Lb}
Ammonia preference	25.000	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	7.200	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	1.000	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	720.000	mgN/mgA/d	ρ_{mN}
Maximum uptake rate for phosphorus	100.000	mgP/mgA/d	ρ_{mP}
Internal nitrogen half sat constant	9.000	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	1.300	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	3.000	/d	k_{dt}
Temp correction	1.070		θ_{dt}
Fraction of dissolution to fast CBOD	1.000		F_f
Settling velocity	1.000	m/d	v_{dt}
Pathogens:			
Decay rate	0.800	/d	k_{dx}
Temp correction	1.070		θ_{dx}
Settling velocity	1.000	m/d	v_x
Light efficiency factor	1.000		α_{path}
pH:			
Partial pressure of carbon dioxide	347.000	ppm	p_{CO2}
Constituent i			
First-order reaction rate	0	/d	
Temp correction	1		θ_{dx}
Settling velocity	0	m/d	v_{dt}
Constituent ii			
First-order reaction rate	0	/d	

Temp correction	1		θ_{dx}
Settling velocity	0	m/d	v_{dt}
Constituent iii			
First-order reaction rate	0	/d	
Temp correction	1		θ_{dx}
Settling velocity	0	m/d	v_{dt}