Total Maximum Daily Loads (TMDLs) Analysis for Shellpot Creek, Delaware

Prepared by:

Watershed Assessment Section
Division of Water Resources
Delaware Department of Natural Resources and Environmental Control
820 Silver Lake Blvd, Suite 220
Dover, DE 19904

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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act requires States to identify water quality impaired waterways and develop Total Maximum Daily Loads (TMDLs) for pollutants that impair those waterways. The Delaware Department of Natural Resources and Environmental Control (DNREC) has identified approximately 9 miles of Shellpot Creek (segments DE300-001-01 and DE300-001-02) as impaired because of elevated nutrient and bacteria levels and low dissolved oxygen concentrations (1) (2). These segments were placed on the State's biannual 303(d) lists and were targeted for TMDL development.

Shellpot Creek Watershed is located in the northeast corner of New Castle County, Delaware, north of Christina River and east of Brandywine River. The stream flows southeastward through piedmont region and enters Delaware River at Wilmington Cherry Island area. It drains about 9000 acres of residential and commercial areas of northern Wilmington, Delaware. Within the watershed, five NPDES facilities are identified. They are located in the area that drains to the lower segments of the stream, east of Rt. 13. However, their treated wastewater and process water discharge to Delaware River. Only storm water outfalls and a Combined Sewer Outflows (CSO) outfall discharge to Shellpot Creek.

The development of Shellpot Creek TMDLs is based on the assessment of Shellpot Creek water quality under two different environmental conditions – average condition and summer critical condition. Average condition considers average flow and averages of water quality during the period of 2000 – 2003. Critical condition considers 7Q10 flow and summer (July – September) water quality during the period of 2000 – 2003.

The U.S. EPA's Enhanced Stream Water Quality Model (Qual2E) is used as the framework for the water quality of nutrient and dissolved oxygen assessment. Water quality data collected during 2000-2003 was used to calibrate the model and data collected during the summer from the same period was used to simulate summer critical condition.

Using the calibrated model, several load reduction scenarios under average condition and critical summer condition were evaluated. The results of the evaluation showed that, at least, a 35% nutrient load reduction from lower portions of the watershed was needed to achieve water quality standards and nutrient targets in the Shellpot Creek (5.5 mg/l for dissolved oxygen, 3 mg/l for total nitrogen, and 0.2 mg/l for total phosphorous). The lower portion of the watershed is the area south of Business Route 13, Wilmington, Delaware.

Bacteria impairments were not included in the QUAL2E modeling but were evaluated at different flow conditions to determine the reductions required in the Shellpot Creek to achieve water quality standards (100 CFU enterococci/100mL geometric mean, 185 CFU enterococci/100 mL single sample maximum).

Considering this proposed TMDL, total nitrogen from the area below Business Route 13, Wilmington, Delaware will be reduced from baseline load of 19.2 lb/day to TMDL load of 12.5 lb/day under average condition. Similarly, total phosphorous will be reduced from baseline load of 2.0 lb/day to TMDL load of 1.3 lb/day. Total nitrogen and total phosphorous from the area above Business Route 13 will be capped at 89.4 lb/day and 5.7 lb/day respectively under average condition. And bacteria loads will be reduced by 77%.

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act (CWA) as amended by the Water Quality Act of 1987, requires States to identify impaired waters to develop Total Maximum Daily Loads (TMDLs) for pollutants of concern. The Delaware Department of Natural Resources and Environmental Control (DNREC) has identified 8.7 miles of Shellpot Creek (from its headwater to its confluence with Delaware River) as water quality impaired. It has been placed on the biannual 303 (d) lists, and has been targeted for TMDL development. Figure 1-1 is a map showing the Shellpot Creek Watershed. The red and orange lines on the map show the impaired stream segments that are listed on 303 (d) Lists (2) with red lines representing nutrient and bacteria impaired segments, and orange lines representing dissolved oxygen impaired segments. Table 1-1 is the excerpt from the 303 (d) List of 2002 for the Shellpot Creek.

Table 1-1 Excerpts from the 2002 303(d) List for Shellpot Creek (2)

WATERBODY ID (TOTAL SIZE)	WATERSHED NAME	SEGMENT	DESCRIPTION	SIZE AFFECTED	POLLUTANT(S) AND/OR STRESSOR(S)	PROBABLE SOURCE(S)	TARGET DATE FOR TMDL
DE300-001-01 (1.0 miles)	Shellpot Creek	Lower Shellpot Creek	From the head of tide below the east set of railroad tracks to the mouth of the Delaware River	1.0 mile	Nutrients, DO / Bacteria	NPS Delaware River	2004
DE300-001-02 (14.2 miles)	Shellpot Creek	Upper Shellpot Creek	From the headwaters to the head of tide below the east set of railroad tracks	7.7 miles	Nutrients, Bacteria	NPS	2004

1.1 Shellpot Creek Watershed

Shellpot Creek Watershed is located in the northeast corner of New Castle County, Delaware, north of Christina River, and east of Brandywine River. For management purpose, Stoney Run Sub-watershed on the north side of Shellpot Creek is included in the Shellpot Creek Watershed in the State of Delaware Surface Water Quality Standards (3). The total drainage area of the watershed is about 9200 acres (nearly 15 square miles).

Shellpot Creek flows southeastward through piedmont region, touches northern edge of City of Wilmington, and enters Delaware River at Wilmington Cherry Island area. There are no major water impoundments along Shellpot Creek. The dominant portion of the stream is free flowing stream. The upper portion is shallow, very rocky, and has steep slope. The stream water in this area is clear. The middle portion of the stream has pebble and sand bottom and clear water. Only the most downstream stretch, about a half mile of the creek is tidally influenced, with wider channel and sluggish water passing through marsh area. A weir is located about a half mile upstream from its mouth. The stream goes through highly industrialized area before entering Delaware River. Looking down stream, left bank of the lower one-mile stretch of the Creek is occupied by Connective’s Wilmington Power Plant, and the right bank is sewage disposal ponds of City of Wilmington’s Sewage Treatment Plant. The water in this stretch looks murky, with trash and garbage visible from the road (Station 102041 at Hay Road near Cherry Island) during field reconnaissance in April 2004. Five NPDES facilities are identified and located in the area east of Rt. 13.

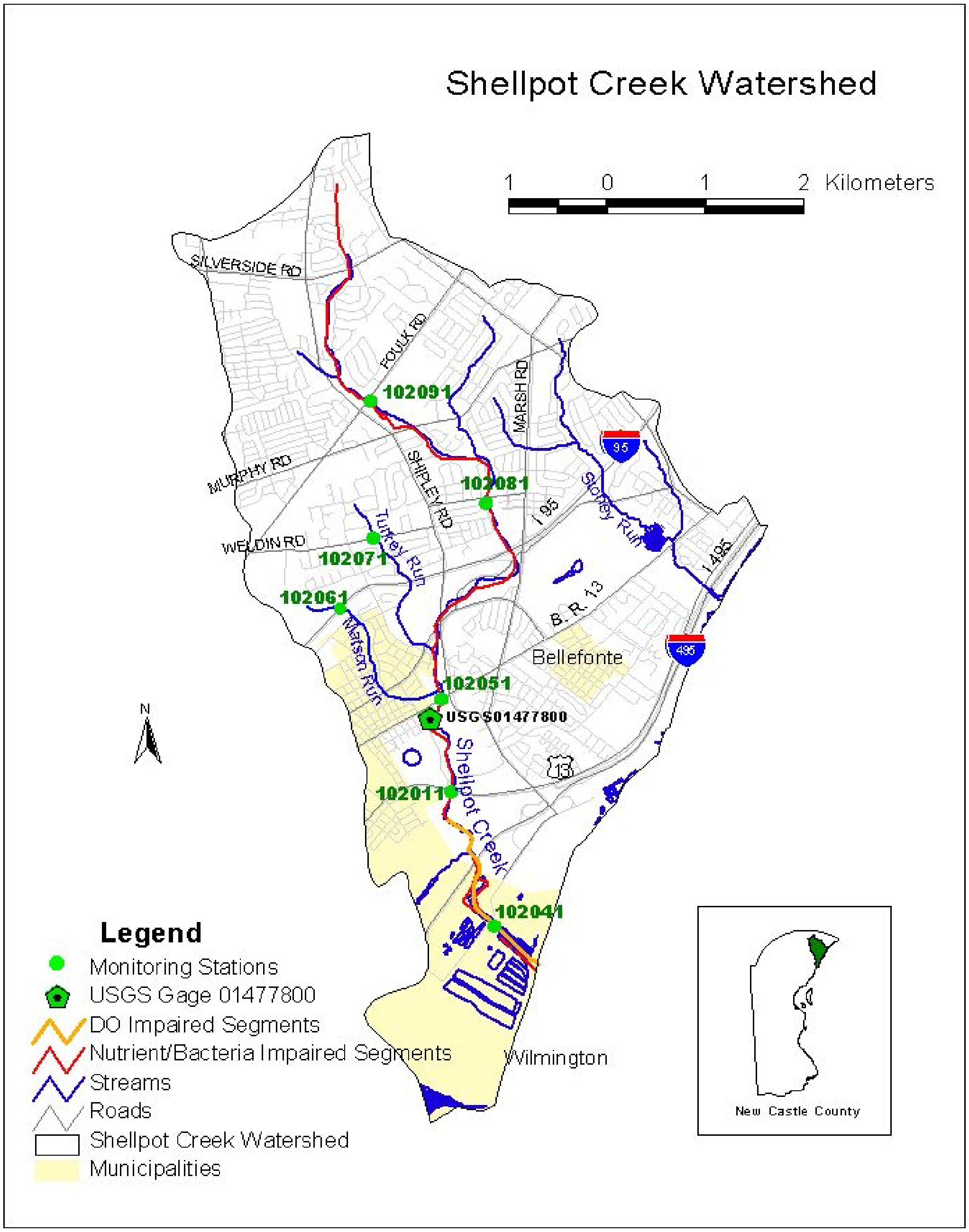


Figure 1 – 1 Shellpot Creek Watershed Map

The watershed is a highly urbanized area dominated by commercial, residential, and industrial land uses. The detailed land use information for this watershed according to 2002 Delaware Office of Planning land cover data is shown in Figure 1-2. The land use activity in the watershed consists of 8320 acres of residential, commercial and industrial area (90% of the watershed), 520 acres of wooded area (6% of the watershed), and 357 acres of other types of land use (4% of the watershed).

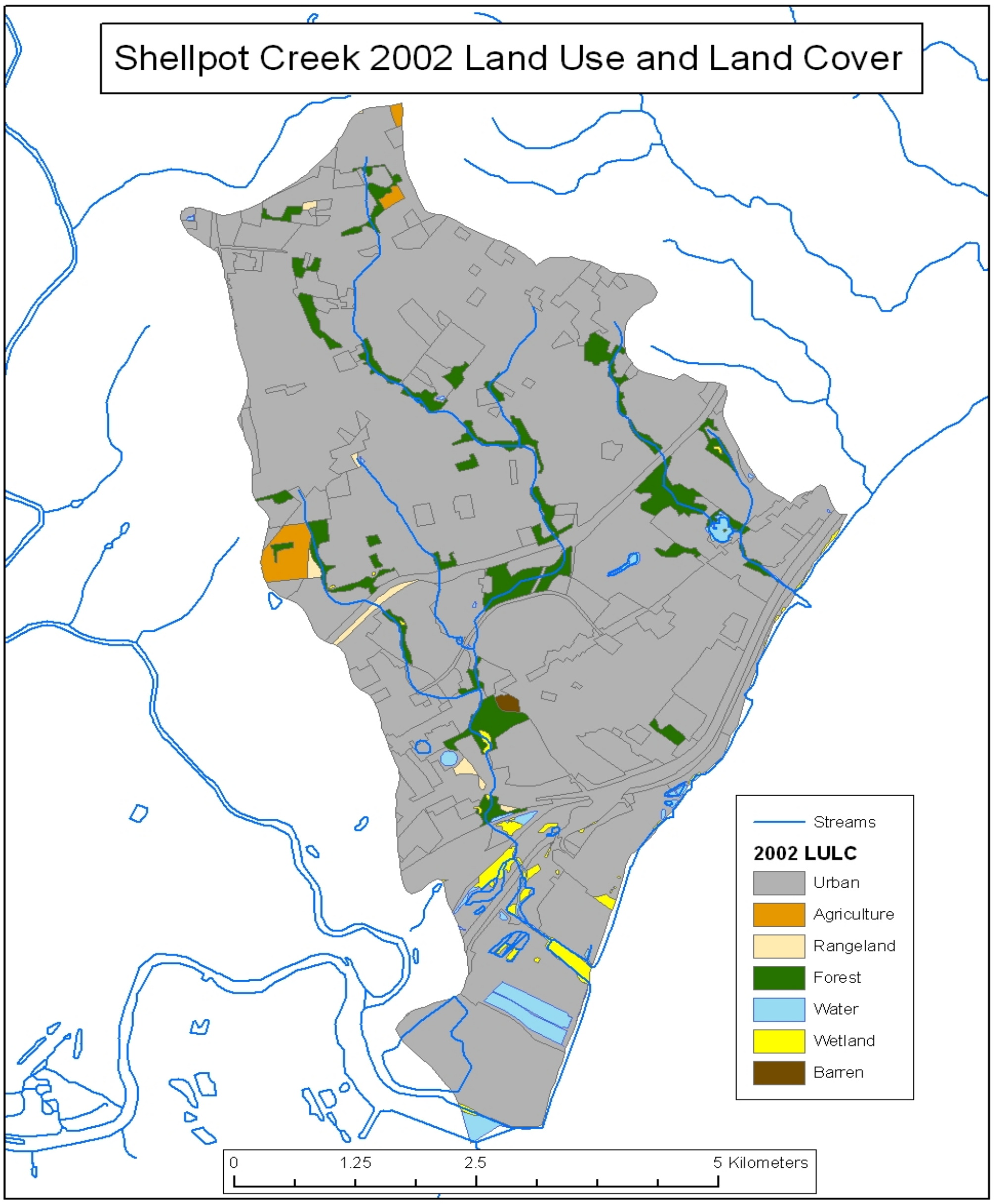


Figure 1-2 Shellpot Creek Watershed 2002 Land Use and Land Cover

Soils in the Shellpot Creek watershed are predominantly Neshaminy-Neshaminy-Talleyville-Urban association, considered by the Natural Conservation Service as "well drained, medium textured soils, relatively undisturbed to severely disturbed". The soil in upper reaches of the watershed is generally Nashaminy-Aldino-Wachung association described as "well drained, moderately well drained and poorly drained, medium textured soils". Moving downstream, soil changes into Aldino-Keypot-Mattapex-Urban association described as "moderately well drained, medium textured soils, relatively undisturbed to severely disturbed" with moderately fine or fine subsoils. Subsoils for most of the watershed are moderately fine or medium textured (1).

1.2 Designated Uses

The purpose of establishing TMDLs is to reduce pollutants to levels that would result in achieving applicable water quality standards and support designated uses of the stream. Section 3 of the State of Delaware Surface Water Quality Standards, as amended, July 11, 2004, specifies the following designated uses for the waters of the Shellpot Creek (3):

- Primary Contact Recreation
- Secondary Contact Recreation
- Fish, Aquatic Life, and Wildlife
- Agricultural Water Supply (for freshwater segments)
- Industrial Water Supply

1.3 Applicable Water Quality Standards and Nutrient Guidelines

To protect designated uses, the following sections of the State of Delaware Surface Water Quality Standards, as amended July 2004, provide specific narrative and numeric criteria concerning the waters in Shellpot Creek Watershed (3):

Section 4 Criteria to Protect Designated Uses
Section 5 Antidegradation and ERES Waters Policies

Based on the above sections, the following is a brief summary of pertinent water quality standards that are applicable to the waters of Shellpot Creek Watershed:

a. Dissolved Oxygen (D.O.):
- Daily average shall not be less than 5.5 mg/l
- 4.0 mg/l instantaneous minimum

b. 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.

c. Bacteria (enterococcus):
- 30 day geometric mean shall not exceed 100 CFU/100mL
- Single sample maximum shall not exceed 185 CFU/100mL

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

With regard to nutrients, and in the absence of national numeric nutrient criteria, DNREC has used upper thresholds of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus as indicators of excessive nutrient levels in the surface waters. The above threshold values have been used as a guideline for 305 (b) assessments, 303(d) listing of impaired waters, and are generally accepted by the scientific community to be an indication of over-enriched waters.

1.4 Stream Water Quality Condition

To support water quality assessment, two long-term monitoring stations (102041 and 102011) were established at lower segments of the Shellpot Creek. Furthermore, during 2000 – 2003, additional monitoring sites were selected and were monitored to support development of the TMDL for this watershed. The monitoring sites in the watershed are listed in Table 1-2 and are shown on Figure 1-1. At each monitoring station, grab water samples were collected four times a year and were analyzed for a suite of 24 water quality parameters (4). Water quality concentrations of dissolved oxygen, total nitrogen and total phosphorous as well as water temperatures collected during 2000-2003 at five monitoring sites along the main stem of the Shellpot Creek are presented in Figure 1-4 and the average values of the same parameters are presented in Figure 1-5. More water quality monitoring data collected during the period are attached into Appendix B.

Table 1-2 Shellpot Creek Water Quality Monitoring Sites

Station	Site description	Long-term monitoring	TMDL monitoring
***Shellpot Creek Main stem** (from downstream up)*			
102041	Cherry Island at Rt 501 bridge	√	√
102011	Rt 13 (Governor Printz Blvd) Bridge	√	√
102051	Rt 13 Bus (Market St.) bridge		√
102081	Carr Rd bridge		√
102091	Foulk Rd (Rt 261) bridge		√
Matson Run/ Shellpot Creek			
102061	Matson Run at Miller Road bridge		√
Turkey Run/ Shellpot Creek			
102071	Turkey Run at Weldin Rd (Rt. 215) bridge		√

The monitoring data showed that dissolved oxygen violations occurred frequently at the most downstream station (Station 102041), however, the three-year average concentration was above the standard of 5.5 mg/l (see Figures 1-4 and 1-5). Similarly, high nutrient levels were observed at Station 102041 with occasional exceedances of total nitrogen threshold of 3.0 mg/l and total phosphorous threshold of 0.2 mg/l, the average concentrations of total nitrogen and total phosphorous were below their threshold values (see Figures 1-4 and 1-5).

Monitoring data and water quality assessment prior to 2000 are also available. Based on water quality data collected during 1996 -2001, the State of Delaware 2002 305(b) Report (5) concluded that elevated nutrient levels and low DO concentrations impaired the lower one-mile long of the Shellpot Creek, but that DO and nutrients in the14.2-mile of upper Shellpot Creek met the standard and nutrient target levels. Despite variations of water quality data in certain segments and various times, a watershed-wide TMDL for the Shellpot Creek is required to ensure that all applicable water quality standards are achieved.

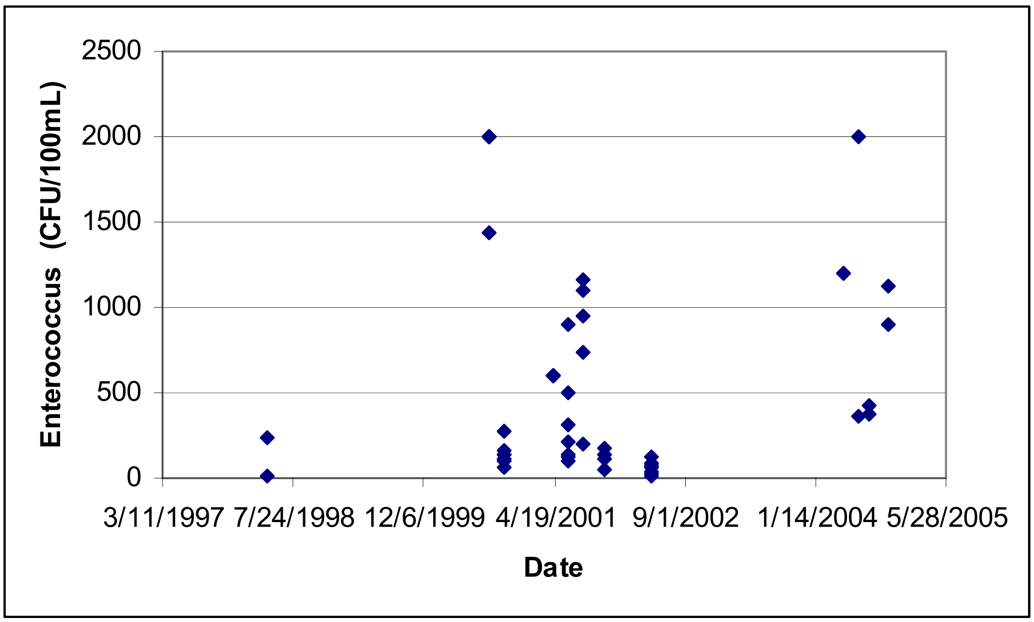


Figure 1-3 Bacteria Concentrations in Shellpot Creek Watershed

The State Water Quality Standard for enterococcus is a geometric mean of 100CFU/100mL. Enterococci are present in faecal material and are used as an indicator organism with which a correlation to illness rates can be established. The level of risk associated with primary contact recreation in waters with an enterococcus concentration of 100CFU/100mL has been deemed appropriate and is the basis for the current State Water Quality Standards for bacteria. Figure 1-3 illustrates the bacteria concentrations in the Shellpot Creek Watershed; it is clearly much greater than the State Water Quality Standards for bacteria.

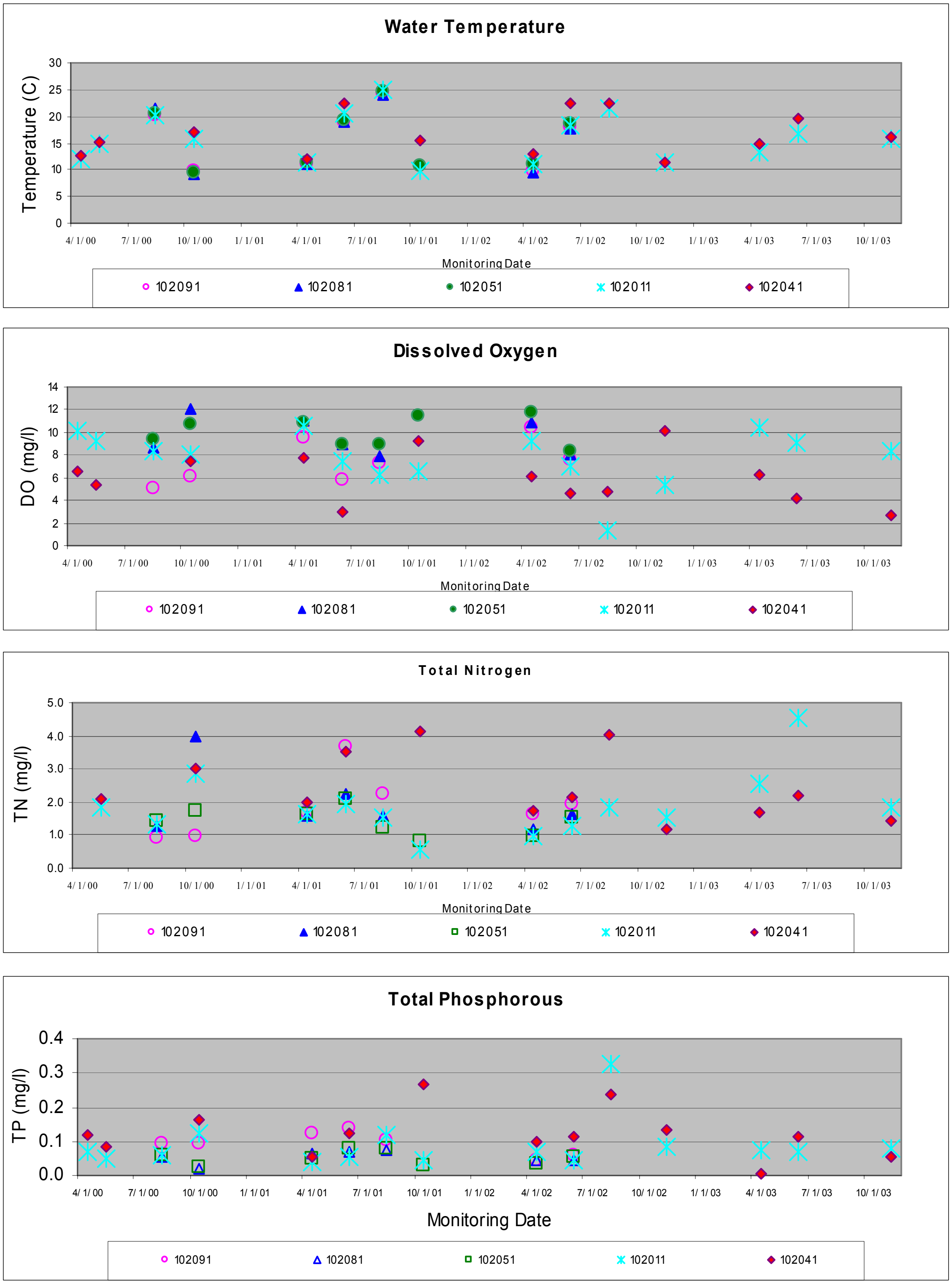


Figure 1-4 Observed Water Temperature, Dissolved Oxygen, Total Nitrogen, and Total Phosphorous at Five Monitoring Locations along the Shellpot Creek

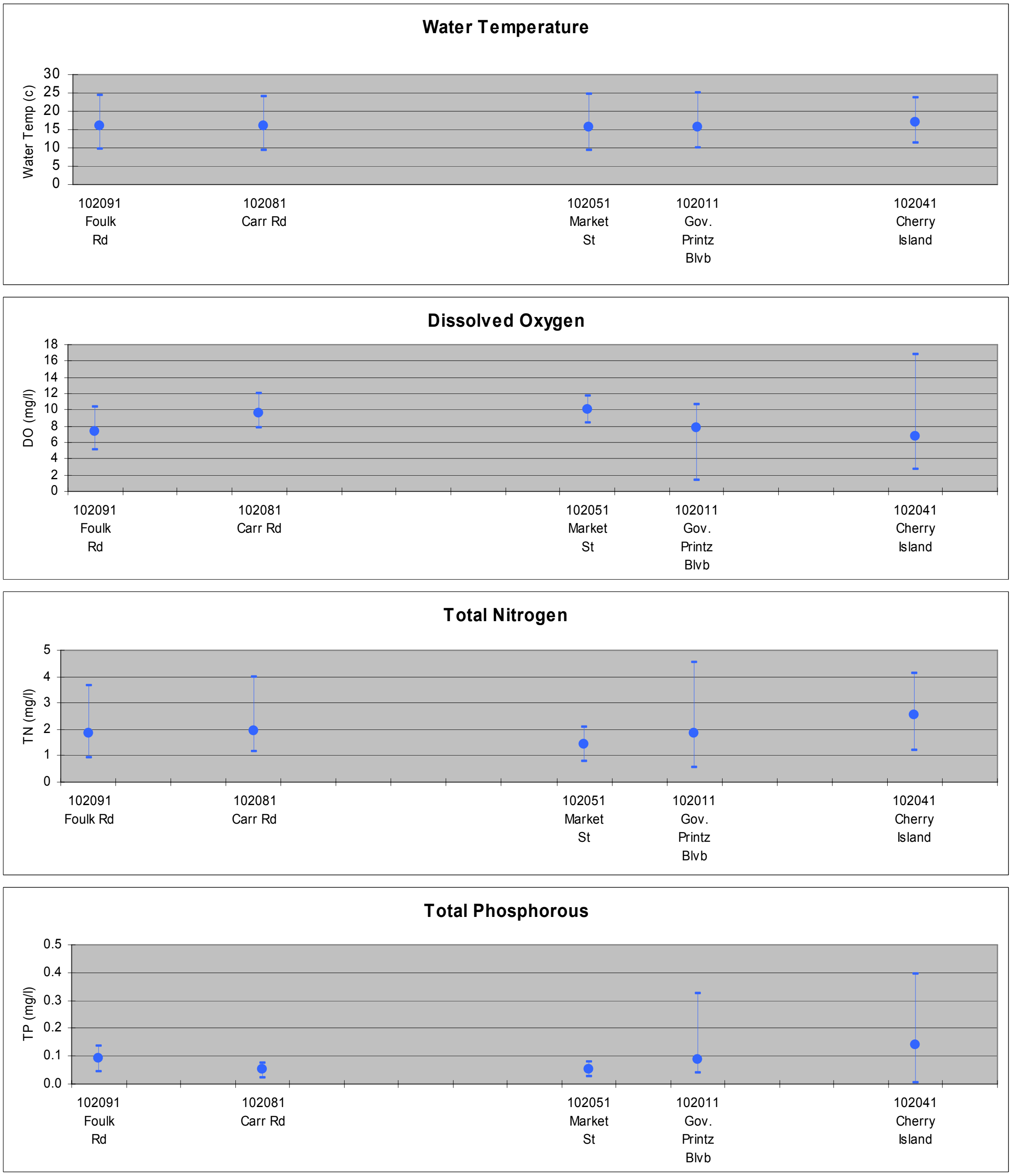


Figure 1-5 Summary of Monitoring Data for Water Temperature, Dissolved Oxygen, Total Nitrogen and Total Phosphorous at Five Monitoring Locations along the Shellpot Creek

1.5 Sources of Pollution

In general, nutrients, oxygen consuming compounds, and bacteria enter surface waters from point and nonpoint sources. Nonpoint source discharges include surface runoffs from urban and other land use activities, septic tanks, and groundwater discharges. Point source discharges include discharges from municipal and industrial wastewater treatment plants (NPDES facilities), Combined Sewer Overflows, etc.

Within the Shellpot Creek watershed, five NPDES facilities are located in the area east of Rt. 13 (see Figure 1-6 and Table1-3 below). However, their treated wastewater and process water are discharged into Delaware River and other streams. The only possible discharge from the five facilities into the Shellpot Creek is from their storm water outfalls. In addition, one of City of Wilmington's Combined Sewer Overflow (CSO 31) is discharged into the Shellpot Creek. Since discharges from storm water outfalls and CSO 31 are expected to occur only during storm events and high flow conditions, they are considered as a source only during bacteria TMDL analysis. This is because during nutrient and DO TMDL analysis (which is established to protect water quality during low flow critical conditions) stormwater and CSO discharge does not occur.

Table 1-3 Point Source Facilities in the Shellpot Creek

PERMIT ID	FACILITY NAME	RECEIVING WATER	DISCHARGE DISCRIPTION
DE 0020320	Wilmington, City of	Delaware River, Christina River, Brandywine Creek, Silverbrook Run	treated waste water, CSO, and storm water
		Shellpot Creek	CSO
DE 0000558	Conectiv Edge Moor Power Plant	Delaware River	cooling water, boiler blowdown, screen backwash, ground water, storm water, and other
		Shellpot Creek	storm water
DE 0050857	IKO Mfg., Inc.	Delaware River	cooling water, storm water, and ground water
DE 0000051	DuPont Edge Moor	Delaware River	treated process water, noncontact cooling water and storm water
		Shellpot Creek via a ditch and a catch basin	storm water
DE 0050962	AMTRAK	Brandywine Creek	storm water
		Shellpot Creek	storm water

Finally, with regard to septic tank systems within the watershed, a Geographic Information System (GIS) database search revealed that a total of 99 septic tank systems

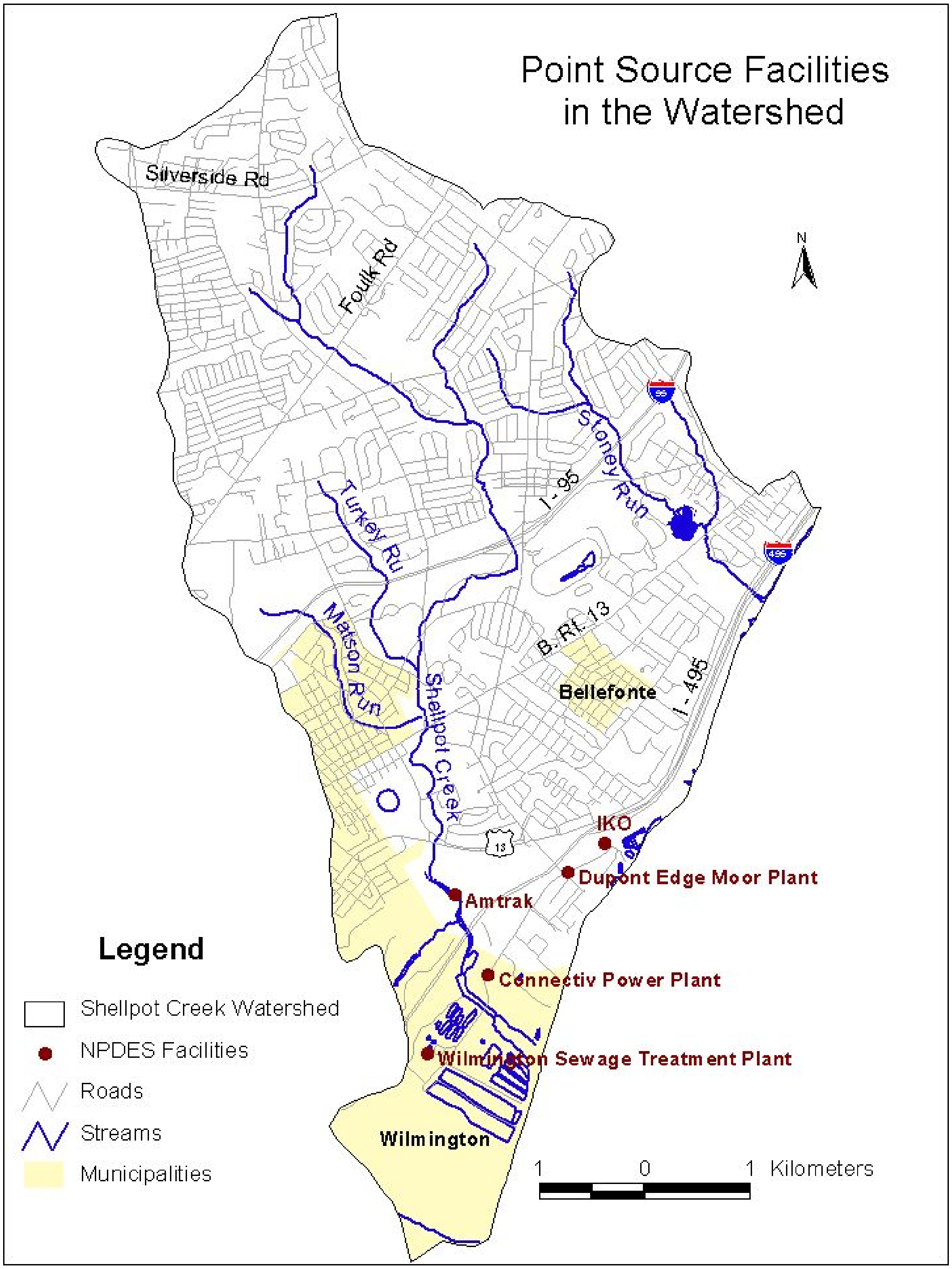


Figure 1-6 Point Source Facilities in the Shellpot Creek Watershed

exist within the Shellpot Creek watershed. However, since none of the above septic systems is within 50 ft buffer of Shellpot Creek, their direct impact to water quality of the Shellpot Creek is considered to be minimal.

1.6 Objective and Scope of Analyzing Shellpot Creek TMDLs

The objective of the TMDL analysis for Shellpot Creek is to estimate the maximum amount of bacteria, dissolved oxygen consuming compounds, and nutrients that Shellpot Creek can receive without violating applicable water quality standards. Under such loads, water quality standards for dissolved oxygen and bacteria will be met at all segments of the stream and total nitrogen and total phosphorous concentrations will be reduced to acceptable levels.

To achieve the objective, the following steps were taken:

- A water quality model of the Shellpot Creek was developed using the U.S. EPA's Qual2E Model as the framework.
- The Shellpot Creek Qual2E model was calibrated to the average hydrologic and environmental conditions of 2000-2003.
- Several pollutant loadings and environmental conditions were evaluated (including critical summer condition).
- Based on the above analyses, a proposed TMDL has been established for the Shellpot Creek watershed.
- Bacteria load reduction was estimated under different flow conditions

Chapter 2 of this report provides a brief review of the Shellpot Creek Qual2E model. The results of model calibration and evaluation of various loading scenarios are presented in Chapter 3. The proposed Shellpot Creek's TMDLs and nonpoint source load allocations are discussed in Chapter 4. Chapter 5 gives a discussion of bacteria load estimation and its reduction calculation under different flow conditions.

2.0 THE SHELLPOT CREEK QUAL2E WATER QUALITY MODEL

2.1 The Enhanced Stream Water Quality Model (Qual2E)

The Enhanced Stream Water Quality Model (Qual2E) is chosen as the framework for Shellpot Creek model development and TMDL analysis. Qual2E is supported by the U.S. EPA and has been widely used for studying the impact of conventional pollutants on streams. DOS version 3.22 of this model is used in this study. Model code was recompiled by Linfield C. Brown to run under Windows XP operating system.

Shellpot Creek has a long-term average flow of about 14 cubic feet per second (cfs) with stream velocities less than one foot per second (ft/s). The stream width in most part of the Creek is less than 20 feet and its depth is less than one foot, except for the most down stream one-mile stretch of the creek. Water quality concerns for Shellpot Creek include elevated nutrient levels and low dissolved oxygen concentration (6).

The Qual2E model is suitable for simulating hydrological and water quality conditions of free flowing streams. It is a simple one-dimensional model that addresses basic stream transport and mixing processes. The kinetic processes employed in Qual2E address nutrient cycles, algal growth, and dissolved oxygen dynamics.

Qual2E model consists of thirteen types of input data groups. Below is a brief summary of the input data groups. A detailed discussion is available in the model's user manual (6). Data inputs for the Shellpot Creek Qual2E model are discussed in the next section.

- Type 1, 1A, and 1B data groups define program control, global algal, nutrient, and light parameters, and temperature correction factors.
- Type 2 data identifies stream reach system by listing reach names and lengths.
- Type 3 data gives flow augmentation information.
- Type 4 data describes each type of computational element in each reach.
- Type 5 data describes hydraulic characteristics of the system.
- Type 6, 6A, and 6B data provide reach varied coefficients and rates related to kinetic processes of BOD, DO, nutrient and algae.
- Type 7 and 7A data define initial conditions of the system.
- Type 8 and 8A data provide incremental inflow values and their concentrations.
- Type 9 data defines stream junction name and order if tributaries are simulated.
- Type 10 and 10A data define headwater conditions.
- Type 11 and 11A data define point load or tributary conditions.
- Type 12 data provides dam reaeration information.
- Type 13 data defines downstream conditions.

2.2 Shellpot Creek Qual2E Model Input Data

The Shellpot Creek Qual2E model is constructed as a one dimensional, steady state model. It simulates average instream water quality conditions including dissolved oxygen, BOD, algae as chlorophyll-*a*, as well as various forms of nitrogen and phosphorous. Water temperature and diurnal changes of algae are not simulated by the model. The model is defined by various input data as described in the previous section. The major input data groups to define the Shellpot Creek Qual2E model are summarized below.

Model Segmentation

The Shellpot Creek Qual2E model consists of five reaches and covers 8.5 kilometers (5.3 miles) starting from its headwaters near 202091 monitoring station (at Foulk Road) to its confluence with Delaware River. Figure 2-1 displays these reaches on the watershed map. Due to the structure of Qual2E, each model reach is further divided into a number of Computational Elements (CE) that must have the same length in the entire model domain. A length of 0.3 kilometer was assigned to Shellpot Creek Qual2E's computational elements. A summary of Shellpot Creek Qual2E model reaches with their lengths and the number of computational elements is presented in Table 2-1.

Table 2-1 Shellpot Creek Qual2E Reaches

Reach Number	Description	Reach Length (km)	Number of Computational Elements
1	Most upstream reach, from headwater below Foulk Rd	1.5	3
2	Upper reach	1.5	3
3	Middle reach, two tributaries of Turkey Run and Matson Run come in	2.0	4
4	Lower reach, below Rt. 13BR to I-495	2.0	4
5	Most downstream reach, from I-495 road crossing to the mouth	1.5	3
Total		8.5	17

Hydraulic Characteristics

The Shellpot Creek Qual2E model uses functional representation, rather than geometric representation, to describe stream hydraulic characteristics and assumes that stream has a rectangular cross-section. Hydraulic characteristics of stream reaches were determined by using the following discharge coefficient equations:

$$\bar{u} = aQ^b$$

$$A_x = Q / \bar{u}$$
$$d = \alpha Q^{\beta}$$

where $\bar{u}$ - mean velocity of stream segment (m/s)
d – depth of stream segment (m)
a, b, α, and β - empirical discharge coefficient constants

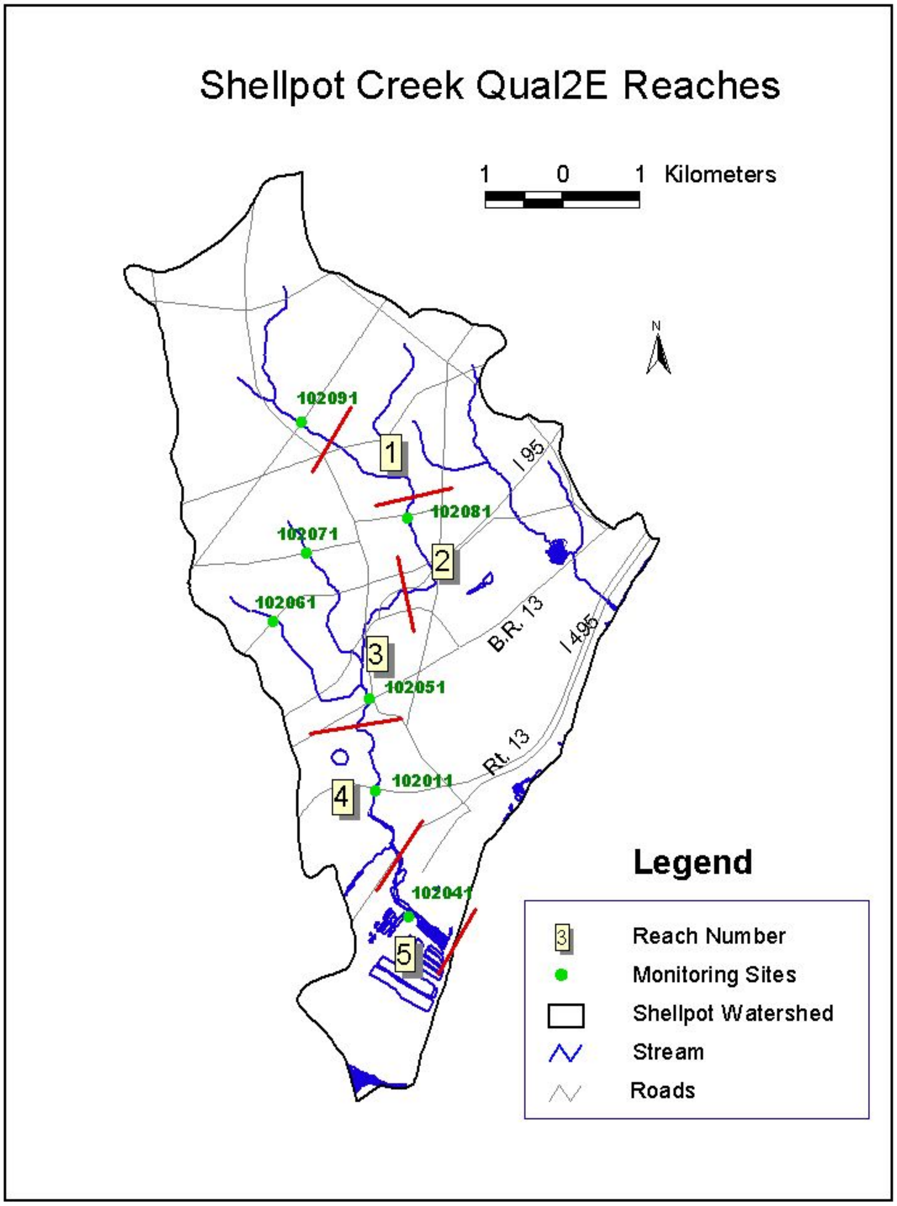


Figure 2-1 Shellpot Creek Qual2E Reaches

Field measurements of stream width, depth, and velocity are generally conducted when water quality samples are collected at monitoring sites. Based on the measurements, average stream width, depth, and velocity at various monitoring sites are calculated and shown in Table 2–2.

Table 2-2 Average Channel Width, Depth and Velocity of Shellpot Creek

Stations (from downstream up)	Stream Segment	Average Width (ft)	Average Depth (ft)	Average Velocity (ft/s)
102041*	Reach 5 – most downstream reach	approx. 55.0	approx. 1.0	
102011	Reach 4 - lower reach	17.0	1.0	0.8
102051	Reach 3 - middle reach	17.5	0.9	0.6
102081	Reach 2 - upper reach	11.5	0.3	0.4
102091	Headwater	3.3	0.3	0.5
102071	Turkey Run	2.0	0.3	0.6
102061	Matson Run	2.0	0.2	0.3

* Data is from field reconnaissance in April 2004.

The field measurements were used to estimate discharge coefficient constants and form the discharge coefficient equations. First, channel depths and velocities at each sampling site were plotted against their corresponding stream-flow measurements. Then, regression analysis of depth vs. flow and velocity vs. flow were performed. From the regression plots, the discharge coefficient constants *a, b,* α, and β were calculated. The discharge function at each sampling site was assumed to represent the hydraulic characteristics of the stream reach containing the sampling site. Table 2-3 shows the estimated discharge coefficient constants and discharge functions.

Table 2-3 Discharge Coefficient Constants for the Shellpot Creek Qual2E Model Reaches

Reach Number	Reach Description	Station	Mean Velocity (m/s)	Depth (m)
			u = a Q ^b	d = α Q ^β
1	Most up stream		u = 0.1619 Q ^ 0.08	d = 0.8129 Q ^ 0.7134
2	Upper reach	102081	u = 0.1619 Q ^ 0.08	d = 0.8129 Q ^ 0.7134
3	Middle reach	102051	u = 0.3268 Q ^ 0.4264	d = 0.4956 Q ^ 0.4948
4	Lower reach	102011	u = 0.2528 Q ^ 0.4	d = 0.6461 Q ^ 0.6
5	Most Downstream reach	102041	u = 0.05	d = 0.6

Stream Flow

Both annual-average flow and summer-average flow were considered for Shellpot Creek model development and TMDL analysis. Annual-average flow was calculated by averaging daily stream flow over the period of 2000 – 2003. For the summer-average flow, daily stream flows during the months of July, August, and September of the years 2000, 2001, and 2002 were averaged. Annual-average flow was used to calibrate the model and evaluate load reduction scenarios for annual-average conditions of a typical year in the Shellpot Creek. Similarly, the summer-average low flow was used to evaluate summer critical condition and its load reduction scenarios.

USGS gauging station 01477800 is located on the Shellpot Creek near monitoring station 102051 in Wilmington, Delaware. Stream drainage area at the gaging station is 7.46 square miles. Daily stream flows recorded at this station were used to estimate stream flow at various locations of the Shellpot Creek using flow to drainage area ratio. The annual-average flow at this station was 11.06 cubic feet per second, and the summer-average low flow was 4.42 cubic feet per second during the period of 2000 – 2003 (7). Table 2-4 lists drainage areas as well as estimated annual-average and summer-average flows at various parts of the Shellpot Creek watershed.

Table 2-4. Annual-Average Flow and Summer-Average Low Flow at Various Locations of the Shellpot Creek Watershed

Description of Drainage Area	Drainage Area	Annual-average Flow (2000-2003)		Summer (July-Sept) Low Flow (2000 - 2002)	
	km2	cfs	m3/s	cfs	m3/s
Headwater	6.59	3.77	0.11	1.51	0.04
A tributary in Reach 1	1.96	1.12	0.03	0.45	0.01
Reach 1 incremental inflow	1.27	0.73	0.02	0.29	0.01
Reach 2 incremental inflow	1.66	0.95	0.03	0.38	0.01
Turkey Run, a tributary in reach 3	2.32	1.33	0.04	0.53	0.02
Matson Run, a tributary in reach 3	3.40	1.95	0.06	0.78	0.02
Reach 3 incremental inflow	2.24	1.28	0.04	0.51	0.01
Reach 4 incremental inflow	2.92	1.67	0.05	0.67	0.02
Reach 5 incremental inflow	1.47	0.84	0.02	0.34	0.01
Total	23.83	13.64	0.39	5.45	0.15

System Parameters

The physical, chemical, and biological processes simulated by Qual2E model are represented by a set of mathematical equations containing many parameters. Some of these parameters are global constants, some are spatial variables, and some are temperature dependent coefficients. Detailed descriptions of these parameters and their associated processes are available in the Qual2E model user's manual. Global constants and reach variable coefficients used in the calibrated Shellpot Creek Qual2E model are listed in Table 2-5 and Table 2-6.

Table 2-5 Global Constants of Shellpot Creek Qual2E

Parameter	Description	Unit	Value
α_1	Fraction of algal biomass that is Nitrogen	mg-N / mg A	0.08
α_2	Fraction of algal biomass that is Phosphorus	mg-p / mg A	0.014
α_3	O_2 production per unit of algal growth	mg-O / mg A	1.6
α_4	O_2 uptake per unit of algae respired	mg-O / mg A	2
α_5	O_2 uptake per unit of NH_3 oxidation	mg-O / mg N	3.43
α_6	O_2 uptake per unit of NO_2 oxidation	mg-O / mg N	1.1
μ_{max}	maximum algal growth rate	day-l	3
ρ	Algal respiration rate	day-l	0.05
K_L	Light saturation coefficient (Option 2)	langleys/min	0.025
K_N	Half- saturation constant for nitrogen	mg-N/L	0.005
K_p	Half- saturation constant for phosphorus	mg-P/L	0.001
λ1	Linear algal self-shading coefficient	(1/m) / (ug Chl-a/L)	0.0008
λ2	Nonlinear algal self- shading coefficient	(1/m) / (ug Chl-a/L)**2/3	0
P_N	Algal preference factor for ammonia	-	0.9

Table 2-6 Reach Variable Coefficients of Shellpot Creek Qual2E

Parameter	Description	Unit	Range
α0	Ratio of chlorophyll -a to algal biomass	ug Chl-*a*/ mg A	50
λ0	Non-algal light extinction coefficient	1/m	0
σ_1	Algal settling rate	m/day	0
σ_2	Benthos source rate for dissolved phosphorous	mg-p / m2-day	0
σ_3	Benthos source rate for ammonia nitrogen	mg-N / m2-day	0 - 300
σ_4	Organic nitrogen settling rate	day-l	0
σ_5	Organic phosphorus settling rate	day-l	0
K_1	Carbonaceous deoxygeneration rate constant	day-l	0.3 - 0.5
K_2	Reaeration rate constant	day-l	calculated internally (options 1 and 5)

K_3	Rate of loss of BOD due to settling	day-l	0
K_4	Benthic oxygen uptake (SOD)	mg-O / m2-day	0 – 2.2
β1	Rate constant for the biological oxidation of NH3 to NO2	day -1	0.3
β2	Rate constant for the biological oxidation of NO2 to NO3	day-l	1
β3	Rate constant for the hydrolysis of organic- N to ammonia	day-l	0.25
β4	Rate constant for the decay of organic-P to dissolved-P	day-l	0.1

Boundary Conditions

Qual2E model uses specific data groups to define model boundary conditions. It uses the headwater data group to define most upstream boundary condition of a model domain. Downstream boundary condition can be defined by user, or can be computed internally. The point source data group defines point source discharges as well as small tributaries that enter simulated stream segments.

Water quality conditions of the headwater and the tributary entering to the first reach of the model were defined by monitoring data collected at station 102091 (at Foulk Road). Water quality of the tributaries of Turkey Run and Matson Run entering the model at reach 3 were defined by data collected at stations 102071 and 102061 respectively. Monitoring data collected at each above-mentioned site were averaged over the entire monitoring period of 2000 – 2002 to define the boundary conditions of model calibration run as well as load reduction scenario runs for annual-average flow conditions. Similarly, data collected during the summer months (July, August, and September) over the period of 2000 – 2002 were averaged to define the boundary conditions of the model scenario runs for summer-average low flow conditions.

Model option of internally calculating downstream boundary conditions was selected for the Shellpot Creek Qual2E Model.

Incremental Inflows

The incremental inflow data group in Qual2E defines condition 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.

Water quality characteristics of the incremental inflow for the Shellpot Creek Qual2E Model were estimated based on assigning surface runoff concentrations to various land uses. The surface runoff concentrations as listed in Table 2-7, were originally used by HydroQual, Inc. in developing a water quality model for the Murderkill River watershed, Delaware. HydroQual considered literature values as well as land use studies in Delaware to arrive at the runoff concentrations (8). To apply runoff concentrations to the Shellpot Creek, the assigned phosphorous concentration of surface runoffs was reduced and dissolved oxygen concentration was increased based on observed concentrations at monitoring sites. Table 2-7 lists the assigned surface runoff concentrations for the Shellpot Creek.

Table 2-7 Surface Runoff Concentrations for Each Land Use Type

System	Units	Urban or Built-up Land	Agricultural Land	Rangeland	Forest Land	Water	Wetland	Barren Land
NH3	mg/l	0.110	0.290	0.120	0.120	0.120	0.120	0.120
NO3	mg/l	0.390	1.540	0.350	0.350	0.350	0.350	0.350
PO4	mg/l	0.045	0.093	0.039	0.039	0.039	0.039	0.039
Phyto	mg/l	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CBOD	mg/l	10.000	10.000	2.000	2.000	2.000	2.000	2.000
DO	mg/l	8.000	6.667	8.000	8.000	8.000	5.333	8.000
OrgN	mg/l	0.910	1.310	1.140	1.140	1.140	1.140	1.140
OrgP	mg/l	0.114	0.105	0.039	0.039	0.039	0.039	0.039

The fractions of different land uses in Shellpot Creek Watershed were calculated using State of Delaware's 2002 land use and land cover data. For a sub-watershed draining directly into a modeled reach, its land use data was broken down into seven major types as listed in Table 2-7, and the fraction of each type of land use area to its total sub-watershed area was calculated. Considering the fraction of each land use type in a reach and assigning appropriate runoff concentrations for the land use type, a reach-wide incremental inflow concentration was calculated for the seven land use types and are presented in Table 2-8.

Table 2-8 Incremental Inflow Concentrations for Shellpot Qual2E

Concentration	NH3	NO3	PO4	CHL - *a*	DO	OrgN	OrgP	BOD5
Unit	mg/l	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l	mg/l
Reach 1	0.111	0.387	0.045	0.000	8.000	0.929	0.108	5.729
Reach 2	0.111	0.386	0.044	0.000	8.000	0.935	0.106	5.597
Reach 3	0.111	0.385	0.044	0.000	8.000	0.940	0.104	5.485
Reach 4	0.112	0.368	0.044	0.000	7.880	0.945	0.102	5.380
Reach 5	0.111	0.352	0.044	0.000	7.743	0.937	0.105	5.550

Unanalyzed Constituents

Each of boundary data groups and incremental inflow data groups require concentration for a set of specific constituents including dissolved oxygen, BOD, chlorophyll-*a*, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorous, dissolved phosphorous, and water temperature. The above constituents are required for the model input file. However, since organic nitrogen, nitrite nitrogen, nitrate nitrogen, and organic phosphorous were not directly analyzed as part of Department's routine water quality monitoring, their concentrations were estimated according to the following relationships:

Organic Nitrogen	=	(TKN) - (Ammonia Nitrogen)
Nitrite Nitrogen	=	0.1* (Nitrite Nitrogen + Nitrate Nitrogen)
Nitrate Nitrogen	=	0.9* (Nitrite Nitrogen + Nitrate Nitrogen)
Organic Phosphorous	=	(Total Phosphorous) - (Dissolved Phosphorous)

Input data for Shellpot Creek Qual2E model calibration is presented in Appendix A.

3.0 MODEL CALIBRATION AND SCENARIO ANALYSIS

3.1 Model Calibration / Average Baseline Condition

The Shellpot Creek Qual2E Model was calibrated based on average water quality conditions observed during 2000-2003 period and annual-average flow for the same period. The input and output data for the Shellpot Creek Qual2E Model calibration is presented in Appendix A.

Figures 3-1 displays calibration results of several water quality constituents including nutrient forms and dissolved oxygen. Model calibration results are presented as solid lines while observed water quality data at four monitoring sites (102081, 102051, 102011, and 102041 from upstream to down stream) along the Shellpot Creek are summarized and shown by symbols representing mean, maximum, and minimum values.

The calibration results show that simulated dissolved oxygen concentrations are very close to the observed values and are calibrated well. Similarly, nitrogen and phosphorous are calibrated reasonably well and within acceptable range.

This calibrated model for average condition during the period of 2000-2003 is considered to form the baseline condition for the Shellpot Creek. Figures 3-1 shows that, under average condition, dissolved oxygen levels meet water quality standard of 5.5 mg/l at all reaches. Similarly, nutrient concentrations meet the target thresholds of 3 mg/l for total nitrogen and 0.2 mg/l for total phosphorous. Total nitrogen and total phosphorous loads for the watershed under average condition are listed in Table 3-1, the loads were divided into loads from upstream reaches and loads from down stream reaches.

Table 3-1 Total Nutrient Loads of Shellpot Creek Under Average Condition

Model Condition	Load From Upstream Sub-watershed (Reaches 1-3)		Load From Downstream Sub-watershed (Reaches 4-5)	
	TN (lb/d)	TP (lb/d)	TN (lb/d)	TP (lb/d)
Average Baseline (Sh404)	89.4	5.7	19.2	2.0

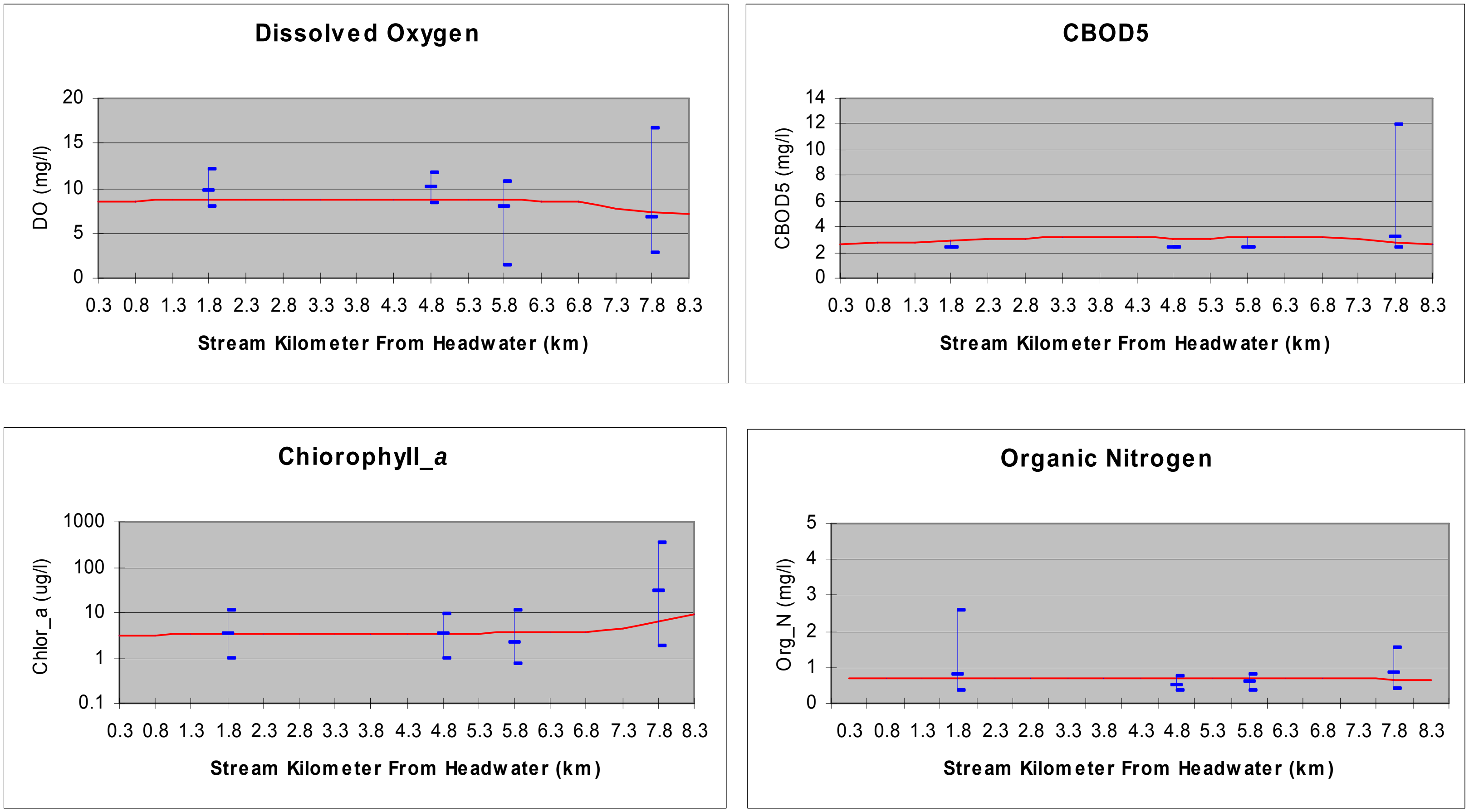


Figure 3-1 Calibration Results of Shellpot Creek Qual2E Model

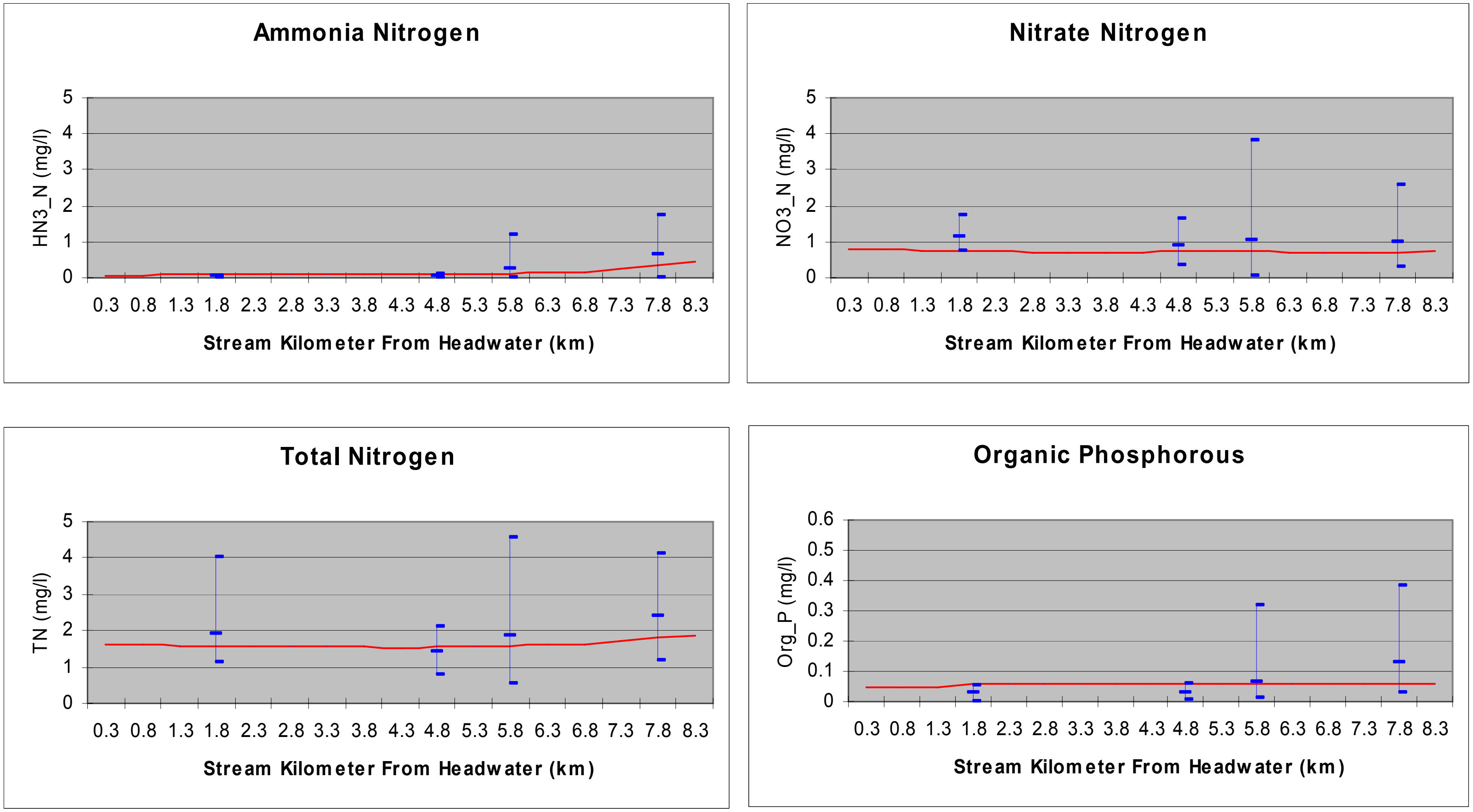
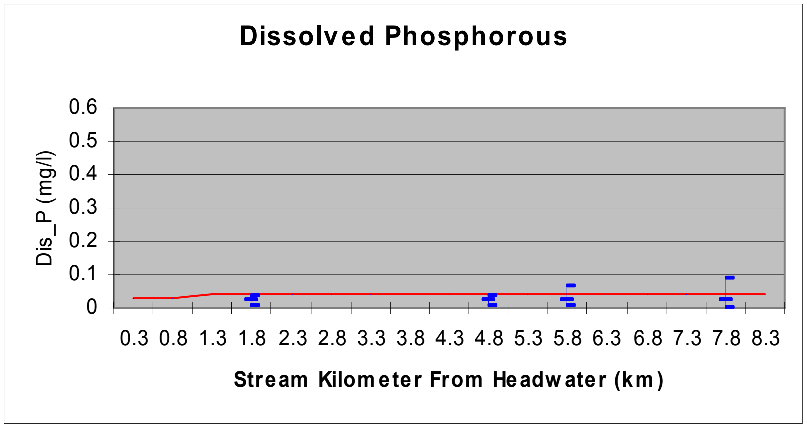


Figure 3-1 Calibration Results of Shellpot Creek Qual2E Model – Conti.



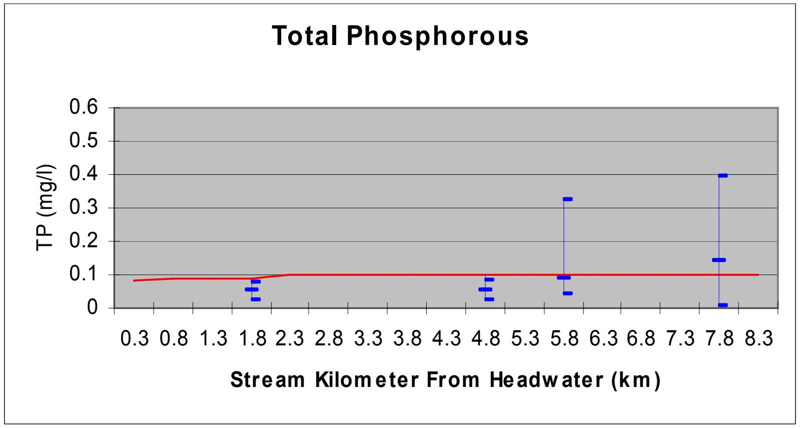


Figure 3-1 Calibration Results of Shellpot Creek Qual2E Model – Conti.

3.2 Summer Critical Condition Analysis

Summer 7Q10 Baseline Scenario

Low flows coupled with warm summer temperatures were observed during the months of July, August, and September, hence constituted critical condition for aquatic life in the stream. Monitoring data showed that violation of dissolved oxygen standard occurred more frequently during summer months than other months of the year.

Water quality condition during summer was simulated using the calibrated model. Water quality data collected during July, August, and September were considered summer month samples and were averaged over the years of 2000-2003. These average concentrations were used to represent headwater streams and tributary inputs to the model. Stream flow and model initial water temperature input were also adjusted to represent the critical condition of 7Q10 flow and water temperature of 24 ^{o}C. The results of the critical condition simulation are shown in Figure 3-2 as dark blue lines.

As seen in Figure 3-2, the model results show that dissolved oxygen levels meet applicable water quality standard of 5.5 mg/l at all upstream reaches. Only the most down stream reach (1.5 km long) has dissolved oxygen concentrations below the standard. Similarly, total nitrogen concentrations at the most downstream reach exceeded the threshold value of 3 mg/l. At the same time, total phosphorous concentrations at all reaches are below the threshold value of 0.2 mg/l. Considering violations of the DO standard and total nitrogen target at the most downstream reach, the following load reduction analysis is performed.

35% Load Reduction Scenario under 7Q10 Condition

As indicated above, the results of critical condition analysis showed that water quality standard with regard to dissolved oxygen and total nitrogen target were not met at the most downstream reach of the Shellpot Creek. Upon closer review of physical and environmental condition, it is clear that the characteristics of the most down stream reach of the Shellpot Creek are quite different from the rest of the creek. The major part of the creek is fast free flowing stream, has steep slope, and flows through a shallow, well-defined channel. The surrounding areas are mainly residential and commercial. Water in the upper and middle reaches of the creek is clear. In contrast, the most down stream reach (about 1.5 km) is under tidal influence, has a relatively flat bottom slope, and moves very slowly through a marsh wetland area. Its surrounding area is highly industrialized area with sewage disposal ponds on the right bank and utility plant on the left bank. Water in this reach is muddy and murky.

To establish the necessary load reductions for achieving water quality standard in the lower reaches of the Shellpot Creek under summer critical condition, several load reduction scenarios were assessed. Among the scenarios, the one considered a 35%

reduction of nutrient loads from nonpoint sources at the last two reaches (reach number 4 and 5 at down stream) are presented in Figure 3-3 in red lines, as the results of the reduction would met the DO standard and nutrient TMDL targets. For this scenario, 35% reduction rate was applied to nutrient and BOD concentrations of the incremental flows as well as SOD and benthos flux rates associated with the last two reaches.

From Figure 3-3, it can be concluded that 35% reduction of nutrient loads from nonpoint sources would result in increasing dissolved oxygen levels at the most down stream reach to above the standard of 5.5 mg/l. At the same time, total nitrogen levels at the downstream reaches were reduced from above target value of 3 mg/l to the level below or at the target value. And total phosphorous levels were further reduced below the target value of 0.2 mg/l.

3.3 Sensitivity Analysis

In order to assess the Shellpot Creek Qual2E Model's sensitivity to changes of various environmental parameters used in the model, a sensitivity analysis was performed. For this analysis, the Shellpot Creek Qual2E Model was run while model parameters were changed one at a time at 50% rate. Then, the percentage changes of dissolved oxygen concentration, total nitrogen and total phosphorous at the last computational element of the model were projected and recorded. The last computational element of the model has the lowest dissolved oxygen concentration in the stream under average condition.

The results of the sensitivity analysis showed that dissolved oxygen is most sensitive to changes in water temperature, sediment ammonia flux, sediment oxygen demand, and reaeration rate. A complete list of the results of the sensitivity analysis is provided in Appendix C.

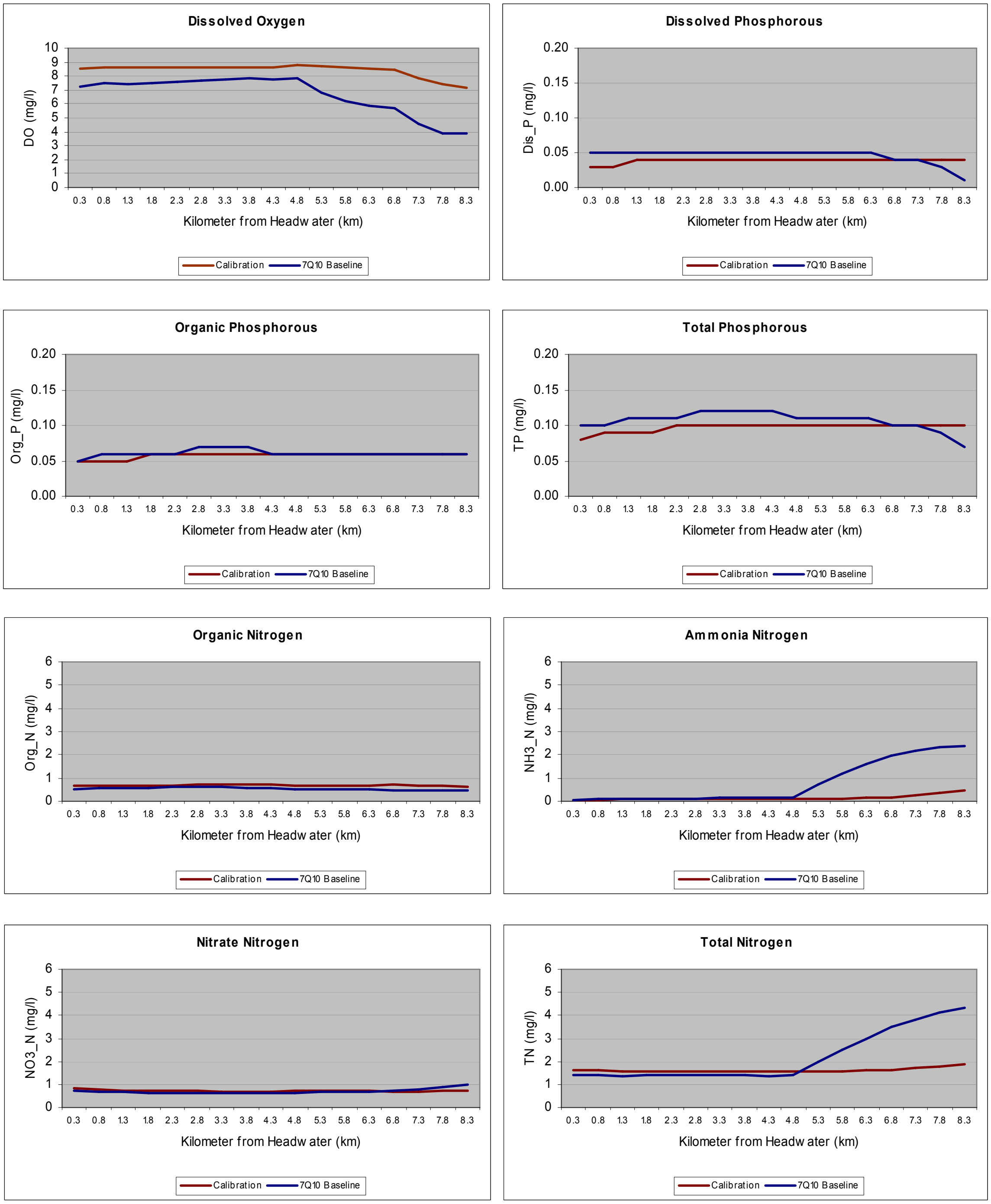


Figure 3-2 Results of 7Q10 Baseline Scenario and Calibration Results

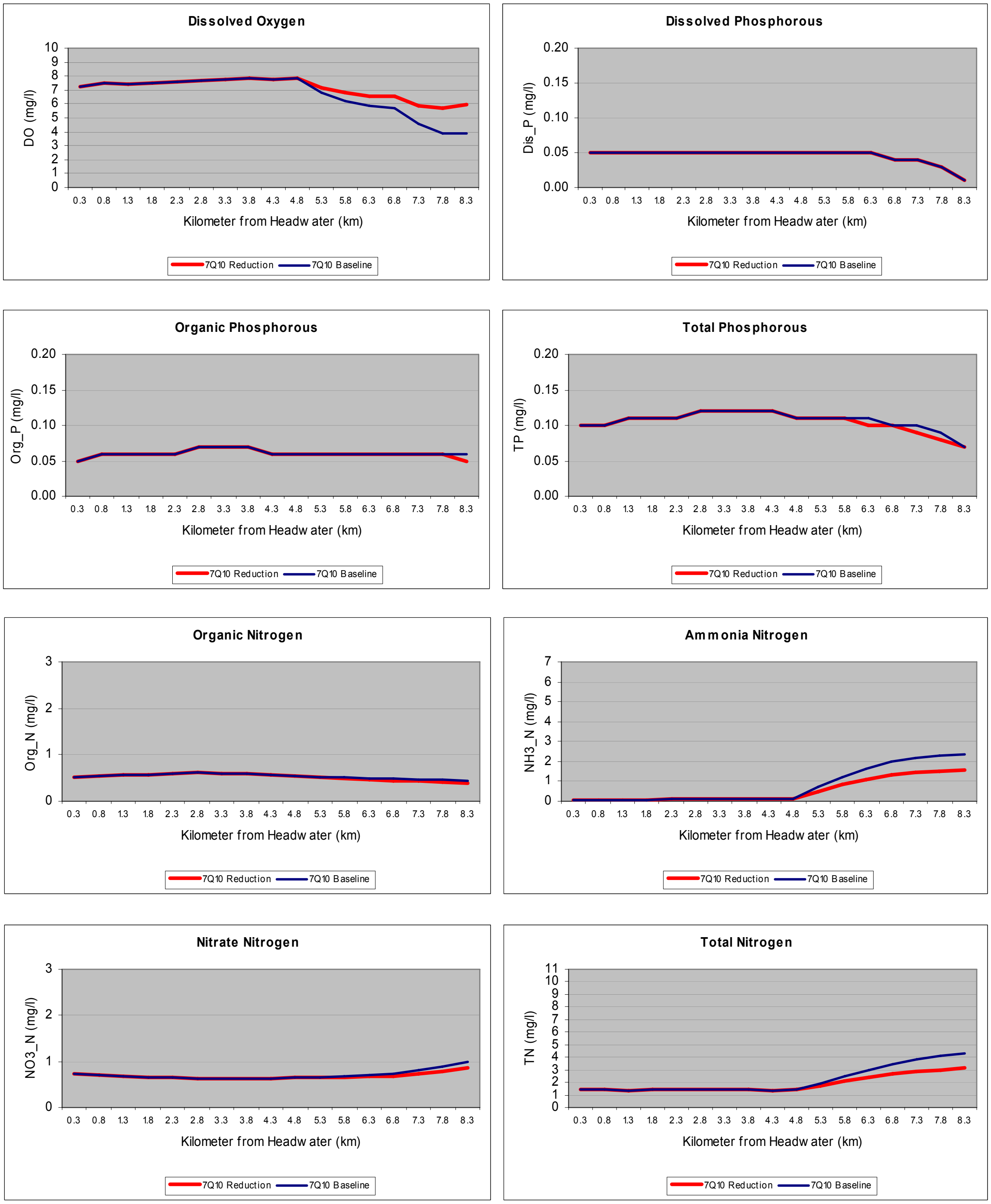


Figure 3-3 Results of 7Q10 Baseline Scenario and 7Q10 Load Reduction Scenario

4.0 ESTABLISHMENT OF THE NUTRIENT TMDL FOR THE SHELLPOT CREEK

As it was stated in Chapter 1 of this report, the applicable State of Delaware water quality standard for dissolved oxygen at fresh water stream is 5.5 mg/l, and the TMDL nutrient target levels are 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorous. The model simulation results, as discussed in Chapter 3, show that, under average condition of 2000 - 2003, water quality in Shellpot Creek met water quality standard and nutrient target. However, to attain applicable water quality standards and nutrient targets under summer 7Q10 critical conditions, it was determined that nonpoint source loads from the most down stream reaches should be reduced by 35% and nutrient loads from upstream reaches should be capped.

Applying the 35% reduction rate to the average condition resulted in establishment of nutrient TMDLs for the Shellpot Creek. Table 4.1 shows nutrient loads under baseline scenario and TMDL scenario. Total nonpoint source loads from drainage areas upstream of Rt. 13 shall be capped at 89.4 lb/day for total nitrogen and 5.7 lb/day for total phosphorous. Nonpoint source loads from drainage areas down stream of the Rt. 13 shall be reduced from 19.2 lb/day to 12.5 lb/day for total nitrogen and from 2.0 lb/day to 1.3 lb/day for total phosphorous.

Table 4-1 Shellpot Creek Nutrient Baseline and TMDL Loads

Nutrient Load Condition	Load From Drainage Area Upstream of Rt. 13 (Reaches 1-3)		Load From Drainage Area Downstream of Rt. 13 (Reaches 4-5)	
	TN (lb/d)	TP (lb/d)	TN (lb/d)	TP (lb/d)
Baseline Condition	89.4	5.7	19.2	2.0
TMDL Condition	89.4	5.7	12.5	1.3

A TMDL is defined as:

$$TMDL = WLA + LA + MOS$$

Where: WLA: waste load allocation for point sources
LA: load allocation for nonpoint sources
MOS: margin of safety to account for uncertainties and lack of data

As discussed in Chapter 3, the nutrient loads are entirely from nonpoint sources under average and critical low flow conditions. However, the entire New Castle County in Delaware is covered by Municipal Separate Storm Sewer System (MS4) permitting system. The US EPA guidelines require that nonpoint source loads for MS4 municipalities be considered as Waste Load Allocation (WLA) instead of Load Allocation (LA). Considering the above, elements of Shellpot Creek TMDL are presented in Table 4-2. All nutrient TMDL loads are allocated to MS4 municipality (as a WLA) with zero loads allocated to nonpoint sources (as a LA). For this TMDL, an implicit margin of safety has been considered through using conservative assumptions regarding reaction rates, pollutant loads, and simultaneous occurrence of critical environmental conditions such as low flow and high temperature.

Table 4-2 Shellpot Creek Nutrient TMDL WLA and LA

Source	Load From Upstream Sub-watershed (Reaches 1-3)		Load From Downstream Sub-watershed (Reaches 4-5)	
	TN (lb/d)	TP (lb/d)	TN (lb/d)	TP (lb/d)
WLA to MS4	89.4	5.7	12.5	1.3
LA to NPS	0	0	0	0
TMDL	89.4	5.7	12.5	1.3

5.0 ESTABLISHMENT OF THE BACTERIA TMDL FOR THE SHELLPOT CREEK

As it was stated in Chapter 1 of this report, the applicable State of Delaware water quality standard for enterococcus in a fresh water stream is a geometric mean not to exceed 100CFU/100mL and a single sample maximum not to exceed 185 CFU/100 mL. The geometric mean at the 1st, 2nd, 3rd and 4th flow quartile are 133 CFU/100 mL, 800 CFU/100 mL, 891 CFU/100 mL, and 382 CFU/100 mL, respectively. An overall reduction of 77% in the bacteria loading (85% MS4, 28% CSO) is required for the water quality in Shellpot Creek to meet the State water quality standards.

5.1 BACTERIA CONCENTRATIONS VERSUS FLOW RATES

The daily flow rates in the Shellpot Creek (from USGS station 01477800) were divided into four ranges: the first, second, third and forth quartile with the first being the lowest 25%and the forth being the highest 25%. The average flow and bacteria concentrations in the stream for each quartile were calculated and are shown in Table 5-1 and Figure 5-1.

Table 5-1 Shellpot Creek Flow Ranges vs. Bacteria Concentrations

	Flow range (ft^3/sec)	Average flow rate (ft^3/sec)	Geometric mean enterococcus concentration (CFU/100mL)
1st quartile	≤ 1.6	0.94	133
2nd quartile	1.6 – 2.2	1.79	800
3rd quartile	2.2 – 4.8	3.31	891
4th quartile	≥ 4.8	32.22	382

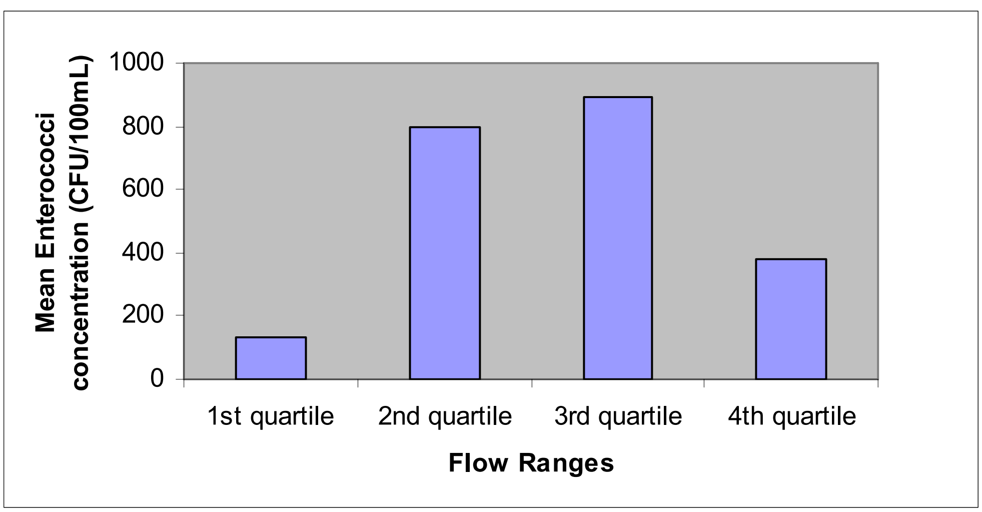


Figure 5-1 **Shellpot Creek Flow Ranges vs. Bacteria Concentrations**

5.2 BACTERIA LOADING VERSUS FLOW RATES

The daily, baseline load was determined by multiplying the average quartile flow by the geometric mean concentration for that quartile (Table 5-2 and Figure 5-2). The loading from Wilmington combined sewer outfall #31 (CSO 31) is included in the 4th quartile because it is reasonable to assume that discharges only occur in high flow situations when precipitation is most likely occurring. CSO 31 is located off Bowers Street, southeast of Northeast Elementary School and discharges into an unnamed tributary of the Shellpot Creek.

Table 5-2 Shellpot Creek Flow Ranges vs. Baseline Bacteria Loadings

	Flow (L/day)	Total Baseline Load (CFU/day)	NPS Baseline (CFU/day)	CSO 31 Baseline (CFU/day)
1st quartile	2,299,371	3.0E+09	3.0E+09	
2nd quartile	4,378,590	3.5E+10	3.5E+10	
3rd quartile	8,096,722	7.2E+10	7.2E+10	
4th quartile	78,814,615	3.0E+11	2.5E+11	5.4E+10

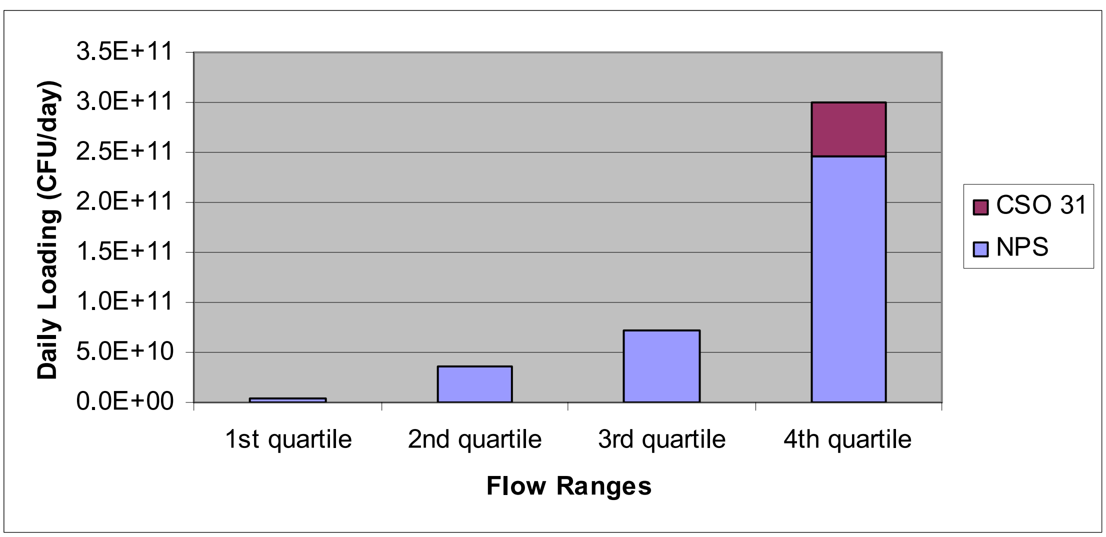


Figure 5-2 **Shellpot Creek Flow Ranges vs. Baseline Bacteria Loading**

5.3 BACTERIA REDUCTIONS AND TMDL WASTE LOAD ALLOCATIONS

It is assumed that the only sources of bacteria entering the Shellpot Creek are non-point sources (NPS: runoff, subsurface flow, failing septic systems, resuspension from sediment, direct deposition, etc.) and the discharges from CSO 31. All NPS sources are combined and are considered as one and a MS4 WLA is determined by reducing the NPS baseline loading by an appropriate level to ensure the State water quality standards are met. CSO 31 currently captures 79% and discharges 21% of the stormwater/sanitary sewer flow from the 172 acres that it services. The CSO WLA reflects an increase in capture to 85%. An overall reduction of 77% is required; reductions in the 1st, 2nd, 3rd and 4th flow quartile are 25%, 88%, 89%, and 74%, respectively. The 4th quartile flow reduction is a combination of an 84% reduction in NPSs and a 28% reduction from CSO 31; see Table 5-3 and Figure 5-3.

Table 5-3 Shellpot Creek Baseline and TMDL Waste Load Allocations

	Total Baseline Load (CFU/day)	Total TMDL Load Allocations (CFU/day)	NPS Allocations (MS4 WLA, CFU/day)	CSO 31 WLA (CFU/day)	% Reductions
1st quartile	3.0E+09	2.3E+09	2.3E+09		25%
2nd quartile	3.5E+10	4.4E+09	4.4E+09		88%
3rd quartile	7.2E+10	8.1E+09	8.1E+09		89%
4th quartile	3.0E+11	7.9E+10	4.0E+10	3.9E+10	74% (84% NPS, 28% CSO)

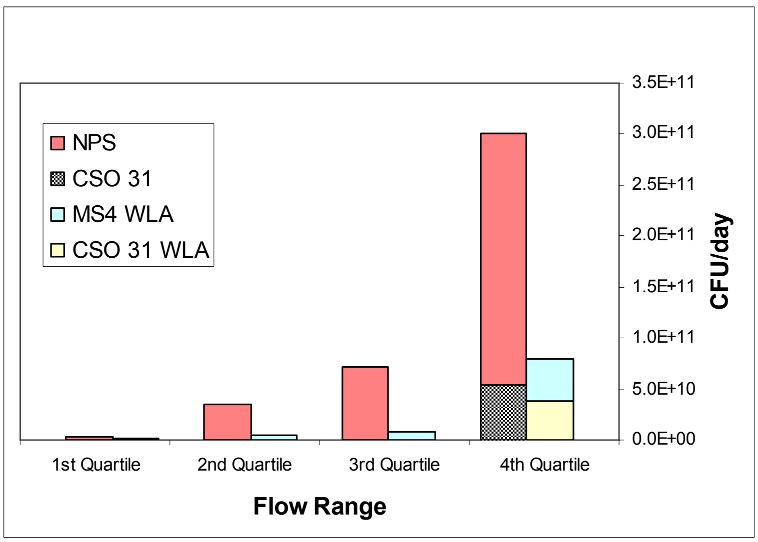


Figure 5-3 **Shellpot Creek Baseline and TMDL Waste Load Allocations**

5.4 SOURCE TRACKING ADJUSTMENT FACTOR

The Source Tracking Adjustment Factor (STAF) is a multiplier used to normalize human health risk associated with total fecal enterococci counts to enterococci counts derived exclusively from human sources. Bacteria source tracking (BST) data and the STAF, when available, will be used throughout the State to determine the sources of fecal contamination and in the development of pollution control strategies (PCSs).

6.0 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 will be discussed in the following, the Shellpot Creek TMDL meets the above 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 bacteria and nutrient guidelines for total nitrogen and total phosphorous in the Shellpot Creek. The dissolved oxygen criteria for fresh water streams is 5.5 mg/l; the enterococcus criteria is 100 CFU/100ml as 30 day geometric mean and 185 as single sample maximum; and the TMDL nutrient target levels are 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorous. The results of the TMDL scenario indicate that dissolved oxygen criteria and nutrient target values were met in all segments of Shellpot Creek. For bacteria, the analysis shows that 77% reduction of bacteria loads in the watershed would result in achieving bacteria water quality standards. Therefore, it can be concluded that the proposed TMDL meets the applicable water quality criteria and target 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 have been calculated, as presented in Table 4-1 for nutrients and Table 5-3 for bacteria. The proposed TMDLs allocate the nutrient loads generated from nonpoint sources to MS4 municipality as a Waste Load Allocation (WLA). With regard to bacteria, Waste Load Allocations are assigned to City of Wilmington’s CSO 31 and to the MS4 Municipality. Therefore, it can be concluded that the proposed TMDLs include allocations for point and nonpoint sources.

3. The TMDLs must consider the impact of background pollutants.
The Shellpot Creek TMDLs is established based on a calibrated Qual2E water quality model. Significant amount of water quality data collected in the watershed was used to develop and calibrate the model. Since background conditions are reflected in the calibrated model and the monitoring data, it can be concluded that the impact of

background pollutants is accounted in this TMDL analysis.

4. The TMDLs must consider critical environmental conditions.
Low stream flow during summer months coupled with high water temperature is a critical condition for Shellpot Creek and has been considered in this TMDL analysis. A modeling scenario that incorporated the summer low flow with high water temperature was simulated. In this scenario, the headwater condition and tributary inflow condition were defined using the data collected during the summer months (July, August, and September) in 2000-2003. Details of the model inputs and results of the model run are discussed in Chapter 3 which showed that 35% nonpoint source nutrient load reductions from area of the watershed that drain to the lower segments of the Shellpot Creek would result in achieving all applicable water quality standards and nutrient targets. Therefore, the critical condition for Shellpot Creek is considered in this analysis.

5. The TMDLs must consider seasonal variations.
Seasonal variations are considered in development of the Shellpot Creek Qual2E Model. The data used to define model inputs were collected during 2000-2003 period in different months and seasons, reflecting seasonal variations. In addition, the model was run under summer low flow condition. Therefore, the seasonal variations are considered in the analysis.

The data used for the bacteria analyses was collected over approximately 6 years with data points at each season being represented. Therefore, seasonal variations were considered for this 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 TMDL analysis. The Shellpot Creek Qual2E model was calibrated using conservative assumptions regarding reaction rates, pollutant loads, and simultaneous occurrence of critical environmental conditions such as low flow and high temperature. Consideration of these conservative assumptions contributed to an implicit margin of safety.

An explicit margin of safety is incorporated in the Source Tracking Adjustment Factor (STAF), a tool that will be used in the implementation and BMP design following adoption of the TMDL, therefore an adequate margin of safety is included in the bacteria TMDL (waste) load allocations.

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

The Proposed Shellpot Creek TMDLs were presented during a public workshop on June 15, 2005. A public hearing was also held on September 7, 2005. Notices advertising the public workshop and hearing were published in two local and regional newspapers. In addition, notice of the public hearing and proposed regulations were published in the August 1, 2005 issue of the Delaware Register of Regulations (Volume 9, Issue 2). Considering this, it can be concluded that the Shellpot Creek TMDLs have been subject to significant public participation.

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

The Shellpot Creek TMDL considers reduction of nutrients and bacteria loads from point and nonpoint sources. As the result of these reductions, water quality standards with regard to dissolved oxygen and enterococcus bacteria will be met in all segments of the Shellpot Creek.

Following adoption of the Shellpot Creek TMDL, the DNREC, in association with local citizen groups and other affected parties, will develop a Pollution Control Strategy to implement the requirements of the proposed Shellpot Creek TMDL Regulation. Therefore, it can be concluded that there is a reasonable assurance that the Shellpot Creek TMDLs will be met.

REFERENCES

1. "State of Delaware 1996 Watershed Assessment Report (305(b))", Department of Natural Resources and Environmental Control, April 1, 1996.

2. "Final Determination for the State of Delaware 2002 Clean Water Act Section 303(d) List of Waters Needing TMDLs", Department of Natural Resources and Environmental Control, 2002.

3. "State of Delaware Surface Water Quality Standards, as amended July 11, 2004," Department of Natural Resources and Environmental Control, Division of Water Resources.

4. "State of Delaware Surface Water Quality Monitoring Program FY2000", Department of Natural Resources and Environmental Control, May 3, 1999.

5. "State of Delaware 2002 Watershed Assessment Report (305(b))", Department of Natural Resources and Environmental Control, April 1, 2002.

6. "Linfield C. Brown and Thomas O. Barnwell, Jr., The Enhanced Stream Water Quality Models Qual2E and Qual2E-UNCAS: Documentation and User Manual, EPA/600/3-87/007, May 1987, Environmental Research laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia, 30613.

7. "Water Resource Data, Maryland, Delaware, and Washington, D.C., Water Year 2002, Volume 1. Surface-Water Data", U.S. Geological Survey.

8. "A model for the Murderkill River Watershed", HydroQual Inc., February 2001

Appendix A – Input and Output Data for Shellpot Creek Qual2E Model Calibration

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                                        * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                                                     Version 3.22  --  May 1996

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                             QUAL-2E PROGRAM TITLES
TITLE01              sh404, based on sh403
TITLE02              calibration,
TITLE03   NO         CONSERVATIVE MINERAL   I
TITLE04   NO         CONSERVATIVE MINERAL  II
TITLE05   NO         CONSERVATIVE MINERAL III
TITLE06   NO         TEMPERATURE
TITLE07  YES         5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES         ALGAE AS CHL-A IN UG/L
TITLE09  YES         PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                (ORGANIC-P; DISSOLVED-P)
TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
TITLE12                (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES         DISSOLVED OXYGEN IN MG/L
TITLE14   NO         FECAL COLIFORM IN NO./100 ML
TITLE15   NO         ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                     CARD TYPE
LIST DATA INPUT             0.00000                                        0.00000
WRITE OPTIONAL SUMMARY      0.00000                                        0.00000
NO FLOW AUGMENTATION        0.00000                                        0.00000
STEADY STATE                0.00000                                        0.00000
NO TRAP CHANNELS            0.00000                                        0.00000
PRINT LCD/SOLAR DATA        0.00000                                        0.00000
PLOT DO AND BOD             0.00000                                        0.00000
FIXED DNSTM CONC (YES=1)=   0.00000          5D-ULT BOD CONV K COEF  =     0.23000
INPUT METRIC            =   1.00000          OUTPUT METRIC           =     1.00000
NUMBER OF REACHES       =   5.00000          NUMBER OF JUNCTIONS     =     0.00000
NUM OF HEADWATERS       =   1.00000          NUMBER OF POINT LOADS   =     3.00000
TIME STEP (HOURS)       =   0.00000          LNTH. COMP. ELEMENT (KM)=     0.50000
MAXIMUM ROUTE TIME (HRS)= 100.00000          TIME INC. FOR RPT2 (HRS)=     0.00000
LATITUDE OF BASIN (DEG) =  39.50000          LONGITUDE OF BASIN (DEG)=    75.30000
STANDARD MERIDIAN (DEG) =  75.00000          DAY OF YEAR START TIME  =   196.00000
EVAP. COEF.,(AE)        =   0.00001          EVAP. COEF.,(BE)        =     0.00001
ELEV. OF BASIN (METERS) = 100.00000          DUST ATTENUATION COEF.  =     0.10000
ENDATA1                     0.00000                                        0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                            CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300          O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1000
O PROD. BY ALGAE (MG O/MG A)   =    1.6000          O UPTAKE BY ALGAE (MG O/MG A)  =    2.0000
N CONTENT OF ALGAE (MG N/MG A) =    0.0800          P CONTENT OF ALGAE (MG P/MG A) =    0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=    3.0000          ALGAE RESPIRATION RATE (1/DAY) =    0.0500
N HALF SATURATION CONST. (MG/L)=    0.0050          P HALF SATURATION CONST. (MG/L)=    0.0010
LIN ALG SHADE CO (1/M-UGCHA/L) =    0.0008          NLIN SHADE (1/M-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0000          LIGHT SAT'N COEF (LANGLEYS/MIN)=    0.0250
DAILY AVERAGING OPTION(LAVOPT) =    2.0000          LIGHT AVERAGING FACTOR (AFACT  =    0.9500
NUMBER OF DAYLIGHT HOURS (DLH) =   14.0000          TOTAL DAILY SOLR RAD (LANGLEYS)=  380.0000
ALGY GROWTH CALC OPTION(LGROPT)=    2.0000          ALGAL PREF FOR NH3-N (PREFN)   =    0.9000
ALG/TEMP SOLAR RAD FACT(TFACT) =    0.4500          NITRIFICATION INHIBITION COEF  =   10.0000
ENDATA1A                            0.0000                                              0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE

THETA( 1)      BOD DECA       1.047     DFLT
THETA( 2)      BOD SETT       1.024     DFLT
THETA( 3)      OXY TRAN       1.024     DFLT
THETA( 4)      SOD RATE       1.060     DFLT
THETA( 5)      ORGN DEC       1.080     USER
THETA( 6)      ORGN SET       1.024     DFLT
THETA( 7)      NH3 DECA       1.083     DFLT
THETA( 8)      NH3 SRCE       1.074     DFLT
THETA( 9)      NO2 DECA       1.047     DFLT
THETA(10)      PORG DEC       1.047     DFLT
THETA(11)      PORG SET       1.024     DFLT
THETA(12)      DISP SRC       1.074     DFLT
THETA(13)      ALG GROW       1.047     DFLT
THETA(14)      ALG RESP       1.047     DFLT
THETA(15)      ALG SETT       1.024     DFLT
THETA(16)      COLI DEC       1.047     DFLT
THETA(17)      ANC DECA       1.000     DFLT
THETA(18)      ANC SETT       1.024     DFLT
THETA(19)      ANC SRCE       1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT              R. MI/KM            R. MI/KM
STREAM REACH     1.0  RCH= Segment 1         FROM          8.5     TO          7.0
STREAM REACH     2.0  RCH= Segment 2         FROM          7.0     TO          5.5
STREAM REACH     3.0  RCH= Segment 3         FROM          5.5     TO          3.5
STREAM REACH     4.0  RCH= Segment 4         FROM          3.5     TO          1.5
STREAM REACH     5.0  RCH= Segment 5         FROM          1.5     TO          0.0
```

ENDATA2	0.0	0.0	0.0

$$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE	REACH	AVAIL HDWS	TARGET	ORDER OF AVAIL SOURCES					
ENDATA3	0.	0.	0.0	0.	0.	0.	0.	0.	0.

$$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD	1.	3.	1.2.6.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	2.	3.	2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	3.	4.	2.2.6.6.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	4.	4.	2.2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	5.	3.	2.2.5.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
ENDATA4	0.	0.	0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

$$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE	REACH	COEF-DSPN	COEFQV	EXPOQV	COEFQH	EXPOQH	CMANN
HYDRAULICS	1.	100.00	0.162	0.080	0.813	0.713	0.040
HYDRAULICS	2.	100.00	0.162	0.080	0.813	0.713	0.040
HYDRAULICS	3.	100.00	0.327	0.426	0.496	0.495	0.040
HYDRAULICS	4.	100.00	0.253	0.400	0.646	0.600	0.040
HYDRAULICS	5.	100.00	0.026	0.000	0.600	0.000	0.040
ENDATA5	0.	0.00	0.000	0.000	0.000	0.000	0.000

$$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE			DUST	CLOUD	DRY BULB	WET BULB	ATM		SOLAR RAD
	REACH	ELEVATION	COEF	COVER	TEMP	TEMP	PRESSURE	WIND	ATTENUATION
TEMP/LCD	1.	30.48	0.10	0.10	25.00	20.00	980.00	2.50	1.00
TEMP/LCD	2.	30.48	0.10	0.10	25.00	20.00	980.00	2.50	1.00
TEMP/LCD	3.	30.48	0.10	0.10	25.00	20.00	980.00	2.50	1.00
TEMP/LCD	4.	30.48	0.10	0.10	25.00	20.00	980.00	2.50	1.00
TEMP/LCD	5.	30.48	0.10	0.10	25.00	20.00	980.00	2.50	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	K1	K3	SOD	K2OPT	K2	COEQK2	OR	EXPQK2
				RATE			TSIV COEF	OR	SLOPE
							FOR OPT 8		FOR OPT 8
REACT COEF	1.	0.30	0.00	0.000	5.	0.00	0.000		0.00000
REACT COEF	2.	0.30	0.00	0.000	5.	0.00	0.000		0.00000
REACT COEF	3.	0.30	0.00	0.000	5.	0.00	0.000		0.00000
REACT COEF	4.	0.50	0.00	0.300	5.	0.00	0.000		0.00000
REACT COEF	5.	0.50	0.00	2.200	1.	2.00	0.000		0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000		0.00000

$$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE	REACH	CKNH2	SETNH2	CKNH3	SNH3	CKNO2	CKPORG	SETPORG	SPO4
N AND P COEF	1.	0.25	0.00	0.30	0.00	1.00	0.10	0.00	0.00
N AND P COEF	2.	0.25	0.00	0.30	0.00	1.00	0.10	0.00	0.00
N AND P COEF	3.	0.25	0.00	0.30	0.00	1.00	0.10	0.00	0.00
N AND P COEF	4.	0.25	0.00	0.30	100.00	1.00	0.10	0.00	0.00
N AND P COEF	5.	0.25	0.00	0.30	300.00	1.00	0.10	0.00	0.00
ENDATA6A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	50.00	0.00	0.00	0.00	0.00	0.00	0.00
ALG/OTHER COEF	2.	50.00	0.00	0.00	0.00	0.00	0.00	0.00
ALG/OTHER COEF	3.	50.00	0.00	0.00	0.00	0.00	0.00	0.00
ALG/OTHER COEF	4.	50.00	0.00	0.00	0.00	0.00	0.00	0.00
ALG/OTHER COEF	5.	50.00	0.00	0.00	0.00	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	2.	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	3.	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	4.	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	5.	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INITIAL COND-2	1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	3.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	4.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-2	5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENDATA7A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	0.021	15.60	8.00	5.73	0.00	0.00	0.00	0.00	0.00

INCR INFLOW-1	2.	0.027	15.60	8.00	5.58	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	3.	0.036	15.60	8.00	5.49	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	4.	0.047	15.60	7.80	5.38	0.00	0.00	0.00	0.00	0.00
INCR INFLOW-1	5.	0.024	15.60	7.70	5.55	0.00	0.00	0.00	0.00	0.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE	REACH	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
INCR INFLOW-2	1.	0.00	0.93	0.11	0.04	0.39	0.11	0.05
INCR INFLOW-2	2.	0.00	0.94	0.11	0.04	0.39	0.11	0.04
INCR INFLOW-2	3.	0.00	0.94	0.11	0.04	0.38	0.10	0.04
INCR INFLOW-2	4.	0.00	0.94	0.11	0.04	0.37	0.10	0.04
INCR INFLOW-2	5.	0.00	0.94	0.11	0.04	0.35	0.10	0.04
ENDATA8A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	Shellpot Headwtr	0.11	14.62	8.51	2.40	0.00	0.00	0.00
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	HDWTR ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	NO3-N	ORG-P	DIS-P
HEADWTR-2	1.	0.00	0.00E+00	3.24	0.67	0.06	0.09	0.83	0.05	0.03
ENDATA10A	0.	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	Segmt1 Trib	0.00	0.03	14.25	8.71	2.40	0.00	0.00	0.00
POINTLD-1	2.	Turkey Run	0.00	0.04	14.25	8.71	2.40	0.00	0.00	0.00
POINPLD-1	3.	Matson Run	0.00	0.06	13.59	9.42	2.40	0.00	0.00	0.00
ENDATA11	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE	POINT LOAD ORDER	ANC	COLI	CHL-A	ORG-N	NH3-N	NO2-N	N03-N	ORG-P	DIS-P
POINTLD-2	1.	0.00	0.00E+00	3.33	0.63	0.05	0.07	0.70	0.05	0.05
POINTLD-2	2.	0.00	0.00E+00	3.33	0.63	0.05	0.07	0.70	0.05	0.05
POINTLD-2	3.	0.00	0.00E+00	3.57	0.57	0.03	0.11	1.10	0.04	0.02
ENDATA11A	0.	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

	DAM	RCH	ELE	ADAM	BDAM	FDAM	HDAM
ENDATA12	0.	0.	0.	0.00	0.00	0.00	0.00

$$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

CARD TYPE	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
ENDATA13	DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED							

$$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

CARD TYPE	CHL-A	ORG-N	NH3-N	NO2-N	NH3-N	ORG-P	DIS-P
ENDATA13A	DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED						

STEADY STATE ALGAE/NUTRIENT/DISSOLVED OXYGEN SIMULATION; CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	17
ALGAE GROWTH RATE	2	17
ALGAE GROWTH RATE	3	17
ALGAE GROWTH RATE	4	17
ALGAE GROWTH RATE	5	17
ALGAE GROWTH RATE	6	17
ALGAE GROWTH RATE	7	0
ALGAE GROWTH RATE	8	0

SUMMARY OF CONDITIONS FOR ALGAL GROWTH RATE SIMULATION:

1. LIGHT AVERAGING OPTION. LAVOPT= 2

   METHOD: MEAN SOLAR RADIATION DURING DAYLIGHT HOURS

   SOURCE OF SOLAR VALUES: DATA TYPE 1A
   DAILY NET SOLAR RADIATION: 1400.300 BTU/FT-2 (380.000 LANGLEYS)
   NUMBER OF DAYLIGHT HOURS: 0.0
   PHOTOSYNTHETIC ACTIVE FRACTION OF SOLAR RADIATION (TFACT): N/A
   MEAN SOLAR RADIATION ADJUSTMENT FACTOR (AFACT): 0.950

2. LIGHT FUNCTION OPTION: LFNOPT= 2

   SMITH FUNCTION, WITH 71% IMAX = 0.025 LANGLEYS/MIN

3. GROWTH ATTENUATION OPTION FOR NUTRIENTS. LGROPT= 2

   MINIMUM OF NITROGEN, PHOSPHORUS: FL*MIN(FN,FP)

DISSOLVED OXYGEN IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8.56	8.59	8.63																	
2	8.63	8.63	8.63																	
3	8.63	8.64	8.66	8.78																
4	8.70	8.62	8.55	8.47																
5	7.82	7.41	7.15																	

5-DAY BIOCHEMICAL OXYGEN DEMAND ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2.58	2.73	2.77																	
2	2.88	2.99	3.08																	
3	3.16	3.23	3.16	3.07																
4	3.11	3.14	3.16	3.18																
5	3.06	2.83	2.63																	

ORGANIC NITROGEN AS N IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.68	0.68	0.68																	
2	0.69	0.69	0.70																	
3	0.70	0.71	0.70	0.68																
4	0.69	0.69	0.69	0.70																
5	0.68	0.66	0.63																	

AMMONIA AS N IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.07	0.07	0.08																	
2	0.08	0.09	0.09																	
3	0.10	0.10	0.10	0.09																
4	0.11	0.12	0.13	0.15																
5	0.25	0.36	0.45																	

NITRITE AS N IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.09	0.08	0.08																	
2	0.07	0.07	0.07																	
3	0.06	0.06	0.06	0.07																
4	0.07	0.06	0.06	0.06																
5	0.06	0.07	0.08																	

NITRATE AS N IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.81	0.79	0.75																	
2	0.74	0.72	0.71																	
3	0.70	0.68	0.68	0.74																
4	0.73	0.72	0.71	0.70																
5	0.70	0.71	0.72																	

ORGANIC PHOSPHORUS AS P IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.05	0.05	0.05																	
2	0.06	0.06	0.06																	
3	0.06	0.06	0.06	0.06																
4	0.06	0.06	0.06	0.06																
5	0.06	0.06	0.06																	

DISSOLVED PHOSPHORUS AS P IN MG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.03	0.03	0.04																	
2	0.04	0.04	0.04																	
3	0.04	0.04	0.04	0.04																
4	0.04	0.04	0.04	0.04																
5	0.04	0.04	0.04																	

ALGAE AS CHL-A IN UG/L ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	3.23	3.23	3.28																	
2	3.30	3.32	3.35																	
3	3.38	3.40	3.41	3.48																
4	3.51	3.57	3.63	3.70																
5	4.42	6.33	8.94																	

ALGAE GROWTH RATES IN PER DAY ARE ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.47	1.47	1.47																	
2	1.47	1.47	1.48																	
3	1.48	1.48	1.48	1.47																
4	1.47	1.47	1.47	1.48																
5	1.48	1.48	1.48																	

PHOTOSYNTHESIS-RESPIRATION RATIOS ARE ITERATION 8

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

```
1 25.77 25.80 25.85
2 25.87 25.87 25.88
3 25.89 25.89 25.91 25.85
4 25.86 25.87 25.87 25.88
5 25.89 25.90 25.91
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***** STEADY STATE SIMULATION *****

** HYDRAULICS SUMMARY **

ELE ORD	RCH NUM	ELE NUM	BEGIN LOC KILO	END LOC KILO	FLOW CMS	POINT SRCE CMS	INCR FLOW CMS	VEL MPS	TRVL TIME DAY	DEPTH M	WIDTH M	VOLUME K-CU-M	BOTTOM AREA K-SQ-M	X-SECT AREA SQ-M	DSPRSN COEF SQ-M/S
1	1	1	8.50	8.00	0.11	0.00	0.01	0.136	0.043	0.173	4.851	0.42	2.60	0.84	0.39
2	1	2	8.00	7.50	0.12	0.00	0.01	0.137	0.042	0.180	4.912	0.44	2.64	0.88	0.41
3	1	3	7.50	7.00	0.16	0.03	0.01	0.140	0.041	0.220	5.203	0.57	2.82	1.14	0.50
4	2	1	7.00	6.50	0.17	0.00	0.01	0.140	0.041	0.229	5.263	0.60	2.86	1.20	0.51
5	2	2	6.50	6.00	0.18	0.00	0.01	0.141	0.041	0.237	5.319	0.63	2.90	1.26	0.53
6	2	3	6.00	5.50	0.19	0.00	0.01	0.142	0.041	0.246	5.374	0.66	2.93	1.32	0.55
7	3	1	5.50	5.00	0.20	0.00	0.01	0.163	0.035	0.221	5.430	0.60	2.94	1.20	0.58
8	3	2	5.00	4.50	0.20	0.00	0.01	0.166	0.035	0.226	5.449	0.62	2.95	1.23	0.60
9	3	3	4.50	4.00	0.25	0.04	0.01	0.182	0.032	0.251	5.539	0.69	3.02	1.39	0.72
10	3	4	4.00	3.50	0.32	0.06	0.01	0.200	0.029	0.280	5.638	0.79	3.10	1.58	0.87
11	4	1	3.50	3.00	0.33	0.00	0.01	0.162	0.036	0.331	6.122	1.01	3.39	2.03	0.81
12	4	2	3.00	2.50	0.34	0.00	0.01	0.164	0.035	0.338	6.122	1.03	3.40	2.07	0.83
13	4	3	2.50	2.00	0.35	0.00	0.01	0.166	0.035	0.345	6.122	1.06	3.41	2.11	0.86
14	4	4	2.00	1.50	0.36	0.00	0.01	0.169	0.034	0.352	6.122	1.08	3.41	2.15	0.88
15	5	1	1.50	1.00	0.37	0.00	0.01	0.026	0.223	0.600	23.782	7.14	12.49	14.27	0.21
16	5	2	1.00	0.50	0.38	0.00	0.01	0.026	0.223	0.600	24.295	7.29	12.75	14.58	0.21
17	5	3	0.50	0.00	0.39	0.00	0.01	0.026	0.223	0.600	24.808	7.44	13.01	14.88	0.21

***** STEADY STATE SIMULATION *****

** REACTION COEFFICIENT SUMMARY **

RCH NUM	ELE NUM	DO SAT MG/L	K2 OPT	OXYGN REAIR 1/DAY	BOD DECAY 1/DAY	BOD SETT 1/DAY	SOD RATE G/M2D	ORGN DECAY 1/DAY	ORGN SETT 1/DAY	NH3 DECAY 1/DAY	NH3 SRCE MG/M2D	NO2 DECAY 1/DAY	ORGP DECAY 1/DAY	ORGP SETT 1/DAY	DISP SRCE MG/M2D	COLI DECAY 1/DAY	ANC DECAY 1/DAY	ANC SETT 1/DAY	ANC SRCE MG/M2D
1	1	9.27	5	4.14	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
1	2	9.27	5	4.05	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
1	3	9.27	5	3.56	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
2	1	9.27	5	3.11	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
2	2	9.27	5	2.98	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
2	3	9.27	5	2.86	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
3	1	9.27	5	3.28	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
3	2	9.27	5	3.73	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
3	3	9.27	5	3.68	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
3	4	9.27	5	3.57	0.27	0.00	0.00	0.21	0.00	0.26	0.00	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
4	1	9.27	5	2.89	0.46	0.00	0.27	0.21	0.00	0.26	86.68	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
4	2	9.27	5	2.25	0.46	0.00	0.27	0.21	0.00	0.26	86.68	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
4	3	9.27	5	2.23	0.46	0.00	0.27	0.21	0.00	0.26	86.68	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
4	4	9.27	5	2.21	0.46	0.00	0.27	0.21	0.00	0.26	86.68	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
5	1	9.27	1	2.05	0.46	0.00	1.96	0.21	0.00	0.26	260.05	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
5	2	9.27	1	1.91	0.46	0.00	1.96	0.21	0.00	0.26	260.05	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00
5	3	9.27	1	1.91	0.46	0.00	1.96	0.21	0.00	0.26	260.05	0.91	0.09	0.00	0.00	0.00	0.00	0.00	0.00

***** STEADY STATE SIMULATION *****

** WATER QUALITY VARIABLES **

RCH NUM	ELE NUM	TEMP DEG-C	CM-1	CM-2	CM-3	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P COLI MG/L #/100ML	ANC	CHLA UG/L
1	1	18.00	0.00	0.00	0.00	8.56	2.58	0.68	0.07	0.09	0.81	1.64	0.05	0.03	0.08.00E+00	0.00	3.23
1	2	18.00	0.00	0.00	0.00	8.59	2.73	0.68	0.07	0.08	0.79	1.63	0.05	0.03	0.09.00E+00	0.00	3.23
1	3	18.00	0.00	0.00	0.00	8.63	2.77	0.68	0.08	0.08	0.75	1.58	0.05	0.04	0.09.00E+00	0.00	3.28
2	1	18.00	0.00	0.00	0.00	8.63	2.88	0.69	0.08	0.07	0.74	1.58	0.06	0.04	0.09.00E+00	0.00	3.30
2	2	18.00	0.00	0.00	0.00	8.63	2.99	0.69	0.09	0.07	0.72	1.57	0.06	0.04	0.10.00E+00	0.00	3.32
2	3	18.00	0.00	0.00	0.00	8.63	3.08	0.70	0.09	0.07	0.71	1.57	0.06	0.04	0.10.00E+00	0.00	3.35
3	1	18.00	0.00	0.00	0.00	8.63	3.16	0.70	0.10	0.06	0.70	1.56	0.06	0.04	0.10.00E+00	0.00	3.38
3	2	18.00	0.00	0.00	0.00	8.64	3.23	0.71	0.10	0.06	0.68	1.56	0.06	0.04	0.10.00E+00	0.00	3.40
3	3	18.00	0.00	0.00	0.00	8.66	3.16	0.70	0.10	0.06	0.68	1.54	0.06	0.04	0.10.00E+00	0.00	3.41
3	4	18.00	0.00	0.00	0.00	8.78	3.07	0.68	0.09	0.07	0.74	1.58	0.06	0.04	0.10.00E+00	0.00	3.48
4	1	18.00	0.00	0.00	0.00	8.70	3.11	0.69	0.11	0.07	0.73	1.59	0.06	0.04	0.10.00E+00	0.00	3.51
4	2	18.00	0.00	0.00	0.00	8.62	3.14	0.69	0.12	0.06	0.72	1.59	0.06	0.04	0.10.00E+00	0.00	3.57
4	3	18.00	0.00	0.00	0.00	8.55	3.16	0.69	0.13	0.06	0.71	1.60	0.06	0.04	0.10.00E+00	0.00	3.63
4	4	18.00	0.00	0.00	0.00	8.47	3.18	0.70	0.15	0.06	0.70	1.61	0.06	0.04	0.10.00E+00	0.00	3.70
5	1	18.00	0.00	0.00	0.00	7.82	3.06	0.68	0.25	0.06	0.70	1.70	0.06	0.04	0.10.00E+00	0.00	4.42
5	2	18.00	0.00	0.00	0.00	7.41	2.83	0.66	0.36	0.07	0.71	1.79	0.06	0.04	0.10.00E+00	0.00	6.33
5	3	18.00	0.00	0.00	0.00	7.15	2.63	0.63	0.45	0.08	0.72	1.88	0.06	0.04	0.10.00E+00	0.00	8.94

***** STEADY STATE SIMULATION *****

** ALGAE DATA **

ELE ORD	RCH NUM	ELE NUM	CHLA UG/L	ALGY GRWTH 1/DAY	ALGY RESP 1/DAY	ALGY SETT M/DAY	A P/R RATIO *	NET P-R MG/L-D	NH3 PREF *	NH3-N FRACT N-UPTKE *	LIGHT EXTCO 1/M	ALGAE GROWTH RATE ATTEN FACTORS LIGHT *	NITRGN *	PHSPRS *
1	1	1	3.23	1.47	0.05	0.00	25.77	0.15	0.90	0.43	0.00	0.55	0.99	0.97
2	1	2	3.23	1.47	0.05	0.00	25.80	0.15	0.90	0.46	0.00	0.55	0.99	0.97
3	1	3	3.28	1.47	0.05	0.00	25.85	0.15	0.90	0.47	0.00	0.55	0.99	0.97
4	2	1	3.30	1.47	0.05	0.00	25.87	0.15	0.90	0.50	0.00	0.55	0.99	0.97
5	2	2	3.32	1.47	0.05	0.00	25.87	0.15	0.90	0.52	0.00	0.55	0.99	0.97
6	2	3	3.35	1.48	0.05	0.00	25.88	0.15	0.90	0.55	0.00	0.55	0.99	0.97
7	3	1	3.38	1.48	0.05	0.00	25.89	0.15	0.90	0.56	0.00	0.55	0.99	0.97
8	3	2	3.40	1.48	0.05	0.00	25.89	0.15	0.90	0.58	0.00	0.55	0.99	0.97
9	3	3	3.41	1.48	0.05	0.00	25.91	0.16	0.90	0.57	0.00	0.55	0.99	0.98
10	3	4	3.48	1.47	0.05	0.00	25.85	0.16	0.90	0.52	0.00	0.55	0.99	0.97
11	4	1	3.51	1.47	0.05	0.00	25.86	0.16	0.90	0.57	0.00	0.55	0.99	0.97
12	4	2	3.57	1.47	0.05	0.00	25.87	0.16	0.90	0.60	0.00	0.55	0.99	0.97
13	4	3	3.63	1.47	0.05	0.00	25.87	0.16	0.90	0.63	0.00	0.55	0.99	0.97
14	4	4	3.70	1.48	0.05	0.00	25.88	0.17	0.90	0.65	0.00	0.55	0.99	0.97
15	5	1	4.42	1.48	0.05	0.00	25.89	0.20	0.90	0.76	0.00	0.55	0.99	0.97
16	5	2	6.33	1.48	0.05	0.00	25.90	0.29	0.90	0.82	0.01	0.55	1.00	0.98
17	5	3	8.94	1.48	0.05	0.00	25.91	0.41	0.90	0.85	0.01	0.55	1.00	0.98

***** STEADY STATE SIMULATION *****

** DISSOLVED OXYGEN DATA **

ELE ORD	RCH NUM	ELE NUM	TEMP DEG-C	DO SAT MG/L	DO MG/L	DO DEF MG/L	DAM INPUT MG/L	NIT INHIB FACT	COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE (MG/L-DAY)						
									F-FNCTN INPUT	OXYGN REAIR	C-BOD	SOD	NET P-R	NH3-N	NO2-N
1	1	1	18.00	9.27	8.56	0.72	0.00	1.00	199.33	2.96	-0.70	0.00	0.15	-0.06	-0.09
2	1	2	18.00	9.27	8.59	0.68	0.00	1.00	10.93	2.75	-0.75	0.00	0.15	-0.07	-0.08
3	1	3	18.00	9.27	8.63	0.64	0.00	1.00	50.53	2.28	-0.76	0.00	0.15	-0.07	-0.08
4	2	1	18.00	9.27	8.63	0.64	0.00	1.00	10.34	1.99	-0.79	0.00	0.15	-0.07	-0.07
5	2	2	18.00	9.27	8.63	0.64	0.00	1.00	9.85	1.91	-0.82	0.00	0.15	-0.08	-0.07
6	2	3	18.00	9.27	8.63	0.65	0.00	1.00	9.42	1.86	-0.84	0.00	0.15	-0.08	-0.07
7	3	1	18.00	9.27	8.63	0.64	0.00	1.00	10.35	2.11	-0.86	0.00	0.15	-0.09	-0.06
8	3	2	18.00	9.27	8.64	0.63	0.00	1.00	10.09	2.37	-0.88	0.00	0.15	-0.09	-0.06
9	3	3	18.00	9.27	8.66	0.62	0.00	1.00	50.16	2.26	-0.86	0.00	0.16	-0.09	-0.06
10	3	4	18.00	9.27	8.78	0.49	0.00	1.00	64.51	1.75	-0.84	0.00	0.16	-0.08	-0.07
11	4	1	18.00	9.27	8.70	0.57	0.00	1.00	7.82	1.65	-1.42	-0.81	0.16	-0.09	-0.07
12	4	2	18.00	9.27	8.62	0.65	0.00	1.00	7.65	1.47	-1.43	-0.79	0.16	-0.11	-0.06
13	4	3	18.00	9.27	8.55	0.73	0.00	1.00	7.50	1.63	-1.44	-0.77	0.16	-0.12	-0.06
14	4	4	18.00	9.27	8.47	0.80	0.00	1.00	7.35	1.77	-1.45	-0.76	0.17	-0.13	-0.06
15	5	1	18.00	9.27	7.82	1.45	0.00	1.00	0.75	2.98	-1.39	-3.26	0.20	-0.22	-0.06
16	5	2	18.00	9.27	7.41	1.87	0.00	1.00	0.73	3.56	-1.29	-3.26	0.29	-0.32	-0.07
17	5	3	18.00	9.27	7.15	2.12	0.00	1.00	0.71	4.05	-1.20	-3.26	0.41	-0.40	-0.08

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                                 D I S S O L V E D   O X Y G E N   ( M G / L )
       0.0       1.0       2.0       3.0       4.0       5.0       6.0       7.0       8.0       9.0      10.0
R   8.5 ++++.++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*+++++++++++++++
        +    .    +         +         +         +         +         +         +         +    *    +         +
I       +    .    +         +         +         +         +         +         +         +     *   +         +
        +    .    +         +         +         +         +         +         +         +     *   +         +
V       +    .                                                                                *             +
        +    .                                                                                *             +
E       +     .                                                                               *             +
        +     .                                                                               *             +
R       +     .                                                                               *             +
        +    .                                                                                 *            +
    3.5 ++++.                                                                                 *         +++++
        +     .                                                                              *              +
K       +     .                                                                              *              +
        +     .   +         +         +         +         +         +         +         +   *     +         +
I       +    .    +         +         +         +         +         +         +       * +         +         +
        +    .    +         +         +         +         +         +         +   *     +         +         +
L   0.5 ++++.++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*+++++++++++++++++++++++++++++
       0.0       5.0      10.0      15.0      20.0      25.0      30.0      35.0      40.0      45.0      50.0
                       B I O C H E M I C A L   O X Y G E N   D E M A N D   ( M G / L )
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DISSOLVED OXYGEN   = * * * *

BIOCHEMICAL OXYGEN DEMAND = ...

Appendix B: Water Quality Monitoring Data of Shellpot Creek Watershed

Shellpot STORET No. 102011 (US Rt 13 Bridge, Gov Printz Blvd)

Date Month/Day/Year		Water TempC 00010	Air TempC 00020	pH 00400	Flow CFS 00061	Salinity ppt 00096	Secchi IN 00077	SpecC uS/cm field 00094	DO(field) MG/L 00299	DO 00300	CBOD5 MG/L 80082	CBOD20 MG/L 80087	Hard MG/L 00900	TOC MG/L 00680	DOC MG/L 00681
4/25/2000		11.9	12	7.5		0.2		459	10.07	10.24	2.4	2.76	125	6	5
5/23/2000		14.7	18	6.9	FQ	0.2		357.8	9.22	8.6	2.4	2.98	90	5	6
5/23/2000	D	14.7	18	6.9		0.2		357.8	9.22	8.39	2.4	3.11	86	6	5
8/15/2000		20.3	30	7.4	NE	0.1		222.6	8.35	7.39	2.4	2.4	59	4	4
10/10/2000		15.8	9.5	7.3		0.3	14	630	8.08	8.32	2.4	2.4	106	4	4
4/16/2001		11.3	11	6.7	25.04	0.1	NA	310.9	10.62	10.05	2.4	2.4	67	7	7
6/11/2001		20.5	30	7.4	7.06	0.3	NA	532	7.5	7.9	2.4	2.56	137	3	3
8/7/2001		24.9	35	7.6	NA	0.3	NA	559	6.24	5.8	2.4	2.4	149	4	3
8/7/2001	D	24.9	35	7.6	NA	0.3	NA	559	6.24	4.86	2.4	2.4	148	NA	3
10/31/2001		9.9	17	IF	FQ	0.3	NR	550	6.62	6.03	2.4	2.4	177	4	4
10/31/2001	D	9.9	17	IF	FQ	0.3	NR	550	6.62	5.93	2.4	2.4	172	5	4
4/24/2002		10.9	15	7.2	NC	0.23	NC	479	9.27	8.62	2.4	2.4	124	5	4
4/24/2002	D				NE					8.25	2.4	2.4	123	6	5
6/17/2002		18.17	22	7.2	SNF	0.2		386	7	6.7	2.4	2.4	115	4.4	4.1
8/7/2002		21.62	22	6.1	SNF	0.3		611	1.4	0.4	2.4	4.1	160	5.3	4.2
11/13/2002		11.32	6	6.8	SNF	0.1		209	5.4	9.1	2.4	4.19	77.5	10.2	10.1
4/22/2003		13.18	13	7.5	IM	0.3		572	10.5		2.4	2.4	142	E 3.7	E 4.8
6/10/2003		16.88	20	7	IM	0.2		493	9.1		2.4	2.48	121	5.3	5
11/5/2003		15.69	17	6.8	IM	0.2		473	8.3		2.4	2.4	134	5.8	5.3

Date Month/Day/Year		Alkal MG/L 00410	TKjel MG/L 00625	AmoN MG/L 00610	Chloride MG/L 00940	NOXN MG/L 00630	TotalN MG/L ****	DPhos MG/L 00671	TPhos MG/L 00665	TSS MG/L 00530	Chlor-a UG/L 32211	Pheo-a UG/L 32218	Turb FTU 00076	SpecC uS/cm lab 00095
4/25/2000		69	NV#	0.044	80	1.05	#VALUE!	0.005	0.067	8	3	3	2	
5/23/2000		57	0.629	0.092	54	1.22	1.849	0.036	0.049	1	3	3	3	
5/23/2000	D	57	0.761	0.1	56	1.22	1.981	0.034	0.051	2	1	6	3	
8/15/2000		45	0.526	0.073	30	0.82	1.346	0.034	0.058	2	3	3	4	

10/10/2000		50	0.796	0.061	145	2.06	2.856	0.063	0.124	20	10.7	13.6	24
4/16/2001		46	0.675	0.047	55	0.964	1.639	0.009	0.04	6	1	13	8
6/11/2001		76	0.573	0.072	100	1.39	1.963	0.02	0.054	3	1	6	20
8/7/2001		83	0.881	0.093	91	0.641	1.522	0.011	0.12	2	1	9	2
8/7/2001	D	82	JH 0.55	0.106	93	0.618	#VALUE!	0.012	0.073	1	3	5	2
10/31/2001		100	0.466	0.071	108	0.083	0.549	0.005	0.042	1	1	4	2
10/31/2001	D	98	0.502	0.074	102	0.094	0.596	0.005	0.03	1	1	5	2
4/24/2002		72	0.593	0.129	90	0.384	0.977	0.007	0.067	6	3	2	4
4/24/2002	D	74	0.548	0.13	95	0.44	0.988	0.005	0.05	1	3	2	4
6/17/2002		69.7	0.415	0.059	72	0.84	1.255	0.029	0.045	3	1	2	2
8/7/2002		106	1.75	1.18	103	0.062	1.812	J 0.004	0.324	27	2	2	20
11/13/2002		50.6	0.79	J 0.017	33	0.727	1.517	0.042	0.086	9	1	2	8
4/22/2003		68.3	1.74	1.2	127	0.813	2.553	0.014	0.073	2	1	2	1
6/10/2003		61	0.75	0.051	90	3.81	4.56	0.027	0.067	11	J 0.7	2	1
11/5/2003		112	1.3	0.564	89	0.534	1.834	J 0.007	0.08	8	J 1.0	2	8

Shellpot STORET No. 102041 (Cherry Island at Rd 501 Bridge)

Date Month/Day/Year		Water TempC 00010	Air TempC 00020	pH 00400	Flow CFS 00061	Secchi IN 00077	Salinity ppt 00096	SpecC uS/cm field 00094	DO (field) MG/L 00299	DO 00300	CBOD5 MG/L 80082	CBOD20 MG/L 80087	Hard MG/L 00900	TOC MG/L 00680	DOC MG/L 00681
4/25/2000		12.6	11.5	7.2		21	0.3	571	6.6	7.34	2.4	2.4	153	7	6
4/25/2000	D	12.6	11.5	7.2		21	0.3	571	6.6	7.46	2.4	2.4	138	8	6
5/23/2000		15.3	19	7.3		18	0.2	348.3	5.33	4.76	2.4	2.4	100	6	5
10/10/2000		17.1	9	7.3		13	0.4	7460	7.49	6.77	2.4	2.4	134	5	4
4/16/2001		12.1	13	6.6		34	0.2	394	7.77	7.85	2.4	2.66	99	7	7
4/16/2001	D	12.1	13	6.6		34	0.2	394	7.77	8.45	2.4	2.4	74	7	6
6/11/2001		22.4	30	7.2		8	0.3	671	2.92	3.63	2.4	4.16	161	6	5
6/11/2001	D	22.4	30	7.2		8	0.3	671	2.92	3.57	2.4	3.8	157	6	5
10/31/2001		15.5	17	IF		12	1.6	3050	9.19	8.44	2.4	2.4	380	6	4
4/24/2002		12.99	15	7.1	NC	16	0.23	475	6.14	4.21	2.4	2.46	130	7	6

6/17/2002	22.54	22	6.8	18	0.2	401	4.6	4.2	2.4	3	119	6	5.5
8/7/2002	22.31	22	6.5	18	1.2	2263	4.7	4.1	3.7	6.2	280	5.7	5.2
11/13/2002	11.41	6	7.4	18	0.1	269	10.2	4.2	3.01	8.03	59.8	E 10.5	E 10.5
4/22/2003	14.88	13	7	BT 36	0.3	685	6.2		2.4	2.4	165	6	4.6
6/10/2003	19.73	21	6.8	BT 39	0.2	479	4.2		2.4	QC 4.16	131	7.1	6.4
11/5/2003	16.04	17	6.4	30	0.3	540	2.7		2.52	3.14	141	E 5.4	E 6.0

Date		Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo-a	Turb	SpecC uS/cm
Month/Day/Year		MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU	lab
		00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076	00095
4/25/2000		97	NV#	1.68	87	1.05	#VALUE!	0.008	0.119	20	3	7	19	
4/25/2000	D	98	NV#	1.64	88	1.06	#VALUE!	0.006	0.122	20	3	9	18	
5/23/2000		68	1.1	0.701	62	0.986	2.086	0.016	0.086	16	3	3	14	
10/10/2000		51	0.815	0.114	132	2.2	3.015	0.088	0.164	30	8.01	3.2	32	
4/16/2001		57	1.04	0.259	70	0.931	1.971	0.013	0.053	6	3	9	9	
4/16/2001	D	58	0.959	0.255	70	0.922	1.881	0.013	0.05	7	8	2	9	
6/11/2001		114	3.03	1.75	116	0.51	3.54	0.012	0.121	19	5	4	2	
6/11/2001	D	116	3.18	1.77	115	0.564	3.744	0.01	0.151	22	3	7	18	
10/31/2001		63	1.52	0.377	783	2.59	4.11	0.03	0.269	63	5	7	62	
4/24/2002		90	1.42	0.742	80	0.314	1.734	0.016	0.101	19	3	2	16	
6/17/2002		63.5	1.37	0.592	63	0.764	2.134	0.017	0.116	19	13	4	21	
8/7/2002		68.6	2.83	1.31	634	1.18	4.01	J 0.002	0.235	50	32	3	5	
11/13/2002		40.1	0.817	0.038	25	0.38	1.197	0.043	0.134	25	2	2	26	
4/22/2003		101	0.923	0.025	143	0.775	1.698	J 0.008	J 0.005	8	6	2	11	
6/10/2003		88	1.39	0.713	71	0.818	2.208	0.026	0.115	8	J 1.8	2	9	
11/5/2003		78.7	0.525	JL 0.005	92	0.879	1.404	0.02	0.052	J 4	J 2.2	2	3	

Shellpot STORET No. 102051 (Rt 13 Bud (Market Street))

Date	Water	Air	Flow	pH	Salinity	Secchi	SpecC uS/cm	DO (field)	DO	CBOD5	CBOD20	Hard	TOC	DOC
Month/Day/Year	TempC	TempC	CFS		ppt	IN	field	MG/L		MG/L	MG/L	MG/L	MG/L	MG/L
	00010	00020	00061	00400	00096	00077	00094	00299	00300	80082	80087	00900	00680	00681
8/15/2000	20.4	24.5	FQ	7.8	0.1		234.1	9.39	8.59	2.4	2.4	61	5	4
10/10/2000	9.4	9.5	NA	7.6	0.2	22	4222	10.78	11.38	2.4	2.4	148	4	3
4/16/2001	11.3	11	NA	6.5	0.1	NA	311.5	10.88	11.3	2.4	2.4	64	7	7
6/11/2001	19.3	30	0.81	7.5	0.3	NA	526	8.97	8.17	2.4	24	130	4	2
8/7/2001	24.6	35	NA	7.7	0.3	NA	540	8.89	8.09	2.4	2.4	145	2	3
10/31/2001	10.7	17	FQ	IF	0.2	NR	505	11.48	9.67	2.4	2.4	164	4	4
4/24/2002	10.9	14	NE	7.3	0.2	NC	405	11.7	8.79	2.4	2.4	113	6	4
6/17/2002	18.52	21	SNF	7.2	0.2		422	8.4	8	2.4	2.4	124	4.9	4.4

Date	Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo	Turb
Month/Day/Year	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU
	00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076
8/15/2000	54	0.554	0.039	33	0.864	1.418	0.038	0.058	2	3	3	3
10/10/2000	64	0.382	0.014	78	1.37	1.752	0.021	0.025	3	1	5.61	1
4/16/2001	45	0.764	0.033	56	0.866	1.63	0.01	0.051	3	5	6	9
6/11/2001	70	0.475	0.052	101	1.61	2.085	0.031	0.078	3	5	2	1
8/7/2001	78	0.497	0.053	92	0.748	1.245	0.019	0.08	3	1	7	2
10/31/2001	91	0.46	0.071	106	0.332	0.96	0.005	0.031	3	1	2	4
4/24/2002	65	0.455	0.054	74	0.505	1.513	0.011	0.033	6	9	4	3
6/17/2002	70.7	0.617	0.078	74	0.896	0	0.035	0.054	2	2	2	3

Shellpot STORET No. 102061 (Matson Run at Miller Road Bridge)

Date	Water	Air	Flow	pH	Salinity	Secchi	SpecC uS/cm	DO (field)	DO	CBOD5	CBOD20	Hard	TOC	DOC
Month/Day/Year	TempC	TempC	CFS		ppt	IN	field	MG/L		MG/L	MG/L	MG/L	MG/L	MG/L
	00010	00020	00061	00400	00096	00077	00094	00299	00300	80082	80087	00900	00680	00681
8/15/2000	19.3	23.5	FQ	7.5	0.3		560	8.1	7.61	2.4	2.4	94	4	4
10/10/2000	9.9	10.5	NA	7.4	0.4		7660	9.8	12.91	2.4	2.4	126	4	3

4/16/2001	10.7	10	NA	6.5	0.2		405.7	10.67	11.45	2.4	3	61	E 8	E 9
6/11/2001	17.8	30	FE	7.4	0.4		725	8.5	8.21	2.4	4.13	126	2	3
8/7/2001	Dry - No Sample													
10/31/2001	10.6	17	NA	IF	0.5		1082	9.36	8.97	2.4	2.3	200	5	3
4/24/2002	9.9	13	NC	7.2	0.37	NC	747	11.48	8.33	2.4	2.4	151	2	2
6/17/2002	16.93	21	0.12	7.1	0.4		759	8	8.7	2.4	2.4	151	3.3	2.6

Date	Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo	Turb
Month/Day/Year	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU
	00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076
8/15/2000	43	0.482	0.041	128	0.871	1.353	0.034	0.057	8	5	4	5
10/10/2000	54	0.331	0.01	68	1.7	2.031	0.023	0.024	1	1	5.61	1
4/16/2001	46	1.39	0.059	83	0.623	2.013	0.01	0.075	17	11	10	34
6/11/2001	60	0.581	0.05	303	1.48	2.061	0.025	0.086	8	5	2	3
8/7/2001												
10/31/2001	77	0.587	0.016	274	0.848	1.435	0.005	0.037	17	1	5	4
4/24/2002	60	0.327	0.017	190	1.08	1.407	0.005	0.03	3	1	2	4
6/17/2002	60.8	0.459	0.02	180	1.12	1.579	0.023	0.021	2	1	2	1

Shellpot STORET No. 102071 (Turkey Run at Weldin Road (Rt 215))

Date	Water	Air	pH	Flow	Salinity	Secchi	SpecC uS/cm	DO (field)	DO	CBOD5	CBOD20	Hard	TOC	DOC
Month/Day/Year	TempC	TempC		CFS	ppt	IN	field	MG/L		MG/L	MG/L	MG/L	MG/L	MG/L
	00010	00020	00400	00061	00096	00077	00094	00299	00300	80082	80087	00900	00680	00681
8/15/2000	19.5	23	7.6	FQ	0.1		195.3	6.66	6.48	2.4	2.4	64	7	5
10/10/2000	8.7	10.5	7.4	NA	0.2		4662	10.77	9.03	2.4	2.4	147	10	10
4/16/2001	10.8	10	6.5	NA	0.1		195.6	10.21	9.79	2.4	3.05	68	10	10
6/11/2001	19.1	30	7.2	FE	0.2		314.5	7.48	7.67	2.4	2.4	111	5	4
8/7/2001	Dry - No Sample													
10/31/2001	Dry - No Sample													
4/24/2002	9.6	13	7.3	0.35	0.12	NC	249	9.94	8.82	2.4	2.64	87	6	6
6/17/2002	17.82	20	7	SNF	0.1		301	7.2	7.8	2.4	2.4	103	E 5.0	E 5.1

Date	Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo	Turb

Month/Day/Year	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU
	00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076
8/15/2000	54	0.567	0.041	14	0.664	1.231	0.061	0.105	11	5	6	7
10/10/2000	69	10.4	0.045	83	1.47	11.87	0.033	0.042	2	1	5.61	1
4/16/2001	54	1.38	0.078	20	0.502	1.882	0.032	0.134	5	8	3	19
6/11/2001	90	0.577	0.066	50	0.816	1.393	0.056	0.103	1	3	3	1
8/7/2001												
10/31/2001						0						
4/24/2002	79	0.388	0.017	25	0.018	0.406	0.012	0.057	3	2	2	2
6/17/2002	76.5	0.471	0.037	30	0.76	1.231	0.074	0.101	2	1	2	1

Shellpot STORET No. 102081 (Shellpot Crk at Carr Road Bridge)

Date	Water	Air	pH	Flow	Salinity	Secchi	SpecC uS/cm	DO(field)	DO	CBOD5	CBOD20	Hard	TOC	DOC
Month/Day/Year	TempC	TempC		CFS	ppt	IN	field	MG/L		MG/L	MG/L	MG/L	MG/L	MG/L
	00010	00020	00400	00061	00096	00077	00094	00299	00300	80082	80087	00900	00680	00681
8/15/2000	21.5	23	7.8	0.43	0.1		215.5	8.7	8.12	2.4	2.4	52	4	4
10/10/2000	9.3	10.5	7		0.2		3784	12	8.8	2.4	2.4	157	2	2
4/16/2001	11.1	10	6.6	NA	0.1		229.7	10.98	12.1	2.4	2.41	59	8	8
6/11/2001	19.1	30	7.5	1.15	0.2		449.3	8.88	9.13	2.4	2.4	105	4	3
8/7/2001	24	32	7.7	NA	0.2	NA	492.7	7.84	8.08	2.4	2.4	118	2	2
10/31/2001	Dry - No Sample													
4/24/2002	9.6	73	7.4	NC	0.16	NC	329	10.9	7.51	2.4	2.4	92	5	4
6/17/2002	17.57	20	7.2	0.31	0.2		361	8	7.9	2.4	2.4	98.5	4.2	3.7

Date	Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo	Turb
Month/Day/Year	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU
	00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076
8/15/2000	42	0.478	0.033	33	0.822	1.3	0.036	0.054	2	3	3	2
10/10/2000	48	2.59	0.011	173	1.41	4	0.022	0.022	1	1	5.61	1
4/16/2001	42	0.802	0.037	34	0.774	1.576	0.01	0.063	3	11	2	9
6/11/2001	57	0.534	0.037	83	1.71	2.244	0.033	0.068	1	3	3	1
8/7/2001	61	0.413	0.02	85	1.19	1.603	0.019	0.074	3	3	3	1

10/31/2001						1.15						
4/24/2002	54	0.393	0.035	60	0.757	1.655	0.005	0.042	7	2	2	5
6/17/2002	55.4	0.465	J 0.017	64	1.19	0	0.037	0.045	2	1	2	1

Shellpot STORET No. 102091 (Shellpot Crk at Foulk Road (Rt 261))

							SpecC							
Date	Water	Air	pH	Flow	Salinity	Secchi	uS/cm	DO (field)	DO	CBOD5	CBOD20	Hard	TOC	DOC
Month/Day/Year	TempC	TempC		CFS	ppt	IN	field	MG/L		MG/L	MG/L	MG/L	MG/L	MG/L
	00010	00020	00400	00061	00096	00077	00094	00299	00300	80082	80087	00900	00680	00681
8/15/2000	20.3	24	7.2	0.13	0.1		220.3	5.1	4.35	2.4	2.4	65	4	4
10/10/2000	9.8	10.5	7.6		0.2		3663	6.17	5.42	2.4	2.69	121	5	4
4/16/2001	11.1	10	6.3	NA	0.1		180.6	9.57	9.13	2.4	2.78	57	7	7
6/11/2001	18.8	30	7.2	FE	0.3		526	5.83	6.56	2.4	2.96	124	4	4
8/7/2001	24.2	33	7.6	NA	0.2	NA	395.5	7.24	6.35	2.4	2.4	111	2	2
10/31/2001	Dry - No Sample													
4/24/2002	9.8	14	7.2	0.72	0.13	NC	270	10.4	6.94	2.4	2.98	98	4	4
6/17/2002	18.09	20	7	0.1	0.1		273	7.6	7.7	2.4	2.4	90.9	4.5	3.8

Date	Alkal	TKjel	AmoN	Chloride	NOXN	TotalN	DPhos	TPhos	TSS	Chlor-a	Pheo	Turb
Month/Day/Year	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	UG/L	UG/L	FTU
	00410	00625	00610	00940	00630	****	00671	00665	00530	32211	32218	00076
8/15/2000	64	0.636	0.13	19	0.298	0.934	0.027	0.094	5	3	7	3
10/10/2000	98	JH .558	0.16	45	0.436	#VALUE!	0.006	0.096	28	2.67	8.54	22
4/16/2001	47	0.842	0.169	17	0.821	1.663	0.058	0.125	2	1	10	11
6/11/2001	97	3.08	0.111	134	0.598	3.678	0.009	0.137	8	3	7	5
8/7/2001	55	0.281	0.034	56	1.94	2.221	0.065	0.103	3	5	2	1
10/31/2001						0						
4/24/2002	70	0.456	0.053	34	1.16	1.616	0.01	0.045	12	4	2	5
6/17/2002	51.8	0.468	0.037	37	1.47	1.938	0.051	0.059	2	1	2	1

BT=Bottom.
E=Value exceeds a theoretically equal or greater value, however, the difference isn't significant.

FE=

FQ=No Flow

IF=Field instrument malfunctioned; no measurement taken.

IM=Instrument malfunctioned, no measurement taken.

J=Analyte present, reported value is estimated.

JL=Result is likely underestimated due to matrix effect.

JH=Result is likely overestimated due to matrix effect.
NA=Not analyzed but required by work plan. Sample collected but not analyzed due to lab error

NC=Sample not collected but required by work plan
NE=Field measurement not taken due to uncontrollable event, depth of water too deep/shallow.

NR=Not required by workplan

NV# = Analytical result not valid

QC=Quality control value is outside acceptance limits.

SNF=Site has no flow.

Appendix C: Summary of Sensitivity Analysis

Parameter (Notation in Qual2E)	Parameter Description	Unit	Value used at Last Reach (rch5) of Shellpot Model	Input Change (%)	Response (%) at the Last Element (Ele3) of the Last Reach (Rch5)		
					DO	TN	TP
α0	Ratio of chlorophyll -a to algal biomass	ug Chl-*a*/ mg A	50	50	0.00	0.00	0.00
				-50	0.00	0.00	0.00
σ_1	Algal settling rate	m/day	0	mid of recommended value	-0.70	0.00	0.00
σ_2	Benthos source rate for dissolved phosphorous	mg-p / m2-day	0		0.00	0.00	0.00
					0.00	0.00	0.00
σ_3	Benthos source rate for ammonia nitrogen	mg-N / m2-day	300	50	-12.03	218.09	0.00
				-50	0.42	-7.98	0.00
σ_4	Organic nitrogen settling rate	day-I	0	mid of recommended value	0.00	-1.06	0.00
σ_5	Organic phosphorus settling rate	day-I	0	mid of recommended value	0.00	0.00	0.00
K_1	Carbonaceous deoxygeneration rate constant	day-I	0.5	50	-3.08	0.00	0.00
				-50	3.64	0.00	0.00
K_2	Reaeration rate constant	day-I	2	50	6.15	0.00	0.00
				-50	-9.37	0.00	0.00
K_3	Rate of loss of BOD due to settling	day-I	0		0.56	0.00	0.00
					-0.56	0.00	0.00
K_4	Benthic oxygen uptake (SOD)	mg-O / m2-day	2.2	50	-8.25	0.00	0.00
				-50	8.25	0.00	0.00
β1	Rate constant for the biological oxidation of NH3 to NO2	day -1	0.3	50	-0.70	0.00	0.00
				-50	0.84	0.00	0.00
β2	Rate constant for the biological oxidation of NO2 to NO3	day-I	1	50	-0.14	0.00	0.00
				-50	0.14	0.00	0.00
β3	Rate constant for the hydrolysis of organic- N to ammonia	day-I	0.25	50	-0.14	0.00	0.00
				-50	0.14	0.00	0.00
β4	Rate constant for the decay of organic-P to dissolved-P	day-I	0.1	50	0.00	0.00	0.00
				-50	0.00	0.00	0.00
T	Initial water temperature	C	18	50	-23.92	13.30	0.00
				-50	22.24	-7.45	0.00