Total Maximum Daily Loads of Phosphorus for Southeast Creek, Queen Anne's County, Maryland

FINAL

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List of Abbreviations

BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CAFO	Confined Animal Feeding Operations
CBOD	Carbonaceous Biochemical Oxygen Demand
CBP	Chesapeake Bay Program
CEAM	Center for Exposure Assessment Modeling
cfs	Cubic feet per second
Chl *a*	Chlorophyll *a*
COMAR	Code of Maryland Regulations
CWAP	Clean Water Action Plan
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
EUTRO 5.1	Eutrophication Module of WASP 5.1
FSA	Farm Service Agency
ft	feet
kg/yr	Kilogram per year
km	kilometer
km^2	Kilometers squared
LA	Load Allocation
lbs/yr	Pounds per year
LILAC	Low Income Loans for Agricultural Conservation
MACS	Maryland's Agricultural Cost Share Program
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
mgd	Million gallons per day
mg/l	Milligrams per Liter
MOS	Margin of Safety
NBOD	Nitrogenous Biochemical Oxygen Demand
NH_4	Ammonia
$NO_{2\text{-}3}$	Nitrate + Nitrite
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
ON	Organic Nitrogen
OP	Organic Phosphorus
PO_4	Ortho-Phosphate
SCEM	Southeast Creek Eutrophication Model
SOD	Sediment Oxygen Demand

TMDL	Total Maximum Daily Load
µg/l	Micrograms per Liter
USGS	United States Geological Survey
WASP 5.1	Water Quality Analysis Simulation Program Version 5.1
WLA	Waste Load Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

This document proposes to establish a Total Maximum Daily Load (TMDL) of phosphorus for Southeast Creek (basin number 02-13-05-08). Southeast Creek drains to the Chester River and is part of the Upper Eastern Shore Tributary Strategy Basin. The tidal portion of Southeast Creek was identified on the State's 1996 list of Water Quality Limited Segments (WQLSs) as impaired by nutrients, suspended sediments and fecal coliform. Water quality data and modeling analyses suggest that the nutrient phosphorus is the cause of excessive algal growth in the Southeast Creek (supporting data are provided in Appendix A); therefore, this TMDL is established for phosphorus to address the nutrient impairment. The water quality goal of this TMDL is to reduce high chlorophyll *a* concentrations (a surrogate for algal blooms) and to maintain the dissolved oxygen (DO) concentration at a level where the designated uses for Southeast Creek will be met. The suspended sediment and fecal coliform impairments will be addressed at a later date.

The TMDL was determined using the WASP5.1 water quality model. The modeling analyses investigated seasonal variations indicating that phosphorus causes excessive algal growth during low flow and average annual flow conditions. Therefore, a loading cap on phosphorus entering Southeast Creek is established for low flow and average annual flow conditions. This will ensure that loads during the higher flow seasons do not contribute to impairments observed during low flow seasons.

The low flow TMDL for phosphorus is 259 lbs/month, which applies during the period May 1 through October 31. The allowable loads have been allocated between point and nonpoint sources. The nonpoint source loads are allocated as 130 lbs/month. The point source loads are allocated as 122 lbs/month. An explicit margin of safety makes up the balance of the allocation.

The average annual TMDL for phosphorus is 21,113 lbs/yr. Baseline average annual nonpoint source loads estimates, from which reductions are computed, are based on the Environmental Protection Agency (EPA) Chesapeake Bay Program (CBP) watershed model averaged from 1984 to 1999. The allowable loads have been allocated between point and nonpoint sources. The nonpoint source loads are allocated as19,078 lbs/yr. The point source loads are allocated as 1,462 lbs/yr. An explicit margin of safety makes up the balance of the allocation.

Four factors provide assurance that this TMDL will be implemented. First, NPDES permits will assure implementation for point sources. Second, Maryland has several well-established programs to draw upon, including Maryland's Tributary Strategies for Nutrient Reductions developed in accordance with the Chesapeake Bay Agreement. Third, Maryland's Water Quality Improvement Act of 1998 requires that nutrient management plans be implemented for all agricultural lands throughout Maryland. Finally, Maryland adopted a watershed cycling strategy, assuring that future monitoring and TMDL evaluations of Southeast Creek are conducted.

1.0 INTRODUCTION

Section 303(d)(1)(C) of the federal Clean Water Act and U.S. Environmental Protection Agency's (EPA) implementing regulations direct each State to develop a Total Maximum Daily Load (TMDL) for each impaired water quality limited segment on the Section 303(d) list, taking into account seasonal variations and a protective margin of safety (MOS) to account for uncertainty. A TMDL reflects the total pollutant loading of the impairing substance a water body can receive and still meet water quality standards.

TMDLs are established to achieve and maintain water quality standards. Water quality standards are the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, and shellfish propagation and harvest. Water quality criteria can be either a narrative statement or a numeric value designed to protect the designated uses. Criteria may differ among waters that have different designated uses.

Southeast Creek was first identified on the 1996 303(d) list submitted to EPA by the Maryland Department of the Environment (MDE). It was listed as impaired by nutrients due to signs of eutrophication, suspended sediments and fecal coliform (the suspended sediments and fecal coliform impairments will be addressed at a later date). This document addresses only the nutrient impairment. Eutrophication is the overenrichment of aquatic systems by excessive inputs of nutrients, especially nitrogen and phosphorus. Nutrients act as fertilizer leading to excessive growth of aquatic plants. Algae eventually die and decompose leading to bacterial consumption of dissolved oxygen (DO). Observed data and model sensitivity analyses indicate that algal growth is limited by the availability of phosphorus in Southeast Creek. For this reason, it is possible to eliminate the nutrient impairment by limiting the amount of phosphorus entering the waterbody, without regard to the loadings of other nutrients.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Southeast Creek is located within Queen Anne's County, Maryland (Figure 1). It drains into the Chester River, which in turn drains to Chesapeake Bay. The creek is approximately 5.1 miles (8.1 kilometers) in length, from its confluence with the Chester River to the tidal upper reaches of its headwaters. The Southeast Creek watershed has an area of approximately 34,994 acres (141.6 km^2). As seen in Figure 2, the land use in the watershed consists of mixed agriculture (23,560 acres or 67.3%), forest and other herbaceous cover (9,835 acres or 28.1%), urban (961 acres or 2.8%), and water (638 acres or 1.8%).

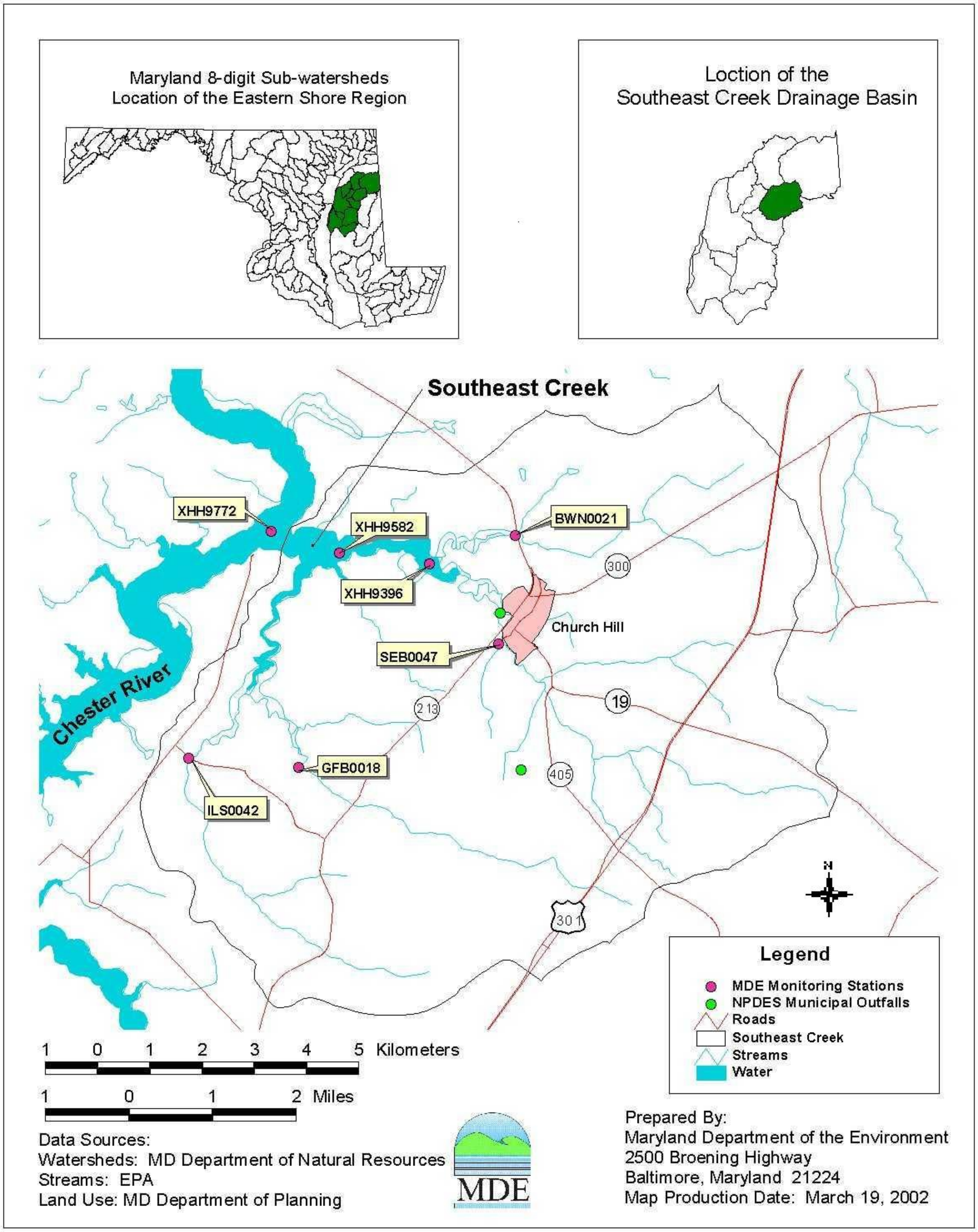

Figure 1: Location Map of the Southeast Creek Drainage Basin within Queen Anne's County

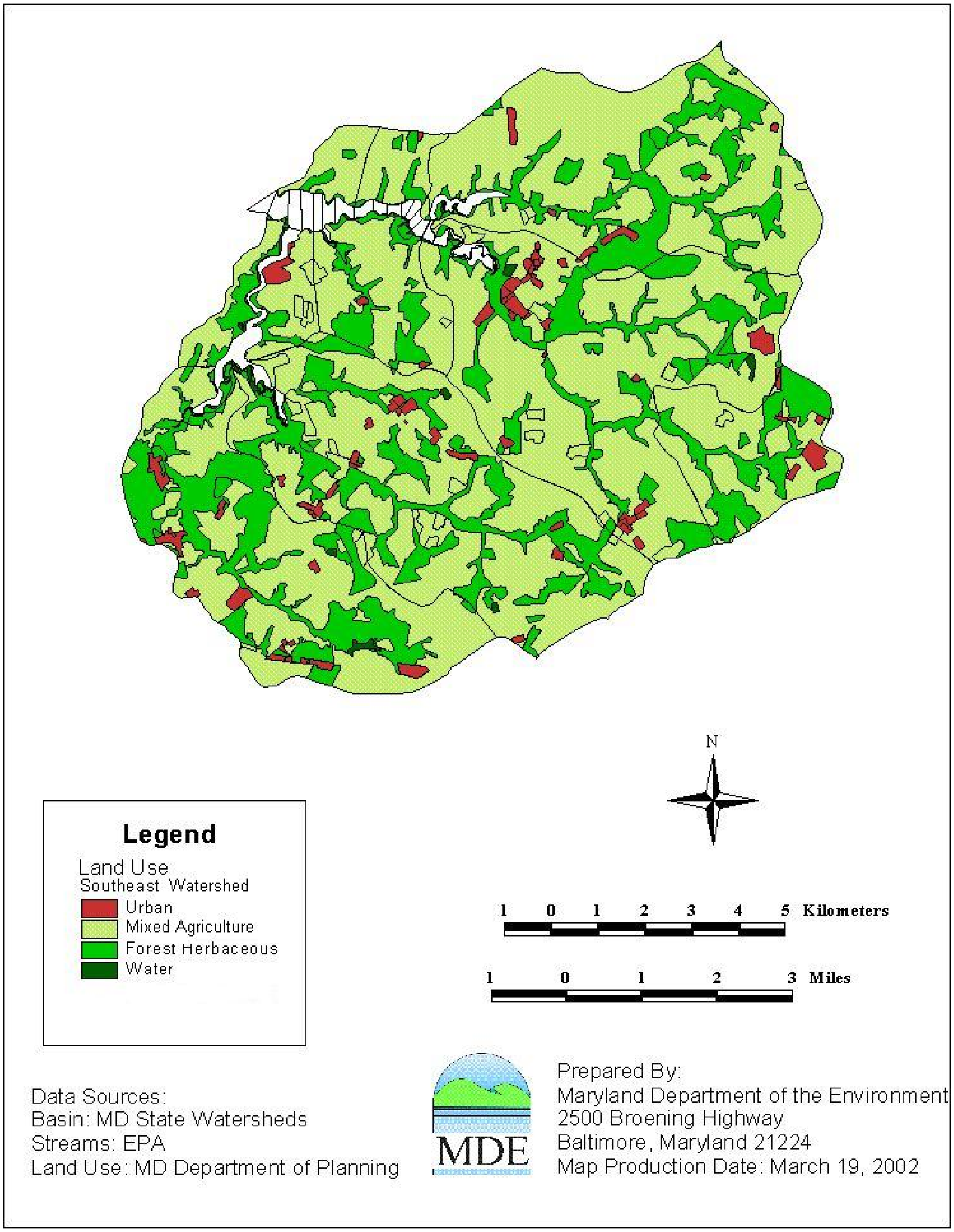

Figure 2: Land Use in the Southeast Creek Drainage Basin

The land use is based on 1997 Maryland Department of Planning (MDP) land cover data, and 1997 Farm Service Agency (FSA) information. Figure 3 shows the relative amounts of the different land uses.

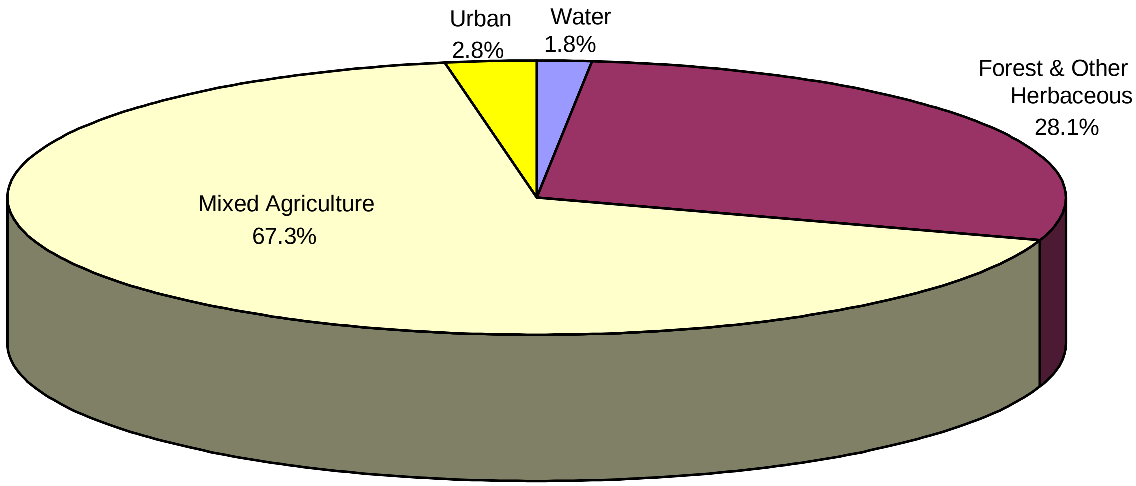

Figure 3: Proportions of Land Use in the Southeast Creek Drainage Basin

Southeast Creek is tidal throughout its navigable reach, extending from the confluence with the Chester River to approximately 3 miles (5 kilometers) up to the head of tide. The water quality model extends to the non-tidal region for approximately 2 miles upstream of the head of tide. The depths of the creek range from about 0.5 feet (0.15 meters) near the headwaters to greater than 7 feet (2.1 meters) at the mouth of the creek. Widths can vary from 185 ft (55 meters) at the tidal headwaters to 550 ft (165 meters) at the mouth.

In the Southeast Creek watershed, the estimated average annual total nitrogen load is 547,394 lbs/yr (248,294 kg/yr), and the total phosphorus load is 50,589 lbs/yr (22,947 kg/yr). The nonpoint source (NPS) nitrogen load is 545,711 lbs/yr (247,529 kg/yr), and the NPS phosphorus load is 49,127 lbs/yr (22,283 kg/yr). The estimated average annual nitrogen load for point sources is 1,683 lbs/yr (765 kg/yr) and the estimated average annual phosphorus load is 1,462 lbs/yr (665 kg/yr). Figure 4 shows the relative amounts of nitrogen and phosphorus point source and NPS loadings. The NPS loads were determined using land use loading coefficients. The land use information was based on 1997 MDP data, with refinements to cropland based on 1997 FSA data. The total NPS load was calculated by summing all of the individual land use areas and multiplying by the corresponding land use loading coefficient. The loading coefficients were based on the results of the Phase 4.3 Chesapeake Bay Watershed Model (U.S.EPA, 1996), a continuous simulation model. The Chesapeake Bay Program (CBP) loading coefficients account for atmospheric deposition, loads from septic tanks and loads coming from urban development, agriculture and forestland. These long-term average load values are presented to give the reader a reasonable estimate of the source contributions, and a sense of "current" conditions.

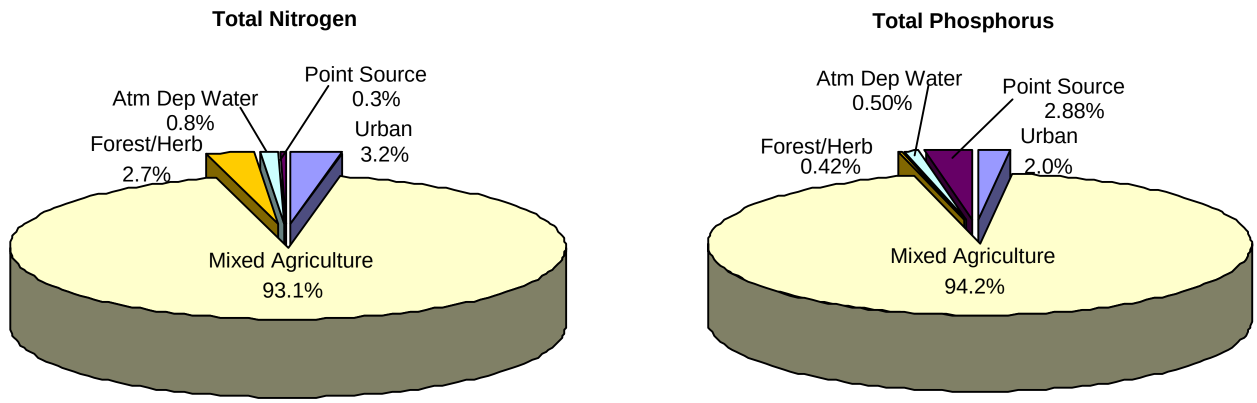

Figure 4: Estimated Average Annual Nitrogen and Phosphorus Point and Nonpoint Source Loads

There are two point sources in the Southeast Creek watershed: the Church Hill Waste Water Treatment Plant (WWTP) and the Eastern Pre-Release Unit WWTP. For modeling purposes, the Eastern Pre-Release Unit WWTP was considered as part of the upstream background load, because it is located far away from the Southeast Creek and its discharge is four times less that that of the Church Hill WWTP. During 1999, the time period used to calibrate the simulation model, loads from Church Hill WWTP were estimated to contribute 916 lbs/yr (416 kg/yr) of nitrogen and 259 lbs/yr (117 kg/yr) of phosphorus. The flows to segment 20 of Southeast Creek from Church Hill WWTP were 21, 78, 116 and 145 times less than NPS discharge to this segment for critical, summer, spring and average annual flows, respectively. This information was obtained from discharge monitoring reports stored in MDE's point source database.

2.2 Water Quality Characterization

Four water quality parameters associated with the observed impairment of Southeast Creek - chlorophyll *a* (Chl *a*), DO, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP) - are presented in Figures 5 through 8 below. These data were collected by MDE at seven water quality stations in Southeast Creek and its branches during 1999. Three sets of samples were collected during seasonal low flow periods during Summer 1999 (13-July-99, 10-Aug-99, 08-Sept-99) and three sets were collected during high flow periods in Spring 1999 (10-Mar-99, 06-Apr-99, 03-May-99). The reader is referred to Figure 1 for the locations of the water quality sampling stations. Table 1 presents the distance of each station from the mouth of the river.

Table 1: Location of Water Quality Monitoring Stations along Southeast Creek

Water Quality Station		Distance from the Mouth (km)
Southeast Creek Mainstem		
XHH9772	(Chester River)	0.00
XHH9582		1.49
XHH9396		3.85
SEB0047		8.14
Browns Branch		
BWN0021*		7.11
Island Creek		
ILS0042*		7.59
Granny Finley Branch		
GFB0018*		7.98

*Non-tidal stations

Problems associated with eutrophication are most likely to occur during the summer season (July, August, September). During this season, there is typically less stream flow available to flush the system, more sunlight to grow aquatic plants, and warmer temperatures. These conditions are favorable for biological processes of both plant growth and dead plant matter decay. Because problems associated with eutrophication are usually most acute during the summer season, temperature, flow, sunlight and other parameters associated with this period represent critical conditions for the TMDL analysis. As discussed below, the TMDL analysis also considers other seasons; however, the data collected during the high flow period (March, April, May) do not show chlorophyll *a* or DO problems. The following graphs present data from the low flow period. Additional data, including those for the high flow periods, are presented in Appendix A.

Tables 2 through 5 present data collected during Summer 1999, including the three additional stations located at three different branches of the creek. Figures 5 through 8 present sampling data collected in the mainstem and branches of Southeast Creek, as well as longitudinal profiles of the water quality data collected in the mainstem during Summer 1999. The sampling region covers the entire tidal portion of the Southeast Creek from its confluence with the Chester River, (Station XHH9772) up to just above the head of tide (Station SEB0047). Data for several nontidal lateral branches were also collected.

Figure 5 presents two longitudinal profiles of chlorophyll *a* data collected during the 1999 spring period, which are associated with higher flows, and summer period, which are associated with lower flows. During the spring period, shown in the left panel of Figure 5, the ambient chlorophyll *a* concentrations are generally below 10 µg/l, with a maximum value of about 16 µg/l near the confluence of the Chester River. During the summer period, shown in the right panel of Figure 5, an algal bloom of about 68 µg/l is observed. Data presented in Table 2 indicates that chlorophyll *a* also reached about 64 µg/l in one of the nontidal branches (Station ILS0042).

Table 2: Chlorophyll *a* data

	Stations	Distance from Mouth (km)	10-Mar -99	06-Apr -99	03-May -99	Average High flow	13-Jul -99	10-Aug -99	08-Sep -99	Average Low flow	Average Annual
			SE Creek M ainstem				**SE Creek M ainstem**				
0	XHH9772	0.00	3.0	2.0	16.4	7.13	15.2	10.5	6.5	10.73	8.93
1	XHH9582	1.49	2.8	5.5	6.5	4.93	5.2	5.2	3.2	4.53	4.73
2	XHH9396	3.85	4.1	6.5	5.2	5.27	3.5	8.5	67.8	26.60	15.93
3	*SEB0047*	*8.14*	*1.9*	*5.4*	*8.2*	*5.17*	*1.2*	*6.0*	*13.5*	*6.90*	*6.03*
			SE Creek Branches				**SE Creek Branches**				
4	*BWN0021*	*7.11*	*1.1*	*5.1*	*7.0*	*4.40*	*0.6*	*1.0*	*9.7*	*3.77*	*4.08*
5	*GFB0018*	*7.98*	*4.5*	*5.6*	*7.5*	*5.87*	*1.2*	*1.5*	*4.5*	*2.40*	*4.13*
6	*ILS0042*	*7.59*	*14.0*	*13.5*	*2.0*	*9.83*	*63.9*	*18.9*	*31.4*	*38.07*	*23.95*

Note: Nontidal stations are in italics Chlorophyll *a* concentrations in µg/l

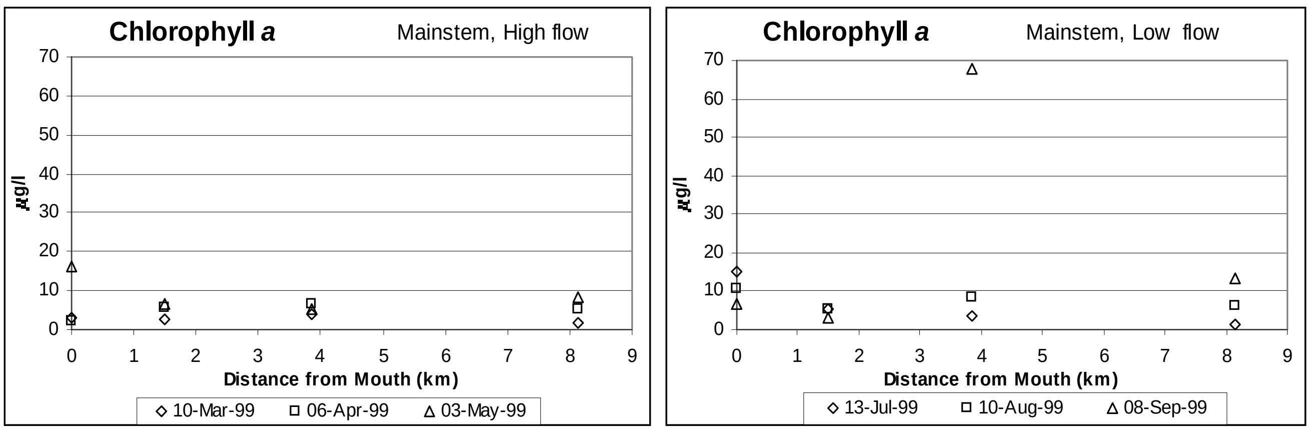

Figure 5: Longitudinal Profile of Chlorophyll *a* Data (High and Low Flow)

Figure 6 presents two longitudinal profiles of dissolved oxygen (DO) data collected during the 1999 spring period, which are associated with higher flows, and summer period, which are associated with lower flows. During the spring period, shown in the left panel of Figure 6, the ambient DO concentrations are well above the criterion of 5.0 mg/l, ranging from about 7.5 mg/l to 14.0 mg/l. During the summer period, shown in the right panel of Figure 6, many DO values near the criterion of 5.0 mg/l are observed, falling below the criterion in one case (3.8 mg/l). Data presented in Table 3 indicates that DO in one of the nontidal branches also fell below the criterion of 5.0 mg/l (Station ILS0042).

Table 3: Dissolved Oxygen data

	Stations	Distance from Mouth (km)	10-Mar -99	06-Apr -99	03-May -99	Average High flow	13-Jul -99	10-Aug -99	08-Sep -99	Average Low flow	Average Annual
			SE Creek Mainstem				**SE Creek Mainstem**				
0	XHH9772	0.00	11.1	7.9	7.8	8.93	5.8	5.6	5.9	5.77	7.35
1	XHH9582	1.49	11.1	7.9	8.5	9.17	5.4	5.4	3.8	4.87	7.02
2	XHH9396	3.85	11.4	7.9	8.0	9.10	5.0	5.4	5.3	5.23	7.17
3	*SEB0047*	*8.14*	*13.9*	*10.4*	*9.8*	*11.37*	*8.2*	*7.9*	*6.7*	*7.60*	*9.48*
			SE Creek Branches				**SE Creek Branches**				
4	*BWN0021*	*7.11*	*12.8*	*10.7*	*9.6*	*11.03*	*8.3*	*8.7*	*7.2*	*8.07*	*9.55*
5	*GFB0018*	*7.98*	*12.7*	*10.0*	*9.7*	*10.80*	*7.7*	*6.8*	*5.8*	*6.77*	*8.78*
6	*ILS0042*	*7.59*	*13.0*	*9.6*	*8.2*	*10.27*	*3.5*	*4.1*	*6.5*	*4.70*	*7.48*

Note: Nontidal stations are in italics DO concentrations in mg/l

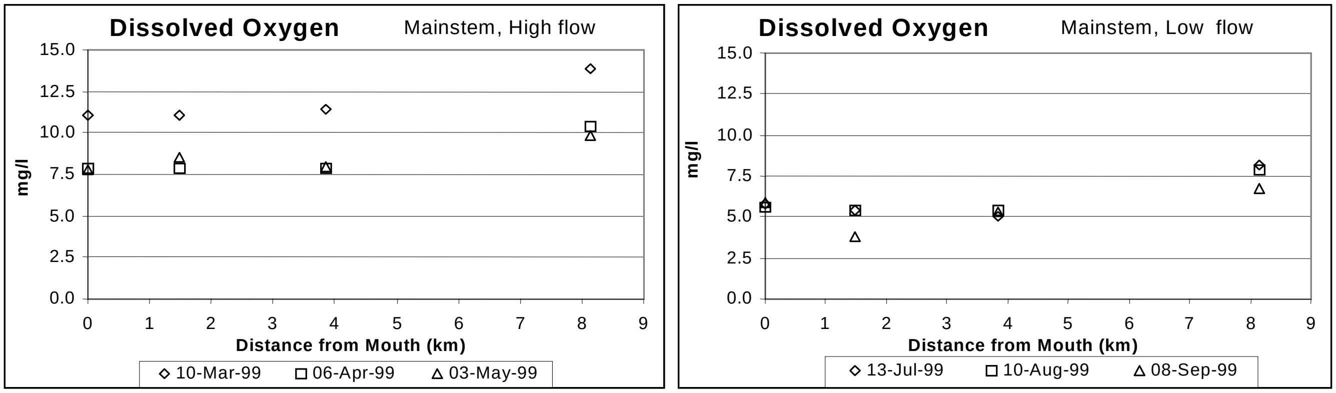

Figure 6: Longitudinal Profile of Dissolved Oxygen Data (High & Low Flow)

Figure 7 presents a longitudinal profile of the mainstem data for Dissolved Inorganic Nitrogen (DIN) measured as ammonia plus nitrate plus nitrite for samples collected in summer 1999 during low and high flow conditions. The concentration of DIN varies greatly throughout the length of the creek with values ranging between 0.126 mg/l (station XHH9772) and 8.2 mg/l (station BWN0021). Table 4 includes data collected in the lateral branches. The highest values were observed at two nontidal stations: BWN0021 and SEB0047 during both high and low flow periods.

Table 4: Dissolved Inorganic Nitrogen (DIN) data

	Stations	Distance from Mouth (km)	10-Mar -99	06-Apr -99	03-May -99	Average High flow	13-Jul -99	10-Aug -99	08-Sep -99	Average Low flow	Average Annual
			SE Creek Mainstem				**SE Creek Mainstem**				
0	XHH9772	0.00	1.140	1.257	0.660	1.019	0.126	0.156	0.395	0.226	0.6223
1	XHH9582	1.49	1.928	1.518	0.639	1.362	0.281	0.230	0.586	0.366	0.8637
2	XHH9396	3.85	2.802	1.775	0.598	1.725	0.362	0.244	0.433	0.346	1.0357
3	*SEB0047*	*8.14*	*4.708*	*3.335*	*4.945*	*4.329*	*6.732*	*7.360*	*4.221*	*6.104*	*5.2168*
			SE Creek Branches				**SE Creek Branches**				
4	*BWN0021*	*7.11*	*5.364*	*3.854*	*4.617*	*4.612*	*6.532*	*8.203*	*5.373*	*6.703*	*5.6572*
5	*GFB0018*	*7.98*	*3.675*	*2.162*	*2.871*	*2.903*	*1.677*	*0.984*	*0.569*	*1.077*	*1.9897*
6	*ILS0042*	*7.59*	*1.510*	*0.761*	*0.705*	*0.992*	*0.711*	*0.461*	*0.752*	*0.641*	*0.8167*

Note: Nontidal stations are italics DIN concentrations in mg/l

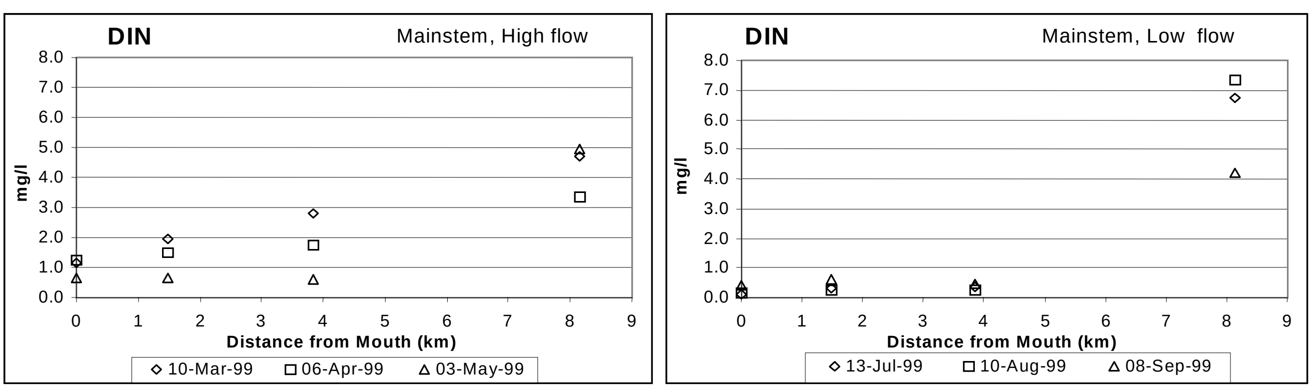

Figure 7: Longitudinal Profile of DIN Data (High & Low Flow)

Figure 8 presents the longitudinal profile of the mainstem data for Dissolved Inorganic Phosphorus (DIP) measured as dissolved ortho-phosphate levels in samples collected in summer 1999 surveys during low and high flow conditions. All values are in the range between 0.005 to 0.275 mg/l. Higher phosphorus concentrations are generally observed at the nontidal stations, and lower concentrations are observed in the tidal waters suggesting consumption of nutrients due to algal growth.

Table 5: Dissolved Inorganic Phosphorus data

	Stations	Distance from Mouth (km)	10-Mar -99	06-Apr -99	03-May -99	Average High flow	13-Jul -99	10-Aug -99	08-Sep -99	Average Low flow	Average Annual
			SE Creek Mainstem				**SE Creek Mainstem**				
0	XHH9772	0.00	0.022	0.033	0.009	0.021	0.021	0.024	0.043	0.029	0.0253
1	XHH9582	1.49	0.019	0.026	0.005	0.017	0.027	0.027	0.059	0.038	0.0272
2	XHH9396	3.85	0.021	0.017	0.006	0.015	0.029	0.010	0.031	0.023	0.0190
3	*SEB0047*	*8.14*	*0.021*	*0.035*	*0.018*	*0.025*	*0.066*	*0.034*	*0.061*	*0.054*	*0.0392*
			SE Creek Branches				**SE Creek Branches**				
4	*BWN0021*	*7.11*	*0.016*	*0.021*	*0.014*	*0.017*	*0.032*	*0.008*	*0.051*	*0.030*	*0.0237*
5	*GFB0018*	*7.98*	*0.028*	*0.058*	*0.033*	*0.040*	*0.108*	*0.088*	*0.275*	*0.157*	*0.0983*
6	*ILS0042*	*7.59*	*0.015*	*0.023*	*0.027*	*0.022*	*0.061*	*0.024*	*0.076*	*0.054*	*0.0377*

Note: Nontidal stations are in italics DIP concentrations in mg/l

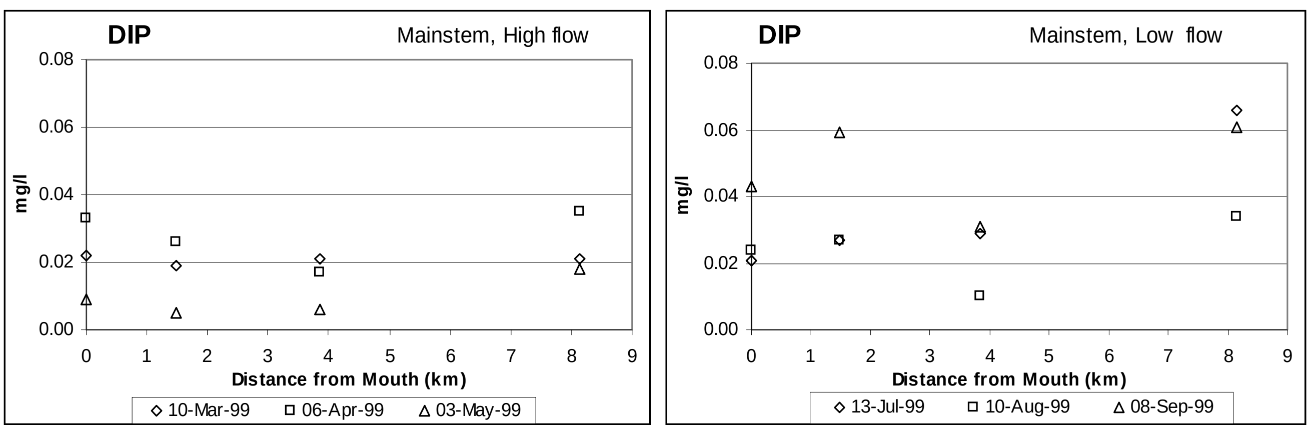

Figure 8: Longitudinal Profile of DIP Data (High & Low Flow)

2.3 Water Quality Impairment

The Maryland Water Quality Standards Surface Water Use Designation (Code of Maryland Regulations (COMAR) 26.08.02.07) for Southeast Creek is Use I – *water contact recreation, fishing, and protection of aquatic life and wildlife*. The water quality impairment of the Southeast Creek system, addressed by this TMDL, consists of an over-enrichment of nutrients. Nutrient loadings from primarily nonpoint sources have resulted in higher than acceptable chlorophyll *a* concentrations. Point source contributions are significantly lower than nonpoint source contributions. Also, some DO concentrations were observed below the minimum criteria of 5.0 mg/l in samples taken during the 1999 surveys. Finally, the high concentrations of chlorophyll *a* suggest the possibility of low DO concentrations from diurnal variations in oxygen due to algal respiration during non-daylight hours.

Maryland's General Water Quality Criteria prohibit pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses. See COMAR 26.08.02.03B(2). Excessive eutrophication, indicated by elevated levels of chlorophyll *a*, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. The chlorophyll *a* concentrations in the upper reaches of Southeast Creek have been observed to reach up to 68 μg/l and the DO concentrations has been observed as low as 3.8 mg/l. These levels have been associated with excessive eutrophication.

3.0 TARGETED WATER QUALITY GOALS

The overall objective of the TMDL established in this document is to reduce phosphorus loads to levels that are expected to result in meeting water quality criteria associated with eutrophication that support the Use I designation. Specifically, reduction in the phosphorus loads is intended to control excessive algal growth. Excessive algal growth can lead to violations of the numeric DO criteria, associated fish kills, and the violation of various narrative criteria associated with nuisances, such as odors, and impedance of direct contact use and the loss of habitat for the growth and propagation of aquatic life and wildlife.

In summary, the TMDLs for phosphorus are intended to:

1. Assure that a minimum DO concentration of 5.0 mg/l is maintained throughout the Southeast Creek system; and

2. Resolve violations of narrative criteria associated with excess nutrient enrichment of the Southeast Creek system, as reflected in chlorophyll *a* level greater than 50 μg/l in the poorly flushed tidal embayment.

The chlorophyll *a* water quality level is based on the designated uses of Southeast Creek, guidelines set forth by Thomann and Mueller (1987), and by the EPA Technical Guidance Manual for Developing TMDLs, Book 2, Part 1 (1997).

4.0 TOTAL MAXIMUM DAILY LOADS AND ALLOCATIONS

4.1 Overview

This section describes how the phosphorus TMDL and load allocations for point sources and nonpoint sources were developed for Southeast Creek. The second section describes the modeling framework for simulating nutrient loads, hydrology and water quality responses. The third and fourth sections summarize the scenarios that were explored using the model. The assessment investigates water quality responses assuming different stream flow and nutrient loading conditions. The fifth and sixth sections present the modeling results in terms of a TMDL and allocate the TMDL between point sources and nonpoint sources. The seventh section explains the rationale for the margin of safety. Finally, the pieces of the equations are combined in a summary accounting of the TMDL for seasonal low flow conditions and for average annual flows.

4.2 Analysis Framework

The computational framework chosen for the Southeast Creek TMDL was the Water Quality Analysis Simulation Program version 5.1 (WASP5.1). This water quality simulation program provides a generalized framework for modeling contaminants fate, transport in surface waters and is based on the finite-segment approach (Di Toro *et al.*, 1983). WASP5.1 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, Georgia (Ambrose *et al.*, 1993). EUTRO 5.1 is the component of WASP5.1 that simulates eutrophication, incorporating eight water quality constituents in the water column and the sediment bed.

The WASP5.1 model was implemented in a steady-state mode. This mode of using WASP5.1 simulates constant flow and average waterbody volume over the tidal cycle. The tidal mixing is accounted for using dispersion coefficients, quantifying the exchange of conservative substances between WASP5.1 model segments. The model simulates an equilibrium state of the waterbody, which in this case considered low flow and average annual flow conditions, described in more detail below. Limitations of this modeling framework are discussed in Appendix A.

The spatial domain of Southeast Creek Eutrophication Model (SCEM) extends from the confluence of Southeast Creek for about 8 km up the mainstem. The modeling domain is represented by 20 WASP model segments; however, supplemental computations of potential algal growth under the TMDL control scenarios were performed for a nontidal tributary located outside of the WASP modeling domain. A diagram of the WASP model segmentation is presented in Appendix A (Figure A7). Freshwater flows and NPS loadings from these subwatersheds are taken into consideration by dividing the drainage basin into 9 subwatersheds; also assuming the flows and loadings are direct inputs to the SCEM.

The nutrient TMDL analysis consists of two broad elements: an assessment of low flow loading conditions and an assessment of average annual loading. The low flow TMDL analysis investigates the critical conditions under which symptoms of eutrophication are typically most acute (late summer when flows are low, system is poorly flushed and when sunlight and temperatures are most conducive to excessive algal production).

The water quality model was calibrated to reproduce observed water quality characteristics for both observed low flow and observed high flow conditions. The calibration of the model for these two flow regimes establishes an analysis tool that may be used to assess a range of scenarios with differing flow and nutrient loading conditions. Observed 1999 water quality data was used to support the calibration process, as explained further in the "Nonpoint Source Loadings" section of Appendix A.

The estimation of stream flow, used in the critical low flow analyses, was based on a regression analysis making use of 30 years of data from United States Geological Survey (USGS) flow gages located between the Sassafras and Chester Rivers (Station # 01493500) and on the Chester River (Station # 01493000, Station # 01493112). The estimation of the average annual flow in Southeast Creek builds upon an analysis of flow data from the same USGS stations in 1984 - 1999. This time period is consistent with that used in the average annual flow scenario. The methods used to estimate stream flows are described further in the "Freshwater Flows" section of Appendix A.

Two point sources of nutrients were in the Southeast Creek watershed when the 1999 data was collected: the municipal wastewater treatment plants in Church Hill and the Eastern Pre-Release Unit. However, MDE point source discharge data was used to estimate only the Church Hill point source load for the 1999 calibration because the Eastern Pre-Release Unit is located far away from Southeast Creek (more than 4 km), and its discharge is four times less than that of the Church Hill WWTP (See Section 2.1, *General Setting and Source Assessment* for further discussion). For modeling purposes it is considered as part of the upstream background load. Its contribution has been accounted for implicitly by observed concentrations at the water quality segment boundary (segment 20).

The methods of estimating NPS loadings are described in Section 4.3. In brief, low flow NPS loads were derived from concentrations observed during low flow sampling in 1999 multiplied by the estimated critical low flows. Because the low flow loading estimations are based on observed data, they account for all anthropogenic and natural sources. The average annual NPS loads were derived from previous watershed modeling conducted by EPA Chesapeake Bay Program Office for the purpose of average annual conditions. These methods are elaborated upon in Section 4.3 and in the "Nonpoint Source Loadings" section of Appendix A. It is important to note that the estimated NPS loads for baseline conditions (for low flow and average annual flow) solely serve as a rough basis from which to estimate the NPS reduction needed to reach the TMDL limit. The analysis used to estimate the maximum allowable load to the waterbody (TMDL) does not depend on the baseline estimate of the NPS loads. Thus, any uncertainty in the baseline NPS estimation does not affect the certainty of the estimated TMDL.

The concentrations of the nutrients (nitrogen and phosphorus) are modeled in their speciated forms. Nitrogen is simulated as ammonia (NH_3), nitrate and nitrite ($NO_{2\text{-}3}$), and organic nitrogen (ON). Phosphorus is simulated as ortho-phosphate (PO_4) and organic phosphorus (OP). Ammonia, nitrate and nitrite, and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for biological processes such as algal growth, which affect chlorophyll *a* levels and DO concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios represent values that have been measured in the field. These ratios are not expected to vary within a particular flow regime. Thus, a total nutrient value obtained from these model scenarios, under a particular flow regime, is expected to be protective of water quality in Southeast Creek.

4.3 Scenario Descriptions

The WASP model was applied to investigate different nutrient loading scenarios under various stream flow conditions. These analyses allow a comparison of conditions, when water quality problems exist with future conditions that project the water quality response to various simulated load reductions of the impairing substances. By modeling both low flow and average annual loadings, the analyses account for seasonality, a necessary element of the TMDL development process. The analyses are grouped according to *baseline conditions* and *future conditions*, the latter being associated with the TMDL. Both groups include low flow and average annual loading scenarios, for a total of four scenarios.

The baseline conditions are intended to provide a point of reference to compare the future scenarios that simulate the conditions of the TMDL. Defining this baseline, for comparison with the TMDL outcome, is preferred to trying to establish a "current condition." The baseline is defined in a consistent way among different TMDLs and does not vary in time. The alternative of using a "current condition" has the drawback of changing over time, which creates confusion. It is "current" at one point in time for a given TMDL, but TMDL development and review often take several years; by the time the TMDL is done, the "current" condition is no longer current. Also, what constitutes "current" for one TMDL, is different for another TMDL developed at a later time. To avoid this confusion we use "baseline" scenario.

The baseline conditions for nonpoint source loads typically reflect an approximation of loads during the monitoring time frame, in this case, 1999. Baseline point source loads are typically estimated under the assumption of maximum approved water and sewer plan flows and either present permitted concentrations or estimates of expected concentrations at such flow. The baseline conditions often reflect a fixed potential future critical condition, approximating a maximum future loading with no control actions. Specific baseline loading assumptions for the point sources are presented in the "Point Source Loadings" section of Appendix A.

Sensitivity analyses indicate that algal growth is limited by phosphorus. As such, the reduction of nutrients is limited to phosphorus (reference Appendix A where the analysis is shown).

First Scenario: The first scenario represents baseline conditions of the stream at simulated low flow in the creek and low flow loading rates. The method of estimating the critical low flow is described in the "Freshwater Flows" section of Appendix A. The scenario simulates a critical condition when the creek system is poorly flushed, when sunlight and warm water temperatures are most conducive to creating the water quality problems associated with excessive nutrient enrichment.

The nonpoint source nutrient concentrations for the first scenario were computed using the observed data collected during the low flow conditions of July - September of 1999, the same values used in the calibration of the model. The low flow nonpoint source loads were computed as the product of the observed concentrations and the estimated critical low flow. These low flow nonpoint source loads integrate natural and human induced sources, including direct atmospheric deposition and loads from septic tanks, which are associated with base-flow during low flow conditions. For point sources loads, these baseline conditions assume maximum future flow and appropriate parameter concentrations expected to occur at that flow with no additional control actions (see "Point Source Loadings" of Appendix A for more details).

Second Scenario: The second scenario represents baseline conditions of the stream at average flow and average annual loading rate. Summer water temperatures and solar radiation values are used as conservative assumptions in this scenario. The total nonpoint source loads were calculated using loading rates from the EPA Chesapeake Bay Program Phase IV watershed model. The loading rates represent edge-of-stream contributions assuming Best Management Practice (BMP) implementation at levels consistent with expected progress in year 2000. The land use, to which these loading rates were applied, was calculated using 1997 MDP data, and adjusted using 1997 FSA crop acre data. The nutrient loads account for contributions from atmospheric deposition, septic tanks, cropland, pasture, feedlots, forest, and urban land. For point source loads, this scenario assumes maximum future flow and appropriate parameter concentrations expected to occur at that flow with no control actions (see "Point Source Loadings" of Appendix A for more details). A detailed description of this scenario can be found in Appendix A.

Third Scenario: The third scenario represents the future condition of maximum allowable loads during critical low stream flow. The stream flow is the same used in the first scenario.
This scenario simulates a reduction from the baseline conditions scenario of controllable nonpoint source loads in the Southeast Creek watershed. This reduction in nonpoint source loads includes a margin of safety computed as 5% of the NPS load allocation. The point source loads were set at a level necessary to meet water quality standards. In this future condition scenario, reductions in nutrient sediment fluxes and sediment oxygen demand (SOD) were estimated based on the percentage reduction of organic matter settling on the bottom. Further discussion of this scenario is provided in Appendix A.

Fourth Scenario: The fourth scenario provides an estimate of future conditions of maximum allowable average annual loads. The scenario uses an average annual stream flow as in the second scenario. This scenario was conducted assuming high temperatures and sunlight to simulate conditions that are most conducive to algal growth. Because higher stream flows like the average annual flow, typically occur in cooler seasons, the assumptions of high water temperature and solar radiation used in the analysis are conservative with respect to environmental protection.

This scenario simulates a reduction in controllable NPS loads of phosphorus in some subwatersheds of the Southeast Creek watershed. A 5% margin of safety was also included for the nonpoint source load calculation. Reductions in nutrient sediment fluxes and SOD were estimated based on the percent reduction of organic matter settling to the bottom, and computed as a function of the nutrient reduction. Further discussion of this scenario is provided in Appendix A.

4.4 Scenario Results

This section describes the results of the model scenarios in the previous section. The DO concentrations from SCEM model presented in this section are daily minimum DO concentrations. These minimum DO concentrations account for diurnal fluctuations caused by photosynthesis and algal respiration.

Baseline Condition Loading Scenario Results:

First Scenario (Low flow): Simulates critical low stream flow conditions during the summer season. Water quality parameters (e.g., nutrient concentrations) are based on 1999 observed data.

Results for the first scenario, representing the baseline conditions for summer critical low flow, are summarized in Figure 9

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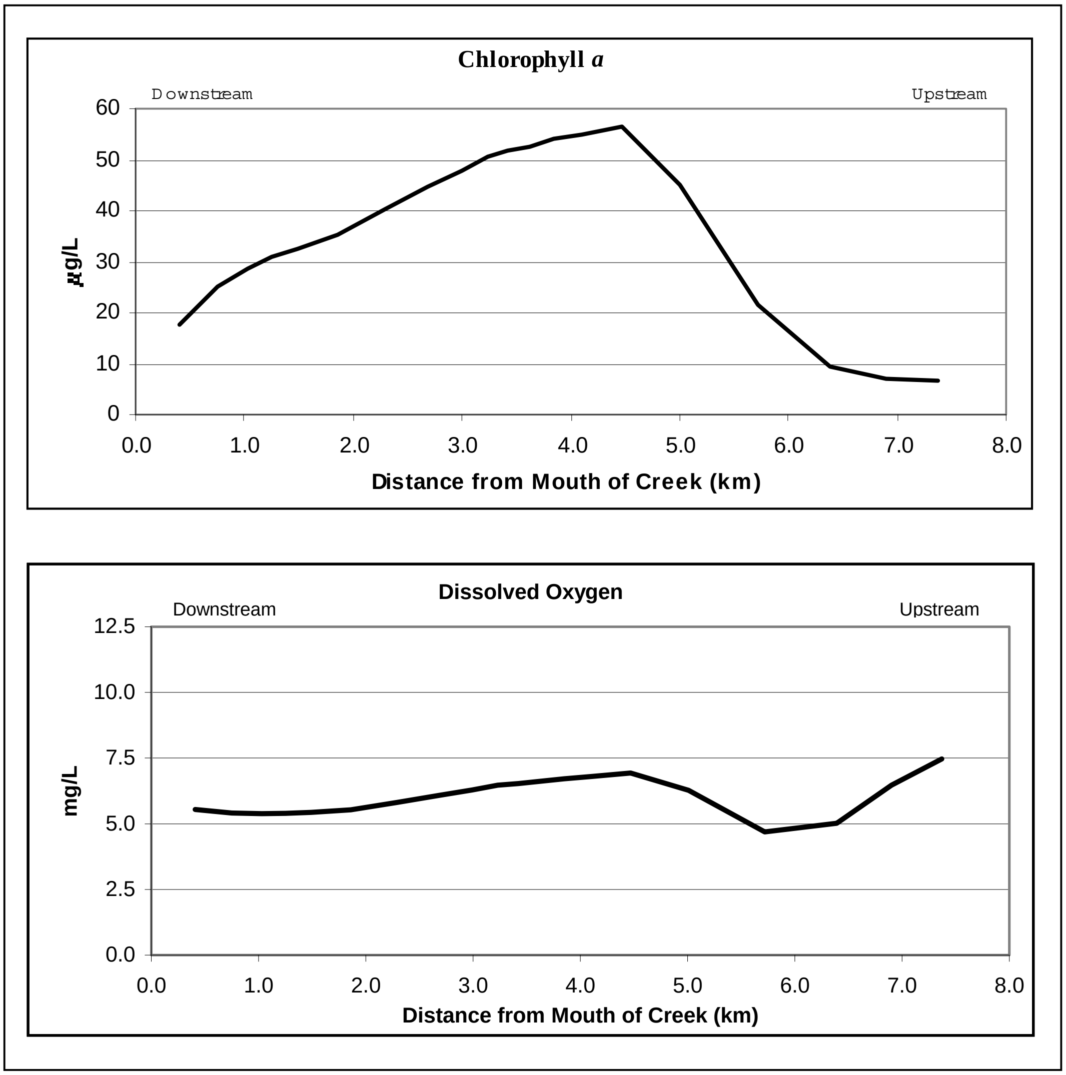

Figure 9: Model Results for the Baseline Low Flow Condition Scenario for Chlorophyll *a* and Dissolved Oxygen (First Scenario)

Under these conditions, chlorophyll *a* concentrations at the middle of the creek and its upper tidal headwater reaches exceed the maximum allowed level of 50 µg/l, with values reaching 56.6 µg/l. DO concentrations remain above the minimum water quality criterion of 5.0 mg/l throughout most parts of the length of the river, although it is slightly under the limit (4.6 mg/l) at the upper part of the river. Church Hill WWTP is the only significant point source of nutrients in the Southeast Creek watershed. Concentration of total phosphorus from this plant equaled 1.95 mg/l in 1999. Maximum allowable concentrations are used in the baseline conditions scenario as a conservative assumption. Temperature of water was estimated as the mean maximum temperature for the period July – September 1984 through 1999.

<u>*Second Scenario (Average Annual Flow)*</u>*:* Simulates historical average annual stream flow condition under summer environmental conditions. Assumes baseline average annual nonpoint source loads, and maximum point source design flow and load, and maximum mean temperature 28.8^{0}C for tidal segments and 23.1^{0}C for nontidal segments (see Appendix A).

Results for the second scenario, representing the baseline conditions for the average annual stream flow and average loads, are summarized in Figure 10.

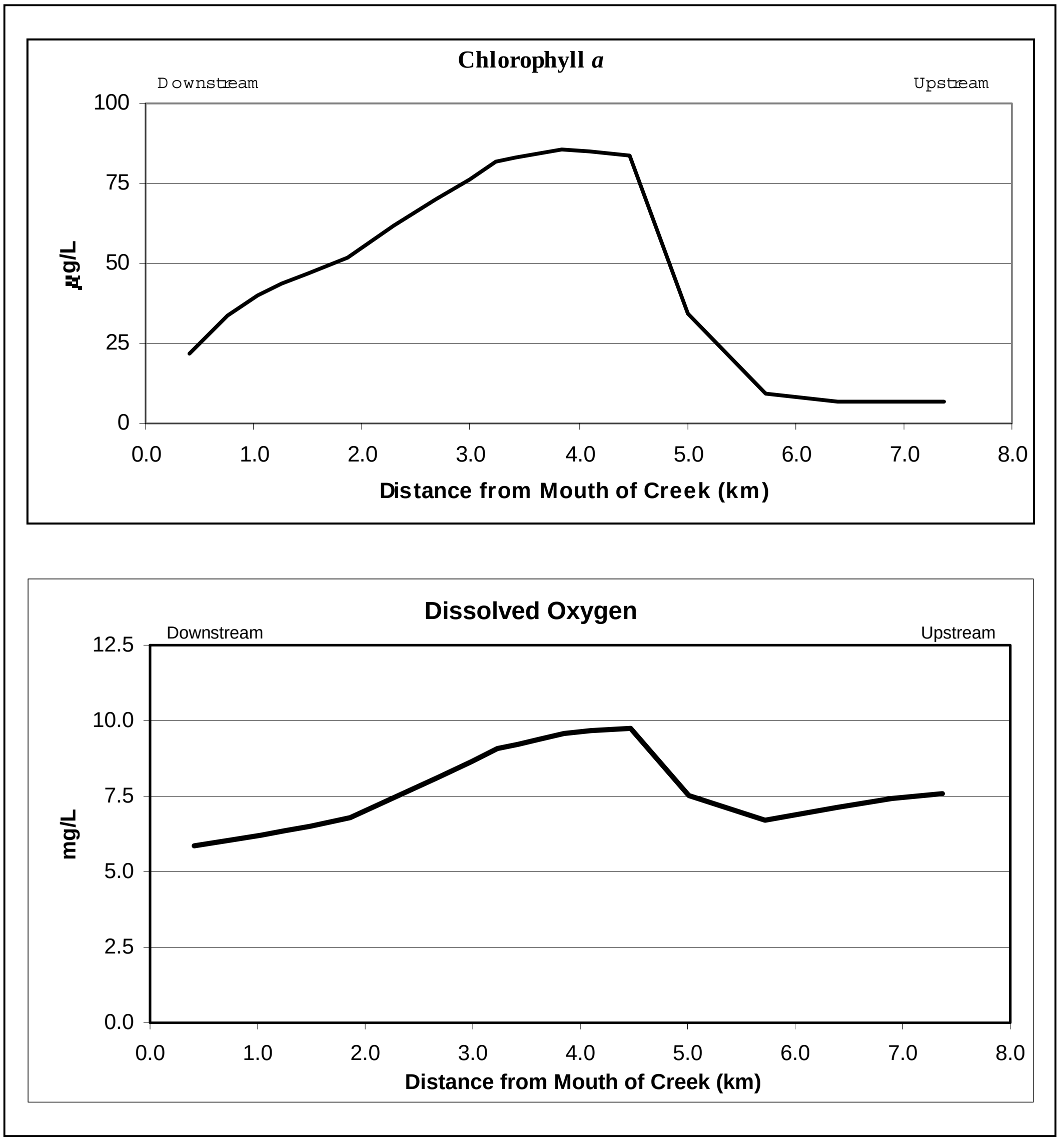

Figure 10: Model Results for the Baseline Average Annual Condition Scenario for Chlorophyll *a* and Dissolved Oxygen (Second Scenario)

Under these conditions, chlorophyll *a* concentrations are higher than in the previous (first) scenario, almost reaching a value of 86 µg/l, and DO concentrations remain above 5.9 mg/l throughout the length of the creek.

Future Condition TMDL Scenario Results:

Third Scenario (Low Flow): Simulates the future condition of maximum allowable loads for critical low stream flow conditions during the summer season (Figure 11).

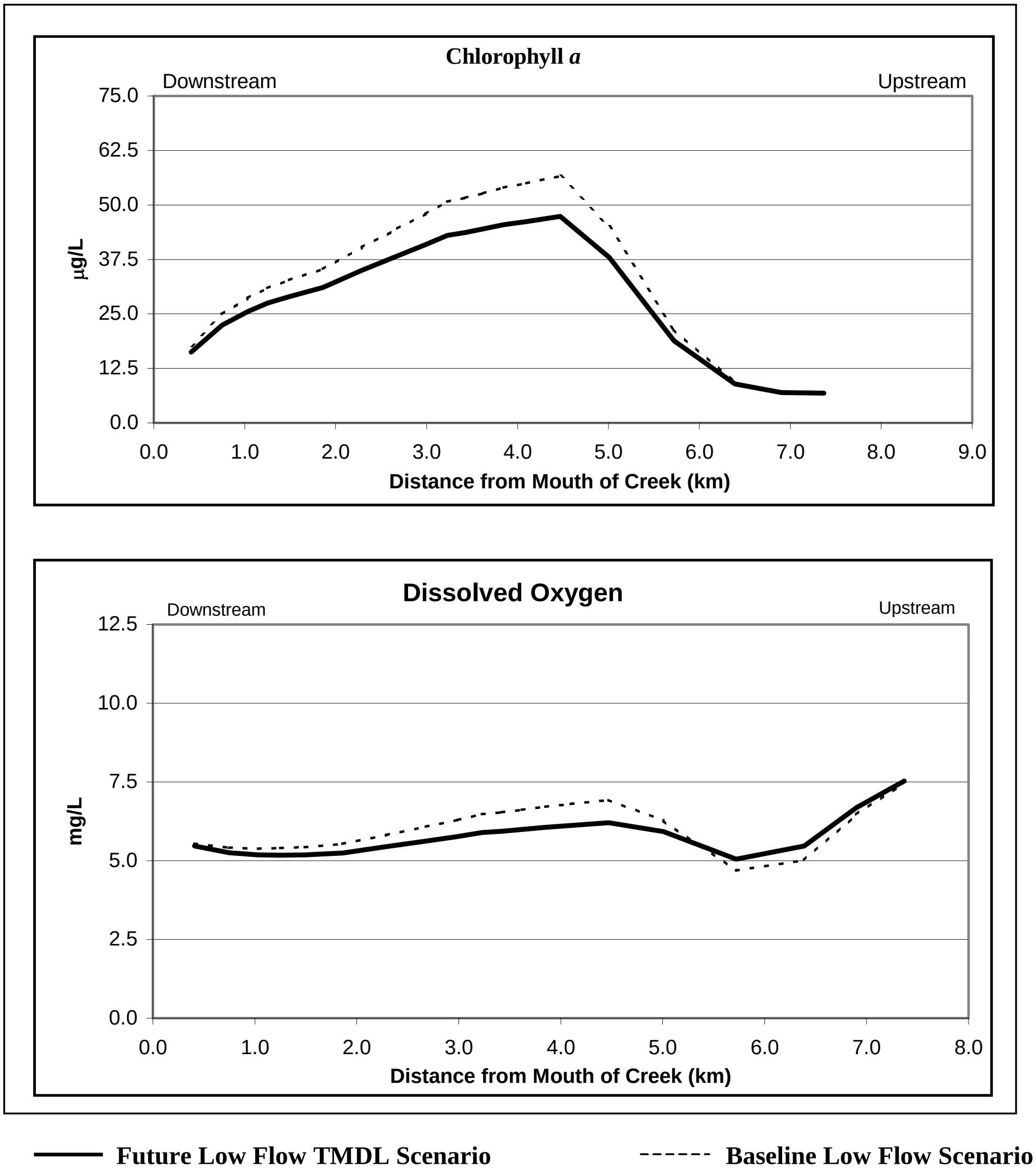

Figure 11: Model Results for the Low Flow Future Condition Scenario for Chlorophyll *a* and Dissolved Oxygen (Third Scenario)

Results for the third scenario (bold line), representing the maximum allowable load for summer critical low flow, are summarized in comparison to the appropriate baseline conditions scenario (dotted line). Under the nutrient load reduction conditions described above for this scenario, the results show chlorophyll *a* concentrations remain below 47.3 µg/l along the entire length of Southeast Creek. For DO, the comparison shows that the nutrient load reductions result in little change, maintaining the DO concentrations above the water quality criterion of 5.0 mg/l along the length of the river. Although chlorophyll a can be a significant source of DO in the water column during daylight hours, chlorophyll *a* consumes DO during non-daylight hours through respiration. The model output reflects minimum DO; however, as chlorophyll *a* decreases, this DO source will decrease also. It can also be noted that the decrease in DO takes place only where chlorophyll *a* concentrations were significant.

It should be noted also, that although the SCEM modeling domain does not include the nontidal tributaries of Southeast Creek, supplemental computations demonstrate that the phosphorus reductions associated with this scenario will limit algal growth to about 50 µg/l in Island Creek where observed data indicated elevated chlorophyll *a* levels. These computations are presented in Appendix A. It is anticipated that dissolved oxygen levels will improve; however, additional monitoring and analyses might indicate the need to target refined load reductions for this tributary in the future (See section 5.0 “Assurance of Implementation”).

Fourth Scenario (Average Annual Flow): Simulates the future condition of maximum allowable annual loads under average annual stream flow and loading conditions.

Results for the fourth scenario (bold line), representing the maximum allowable loads for average annual flow, are summarized in comparison to the appropriate baseline scenario (dotted line) in Figure 12.

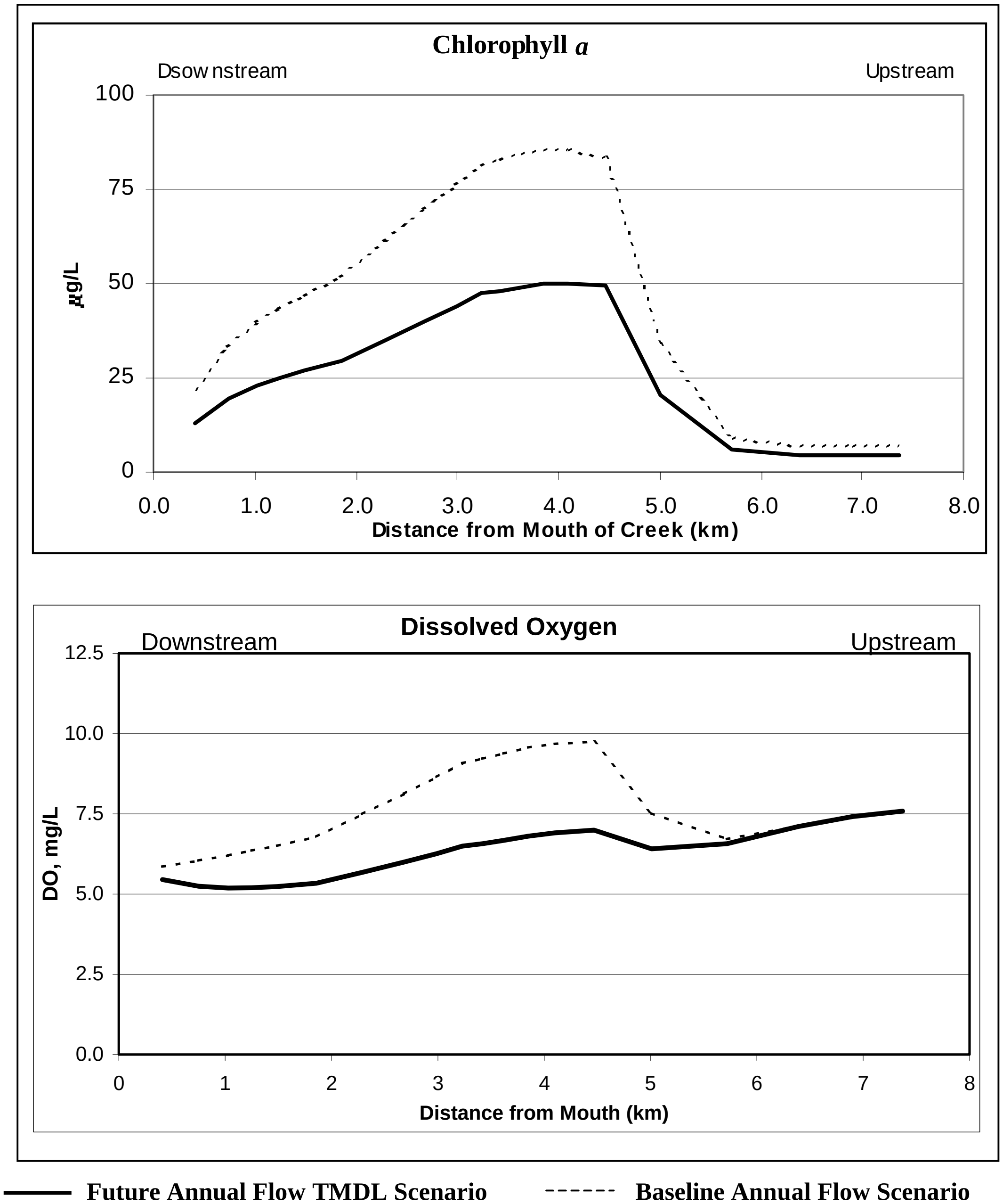

Figure 12: Model Results for the Average Annual Flow Future Condition Scenario for Chlorophyll *a* and Dissolved Oxygen (Fourth Scenario)

Under the load reduction conditions described above for this scenario, the results show that chlorophyll *a* concentrations remain below 50 µg/l along the entire length of Southeast Creek. For DO, the comparison shows that the DO along the length of the river remains above the water quality criterion of 5.0 mg/l for both scenarios.

4.5 TMDL Loading Caps

This section presents the TMDL for phosphorus. The outcomes are presented in terms of the critical low flow TMDL and average annual TMDL. The critical season for excessive algal growth in Southeast Creek is during the summer months, when the river system is poorly flushed. During this critical time, sunlight and warm water temperatures are most conducive to creating the water quality problems associated with excessive nutrient enrichment. The low flow TMDL is stated in monthly terms because these critical conditions occur for limited periods of time. It should be noted that limits placed on average annual loads are accounted for indirectly by adjusting bottom sediment nutrient fluxes and SOD to be consistent with reductions in average annual loads (See Appendix A).

For the low flow months, May 1 through October 31, the following TMDL applies:

Low Flow TMDL:

PHOSPHORUS TMDL: 259 *lbs/month*

The average annual TMDL is established for two purposes. First, it is designed to protect water quality in Southeast Creek. Second, the controls implemented for average annual loads can improve the water quality problems observed in the low flow critical season.

The average annual TMDL for phosphorus is:

Average Annual TMDL:

PHOSPHORUS TMDL: 21,113 *lbs/year*

4.6 Load Allocations Between Point Sources and Nonpoint Sources

The watershed draining to Southeast Creek has one permitted point source that discharges nutrients directly to the creek. The allocations described in this section demonstrate how the TMDL can be implemented to achieve water quality standards in Southeast Creek. Specifically, these allocations show how the sum of phosphorus loadings to Southeast Creek from existing point and nonpoint sources can be maintained safely within the TMDL established here. These allocations demonstrate how this TMDL could be implemented to achieve water quality standards; however, the State reserves the right to revise these allocations provided the allocations are consistent with the achievement of the water quality standard.

Low Flow TMDL Allocations:

The NPS loads of phosphorus simulated in the third scenario represent a 19% reduction from the baseline scenario needed to achieve water quality standards. Recall that the low flow baseline scenario loads were based on nutrient concentrations observed in summer 1999. These NPS loads, based on observed concentrations, account for both “natural” and human-induced components and cannot be separated into specific source categories.

Point source waste load allocations for the summer low flow baseline conditions make up the balance of the total allowable load including a 5% margin of safety. The point source waste load allocation was adopted from results of model Scenario 3. All significant point sources are addressed by this allocation and are described further in the technical memorandum entitled *"Significant Phosphorus Nonpoint Sources and Point Sources in the Southeast Creek Watershed.*" The NPS and point source phosphorus allocations for summer critical low flow conditions are shown in Table 6.

Table 6: Summer Low Flow Allocations

	Total Phosphorus *(lbs/month)*
Nonpoint Source	130
Point Source	122

Average Annual TMDL Allocations:

The average annual nonpoint source phosphorus allocations are represented as the average of the CBP's loads with a 61% reduction in controllable phosphorus NPS loads in all subwatershed loads estimated from the CBP's Phase 4.3 watershed model. The nonpoint source loads assumed in the model account for both "natural" and human-induced components.

Point source load allocations for the average annual flow conditions make up the balance of the total allowable load including a 3% margin of safety. This point source waste load allocation represents the maximum load associated with approved water and sewer plan flows, and concentrations assuming no additional treatment than is currently being used. The point source is addressed by this allocation and is described further in the technical memorandum entitled *"Significant Phosphorus Nonpoint Sources and Point Sources in the Southeast Creek Watershed.*" The NPS and point source phosphorus allocations for summer critical low flow conditions are shown in Table 7.

Table 7: Average Annual Flow Allocations

	Total Phosphorus *(lbs/yr)*
Nonpoint Source	19,078
Point Source	1,462

4.7 Margins of Safety

A margin of safety (MOS) is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = LA + WLA + MOS). The second approach is to incorporate the MOS as conservative assumptions used in the TMDL analysis.

Maryland has adopted margins of safety that combine these two approaches. Following the first approach, the load allocated to the MOS was computed as 5% of the NPS load (7 lbs/month) for phosphorus for the low flow TMDL. Similarly, a 3% MOS was included in computing the average annual TMDL. These explicit phosphorus margins of safety are summarized in Table 8.

Table 8: Expected Summer Low Flow and Average Annual Flow Margins of Safety

	Phosphorus MOS
MOS Low Flow	7 lbs/month
MOS Average Flow	572 lbs/year

In addition to this explicit set-aside MOSs, additional safety factors are built into the TMDL development process. The fourth model scenario, for average annual flow, was run under the assumption of summer temperature and summer solar radiation. When the water is warmer and more sunlight is present, there will be more algal growth and a higher potential for low dissolved oxygen concentrations. The higher temperatures and solar radiation are conservative assumptions that represent a significant MOS.

4.8 Summary of Total Maximum Daily Loads

The low flow TMDL for Southeast Creek, applicable from May 1 – October 31 is as follows:

For Phosphorus (*lbs/month*):

TMDL	**=**	**LA**	**+**	**WLA**	**+**	**MOS**
259	**=**	**130**	**+**	**122**	**+**	**7**

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
MOS = Margin of Safety

Low Flow Average Daily Loads:

On average, the low flow TMDL will result in loads of approximately 9 lbs/day of phosphorus.

The average annual TMDL for Southeast Creek is as follows:

For Phosphorus (*lbs/yr*):

TMDL	=	LA	+	WLA	+	MOS
21,113	=	**19,078**	+	**1,462**	+	**572**

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
MOS = Margin of Safety

Average Annual Flow Daily Loads:

On average, the average annual flow TMDL will result in loads of approximately 58 lbs/day of phosphorus.

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the phosphorus TMDL will be achieved and maintained. Maryland has several well established programs to draw upon: the Water Quality Improvement Act of 1998 (WQIA), and the State's Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction. Also, Maryland has adopted procedures to ensure that future evaluations are conducted for all TMDLs established.

Church Hill WWTP is the only point source located in the Southeast Creek watershed that was modeled explicitly. It has a flow below 80 thousand gallons per day (estimated current flow of 44,000 gallons per day). Phosphorus limits placed on the plant will be implemented through an NPDES Surface Water Discharge Permit.

Maryland's Water Quality Improvement Act of 1998 requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout Maryland. This act specifically requires that phosphorus management plans be developed by December 2001 and be implemented by December 2002 if chemical fertilizer is used, and by 2004-2005 for those who use manure or organic sources (COMAR Title 15 Maryland Department of Agriculture, Subtitle 20 Soil and Water Conservation: (15.20.07.04)). In addition to nutrient management plans, Maryland’s Agricultural Cost Share Program (MACS) has been developed to address potential pollution problems from agriculture and is available to fund Best

Management Practices (BMPs) in this watershed. The Low Income Loans for Agricultural Conservation (LILAC) program also provides loans for projects.

In 1983, the States of Maryland, Pennsylvania, and Virginia, the District of Columbia, the Chesapeake Bay Commission and the U.S. EPA joined in a partnership to restore the Chesapeake Bay. In 1987, through the Chesapeake Bay Agreement, Maryland made a commitment to reduce nutrient loads to the Chesapeake Bay. In 1992, the Bay Agreement was amended to include implementation plans to achieve these nutrient reduction goals. Maryland's resultant Tributary Strategies for Nutrient Reduction provide a framework that will support the implementation of NPS controls in the Lower Eastern Shore Tributary Strategy Basin, including the Southeast Creek watershed. These Tributary Strategies are soon to be updated as part of the Chesapeake 2000 initiative under the Chesapeake Bay Agreement. Maryland is in the forefront of implementing quantifiable NPS controls through the Tributary Strategy efforts. This will help to assure that nutrient control activities are targeted to areas where nutrient TMDLs have been established.

It is reasonable to expect that nonpoint source loads can be reduced during low flow conditions. Although the low flow loads cannot be partitioned specifically into contributing sources, the sources themselves can be identified. These sources include dissolved forms of the impairing substances from groundwater and deposition of nutrients and organic matter to the streambed from higher flow events. When these sources are controlled in combination, it is reasonable to achieve non-point source reductions of the magnitude identified by this TMDL allocation.

Finally, Maryland uses a five-year watershed cycling strategy to manage its waters. Pursuant to this strategy, the State is divided into five regions and management activities will cycle through those regions over a five-year period. The cycle begins with intensive monitoring, followed by computer modeling, TMDL development, implementation activities and follow-up evaluation. The choice of a five-year cycle is motivated by the five-year federal National Pollutant Discharge Elimination System (NPDES) permit cycle. Additional monitoring in the tributaries of Southeast Creek will also be performed. As explained in the document, additional monitoring and analysis of Island Creek will be needed to target load reductions for this tributary. The continuing cycle will ensure that every five years intensive follow-up monitoring will be performed. Thus, the watershed cycling strategy establishes a TMDL evaluation process that assures accountability.

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Appendix A