Total Maximum Daily Loads of Nitrogen and Phosphorus for the Upper and Middle Chester River Kent and Queen Anne's Counties, Maryland

FINAL

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List of Abbreviations

BMP	Best Management Practice
BNR	Biological Nutrient Removal
CAA	Clean Air Act
CBP	Chesapeake Bay Program
CE-QUAL-ICM	Corps of Engineers-Water Quality-Integrated Compartment Model
CFD	Cumulative Frequency Distribution
CH3D-WES	Curvilinear Hydrodynamic in Three Dimensions – Waterways Experiment
Chl*a*	Active Chlorophyll *a*
COMAR	Code of Maryland Regulations
CRA	Chester River Association
CWA	Clean Water Act
CWAP	Clean Water Action Plan
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DO	Dissolved Oxygen
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DOSP	Delaware Office of State Planning
ENR	Enhanced Nutrient Removal
EPA	Environmental Protection Agency
FA	Future Allocation
FSA	Farm Services Agency
HSPF	Hydrological Simulation Program FORTRAN
LA	Load Allocation
lbs/yr	Pounds per Year
LPON	Labile Particulate Organic Nitrogen
m^3/s	Cubic Meters per Second
MD	Maryland
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
mg/l	Milligrams per Liter
mgd	Million Gallons per Day
MDP	Maryland Department of Planning
MOS	Margin of Safety
NBOD	Nitrogenous Biochemical Oxygen Demand
NH_3	Ammonia
NH_4	Ammonium Nitrogen
NO_{2-3}	Nitrate + Nitrite
NOx	Oxides of Nitrogen
NPDES	National Pollutant Discharge Elimination System

NPS	Nonpoint Source
ON	Organic Nitrogen
OP	Organic Phosphorus
PCBs	Poly-Chlorinated Biphenyls
PS	Point Source
PO_4	Ortho-Phosphate
RPON	Refractory Particulate Organic Nitrogen
RPOP	Refractory Particulate Organic Phosphorus
SOD	Sediment Oxygen Demand
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant
µg/l	Micrograms per Liter

EXECUTIVE SUMMARY

This document, upon approval by U.S. Environmental Protection Agency, establishes Total Maximum Daily Loads (TMDLs) for nitrogen and phosphorus in the Upper Chester River (basin number 02-13-05-10) and the Middle Chester River (basin number 02-13-05-09). The Upper Chester River and Middle Chester River are part of the Upper Eastern Shore Tributary Strategy Basin. These river segments are impaired by the nutrients nitrogen and phosphorus, which cause excessive algal blooms accompanied by reduced concentrations of dissolved oxygen.

The Upper Chester River, located within Kent and Queen Anne's Counties, was first identified on the State's 1996 303(d) list as impaired by nutrients, sediments, and bacteria, with listings added in 2002 for evidence of biological impacts, and in 2004 for methylmercury in fish tissue in one of the basin's impoundments (Millington Wildlife Management Ponds). The sediment, bacteria, biological, and methylmercury in fish tissue impairments will be addressed separately.

The Middle Chester River, located within Kent and Queen Anne's Counties, was first identified on the State's 1996 303(d) list as impaired by nutrients, sediments, and bacteria. In 2002, poly-chlorinated biphenyls (PCBs) in fish tissue and evidence of biological impacts were added, with additional subbasins listed as impaired by evidence of biological impacts in 2004. TMDLs to address the nutrient and sediment listings of Urieville Community Lake, an impoundment within the Middle Chester Watershed, were submitted and approved in 1999; the sediment, bacteria, PCBs in fish tissue and biological impacts will be addressed separately.

The water quality goal of these TMDLs is to reduce high chlorophyll *a* (Chl*a*) concentrations (a surrogate for algal blooms) and to maintain dissolved oxygen (DO) at a level supportive of the designated uses for the Upper and Middle Chester Rivers. The TMDLs for the nutrients nitrogen and phosphorus were determined using a time-variable, three-dimensional water quality eutrophication model package that includes a water quality model, Corps of Engineers-Water Quality-Integrated Compartment Model (CE-QUAL-ICM); and a hydrodynamic model, Curvilinear Hydrodynamic in Three Dimensions (CH3D). Loading caps for total nitrogen and total phosphorus entering the Upper and Middle Chester Rivers are established for the growing season (critical conditions) and for average annual flow conditions.

The growing season TMDLs apply from May 1 through October 31. For the Upper Chester River, the growing season TMDL for nitrogen is 246,717 lbs/growing season, and the growing season TMDL for phosphorus is 8,573 lbs/growing season. The allowable loads have been allocated between point and nonpoint sources. The Upper Chester River nonpoint sources are allocated 224,377 lbs/growing season of total nitrogen, and 6,872 lbs/growing season of total phosphorus. The Upper Chester River point sources are allocated 11,913 lbs/growing season of nitrogen, and 1,366 lbs/growing season of phosphorus. An explicit margin of safety makes up the remainder of the nitrogen and phosphorus allocations.

For the Middle Chester River, the growing season TMDL for nitrogen is 116,149 lbs/growing season, and the growing season TMDL for phosphorus is 5,048 lbs/growing season. The Middle

Chester River nonpoint sources are allocated 92,534 lbs/growing season of total nitrogen, and 2,649 lbs/growing season of total phosphorus. The Middle Chester River point sources are allocated 19,275 lbs/growing season of nitrogen, and 2,286 lbs/growing season of phosphorus. An explicit margin of safety makes up the remainder of the nitrogen and phosphorus allocations.

The average annual TMDL for the Upper Chester River for nitrogen is 614,612 lbs/yr, and for phosphorus is 34,354 lbs/yr. The allowable loads have been allocated between point and nonpoint sources. The Upper Chester River nonpoint source loads are allocated 561,653 lbs/year of total nitrogen and 29,078 lbs/year of total phosphorus. The Upper Chester River point sources are allocated 26,451 lbs/year of total nitrogen and 3,810 lbs/year of total phosphorus. An explicit margin of safety makes up the balance of the allocation.

The average annual TMDL for the Middle Chester River for nitrogen is 275,437 lbs/yr, and for phosphorus is 16,709 lbs/yr. The Middle Chester River nonpoint source loads are allocated 217,447 lbs/year of total nitrogen and 10,047 lbs/year of total phosphorus. The Middle Chester River point sources are allocated 47,567 lbs/year of total nitrogen and 6,188 lbs/year of total phosphorus. An explicit margin of safety makes up the balance of the allocation.

Previously, MDE had calculated a phosphorus and sediment TMDL for Urieville Community Lake. The Urieville Community Lake Watershed is located in the Middle Chester River Watershed. The average annual phosphorus TMDL for Urieville Community Lake Watershed was set at 509 lbs/yr. The TMDL calculation for the Middle Chester River incorporates the results of the Urieville Community Lake TMDL.

Six factors provide assurance that these TMDLs will be implemented. First, National Pollutant Discharge Elimination System (NPDES) permits will play an important role in assuring implementation. 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. Fourth, the Bay Restoration Fund provides funding to Waste Water Treatment Plants for enhanced nutrient removal, and for cover crops and septic system upgrades. Fifth, the Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act) also provides funding for nonpoint source implementation. Finally, Maryland has adopted a watershed cycling strategy, which will ensure that routine future monitoring and TMDL evaluations are conducted.

1.0 INTRODUCTION

Section 303(d)(1)(C) of the federal Clean Water Act and the applicable federal 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 waterbody 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 support of aquatic life, swimming, drinking water supply, and shellfish propagation and harvest. Designated uses may be temporally and spatially distinct, depending on the use to be protected. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses, and may incorporate elements of frequency, duration and magnitude.

The Upper and Middle Chester Rivers were first identified on the 1996 303(d) list submitted to the Environmental Protection Agency (EPA) by the Maryland Department of the Environment (MDE). They were listed as being impaired by nutrients due to signs of eutrophication. Eutrophication is the over-enrichment of aquatic systems by excessive inputs of nutrients, especially nitrogen and phosphorus. The nutrients act as a fertilizer leading to the excessive growth of aquatic plants, which eventually die and decompose, leading to bacterial consumption of dissolved oxygen. For this reason, it is generally possible to eliminate the impairment by limiting the amount of nutrients that enters the waterbody. Accordingly, this document, upon approval by the EPA, establishes TMDLs for nitrogen and phosphorus in the Upper and Middle Chester Rivers. The Middle Chester TMDL takes into account the previously calculated Urieville Community Lake TMDL for phosphorus and sediment. The Upper and Middle Chester River Basins have also been identified on the 303(d) list as impaired by bacteria (fecal coliform), suspended sediments and impacts to biological communities. Millington Wildlife Management Ponds in the Upper Chester River are additionally listed as impaired by methylmercury in fish tissue, and the Middle Chester River is listed as impaired by toxics (PCBs in fish tissue). These remaining impairments will be addressed at a future time.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

2.1.1 Watershed Description

The Upper Chester River Watershed is located within Kent and Queen Anne's Counties, Maryland, with its headwaters in New Castle and Kent Counties, Delaware (Figure 1). The Middle Chester River is located within Kent and Queen Anne's Counties (Figure 1). The Upper, Middle and Lower Chester Rivers make up the Chester River from its confluence with the Bay to its headwaters at New Castle. The Upper and Middle Chester Rivers are approximately 32.2 kilometers (20 miles) in length, from the downstream extent to the upper reaches of the headwaters. The Upper Chester River is approximately 16.9 kilometers (10.5 miles) and the Middle Chester River is approximately 15.3 kilometers (9.5 miles) in length. The Upper Chester River extends from the headwaters downstream to the confluence with Foreman Branch, and the Middle Chester extends from that point downstream to the confluence with Southeast Creek.

The upper region of the Upper Chester River Watershed, near the Maryland and Delaware border, consists of uninhabited forests and wetlands, which are part of the Millington Wildlife Management Area. This is an area of approximately 3,800 acres, which drains into Cypress Branch, northeast of Millington. The Upper and Middle Chester River Watersheds are situated in Kent and Queen Anne's Counties, which are agriculturally diverse and high in the production of corn, wheat and soybean. The Middle Chester is among those Maryland watersheds with the least impervious surface, lowest population density, the least wetland loss and the highest soil erodibility. The average size of a farm in this region is about 400 acres (Shanks, 2001).

Three watersheds converge just upstream of State Route 301: spillage from Mill Pond at Millington, which enters upstream of State Route 313 from the northeast; the flow of Andover-Sewell Branch, which deposits freshwater flow at this point, carrying drainage from Delaware; and the outlet of Unicorn Branch at the United States Geological Survey (USGS) gauging station below the impoundment of Unicorn Lake. The waters from this point to Crumpton are considered tidally-influenced. Morgan Creek is the largest tidally-influenced tributary of the Chester River. It is free-flowing to the USGS gauging station on Wallis Brothers Road, just east of Urieville Community Lake.

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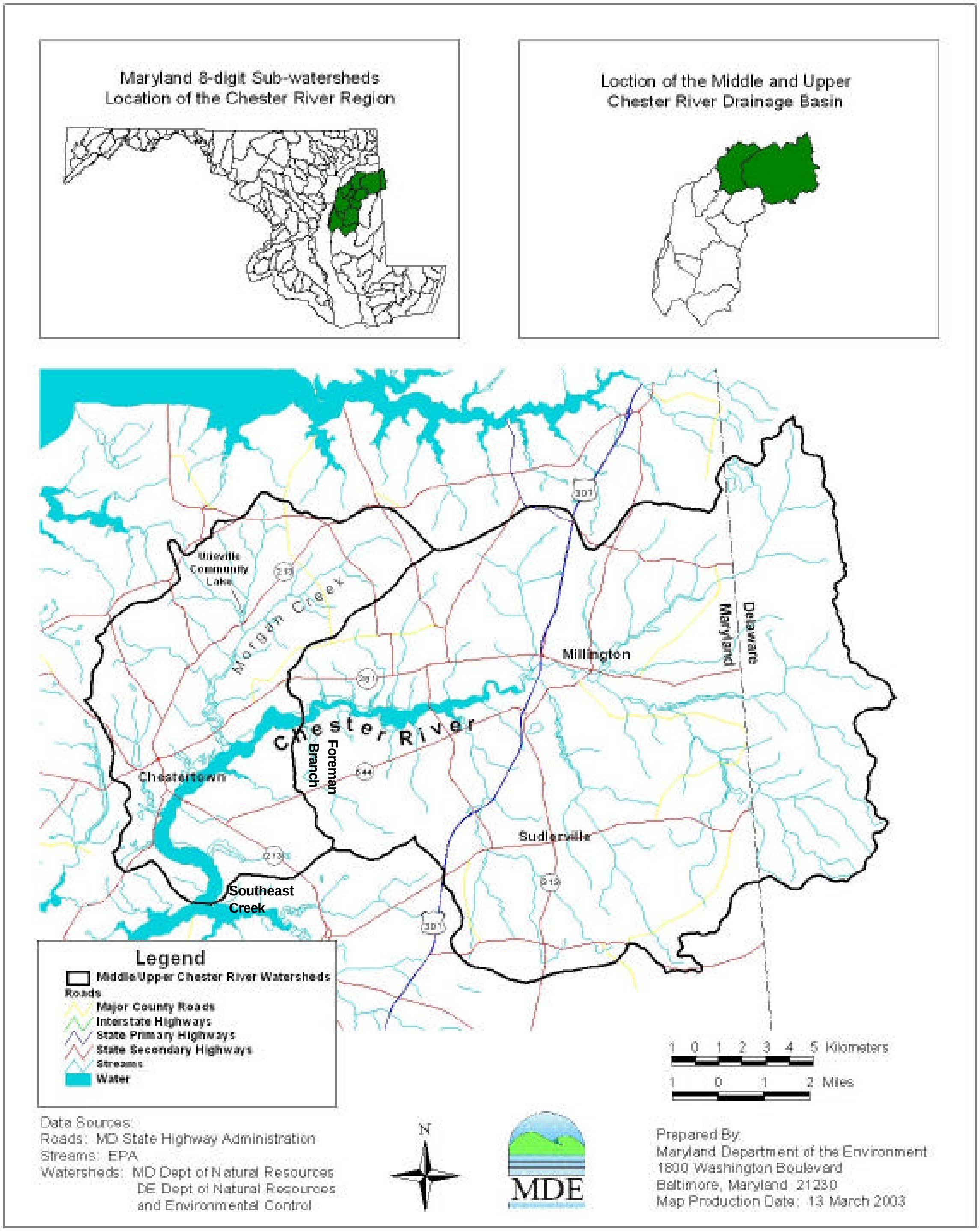


Figure 1: Location Map of the Upper and Middle Chester River Watersheds within Maryland and Delaware

2.1.2 Land Use

The spatial distribution of the major land uses in the Upper and Middle Chester Watersheds are shown in Figure 2. The land use is based on 1997 Maryland Department of Planning (MDP) land cover data, 1997 Delaware Office of State Planning (DOSP) land cover data, and 1997 Farm Service Agency (FSA) information.

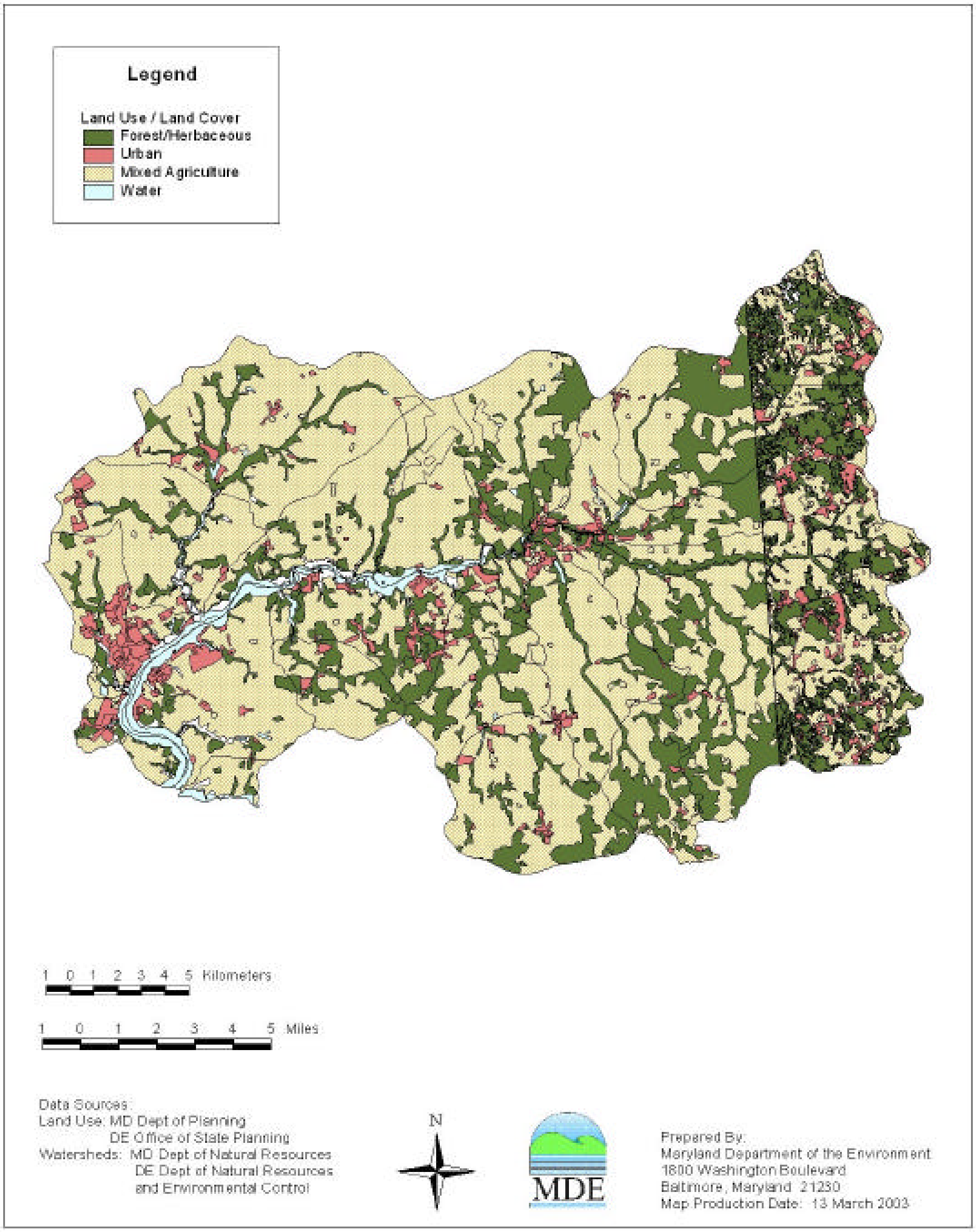


Figure 2: Predominant Land Use in the Upper and Middle Chester River Watersheds

The Upper Chester River Watershed is approximately 113,485 acres (459 km^2), and the Middle Chester River Watershed is approximately 36,060 acres (146 km^2). The land use displayed in Figure 2 incorporates the information from the MDP and DOSP. The FSA information was used to check and refine the delineation of agricultural land in the watersheds. More information about the Upper and Middle Chester River Watersheds can be found in the "Chester River Watershed HSPF Model Report" (MDE, 2001)

As shown in Figure 3a, the land use in the Upper Chester Watershed is predominantly mixed agriculture (62,897 acres or 54.5%), with forest (41,701 acres or 36.1%), urban (2,837 acres or 2.5%), and pasture (6,050 acres or 5.2%) in smaller amounts.

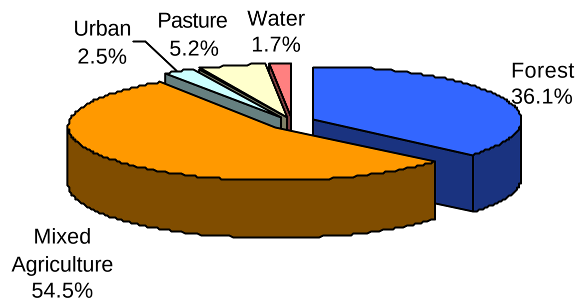


Figure 3(a): Proportions of Land Use in the Upper Chester Watershed

The Middle Chester Watershed as shown in Figure 3(b) consists mostly of mixed agriculture (26,404 acres or 68.8%), with the remaining land use being forest (5,436 acres or 14.2%), urban (2,838 acres or 7.4%), and pasture (1,372 acres or 3.6%).

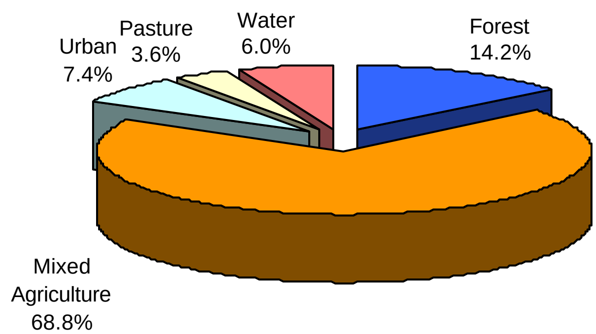


Figure 3(b): Proportions of Land Use in the Middle Chester Watershed

2.1.3 Geology

The Upper and Middle Chester River Watersheds lie within the Atlantic Coastal Plain region. This portion of the Atlantic Coastal Plain consists of three regions: alluvial deposits (on flood plains and tidal marshes); the Talbot plain; and the Wicomico plain. Wetlands are abundant in the Coastal Plain due to the low topographical relief and high groundwater characteristics of the region (USDA, 1966 and 1982).

2.1.4 Nutrients Source Assessment

2.1.4.1 Point Sources (PS): Municipal and Industrial Wastewater Treatment Plants Loads

For the model calibration period (1997-1999), MDE considered a total of six current PSs that discharge within the Upper and Middle Chester River Watersheds. Information was reviewed from discharge monitoring reports stored in MDE's PS database. The locations of the PSs in the Upper and Middle Chester River Watersheds are shown in Figure 4.

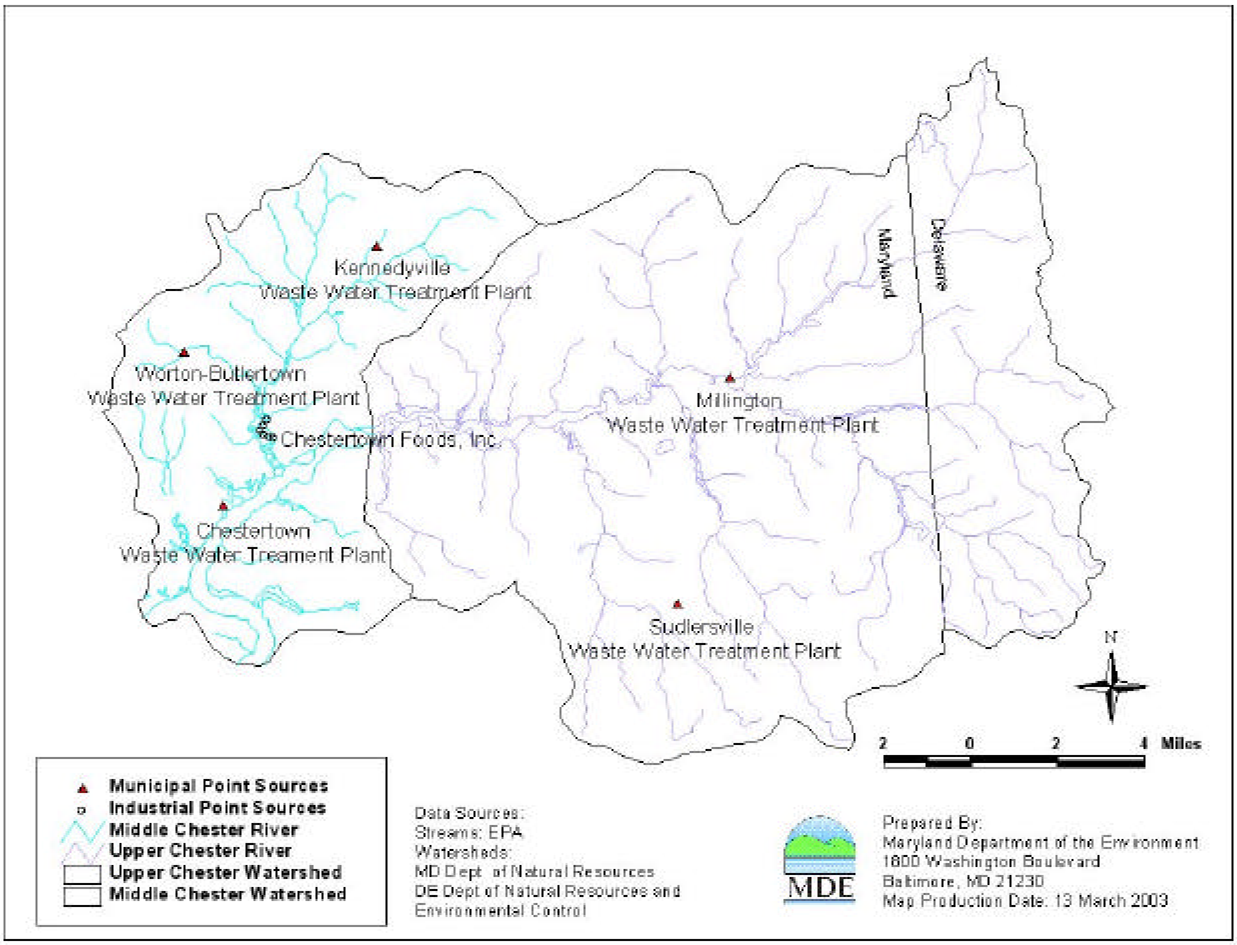


Figure 4: PS locations in the Upper and Middle Chester River Watersheds

The Upper Chester River Watershed has two municipal PSs: Millington Waste Water Treatment Plant (WWTP) and Sudlersville WWTP. Table 1(a) shows the average annual flows and Total Nitrogen (TN), Total Phosphorus (TP) loads for the period of 1997-1999 in the Upper Chester River Watershed. The PS data for flows and loads are consistent with the modeling period.

Table 1(a): Upper Chester River Watershed PS Flows and Loads for the period 1997-1999

Upper Chester River PS Flows and Loads					
Year	**Flow**	**TN**		**TP**	
	mgd	lbs/yr	kg/yr	lbs/yr	kg/yr
1997	0.22	12,144	5,508	2,024	918
1998	0.13	7,255	3,291	1,209	548
1999	0.13	6,479	2,939	1,080	490
Average	0.16	8,626	3,913	1,438	652

The Middle Chester River Watershed has three municipal WWTPs (Kennedyville, Worton-Butlertown, and Chestertown) and one industrial PS (Chestertown Foods, Inc.). Table 1(b) shows the average annual flows and TN, TP loads for the period 1997 through 1999 in the Middle Chester River Watershed. The summary flows and loads include both industrial and municipal PSs.

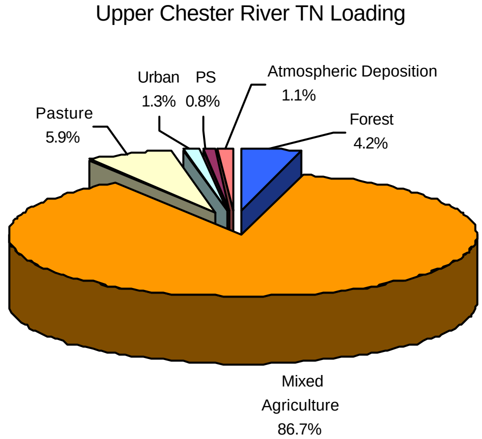
Table 1(b): Middle Chester River Watershed PS Flows and Loads for the period 1997-1999

Middle Chester River PS Flows and Loads					
Year	**Flow**	**TN**		**TP**	
	mgd	lbs/yr	kg/yr	lbs/yr	kg/yr
1997	0.77	49,892	22,630	9,898	4,490
1998	0.86	26,187	11,878	8,959	4,064
1999	0.82	21,432	9,721	9,508	4,313
Average	0.82	32,504	14,743	9,455	4,289

2.1.4.2 Nonpoint Source (NPS) Loads

NPS loads for the Upper and Middle Chester Watersheds were determined using MDE's Chester River Watershed Model. The Chester River Watershed Model was calibrated for the period 1997 to 1999. The Chester River Watershed Model uses the loading coefficients from the Chesapeake Bay Watershed Model (Phase 4.3), based on the U.S. EPA Hydrologic Simulation Program-Fortran (HSPF) continuous simulation model (see U.S. EPA Chesapeake Bay Program, 1996). The loading coefficients for the model were obtained from watershed segments 380, 390, 820 and 830 of the Chesapeake Bay Program (CBP)'s watershed model. MDE's model uses finer segmentation and detailed land use to address the local impairments. The model's land use information is based on 1997 MDP and 1997 DOSP data, with refinements to cropland acres in Maryland, based on 1997 FSA data. The CBP loading rates represent edge-of-stream loads for the year 2000, assuming Best Management Practices (BMPs) implementation at levels consistent with current progress; they account for atmospheric deposition, loads coming from urban development, agriculture, and forestland. Details of MDE's watershed model, developed to estimate these NPS loads, can be found in "Chester River Watershed HSPF Model Report" (MDE, 2001).

In the Upper Chester River Watershed, the estimated annual average NPS TN and TP loads are 1,260,612 lbs/yr (571,804 kg/yr), and 95,481lbs/yr (43,309 kg/yr), respectively. The NPS loadings are further divided into loadings from individual land uses. Figures 5(a) and 5(b) show the relative amounts of nitrogen and phosphorus PS and NPS loadings in the Upper and Middle Chester Rivers during the calibration period. The loading analysis does not take into account the loading rates in 1999, due to extreme wet and dry weather conditions that year.



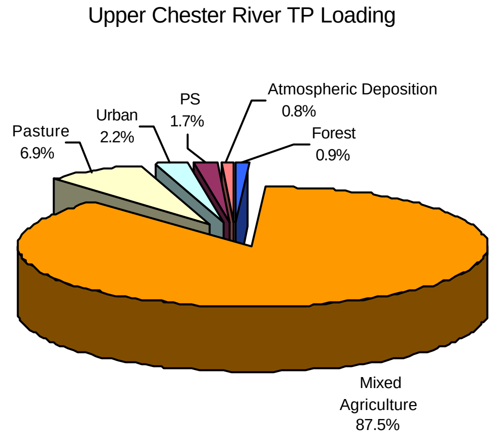
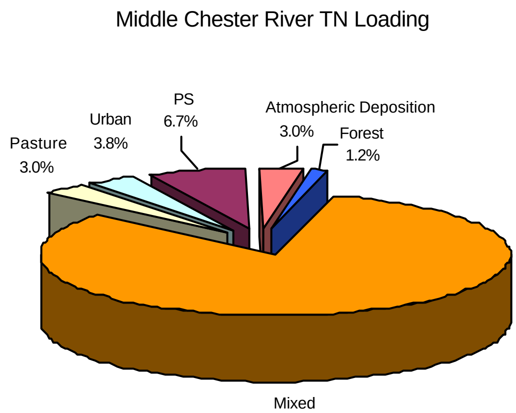
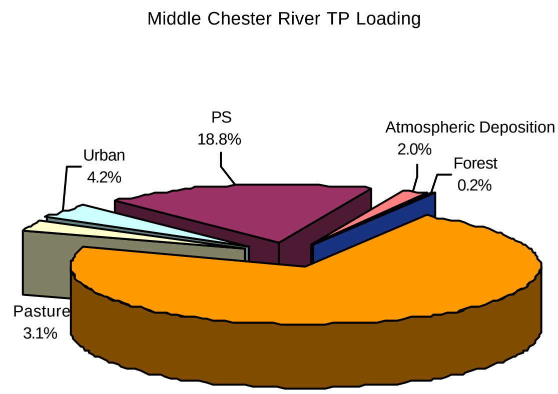


Figure 5(a): Percentages of Average Annual Nitrogen and Phosphorus Point and Nonpoint Source Loads in the Upper Chester River

In the Middle Chester River Watershed, the estimated annual average NPS TN and TP loads are 514,863 lbs/yr (233,538 kg/yr), and 39,728 lbs/yr (18,020 kg/yr), respectively.





Agriculture
82.3%

Mixed
Agriculture
71.7%

Figure 5(b): Percentages of Average Annual Nitrogen and Phosphorus Point and Nonpoint Source Loads in the Middle Chester River

2.2 Water Quality Characterization

The water quality monitoring data used in the TMDL analysis was obtained from four different sources: CBP, MDE, University of Maryland Center for Environmental Science (UMCES) and the Chester River Association (CRA). The CBP has sponsored a long-term water quality sampling station (ET4.1) in the Upper Chester River since 1984 to monitor its chemical, physical, and biological parameters. MDE monitored the Upper and Middle Chester Rivers intensively during 1999 for parameters similar to those analyzed for the CBP long-term station. MDE conducted six water quality surveys during this period. Three sets of samples were collected during the growing season (14-July-99, 11-Aug-99, 9-Sept-99) and three during the rest of the year (15-Mar-99, 7-April-99, 5-May-99). The UMCES data are from a project sponsored by MDE, “Monitoring of Sediment Oxygen and Nutrient Exchange in the Chester River Estuary in Support of TMDL Development” (UMCES, 2002). The data consist of net sediment-water exchanges, nutrient content of surface sediments, and measurements of water quality conditions in near-bottom water (UMCES, 2002). The CRA has been monitoring the water quality of the Chester River through its volunteer monitoring program at various sites. The CRA data were used for analyzing water quality trends in the Upper and Middle Chester Rivers.

Table 2(a) presents the locations of the water quality monitoring stations along the main stem of the Upper and Middle Chester Rivers. Table 2(b) presents the additional water quality monitoring and flow gage stations used in the modeling process, but located in the tributaries of the Upper and Middle Chester Rivers. Figure 6 presents the locations of the sampling stations. The sampling region covers the entire tidal portion of the Upper and Middle Chester Rivers.

Table 2(a): Location of Water Quality Monitoring Stations along the Main Stem of the Upper and Middle Chester Rivers

Station	Water Quality Station	Data Source	Kilometers from the mouth of the Middle Chester
CH1	XHH9772	MDE	0.0
CH2	XIH1477	MDE	1.3
CH3	XIH1164	MDE	3.7
CH4	XIH1960	MDE	5.7
CH5	Washington College Boat Dock	CRA	6.3
CH6	XIH2463	MDE	6.9
CH7	Heron Point	CRA	9.1
CH8	XIH3276	MDE	9.2
CH9	XIH3889	MDE	11.2
CH10	XIH4497	MDE	12.8
CH11	XII4711	MDE	14.8
CH12	CHE0347	MDE	16.7
CH13	Crumpton Public Landing	CRA	19.2
CH14	CHE0367	MDE	19.8
CH15	ET4.1	CBP	20.0
CH16	CHE0410	MDE	23.7
CH17	CHE0440	MDE	25.4
CH18	Millington	CRA	25.5

Table 2(b): Additional Water Quality and Flow Stations in the Upper and Middle Chester Rivers

Station	Data Source
AND0014	MDE
CYR0004	MDE
MZB0006	MDE
UNI0007	MDE
RLB0024	MDE
MGN0062	MDE
UOS0003	MDE
UOP0006	MDE
MGN0009	MDE
RAD0025	MDE
1493500	USGS

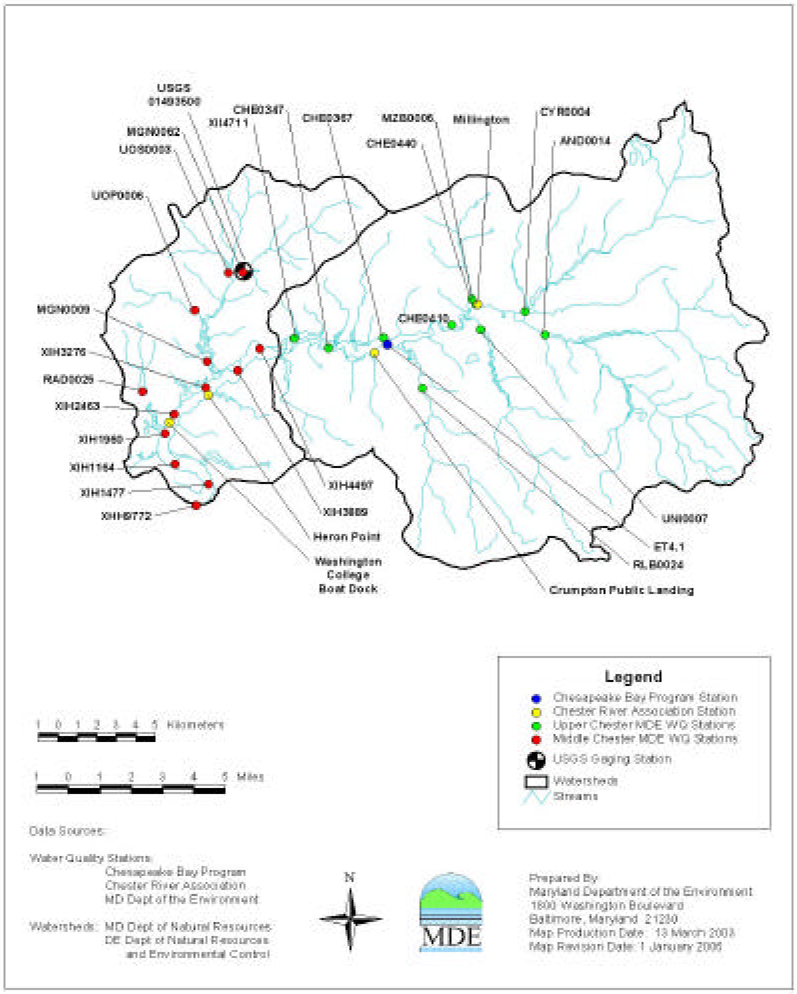


Figure 6: Location of Water Quality Stations in the Upper and Middle Chester Rivers

Problems associated with eutrophication are most likely to occur during the growing season (May 1st to October 31st). The rest of the year is referred to as the non-growing season. During the growing season, there is typically less stream flow available to flush the system, more sunlight to grow aquatic plants, and warmer temperatures, which are favorable conditions for biological processes of both plant growth and dead plant matter decay. Because problems associated with eutrophication are usually most acute during the growing season, the temperature, flow, sunlight and other parameters associated with this period represent critical conditions for the TMDL analysis.

Figures 7 through 12 present four water quality parameters associated with the eutrophication concerns of the Upper and Middle Chester Rivers: chlorophyll *a* (Chl*a*), dissolved oxygen (DO), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP). Figures 8 and 10 use the long-term data collected by CBP to show interannual patterns of one location. Figures 7, 9, 11 and 12 show MDE data collected during the growing period in 1999, presented as a longitudinal profile.

Figure 7 presents a longitudinal profile of Chl*a* data collected during a portion of the growing season. Ambient Chl*a* concentrations during the growing season are mostly above 50 µg/l in the upstream waters in the Upper Chester region, with two values higher than 100 µg/l. The values decrease downstream.

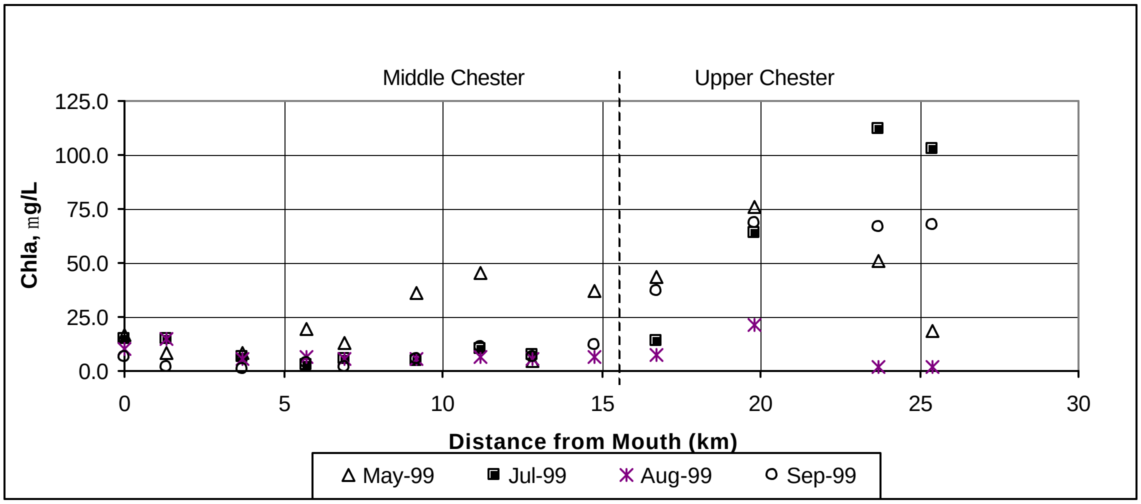


Figure 7: Longitudinal Profile of MDE Surface Chl*a* Data

Figure 8 presents the time series of surface Chl*a* concentrations in the Upper Chester River from January 1997 to December 1999 for the CBP long-term monitoring station. Chl*a* concentrations are higher during warmer months and lower during colder months. The data show several values above 100 µg/l in late Fall of 1998.

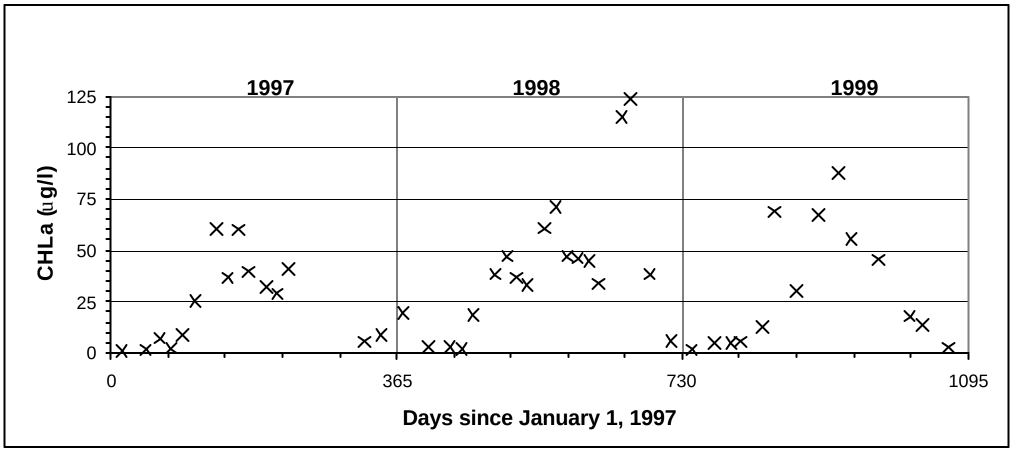


Figure 8: Time Series of CBP Surface Chl*a* Data at Upper Chester River Station ET 4.1 (River mile 20)

A longitudinal profile for DO concentrations during a portion of the 1997 growing season is depicted in Figure 9. At the stations downstream of the 9.5-mile mark, most of the DO values are above 5.0 mg/l, except in the month of September.

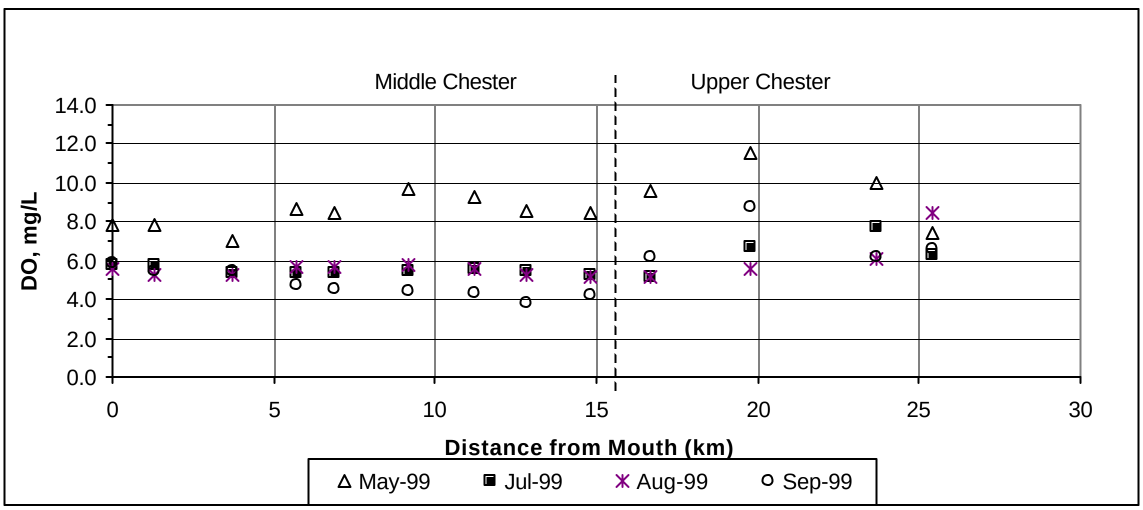


Figure 9: Longitudinal Profile of MDE Surface Dissolved Oxygen Data

Figure 10 presents the time series of DO concentrations in the Upper Chester River from January 1997 to December 1999 for the CBP long-term monitoring station, a three-year period that includes wet and dry years.

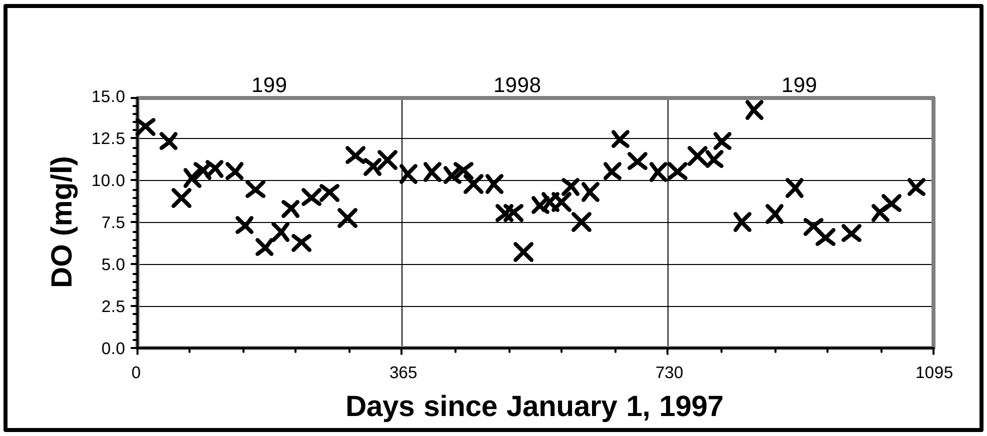


Figure 10: Time Series of CBP Surface DO Data at Upper Chester River Station ET 4.1 (River mile 20)

Figure 11 presents longitudinal profiles of DIN measured as ammonia plus nitrate plus nitrite levels in the samples collected in 1999, during a portion of the growing season. The concentrations remain fairly constant during the growing season.

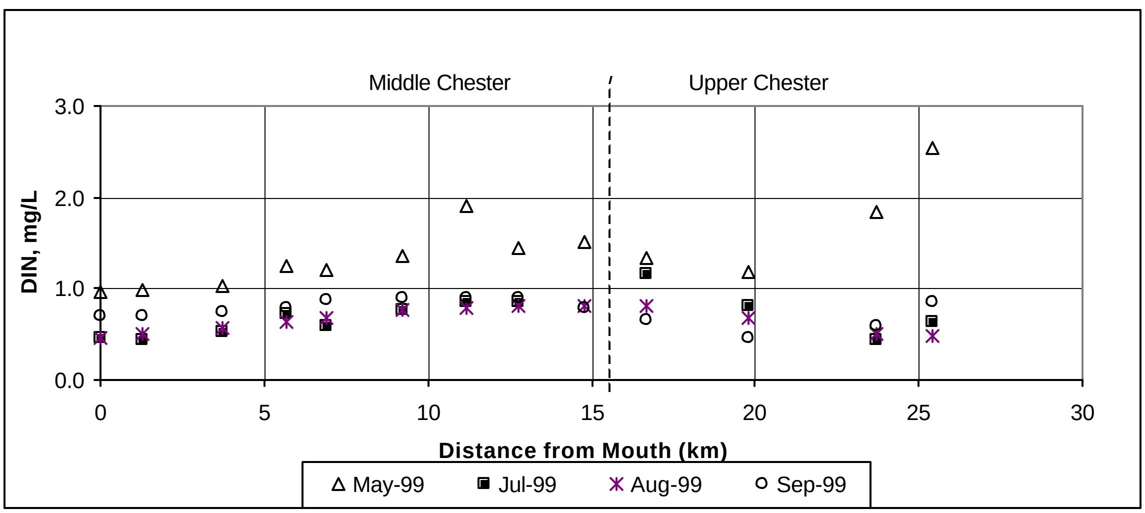


Figure 11: Longitudinal Profile of MDE Dissolved Inorganic Nitrogen Data

Figure 12 presents longitudinal profiles of DIP, as indicated by ortho-phosphate levels measured in samples collected in 1999, during a portion of the growing season. The concentrations are low in the Upper Chester River, but increase downstream. The low values at the headwaters indicate possible consumption due to algal growth.

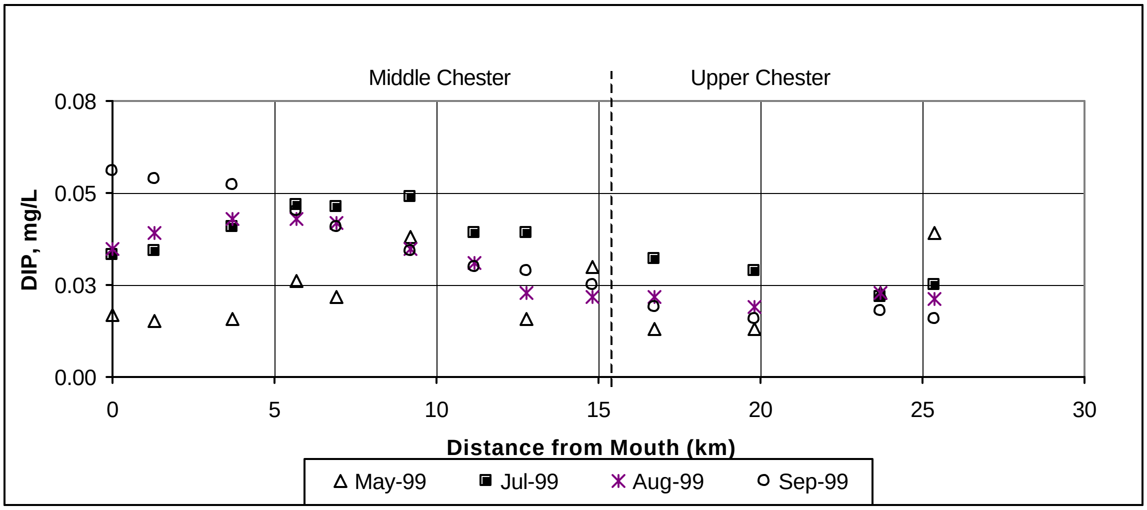


Figure 12: Longitudinal Profile of MDE Dissolved Inorganic Phosphorus Data

2.3 Water Quality Impairment

The Maryland Water Quality Standards Stream Segment Designations for the Upper Chester River and Middle Chester River, are Use II: Tidal Waters: Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting (Code of Maryland Regulations (COMAR) 26.08.02.08 G (2)(a)(b)). Designated uses present in the Upper and Middle Chester Rivers are:

1) Migratory Spawning and Nursery Use,
2) Seasonal Shallow Water Submerged Aquatic Vegetation Use,
3) Open Water Fish and Shellfish Use.

Since the Seasonal Shallow Water Submerged Aquatic Vegetation Use is included in the Open Water Fish and Shellfish Use, the analysis is limited to only the first and third designated uses. Currently there is no shellfish harvesting in the Upper Chester River. The upper portion of the Middle Chester River has no shellfish harvesting, while the lower portion has restricted shellfish harvesting.

The water quality impairment of the Upper and Middle Chester Rivers being addressed by this TMDL analysis consists of DO concentrations less than the numeric criteria for DO for the designated uses of Use II waters ((COMAR 26.08.02.03.A(2)), and elevated levels of Chl*a*. In the Upper and Middle Chester Rivers, data are not sufficient to assess the 7-day and minimum DO criteria for attainment of the designated uses; thus, the model calibration results are used.

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 ((COMAR 26.08.02.03B(2)). Excessive eutrophication, indicated by elevated levels of Chl*a*, can produce nuisance levels of algae and interfere with designated uses such as support of aquatic life, fishing and swimming. The Chl*a* concentration in the Upper Chester River exceeds 100 µg/l in several places. These levels have been associated with excess eutrophication (Thomann and Mueller, 1987).

3.0 TARGETED WATER QUALITY GOAL

The objective of the nutrient TMDLs established in this document is to ensure the DO concentrations and Chl*a* levels in the Upper and Middle Chester Rivers support the attainment of their designated uses. Specifically, the TMDLs for nitrogen and phosphorus in the Upper and Middle Chester Rivers are intended to control excessive algal growth and to increase DO concentrations in areas not meeting water quality criteria. Excessive algal growth can contribute to: violations of the numeric DO criteria, toxic algal blooms, associated fish kills, violation of narrative criteria associated with nuisance conditions such as odors, and the loss of habitat for the growth and propagation of aquatic life and wildlife. In summary, the TMDLs for nitrogen and phosphorus are intended to:

(1) Ensure that minimum DO concentrations specified for each designated use of the Upper and Middle Chester Rivers are maintained; and
(2) Resolve violations of narrative criteria associated with excess nutrient enrichment.

Table 3 presents the DO numeric criteria for the three designated uses in the Upper and Middle Chester Rivers. The designated uses specific to DO levels are based on specific numeric criteria for Use II waters set forth in COMAR 26.08.02.03-3 C (8)(b-d).

Table 3: DO Numeric Criteria for Designated Use Subcategories in the Upper and Middle Chester Rivers

Designated Use Subcategory	Period	Dissolved Oxygen Criteria
Seasonal Migratory Fish Spawning and Nursery	▪ February 1st through May 31st inclusive.	▪ ≥ 6.0 mg/l 7-day average ▪ ≥ 5.0 mg/l 1-day minimum
Open Water Fish and Shellfish	▪ June 1st through January 31st inclusive.	▪ ≥ 5.0 mg/l 30-day average ▪ ≥ 5.5 mg/l 30-day average (for tidal fresh) – year round ▪ ≥ 4.0 mg/l 7-day average ▪ ≥ 3.2 mg/l instantaneous minimum ▪ ≥ 4.3 mg/l instantaneous minimum for water temp > 29° C for protection of endangered Shortnose Sturgeon

The Chl*a* level goals used in this analysis are guidelines set forth by Thomann and Mueller (1987) and by the EPA Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2, Part 1 (1997). The Chl*a* narrative criteria ((COMAR 26.08.02.03-3 C (10)) states: "Chlorophyll *a* - Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences that would render tidal waters unsuitable for designated uses." The Thomann and Mueller guidelines above acknowledge "'Undesirable' levels of phytoplankton [Chl*a*] vary considerably depending on water body." MDE has determined per Thomann and Mueller (1987), that it is acceptable to maintain Chl*a* concentrations below a maximum of 100 µg/l, and also to target, with some flexibility depending on waterbody characteristics, a 30-day rolling average of approximately 50 µg/l. Consistent with the guidelines set forth above, MDE's interpretation of narrative criteria for chlorophyll *a* in the Upper and Middle Chester River consists of the following goals:

(1) Ensure that instantaneous concentrations remain below 100 µg/l at all times and
(2) Minimize exceedances of the 50 µg/l, 30-day rolling average, to a frequency that will not result in ecologically undesirable conditions.

4.0 TOTAL MAXIMUM DAILY LOADS AND ALLOCATIONS

4.1 Overview

The following section describes the modeling frameworks used for simulating nutrient loads, hydrology, and water quality responses. Section 4.2 explains the calibration period and summarizes the modeling framework, calibration results and TMDL analyses framework. Section 4.3 describes how the nutrient TMDLs and load allocations for PSs and NPSs were developed for the Upper and Middle Chester Rivers. The assessment investigates water quality responses using 1997 stream flow and different nutrient loading conditions. Section 4.4 presents the modeling results in terms of the TMDLs and Section 4.5 allocates the TMDLs between PSs and NPSs. Section 4.6 explains the rationale for the margin of safety and the last section summarizes the TMDLs for the growing season and the average annual conditions.

4.2 Analysis Framework

4.2.1 Computer Modeling Framework

To develop a TMDL, a linkage must be defined between the selected targets or goals and the identified sources. This linkage establishes the cause-and-effect relationship between the pollutant of concern and the pollutant sources. The relationship can vary seasonally, particularly for NPSs, with factors such as precipitation. Once defined, the linkage yields the estimate of total loading capacity or TMDL (U.S. EPA, 1999). The models were calibrated to the period of 1997-1999, which was the most recent period for which all of the needed data were available (flow, land use, weather, discharge and monitoring data) and consistent with the CBP modeling efforts of the Tributary Strategies.

The analysis framework consists of three major modeling components: the watershed model, the hydrodynamic model and the water quality model. The watershed model calculates the hydrology, NPS and PS loadings, which are then linked to the hydrodynamic and water quality models. The hydrodynamic model transports the modeled substances and the HSPF watershed model mentioned previously (Section 2.1.4.2) simulates the fate and transport of pollutants over the entire hydrologic cycle, and was used to estimate flow and nutrient loads from the watershed sub-basins. See "Chester River Basin Watershed HSPF Model Report" (MDE, 2001). The water quality model addresses sources and sinks resulting from biological, chemical and physical processes.

There were six regulated PSs of nutrients in the Upper and Middle Chester River Watersheds during the 1997 to 1999 model calibration period as described in Section 2.1.4.1. The Upper Chester has two minor municipal sources: Millington WWTP and Sudlersville WWTP. The Middle Chester River has three municipal PSs (Kennedyville WWTP, Worton-Butlertown WWTP and Chestertown WWTP) and one industrial PS (Chestertown Foods, Inc.).

The simulations of the hydrodynamics and water quality in the tidal portion of the Chester River were done with the Curvilinear Hydrodynamics in 3-Dimensions - Waterways Experiment Station (CH3D-WES) and the Corps of Engineers Water Quality Integrated Compartment Model (CE-QUAL-ICM) models respectively. The CH3D-WES is a time-variable, three-dimensional hydrodynamic, salinity, and temperature model. The output from the CH3D-WES model is then linked into the CE-QUAL-ICM model. The model computes constituent concentrations resulting from transport and transformations. The CE-QUAL-ICM water quality model was initially developed as one component of a model package employed to study eutrophication processes in Chesapeake Bay. For details of the model framework refer to "Hydrodynamic and Eutrophication Model of the Chester River Estuary and The Eastern Bay Estuary" (Kim and Cerco, 2003).

Since many studies have shown significant influence of Chesapeake Bay water on its tributaries, the spatial domain of the Chester River Basin Eutrophication Model extends longitudinally from the mouth of the Susquehanna River about 190 miles seaward to the mouth of the Patuxent River, which defines the extent of the upper Chesapeake Bay. The model includes detailed segmentation of the Chester (Lower, Middle and Upper), Miles and Wye Rivers. A diagram of the model segmentation is presented in Kim and Cerco (2003).

There are a total of 23 surface cells in the Upper and Middle Chester Rivers modeling domain as seen in Figures 13(a) and 13(b). Figure 13(a) shows the schematic flow diagram of the water quality model. Figure 13(b) shows the modeling grid in relation to its position in the watershed. The Upper Chester River consists of eight water quality cells (40001 to 40008), where 40001 is at the headwaters and 40008 is downstream at the border with the Middle Chester River. The Middle Chester River main stem consists of 12 surface cells (40009 to 40020), where 40009 is upstream and 40020 is downstream of the Middle Chester, plus three surface cells 43010, 42010 and 41010 in Morgan Creek (43010 is upstream and 41010 is downstream). Morgan Creek joins with the Middle Chester River at water quality cell 40010. Freshwater flows and NPS loadings from watersheds are evenly distributed into the adjacent water quality model cells.

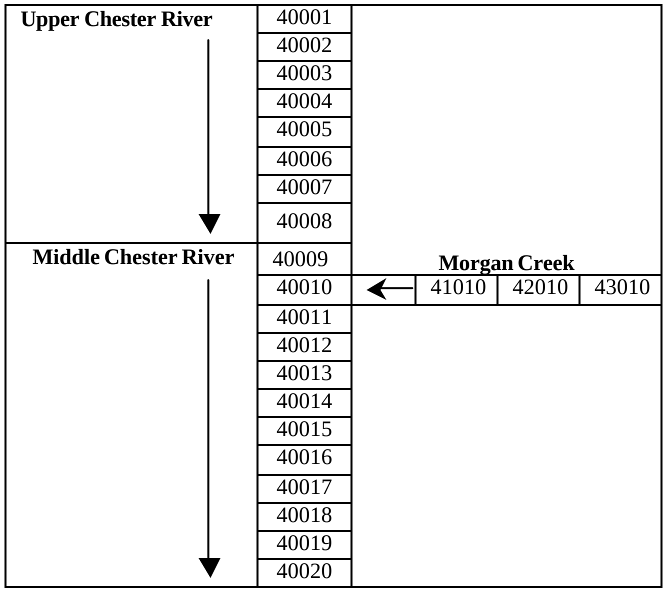


Figure 13(a): Schematic Flow diagram of the CE-QUAL-ICM model segments for the Upper and Middle Chester Rivers

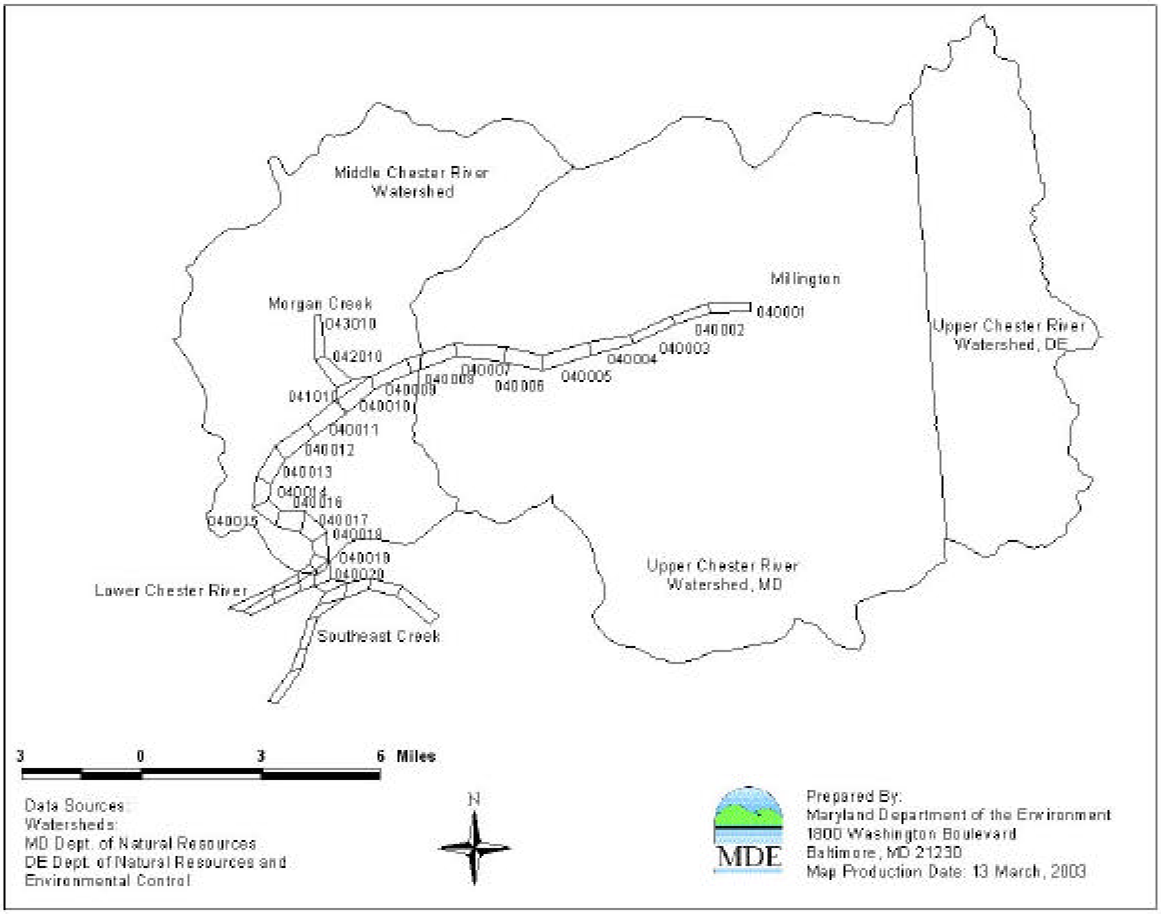


Figure 13(b): CE-QUAL-ICM model segments for the Upper and Middle Chester Rivers

4.2.1.1 Calibration

The water quality model CE-QUAL-ICM described above was calibrated to reproduce observed water quality characteristics for 1997 through 1999 conditions. Observed water quality data collected by CBP, MDE, UMCES and CRA were used to support the calibration process, as explained further in “Hydrodynamic and Eutrophication Model of the Chester River Estuary and The Eastern Bay Estuary” (Kim and Cerco, 2003) and Appendix A. All time series and longitudinal profiles related to the calibration of the model can be found in Kim and Cerco (2003).

Figure 14 is the Chl*a* calibration plot for the long term monitoring station ET4.1 situated in the Upper Chester River. ET4.1 is a CBP-sponsored detailed long-term monitoring station located at surface water quality cell 40005 in the model. Figure 14 shows the expected seasonal pattern in Chl*a* concentrations and a model calibration that tracks concentrations well, except for several outlying values in the fall of 1998.

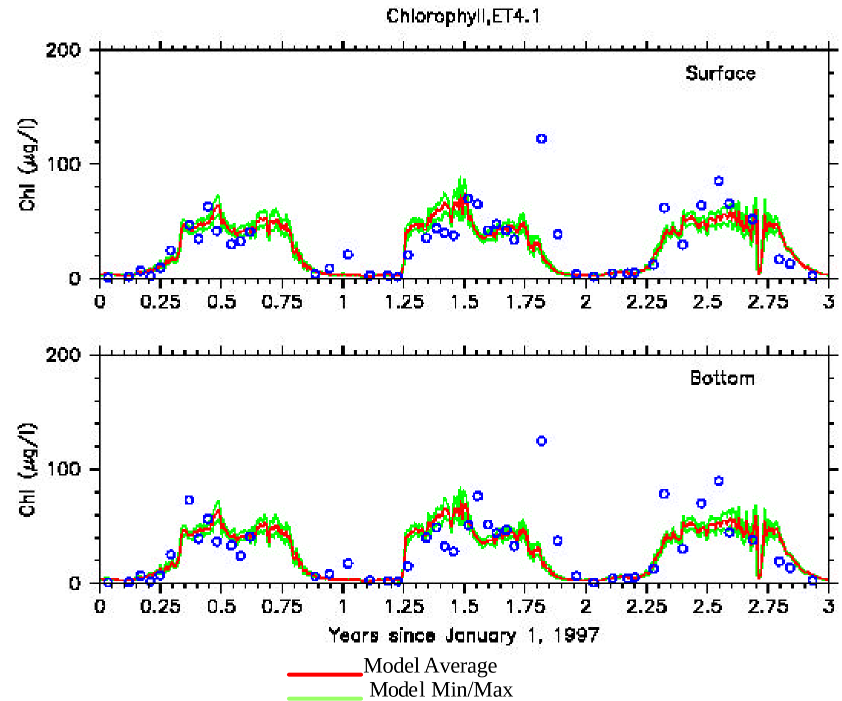


Figure 14: Model Results for the Calibration (1997-1999) for Chl*a* in the Upper Chester River ET4.1 Continuous Long Term Station

Figure 15 shows the model calibration results for DO against monitoring data in the Upper Chester River at station ET4.1. The model calibration captures the seasonal pattern of the DO levels during the growing and non-growing season of the three years.

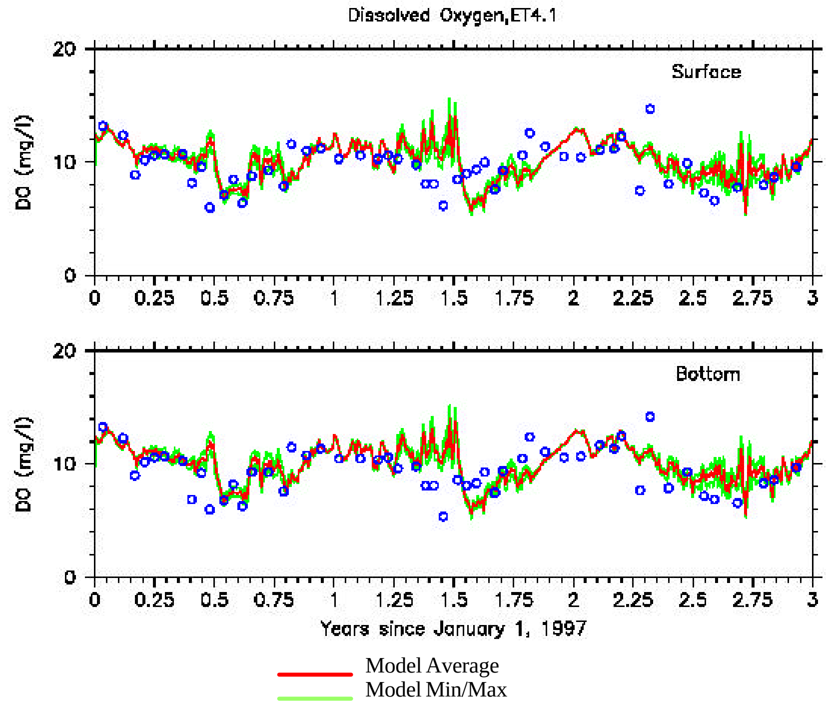


Figure 15: Model Results for the Calibration (1997-1999) for DO in the Upper Chester River ET4.1 Continuous Long Term Monitoring Station

The Middle Chester River has several monitoring stations sponsored by the CRA, which provided monitoring information for trend analysis. The results presented in Figure 16 are the data for the CRA station at Washington College Dock. In addition, data at Heron Point, Crumpton Public Landing and Millington were analyzed (see Table 2 for locations). The data recorded at these stations are not depth specific and therefore not used for calibration of the model. The calibrated model output was compared with the CRA data for verification of the results and analysis of trends.

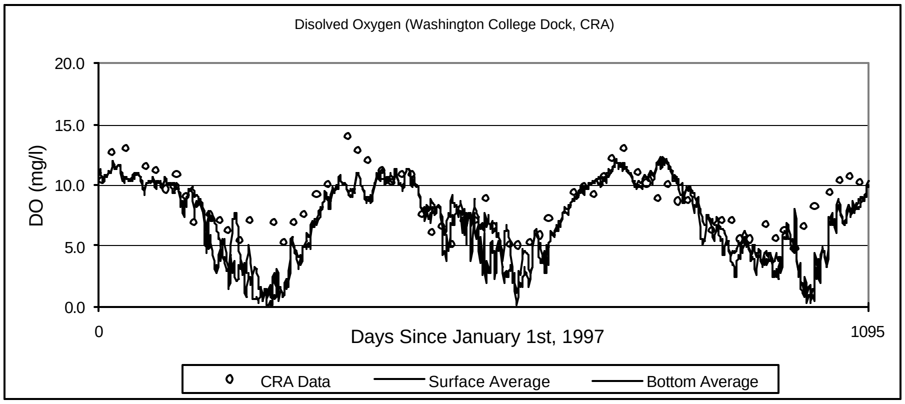


Figure 16: Model Results for the Calibration (1997-1999) for DO in the Middle Chester River at Washington College Dock by Chester River Association

4.2.2 TMDL Analysis Framework

The nutrient TMDL analysis consists of two broad elements: an assessment of growing season loading conditions and an assessment of average annual loading conditions. Both the growing season and the average annual flow TMDL analyses investigate the critical conditions under which symptoms of eutrophication are typically most acute, *i.e.*, for average annual flow in dry years or very wet years and/or for the growing season, especially late summer when flows are very low, when the system is poorly flushed and when sunlight and temperatures are most conducive to excessive algal production.

Although the model was run for the period 1997-1999, only the output from 1997 was used to investigate different nutrient loading scenarios and calculate the annual average and growing season TMDLs for the Upper and Middle Chester Rivers because:

- In 1999, the region experienced extreme weather conditions (prolonged drought followed by Hurricane Floyd) resulting in atypically high flows and loads,
- The Tributary Strategies scenario (Version 6) used as the TMDL scenario was available only until the end of 1997;
- Based on the flow gauge on Morgan Creek near Kennedyville, USGS 01493500 (see Figure 6), it was determined that the flow in 1997 is representative of the average annual flow and loads.

The analysis allows a comparison of loading conditions and future conditions that project the water quality response to various simulated load reductions of the impairing substances. The analysis accounts for seasonality, a necessary element of the TMDL development process.

4.2.2.1 Dissolved Oxygen Analytical Framework

In 2005, MDE adopted the CBP DO criteria attainment methodology utilizing DO biological reference curves to represent the spatial and temporal distribution of DO concentrations necessary to support living resources. MDE is applying this methodology using Cumulative Frequency Distributions (CFDs) for the Upper and Middle Chester Rivers generated from the model output, and compared against the CBP reference curves, to assess spatial and temporal DO criteria exceedances. This method quantifies and visualizes the degree of criteria attainment or exceedance, incorporating the percent of area or volume of a region that meets or exceeds the DO criterion for specific designated uses, and how often this criterion is met or exceeded. Using the CFD generated from the model data, the calibrated and verified assessment results express exceedances over the reference curve (violations of the allowable criteria limit) as percentages of the total time-volume for the area. These percentages are then used to determine whether a load reduction (TMDL) is required to meet the designated use.

CFDs for DO represent the spatial and temporal distribution of DO concentrations in areas supporting species and communities the criteria were established to protect. The curves are based on empirical, biologically-based field data wherever possible. The CBP DO criteria have several duration curves: 30-day mean, 7-day mean, 1-day mean and instantaneous minimum. Given the limitations in direct monitoring at the temporal scales required for assessing attainment of the instantaneous minimum, 1-day mean and 7-day mean criteria, *EPA indicates that the states can either waive attainment assessments for these criteria until monitoring at the required temporal scales is implemented, or apply statistical methods to estimate probable attainment (EPA, April 2003).* Since the monitoring data are not available, and the statistical methods have not been established, MDE will assess the DO attainment for only the 30-day component of the Open Water Use DO criteria in the Upper and Middle Chester Rivers. For the Migratory Fish Nursery and Spawning Use, EPA indicates that until more data are collected to better assess the attainment of the 7-day mean and instantaneous minimum criteria of this designated use, the Open Water DO reference curve should be applied (EPA, 2003). Due to limited data at the temporal scale needed to develop site specific DO reference curves, MDE has adopted the CBP DO criteria reference curve for the Migratory Fish Spawning and Nursery Use and Open Water Use (Figure 17 below).

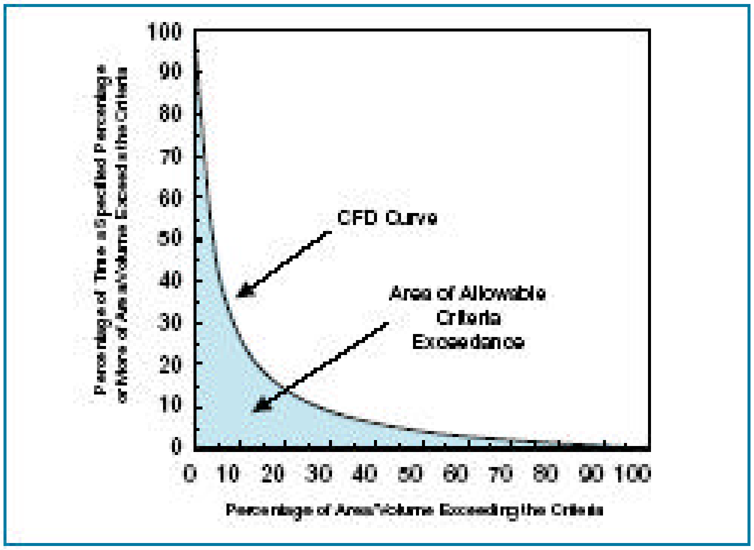


Figure 17: Cumulative Frequency Distribution curve representing an approximately 10 percent allowable exceedance equally distributed between time and space (CBP, 2003)

For more information on monitoring, assessment of DO criteria attainment, and CBP DO reference curves, please refer to the CBP document entitled “Ambient Water Quality Criteria for the Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and its Tidal Tributaries” (EPA, April 2003).

4.2.2.2 Chlorophyll *a* Analytical Framework

Model results were compared to the quantitative implementation of the narrative Chl*a* criteria stated as: (1) ensuring that instantaneous concentrations remain below 100 µg/l at all times and (2) minimizing exceedances of the 50 µg/l, 30-day rolling average, to a frequency that will not result in ecologically undesirable conditions.

4.3 Scenario Descriptions and Results

The scenarios are grouped according to *baseline conditions* and *future conditions*, the latter being associated with the TMDLs. Both scenarios were used to estimate growing season and average annual TMDLs. The baseline condition is intended to provide a point of reference by which to compare future scenarios that simulate conditions of a TMDL. From the three-year calibration period, 1997 was used as the baseline conditions scenario (see Section 4.2.2 for rationale). The baseline condition for NPS loads typically reflects an approximation of loads during the monitoring time frame, in this case, 1997. Baseline PS loads were also estimated using 1997 discharge monitoring data for nutrients and flow.

Another scenario that was investigated during the development of the TMDL (Scenario I) is described in Appendix D of this document. Scenario I investigates the NPS load reductions necessary to achieve the Chl*a* 30-day rolling average target goal of 50 µg/l. Scenario I results in impractically high load reductions to agricultural land, *i.e.*, beyond what current technology can achieve. Scenario I was not considered for the calculation of the TMDLs because of the unattainable reductions needed for the achievement of the Chl*a* 30-day rolling average target.

4.3.1 Baseline Conditions Scenario

The baseline conditions scenario represents the observed conditions of the river during 1997. This scenario simulates the different flow and nutrient loading conditions throughout the year. The system was simulated to account for loading and hydrological conditions that address the critical conditions of the system including seasonality during the summer months, when the river system is poorly flushed, and sunlight and warm water temperatures are most conducive to creating the water quality problems associated with excessive nutrient enrichment.

Refer to Section 4.2.1 and Kim and Cerco (2003) for details of the transport and eutrophication model used for the baseline conditions scenario. The NPS nutrient concentrations for the baseline scenario were estimated from the MDE's HSPF model of the Chester River Basin. The HSPF simulates NPS loads and integrates all natural and human induced sources (including direct atmospheric deposition) associated with river base flow during growing season conditions [See "Chester River Basin Watershed HSPF Model Report"(MDE, 2001)]. For PS loads, this scenario uses the municipal and industrial discharge monitoring data from 1997.

4.3.2 Baseline Conditions Scenario Results

Results for DO and Chl*a* at ET4.1 (Cell 40005) for the baseline conditions scenario are summarized in Figures 18 and 19. The baseline condition is based on the calibration period of 1997.

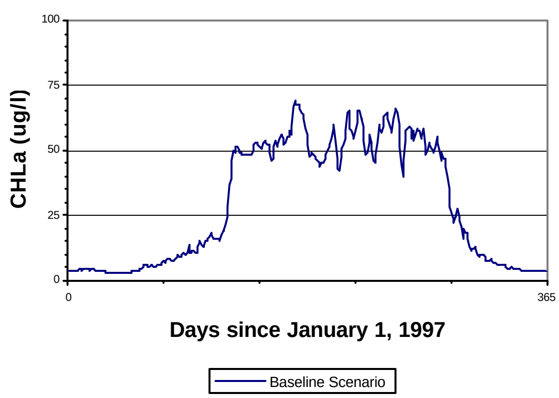


Figure 18: Model Results for the Baseline Conditions Scenario for Surface Chl*a* in the Upper Chester River at ET4.1 Continuous Long Term Monitoring Station

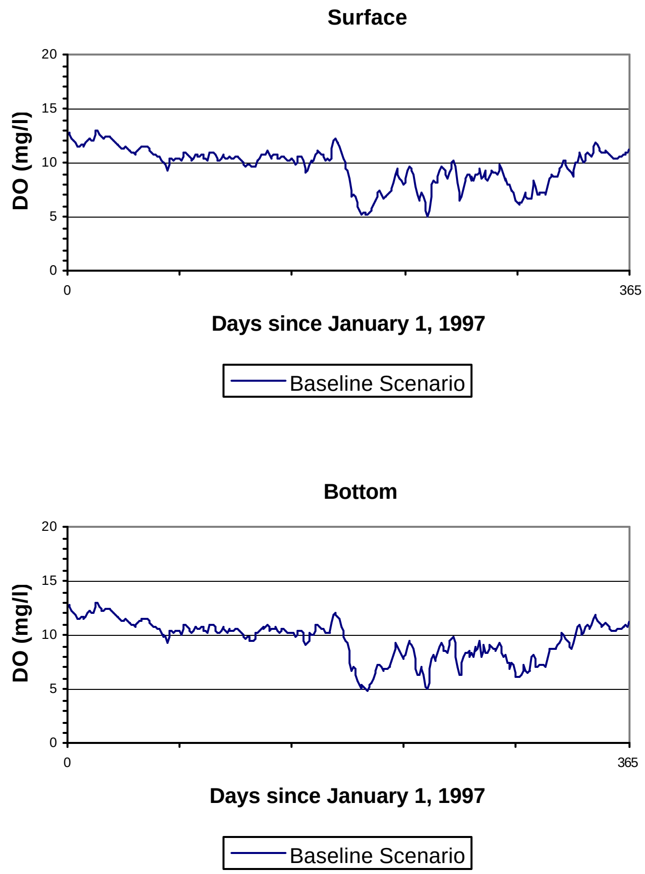


Figure 19: Model Results for the Baseline Conditions Scenario for DO in the Upper Chester River at ET4.1 Continuous Long Term Monitoring Station

4.3.2.1 Dissolved Oxygen Assessment of Baseline Conditions Scenario

For the DO assessment of the Baseline Conditions Scenario for the Upper and Middle Chester Rivers, the reference curves as established by CBP were used. Since available data for the Chester River were insufficient, MDE is using the calibrated model output for the Cumulative Frequency Distribution (CFD) attainment analysis. A DO CFD curve (or "attainment curve") was developed using the calibrated model DO output for 1997 (the baseline conditions scenario period). The development of the CFD was based on estimates of spatial exceedance percentages for all data available during the assessment period. Separate attainment curves or CFDs were then developed for Migratory Fish and Spawning, and for Open Water. The Seasonal Shallow Water Submerged Aquatic Vegetation criterion is covered under the Open Water criteria.

The reference curves for the above criteria were obtained from the CBP. The attainment curve, which assesses conditions in the stream segment during the assessment period, is compared to the corresponding reference curve. The area below the reference curve reflects criteria attainment (also referred to as "allowable" criteria exceedance). The area above the reference curve reflects criteria non-attainment (or "non-allowable" exceedances). These areas of "non-allowable" exceedance indicate non-attainment of the established designated use, and are estimated as percentages of non-attainment of the specific designated use under analysis.

The assessments of the DO criteria attainment for the Migratory Fish Spawning and Nursery Designated Use for the Upper and Middle Chester Rivers apply from February 1st to May 31st. In each case, the attainment curve is below the reference curve, indicating that there are no DO violations in the Upper and Middle Chester Rivers during the period of February 1st to May 31st (See Figures E-2 and E-3 in Appendix E).

The assessment of the DO criteria attainment for the Open Water Designated Use, which applies from June 1st to January 31st, shows that in the Upper and Middle Chester Rivers there are areas of "non-allowable" criteria exceedance of 5% and 41%, respectively. This is the time during which DO levels are not meeting the required criteria in the Upper and Middle Chester (See Figures E-4 and E-5 in Appendix E).

4.3.2.2 Chlorophyll *a* Assessment of Baseline Condition Scenario

The Chl*a* levels in the baseline conditions scenario output were analyzed using a 30-day rolling average as referenced in section 4.2.2.2. The analysis shows that the 100 µg/l is uniformly and consistently met but the 30-day rolling average Chl*a* levels tend to be greater than the 50 µg/l target goal throughout the Upper Chester River. (See Table E-1, Appendix E) In the Middle Chester River, the 30-day rolling average Chl*a* tends to be greater than the 50 µg/l target goal in Morgan Creek and in several of the cells in its mainstem headwaters (See Table E-2, Appendix E).

4.3.3 Future Conditions (TMDL) Scenario

This scenario provides an estimate of future conditions of the Upper and Middle Chester Rivers at maximum allowable average annual and growing season (May 1st to October 31st) loads. The loading rates used in this TMDL scenario are from the Tributary Strategies scenario (Version 6), allocating the loads from the Tributary Strategies scenario for the Chester River CBP watershed segment to MDE's watershed segmentation. The loads allocated to the Urieville Community Lake Watershed from its sediment and phosphorus TMDL were taken into account in the Middle Chester River Watershed (MDE, 1999). The scenario uses the same flows and hydrologic and environmental conditions as the calibration/baseline scenario, but simulates a maximum design flow with lower concentrations of PS nitrogen and phosphorus discharges and a reduction in nitrogen and phosphorus urban loads for the 12 sub-watersheds of the Upper and Middle Chester River system. This future conditions scenario was used to estimate both growing season and average annual flow TMDLs.

In summary, the scenario represents the Tributary Strategies reductions taken from the baseline agricultural loads, as this is the major nutrient contributor to the waterbodies. Agricultural land accounts for approximately 59.7% and 72.4 % of the Upper and Middle Chester River Watersheds, respectively. The corresponding agricultural load percentages for the Upper Chester River are 92.0% for average annual TN and 92.9% for average annual TP; for the

Middle Chester River they are 79.9% for average annual TN, and 66.4% for average annual TP. Therefore, non-agricultural loads, including urban, represent a minor contribution to the total load. Forestland is considered an uncontrollable nutrient contributor.

In the Upper Chester River Watershed, the NPS agricultural loads were reduced by 54% and 49% for TN and TP, respectively. In the Middle Chester River Watershed, the NPS agricultural loads were reduced by 56% and 59% for TN and TP, respectively.

Additionally, in this scenario, the PS loads were set at stringent limits necessary to meet water quality criteria. The PS flows were set at maximum design values and the concentrations at current or future permitting goals. The flows and concentrations used are listed in the following table.

Table 4(a): Upper Chester River Flows and Concentrations for PS

PS	NPDES #	Flow	Effluent Concentration	
		MGD	TN (mg/l)	TP (mg/l)
Millington WWTP	MD0020435	0.105	18.00	3.00
Sudlersville WWTP	MD0020559	0.09(0.075*)	18.00	3.00

*Flow is different in growing season

Table 4(b): Middle Chester River Flows and Concentrations for PS

PS	NPDES #	Flow	Effluent Concentration	
		MGD	TN (mg/l)	TP (mg/l)
Worton-Butlertown WWTP	MD0060585	0.15(0.00*)	18.00	3.00
Kennedyville WWTP	MD0052671	0.030	18.00	3.00
Chestertown Foods, Inc.	MD0002232	0.230	17.83	3.13
Chestertown WWTP*	MD0020010	0.900	5.00(3.00**)	0.30

*Flow or concentration is different in growing season
** Concentration different in growing season

4.3.4 Future Conditions (TMDL) Scenario Results

Model output for the TMDL scenario results are reported in Appendix B. The output analysis and assessment for meeting criteria are described in the following section.

4.3.4.1 Dissolved Oxygen Assessment of Future Conditions (TMDL) Scenario

The Upper and Middle Chester Rivers DO assessment was conducted similarly to that of the baseline condition scenario described previously in Section 4.3.2.1, with the TMDL scenario model output being used for the attainment analysis. In the Upper and Middle Chester Rivers, the Migratory Fish Spawning and Nursery Use was met in the baseline conditions scenario. Since the future conditions scenario reduces loads further, the Migratory Fish Spawning and Nursery Use continues to be met.

The TMDL scenario assessments of the DO criteria attainment for the Open Water Designated Use for the Upper and Middle Chester Rivers are for the period of June 1st to January 31st. They show monthly attainment curves for both rivers compared to the CBP reference curve for this designated use period. In comparison to the baseline conditions scenario, the future conditions scenario shows no areas of "non-allowable" criteria exceedances, indicating no DO violations for these criteria. This represents an absence of DO criteria violation of the Open Water Designated Use, for the TMDL scenario in the Upper and Middle Chester Rivers (See Figures 6-E and 7-E in Appendix E).

4.3.4.2 Chlorophyll *a* Assessment of Future Conditions (TMDL) Scenario

The Chl*a* attainment was checked using time series of the 30-day rolling average as described in Section 4.2.2.2. The criteria goals are to attempt to reduce the 30-day rolling average Chl*a* levels below 50 µg/l, although maintaining peak values less than 100 µg/l is acceptable.[1]

Results indicate that in the Upper Chester River, except for four cells in the upper headwaters, the 30-day rolling average Chl*a* levels remain below 50 µg/l. The Chl*a* levels in the four cells in the headwaters are between 50 and 56 µg/l (cell 40001 to 4004). The results of the Upper Chester River Chl*a* analysis are summarized in Table 3-E, Appendix E. The Upper Chester River TMDL scenario Chl*a* values are all below 100 µg/l.

Nutrient reductions in the Upper Chester River are required for attaining the Chl*a* levels in the mainstem of the Middle Chester River. The scenario results indicate that in the mainstem of the Middle Chester River, the 30-day rolling average for Chl*a* remains below 50 µg/l (cells 40009 to 40020). In Morgan Creek (cells 43010, 42010 and 41010), the future conditions scenario Chl*a* analysis shows that the levels are expected to decrease from 74-84 µg/l to approximately 61-53 µg/l for the surface layer. The results of the Middle Chester River Chl*a* analysis are summarized in Table 4-E, Appendix E. The Middle Chester River TMDL scenario Chl*a* values are all below 100 µg/l.

The reductions required to bring the Chl*a* values in all areas of both the Upper and Middle Chester Rivers to the target goal of less than 50 µg/l at all times was also investigated in the analysis. The results of this scenario (Scenario I) are presented in Appendix D. The analysis of Scenario I shows that the reductions required to meet spatially and temporally uniform application of the 50 µg/l target goal for Chl*a* would not be possible even with stringent point source controls and the existing technology under a voluntary program for nonpoint sources. In the Upper Chester River Watershed the NPS agricultural load reduction would be 67% for TN and 62% for TP. In the Middle Chester River Watershed the NPS agricultural load reduction would be 83% for TN and 84% for TP. Refer to Appendix D for details of the calculations.

4.4 TMDL Loading Caps

This section presents the TMDLs for nitrogen and phosphorus. The outcomes are presented in terms of an average annual and a growing season TMDL. The TMDLs were estimated based on

[1] The guidelines described in Section 3 acknowledge it is acceptable to maintain Chl*a* concentrations below a maximum of 100 µg/l, with a target threshold of less than 50 µg/l based on a 30-day rolling average.

the nutrients loadings as explained in Section 4.3 and the resulting water quality of the Upper and Middle Chester Rivers for the simulated year of 1997. The timeframe selected includes representative wet and dry periods, accounting for seasonality and critical conditions. The detailed calculation of TMDL loading caps can be found in Appendix C. The values in the Middle Chester River take into account the TMDL loads calculated for the Urieville Community Lake Watershed (MDE, 1999). The average annual phosphorus TMDL for Urieville Community Lake Watershed was set at 509 lbs/yr.

For the period of May 1 through October 31, the following TMDLs apply:

Upper Chester River Growing Season TMDLs:

NITROGEN TMDL 246,717 ***lbs/growing season***

PHOSPHORUS TMDL 8,573 ***lbs/growing season***

Middle Chester River Growing Season TMDLs:

NITROGEN TMDL 116,149 ***lbs/growing season***

PHOSPHORUS TMDL 5,048 ***lbs/growing season***

The average annual TMDLs for nitrogen and phosphorus are:

Upper Chester River Average Annual TMDLs:

NITROGEN TMDL 614,612 ***lbs/year***

PHOSPHORUS TMDL 34,354 ***lbs/year***

Middle Chester River Average Annual TMDLs:

NITROGEN TMDL 275,437 ***lbs/year***

PHOSPHORUS TMDL 16,709 ***lbs/year***

4.5 Load Allocations Between PSs and NPSs

During the 1997 to 1999 period, the watersheds draining into the Upper and Middle Chester Rivers had six permitted PSs discharging nutrients. For the TMDL scenario, all of these PSs are given an allocation. The allocations described in this section demonstrate how the TMDLs can be implemented to achieve water quality criteria in local waters and Chesapeake Bay waters. Specifically, these allocations show that the sum of nitrogen and phosphorus nutrient loadings to the Upper and Middle Chester Rivers from existing point and nonpoint sources can be maintained safely within the TMDLs established herein. The State reserves the rights to revise these allocations provided the revisions are consistent with the achievement of water quality standards. The load allocations for the Middle Chester River Watershed include the loading allocations made in the Urieville Community Lake TMDL (MDE, 1999).

4.5.1 Growing Season TMDL Allocations

Growing Season TMDL allocations apply to the period of May 1st to October 31st.

- **NPS Loads**
  The NPS loads of nitrogen and phosphorus simulated in the TMDLs scenario represent the same loads as in the calibration/baseline scenario for both the growing season and the remaining months of the year 1997. NPS loads including agricultural loads, forest loads and atmospheric deposition are assigned to the TMDL as the Load Allocation (LA). The calibration/baseline scenario loads were based on the MDE HSPF model of the Chester River Watershed. The modeling of the watershed accounted for both "natural" and human-induced components, including atmospheric deposition. Details on the HSPF model can be found in "Chester River Watershed HSPF Model Report", (MDE, 2001).

- **Stormwater Loads**
  The urban loads or stormwater loads are considered as part of the Wasteload Allocation (WLA). In November 2002, EPA advised States that the National Pollution Discharge Elimination System (NPDES) regulated stormwater discharges must be addressed by the WLA component of a TMDL. See 40 C.F.R. § 130.2(h).

- **PS Loads**
  In the Upper Chester River, for the Millington WWTP, concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.15 MGD for the entire year. For the Sudlersville WWTP the concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.075 MGD for May 1st to October 31st and 0.09 MGD for the rest of the year.
  In the Middle Chester River, the Chestertown WWTP concentrations were set at an average 4.0 mg/l (growing season 3 mg/l and non-growing season 5 mg/l) and 0.3 mg/l for TN and TP respectively, with a flow of 0.9 MGD throughout the year. The Kennedyville WWTP concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.03 MGD throughout the year. The Worton-Butlertown WWTP concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.15 MGD for the period of September 1st to April 30th. There is no discharge from this PS during May 1st to August 31st. The industrial PS concentrations were set at 17.83 mg/l and 3.13 mg/l for TN and TP respectively, with a flow of 0.23 MGD for the entire year.

  All PSs are addressed by this allocation and are described further in the technical memorandum entitled *"Nutrient Point Sources in the Upper and Middle Chester River Watersheds"*. The nitrogen and phosphorus allocations for growing season conditions are presented in Table 1(a) and Table 1(b) of the memorandum.

The TMDL, including loads from stormwater discharges, is now expressed as:

TMDL = WLA [Industrial/Municipal PS + Regulated Stormwater PS] + LA + MOS

Where: **TMDL** = Total Maximum Daily Load
WLA = Waste Load Allocation (PS)
LA = Load Allocation (NPS)
MOS = Margin of Safety

Table 5(a): Growing Season Allocations for the Upper Chester River

	Total Nitrogen ***(lbs/growing season)***	**Total Phosphorus** ***(lbs/growing season)***
NPS[1]	224,377	6,872
PS[2]	11,913	1,366
MOS[3]	10,427	335
Total	246,717	8,573

1. Excluding urban stormwater loads.
2. Including urban stormwater loads.
3. Representing 5% of agricultural loads.

Table 5(b): Growing Season Allocations for the Middle Chester River

	Total Nitrogen ***(lbs/growing season)***	**Total Phosphorus** ***(lbs/growing season)***
NPS[1]	92,534	2,649
PS[2]	19,275	2,286
MOS[3]	4,339	113
Total	116,149	5,048

1. Excluding urban stormwater loads.
2. Including urban stormwater loads.
3. Representing 5% of agricultural loads.

4.5.2 Average Annual TMDL Allocations

- **NPS Loads**

  The NPS loads simulated in the HSPF model account for both "natural" and human-induced components. NPS loads include agricultural loads, forest loads and atmospheric deposition. Reductions were made to agricultural and atmospheric deposition loads. An additional 5% MOS of safety is taken from the agricultural loads.

- **Stormwater Loads**
  The urban loads or stormwater loads are considered as part of the WLA. However, no reductions were made to these loads.

- **PS Loads**
  In the Upper Chester River, for the Millington WWTP, concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.15 MGD for the entire year. For the Sudlersville WWTP the concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.075 MGD for May 1st to October 31st and 0.09 MGD for the rest of the year.

  In the Middle Chester River, the Chestertown WWTP concentrations were set at an average 4.0 mg/l (growing season 3 mg/l and non-growing season 5 mg/l) and 0.3 mg/l for TN and TP respectively, with a flow of 0.9 MGD throughout the year. The Kennedyville WWTP concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.3 MGD throughout the year. The Worton-Butlertown WWTP concentrations were set at 18.0 mg/l and 3.0 mg/l for TN and TP respectively, with a flow of 0.15 MGD for the period or September 1st to April 30th. There is no discharge from this PS during the remainder of the year. The industrial PS concentrations were set at 14.4 mg/l and 3.3 mg/l for TN and TP respectively, with a flow of 0.23 MGD for the entire year.

Table 6(a): Average Annual Allocations for the Upper Chester River

	Total Nitrogen *(lbs/yr)*	**Total Phosphorus *(lbs/yr)***
NPS[1]	561,653	29,078
PS[2]	26,451	3,810
MOS[3]	26,507	1,466
Total	614,612	34,354

1. Excluding urban stormwater loads.
2. Including urban stormwater loads.
3. Representing 5% of agricultural loads.

Table 6(b): Average Annual Allocations for the Middle Chester River

	Total Nitrogen *(lbs/yr)*	**Total Phosphorus *(lbs/yr)***
NPS[1]	217,447	10,047
PS[2]	47,567	6,188
MOS[3]	10,424	474
Total	275,437	16,709

1. Excluding urban stormwater loads.
2. Including urban stormwater loads.
3. Representing 5% of agricultural loads.

4.6 Margins of Safety

A MOS is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural water bodies. 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 = Load Allocation (LA) + Waste Load Allocation (WLA) + MOS. The second approach is to incorporate the MOS as conservative assumptions in the TMDL analysis.

Maryland has adopted a MOS for these TMDLs using the above-mentioned first approach. The reserved load allocated to the MOS was computed as 5% of the agricultural nitrogen and phosphorus loads. The major nutrient contributions in these TMDLs are from agricultural sources. For the growing season and the annual average flow TMDLs in the Upper and Middle Chester Rivers, this MOS represents 5% of the total agricultural loads. These explicit nitrogen and phosphorus margins of safety are summarized in Table 7(a) and 7(b).

Table 7(a): Upper Chester River Growing Season and Annual Margins of Safety (MOS)

	Total Nitrogen	Total Phosphorus
MOS Growing Season	10,427 lbs/growing season	335 lbs/growing season
MOS Annual	26,507 lbs/yr	1,466 lbs/yr

Table 7(b): Middle Chester River Growing Season and Annual Margins of Safety (MOS)

	Total Nitrogen	Total Phosphorus
MOS Growing Season	4,339 lbs/growing season	113 lbs/growing season
MOS Annual	10,424 lbs/yr	474 lbs/yr

4.7 Summary of Total Maximum Daily Loads

4.7.1 Upper Chester River TMDL Loads

The summary of the TMDL loads for the Upper Chester River follows. The growing season TMDLs, applicable from May 1 – October 31:

For Nitrogen (*lbs/growing season*):

TMDL	=	LA	+	WLA	+	MOS
246,717	**=**	**224,377**	**+**	**11,913**	**+**	**10,427**

For Phosphorus (*lbs/growing season*):

TMDL	=	LA	+	WLA	+	MOS
8,572	**=**	**6,872**	**+**	**1,366**	**+**	**335**

The average annual flow TMDLs for the Upper Chester River:

For Nitrogen (*lbs/year*):

TMDL	=	LA	+	WLA	+	MOS
614,612	=	561,653	+	26,452	+	26,507

For Phosphorus (*lbs/year*):

TMDL	=	LA	+	WLA	+	MOS
34,354	=	29,078	+	3,810	+	1,466

Where: TMDL = Total Maximum Daily Load
LA = Load Allocation (NPS)
WLA = Waste Load Allocation (PS)
MOS = Margin of Safety

Average Daily Loads for the Upper Chester River:

On average, the growing season TMDLs will result in loads of approximately 1,341 lbs/day of nitrogen and 47 lbs/day of phosphorus. Similarly, the average flow TMDLs will result in loads of approximately 1,684 lbs/day of nitrogen and 94 lbs/day of phosphorus.

4.7.2 Middle Chester River TMDL Loads

The summary of the TMDL loads for the Middle Chester River follows. The growing season TMDLs, applicable from May 1 – October 31:

For Nitrogen (*lbs/growing season*):

TMDL	=	LA	+	WLA	+	MOS
116,149	=	92,534	+	19,275	+	4,339

For Phosphorus (*lbs/growing season*):

TMDL	=	LA	+	WLA	+	MOS
5,048	=	2,649	+	2,286	+	113

The average annual flow TMDLs for the Middle Chester River:

For Nitrogen (*lbs/year*):

TMDL	=	LA	+	WLA	+	MOS
275,437	**=**	**217,447**	**+**	**47,567**	**+**	**10,424**

For Phosphorus (*lbs/year*):

TMDL	=	LA	+	WLA	+	MOS
16,709	**=**	**10,047**	**+**	**6,188**	**+**	**474**

Where: TMDL = Total Maximum Daily Load
LA = Load Allocation (NPS)
WLA = Waste Load Allocation (PS)
MOS = Margin of Safety

<u>Average Daily Loads for the Middle Chester River:</u>

On average, the growing season TMDLs will result in loads of approximately 631 lbs/day of nitrogen and 27 lbs/day of phosphorus. Similarly, the average flow TMDLs will result in loads of approximately 755 lbs/day of nitrogen and 46 lbs/day of phosphorus.

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the nitrogen and phosphorus TMDLs will be achieved and maintained. For both TMDLs, Maryland has several well-established programs to draw upon: the Water Quality Improvement Act of 1998 (WQIA), the Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act), the Bay Restoration Fund and the Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction. Also, Maryland has adopted procedures to assure that future evaluations are conducted for all TMDLs that are established.

The implementation of PS nutrient controls will be executed through the Bay Restoration Fund Enhanced Nutrient Reduction (ENR) strategy and the NPDES permits. The Bay Restoration Fund ENR program provides up to 100 percent state grant funds to local governments to retrofit or upgrade wastewater treatment plants (WWTP) to remove a greater portion of nutrients from discharges. ENR technologies allow sewage treatment plants to provide a highly advanced level of nutrient removal. The ENR strategy builds on the success of the biochemical nutrient removal (BNR) program already in place. Upon completion of the upgrade, the NPDES permits will require the permittee to make a best effort to meet the load goals providing reasonable assurance of implementation. The NPDES permits should also be consistent with the assumptions made in the TMDL (e.g., flow, effluent nutrients concentrations, CBOD, DO, etc.).

Maryland's WQIA requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout Maryland. This act specifically requires that nutrient management plans for nitrogen be developed and implemented by 2002, and plans for phosphorus to be done by 2005. Maryland's CWAP has been developed in a coordinated manner with the State's 303(d) process. All Category I watersheds identified in Maryland's Unified Watershed Assessment process are totally coincident with the impaired waters list for 2002 approved by EPA. The State is giving a high priority for funding assessment and restoration activities to these watersheds.

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 the development and implementation of plans to achieve these nutrient reduction goals. Maryland's resultant Tributary Strategies for Nutrient Reduction provide a framework supporting the implementation of NPS controls in the Upper Eastern Shore Tributary Strategy Basin, which includes the Upper and Middle Chester River Watersheds. Maryland is in the forefront of implementing quantifiable NPS controls through the Tributary Strategy efforts. This will help to assure nutrient control activities are targeted to areas in which nutrient TMDLs have been established.

It is reasonable to expect that NPS loads can be reduced during growing season conditions. The nutrient loads sources during growing season include dissolved forms of the impairing substances from groundwater, the effects of agricultural ditching and animals in the stream, and deposition of nutrients and organic matter to the stream bed from higher flow events. When these sources are controlled in combination, it is reasonable to achieve NPS reductions of the magnitude identified by this TMDL allocation.

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 NPDES permit cycle. This continuing cycle ensures that every five years intensive follow-up monitoring will be performed. Thus, the watershed cycling strategy establishes a TMDL evaluation process that assures accountability.

In April 2002, the Maryland Department of Natural Resources published a Watershed Restoration Action Strategy (WRAS) document for the Middle Chester River. The purpose of the document is to present a strategy to reduce NPS pollution that contribute to impairments in the watershed, while at the same time conserving the unique, high quality natural resources. The strategy was developed through the combined efforts of the general public, watershed stakeholders, local and county governments, non-profit organizations and State and Federal agencies. The document outlines the conditions in the watershed, the potential sources of pollution and impairments, and actions that can be taken to address these issues. It is anticipated that this strategy will assure TMDL implementation for NPSs.

In addition, EPA Region 4 and EPA Region 6 have indicated that reductions in atmospheric contributions will be accomplished over time through existing and proposed Clean Air Act regulatory controls that will ensure significant reduction in airborne nutrient loading on a nationwide basis by reducing atmospheric emissions. Additionally, the following actions taken by EPA and the State of Maryland are also underway to assure the reduction of air deposition:

- To date, EPA has promulgated approximately 100 New Source Performance Standards under Section 111 of the Clean Air Act (CAA), of which about ten directly control nitrogen oxide (NOx) emissions;
- Because NOx is a precursor to ozone, Maryland and other states must apply similar requirements to major stationary sources of NOx emissions, including application of reasonably available control technology;
- The CAA Acid Rain Program specifies a two-part strategy to reduce NOx emissions from coal-fired electric power plants. EPA estimates that this program has resulted in 40% reduction in NOx emission rates from large utility boilers. Additional controls are expected over the next several years;
- In 1994, Maryland and other states signed a Memorandum of Understanding to achieve regional emission reductions of NOx (a.k.a. "OTC NOx Budget Program"). The agreement calls for the adoption of regulations to reduce NOx emissions in 1999 and further reduce emissions in 2003;
- In 1998, EPA issued the "NOx SIP Call" which assigns a cap on growing season NOx emissions to be achieved by 2007;
- In 1999, EPA announced new limits for tailpipe emissions of NOx. These standards would require a 77% emissions reduction in cars over the next ten years;
- The proposed Clear Skies Act of 2003, aimed at power plants, estimates to reduce NOx emissions from Maryland sources by 70% by 2020, and 77% reductions in total NOx emissions in Maryland from 2000 levels. The estimated NOx deposition to the Chesapeake Bay watershed would be reduced up to 20%;
- Maryland and the other Chesapeake Bay states have agreed to incorporate nitrogen reductions resulting from the Clear Skies legislation as part of the overall plan to reduce nutrient loadings to the Bay.

The Federal Nonpoint Source Management Program (§ 319 of the Clean Water Act) also provides funding for non point source implementation.

It should be noted that a portion of the drainage basin of the Upper Chester River (also referred to as "Upstream") lies in Delaware, beyond the jurisdictional and regulatory authority of Maryland. Load allocations to Delaware sources are consistent with and equitable to allocations given to sources in Maryland, and are reasonable and achievable with existing technology and practices. It will be incumbent upon the state of Delaware, and failing that the EPA, to ensure that this TMDL is implemented in Delaware.

REFERENCES

Cerco, C.F. and T.M. Cole. Three-dimensional eutrophication model of Chesapeake Bay: Volume 1, main report. Technical Report EL-94-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 1994.

Cerco, C.F. and T.M. Cole. User's guide to the CE-QUAL-ICM three-dimensional eutrophication model. Technical Report EL-95-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 1995.

Code of Maryland Regulations, 26.08.02.08J(2)(b), 26.08.02.03A(2), 26.08.02.03B(2), 26.08.02.03-3C(8)(b-d), 26.08.02.03-3C(10).

DiToro, D. M. and J.J. Fitzpatrick. Chesapeake Bay sediment flux model. Contract Report EL-93-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1993.

DiToro, D. M., S. Lowe and J. Fitzpatrick. Application of a water column-sediment eutrophication model to a mesocosm experiment I. Calibration. J. Environ. Engr. ASCE. 2001.

Kim, Sung-Chan and Cerco, Carl. Hydrodynamic and eutrophication model of the Chester River estuary and the Eastern Bay estuary. 2003.

Johnson, B. H., Heath, R.E. and Bernard B. Hsieh. User’s guide for a three-dimensional numerical hydrodynamic, salinity, and temperature model of Chesapeake Bay. Technical Report HL-91-20, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 1991.

Maryland Department of Environment, “Chester River Watershed HSPF Model Report” 2001.

Maryland Department of Environment, “TMDLs of Phosphorus and Sediments to Urieville Community Lake in Kent County, MD” 1999.

Maryland Department of Planning. 2000 Reference for Land Use.

Mortimer, C. H. The exchange of dissolved substances between mud and water. I and II. J. Ecol., 29:29:280-329, 1941.

Mortimer, C. H. The exchange of dissolved substances between mud and water in lakes. III and IV. J. Ecol., 30:147-201. 1942.

Shanks, Ken (2001). Editor and Primary Author, “Middle Chester River Stream Corridor Assessment Survey”, Maryland Department of Natural Resources.

Thomann, Robert V., John A. Mueller "Principles of Surface Water Quality Modeling and Control." HarperCollins Publisher Inc., New York, 1987.
UMCES, "Monitoring of Sediment Oxygen and Nutrient Exchanges in the Chester River Estuary in Support of TMDL Development", University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, TS-400-03-CBL, 2002.

U.S.D.A, "Soil Survey of Kent County, Maryland, January, 1982.

U.S.D.A, "Soil Survey: Queen Anne's County, Maryland, September, 1966.

U.S. EPA, "Guidance for water quality based decisions: The TMDL process," Office of Water, Washington D.C., 1991.

U.S. EPA, "Technical Guidance Manual for Developing Total Maximum Daily Loads, Book2: Streams and Rivers, Part 1: Biochemical Oxygen Demand/ Dissolved Oxygen and Nutrients/ Eutrophication," Office of Water, Washington D.C., March 1997.

U.S. EPA. "Protocol for Developing Nutrient TMDLs". EPA 841-B-99-007. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 135 pp., 1999.

U.S. EPA, "Ambient Water Quality Criteria for the Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries". Region III, Chesapeake Bay Program Office. April 2003.

U.S. EPA Chesapeake Bay Program, "Chesapeake Bay Program: Watershed Model Application to Calculate Bay Nutrient Loadings: Final Findings and Recommendations," and Appendices, 1996.