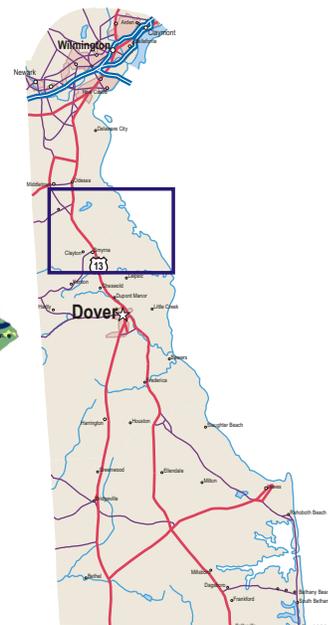
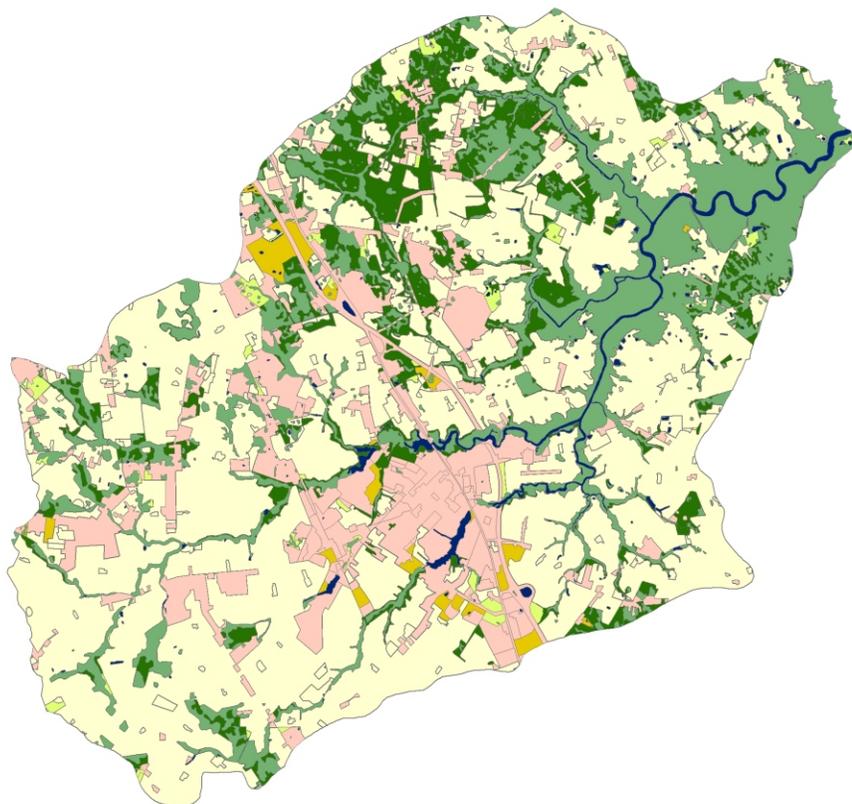


Delaware Department of Natural Resources
and Environmental Control

Smyrna River Watershed Proposed TMDLs



DNRE0070

August 2006



PREFACE

The draft Proposed TMDLs for the Smyrna River watershed were reviewed during a public workshop held on 11 May, 2006. All comments received at the workshop and during the May 1 through 31 comment period were considered by DNREC. This report has been updated to address public comments by Mid-Atlantic Environmental Law Center (Sections 1.1, 2.0, 4.0, 4.2, 6.1, 6.4 and 6.5).

CONTENTS

<u>Section</u>	<u>Page</u>
PREFACE.....	i
CONTENTS	ii
FIGURES.....	iii
TABLES	iv
1 INTRODUCTION.....	1-1
1.1 303(d) LISTED WATERBODIES.....	1-1
1.2 DESIGNATED USES.....	1-3
1.3 APPLICABLE WATER QUALITY STANDARDS AND NUTRIENT GUIDELINES	1-3
2 MODELING FRAMEWORKS.....	2-1
2.1 MODEL SEGMENTATION/DELINEATION	2-2
3 WATERSHED CHARACTERISTICS.....	3-1
3.1 LANDUSE.....	3-1
3.2 POINT SOURCES	3-1
4 WATERSHED MONITORING.....	4-1
4.1 OVERALL WATER QUALITY ASSESSMENT.....	4-2
4.2 SOURCES OF POLLUTION.....	4-2
5 SCOPE AND OBJECTIVES OF THE TMDL ANALYSIS.....	5-1
5.1 TOTAL MAXIMUM DAILY LOADS AND THEIR ALLOCATIONS	5-1
5.2 TMDL ENDPOINTS	5-2
5.3 TMDL MODEL OUTPUT PRESENTATION	5-3
5.4 INTERPRETATION OF RESULTS.....	5-4
6 PROPOSED TMDL LOAD REDUCTION.....	6-1
6.1 CONSIDERATION OF THE IMPACT OF BACKGROUND POLLUTANTS	6-1
6.2 CONSIDERATION OF CRITICAL ENVIRONMENTAL CONDITIONS.....	6-3
6.3 CONSIDERATION OF SEASONAL VARIATIONS.....	6-4
6.4 CONSIDERATION OF MARGIN OF SAFETY.....	6-4
6.5 CONSIDERATION OF MODEL CAPABILITIES AND LIMITATIONS	6-6
6.6 TMDL IMPLEMENTATION / PUBLIC PARTICIPATION	6-7
7 REFERENCES	7-1
APPENDIX 1 – EXISTING & TMDL MODEL OUTPUT (FRESHWATER)	
APPENDIX 2 – EXISTING & TMDL MODEL OUTPUT (MARINE)	
APPENDIX 3 – SMYRNA RIVER BASELINE LOADINGS	
APPENDIX 4 – SMYRNA RIVER LSPC INPUTS	

FIGURES

<u>Figure</u>	<u>Page</u>
Figure 1. LSPC Model Segmentation Smyrna River Watershed.....	2-4
Figure 2. ECOMSED Grid.....	2-5
Figure 3. RCA Model Segmentation Smyrna River Watershed.....	2-6
Figure 4. Subwatershed Groupings Smyrna River Watershed.....	6-2

TABLES

<u>Table</u>	<u>Page</u>
Table 1. Smyrna River Watershed TMDL Segments	1-2
Table 2. Summary of Land Use in the Smyrna River Watershed.....	3-1
Table 3. MS4 Urban Areas in the Smyrna River Watershed	4-4
Table 4. Smyrna River Point Source WLA (Loads).....	6-3
Table 5. Proposed TMDLs For The Smyrna River Watershed.....	6-3
Table 6. Smyrna River NPS LA by Land Use and Watershed Group.....	6-4

SECTION 1

INTRODUCTION

As required by the Federal Clean Water Act, the Delaware Department of Natural Resources and Environmental Control (DNREC) is responsible for implementing water quality monitoring and assessment activities in the State and also for establishing Total Maximum Daily Loads (TMDLs) on impaired State surface waters as indicated on the State's 303(d) List. In addition, the State of Delaware is under a court-approved Consent Decree (C.A. No. 96-591, D. Del 1996) that requires completion of TMDLs for certain impaired State waters by 2006.

In order to complete these TMDLs, DNREC has contracted with the environmental modeling firm (HydroQual, Inc.) to develop mathematical models of the Smyrna River watershed to assist in developing the TMDLs. These mathematical models include a landside watershed model to calculate nonpoint source (NPS) runoff and quality, a hydrodynamic model to calculate the movement of water in the tidal reaches of the Smyrna River (downstream of Duck Creek Pond), and a water quality model that is coupled to the hydrodynamic model to calculate water quality in the tidal reaches of the river.

As part of the Smyrna River watershed model development, data compilation and analyses were completed in addition to model development, calibration and validation. The data compilation/analysis and model development is presented in the following technical memorandum and report:

- Smyrna River Watershed TMDL Development, Data Analysis Technical Memorandum (HydroQual, 2005); and
- Smyrna River Watershed TMDL Model Development (HydroQual, 2006).

A summary of some of the data and modeling information related to the Smyrna River TMDL is presented below but detailed information relating to data and modeling are contained in these two references.

1.1 303(D) LISTED WATERBODIES

The waterbodies listed on the State of Delaware's 1998, 2002, 2004, and 2006 Draft 303(d) Lists in the Smyrna River Watershed are presented in Table 1. There are a total of 4 listed water segments: 1 tidal segment of the Smyrna River; 2 freshwater stream segments; and 1 freshwater lake. Waterbody ID DE310-003 represents Sawmill Creek and Paw Paw Branch. These segments are listed for nutrients, DO and bacteria with the most probable source of pollutants identified as NPS. The TMDL development in the Smyrna River watershed was completed to address these water quality impairments and present TMDLs that are aimed at improving water quality in the listed segments.

Table 1. Smyrna River Watershed TMDL Segments

Waterbody ID	Segment	Size Affected	Description	Parameters	Probable Source
DE310-001	Lower Smyrna River	10.2 miles	From the head of tide to the Delaware River	Bacteria, DO, nutrients	NPS
DE310-002	Mill Creek	5.2 miles	From the headwaters to Lake Como	Bacteria, DO, nutrients	NPS
DE310-003*	Tributary of Smyrna River	4.2 miles	Tributaries from the headwaters to the confluence with Delaware Bay	Bacteria, DO, nutrients	NPS
DE310-L01	Lake Como and Duck Creek Pond	82.0 acres	Lake Como in Smyrna	Bacteria, DO, nutrients	NPS

*Sawmill Creek and Paw Paw Branch

1.2 DESIGNATED USES

According to the “State of Delaware Surface Water Quality Standards (Amended July 11, 2004)”, the designated uses that must be maintained and protected through the application of appropriate criteria are uses for: industrial water supply; primary contact recreation; secondary contact recreation; fish, aquatic life and wildlife including shellfish propagation; and agricultural water supply in freshwater segments only. These designated uses are applicable to the Smyrna River and are achieved and maintained through the application of water quality standards and criteria as outlined in the next section.

1.3 APPLICABLE WATER QUALITY STANDARDS AND NUTRIENT GUIDELINES

According to the “State of Delaware Surface Water Quality Standards (Amended July 11, 2004)”, water quality standards (WQS) for dissolved oxygen (DO) and *enterococcus* exist. The DO WQSs in freshwater are a daily average of not less than 5.5 mg/L (minimum of 4 mg/L) and in marine waters are a daily average of not less than 5 mg/L (minimum of 4 mg/L). The *enterococcus* WQS consists of two parts, a single sample value not to exceed and a monthly geometric mean. For primary contact recreation in freshwater, the *enterococcus* WQS is a single sample value of 185 colonies/100mL (col/100mL) and a monthly geometric mean of 100 col/100mL. For primary contact recreation in marine waters, the *enterococcus* WQS is single sample value of 104 col/100mL and a monthly geometric mean of 35 col/100mL.

For nutrients, some site-specific or basin-specific standards exist but acceptable nutrient levels are determined based on their ultimate effect on DO or algal levels through nutrient-algal-DO relationships (eutrophication) and/or threshold levels. The nutrient standards are currently in narrative form for controlling nutrient overenrichment and are stated as:

"Nutrient overenrichment is recognized as a significant problem in some surface waters of the State. It shall be the policy of this Department to minimize nutrient input to surface waters from point sources and human induced nonpoint sources. The types of, and need for, nutrient controls shall be established on a site-specific basis. For lakes and ponds, controls shall be designed to eliminate over enrichment."

Although national numeric nutrient criteria have not been established in Delaware, DNREC has used threshold levels of 3.0 mg/L for total nitrogen (TN) and 0.2 mg/L for total phosphorous (TP) for listing waterbodies on the State's 303(d) listings and 305(b) assessment reports and, therefore, will be used as the target nutrient levels for completing nutrient TMDLs in addition to considering nutrient endpoints such as DO and algal levels (chlorophyll-a). Nutrient related algal effects typically require sufficient time for impacts to be noticed (i.e., impacts are long term in nature rather than instantaneous), therefore, the nutrient targets will be assessed based on monthly average nutrient concentrations.

SECTION 2

MODELING FRAMEWORKS

The Smyrna River watershed model was developed to complete nutrient, DO and bacteria TMDLs in the watershed. The model framework is comprised of three components: a landside model, a hydrodynamic model and a water quality model. The landside model characterizes the hydrology and NPS loadings within the watershed. The hydrodynamic model simulates the tidal motion of water due to freshwater flow, density driven currents, and meteorology confined by a realistic representation of the systems bathymetry and also calculates salinity and temperature. The coupled water quality model calculates nutrient mediated algal growth and death, dissolved oxygen (DO), the various organic and inorganic forms of nitrogen, phosphorus, and carbon (BOD). In addition, bacteria (*enterococcus*) kinetics (die-off) are also modeled.

The landside model used in the study is the Loading Simulation Program in C++ (LSPC). The LSPC model uses meteorological conditions (precipitation, evapotranspiration, air temperature, wind speed, dewpoint temperature, cloud cover and solar radiation) and land cover/use data to simulate flow, sediment transport, temperature variations, and water quality processes over the entire hydrologic cycle. Accumulation rates and limits used by LSPC as input parameters are tabulated by landuse in Appendix 4. The model results provide runoff flow and NPS loadings to the hydrodynamic and water quality models.

The hydrodynamic model used in the study is the three-dimensional, time-dependent, estuarine and coastal circulation model Estuary and Coastal Ocean Model (ECOMSED), which has been successfully applied in numerous studies, such as the South Atlantic Bight (NY/NJ), Hudson-Raritan Estuary (NY/NJ), Long Island Sound (NY/CT), Delaware River, Bay and adjacent continental shelf (NJ/PA/MD/DE), Chesapeake Bay (MD/DE), Massachusetts Bay and Boston Harbor (MA), Tar-Pamlico Estuary (NC), and St. Andrew Bay (FL).

The water quality model used in the study is a state-of-the-art eutrophication model Row Column Aesop (RCA) that is directly coupled with the hydrodynamic model, allowing computation of water quality within the tidal cycle. In addition, a sediment flux submodel is also included in the water quality model to allow calculation of sediment oxygen demand (SOD) and sediment nutrient fluxes in response to settled organic matter and its subsequent decay in the sediment. The coupled water quality/hydrodynamic model has been successfully applied in numerous studies including the Hudson-Raritan Estuary (NY/NJ), Long Island Sound (NY/CT), Chesapeake Bay (MD/DE), Massachusetts Bay and Boston Harbor (MA), Jamaica Bay (NY), Tar-Pamlico Estuary (NC), and the Upper Mississippi River (MN). The landside, hydrodynamic and water quality models were calibrated and validated with data collected by Delaware Department of Natural Resources and Environmental Control (DNREC), New Jersey Department of Environmental Protection (NJDEP)

and University of Delaware. These data include ADCP data in the lower estuary, temperature, salinity and water quality (nitrogen, phosphorus, organic carbon, DO, chlorophyll-a, bacteria) data in the tidal Smyrna River and non-tidal upstream areas of the watershed. The calibrated and validated landside, hydrodynamic and water quality models resulted in reasonable representation of both the complex mixing and circulation patterns observed in the study area and the observed nutrient, phytoplankton, organic carbon, DO and bacteria dynamics of the system.

The segments on the State of Delaware's 303(d) list were either modeled in the landside model or the tidal water quality model. Based on data availability, the year 2002 was chosen as the model calibration period. The calibrated landside, hydrodynamic and water quality models were then validated with data from the year 2003. The comparison of both the calibration and validation model results with available data shows that the calibrated models reasonably represent the hydrologic, hydrodynamic, and water quality processes present in the watershed.

The linked landside, hydrodynamic and water quality models were developed to complete the TMDLs in the Smyrna River watershed. Calibration and validation of the models provide a consistent set of model coefficients that realistically represents the datasets in both modeling time periods. The calibrated and validated models are now used to develop TMDLs and load allocations for nutrients, DO and bacteria. Complete details of the models, development and application are presented in the report "Smyrna River Watershed TMDL Model Development" (HydroQual, 2006).

2.1 MODEL SEGMENTATION/DELINEATION

The LSPC model was delineated into 29 sub-watersheds in the Smyrna River watershed (Figure 1). Preliminary model segment delineation was performed based on Digital Elevation Model (DEM) data developed by the University of Delaware and the river reach file information from DNREC. Further refinement of the model segmentation was then completed by inclusion of the location of the water quality stations and flow gages and re-assessment of the DEM and river reach file information.

One hydrodynamic model was completed for the Blackbird Creek, Smyrna River, Leipsic River and Little River watersheds and portions of the Delaware River/Bay upstream and downstream from these watersheds. A marsh area north of the Smyrna River watershed and south of the Blackbird Creek watershed (approximately 9.5 mi²) drains directly into the Delaware River and was excluded from the watershed, hydrodynamic and water quality models. Segmentation of the hydrodynamic model resulted in a 41x72x5 model grid that consisted of 1,114 water segments in the horizontal plane and 5 equal water segments in the vertical dimension, for a total of 5,570 water segments. Figure 2 presents the model segmentation of the hydrodynamic model. For the Smyrna River watershed water quality model, water segments representing the Blackbird Creek, Leipsic River and Little River watersheds were masked out of the above hydrodynamic grid to create a water quality model grid with only 360 water segments in the horizontal plane and 1,800 total with

inclusion of the vertical dimension. The Smyrna River watershed water quality model grid is shown in Figure 3. The hydrodynamic and water quality model segments were developed in the Smyrna River and extended into Delaware River/Bay across the width from the lower river estuary and 5 miles in the upstream/downstream direction. The extension of the model grid into the bay is aimed at minimizing the bay boundary condition effects on the internal model calculations. Bathymetry data for the study area were obtained from NOAA GEODAS CDs (NOAA, 1998) and also DNREC ADCP data. Figure 3 presents the ADCP stations in the Smyrna River. The bathymetry assigned for the segmentation at the most upstream reaches of the tidal river were determined based on the tidal range and a minimum water depth was assigned to avoid main channel segments from drying out at low tide. In addition, the hydrodynamic model represents the wetting and drying of marsh areas in the river. These areas were determined from USGS topographic maps and delineated marsh areas. This was completed to better represent tidal transport in the river. As the tide rises and falls, water flows into and out of the marsh areas. When the tide is low, some of the marsh area segments dry up, or contain no water, and are considered computationally inactive. When the tide rises, water fills these segments and computation continues as normal. Marsh loads are only input into the marsh segments when they are considered wet, or computationally active. Figure 3 shows the model segments that are available for wetting and drying and the delineated marsh areas.

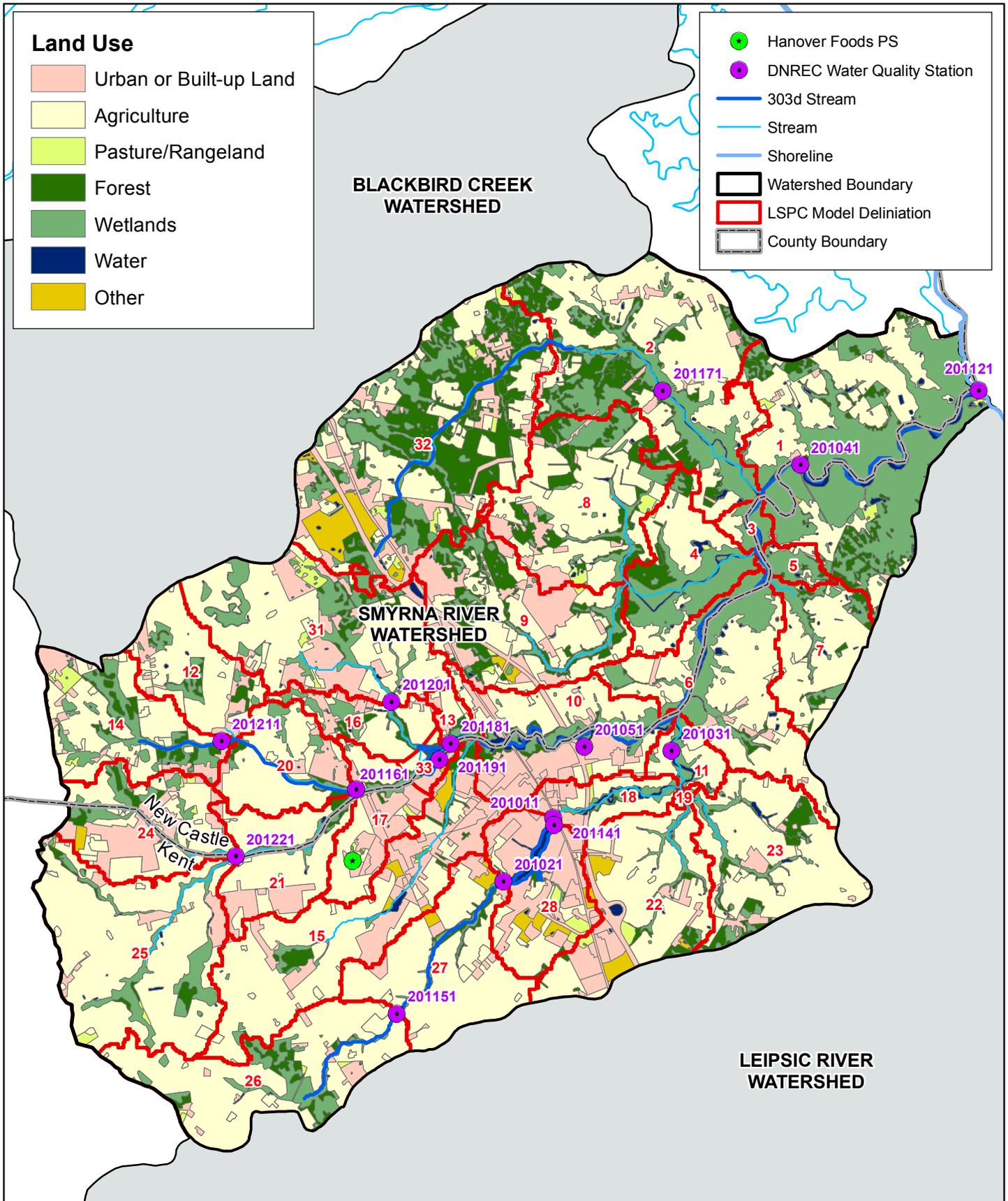
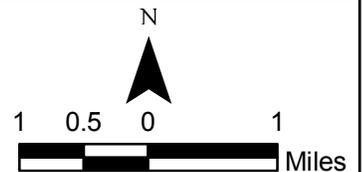
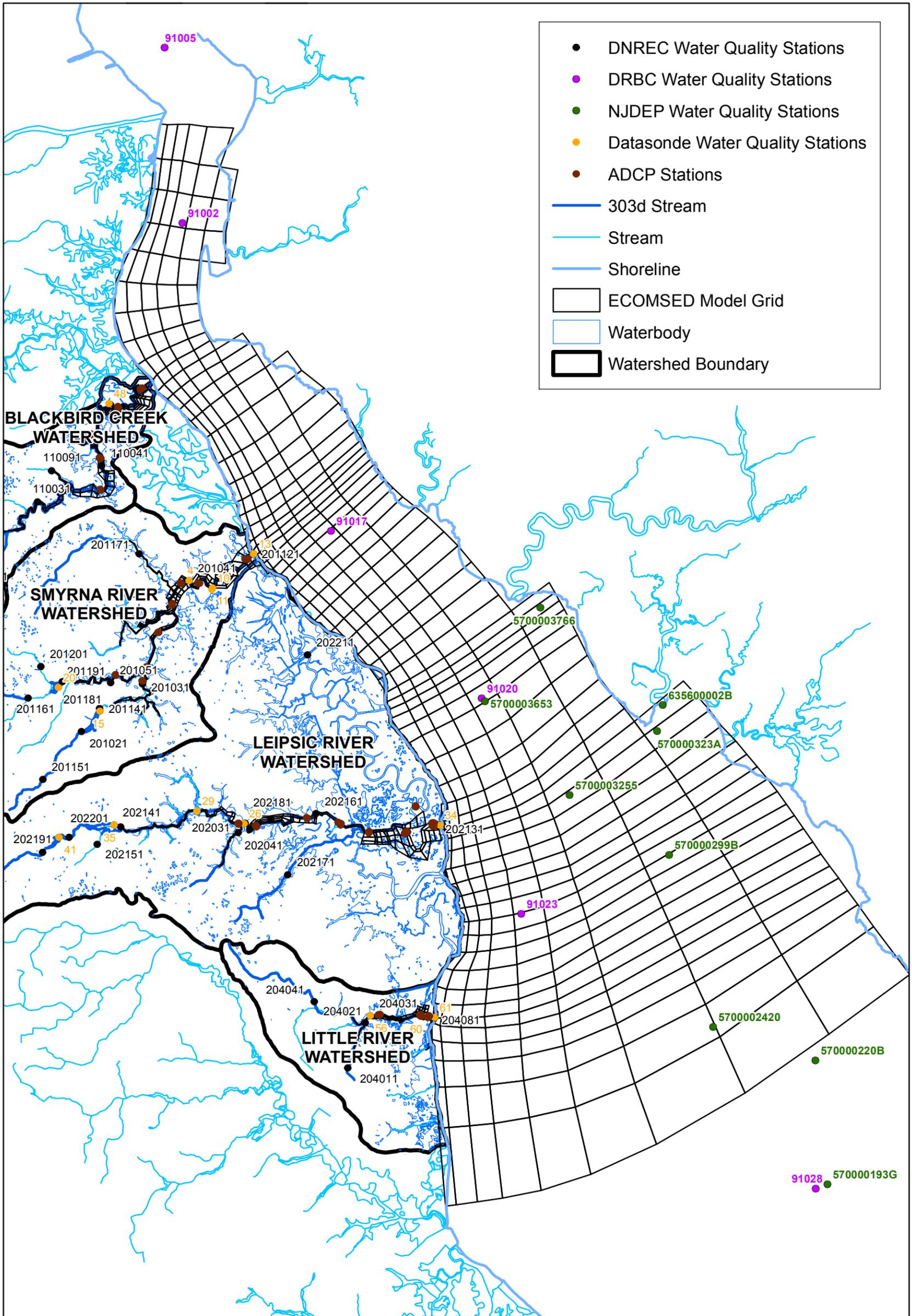


Figure 1: LSPC Model Segmentation
Smyrna River Watershed



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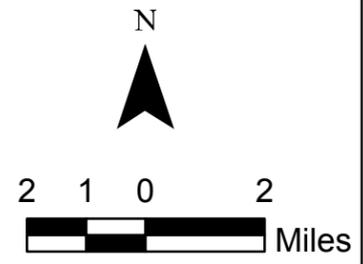


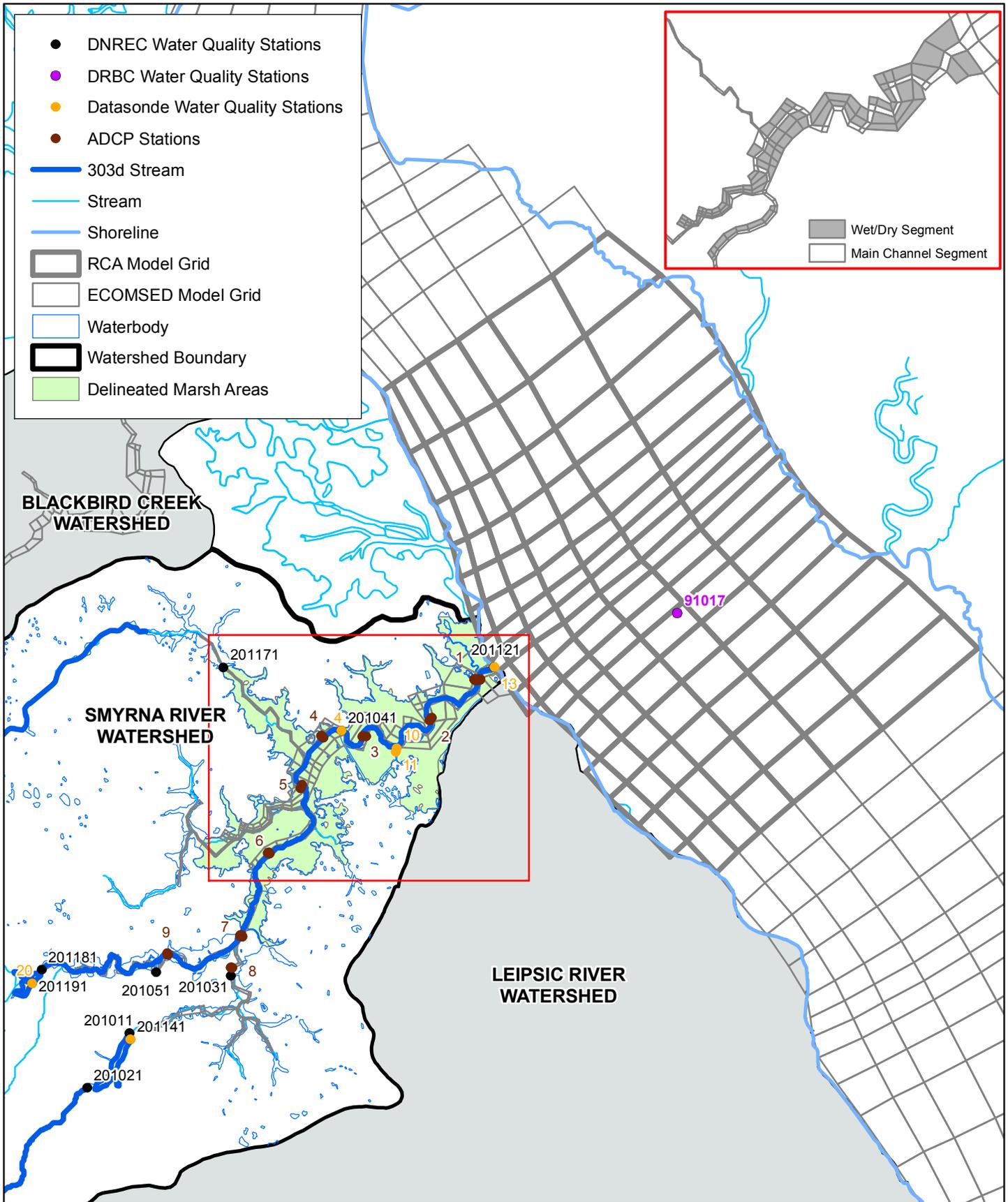
- DNREC Water Quality Stations
- DRBC Water Quality Stations
- NJDEP Water Quality Stations
- Datasonde Water Quality Stations
- ADCP Stations
- 303d Stream
- Stream
- Shoreline
- ECOMSED Model Grid
- Waterbody
- Watershed Boundary



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Figure 2: ECOMSED Grid





**BLACKBIRD CREEK
WATERSHED**

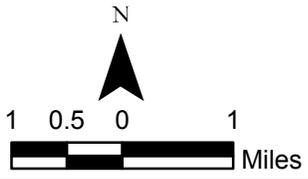
**SMYRNA RIVER
WATERSHED**

**LEIPSIC RIVER
WATERSHED**



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**Figure 3: RCA Model Segmentation
Smyrna River Watershed**



SECTION 3

WATERSHED CHARACTERISTICS

3.1 LANDUSE

Land use information for the year 2002 was obtained from DNREC and is presented in Table 2 and Figure 1. The Smyrna River watershed is approximately 16,568 ha (64 mi²) and is primarily non-urban (85%) with approximately 54% agricultural land use.

3.2 POINT SOURCES

In the Smyrna River watershed, there is one existing point source (PS): the Hanover Foods Plant stormwater and non-process water discharge. This discharge is from stormwater and non-process water discharge that flows into a stormwater pond that only discharges into the Smyrna River when pond levels are high or during storm events. The non-process water is withdrawn from groundwater and operates less frequently during winter months when the facility is not in operation. Flow, biochemical oxygen demand (BOD), total suspended solids (TSS), pH and nutrient information were available for this point source but the flow and loading of relevant parameters were not input into the model as a point source since the stormwater pond collects most of the runoff and only discharges during larger storm events. A septic nutrient load was assigned in the model based on septic distribution in the watershed as provided by DNREC. Animal bacteria loads were assigned similarly based on animal distribution in the watershed as provided by DNREC. Animal nutrient sources were subsumed in the overall land use unit loading values.

Table 2. Summary of Land Use in the Smyrna River Watershed

Land Use	Area (ha)	% Total Area
Agriculture	8,972	54.2
Forest	1,580	9.5
Pasture/Rangeland	95	0.6
Urban/Built-up Land	2,442	14.7
Water	282	1.7
Wetland	3,005	18.1
Others	192	1.2
Total	16,568	100.0

SECTION 4

WATERSHED MONITORING

Monitoring in the Smyrna River watershed has been on-going since the mid-1970s and is aimed at providing information to assess water quality in the watershed but also to assist in the development of TMDL models. The water quality and hydrologic data collected were sufficient to support development and calibration/validation of watershed, hydrodynamic and water quality models for the Smyrna River, tributaries and ponds to establish TMDLs for nutrients, DO and bacteria.

The data provided by DNREC included DNREC water quality monitoring data, land use information, cross-sectional data, Acoustic Doppler Current Profiler (ADCP) data, National Pollutant Discharge Elimination System (NPDES) PS information and datasonde data. In addition, flow data were obtained at available USGS flow gages from the USGS website. Figure 1 shows an overview of the watershed, USGS flow gages, dams and water quality stations. The following data were available.

- **DNREC Water Quality Monitoring Data** – This set of data includes temperature, salinity, pH, total suspended solids (TSS), turbidity, secchi depth, nutrients (nitrogen and phosphorus), DO, carbonaceous biochemical oxygen demand (CBOD), total organic carbon (TOC), dissolved organic carbon (DOC), chlorophyll-a (chl_a), and *enterococcus*. There are 15 stations in the Smyrna River watershed as shown in Figure 1. The available data span from 1994 to 2003, but the majority of the data are between 2002 and 2003. All three models (landside, hydrodynamic and water quality) were calibration with these data.
- **Datasonde Data** – The datasonde data contain tidal salinity, temperature, dissolved oxygen, pH and depth measurements collected between April 2002 and November 2003 for 5 sites in the Smyrna River. The datasonde locations are presented in Figure 3. Temperature and salinity data were used to calibrate/validate the hydrodynamic model. Dissolved oxygen data were used to calibrate/validate the water quality model.
- **NPDES Point Source Data** – The PS database contains information on effluent limits and discharge monitoring data for the one NPDES permitted PS located in the watershed. The PS station is the Hanover Foods Plant (stormwater and non-process water discharge). The location of the discharge is shown in Figure 1. The effluent data contained flow, BOD, TSS, temperature, pH, hardness, TKN, nitrite plus nitrate and total phosphorus. The Hanover Food PS data was not used in the modeling as previously stated in Section 3.2

- **Cross-Sectional Data** – The cross-sectional data include cross-section width, depth, and velocity for a number of stations in the Smyrna River watershed as presented in Figure 1. Although stations are shown along the main stem of the Smyrna River, no actual data are available at these stations. Data are available for stations tributary to the main stem of the river. River geometry was developed for the landside and hydrodynamic models using these data.
- **ADCP Data** – The ADCP data contain tidal velocity measurements conducted on October 5, 2005 for 7 sites in the estuary portion of the Smyrna River. The monitoring locations are presented on Figure 3. These data were used to help define river geometry and aided in calibration of the velocities and water depths in the hydrodynamic model.
- **Flow Data** – No USGS flow data were available for the Smyrna River watershed. The watershed model inputs were based on work completed in the Blackbird Creek and St. Jones River watersheds where USGS gages were available for calibration/validation of the landside model.

4.1 OVERALL WATER QUALITY ASSESSMENT

In general, the water quality data analysis in the Smyrna River watershed indicates that the watershed experiences DO levels less than the State minimum WQS of 4 mg/L with elevated chlorophyll-a levels at many stations throughout the watershed. Potential oxygen demands include sediment oxygen demand (SOD), BOD oxidation, ammonia nitrification and/or algal respiration. These oxygen demands can originate from point and nonpoint sources but also potentially from wetland/marsh loading of organic material. The data indicate sufficient nutrient concentrations at most of the stations to support algal growth. Bacteria concentrations were also elevated at some stations (with maximum *enterococcus* levels above 2,000 #/100mL). Potential bacteria sources include storm water runoff and NPS derived bacterial inputs.

4.2 SOURCES OF POLLUTION

Nonpoint source pollution can be defined as pollution that occurs over large areas as a result of common practices and landuses. Unlike a point source that deposits pollution into a water body at a specific location, nonpoint sources will affect a waterbody at indefinite locations, such as ground water seepage or agricultural runoff along a given stream length. In order to quantify nonpoint sources in the Smyrna River watershed, land areas were classified according to landuse and pollutant build-up and wash-off coefficients and groundwater concentrations. The landuse distribution in the Smyrna River watershed was generalized into the groups shown in Table 2: agriculture, forest, pasture/rangeland, urban/built-up, wetlands and others. Each of these landuses has different

possible sources of pollution that are deposited directly or indirectly to the water system. The “other” landuse includes transitional construction and inland natural sandy areas.

Forested areas account for a little more than 9 percent of the watershed. The types of forest are deciduous, mixed and evergreen. Nutrients and bacteria from wild animals and organic material from plants are common sources of nonpoint pollution.

Wetland areas account for more than 18 percent of the watershed area and are home to many species of plants and wildlife that produce organic, nutrient and bacteria wastes.

Approximately 54 percent of the Smyrna River watershed was classified as agriculture, including cropland, farm related buildings, idle fields, and orchard and nursery landuses. Possible nonpoint sources of pollution from these areas include bacteria and nutrients from animal feed lots, organic material from plants, nutrients from industrial fertilizers, and particulate and dissolved nutrients in runoff.

Pasture/rangeland comprises less than 1 percent of the watershed and includes pasture and herbaceous, brush and mixed rangelands. Nutrients and bacteria from animal grazing or production are common sources of nonpoint pollution.

Urban or built-up landuses often increase nonpoint pollution due to decreased perviousness and increased human development. The urban landuse contains roads, salvage yards, mixed urban, professional retail, single family dwellings, utilities and warehouses. Among the causes of pollution from urban landuses are nutrients and bacteria in runoff from impervious surfaces, nutrients and bacteria from septic systems, nutrients from residential fertilizers, industrial wastes and domestic pet wastes. Approximately 15 percent of the Smyrna River watershed is urban or built-up.

Based on the land use data, the Smyrna River watershed is primarily non-urban (85%) and, therefore, NPSs are an important source of pollution in the watershed. There is one (1) active NPDES permitted PS in the watershed but this is a non-contact cooling water discharge with low loadings of pollutants which was not included in the watershed model. The discharge flows into a stormwater pond which only discharges into the Smyrna River when water levels are high or during storm events. The non-process water is withdrawn from groundwater and operates less frequently during winter months when the facility is not in operation. Flow and pollutant loadings were not input into the model as a point source since the stormwater pond collects most of the runoff and only discharges during larger storm events. Therefore, NPSs are the dominant source of pollution in the watershed.

In addition, New Castle County is classified as an urbanized area and currently has associated MS4 stormwater permits. A boundary of New Castle County was obtained from DNREC and projected onto the Smyrna River watershed LSPC model segmentation and land use data. All urban area in the Smyrna River watershed that is also in New Castle County was considered MS4 urban area for this analysis. Table 3 presents the MS4 urbanized areas by LSPC segment along with the

modeled urban area. The calculated percent MS4 to LSPC urban area will be used to split the urban nonpoint source loads into MS4 point source loads.

Table 3. MS4 Urban Areas in the Smyrna River Watershed

LSPC Segment	Total Area (ha)	LSPC Urban Area (ha)	MS4 Urban Area in New Castle County (ha)	%MS4 Urban Area
1	1401.9	13.1	8.4	64
2	1215.9	44.8	44.8	100
4	412.5	0.8	0.8	100
6	704.9	24.3	5.7	23
8	739.4	75.0	75.0	100
9	749.4	218.1	218.1	100
10	587.3	224.9	41.2	18
12	363.3	45.8	45.8	100
13	63.0	14.2	12.5	88
14	513.7	68.6	68.6	100
16	210.8	38.3	38.3	100
17	278.6	113.1	7.9	7
20	349.5	54.6	54.6	100
21	378.0	68.0	4.6	7
24	479.7	135.2	47.5	35
31	884.5	175.9	175.9	100
32	1500.2	237.8	237.8	100
33	58.5	18.3	0.3	2

SECTION 5

SCOPE AND OBJECTIVES OF THE TMDL ANALYSIS

DNREC has proposed TMDLs for nitrogen, phosphorous, DO and bacteria for the Smyrna River watershed. The proposed TMDLs are the result of various load reduction analyses, which were conducted using the Smyrna River Watershed Model as a predictive tool. The proposed TMDL is designed such that, when implemented, all segments of the Smyrna River system will achieve applicable water quality standards and targets for TN, TP, DO and bacteria. Monitoring in the watershed should continue to assess the impact of load reductions and to determine the associated water quality improvements. In this manner, an adaptive management approach can be followed in the watershed.

In order to complete these TMDLs, mathematical models of the Smyrna River watershed were developed. These mathematical models include a landside watershed model to calculate nonpoint source (NPS) runoff and quality, a hydrodynamic model to calculate the movement of water in the tidal reaches of the Smyrna River (downstream of Duck Creek Pond), and a water quality model that is coupled to the hydrodynamic model to calculate water quality in the tidal reaches of the river.

As part of the Smyrna River watershed model development, data compilation and analyses were completed in addition to model development, calibration and validation. The data compilation/analysis and model development is presented in the following technical memorandum and report:

- Smyrna River Watershed TMDL Development, Data Analysis Technical Memorandum (HydroQual, 2005); and
- Smyrna River Watershed TMDL Model Development (HydroQual, 2006).

In addition, baseline NPS loadings were developed (Figure 4 and Appendix 3) based on the calibration/validation period (2002-2003).

5.1 TOTAL MAXIMUM DAILY LOADS AND THEIR ALLOCATIONS

The calibrated and validated Smyrna River models were used to determine TMDLs for the watershed. This effort involved completing various model load reduction scenarios to ultimately arrive at a load reduction scenario that meets water quality standards or targets. The following procedure was used to develop the load reduction scenarios, wasteload allocations (WLA) and load allocations (LA). An implicit margin of safety (MOS) will be used for the TMDL due to conservative assumptions used in the modeling.

There is one (1) non-contact cooling water PS discharge, the Hanover Foods Plant (stormwater and non-process water discharge), in the watershed along Upper Smyrna River above

Duck Creek Pond. For model calibration/validation and the TMDL analysis, the PS was not included in the watershed model.

In order to address NPS loadings within the watershed, various load reduction scenarios were completed for 20%, 40%, 60% and 80% NPS load reductions. These scenarios were coupled with the WLA loads presented in Table 4. The results of these NPS load reductions scenarios were used to establish the proposed NPS reduction goal for the Smyrna River TMDL. In these analyses, meeting the water quality standards and/or targets reflect achieving the designated uses.

5.2 TMDL ENDPOINTS

For nutrients, the water quality targets were interpreted to represent monthly average nutrient targets of 3 mg/L TN and 0.2 mg/L TP. These targets were applied in both the freshwater and tidal reaches of the watershed. The monthly average approach was chosen because nutrient effects on algae are not immediate, that is sufficient time is required for the consumption of nutrients by algae in increasing their biomass. Given the nature of the streams, lakes, ponds and tidal reaches in the Smyrna River watershed, a monthly time period was considered suitable for assessing nutrient related algal impacts for TMDL development.

For bacteria (*enterococcus*), the water quality standard is two-tiered. The Delaware standards are expressed as a single sample maximum and geometric mean without reference to a time period. Typically, bacteria standards are written in terms of a monthly time period and, therefore, the bacteria standards were applied on a monthly basis for TMDL development. In the freshwater reaches the *enterococcus* geometric mean standard is 100 #/100mL and in the marine reaches the geometric mean standard is 35 #/100mL. Compliance with these standards was based on the calculated maximum 30-day moving geometric mean that occurs in a calendar month.

For DO, the water quality standard is also two-tiered to represent a daily average and daily minimum value. In the freshwater reaches the DO daily average value is 5.5 mg/L with a minimum of 4.0 mg/L. In the marine reaches the DO daily average value is 5.0 mg/L with a minimum of 4.0 mg/L. In the upstream freshwater reaches a steady-state, low-flow (7Q10) DO balance calculation was completed to determine the allowable loads that meet the daily average DO standard of 5.5 mg/L. This approach used the Streeter-Phelps DO deficit method to calculate DO as a function of oxygen demands (CBOD/NBOD from point and nonpoint sources, SOD) and the oxygen source from atmospheric reaeration. The approach used upstream geometry relationships (depth, velocity, width as a function of flow) to represent stream geometry at different flow rates. In addition, total flow calculated by LSPC at the end of a river reach was uniformly distributed along the length of the tributary under consideration. A CBOD and NH₃ decay rate of 2/day at 20°C was used along with a SOD of 1 g/m²/d at 20°C. Atmospheric reaeration at 20°C was calculated using the Tsivoglou equation ($K_a = CUS$, where C is a constant that depends on flow, U is the velocity and S is the slope). All of these rates were temperature corrected to a summer maximum temperature of 25 or

30°C based on available data. An initial DO deficit of 0-3 mg/L (depending on stream reach) and TBOD_u of 5 mg/L was assigned at the upstream end of the reach analyzed.

In order to test the approach against observed data, average NPS BOD and NH₃ loads during the summer months of June through October (2002 and 2003) were obtained from the calibrated LSPC model for the reach under consideration. The average stream flow during this period was also used to represent the average stream conditions for calculating stream geometry. The resulting DO calculation is presented in the top panel of the spatial DO figures in Appendix 1 along with the observed DO data. In general, the DO modeling approach reproduces the lower DO levels observed in Mill Creek, Sawmill Creek and Paw Paw Branch. Since the stream flows during the summer of 2002 were at or below 7Q10 low flow conditions, a minimum stream flow of 0.5 cfs was used to assess whether the NPS load reductions improved DO levels to meet the standard of 5.5 mg/L. This was accomplished reducing the headwaters TBOD_u and stream SOD by 40%, assigning no upstream DO deficit and by removing the NPS TBOD_u load since at 7Q10 low flow conditions when runoff does not occur or is minimal. In other coastal Delaware watersheds it was noted that many of the observed low DO values are reported as being collected in areas with no flow (stagnant, pooled reaches) or are located in headwater areas of small streams that may be dominated by groundwater with low DO levels. Therefore, monitoring of DO in these freshwater reaches should continue to either assess improvements due to the load reductions or to determine potential local sources of oxygen demand.

In the tidal reaches of the watershed, the RCA model output was used to assess instream DO standards. In these downstream tidal reaches of the watershed, background oxygen demands such as sediment oxygen demand (SOD), bay water quality and marsh loadings can cause DO levels to be periodically naturally depressed. Therefore, assessment of compliance with the marine DO standard was based on monthly average model output.

5.3 TMDL MODEL OUTPUT PRESENTATION

The model output for TN, TP, chlorophyll-a, DO and *enterococcus* is presented in a series of figures for comparing the load reduction scenarios to the water quality standards or targets. These model output figures are presented for the three (3) freshwater 303(d) listed segments (Appendix 1) and the one (1) tidal 303(d) listed segment (Appendix 2) at a number of monitoring locations. In the freshwater reaches, the steady-state, low-flow calculated DO as a function of distance is presented where a DO TMDL is required along with the associated DO deficit components. The current and TMDL loading conditions are also presented in this figure. For *enterococcus*, the current and TMDL model output are presented as probability distributions of the 30 day moving geometric mean. Probability distributions are useful for presenting the mean and variation of a data set, and also provide a means for determining compliance (percent exceedance) from a given value (e.g., a water quality standard). The Delaware standards do not allow for a percent of samples exceeding the standard (e.g., 10%) and, therefore, the load reductions are aimed at maintaining the instream

enterococcus levels below the geometric mean standard at all times. For nutrients, monthly average concentrations are compared to the target levels of 3 mg/L for TN and 0.2 mg/L for TP.

In the marine (tidal) reaches, monthly average DO is presented for both the current and TMDL loading conditions along with *enterococcus*. For *enterococcus*, the current and TMDL model output are presented as probability distributions of the 30 day moving geometric mean in the same format as the freshwater reaches. For nutrients, monthly average concentrations are compared to the target levels of 3 mg/L for TN and 0.2 mg/L for TP. Chlorophyll-a is also presented as a monthly average for reference with a target concentration of 25 mg/L.

5.4 INTERPRETATION OF RESULTS

The load reduction scenarios were designed to determine the impact of various NPS load reductions on instream water quality in the freshwater and tidal reaches of the watershed in order to guide in selection of the final TMDL load reduction scenario. Based on the four (4) nutrient load reduction scenarios completed (20%, 40%, 60% and 80% NPS load reductions), a final nutrient NPS load reduction of 40% was selected. Results from this final scenario are presented in Appendix 1 for the freshwater reaches and in Appendix 2 for the tidal reaches.

The 40% nutrient NPS load reduction reduced all instream nutrient levels below their target levels and contributed to DO improvements in both the freshwater and tidal reaches through the associated carbon (BOD) and NH₃ reductions. Although the existing nutrient targets were close to or less than the targets in the freshwater reaches, additional decreases were necessary to meet the nutrient targets in the downstream tidal reaches. NPS chlorophyll-a loads were also reduced by 20% to represent decreased chlorophyll-a concentrations as a result of decreased nutrient concentrations.

For bacteria, a 75% NPS load reduction is required to meet both the freshwater and marine geometric mean standards at all times. These NPS load reductions are greater than needed in the freshwater reaches but are necessary to attain the marine geometric mean standard in the tidal reach of the river.

Therefore, the final load reductions recommended are a 40% NPS reduction of nutrients (including carbon or BOD) loads and a 75% NPS reduction of bacteria (*enterococcus*). These load reductions will allow the instream nutrient targets, DO and bacteria standards to be maintained in the watershed.

SECTION 6

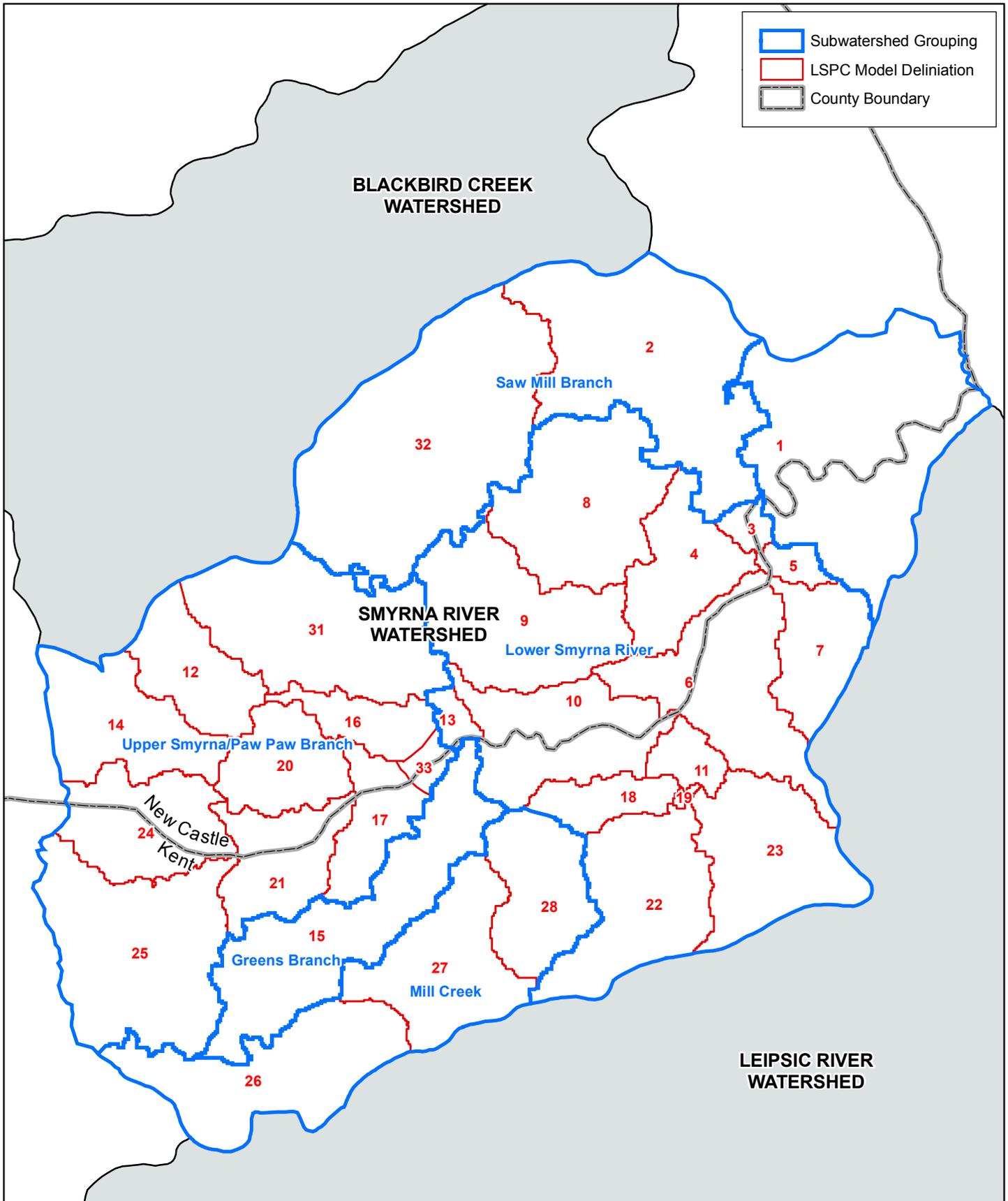
PROPOSED TMDL LOAD REDUCTION

As stated, the proposed TMDL load reduction scenario is a 40% NPS reduction of nitrogen, phosphorus and carbon (BOD) and a 75% NPS reduction of *enterococcus*. These NPS load reductions are coupled with the WLAs presented in Table 4. In both the freshwater and marine (tidal) reaches of the watershed, the nutrient targets, DO and bacteria standards are attained at these TMDL loading levels. Table 5 presents the TMDLs for nitrogen, phosphorus and *enterococcus* for the final proposed load reduction scenario and Table 6 presents a summary of the NPS loadings by sub-watershed and landuse. Figure 4 highlights the sub-watersheds used in Table 6. Appendix 3 presents a summary of the baseline (calibration/validation 2002/2003) for nitrogen, phosphorus and *enterococcus*. These load reduction scenarios are meant as a guide in improving water quality in the Smyrna River watershed and should be periodically revisited to determine whether they are still applicable. In addition, water quality monitoring should continue throughout the watershed to quantify the instream effects of the proposed load reductions and to monitor the calculated water quality improvement in the river.

6.1 CONSIDERATION OF THE IMPACT OF BACKGROUND POLLUTANTS

The Smyrna River watershed TMDLs for nutrients, DO and bacteria were estimated using the results of calibrated/validated models (watershed, hydrodynamic and water quality). The models were developed using data collected in the field to represent model inputs and for calibration/validation of the models. The data collected in the field also reflected background pollutant conditions and Delaware Bay water quality in addition to tidal marsh loadings in the model. Therefore, the impact of background pollutants is accounted for in the model.

The impact of pollutant sources varies significantly according to location in the watershed. The three major sources of nutrients are NPSs, the downstream connection to Delaware River/Bay and marsh contribution of organic matter. The Delaware River/Bay impacts DO and nutrient levels closer to the mouth of Smyrna River. Marshes have an influence on DO levels upstream of the river mouth and within the area of the tidal marshes. The upstream NPSs affect DO and nutrient levels minimally at the river mouth but show a generally increasing influence moving upstream (until dominating the nontidal portion of the creek). These three sources are the major causes of varying levels of background pollutants throughout the watershed and impact the model differently according to location.



-  Subwatershed Grouping
-  LSPC Model Deliniation
-  County Boundary

Figure 4: Subwatershed Groupings
Smyrna River Watershed



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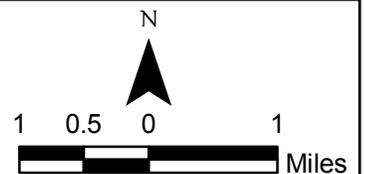


Table 4. Smyrna River Point Source WLA (Loads)

Facility	New Castle County MS4s	Total Load (WLA)
TN (lb/d)	168.0	168.0
TP (lb/d)	12.18	12.18
<i>Enterococcus</i> (#/d)	7.66E+10	7.66E+10

Table 5. Proposed TMDLs For The Smyrna River Watershed

Parameter	WLA	LA	TMDL
TN (lb/d)	168.00	574.23	742.23
TP (lb/d)	12.18	45.64	57.82
<i>Enterococcus</i> (#/d)	7.66E+10	9.71E+10	1.74E+11

6.2 CONSIDERATION OF CRITICAL ENVIRONMENTAL CONDITIONS

Low river flows during summer months coupled with high water temperatures represent critical conditions for nutrient related algal growth and DO assessments. High flow or wet weather conditions are also important for assessing NPSs. Since the Smyrna River watershed does not have a continuous flow gage, flow calibration for the Smyrna River watershed LSPC model was based on the calibrated and validated Blackbird Creek LSPC model where there was a USGS flow gage (#01483200). In the Blackbird Creek watershed, which borders the Smyrna River watershed to the north, the calibration year 2002 was a very dry year compared with the wetter year of 2003. The annual average flows at the Blackbird Creek USGS gage for these two years are 2.8 and 10.2 cfs, respectively. Likewise, in the St. Jones River watershed, which is located immediately south of the Little River and Leipsic River watersheds, a 7Q10 analysis was completed and indicates that the 7Q10 flow for the St Jones River at Dover (USGS gage #01483700) is 0.7 cfs. The minimum average 7-day flow for year 2002 was 0.6 cfs at the St Jones River USGS gage, which is below the 7Q10 flow. Therefore, since the both the Blackbird Creek and St. Jones River watersheds suggest a dry year 2002 and a wet year 2003, the critical dry and wet weather conditions in the Smyrna River watershed are included in the analysis.

6.3 CONSIDERATION OF SEASONAL VARIATIONS

Seasonal variations are considered in the Smyrna River models since the models were calibrated/validated in a time-variable mode for the years 2002-2003. This time period reflects flow and watershed conditions during all four seasons in both a dry and wet year. Therefore, seasonal variations have been considered for this analysis.

Table 6. Smyrna River NPS LA by Land Use and Watershed Group

Parameter	Urban	Agriculture	Pasture	Forest	Wetlands	Total
Lower Smyrna River						
Area (acres)	1,903	7,161	168	1,178	2,296	11,398
TN (lb/d)	68.68	99.54	4.27	6.45	14.26	193.21
TP (lb/d)	4.98	1.33	0.10	0.16	10.69	17.26
<i>Enterococcus</i> (#/d)	3.13E+10	3.87E+07	1.38E+07	5.30E+06	0.00E+00	3.14E+10
Upper Smyrna River/Paw Paw Branch						
Area (acres)	1,907	7,111	61	503	1,399	9,885
TN (lb/d)	51.44	97.85	0.93	2.71	8.59	161.53
TP (lb/d)	3.73	1.30	0.02	0.07	6.44	11.56
<i>Enterococcus</i> (#/d)	2.35E+10	3.81E+07	1.26E+07	2.23E+06	0.00E+00	2.35E+10
Saw Mill Branch						
Area (acres)	698	2,601	255	1,687	1,407	5,950
TN (lb/d)	0.00	35.79	7.20	9.11	8.64	60.74
TP (lb/d)	0.00	0.48	0.18	0.22	6.48	7.36
<i>Enterococcus</i> (#/d)	0.00E+00	1.39E+07	1.02E+07	7.48E+06	0.00E+00	3.16E+07
Greens Branch						
Area (acres)	644	1,304	64	102	72	2,187
TN (lb/d)	40.86	17.94	1.88	0.55	0.44	61.68
TP (lb/d)	2.96	0.24	0.05	0.01	0.33	3.59
<i>Enterococcus</i> (#/d)	1.86E+10	6.98E+06	1.54E+06	4.53E+05	0.00E+00	1.86E+10
Mill Creek						
Area (acres)	814	2,819	153	150	325	4,261
TN (lb/d)	51.61	38.79	3.86	0.81	2.00	97.07
TP (lb/d)	3.74	0.52	0.09	0.02	1.50	5.87
<i>Enterococcus</i> (#/d)	2.35E+10	1.51E+07	1.18E+07	6.67E+05	0.00E+00	2.36E+10

6.4 CONSIDERATION OF MARGIN OF SAFETY

USEPAs technical guidance allows consideration for the margin of safety as implicit or explicit. The margin of safety can account for uncertainty about the relationships between pollutant

loads and receiving water quality in addition to uncertainty in the analysis (USEPA, 2001). An implicit margin of safety is when conservative assumptions are contained in model development and TMDL establishment. An explicit margin of safety is a specified percentage of assimilative capacity that is kept unassigned to account for uncertainties, lack of sufficient data or future growth. An implicit margin of safety has been considered for the Smyrna River TMDL analysis.

The Smyrna River bacteria, nutrient and DO models were constructed with several implicit, conservative assumptions built into the models. In addition, the models represented the complex watershed dynamics and tidal nature of the river as opposed to analyzing with a simple model framework not accounting for these complex processes that would include more uncertainty. As stated in the *Protocol for Developing Pathogen TMDLs* (USEPA, 2001), “trade-offs associated with using simpler approaches include a potential decrease in predictive accuracy and often an inability to predict water quality at fine geographic and time scales ... and the advantages of more detailed approaches are presumably an increase in predictive accuracy and greater spatial and temporal resolution”. The Smyrna River models were also developed from a comprehensive water quality database that was collected over several years (as described in this TMDL Report, Data Memorandum and Modeling Report). This also reduces the uncertainty in the analysis based on a good understanding of water quality dynamics as determined from the available observed field data.

Furthermore for the TMDL scenarios, the reductions were applied to the entire watershed to satisfy the applicable water quality standards or targets at the most critical location rather than to specific reaches upstream of the critical location (i.e., downstream impacts were considered). This results in an implicit margin of safety in upstream areas since load reductions are applied to meet the standards/targets at the critical downstream locations.

It was also assumed that the load reductions required are to be achieved by solely altering practices within the Smyrna River watershed. In the nutrient model this means that the downstream Delaware River/Bay boundary condition loadings are not reduced due to upstream Delaware River controls in the States of Delaware, Pennsylvania, New York and New Jersey not to mention coastal water quality. Since there is intrusion of water from Delaware River/Bay into the river and water quality of Delaware River/Bay will undoubtedly improve in the future, this adds an additional level of conservatism to the analysis since the boundary conditions were not changed for the TMDL analysis.

Finally, critical stream conditions were considered in the TMDL analysis. That is, low-flow and high temperature conditions were part of the period that controlled the establishment of the TMDL loads. These loads, although based on monthly average conditions, reflect the critical conditions that occur within this period. Particularly for discrete sources, the combination of low-flow, high temperature and maximum permit loading conditions represent a rare occurrence and, therefore, provide an additional level of conservatism and implicit margin of safety. For nonpoint sources, critical conditions are more driven by high-flow runoff events and these conditions are also

represented in this TMDL analysis. Also, the BOD oxidation and SOD rates used in the freshwater reaches of the watershed for the DO assessment are on the high side of typical ranges and, therefore, also provide a level of conservatism and implicit margin of safety to the analysis.

Overall, the implicit margin of safety chosen reflects the complex modeling developed for the TMDL analysis, comprehensive database available for model development, conservative modeling assumptions chosen and the overall objective of DNREC to implement TMDLs in a phased, adaptive implementation strategy. The use of an implicit margin of safety allows water quality improvements to be realized within the adaptive management framework while not imposing unnecessary source reduction costs on local stakeholders until real world water quality improvements can be better correlated to economically feasible source controls.

6.5 CONSIDERATION OF MODEL CAPABILITIES AND LIMITATIONS

The Smyrna River watershed model is a valuable tool for the assessment and prediction of water quality parameters (including dissolved oxygen, *enterococcus* and nutrients) in the tidal and nontidal portions of the river. However, just like any model, the Smyrna River watershed model has limitations to go along with its capabilities. In the upstream nontidal reaches, the LSPC model has the ability to calculate instream concentrations at selected points in the river near water quality monitoring stations, lake inflows and outflows, confluences of reaches and other strategically selected locations. The driving functions for the model are the accumulation of pollutants on landuses and the delivery of pollutants to reaches through overland and groundwater flow. Currently, instream processes in LSPC are limited to deposition and first order decay. LSPC cannot calculate instream eutrophication or exchanges between the water column and sediment bed. Moreover, LSPC is a lumped parameter and landuse generalized model that is calibrated for whole watershed analyses and, therefore, LSPC's loading functions should not be used to assess the effects of a specific site on downstream water quality without further research and verification of accumulation rates and runoff concentrations at the site.

For the tidal reaches and estuaries of the Smyrna River watershed, the coupled, three dimensional ECOMSED (hydrodynamic) and RCA (eutrophication, sediment flux and bacteria) models account for the factors that influence water quality in a tidal system. Given the increased complexity of a tidal water body, the ECOMSED and RCA models are well suited to simulate flow and water quality because of their capabilities. It should be noted that the coupled model is loaded with flows and pollutant loads from the LSPC model and is, therefore, influenced by the same factors that limit LSPC. ECOMSED tracks flow and transport according to freshwater flow, density driven currents, wind driven currents and other meteorological influences and can calculate flow, velocity, salinity and temperature at any three dimensional point in the tidal water body.

The RCA eutrophication model can calculate dissolved oxygen, nutrients, carbon and chlorophyll-a concentrations at any three dimensional point in the water body based on sediment

interactions, upstream sources of pollution, tidal flow and chemical interactions. The model also incorporates a net flux of nutrients and carbon (not seasonally varied) from tidal marshes. That is, nutrient and carbon uptake and export from wetlands was not considered in the marsh load but rather represented as an annual average net flux to the river. The RCA bacteria model contains the same transport and loading mechanisms as the eutrophication model along with a first order die-off algorithm to allow for computation of *enterococcus* at any three dimensional point in the tidal Smyrna River watershed. The bacteria model does not account for sediment fluxes or marsh loads to the water body. In general, the influence of nonpoint sources, point sources and boundary conditions from Delaware Bay/River on the water quality in the tidal water bodies of the Smyrna River can be assessed using the RCA eutrophication and bacteria models.

6.6 TMDL IMPLEMENTATION / PUBLIC PARTICIPATION

DNREC will implement the requirements of this TMDL through development of a Pollution Control Strategy. As with all Pollution Control Strategies, DNREC will engage stakeholders through extensive public education and review process. The draft Proposed TMDLs for the Smyrna River watershed were reviewed during a public workshop held on 11 May, 2006. All comments received at the workshop and during the May 1 through 31 comment period were considered by DNREC. This report has been updated to address public comments by Mid-Atlantic Environmental Law Center (Sections 1.1, 2.0, 4.0, 4.2, 6.1, 6.4 and 6.5). Considering these opportunities, it can be concluded there has been adequate opportunity for public participation.

SECTION 7

REFERENCES

- HydroQual, Inc., 2005. Smyrna River Watershed TMDL Development, Data Analysis Technical Memorandum (2005). Submitted to the Delaware Department of Natural Resources and Environmental Control.
- HydroQual, Inc., 2006. Smyrna River Watershed TMDL Model Development (March, 2006). Submitted to the Delaware Department of Natural Resources and Environmental Control.
- HydroQual, Inc, 2006. St. Jones River Watershed Proposed TMDLs (March, 2006). Submitted to the Delaware Department of Natural Resources and Environmental Control.
- USEPA Bacterial Indicator Tool, 2000.
- USEPA, 2001. Protocol for Developing Pathogen TMDLs, First Edition. USEPA Office of Water. EPA 841-R-00-002, January 2001.

APPENDIX 1
EXISTING & TMDL MODEL OUTPUT (FRESHWATER)

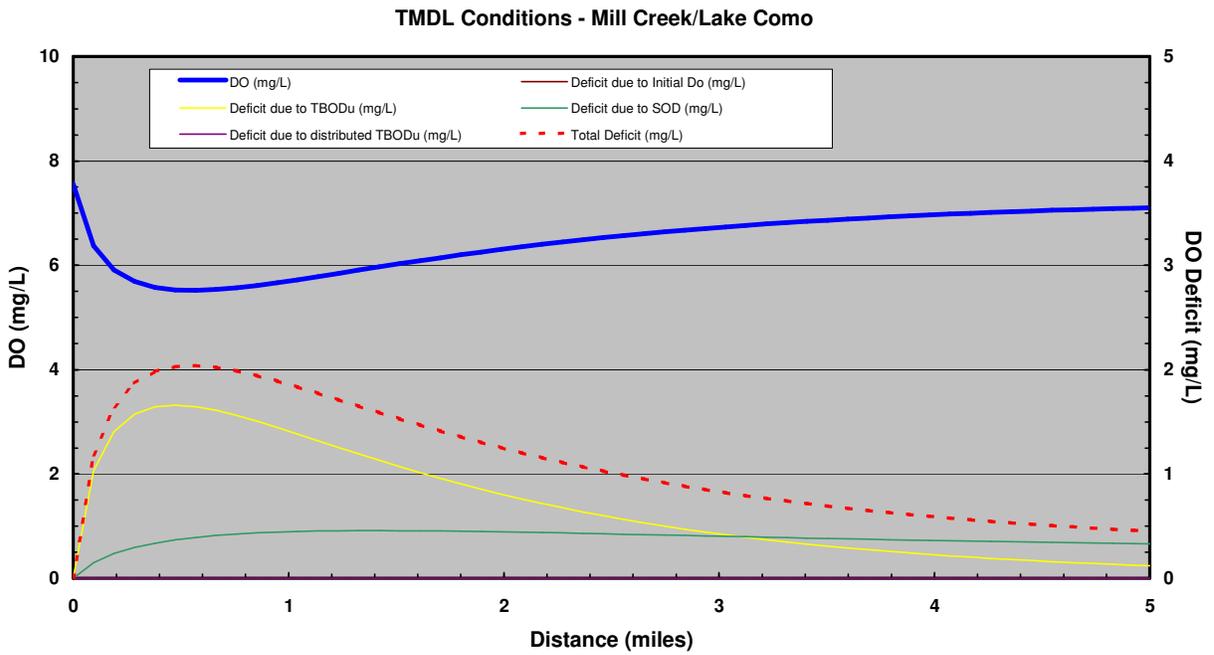
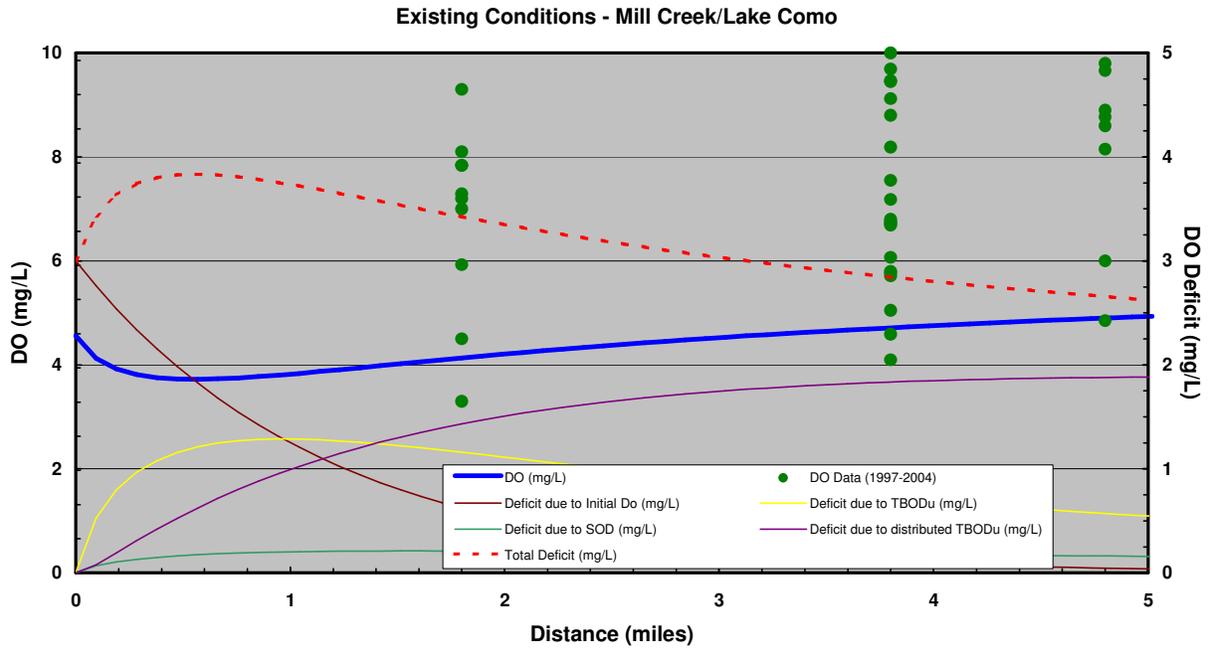
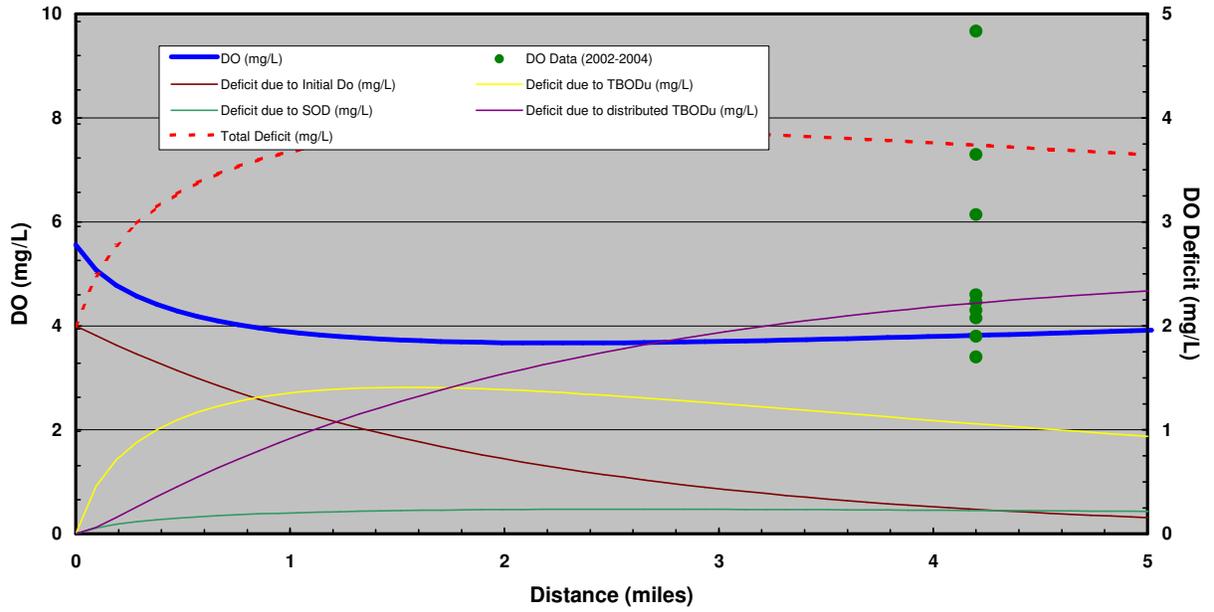


Figure A1. Mill Creek/Lake Como

Existing Conditions - Sawmill Creek



TMDL Conditions - Sawmill Creek

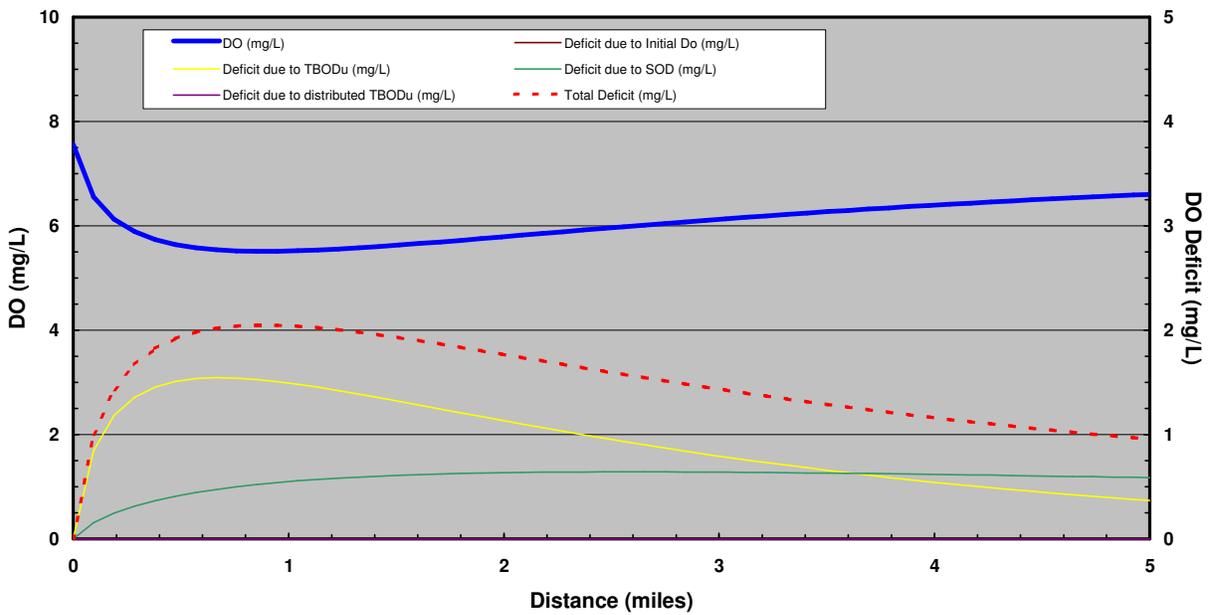


Figure A2. Sawmill Creek

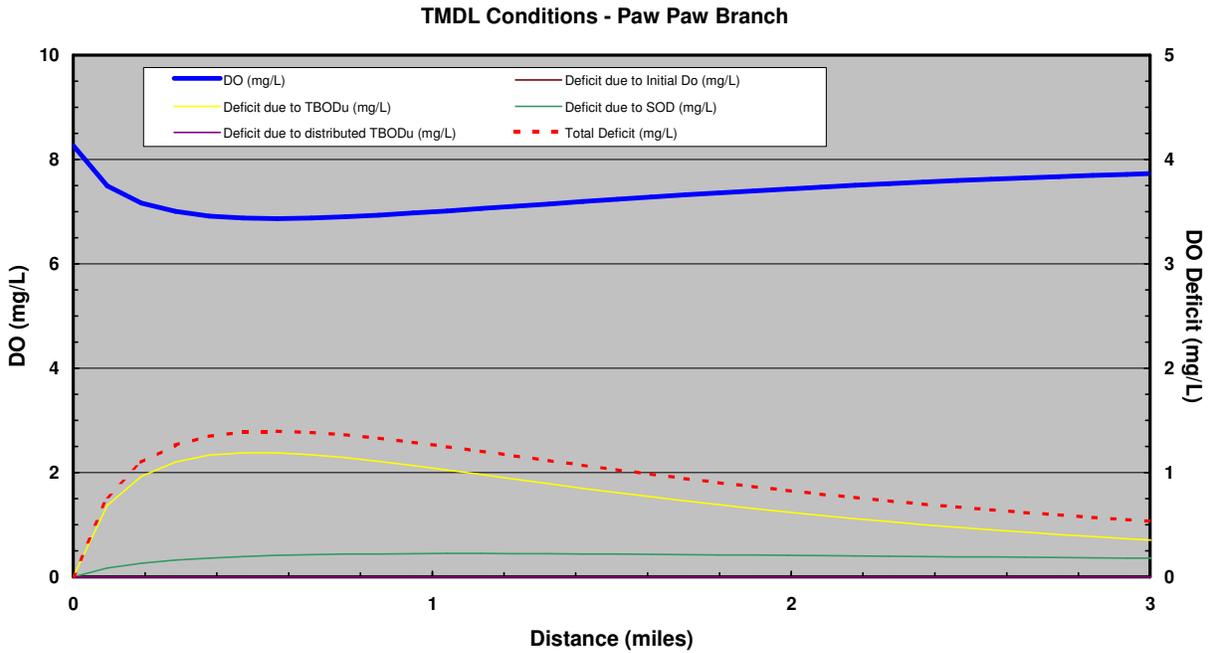
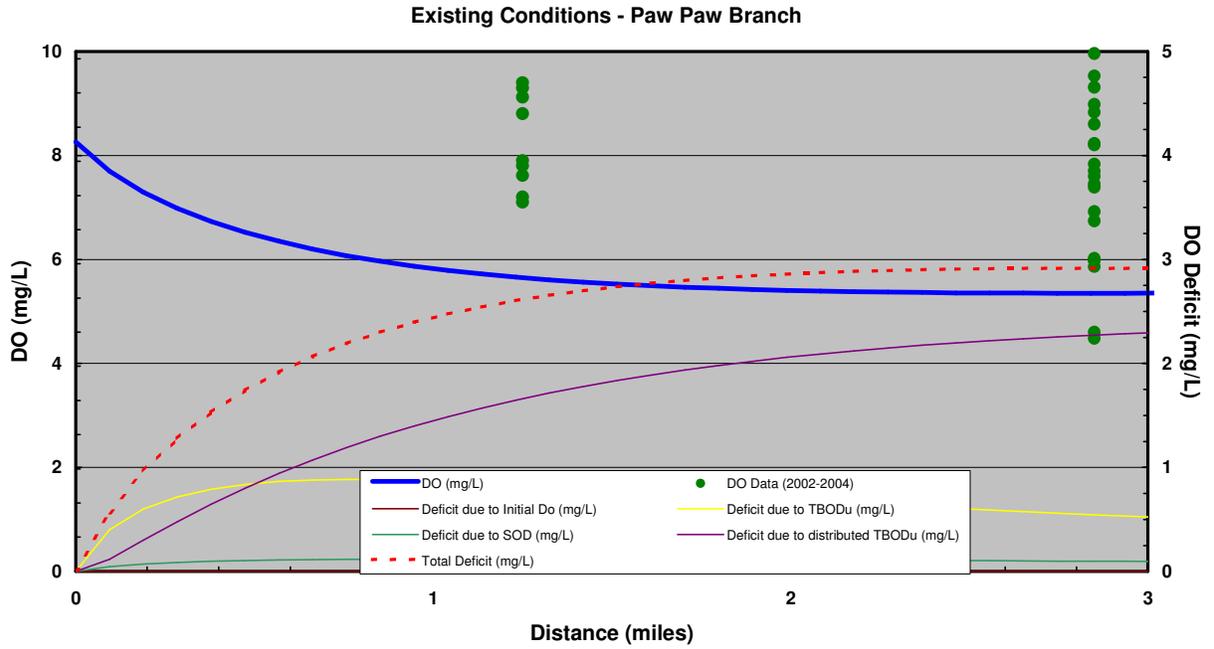
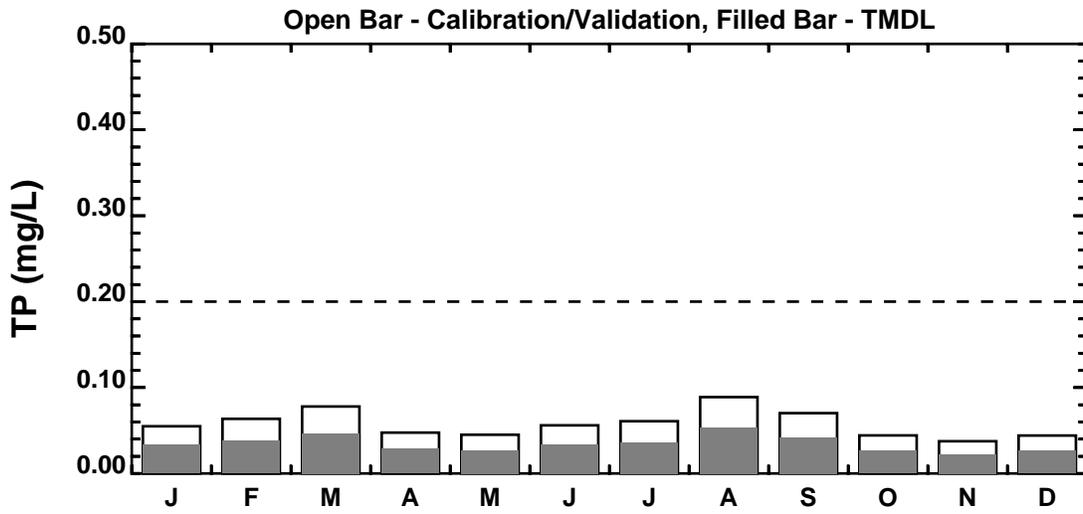
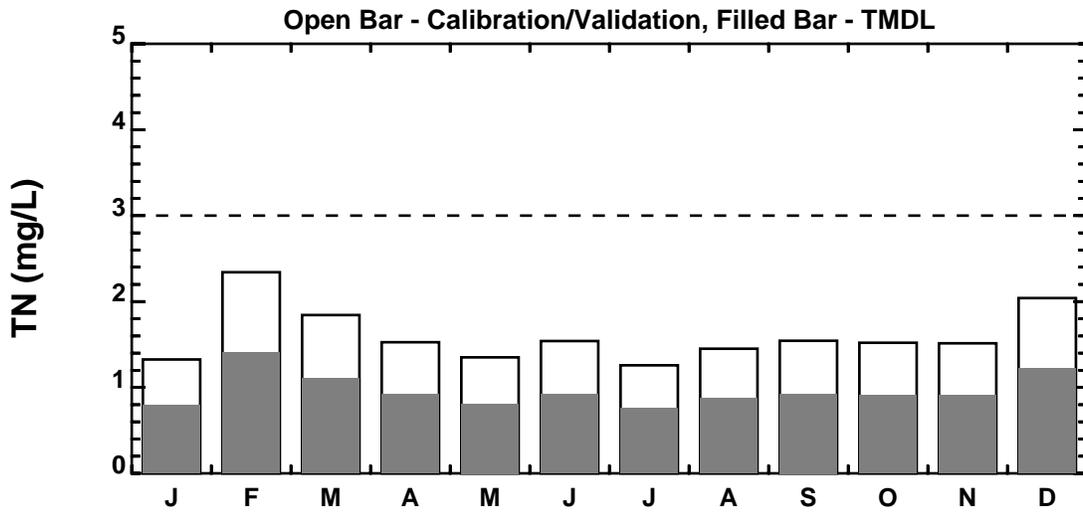
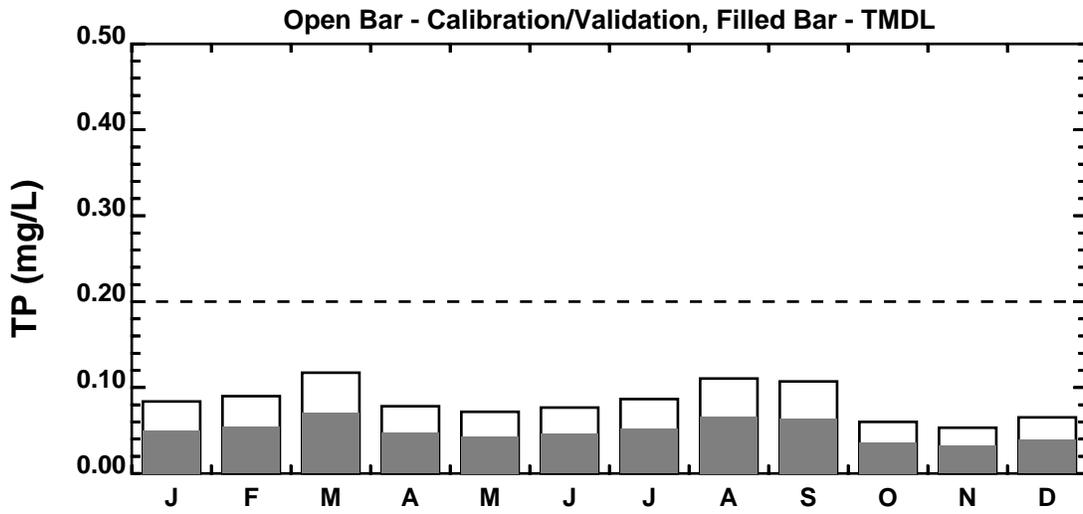
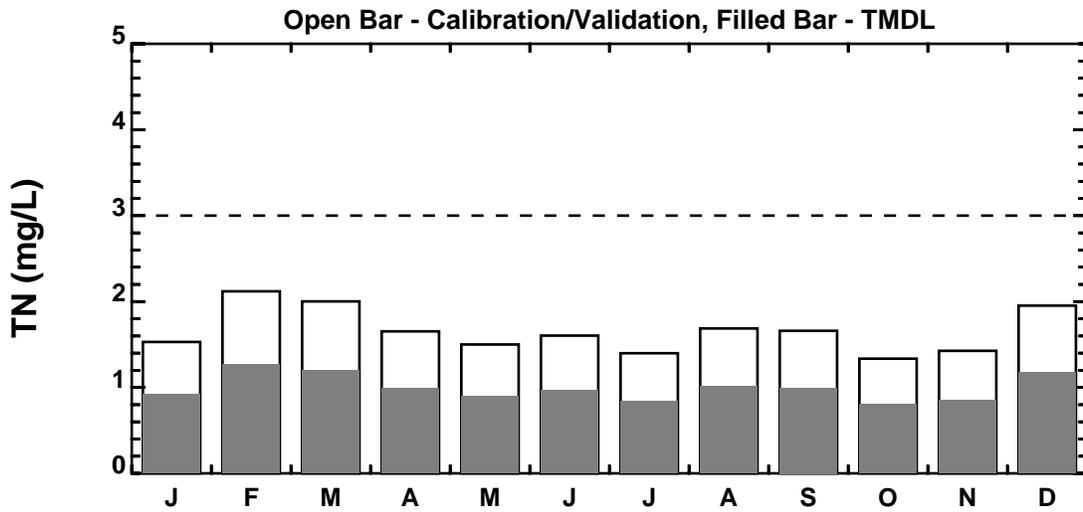


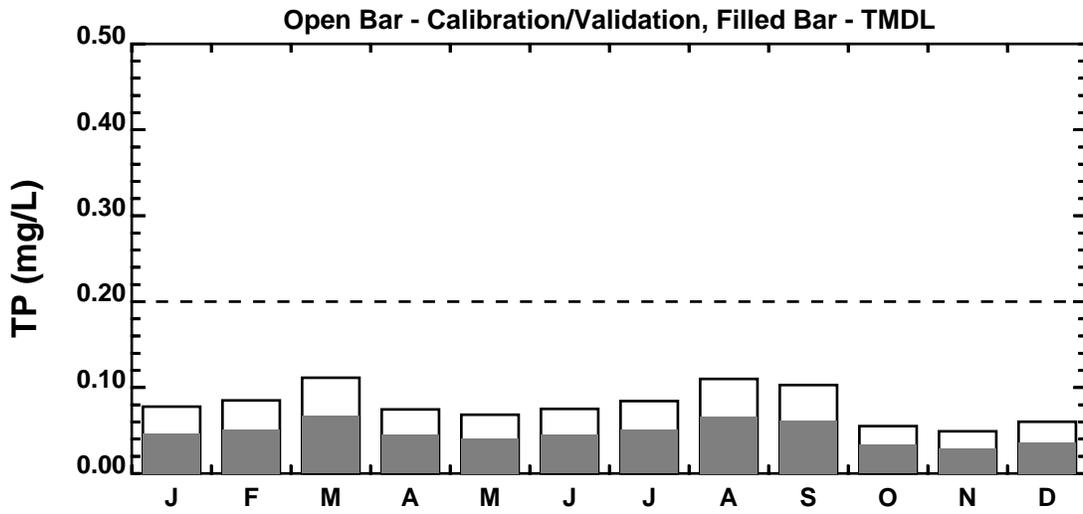
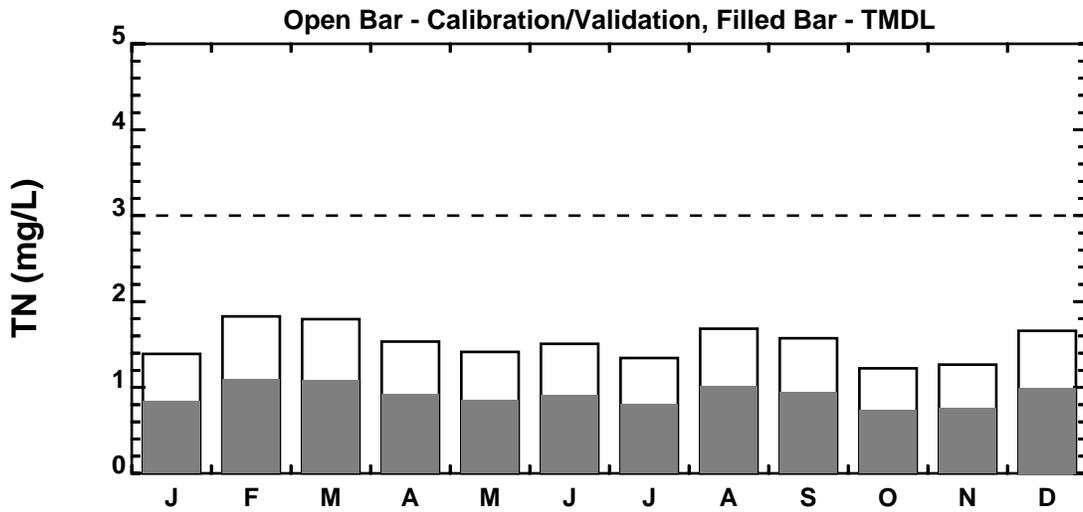
Figure A3. Paw Paw Branch



**Figure A4. Smyrna River (Non-Tidal) - Mill Creek (DE310-003)
Nutrient TMDL Results (2002-2003)
40% NPS Reduction
(Calibration and TMDL Run 14, LSPC Segment 27)**



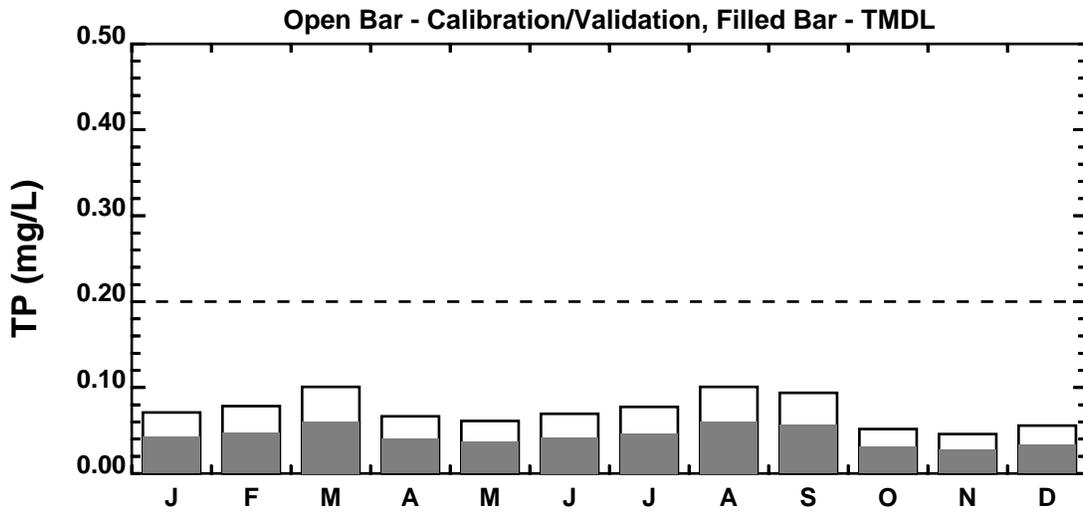
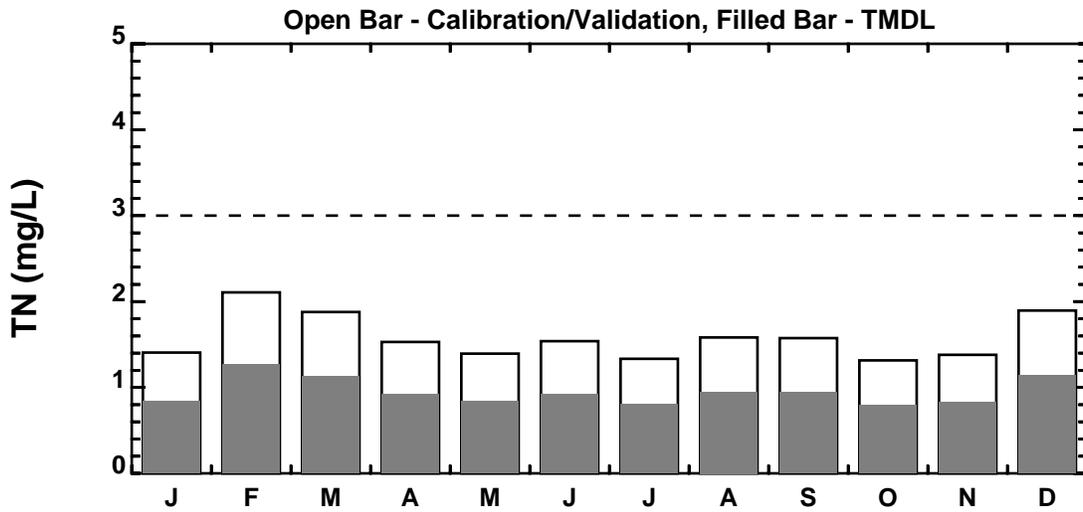
**Figure A5. Smyrna River (Non-Tidal) - Lake Como (DE310-L01)
Nutrient TMDL Results (2002-2003)
40% NPS Reduction
(Calibration and TMDL Run 14, LSPC Segment 28)**



**Figure A6. Smyrna River (Non-Tidal) - Saw Mill Branch
Nutrient TMDL Results (2002-2003)**

40% NPS Reduction

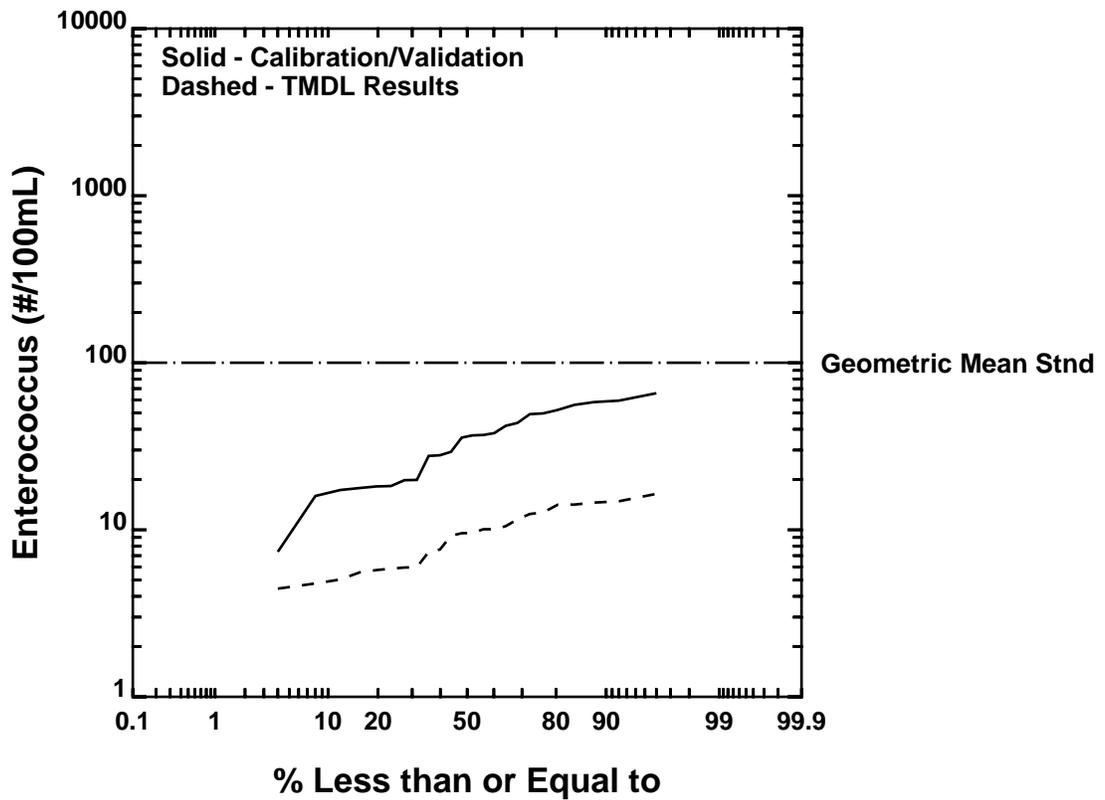
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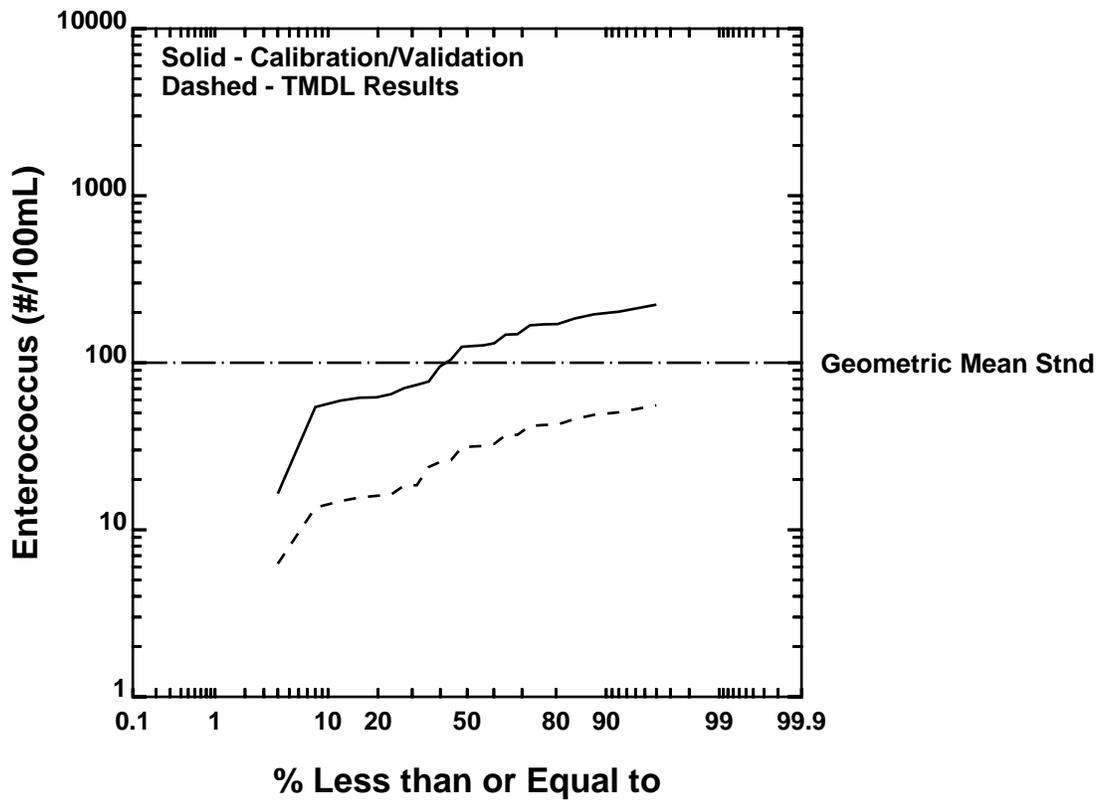
**Figure A7. Smyrna River (Non-Tidal) - Paw Paw Branch (DE310-003)
Nutrient TMDL Results (2002-2003)**

40% NPS Reduction

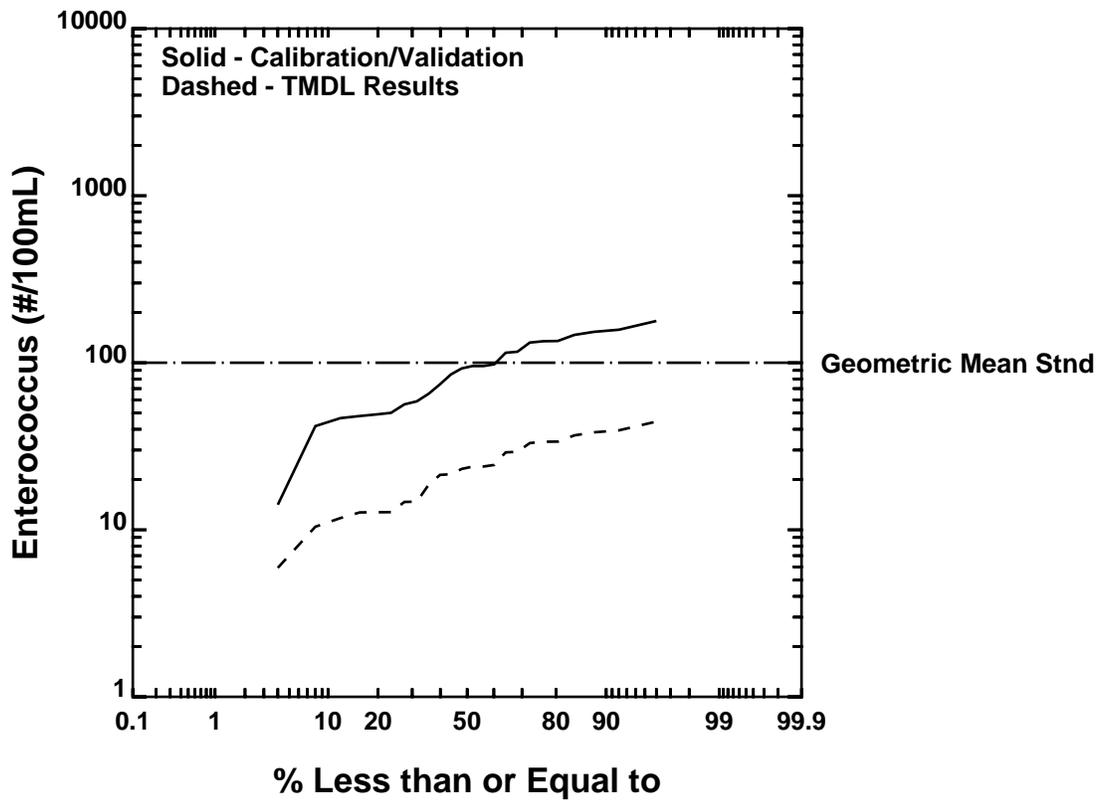
(Calibration and TMDL Run 14, LSPC Segment 20)



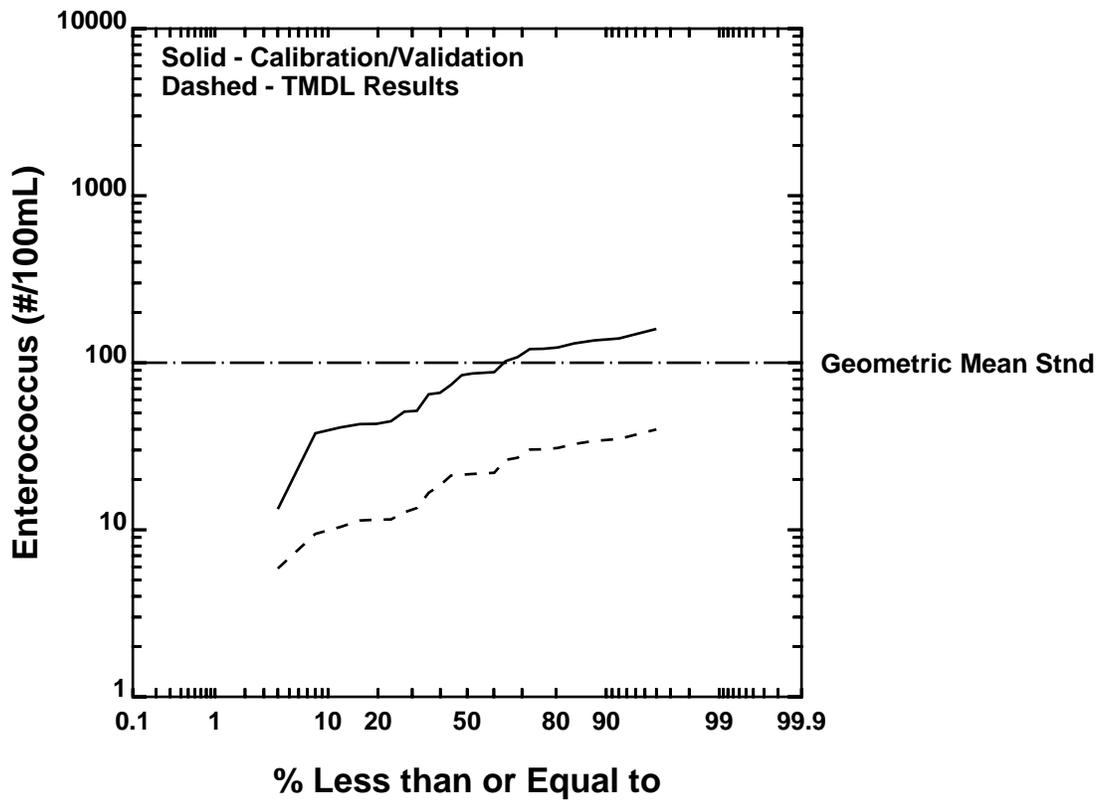
**Figure A8. Smyrna River (Non-Tidal) - Mill Creek (DE310-003)
 Enterococcus TMDL Results (2002-2003)
 75% NPS Reduction
 (Calibration and TMDL Run 14, LSPC Segment 27)**



**Figure A9. Smyrna River (Non-Tidal) - Lake Como (DE310-L01)
 Enterococcus TMDL Results (2002-2003)
 75% NPS Reduction
 (Calibration and TMDL Run 14, LSPC Segment 28)**

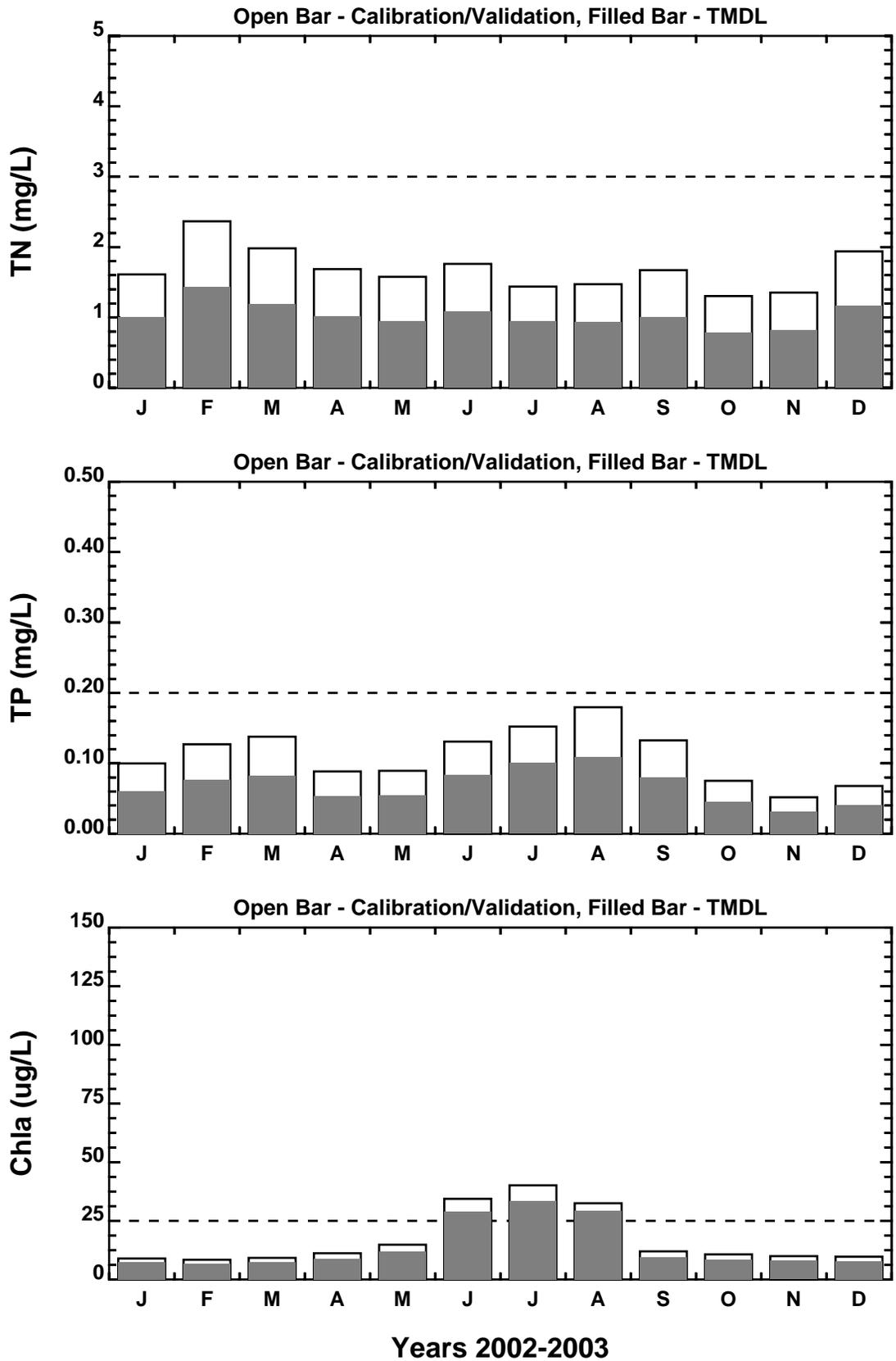


**Figure A10. Smyrna River (Non-Tidal) - Saw Mill Branch
Enterococcus TMDL Results (2002-2003)
75% NPS Reduction
(Calibration and TMDL Run 14, LSPC Segment 32)**



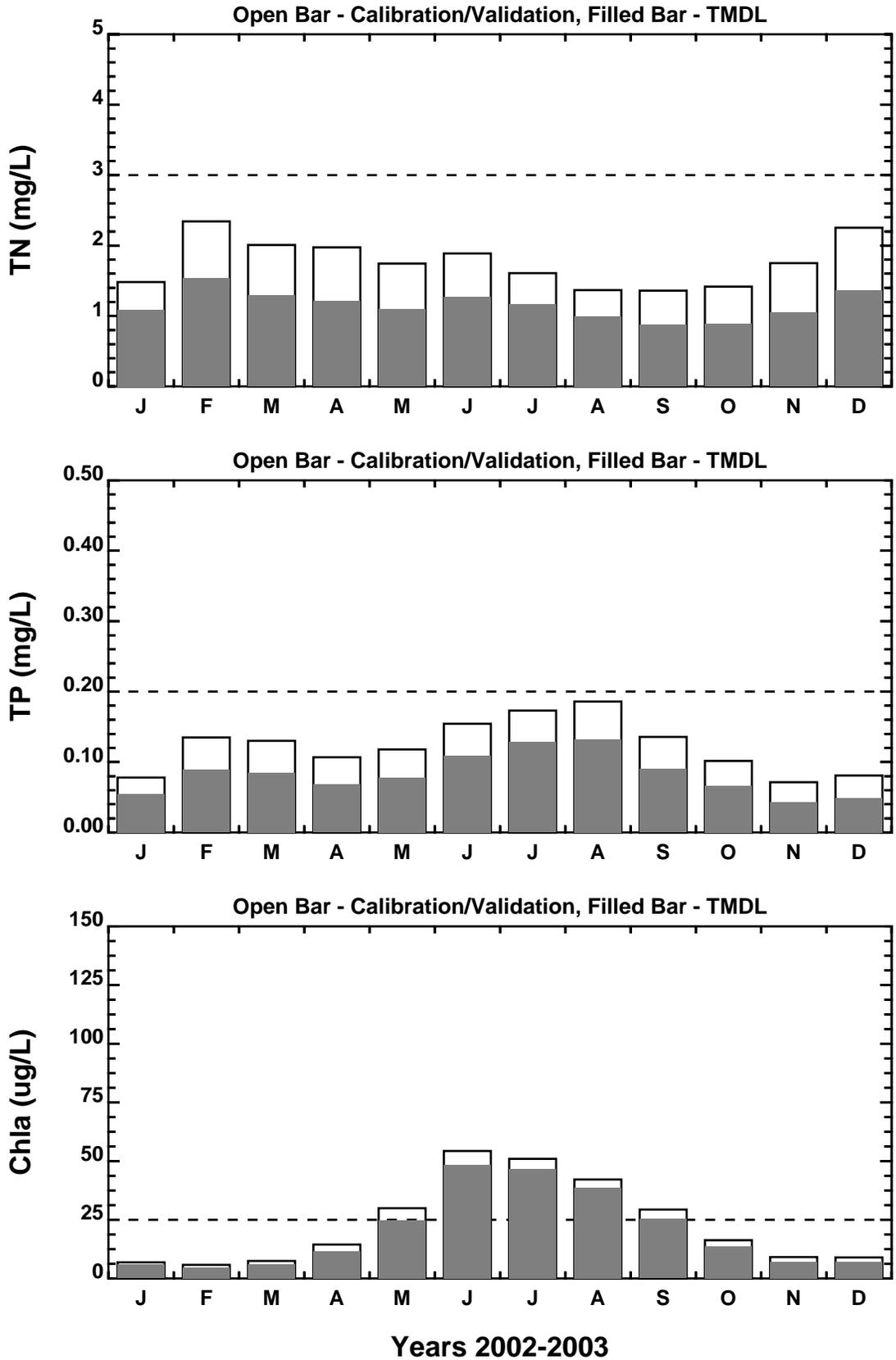
**Figure A11. Smyrna River (Non-Tidal) - Paw Paw Branch (DE310-003)
Enterococcus TMDL Results (2002-2003)
75% NPS Reduction
(Calibration and TMDL Run 14, LSPC Segment 20)**

APPENDIX 2
EXISTING & TMDL MODEL OUTPUT (MARINE)



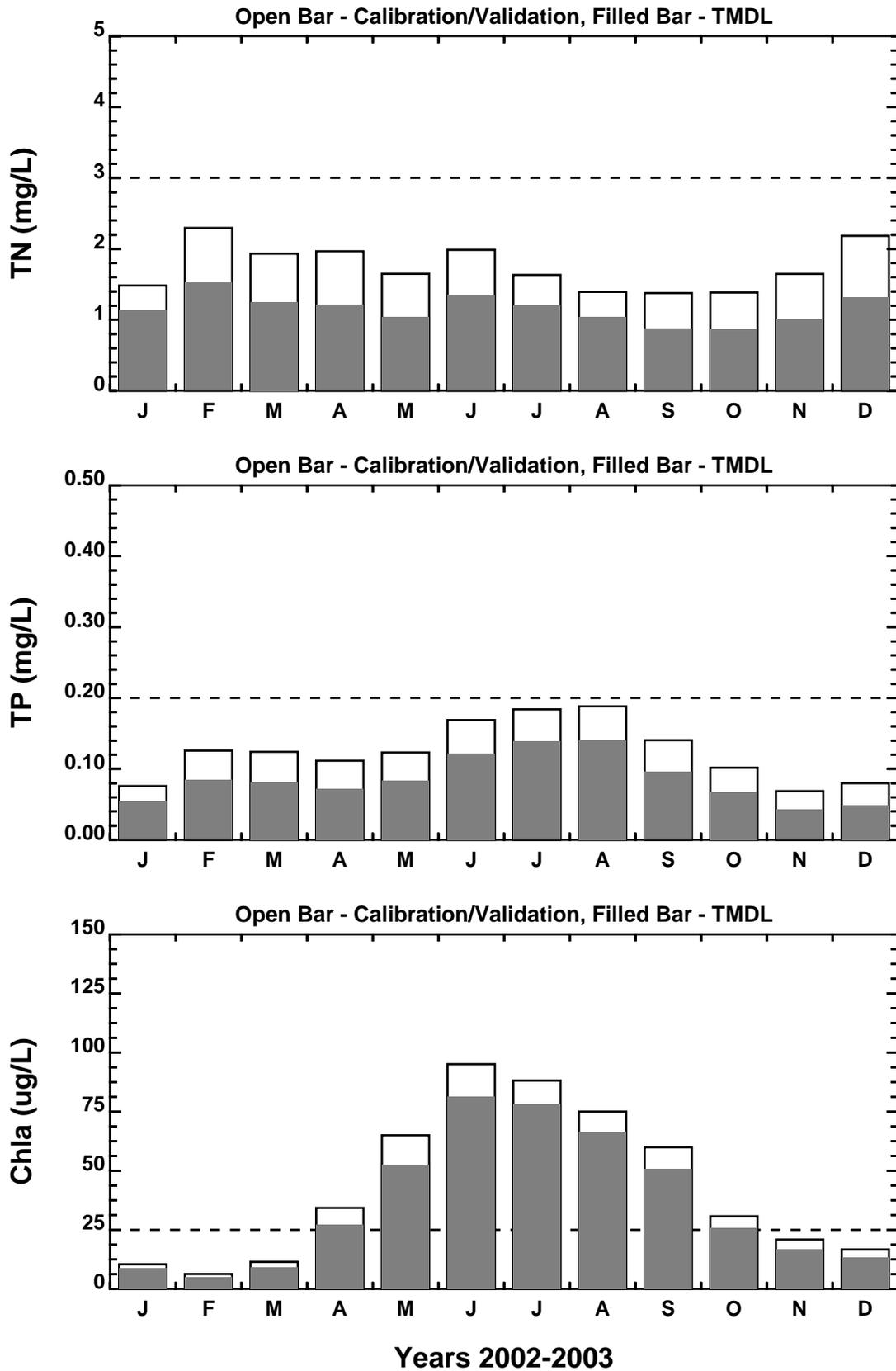
**Figure A12. Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201181 (26,26)
40% NPS Reduction of N/P/C**

(Calibration Run S14, TMDL Run S15)



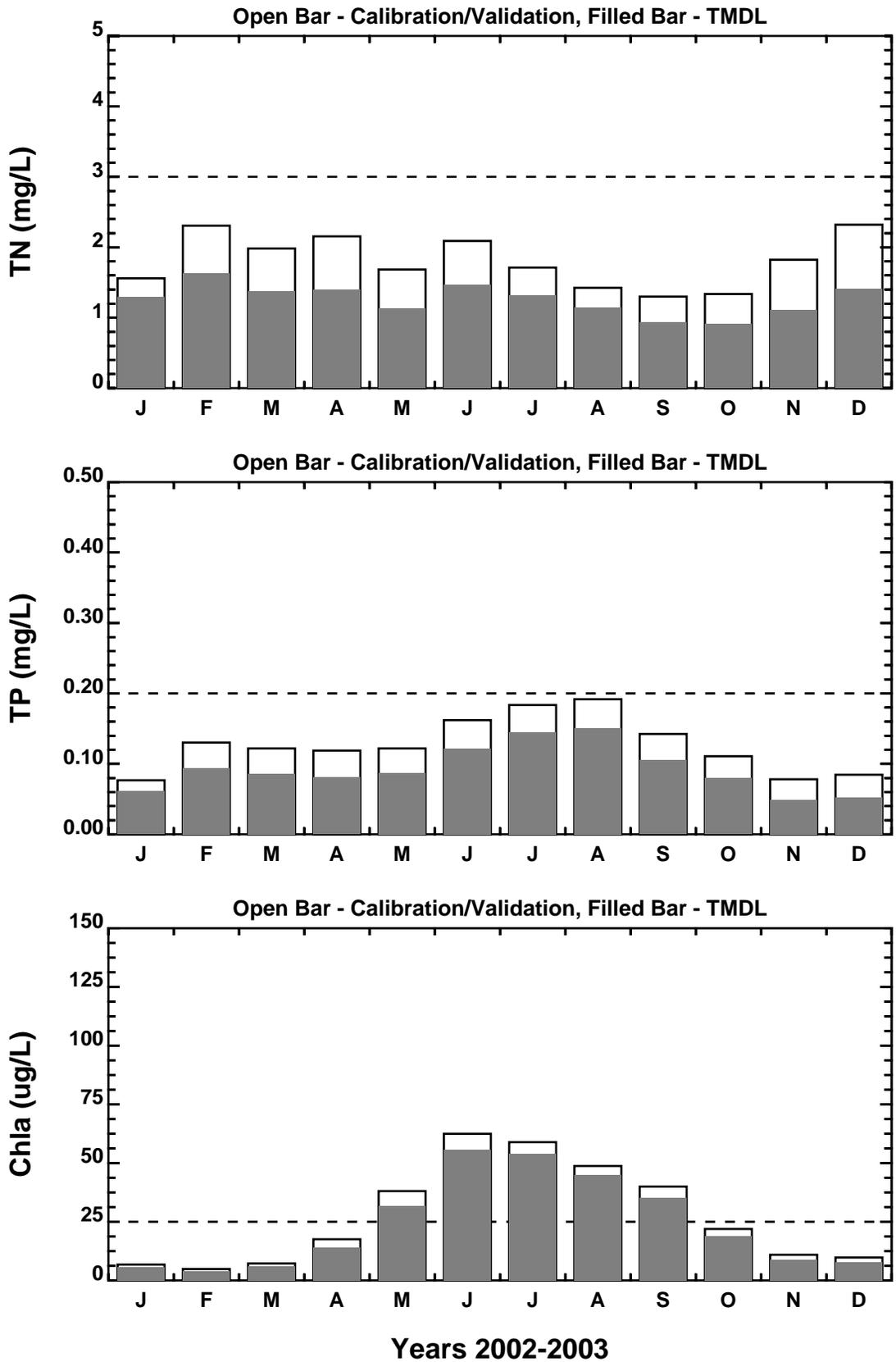
**Figure A13. Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201051 (27,36)
40% NPS Reduction of N/P/C**

(Calibration Run S14, TMDL Run S15)



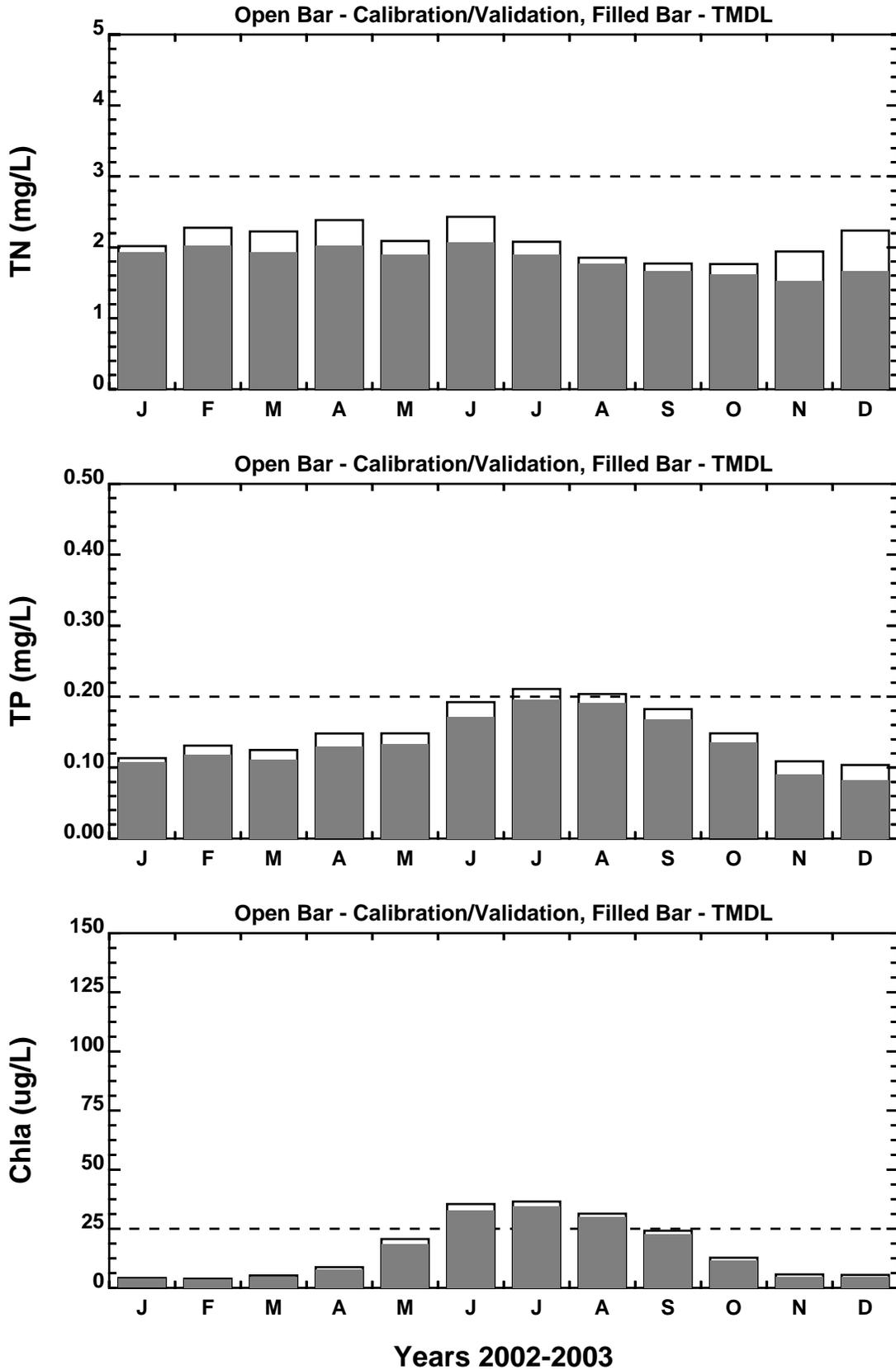
**Figure A14. Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201011 (22,39)
40% NPS Reduction of N/P/C**

(Calibration Run S14, TMDL Run S15)



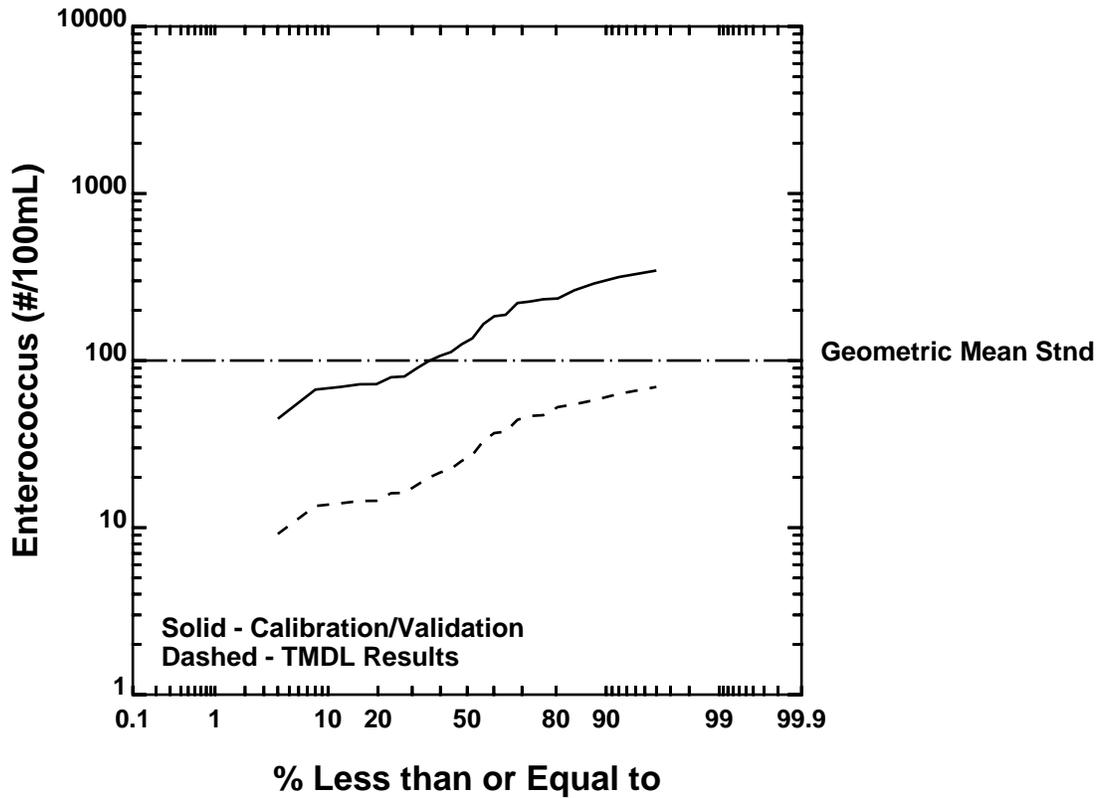
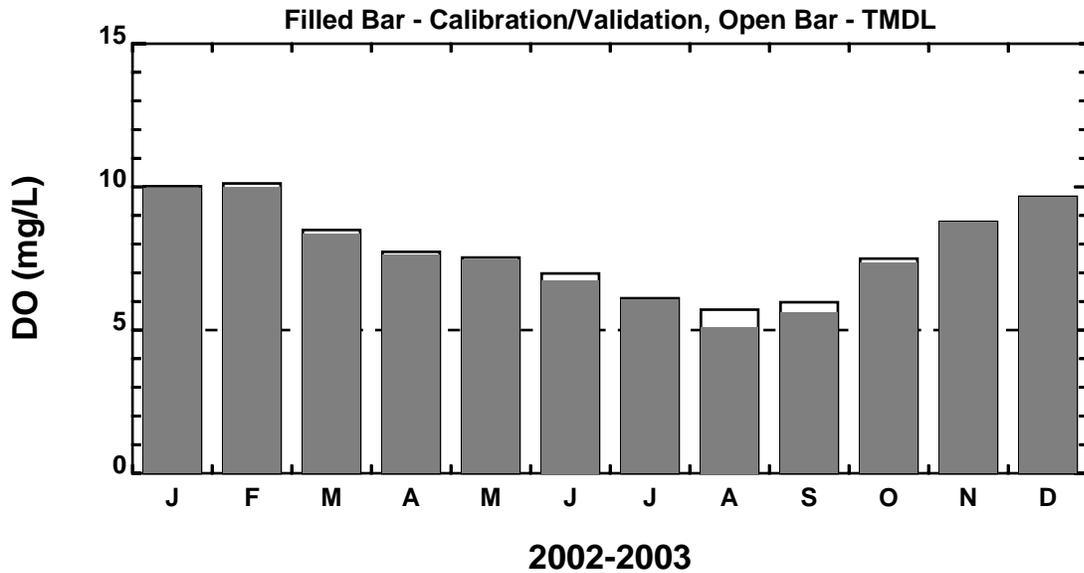
**Figure A15. Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201031 (16,40)
40% NPS Reduction of N/P/C**

(Calibration Run S14, TMDL Run S15)



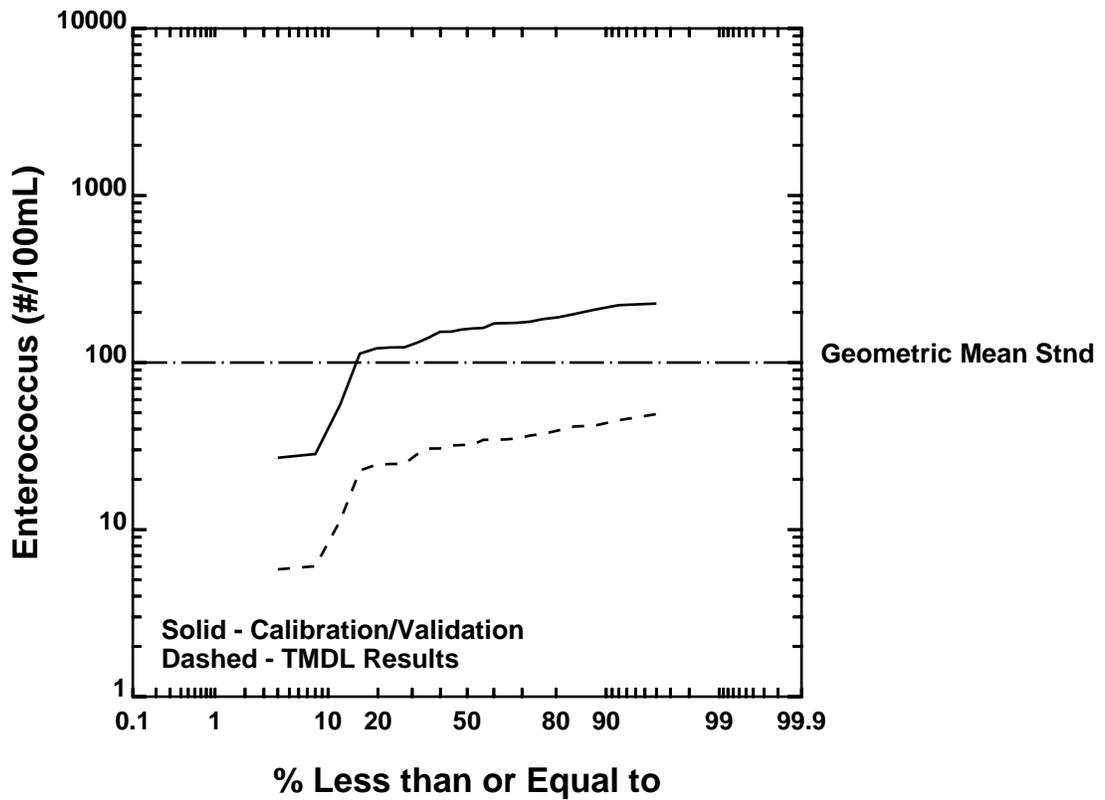
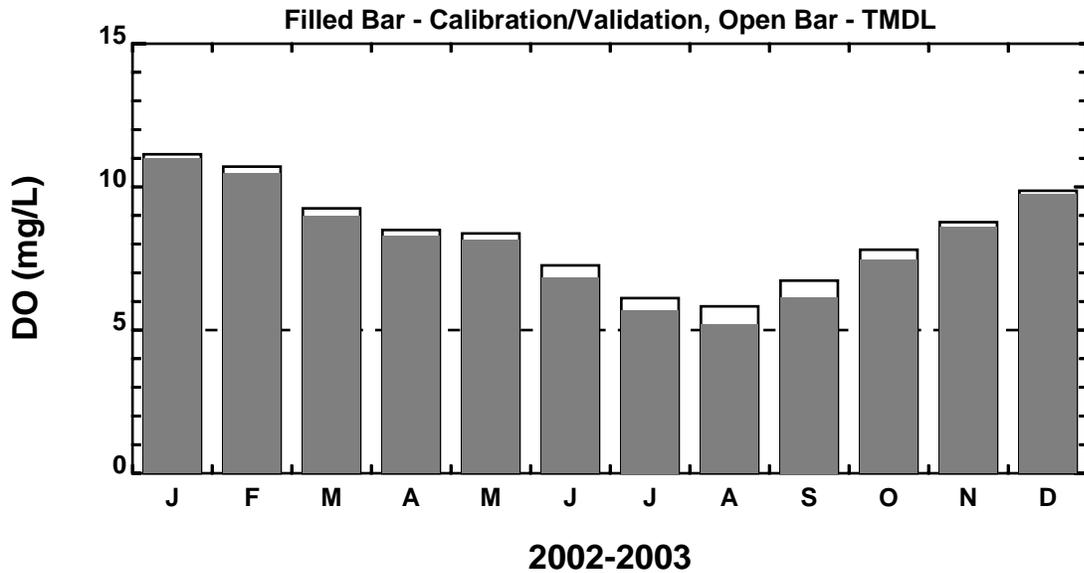
**Figure A16. Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201041 (19,49)
40% NPS Reduction of N/P/C**

(Calibration Run S14, TMDL Run S15)



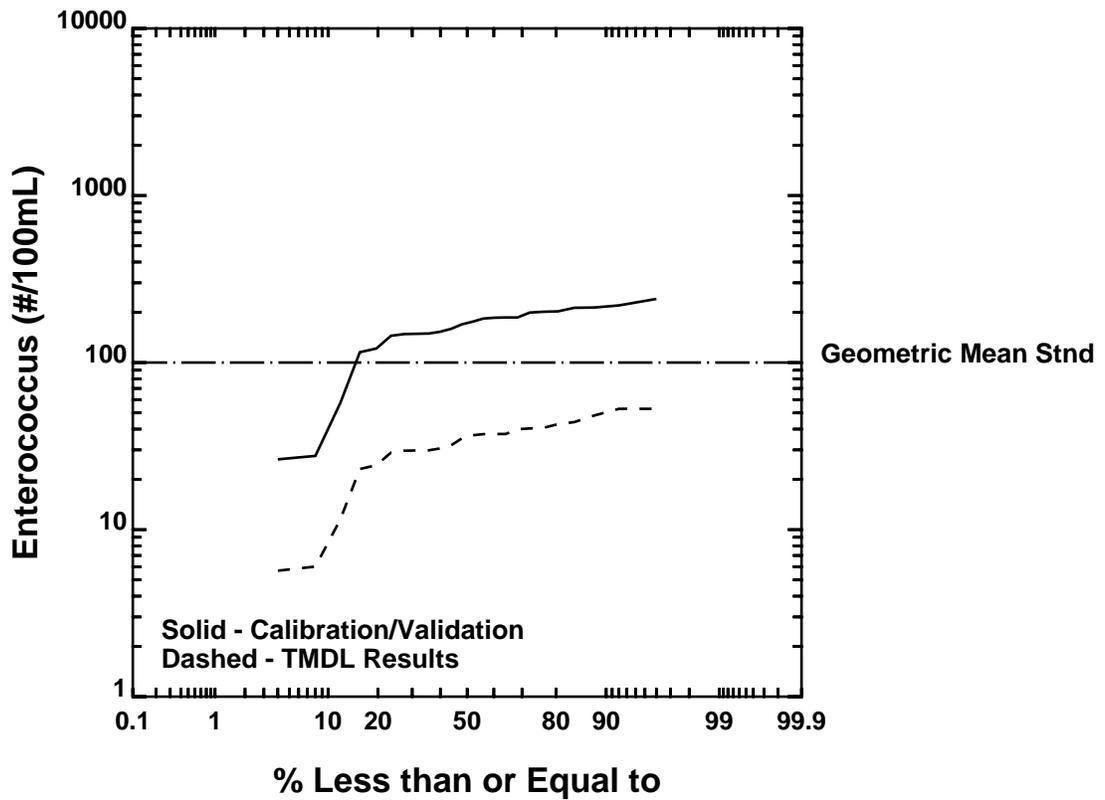
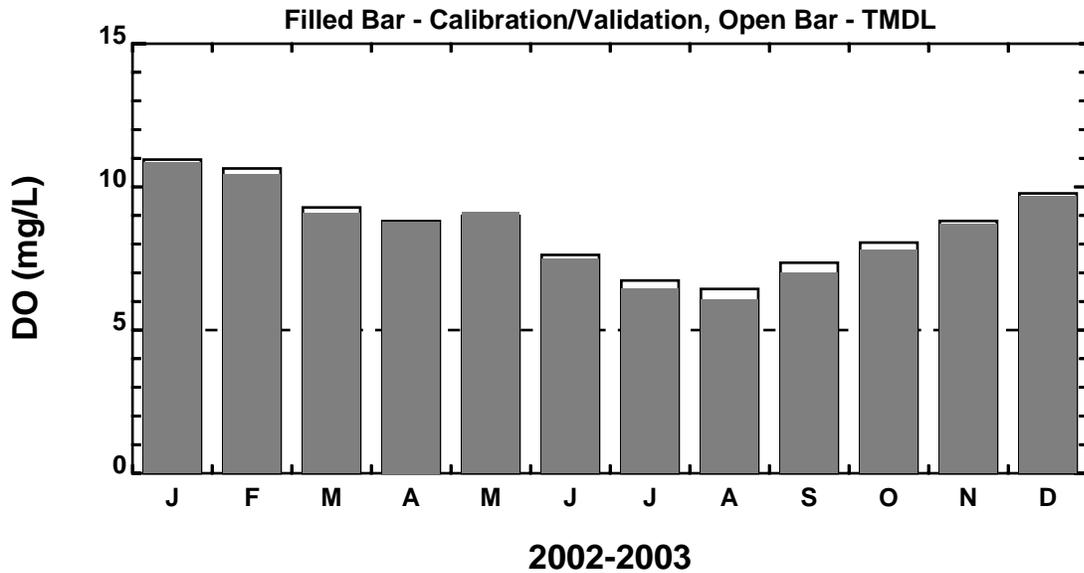
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201181 (26,26)
Figure A17. DO and Enterococcus TMDL Results (2002-2003)
40% NPS Reduction of N/P/C, 75% NPS Reduction of Bacteria

(Euro Calibration Run S14, Euro TMDL Run S15, Pathogen Calibration Run S9, Pathogen TMDL Run S12)



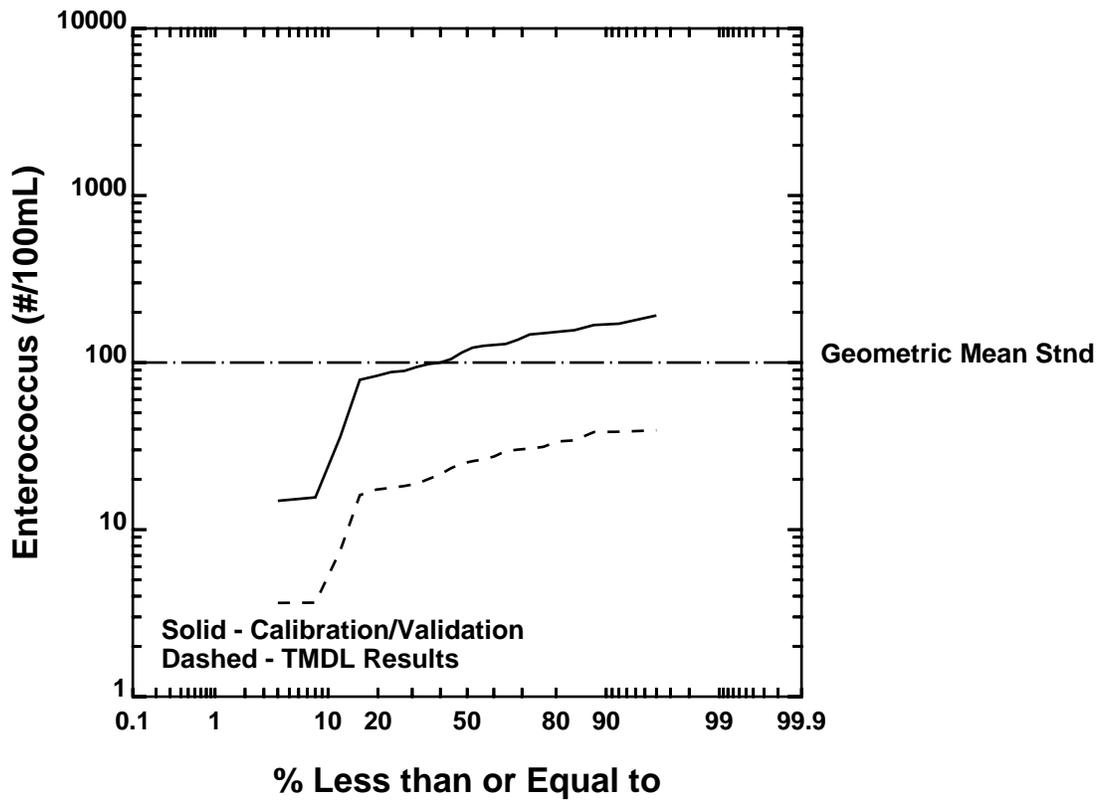
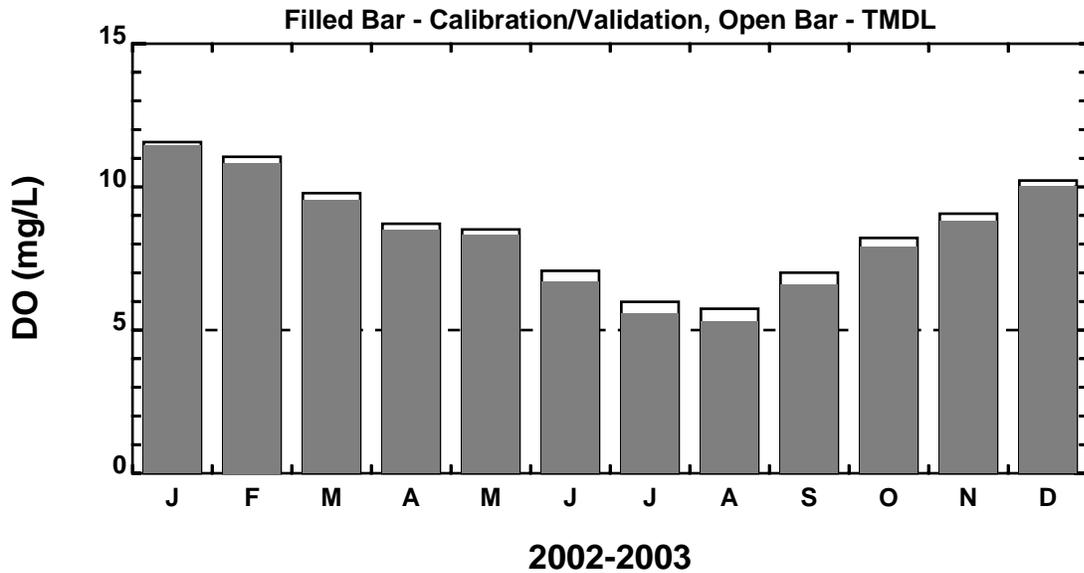
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201051 (27,36)
Figure A18. DO and Enterococcus TMDL Results (2002-2003)
40% NPS Reduction of N/P/C, 75% NPS Reduction of Bacteria

(Euroto Calibration Run S14, Euroto TMDL Run S15, Pathogen Calibration Run S9, Pathogen TMDL Run S12)



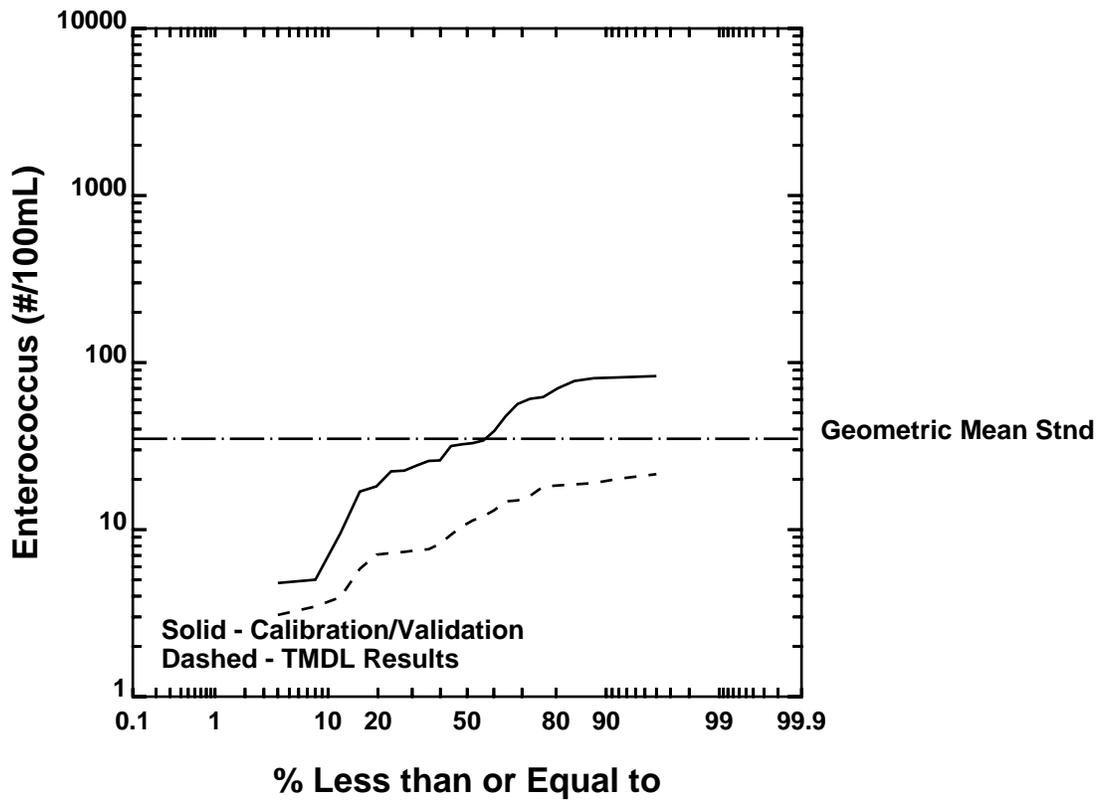
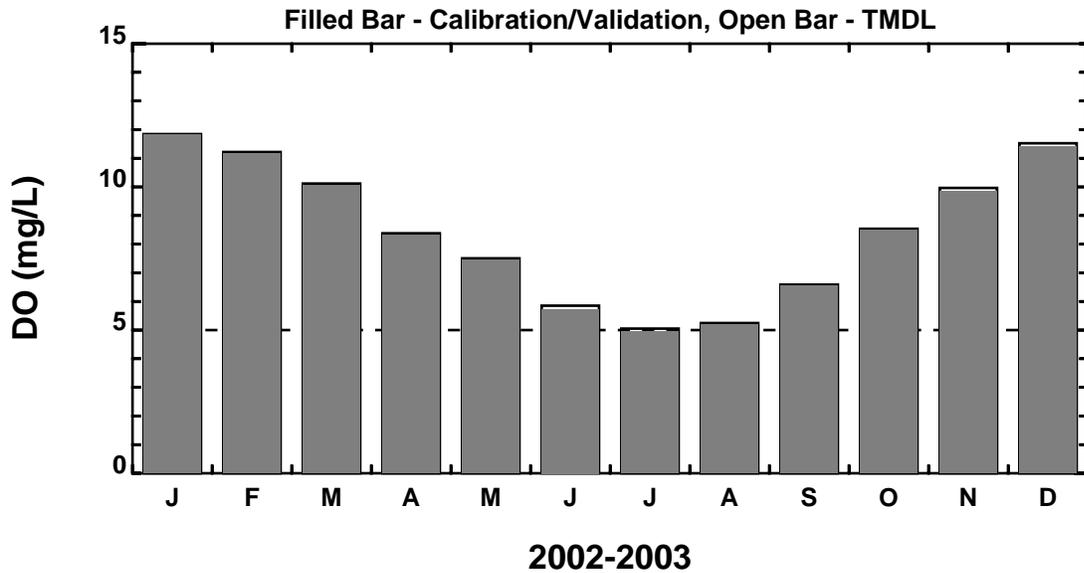
Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201011 (22,39)
Figure A19. DO and Enterococcus TMDL Results (2002-2003)
40% NPS Reduction of N/P/C, 75% NPS Reduction of Bacteria

(Euroto Calibration Run S14, Euroto TMDL Run S15, Pathogen Calibration Run S9, Pathogen TMDL Run S12)



Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201031 (16,40)
Figure A20. DO and Enterococcus TMDL Results (2002-2003)
40% NPS Reduction of N/P/C, 75% NPS Reduction of Bacteria

(Euro Calibration Run S14, Euro TMDL Run S15, Pathogen Calibration Run S9, Pathogen TMDL Run S12)



**Smyrna River (Tidal) - DE310-001 Lower Smyrna River, Station 201041 (19,49)
Figure A21. DO and Enterococcus TMDL Results (2002-2003)
40% NPS Reduction of N/P/C, 75% NPS Reduction of Bacteria**

(Euro Calibration Run S14, Euro TMDL Run S15, Pathogen Calibration Run S9, Pathogen TMDL Run S12)

APPENDIX 3
SMYRNA RIVER BASELINE LOADINGS

TABLE A1

Smyrna River Baseline Point Source Loads	
Facility	Total New Castle County MS4 Load
TN (lb/d)	280.00
TP (lb/d)	20.29
<i>Enterococcus</i> (#/d)	3.06E+11

Baseline Loads For The Smyrna River Watershed			
Parameter	MS4 Load	NPS Load	Total Baseline Load
TN (lb/d)	280.00	957.05	1237.05
TP (lb/d)	20.29	76.07	96.36
<i>Enterococcus</i> (#/d)	3.06E+11	3.88E+11	6.94E+11

TABLE A2

Smyrna River Baseline NPS Loads by Land Use and Watershed Group

Parameter	Urban	Agriculture	Pasture	Forest	Wetlands	Total
Lower Smyrna River						
Area (acres)	594	7,161	168	1,178	2,296	11,398
TN (lb/d)	114.47	165.90	7.12	10.76	23.77	322.01
TP (lb/d)	8.30	2.21	0.17	0.27	17.82	28.77
<i>Enterococcus</i> (#/d)	1.25E+11	1.55E+08	5.51E+07	2.12E+07	0.00E+00	1.26E+11
Upper Smyrna River/Paw Paw Branch						
Area (acres)	811	7,111	61	503	1,399	9,885
TN (lb/d)	85.74	163.08	1.56	4.52	14.32	269.22
TP (lb/d)	6.21	2.17	0.03	0.11	10.73	19.26
<i>Enterococcus</i> (#/d)	9.38E+10	1.52E+08	5.03E+07	8.91E+06	0.00E+00	9.40E+10
Saw Mill Branch						
Area (acres)	0	2,601	255	1,687	1,407	5,950
TN (lb/d)	0.00	59.65	11.99	15.18	14.40	101.23
TP (lb/d)	0.00	0.79	0.30	0.37	10.80	12.27
<i>Enterococcus</i> (#/d)	0.00E+00	5.57E+07	4.07E+07	2.99E+07	0.00E+00	1.26E+08
Greens Branch						
Area (acres)	644	1,304	64	102	72	2,187
TN (lb/d)	68.10	29.90	3.14	0.92	0.74	102.80
TP (lb/d)	4.94	0.40	0.08	0.02	0.55	5.99
<i>Enterococcus</i> (#/d)	7.45E+10	2.79E+07	6.17E+06	1.81E+06	0.00E+00	7.46E+10
Mill Creek						
Area (acres)	814	2,819	153	150	325	4,261
TN (lb/d)	86.01	64.65	6.44	1.35	3.33	161.78
TP (lb/d)	6.23	0.86	0.16	0.03	2.49	9.78
<i>Enterococcus</i> (#/d)	9.41E+10	6.04E+07	4.71E+07	2.67E+06	0.00E+00	9.42E+10

APPENDIX 4
SMYRNA RIVER LSPC INPUTS
(ACCUMULATION RATES & LIMITS)

TABLE A3**Smyrna River Watershed LSPC Accumulation Rates (lb/acre/day) - Calibration Run**

Pollutant	Agriculture	Forest	Pasture/ Rangeland	Urban Pervious	Urban Impervious	Wetlands	Other
BOD	5.0	2.5	3.5	15.0	0.2	2.5	5.0
Organic Nitrogen	2.00	1.00	1.40	6.00	0.08	1.00	2.00
Ammonia	0.50	0.03	0.10	0.07	0.01	0.03	0.07
Nitrite plus Nitrate	9.00	1.00	3.00	5.00	0.06	1.00	3.00
Organic Phosphorus	0.400	0.200	0.280	1.200	0.016	0.200	0.400
Phosphate	0.0150	0.0075	0.0100	0.0250	0.0034	0.0070	0.0100
Enterococcus	7.57E+07	6.59E+07	1.01E+09	9.70E+08	9.70E+08	0.00E+00	0.00E+00

TABLE A4**Smyrna River Watershed LSPC Accumulation Limits (lb/acre) - Calibration Run**

Pollutant	Agriculture	Forest	Pasture/ Rangeland	Urban Pervious	Urban Impervious	Wetlands	Other
BOD	10.0	5.0	7.0	30.0	0.4	5.0	10.0
Organic Nitrogen	4.00	2.00	2.80	12.00	0.16	2.00	4.00
Ammonia	5.00	0.30	1.00	0.70	0.10	0.30	0.70
Nitrite plus Nitrate	90.00	10.00	30.00	50.00	0.60	10.00	30.00
Organic Phosphorus	0.800	0.400	0.560	2.400	0.032	0.400	0.800
Phosphate	0.1500	0.0750	0.1000	0.2500	0.0160	0.0700	0.1000
Enterococcus	1.36E+08	1.19E+08	1.82E+09	1.75E+09	1.75E+09	0.00E+00	0.00E+00