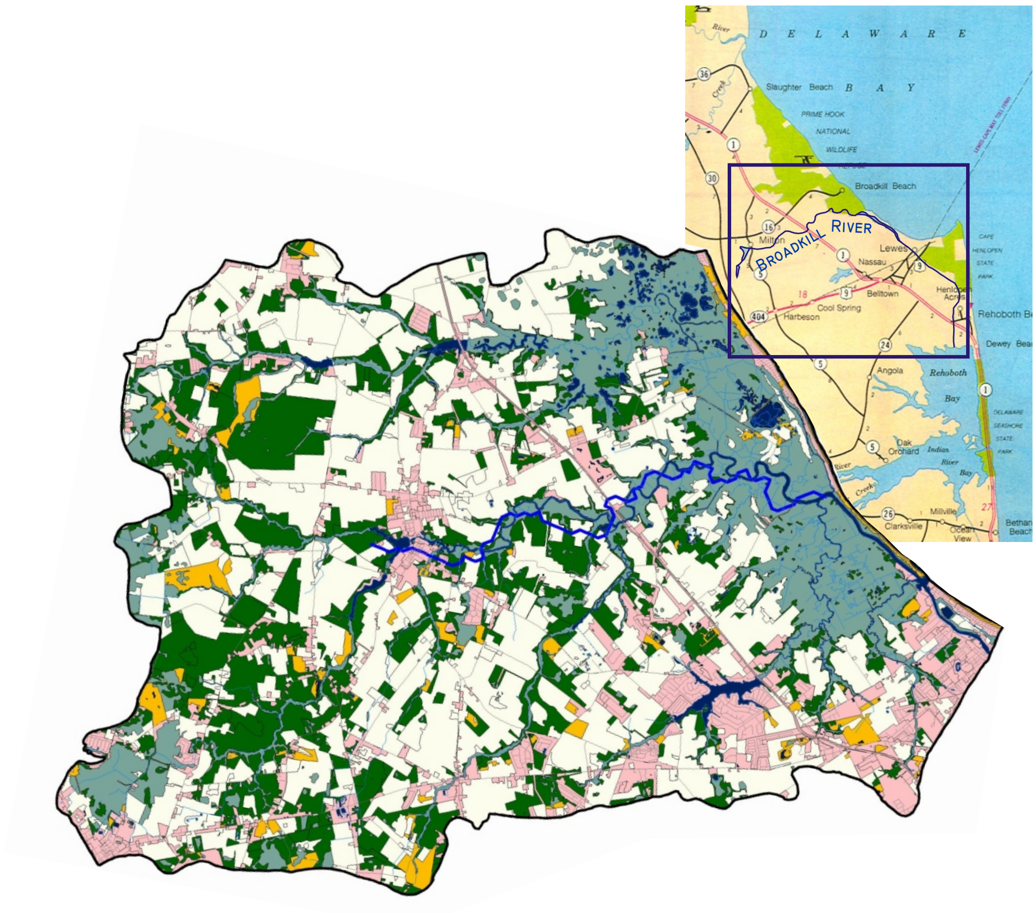
Delaware Department of Natural Resources
and Environmental Control

Broadkill River Watershed Proposed TMDLs



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PREFACE

The draft Proposed TMDLs for the Broadkill River watershed were reviewed during a public workshop held on 16 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, 3.2, 4.0, 4.2, 5.1, 6.1, 6.4 and 6.5 and Appendices 3, 4 and 5) and CABE Associates, Inc. (Sections 3.2, 5.1 and 6.1 and Appendices 3 and 5)

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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 Broadkill 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 Broadkill River (below the City of Milton), 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 Broadkill 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:

- Broadkill River Watershed TMDL Development, Data Analysis Technical Memorandum (HydroQual, 2004); and
- Broadkill River Watershed TMDL Model Development (HydroQual, 2005).

A summary of some of the data and modeling information related to the Broadkill 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 water bodies listed on the State of Delaware's 1998, 2002, 2004 and 2006 Draft 303(d) Lists in the Broadkill River Watershed are presented in Table 1. There are a total of 13 listed water segments: 3 tidal segments of the Broadkill River; 7 freshwater stream segments; and 3 freshwater lakes or ponds. These segments are listed for nutrients, DO and bacteria with the most probable source of pollutants identified as NPS except for a few segments where PS discharges are located. The TMDL development in the Broadkill 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. Broadkill River Watershed TMDL Segments

Water Body ID	Segment	Size Affected	Description	Parameters	Probable Source
DE060-001	Lower Broadkill	8.1 miles	From the confluence with Beaver Dam Creek to mouth at Delaware Bay, excluding Red Mill Pond	Bacteria, DO, nutrients	NPS
DE060-002	Beaverdam Creek	8.3 miles	From the headwaters to the confluence with Broadkill River	Bacteria, DO, nutrients	PS, NPS
DE060-003	Upper Broadkill	5.0 miles	Broadkill River from below Waggamons Pond to the confluence with Beaver Dam Creek	Bacteria, DO, nutrients	PS, NPS
DE060-004	Round Pole Branch	5.2 miles	Tributary from the headwaters to confluence with Upper Broadkill River	Bacteria, DO, nutrients	NPS
DE060-005	Ingrams Branch	7.6 miles	From the headwaters to Waggamons Pond, including Diamond Pond	Bacteria, DO, nutrients	PS, NPS
DE060-005	Ingrams Branch	1.7 miles	Ingrams Branch – western tributary of the headwaters	DO	PS, NPS
DE060-006	Pemberton Branch	5.0 miles	From the headwater to Waggamons Pond	Bacteria, nutrients	NPS
DE060-007-01	Lower Red Mill Branch	5.3 miles	From Red Mill Pond to the confluence with Lower Broadkill River	Bacteria, DO, nutrients	NPS
DE060-007-02	Martin Branch	1.5 miles	From the headwaters to Red Mill Pond	Bacteria, DO, nutrients	NPS
DE060-007-03	Heronwood Branch	1.0 miles	From the headwaters to Red Mill Pond	Bacteria, DO	NPS
DE060-L01	Red Mill Pond	150.0 acres	Pond located on Martin Branch	Bacteria, DO, nutrients	NPS
DE060-L02	Waggamons Pond	35.0 acres	Pond adjacent to Milton	Nutrients	PS, NPS
DE060-L03	Waples and Reynolds Pond	88.8 acres	Ponds located on Sowbridge Branch of Primehook Creek	Bacteria, DO, nutrients	NPS

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 Broadkill 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 over enrichment and are stated as:

> "Nutrient over enrichment 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 water bodies 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 Broadkill 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 Hydrologic Simulation Program FORTRAN (HSPF) that is available with USEPAs multipurpose BASINS package. It uses rainfall, temperature and solar radiation information, land-use, and soil types to simulate the quantity and quality of runoff from urban or agricultural watersheds. Accumulation rates and limits used by HSPF 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). 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 Broadkill 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.

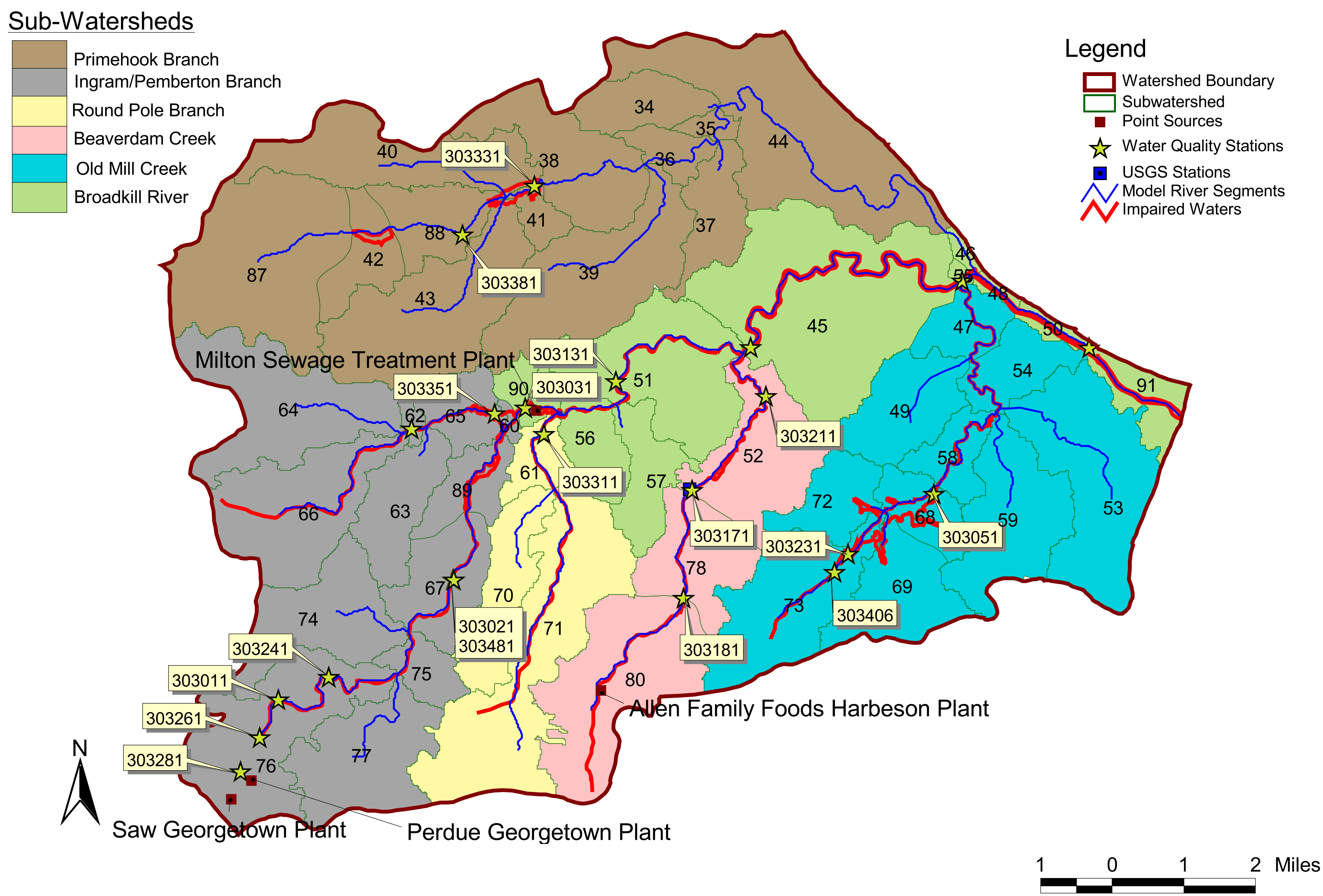
The linked landside, hydrodynamic and water quality models were developed to complete the TMDLs in the Broadkill River watershed. Calibration and validation of the models provide a consistent set of model coefficients that realistically represents the datasets in both modeling time periods. The calibrated 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 "Broadkill River Watershed TMDL Model Development" (HydroQual, 2005).

2.1 MODEL SEGMENTATION/DELINEATION

The HSPF model was delineated into 51 sub-watersheds in the Broadkill 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.

Segmentation of the hydrodynamic and water quality models resulted in a 24x48x10 model grid that consists of 491 water segments in the horizontal plane and 10 equal water segments in the vertical dimension, for a total of 4,910 water segments (Figure 2). The model segments were developed in the Broadkill River and extended into the Delaware Bay approximately 7 miles from the lower river estuary and 10 miles in the lateral 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 estuary were obtained from NOAA GEODAS CDs (NOAA, 1998) and also DNREC ADCP data. Figure 2 presents the ADCP station locations.

Figure 1. Broadkill River Watershed HSPF Model Segmentation



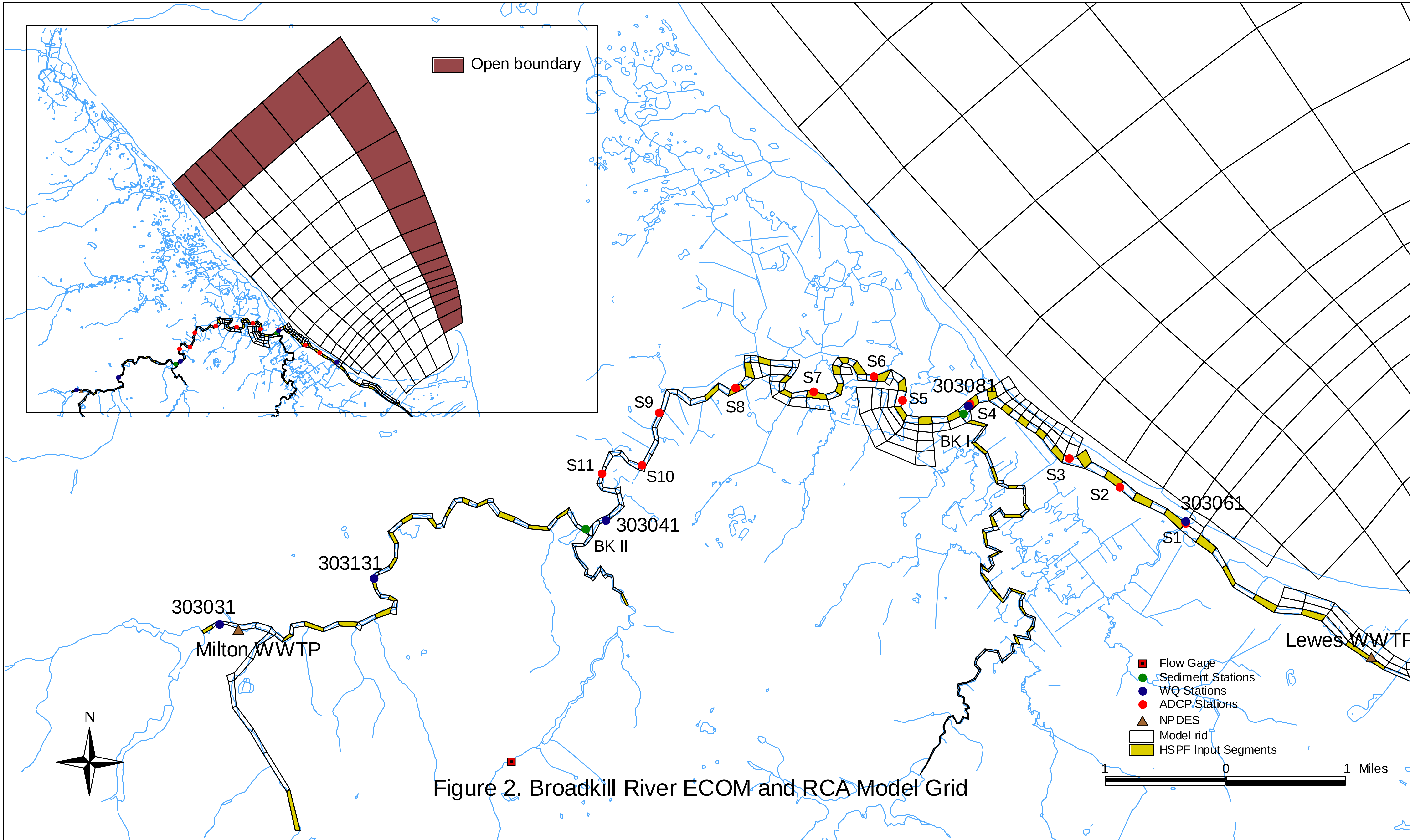


Figure 2. Broadkill River ECOM and RCA Model Grid

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 3. The Broadkill River watershed is approximately 27,771 ha (107 mi^2) and is primarily non-urban (87%) with approximately 41% agricultural land use.

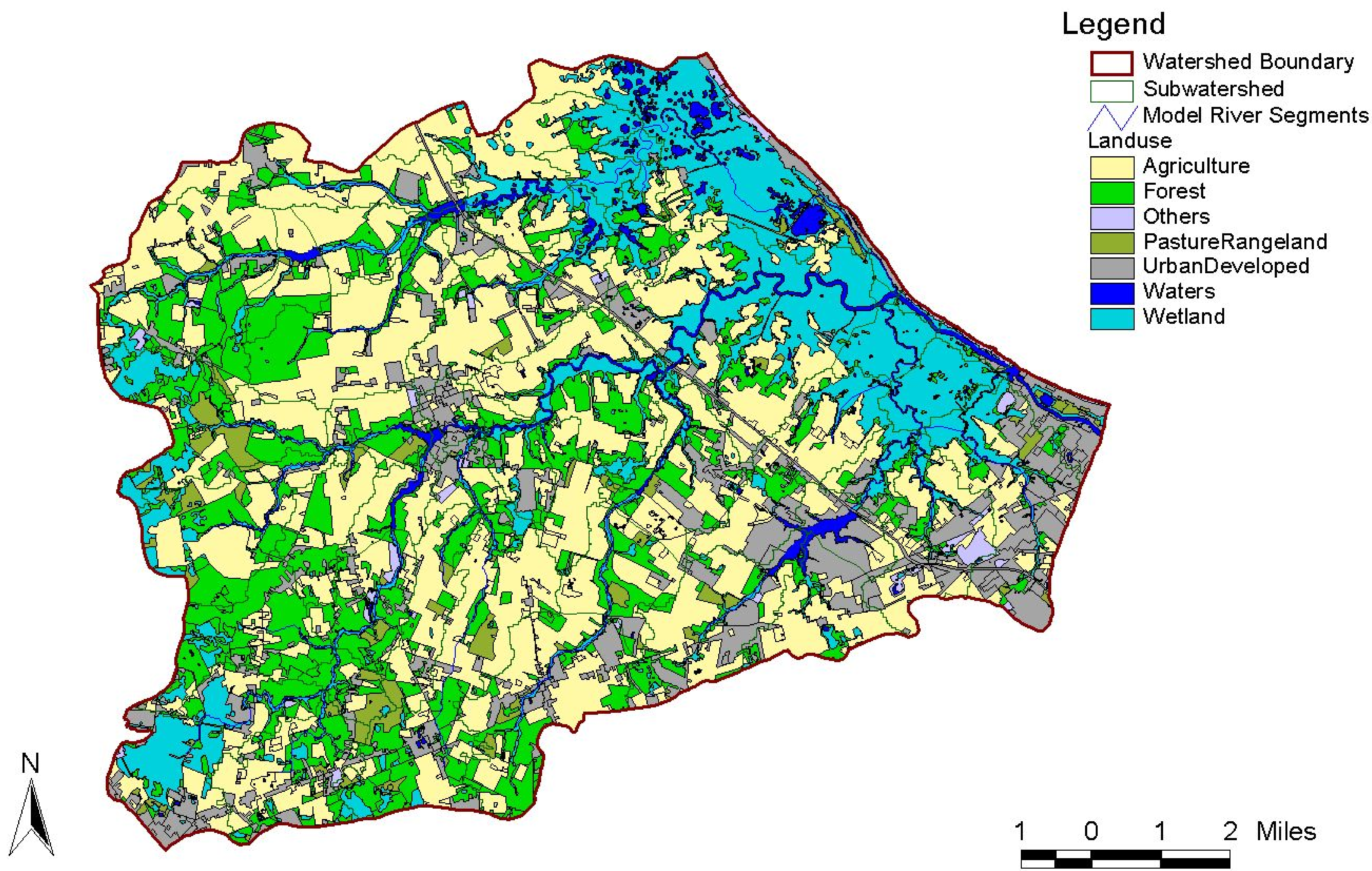
3.2 POINT SOURCES

In the Broadkill River watershed, there are four existing point sources (PS): Allen Family Foods, SAW Georgetown Plant (outfalls 001 and 002), Perdue Georgetown Plant, and City of Milton WWTP. Flow, nutrient, DO, BOD, and TSS information were available for these PSs (see Appendix 5 for current permit limits and effluent data overview). The City of Lewes WWTP is part of the Inland Bays watershed modeling effort and the discharge was included under the Inland Bays TMDL. It was included in the Broadkill River watershed model to properly account for the discharge loadings on Broadkill River water quality. A septic nutrient load was assigned in the model based on septic 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 Broadkill River Watershed

Land Use	Area (ha)	% Total Area
Agriculture	11,333	40.8
Forest	5,893	21.2
Pasture/Rangeland	781	2.8
Urban/Built-up Land	3,589	12.9
Water	719	2.6
Wetland	5,153	18.6
Others	303	1.1
Total	27,771	100.0

Figure 3. Broadkill River Watershed Landuse Distribution



SECTION 4

WATERSHED MONITORING

Monitoring in the Broadkill 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 Broadkill River, tributaries and ponds to establish TMDLs for nutrients, DO and bacteria.

The data provided by DNREC included DNREC water quality monitoring data, DNREC Division of Water Resources (DWR) water quality data, land use information, tidal elevations, cross-sectional data, Acoustic Doppler Current Profiler (ADCP) data, National Pollutant Discharge Elimination System (NPDES) PS information, and a DNREC sediment-water exchange study report. 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, water quality stations, and NPDES PS locations. 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 (chla), and *enterococcus*. There are 28 stations in the Broadkill River watershed as shown in Figures 1 and 2. The available data span from 1994 to 2003, but the majority of the data were collected between 2002 and 2003. All three models (landside, hydrodynamic, and water quality) were calibrated with these data.

- **DNREC DWR Data** – The DWR database contains 15-minute interval data for approximately weekly periods in August and September 2003 for five stations in the Broadkill River watershed. The parameters in the database were salinity, temperature, DO, and pH with station locations shown in Figure 2. ECOMSED and RCA used these tidal data in the calibration process.

- **NPDES Point Source Data** – The point source database contains information on effluent limits and discharge monitoring data for the five NPDES permitted PSs located in the watershed. The point source facilities are: Allen Family Foods Harbeson Plant, SAW Georgetown Plant, Perdue Georgetown Plant, and City of Milton WWTP. The locations are shown in Figure 1. The effluent data usually contained flow, BOD, TSS, temperature, pH, hardness, and sometimes oxygen and nutrients. For model calibration, the time variable monitoring data were input as a point source. (See Appendix 3 for time variable data). Section 5.1 describes how effluent limits were used for TMDL development.

- **Delaware Tidal River Sediment-Water Exchange Study** – This study provides information on sediment-water exchange rates (fluxes) for oxygen (sediment oxygen demand or SOD), nitrogen gas (N_2), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), and soluble reactive phosphorus (SRP) at two sites in both the main stem of the Broadkill River watershed. Figure 2 shows the locations of the sampling sites in the lower Broadkill River. Samples were collected in May, August, and October 2002. Calibration of the RCA sediment flux submodel relied on information gathered in this study.

- **Tidal Data** – Tide elevation data for the Broadkill River watershed are available for 2002 and 2003 at Lewes and Milton. These data were used when calibrating the hydrodynamic model.

- **Cross-Sectional Data** – The cross-sectional data include cross-section width, depth, and velocity for a number of stations in the Broadkill River watershed as shown in Figure 1. Data are available for stations tributary to the main stem of the river. River geometry for the landside and hydrodynamic models was developed using these data.

- **ADCP Data** – The ADCP data contain tidal velocity, elevation and cross-section measurements conducted on September 10, 2003 for 11 sites in the estuary portion of the Broadkill River. The monitoring locations are presented on Figure 2. Except for sites 2 and 11, which have eighteen and sixteen measurements respectively, and site 1, which has no measurements, the other sites all have one or two measurements. These data were used to define river geometry and aided in calibration of the velocities and water depths in the hydrodynamic model.

- **Flow Data** – A USGS flow gage is located within the Broadkill River watershed at Beaverdam Creek near Milton, DE (01484270) with measured daily and 15-minute interval flow data available during 2002 and 2003. The location is shown in Figure 1. These flow data were used when calibrating the landside model.

4.1 OVERALL WATER QUALITY ASSESSMENT

In general, the water quality data analysis in the Broadkill River watershed indicates that the watershed experiences low 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 around 1,000-2,000 #/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 Broadkill 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 Broadkill 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 21 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 nearly 19 percent of the watershed area and are home to many species of plants and wildlife that produce organic, nutrient and bacteria wastes.

Approximately 41 percent of the Broadkill 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 3 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 13 percent of the Broadkill River watershed is urban or built-up.

Based on the land use data, the Broadkill River watershed is primarily non-urban (87%) and, therefore, NPSs are an important source of pollution in the watershed. There are four (4) active NPDES permitted PSs in the watershed that originate from food and poultry processing facilities and municipal WWTPs. Although there are a number of PSs in the watershed, NPSs are still a significant source of pollution in the watershed. There are no MS4 stormwater permits in the Broadkill River watershed and, therefore, urban nonpoint sources will not be assigned to MS4 areas.

SECTION 5

SCOPE AND OBJECTIVES OF THE TMDL ANALYSIS

DNREC has proposed TMDLs for nitrogen, phosphorous, DO and bacteria for the Broadkill River watershed. The proposed TMDLs are the result of various load reduction analyses, which were conducted using the Broadkill River Watershed Model as a predictive tool. The proposed TMDL is designed such that, when implemented, all segments of the Broadkill 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 Broadkill 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 Broadkill River (below the City of Milton), 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 Broadkill 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:

- Broadkill River Watershed TMDL Development, Data Analysis Technical Memorandum (HydroQual, 2004); and
- Broadkill River Watershed TMDL Model Development (HydroQual, 2005).

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

5.1 TOTAL MAXIMUM DAILY LOADS AND THEIR ALLOCATIONS

The calibrated and validated Broadkill 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 are three PS discharges on Ingrams Branch near Georgetown (Perdue and SAW Georgetown – 2 outfalls), one on Beaverdam Creek (Allen Family Foods) and one on the tidal portion of the Broadkill River (City of Milton). For the TMDL model runs, these PSs were assigned effluent characteristics reflective of their current NPDES permit and where specific parameters are not currently contained in the discharge permits, available monitoring data or best professional judgment was used to assign effluent characteristics. If necessary, modification to these effluent characteristics was necessary to attain water quality standards in stream reaches below the discharges. The final PS flows, concentrations and loads used are presented in Tables 3 and 4 and an overview of the effluent data, current permit limits and WLAs for all four PSs is presented in Appendix 5. It should be noted that the City of Lewes WWTP discharge load was included in the Broadkill River watershed model but the associated WLA is covered under the Inland Bays TMDL. In addition, the SAW Georgetown non-contact cooling water discharge was included as a load in the model but a WLA was not developed due to the intermittent nature of the discharge.

In the calibrated/validated watershed model, septic system loads were assigned a nutrient load that reflects failing systems. For the TMDL model runs, these septic system loads were removed to reflect properly operating septic systems (i.e., no system failures).

In order to address NPS loadings within the watershed, various load reduction scenarios were completed for 25%, 50%, 75% and 90% 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 Broadkill 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 Broadkill 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 at critical stream conditions (summer low-flow). 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 representative upstream geometry relationships (depth, velocity, width as a function of flow) to represent stream geometry at different flow rates. In addition, HSPF calculated total flow at the end of a river reach was uniformly distributed along the length of the tributary under consideration. A CBOD and NH_3 decay rate of 1-2/day at 20°C was used along with a SOD of 1 $g/m^2/d$ 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 25-30°C based on measured data. An initial DO deficit of 1-3 mg/L and $TBOD_u$ of 5-10 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 NH_3 loads during the summer months of June through October (2002 and 2003) were obtained from the calibrated HSPF 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 Ingrams Branch, Round Pole Branch, Beaverdam Creek, Martin Branch and Waples/Reynolds Pond. Since the stream flows during the summer of 2002 were at or below 7Q10 low flow conditions, the minimum calculated stream flow in 2002 was used to assess whether the NPS load reductions and assigned PS loads improved DO levels to meet the standard of 5.5 mg/L. This was accomplished by reducing the headwaters $TBOD_u$ and stream SOD by 40%, assigning a 0-1 mg/L upstream DO deficit and by removing the NPS $TBOD_u$ load since runoff at 7Q10 low flow conditions does not occur or is minimal. It should be 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 assessed 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 ten (10) freshwater 303(d) listed segments (Appendix 1) and the three (3) tidal 303(d) listed segments (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 condition are also presented in this figure. For *enterococcus*, the current and TMDL model output are presented as probability distributions. 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, the model projection of monthly average concentrations was compared to the target values 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.

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 in the same format as the freshwater reaches. For nutrients, the model projection of monthly average concentrations was compared to the target values 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) load reduction scenarios completed (25%, 50%, 75% and 90% NPS load reductions), a final 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% 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 NH_3 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. In addition, the marsh loading of organic carbon and its contribution to SOD was reduced by 35% in the TMDL model runs that also contributed to

DO improvements in the tidal reach of the river. This reduced organic carbon load represents potential SOD reductions that may occur as a result of NPS controls in the watershed.

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 PS discharge conditions (Table 3) and 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 1 highlights the sub-watersheds used in Table 6. Appendix 3 presents a summary of the baseline (calibration/validation 2002/2003) loads for nitrogen, phosphorus and *enterococcus*. These load reduction scenarios are meant as a guide in improving water quality in the Broadkill 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.

Table 3. Broadkill River NPDES WLA (Concentrations)

Facility	SAW Georgetown	Perdue Georgetown	Allen Family Foods	City of Milton
NPDES #	0000141	0000469	0000299	0021491
Outfall #	001	002	001	001
Effluent Type	Vegetable processing facility	Poultry Processing Operation	Poultry Processing Operation	Municipal STP
Flow (MGD)	0.33	2.00	1.25	0.35
BOD_5 (mg/L)	10.0	10.0	10.0	15.0
NH_3 (mg/L)	1.0	1.0	1.0	1.0
TN (mg/L)	7.0	7.0	7.0	12.5
TP (mg/L)	0.5	0.5	0.5	4.5
Enterococcus (#/100mL)	100	100	100	33

Table 4. Broadkill River NPDES WLA (Loads)				
Facility	**SAW 001 Georgetown**	**Perdue Georgetown**	**Allen Family Foods**	**City of Milton**
BOD_5 (lb/d)	27.5	166.8	104.3	43.8
NH_3 (lb/d)	2.75	16.7	10.4	2.92
TN (lb/d)	19.3	116.8	73.0	36.5
TP (lb/d)	1.38	8.34	5.21	13.1
Enterococcus (#/d)	1.25e+09	7.57e+09	4.73e+09	4.37e+08

Table 5. Proposed TMDLs for the Broadkill River Watershed			
Parameter	**WLA**	**LA**	**TMDL**
TN (lb/d)	245.6	2224.2	2469.8
TP (lb/d)	28.0	94.7	122.7
Enterococcus (#/d)	1.4e+10	1.0e11	1.1e11

6.1 CONSIDERATION OF THE IMPACT OF BACKGROUND POLLUTANTS

The Broadkill 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. A sensitivity analysis of three major nutrient and carbon sources (NPSs, downstream connection to Delaware River/Bay and marsh contribution of organic matter) was completed to assess the range of impact of each source in the Broadkill River watershed. The Delaware River/Bay impacts DO and nutrient levels in the estuary from the mouth of the Broadkill River to approximately 2.25 miles upstream and as far upstream as the Route 1 Bridge during times of low flow. The largest effects occur in the lower portion of the river near the mouth. Marshes have an influence on the instream DO and nutrient levels from the river mouth to the Route 1 Bridge and influence DO as much as 10

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

Parameter	Urban	Agriculture	Pasture	Forest	Total
Primehook Branch					
Area (acres)	1,679	9,267	235	3,642	14,823
TN (lb/d)	112.4	371.0	16.1	72.9	572.4
TP (lb/d)	3.20	20.28	6.92	0.46	30.86
Enterococcus (#/d)	8.9E+09	9.1E+09	1.6E+09	2.4E+09	2.2E+10
Ingram/Pemberton Branch					
Area (acres)	1,593	4,955	838	5,101	12,487
TN (lb/d)	121.0	224.3	63.8	103.5	512.6
TP (lb/d)	3.14	12.51	2.28	0.69	18.62
Enterococcus (#/d)	6.9E+09	5.8E+09	6.6E+09	3.9E+09	2.3E+10
Round Pole Branch					
Area (acres)	526	2,550	339	1,441	4,856
TN (lb/d)	34.7	102.7	23.4	28.9	189.6
TP (lb/d)	0.99	5.61	0.83	0.18	7.61
Enterococcus (#/d)	2.9E+09	2.5E+09	2.4E+09	9.6E+08	8.7E+09
Beaverdam Creek					
Area (acres)	803	2,881	192	1,516	5,392
TN (lb/d)	50.9	121.2	13.8	30.5	216.5
TP (lb/d)	1.45	6.68	0.49	0.20	8.81
Enterococcus (#/d)	4.8E+09	3.1E+09	1.4E+09	1.1E+09	1.0E+10
Old Mill Creek					
Area (acres)	3,694	4,502	180	1,292	9,668
TN (lb/d)	266.2	200.3	13.5	26.1	506.1
TP (lb/d)	7.38	11.15	0.48	0.17	19.19
Enterococcus (#/d)	2.1E+10	5.2E+09	1.4E+09	9.8E+08	2.9E+10
Broadkill River					
Area (acres)	1,307	3,838	145	1,565	6,855
TN (lb/d)	58.3	128.8	8.4	31.5	227.0
TP (lb/d)	2.21	6.87	0.29	0.20	9.58
Enterococcus (#/d)	6.5E+09	2.9E+09	8.2E+08	8.5E+08	1.1E+10

miles upstream in low flow conditions. The largest effects occur in the middle of the river below the Route 1 Bridge to approximately 2 miles above the mouth. The NPSs affect DO and nutrient levels from 2 miles above the mouth with a generally increasing influence moving upstream (until dominating the nontidal portion of the river). These three sources are the major causes of varying levels of background pollutants throughout the watershed and each source impacts the model differently according to location.

6.2 CONSIDERATION OF CRITICAL ENVIRONMENTAL CONDITIONS

Low river flows during summer months coupled with high water temperatures represent critical conditions for PSs and also for nutrient related algal growth and DO assessments. High flow or wet weather conditions are also important for assessing NPSs. The calibration year 2002 was a very dry year compared with the wetter year of 2003. Therefore, the dry and wet weather conditions in the Broadkill River watershed are included in the analysis.

6.3 CONSIDERATION OF SEASONAL VARIATIONS

Seasonal variations are considered in the Broadkill 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.

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 Broadkill River TMDL analysis.

The Broadkill 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 Broadkill 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. In the case of point sources, the WLAs were assigned as constant loads for the TMDL scenarios at the proposed maximum effluent permit limits. Typical operating conditions at WWTPs are to not exceed permit limits and, therefore, discharge loadings are generally less than the effluent permit limits. Therefore, actual point source loadings will be less than the required permit limits as considered in the analysis. This will add an additional implicit margin of safety to this TMDL analysis.

It was also assumed that the load reductions required are to be achieved by solely altering practices within the Broadkill 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 point 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 Broadkill 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 Broadkill River watershed model has limitations to go along with its capabilities. In the upstream nontidal reaches, the HSPF 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. Moreover, HSPF is a lumped parameter and landuse generalized model that is calibrated for whole watershed analyses and, therefore, HSPF'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 Broadkill 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 HSPF model and is, therefore, influenced by the same factors that limit HSPF. 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 Broadkill 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 Broadkill 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 Broadkill River watershed were reviewed during a public workshop held on 16 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, 3.2, 4.0, 4.2, 5.1, 6.1, 6.4 and 6.5 and Appendices 3, 4 and 5) and CABE Associates, Inc. (Sections 3.2, 5.1 and 6.1 and Appendices 3 and 5). Considering these opportunities, it can be concluded there has been adequate opportunity for public participation.

SECTION 7

REFERENCES

HydroQual, Inc., 2004. Broadkill River Watershed TMDL Development, Data Analysis Technical Memorandum (April 23, 2004). Submitted to the Delaware Department of Natural Resources and Environmental Control.

HydroQual, Inc., 2005. Broadkill River Watershed TMDL Model Development (June, 2005). Submitted to the Delaware Department of Natural Resources and Environmental Control.

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)

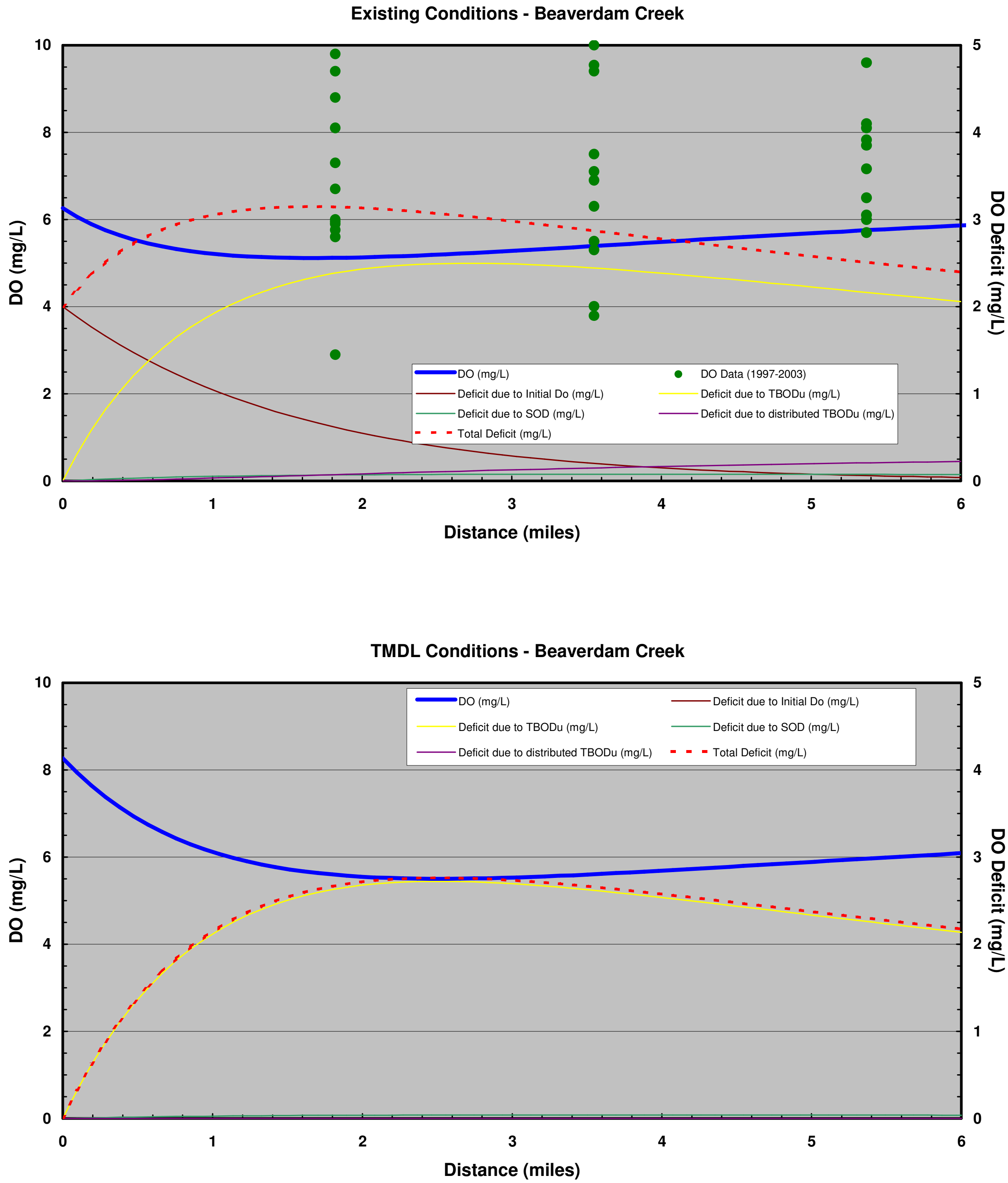
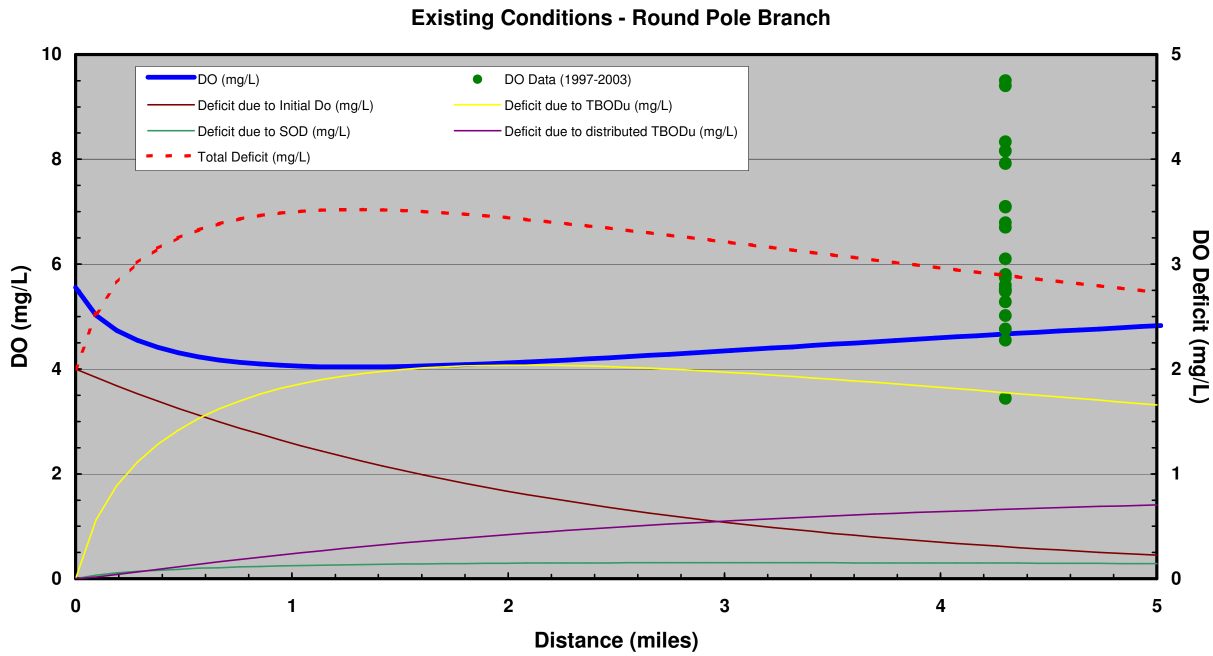


Figure A1. Non-Tidal Beaverdam Creek



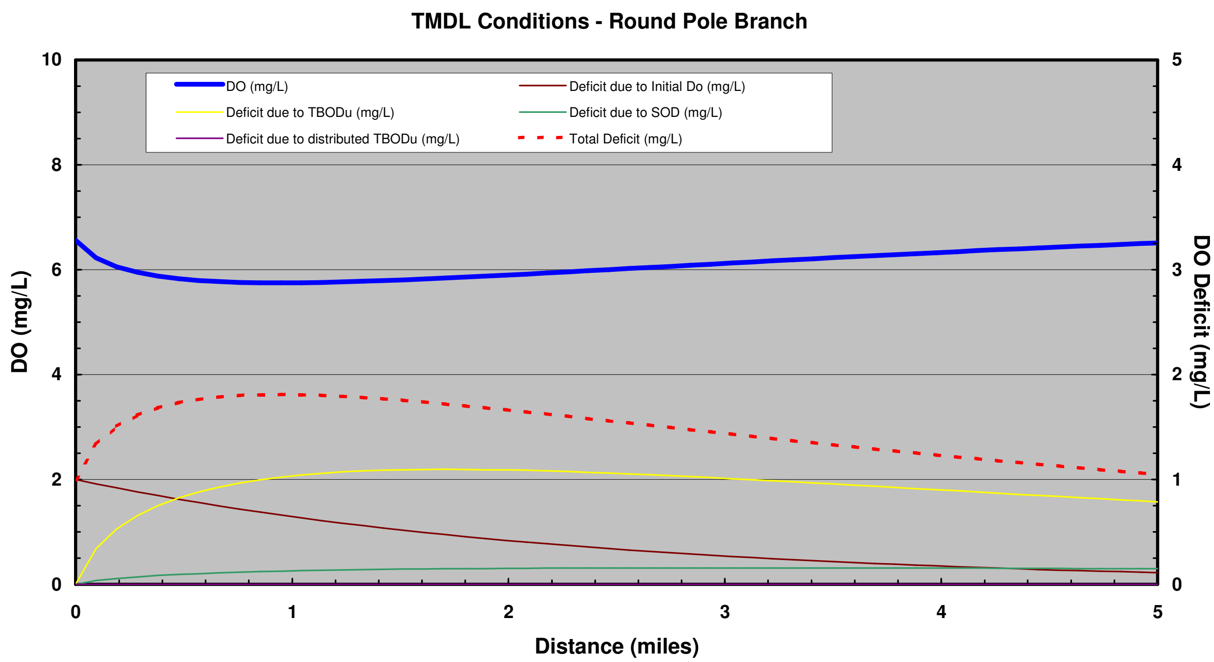
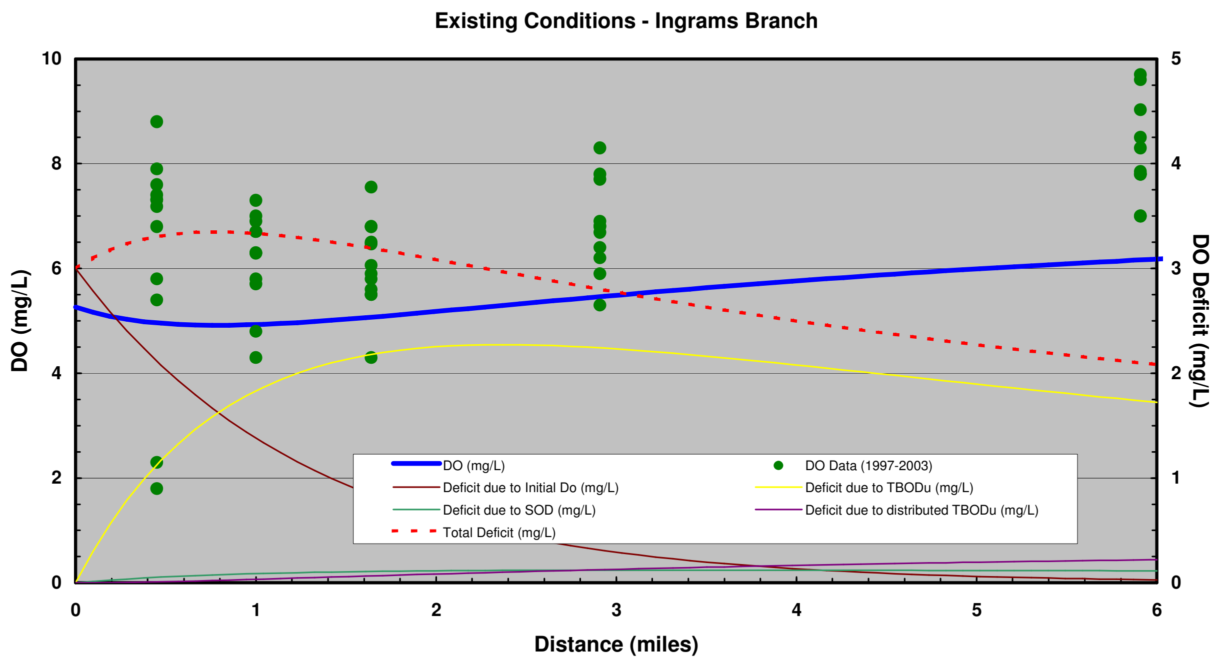


Figure A2. Non-Tidal Round Pole Branch



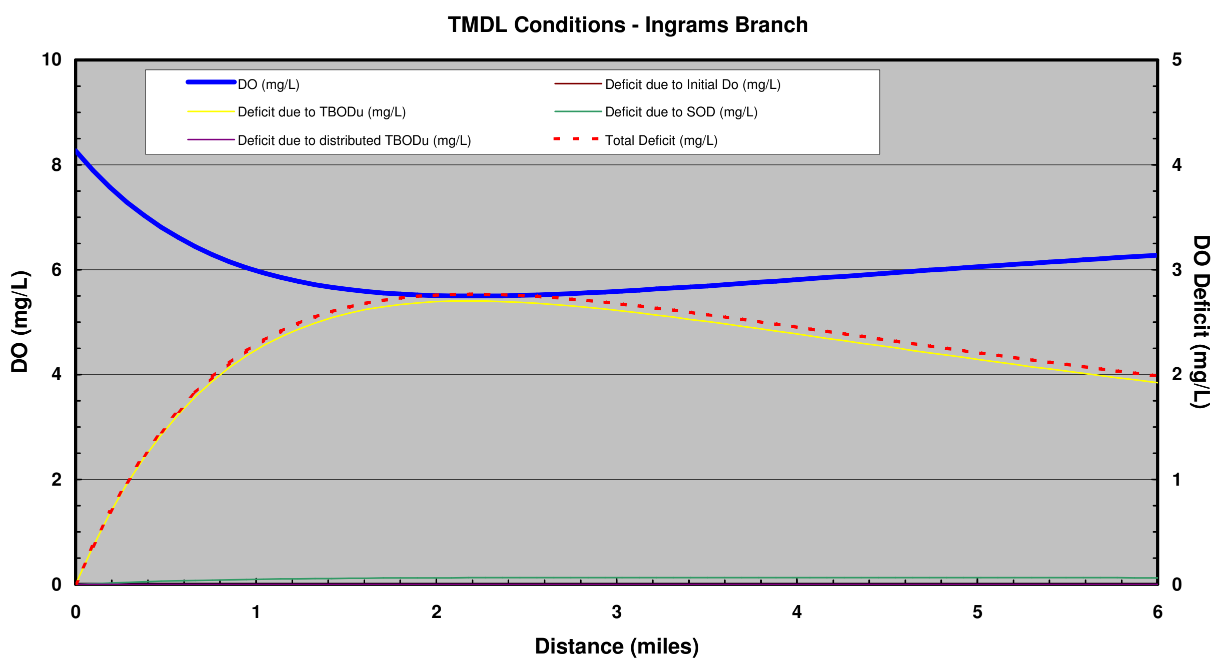
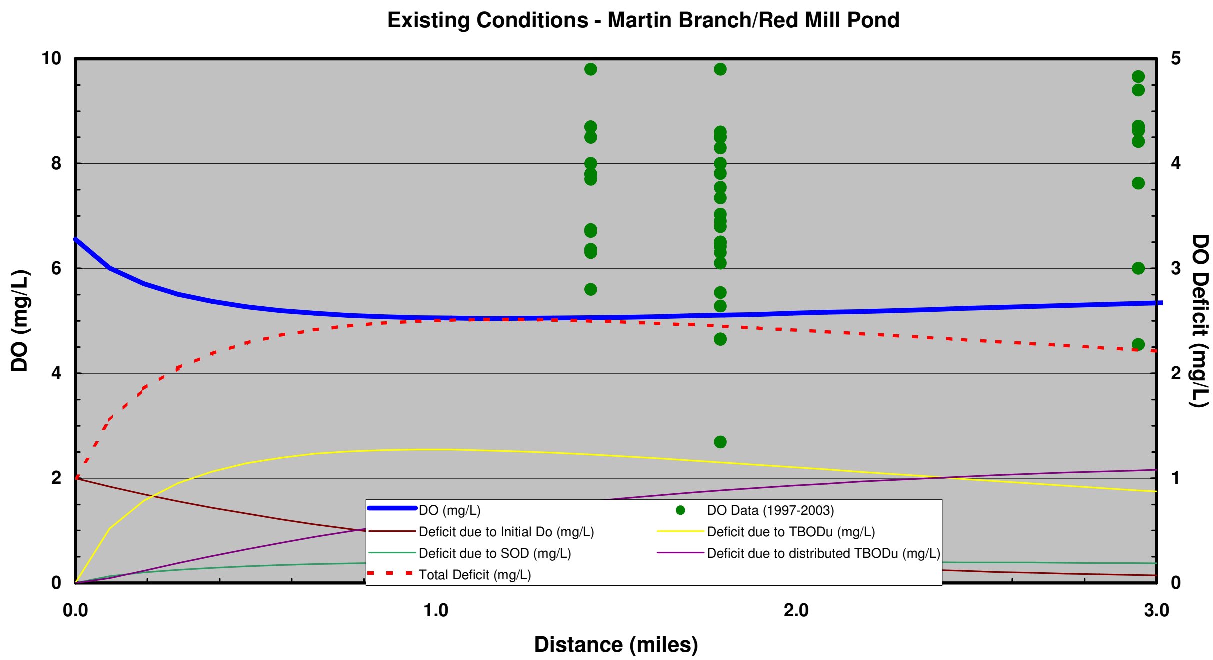


Figure A3. Non-Tidal Ingrams Branch



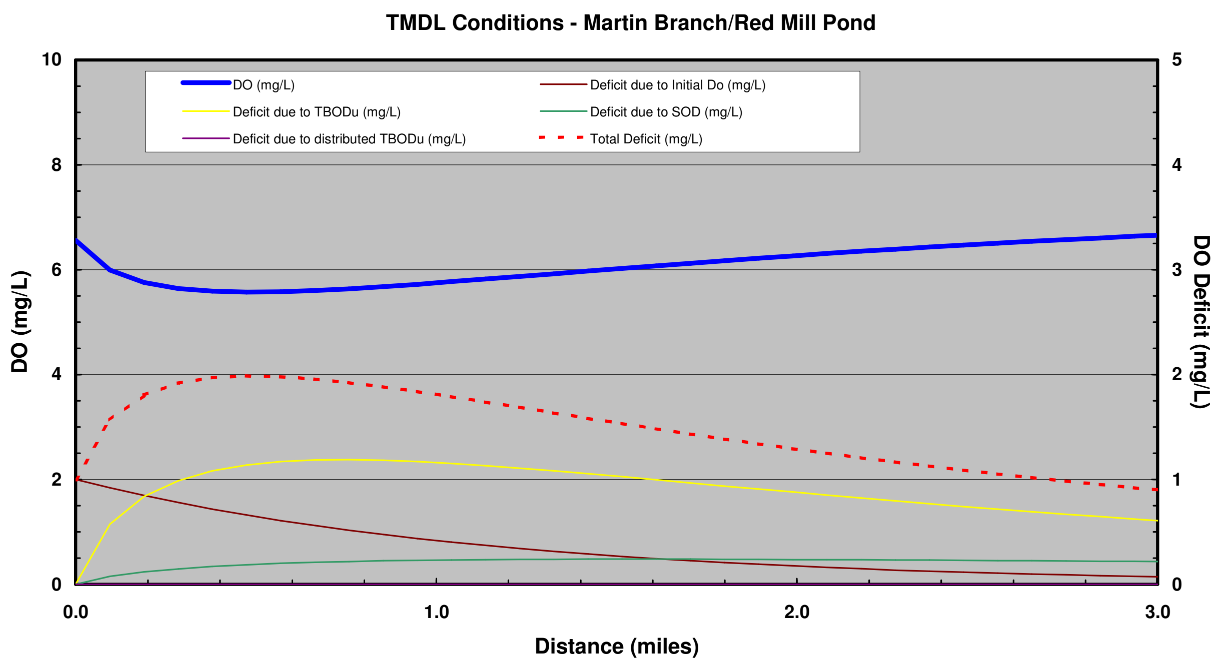
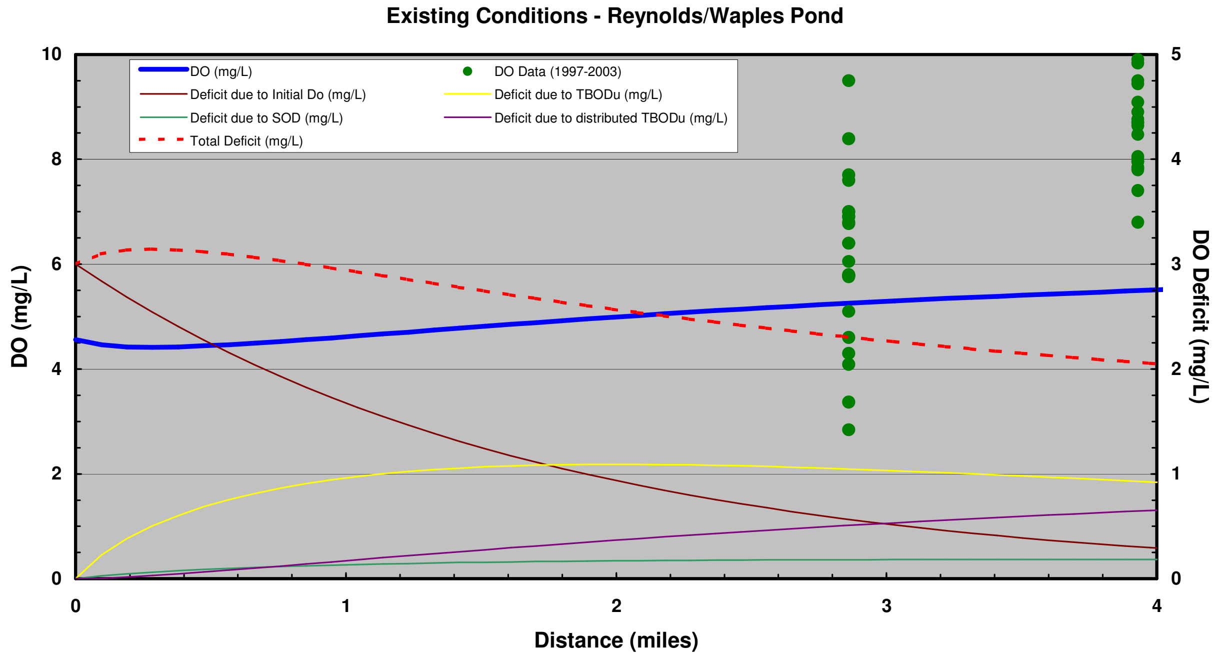


Figure A4. Non-Tidal Martin Branch/Red Mill Pond



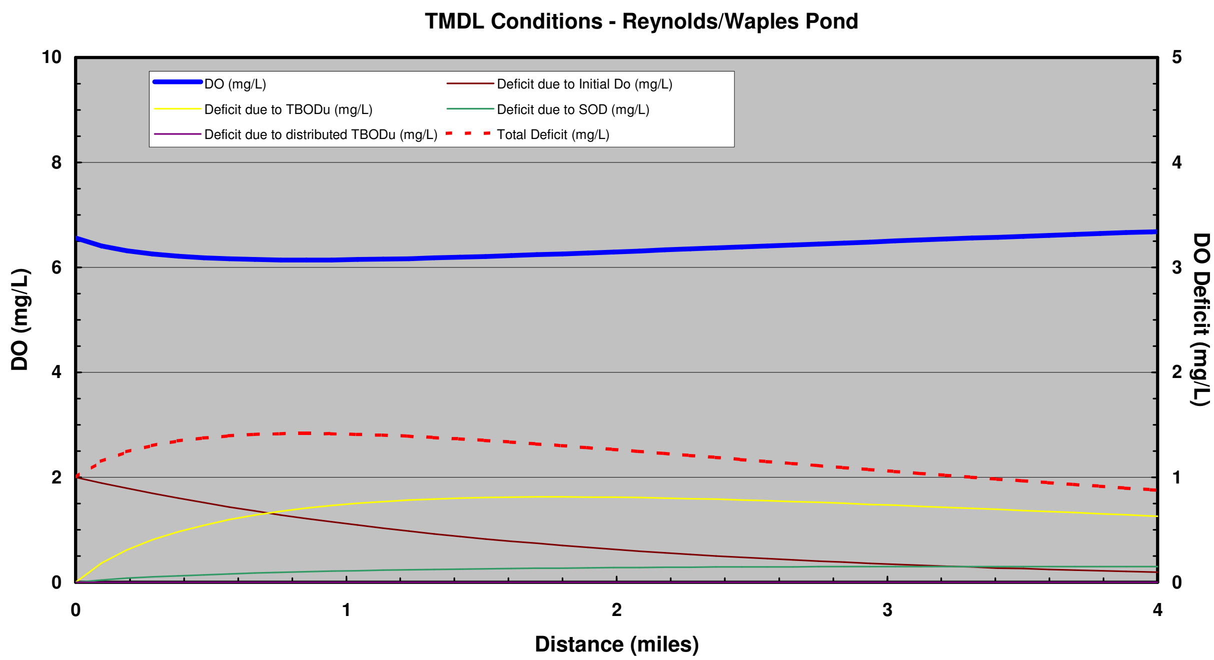


Figure A5. Non-Tidal Reynolds/Waples Pond

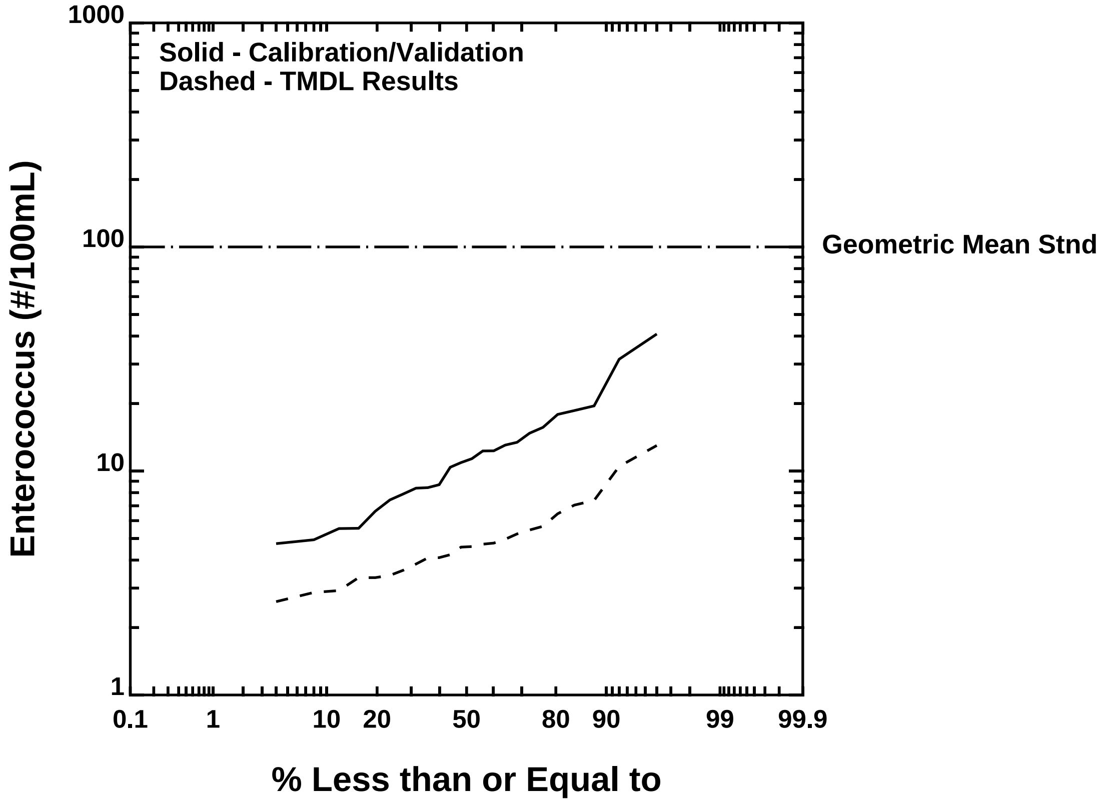


Figure A6. Broadkill River (Non-Tidal) - Beaverdam Creek (DE060-002) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 52)

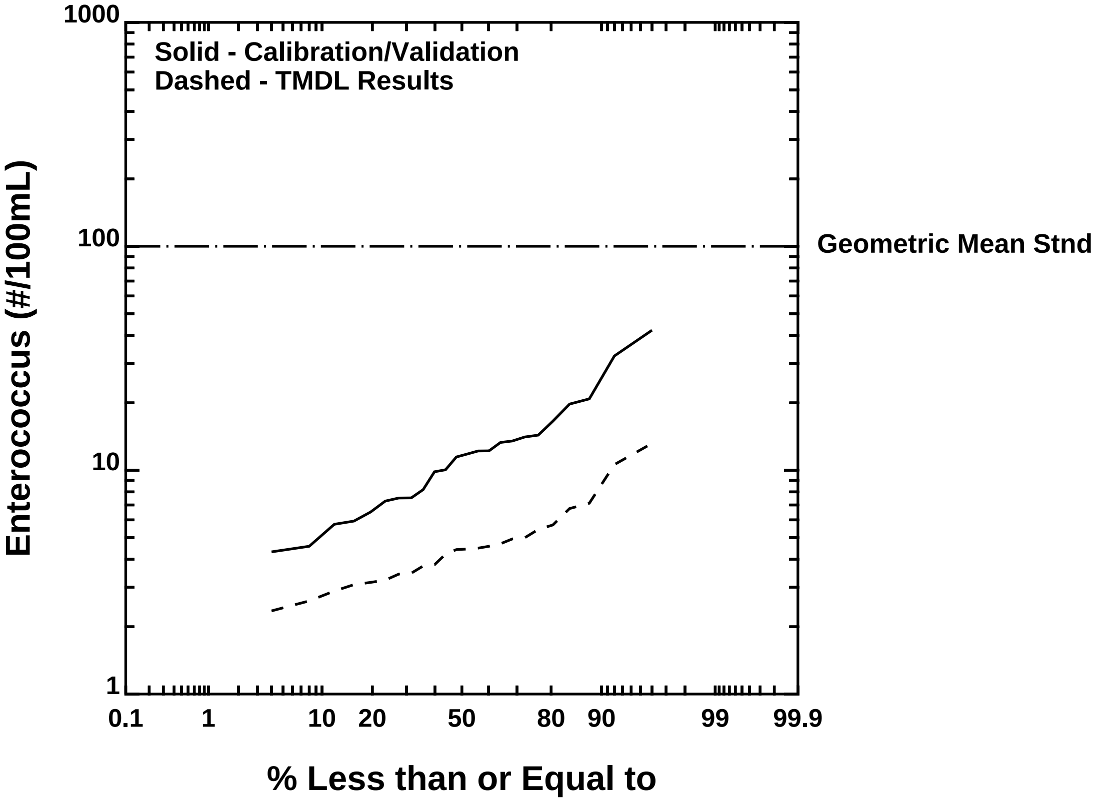


Figure A7. Broadkill River (Non-Tidal) - Round Pole Branch (DE060-004) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 61)

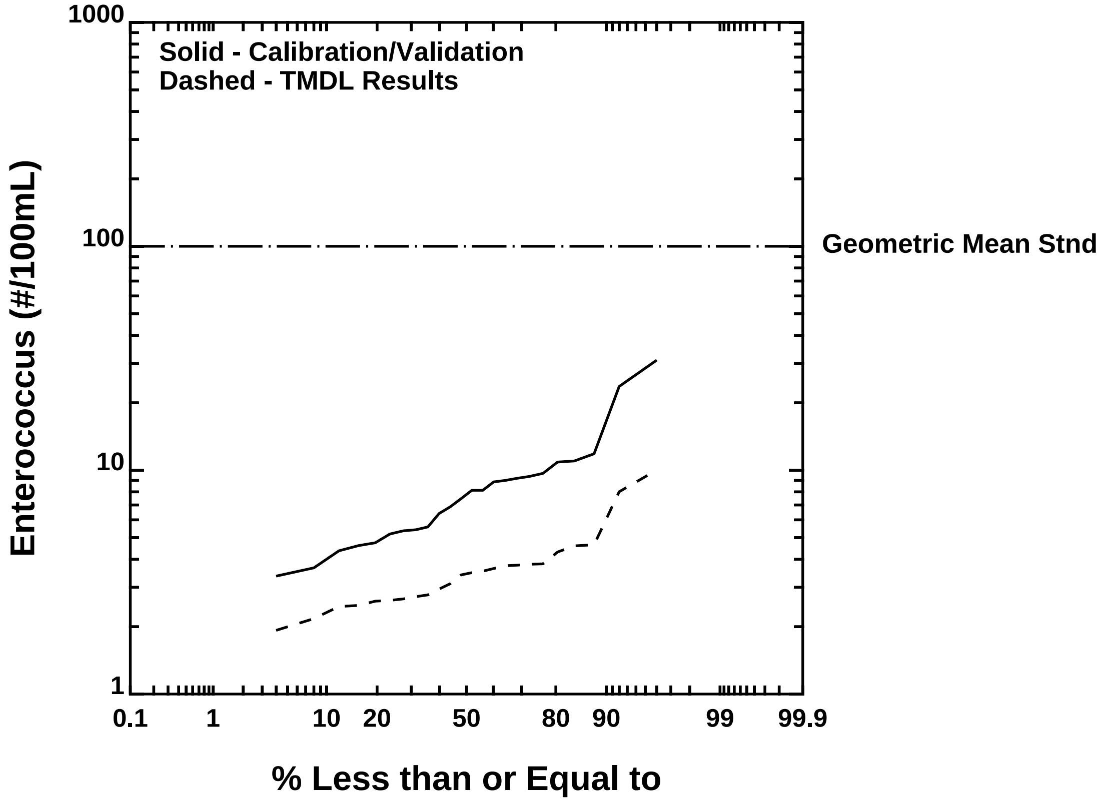


Figure A8. Broadkill River (Non-Tidal) - Ingrams Branch (DE060-005) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 67)

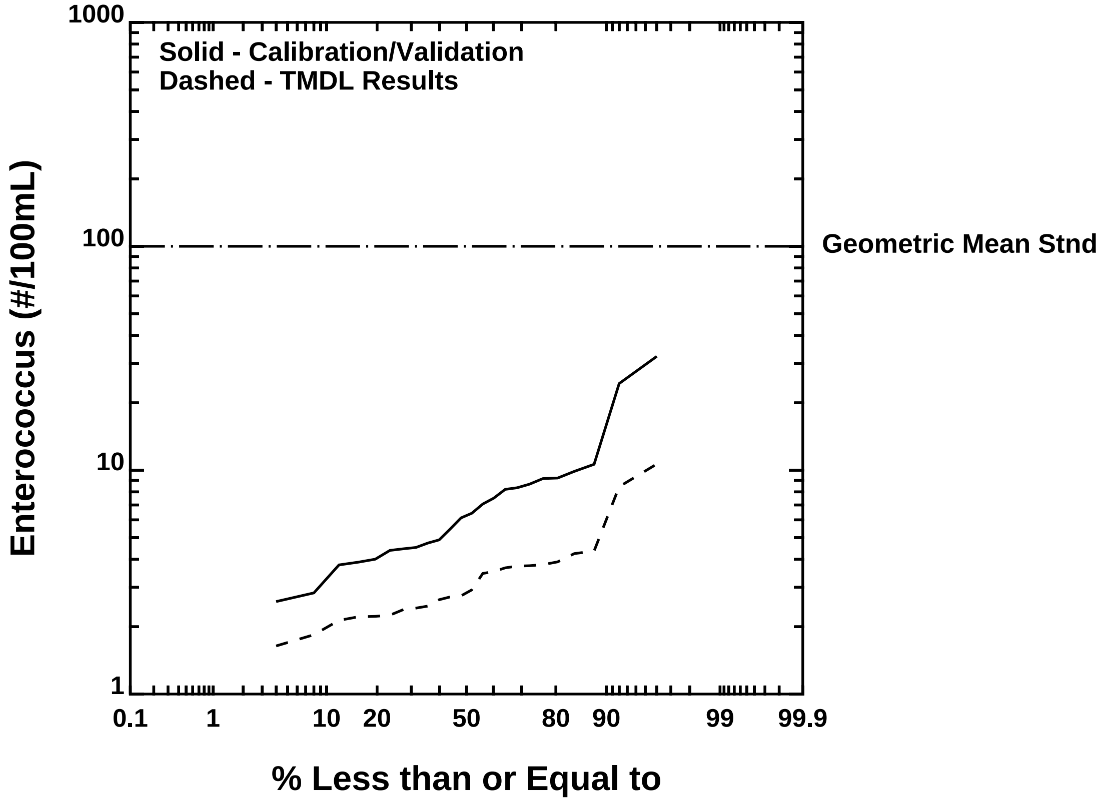


Figure A9. Broadkill River (Non-Tidal) - Pemberton Branch (DE060-006) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 65)

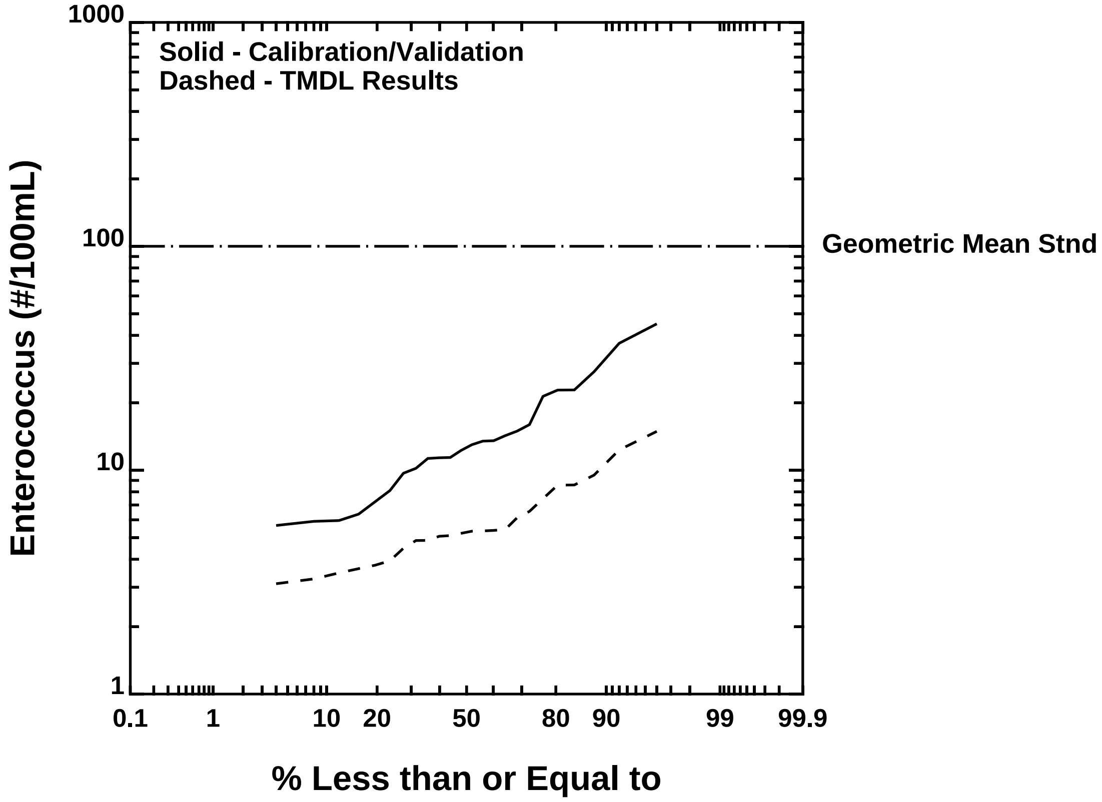


Figure A10. Broadkill River (Non-Tidal) - Martin Branch (DE060-007-02) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 73)

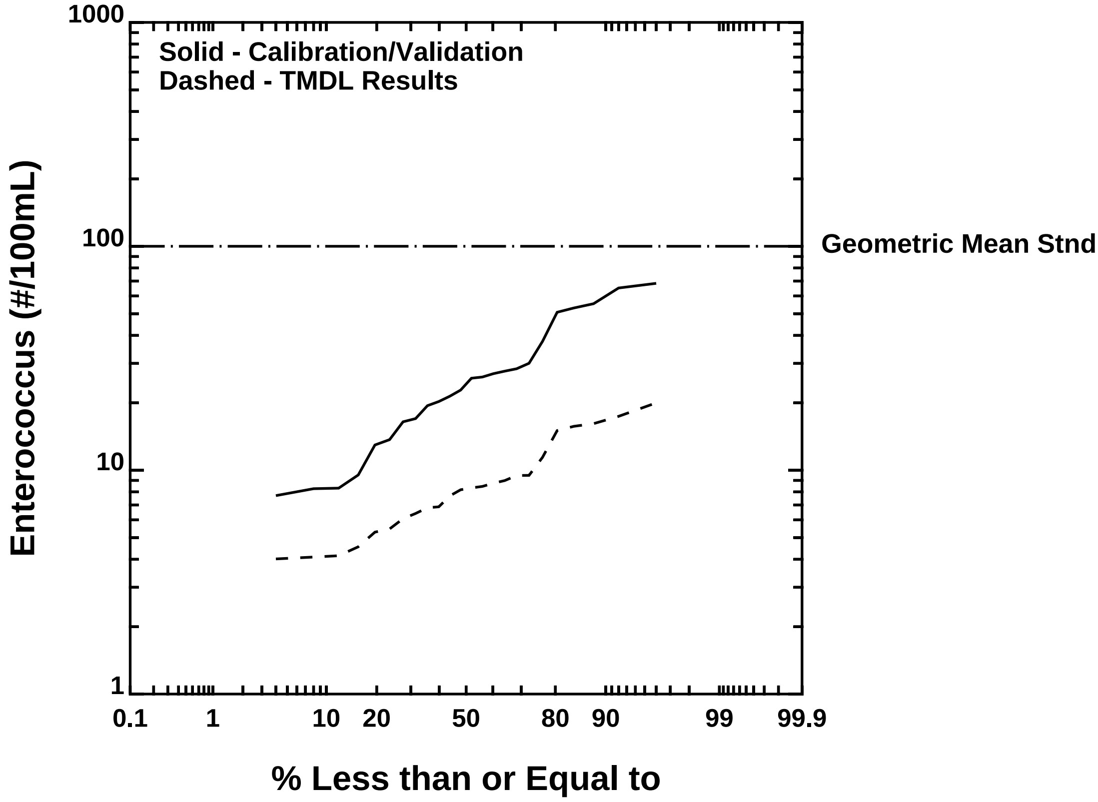


Figure A11. Broadkill River (Non-Tidal) - Red Mill Pond (DE060-L01) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 68)

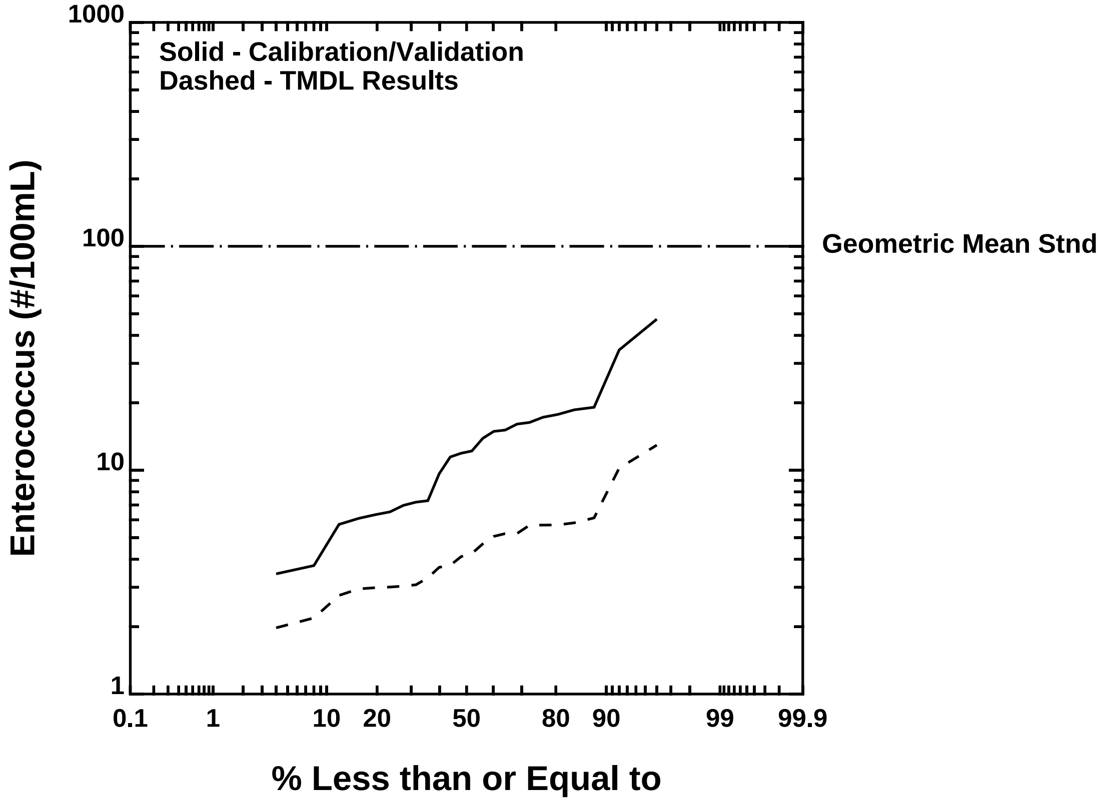


Figure A12. Broadkill River (Non-Tidal) - Waggamons Ponds (DE060-L02) Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 60)

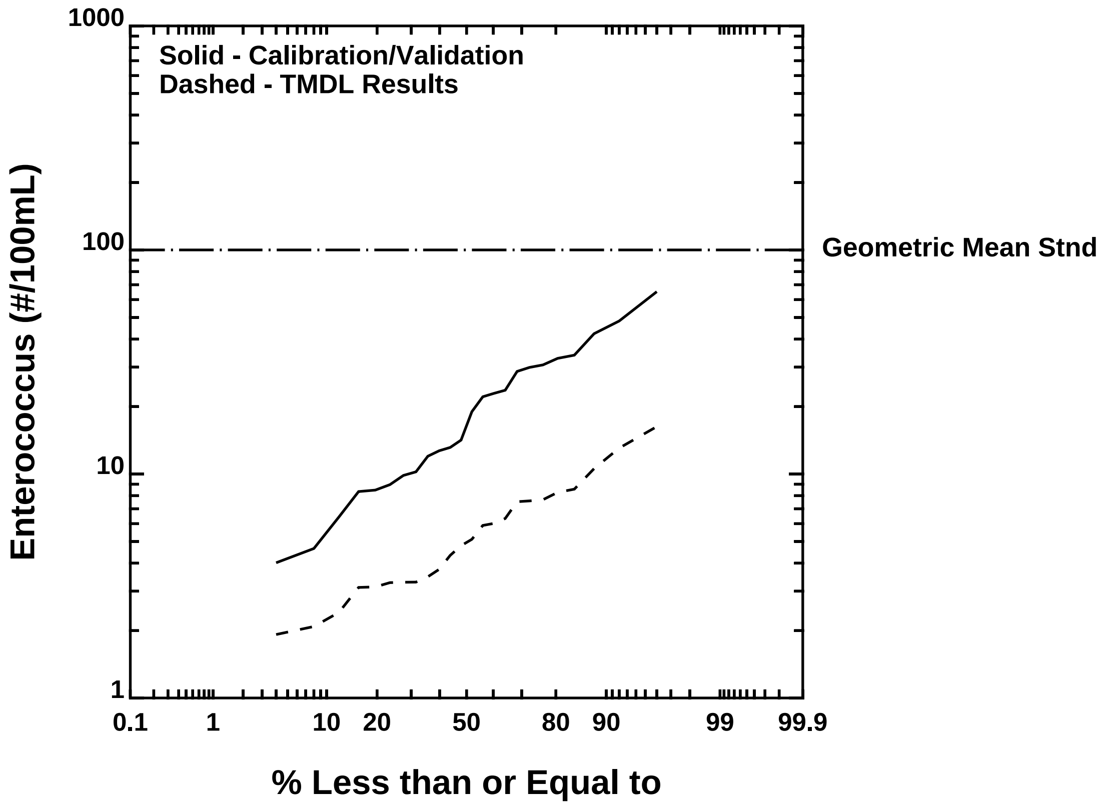


**Figure A13. Broadkill River (Non-Tidal) - Waples & Reynolds Ponds (DE060-L
Enterococcus TMDL Results (2002-2003)**

(Calibration Run 05, TMDL Run 13, HSPF Segment 88)

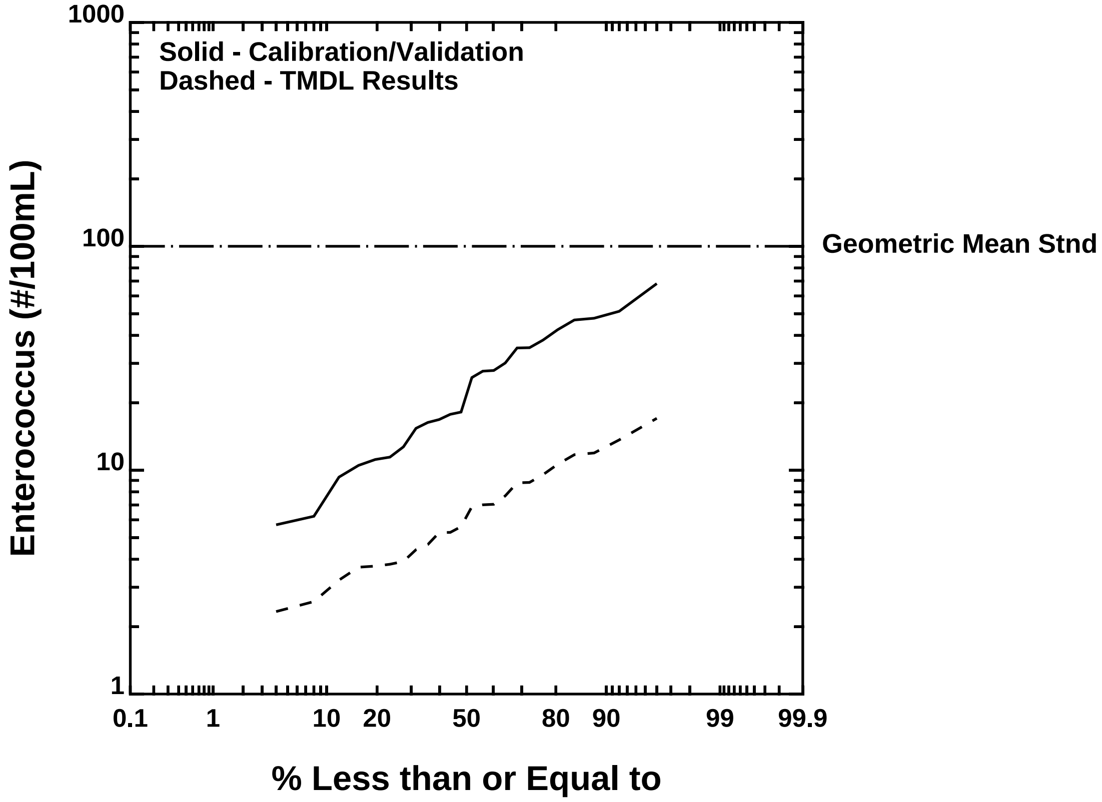


Figure A14. Broadkill River (Non-Tidal) - Waples & Reynolds Ponds (DE060-L Enterococcus TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 41)

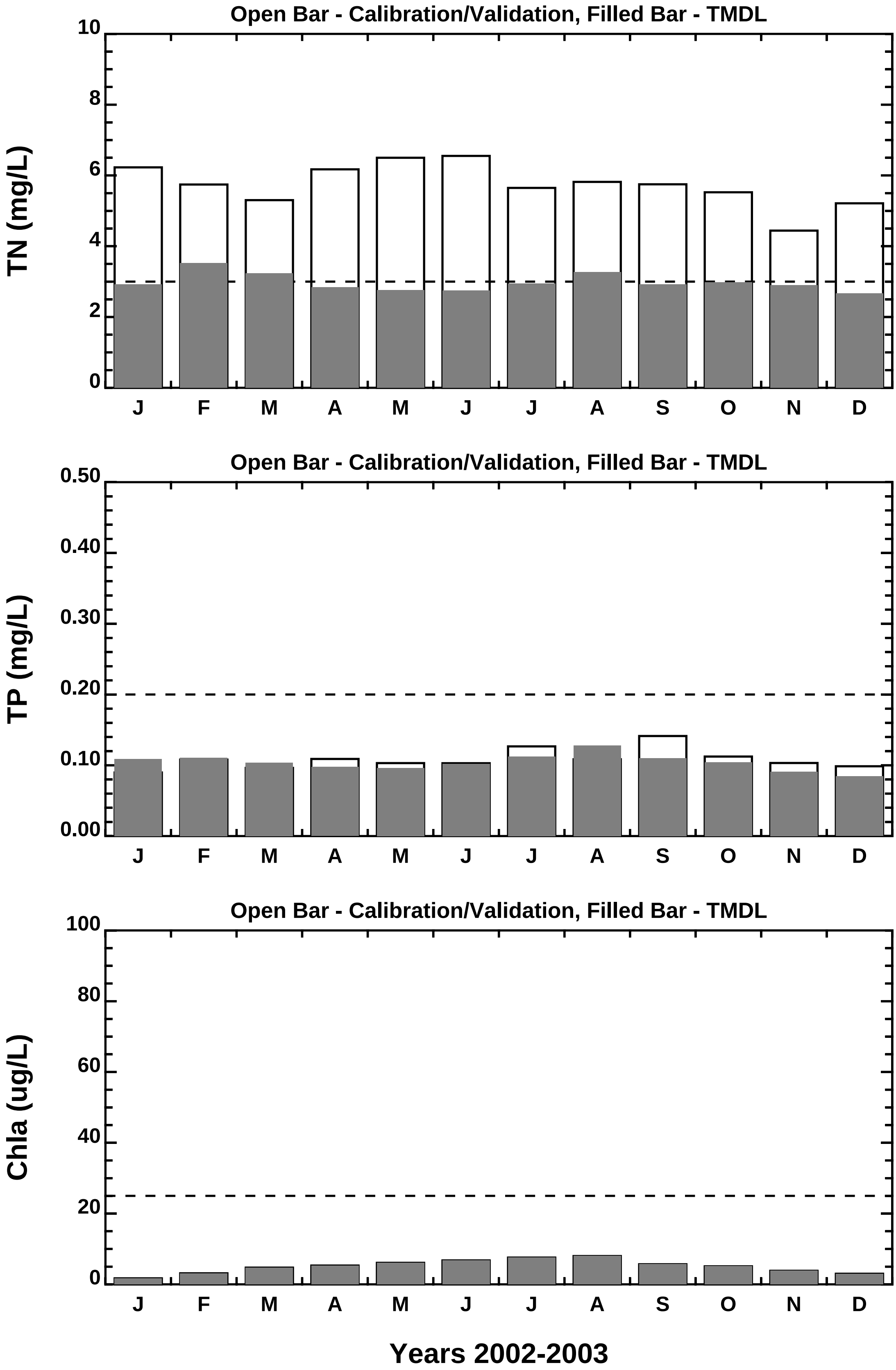


Figure A15. Broadkill River (Non-Tidal) - Beaverdam Creek (DE060-002) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 52)

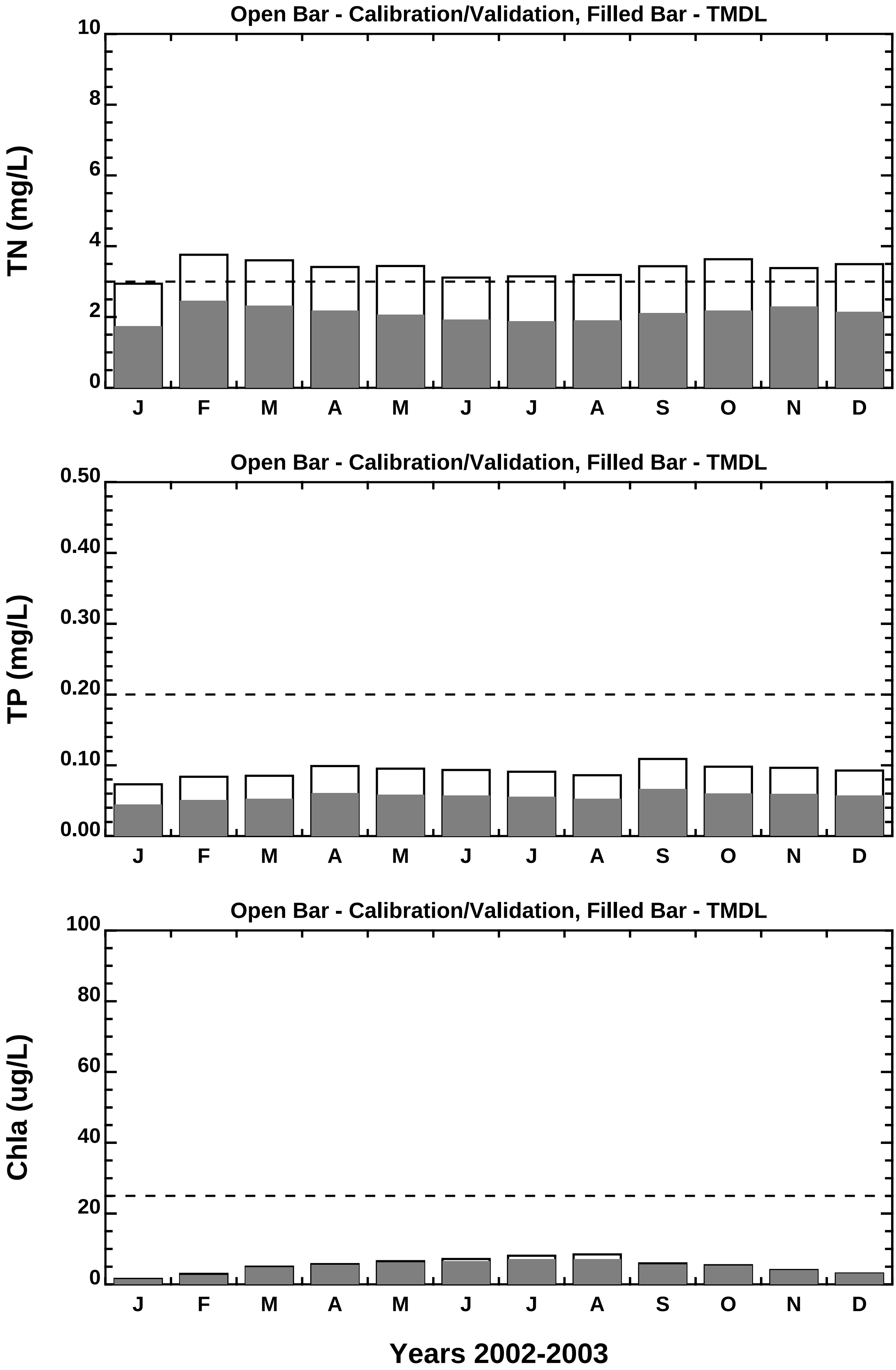


Figure A16. Broadkill River (Non-Tidal) - Round Pole Branch (DE060-004) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 61)

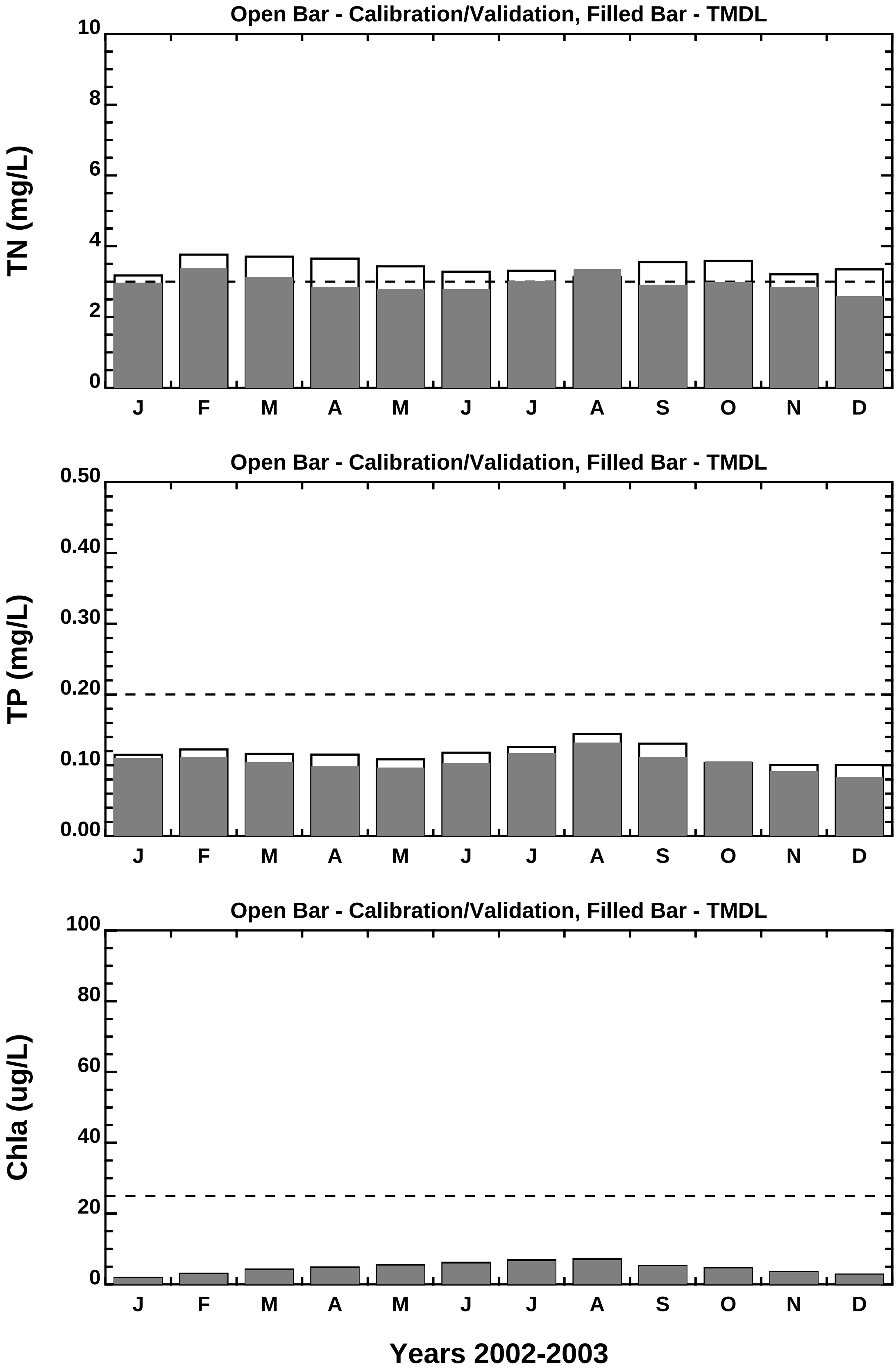


Figure A17. Broadkill River (Non-Tidal) - Ingrams Branch (DE060-005) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 67)

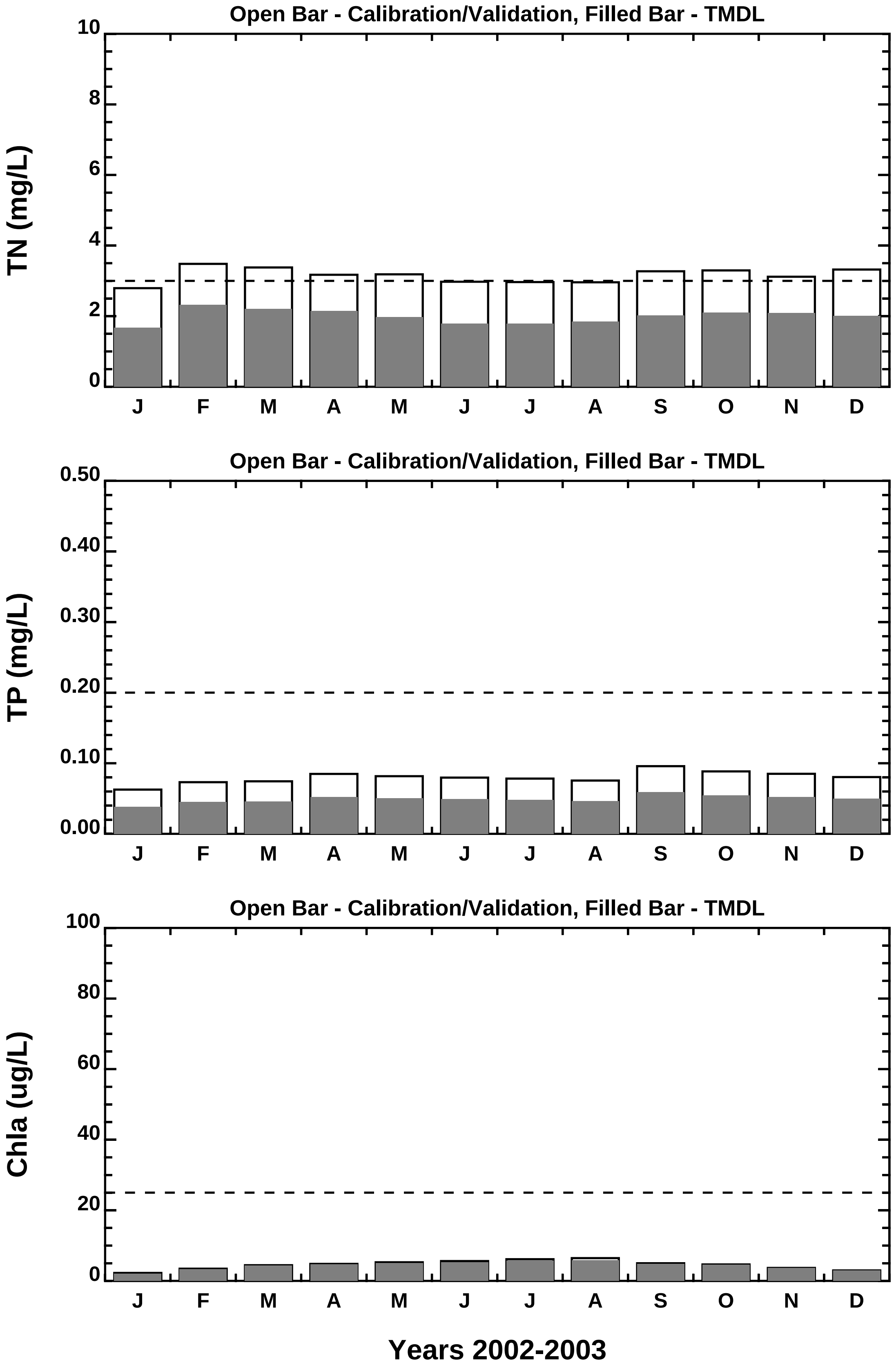


Figure A18. Broadkill River (Non-Tidal) - Pemberton Branch (DE060-006) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 65)

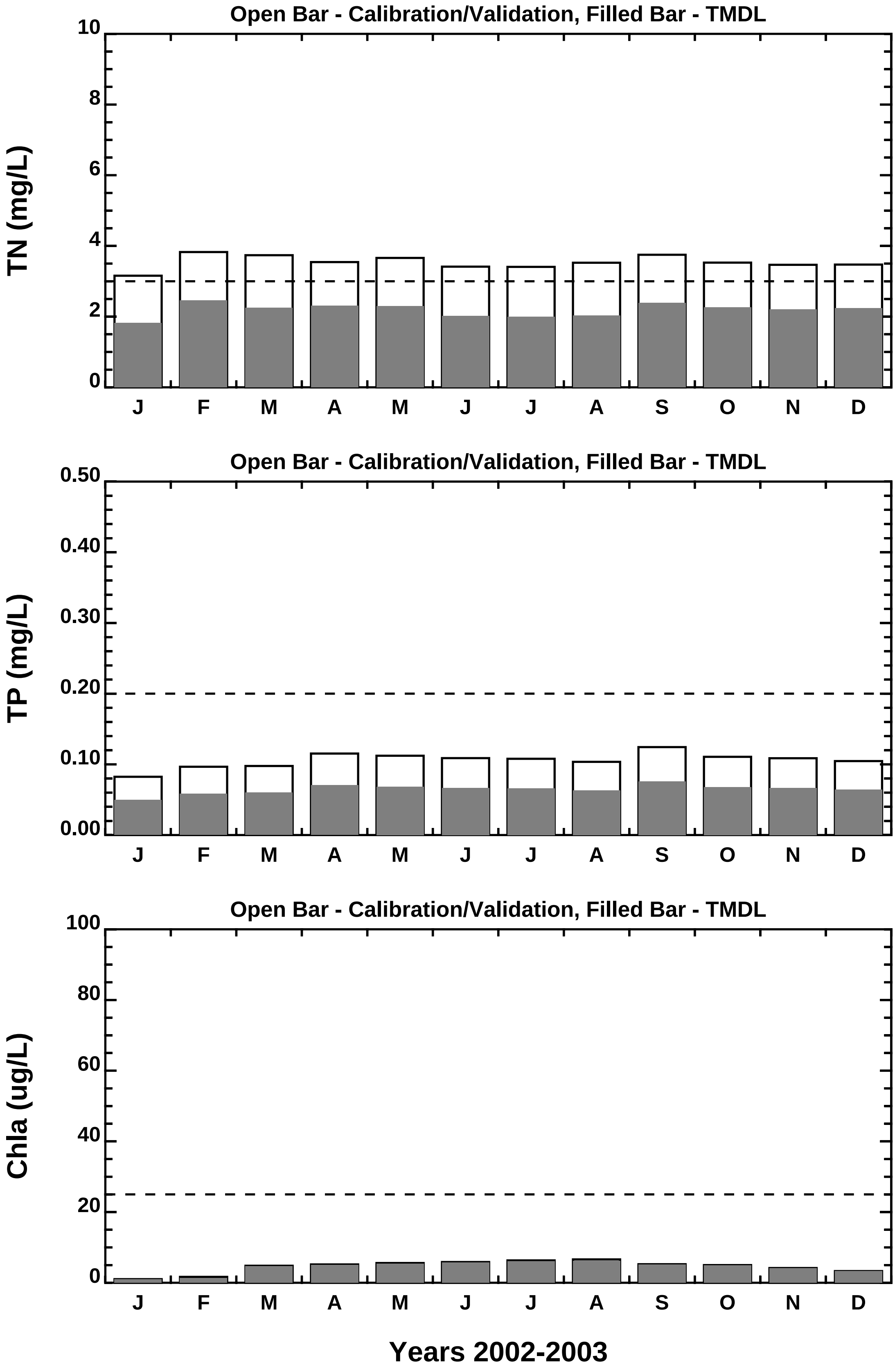


Figure A19. Broadkill River (Non-Tidal) - Martin Branch (DE060-007-02) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 73)

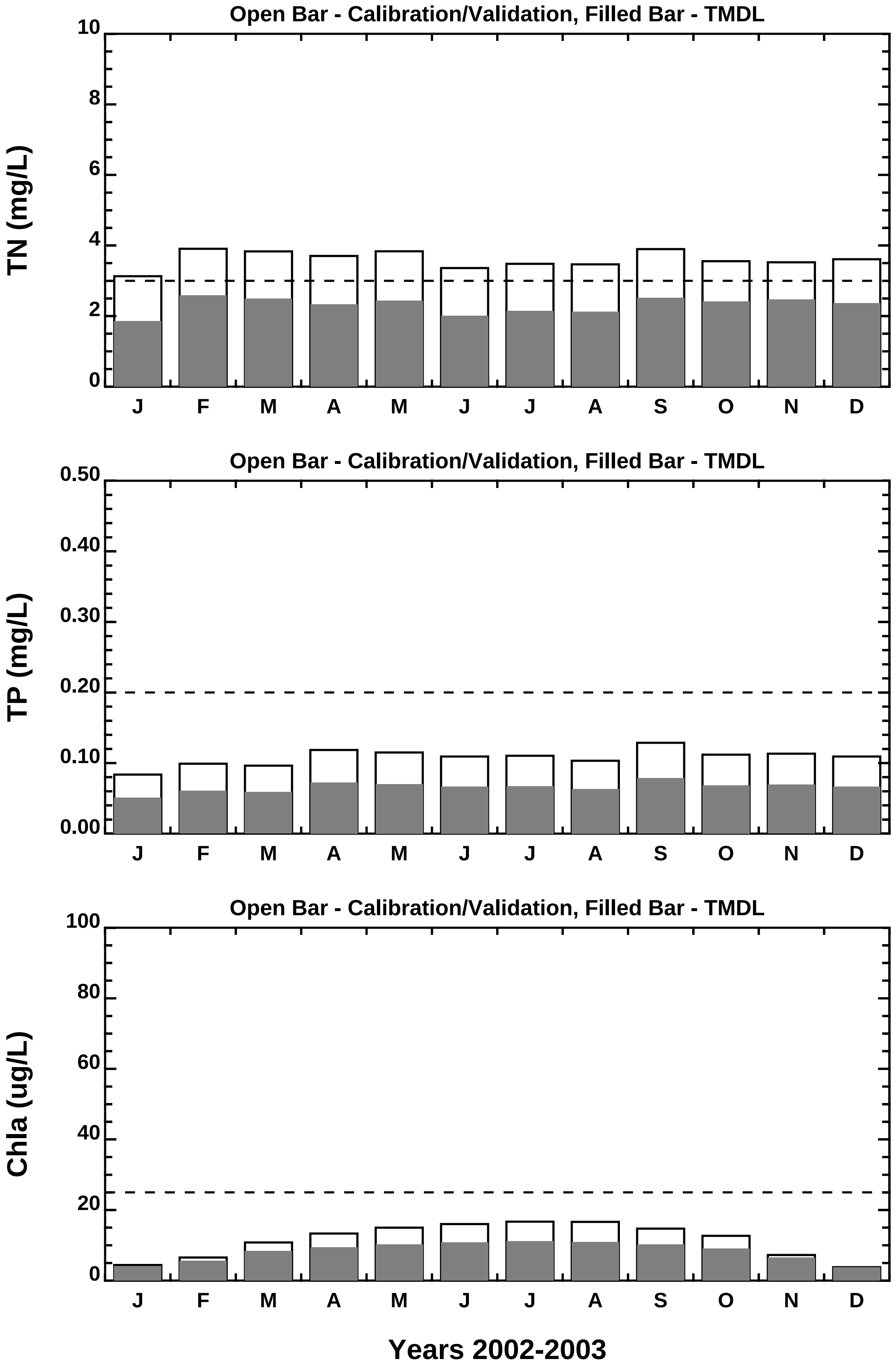


Figure A20. Broadkill River (Non-Tidal) - Red Mill Pond (DE060-L01) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 68)

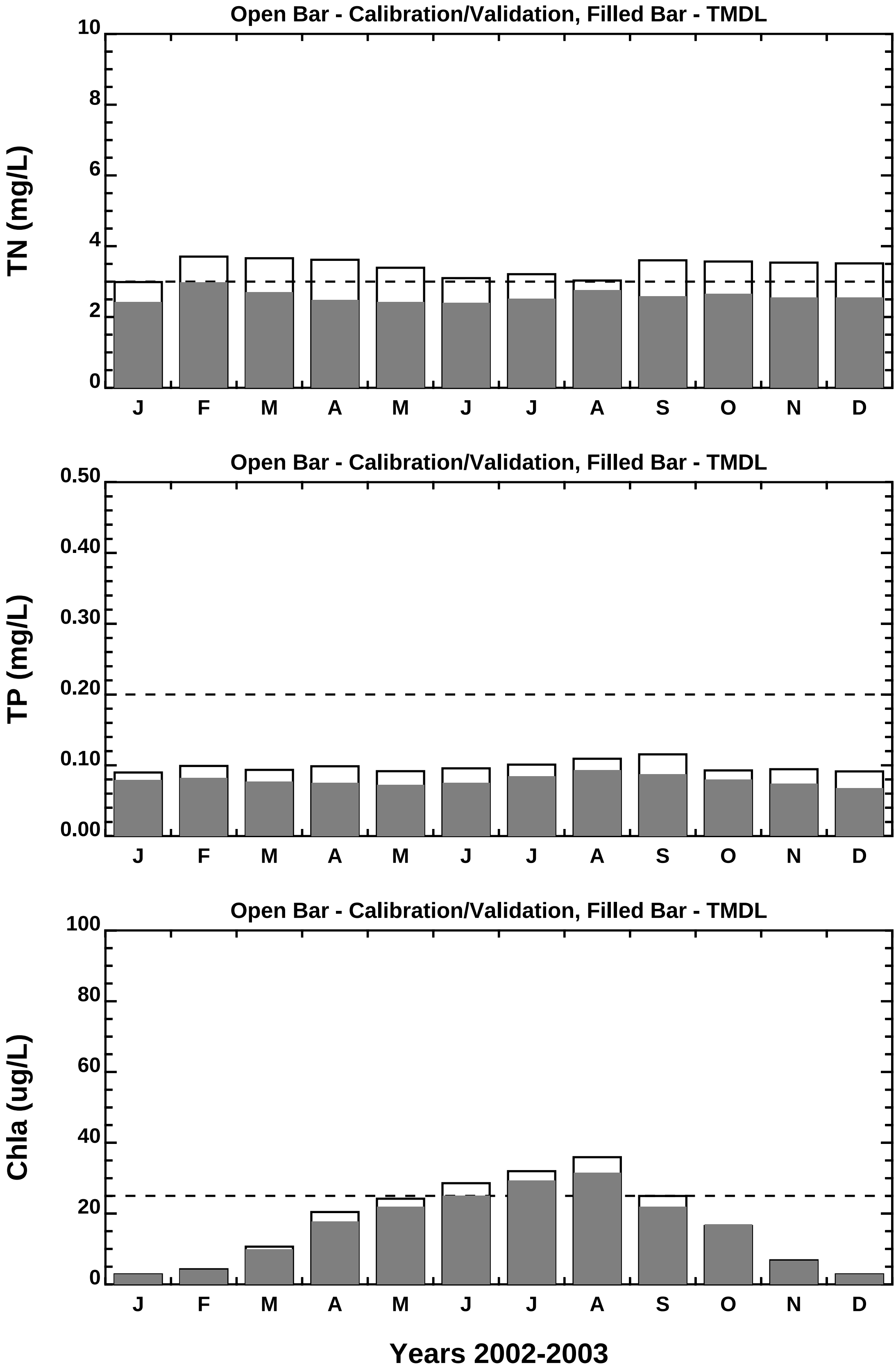


Figure A21. Broadkill River (Non-Tidal) - Waggamons Ponds (DE060-L02) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 60)

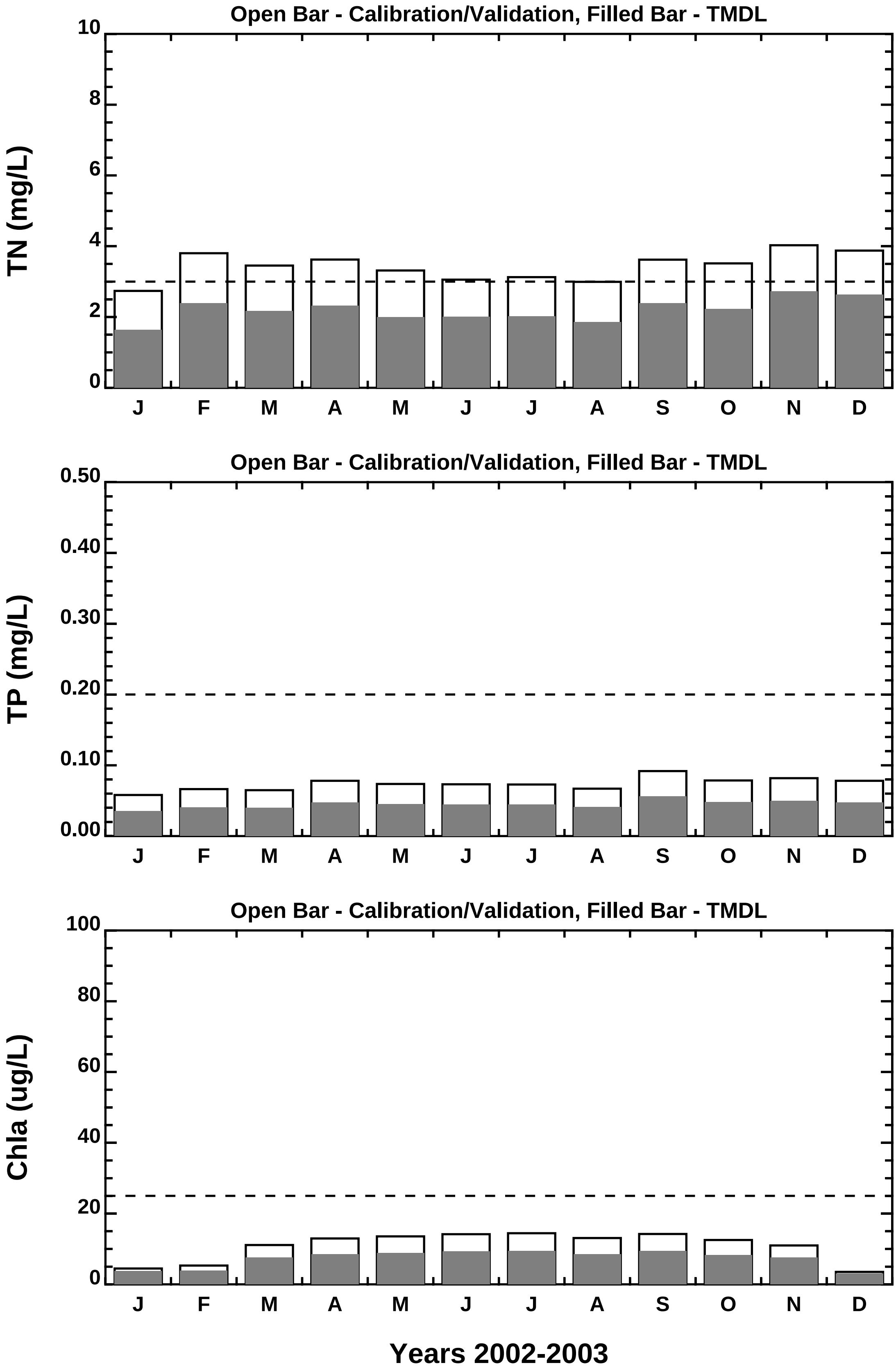


Figure A22. Broadkill River (Non-Tidal) - Waples & Reynolds Ponds (DE060-L03) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 88)

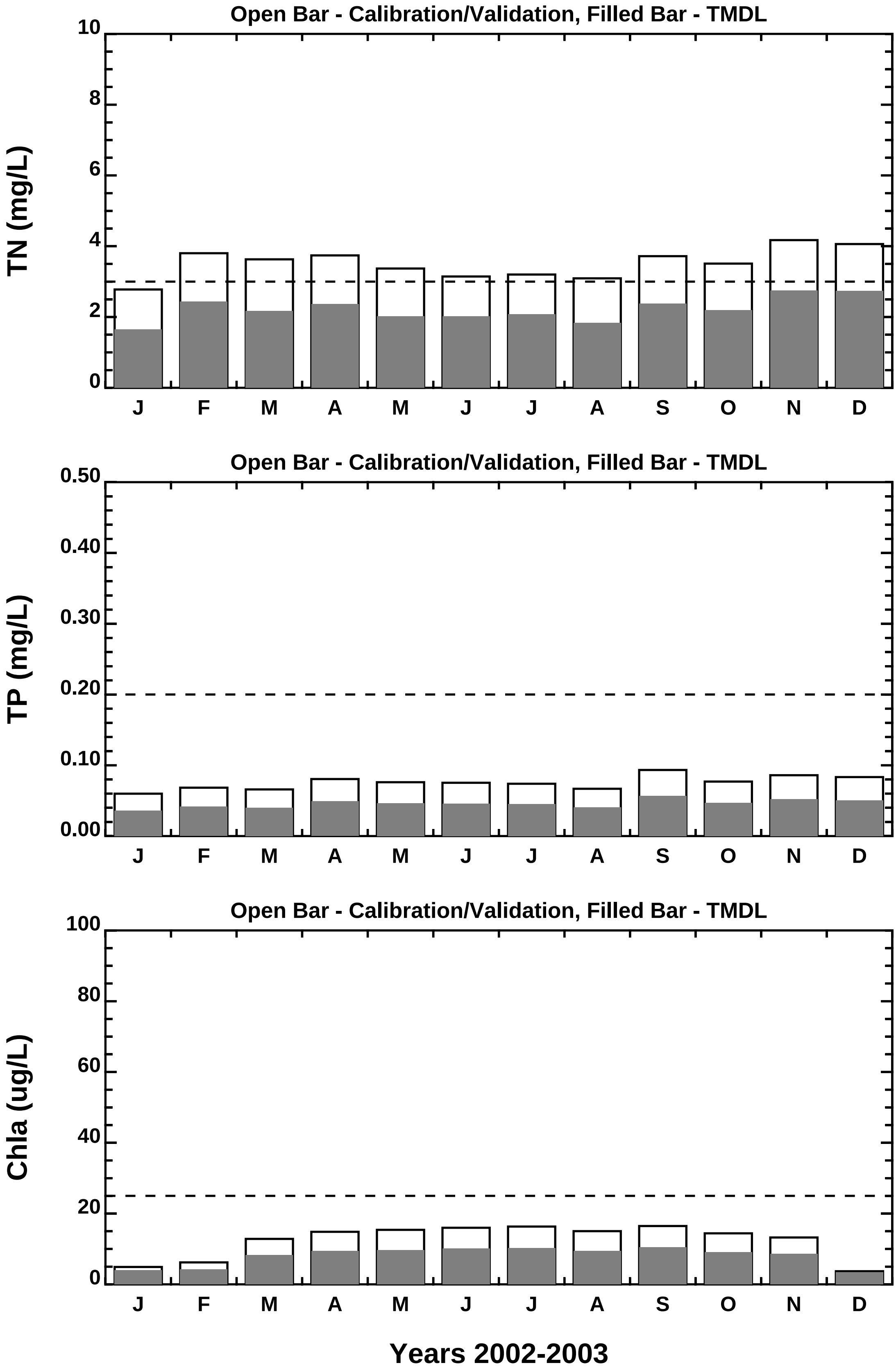
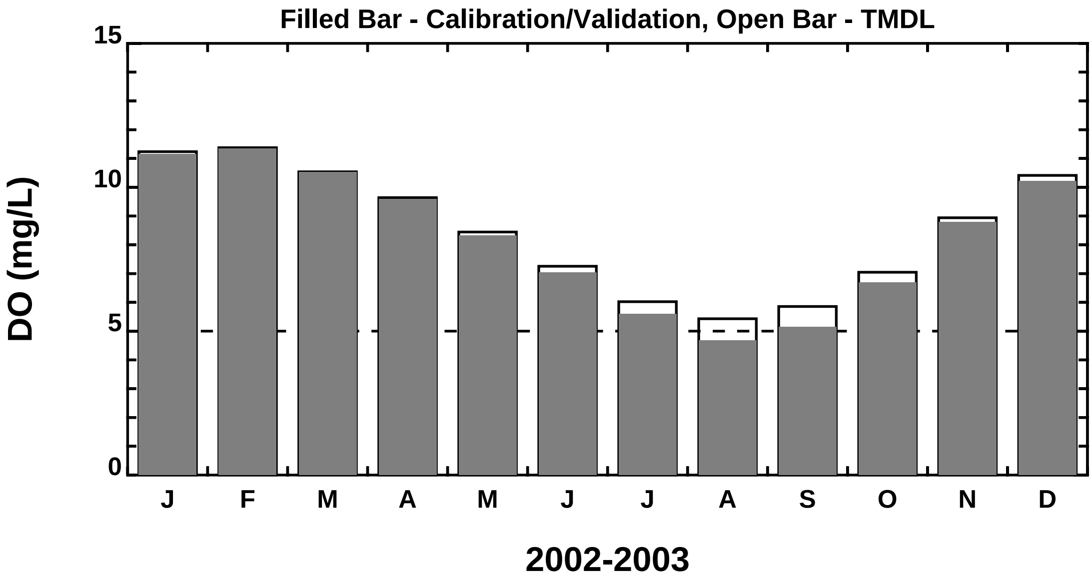


Figure A23. Broadkill River (Non-Tidal) - Waples & Reynolds Ponds (DE060-L03) Nutrient and Chlorophyll-a TMDL Results (2002-2003)

(Calibration Run 05, TMDL Run 13, HSPF Segment 41)

APPENDIX 2

EXISTING & TMDL MODEL OUTPUT (MARINE)



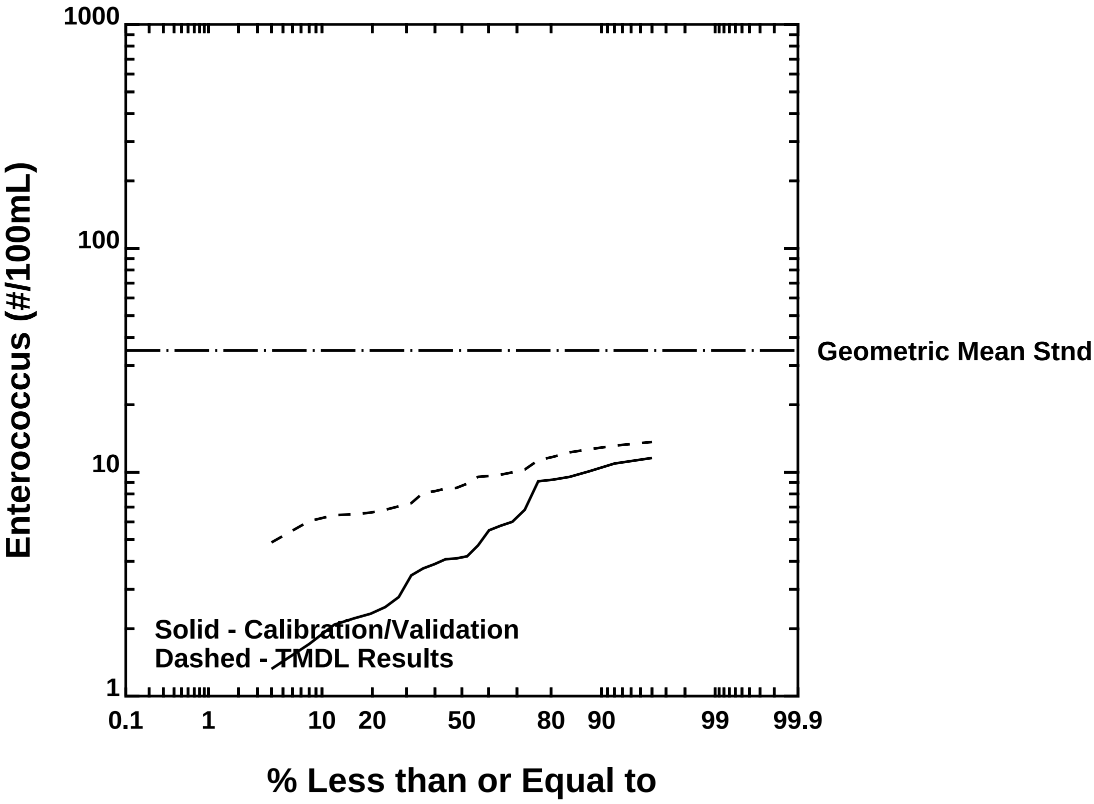
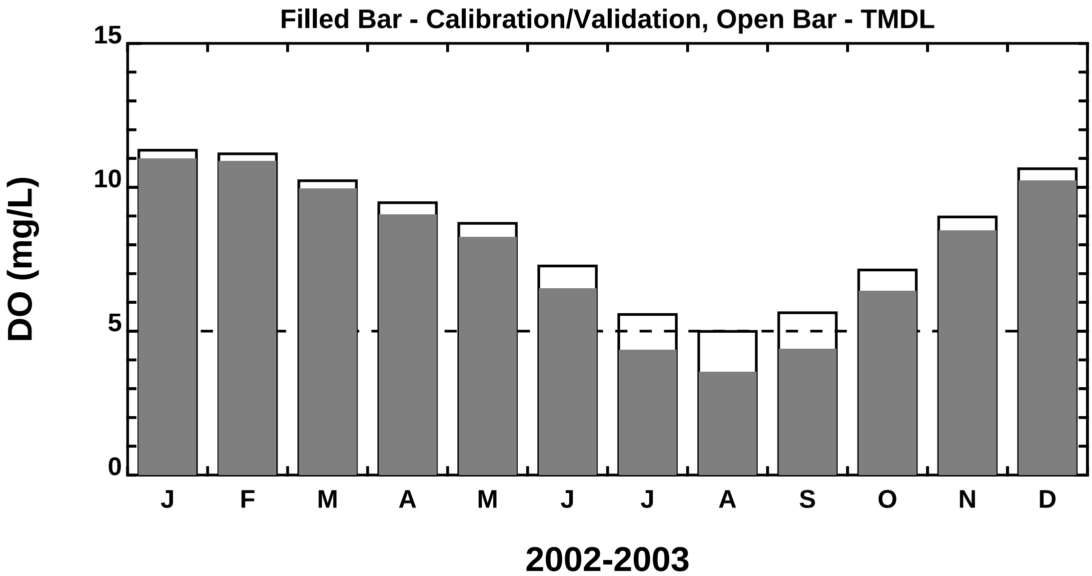


Figure A25. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303061) DO and Enterococcus TMDL Results (2002-2003)

(Calibration Run 58, TMDL Run 67x)



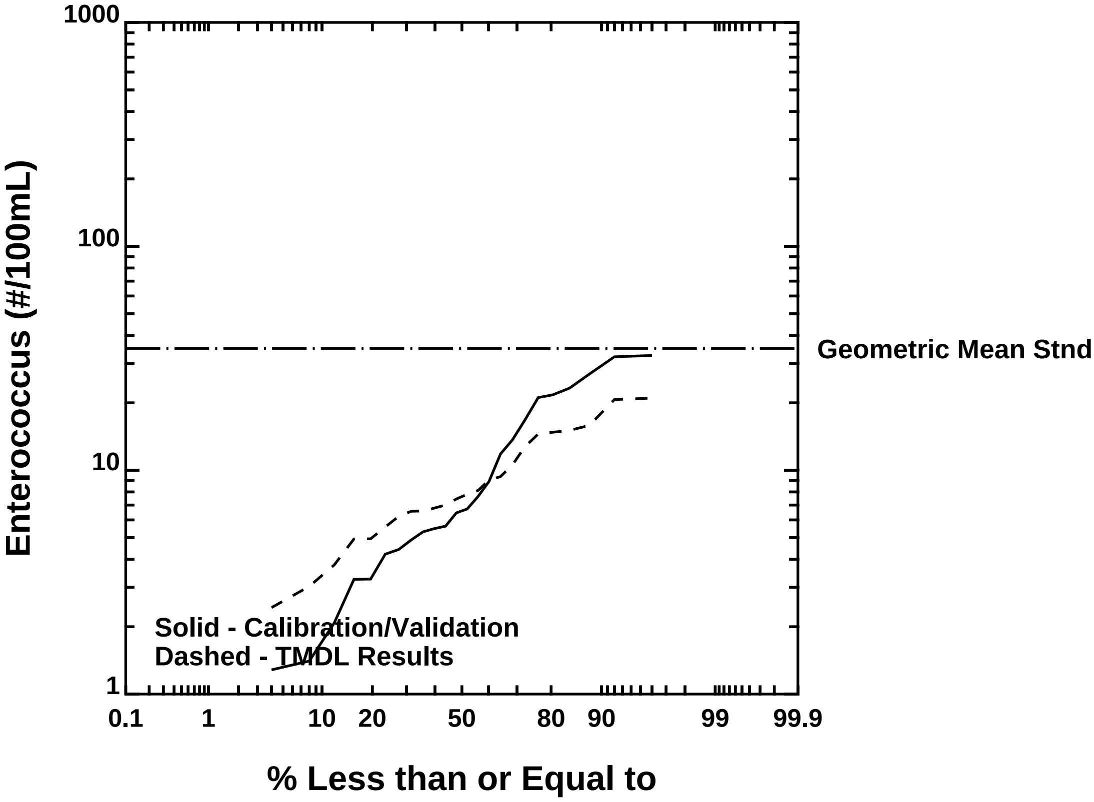
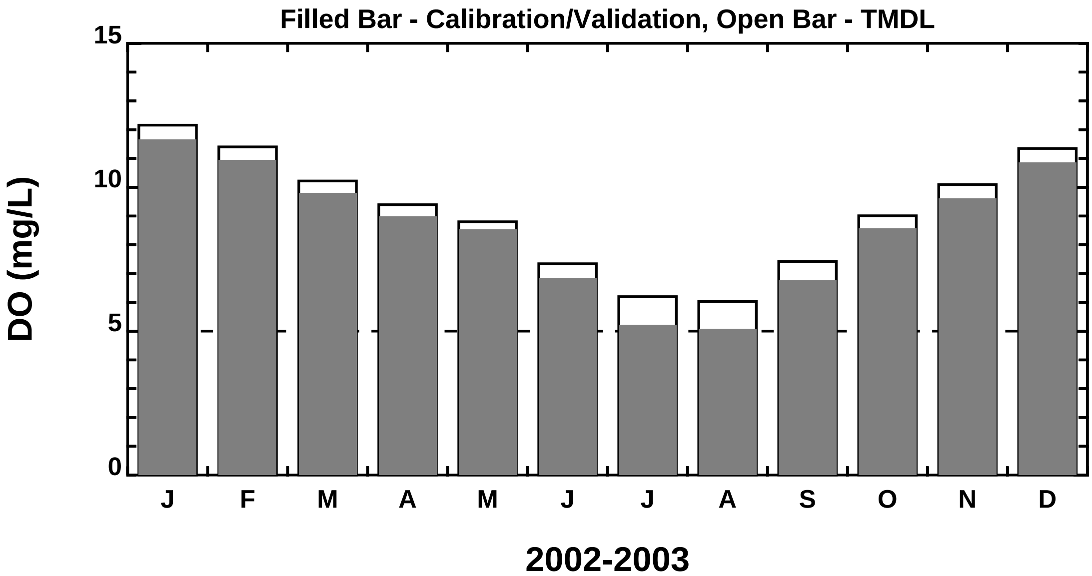


Figure A26. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303081) DO and Enterococcus TMDL Results (2002-2003)

(Calibration Run 58, TMDL Run 67x)



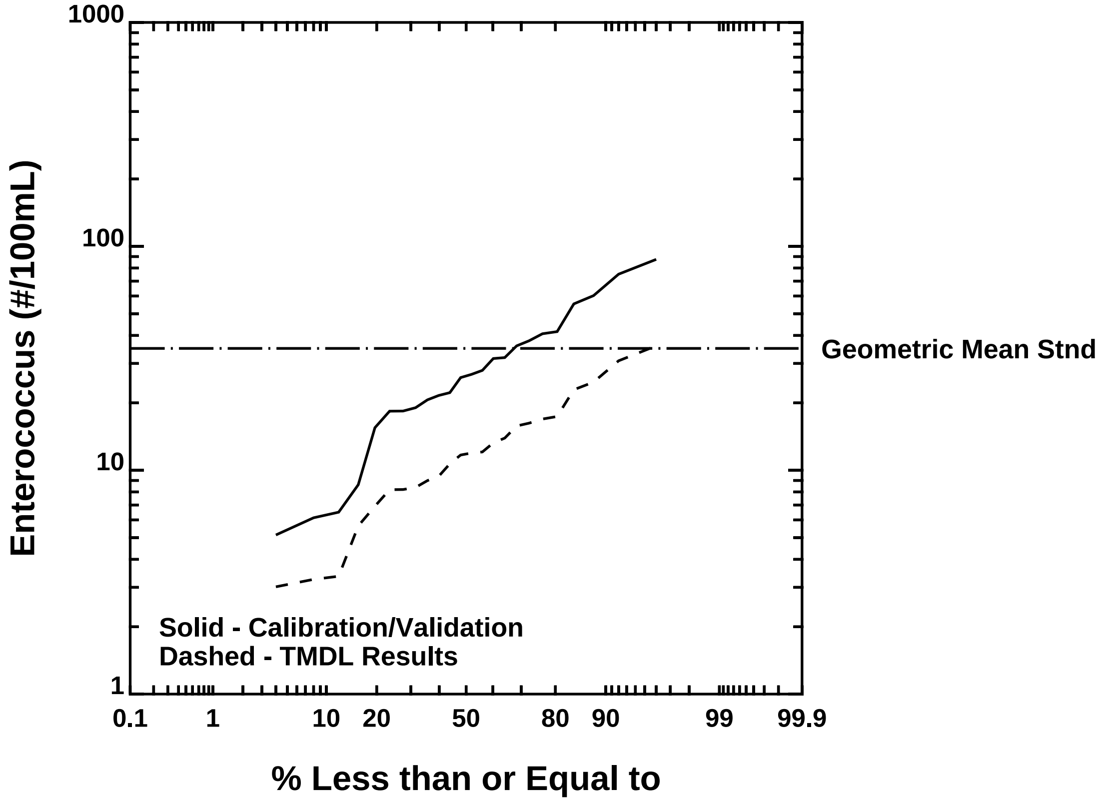
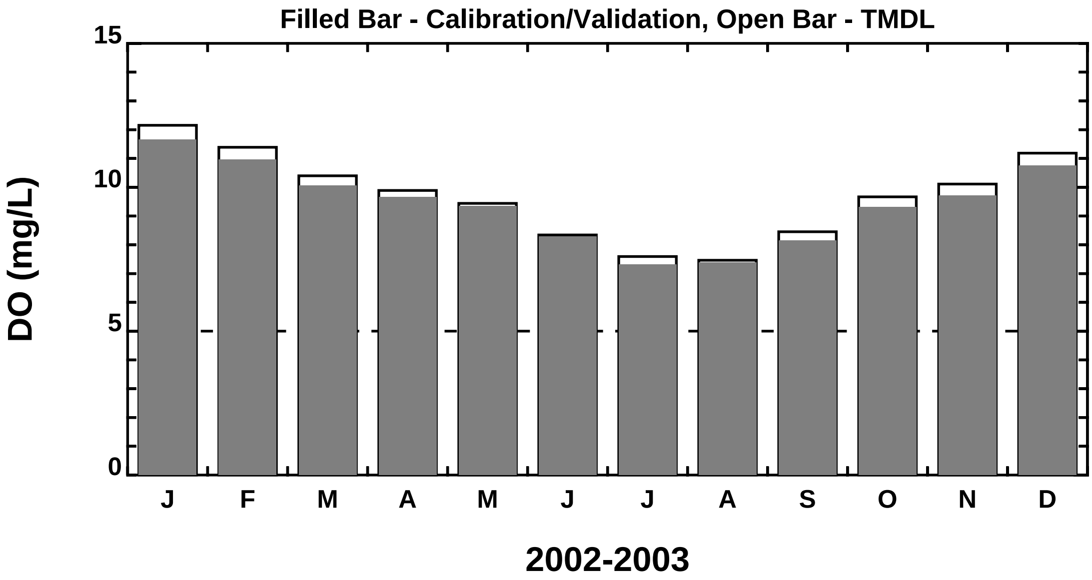


Figure A27. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303041) DO and Enterococcus TMDL Results (2002-2003)

(Calibration Run 58, TMDL Run 67x)



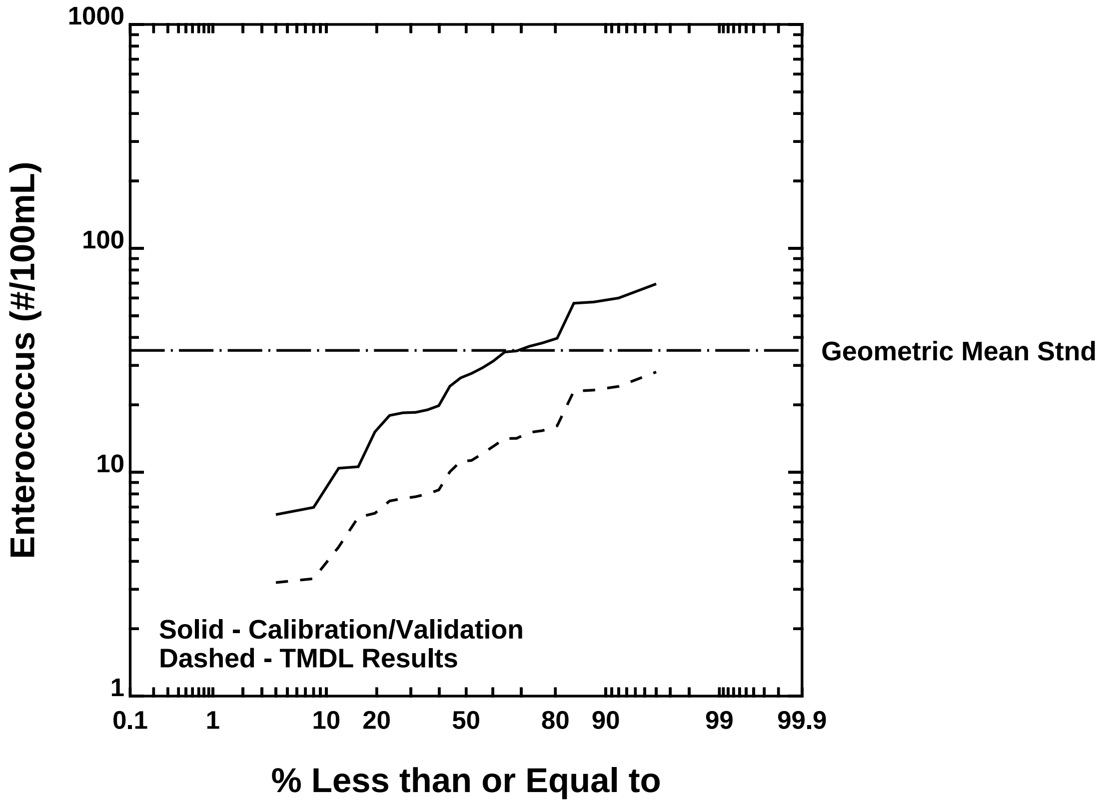
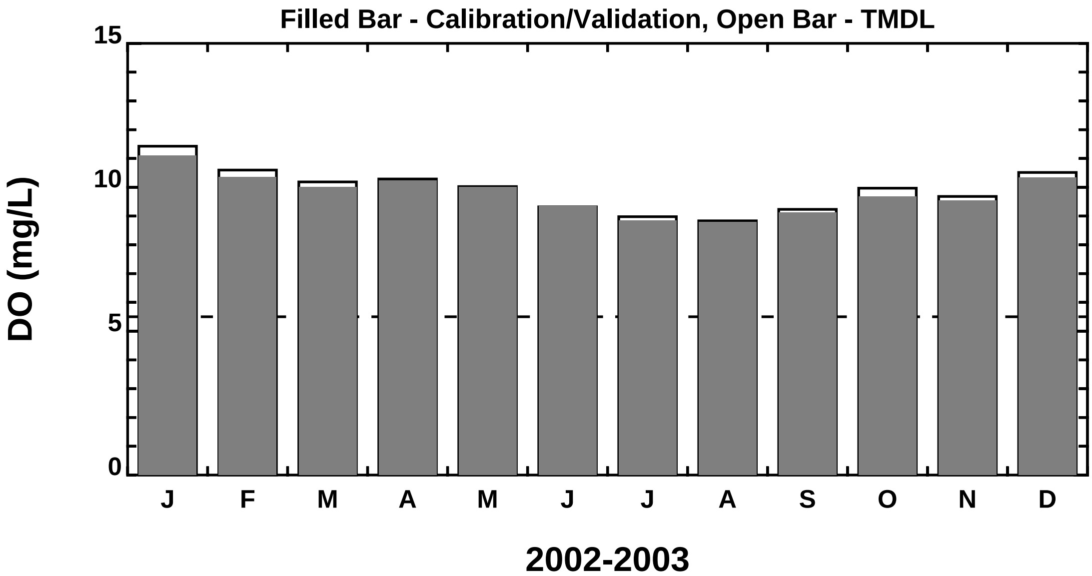


Figure A28. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303131) DO and Enterococcus TMDL Results (2002-2003)

(Calibration Run 58, TMDL Run 67x)



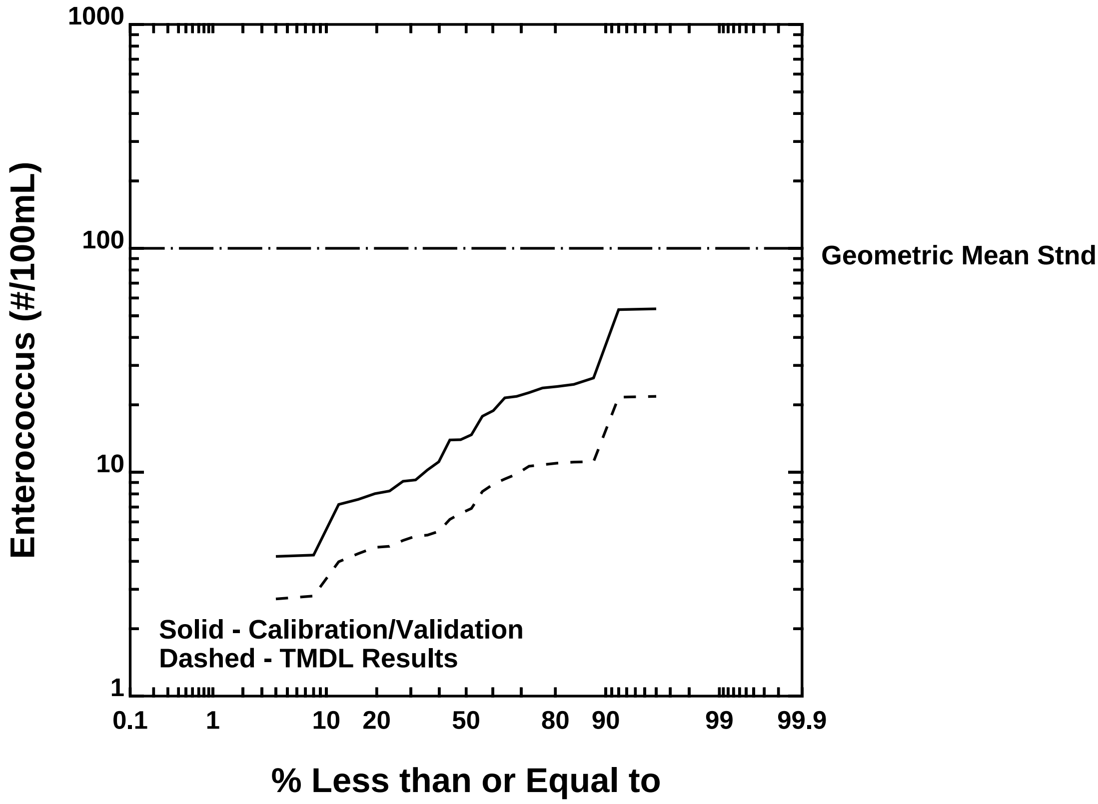
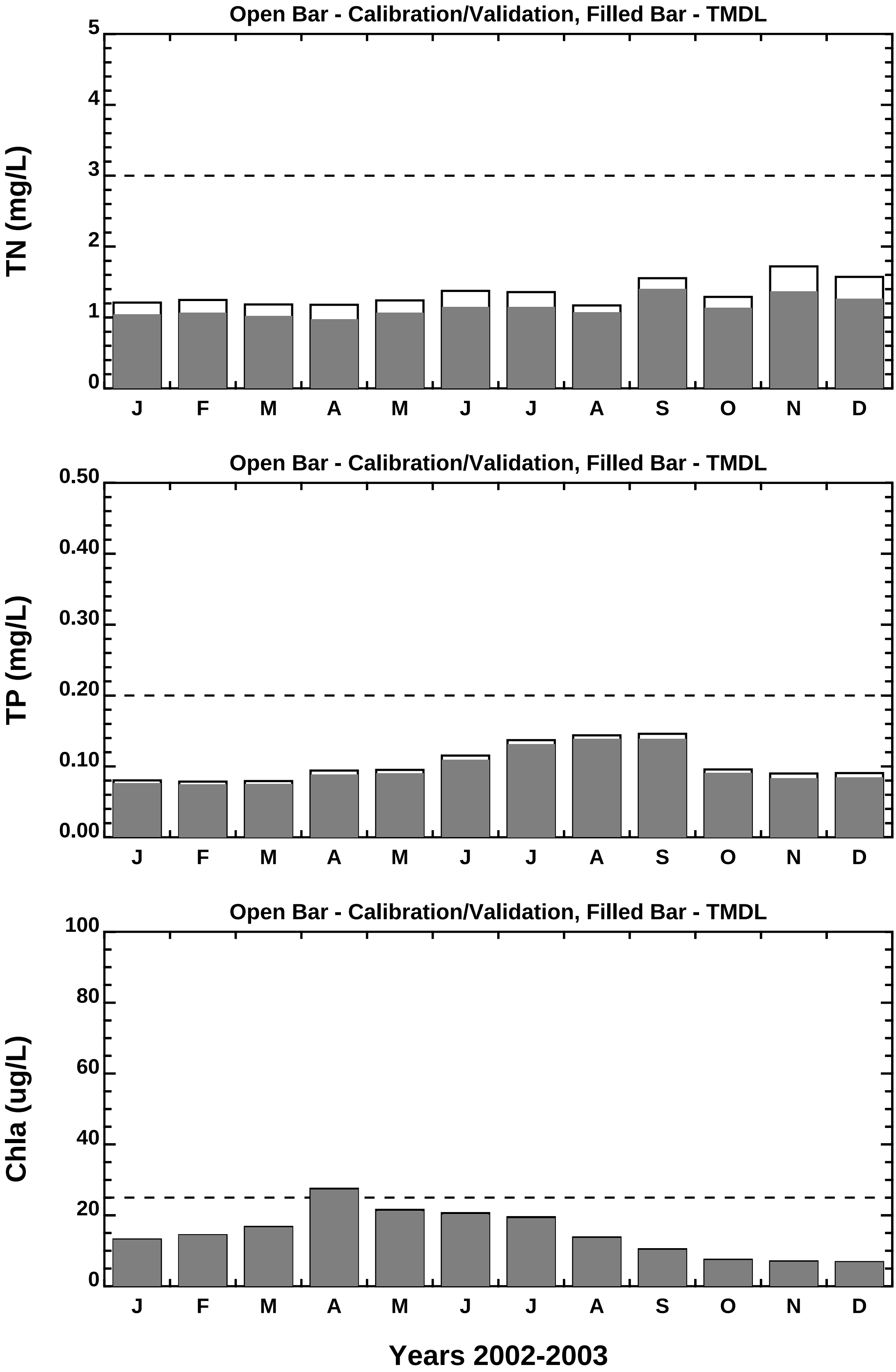


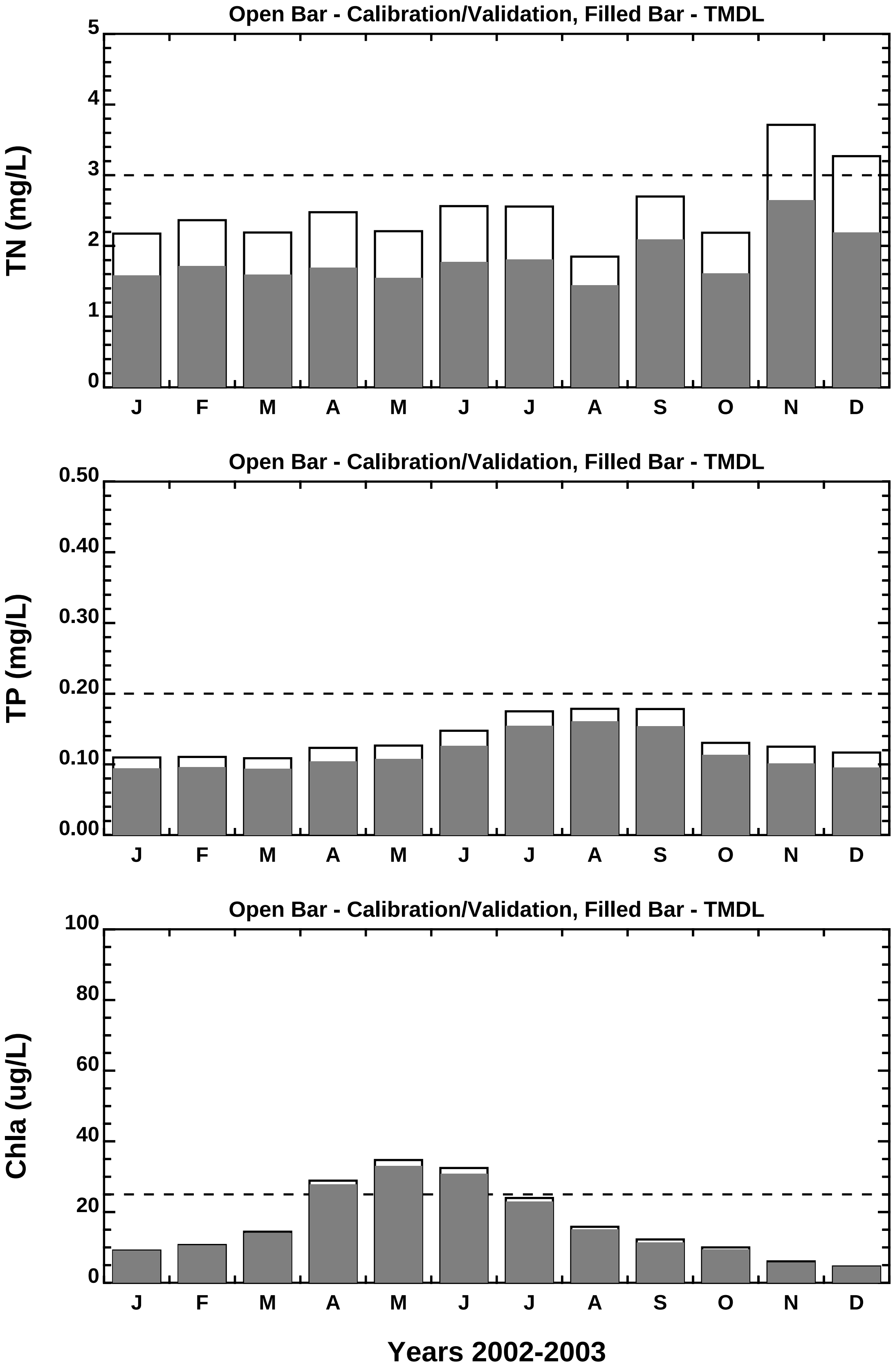
Figure A29. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303031) DO and Enterococcus TMDL Results (2002-2003)

(Calibration Run 58, TMDL Run 67x)



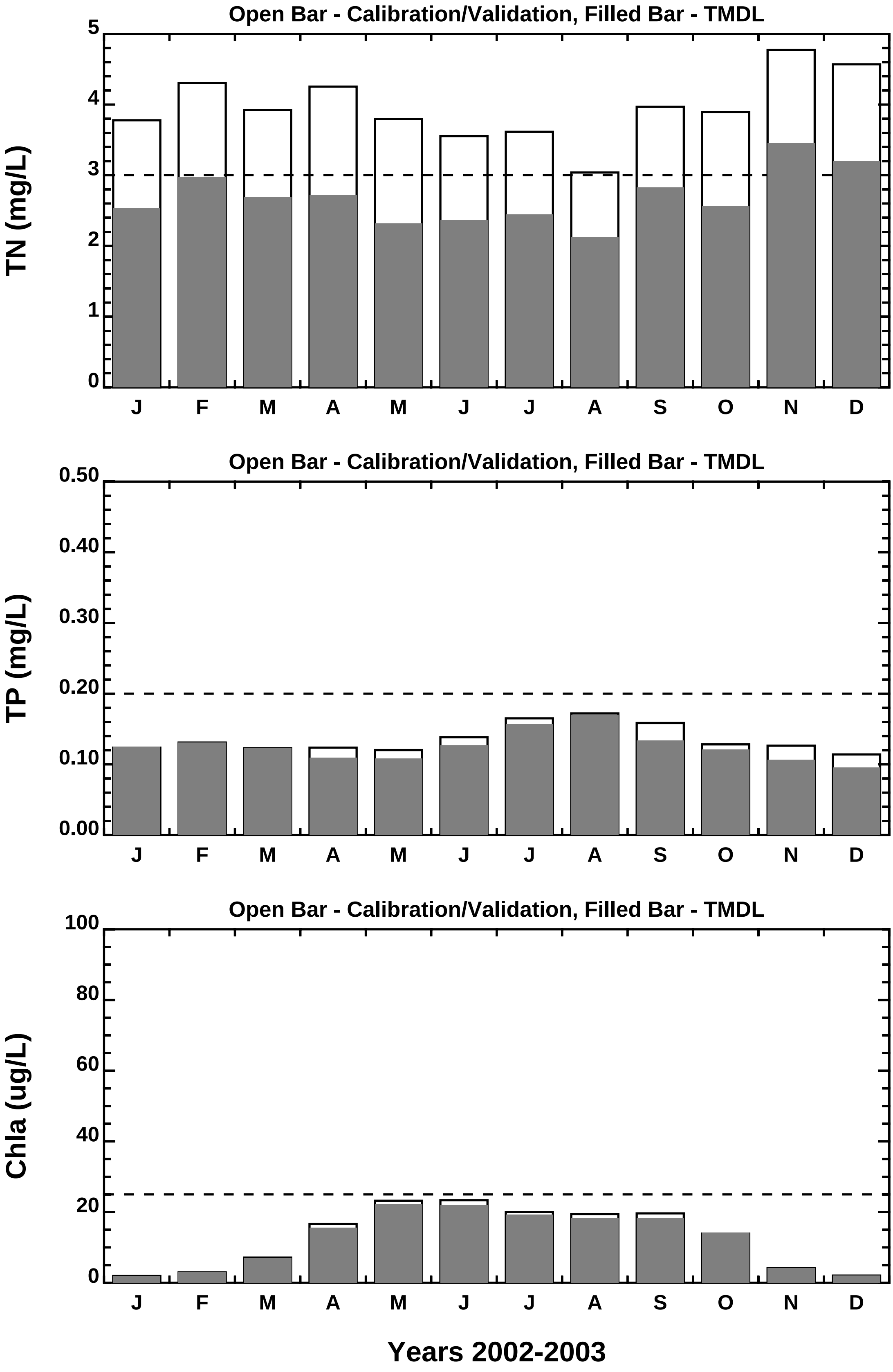
Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Figure A30. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303061)

(Calibration Run 58, TMDL Run 67x)



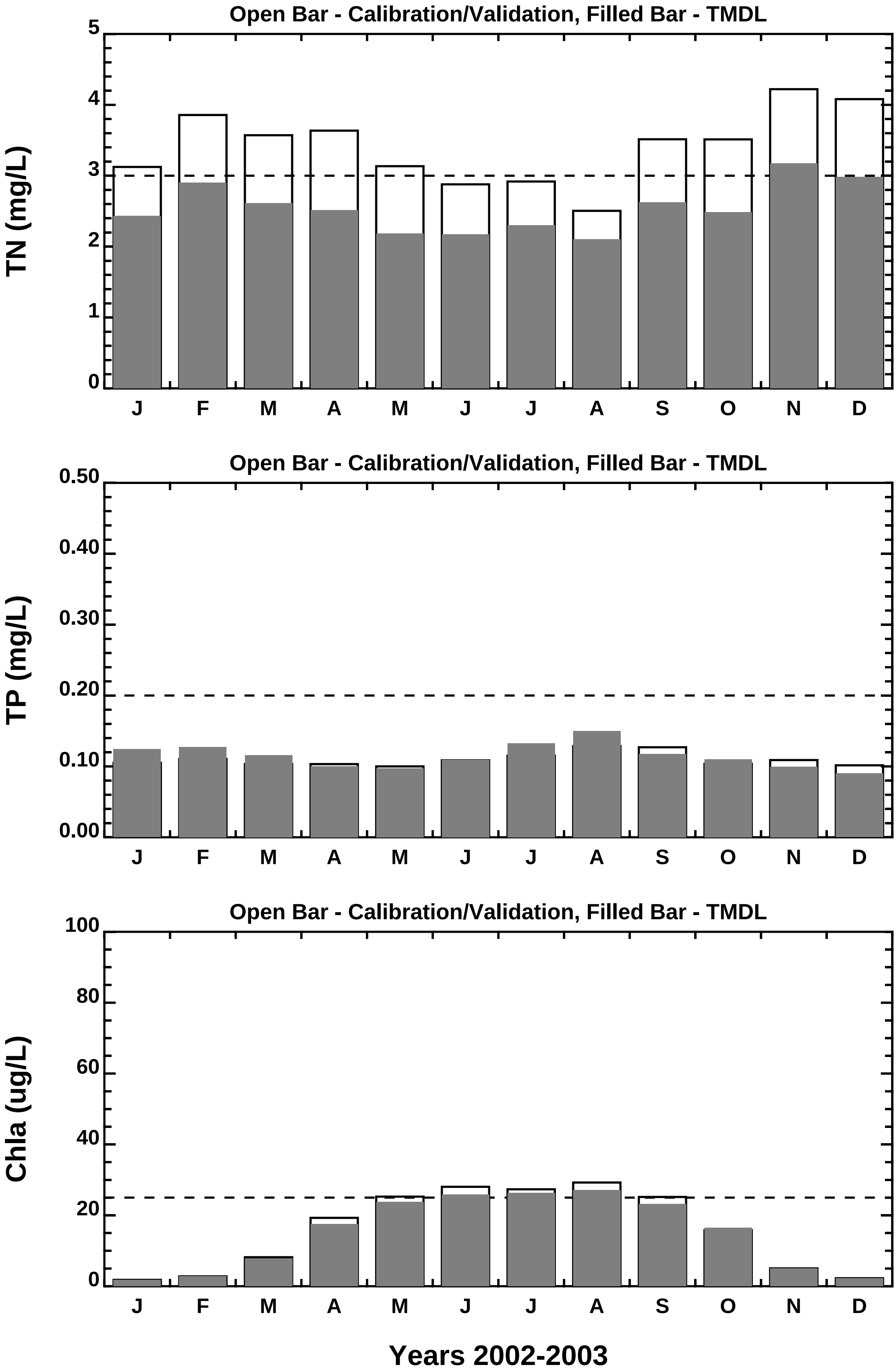
Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Figure A31. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303081)

(Calibration Run 58, TMDL Run 67x)



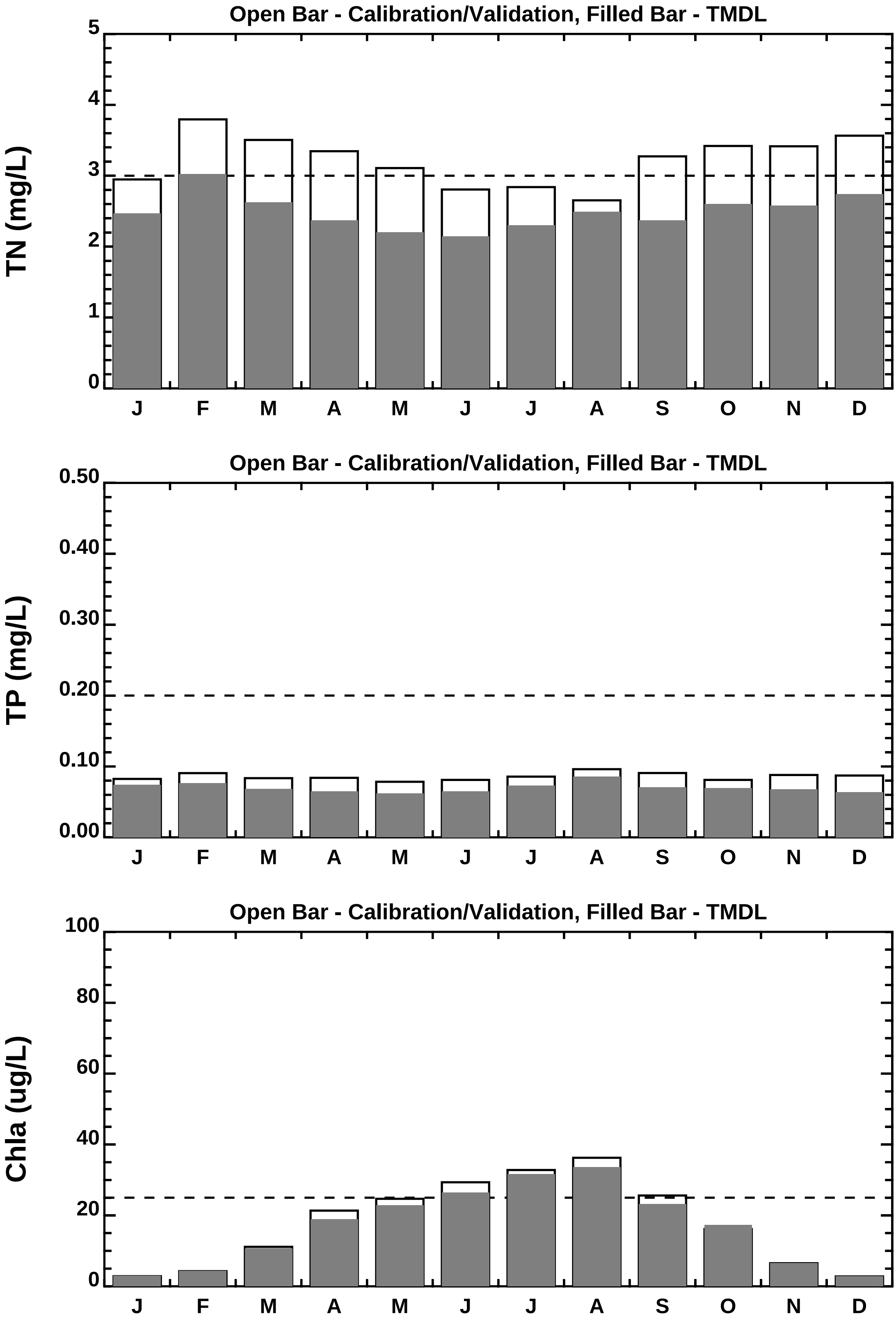
Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Figure A32. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303041)

(Calibration Run 58, TMDL Run 67x)



Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Figure A33. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303131)

(Calibration Run 58, TMDL Run 67x)



Nutrient and Chlorophyll-a TMDL Results (2002-2003)
Figure A34. Broadkill River (Tidal) - DE290-001-01 & -02 (Station 303031)

(Calibration Run 58, TMDL Run 67x)

APPENDIX 3

BROADKILL RIVER BASELINE LOADINGS

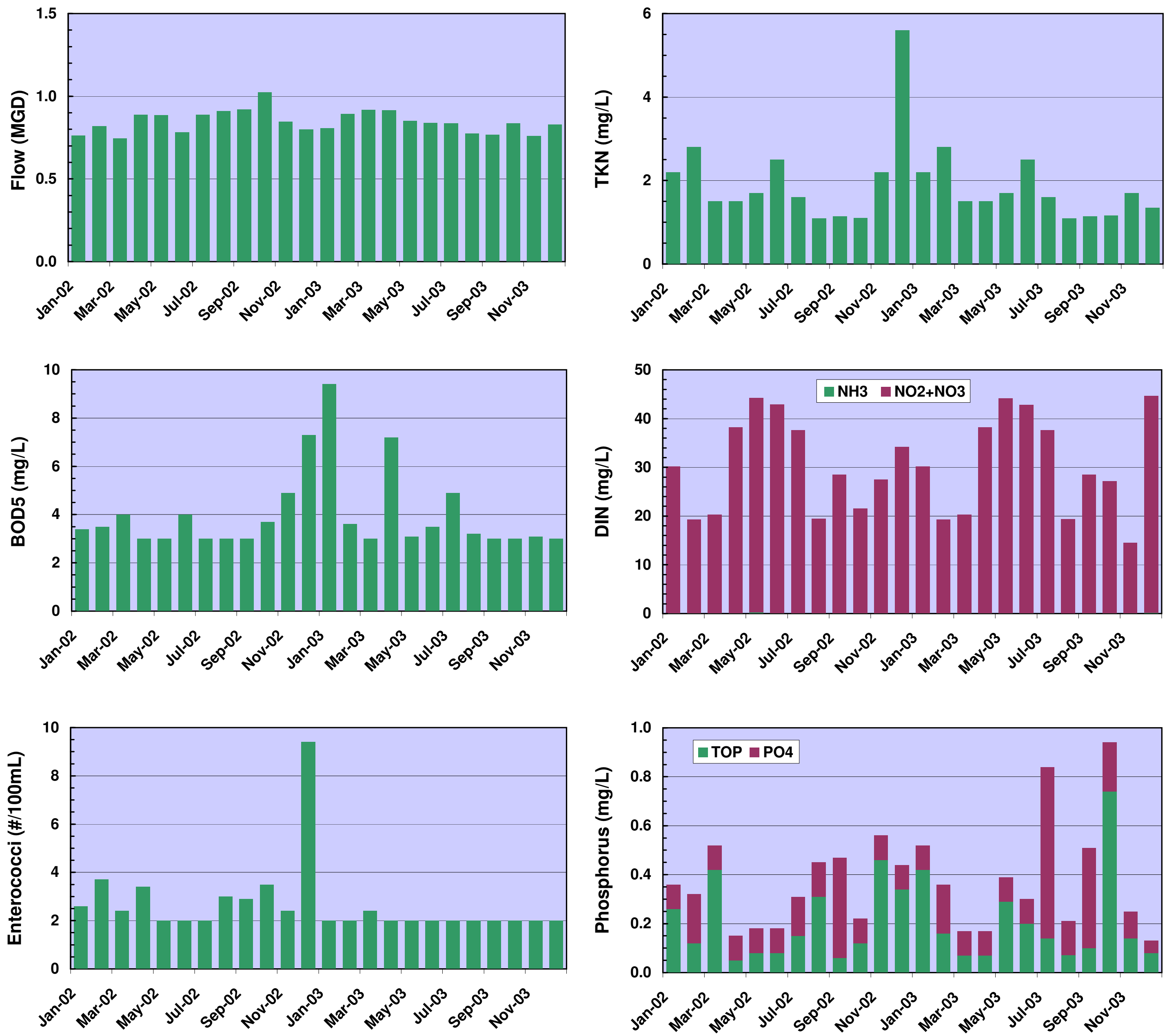


Figure A35. Allen Family Foods WWTP Baseline Characteristics (2002-2003)

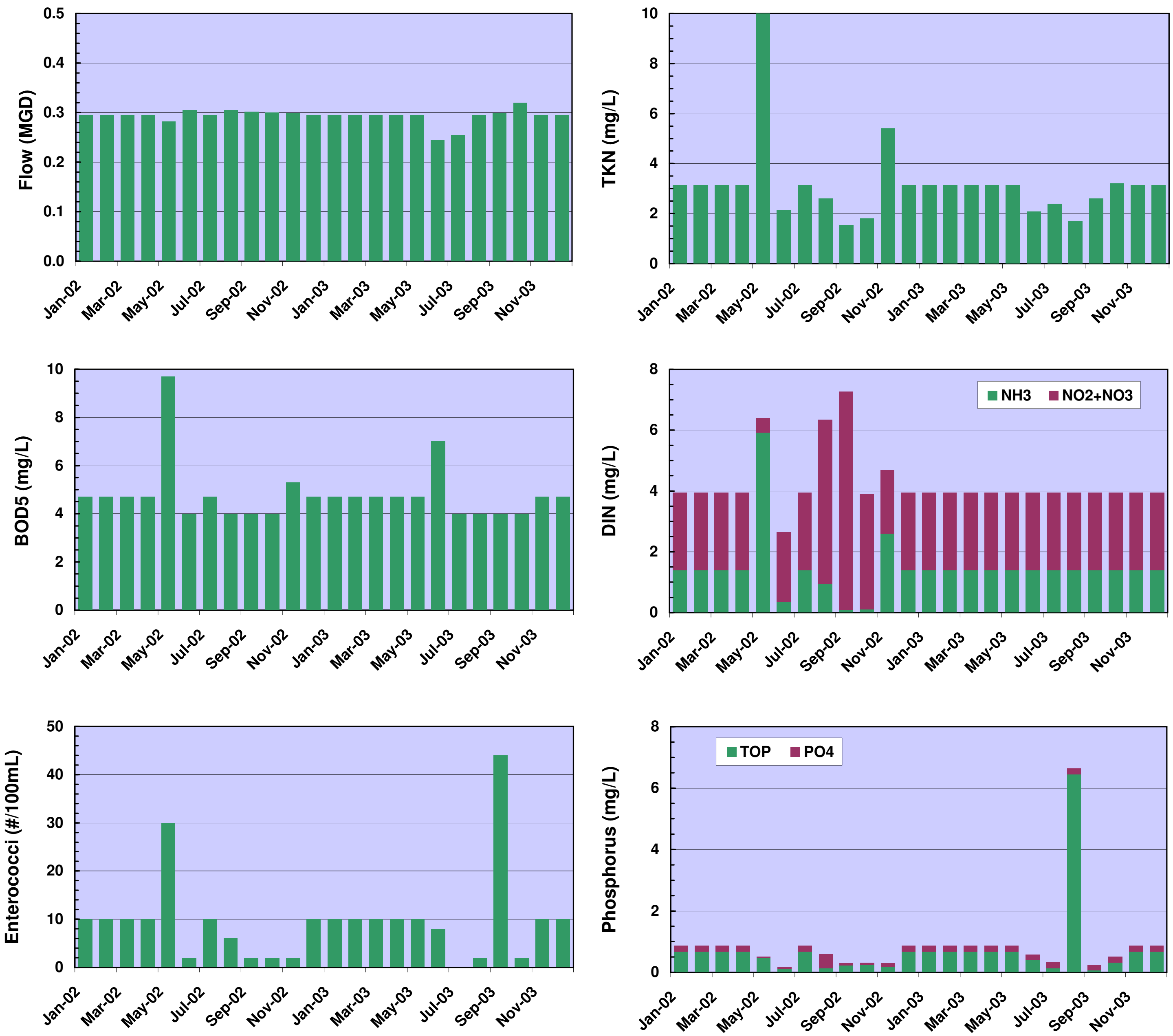


Figure A36. SAW WWTP (001) Baseline Characteristics (2002-2003)

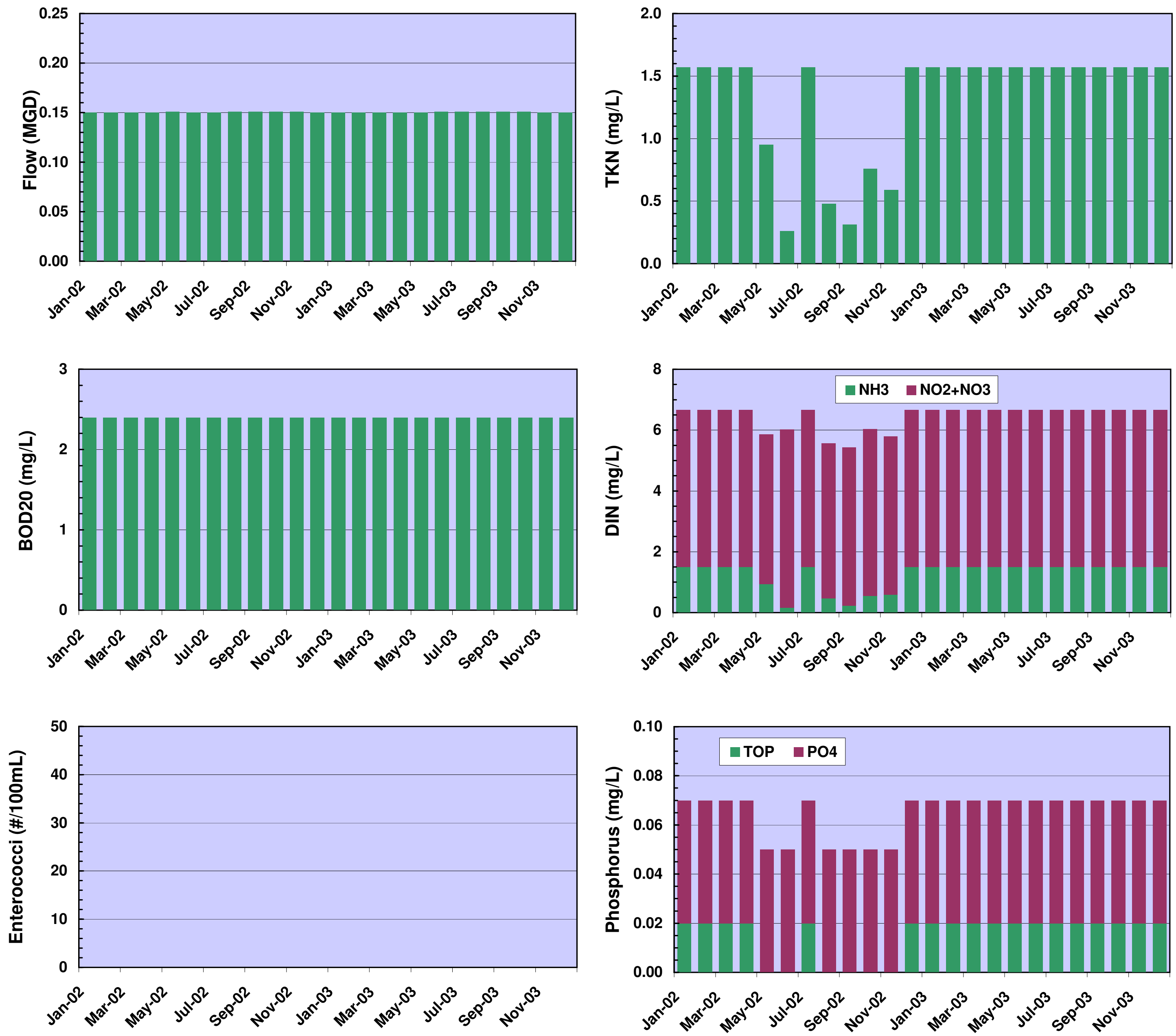


Figure A37. SAW WWTP (002) Baseline Characteristics (2002-2003)

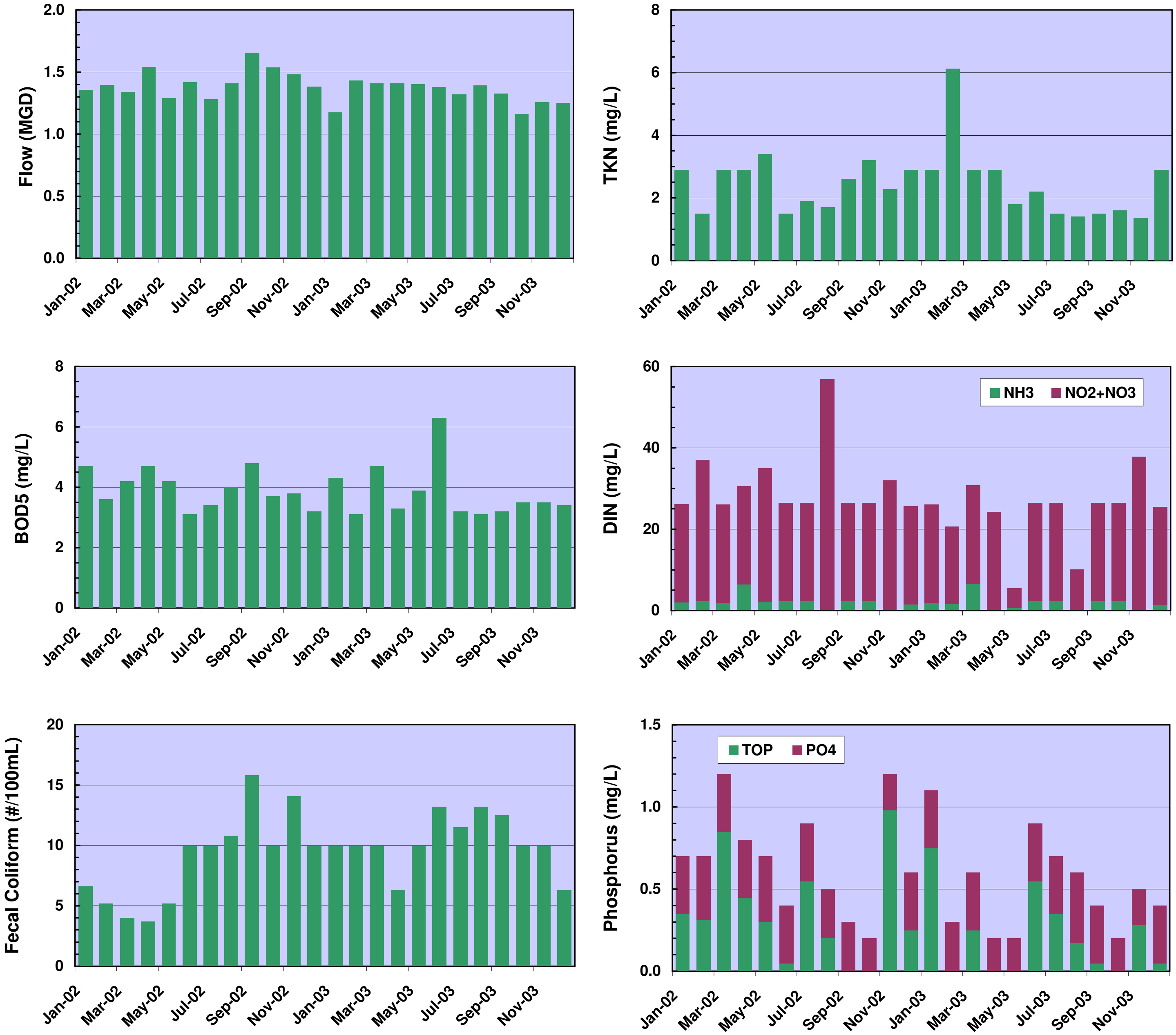


Figure A38. Perdue WWTP Baseline Characteristics (2002-2003)

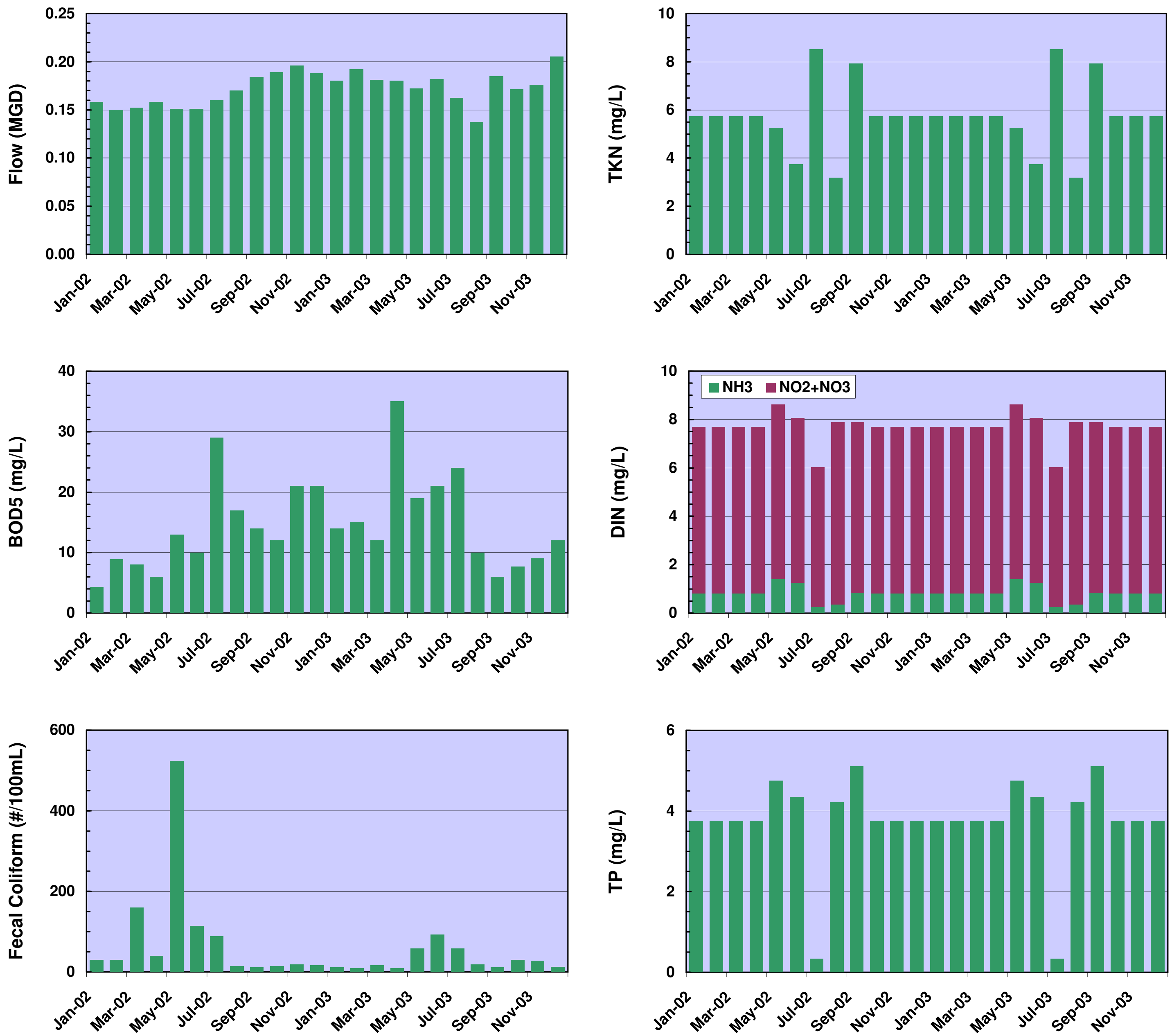


Figure A39. Milton WWTP Baseline Characteristics (2002-2003)

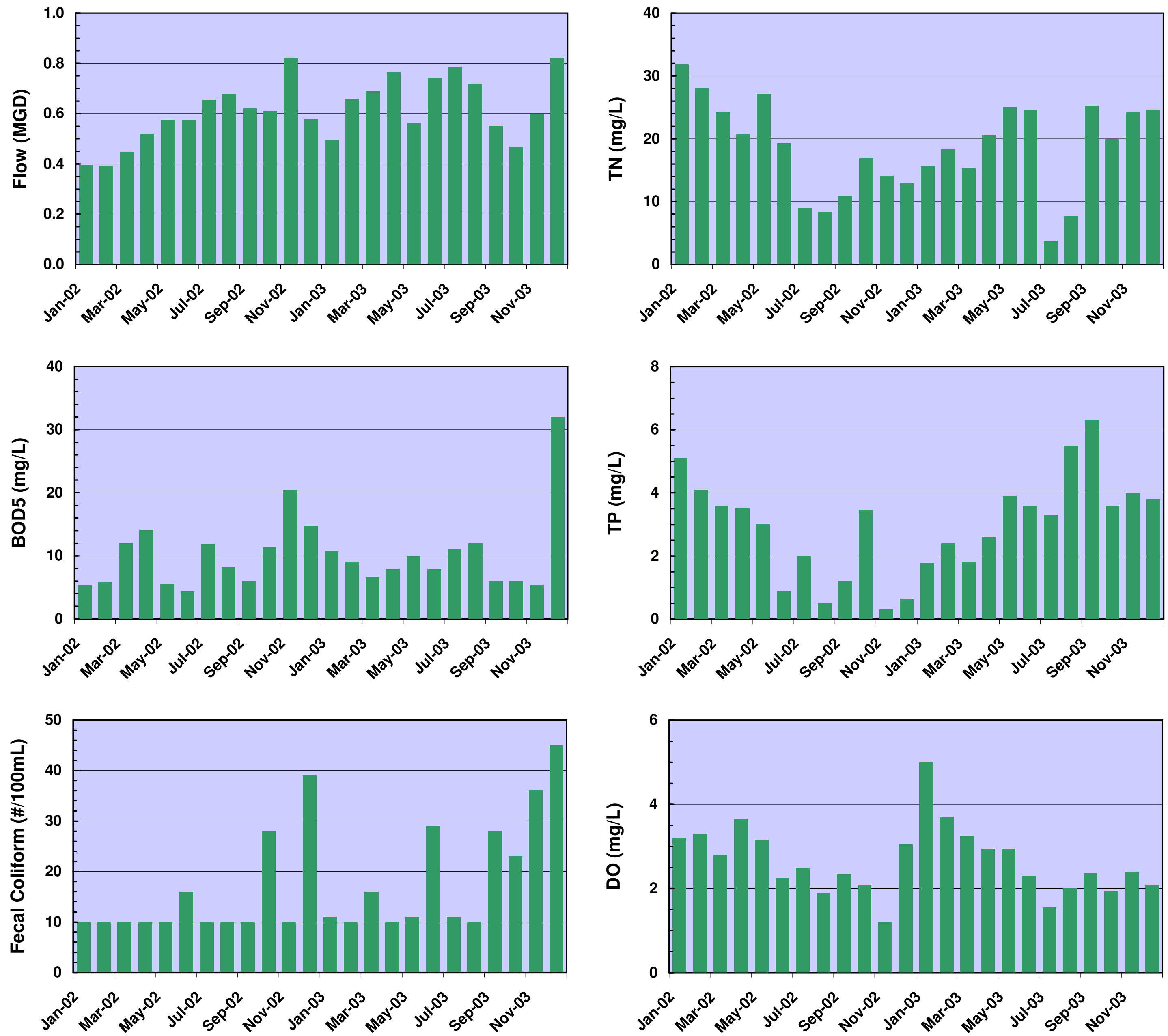


Figure A40. Lewes WWTP Baseline Characteristics (2002-2003)

TABLE A1

Broadkill River Baseline Point Source Loads

Facility	SAW 001 Georgetown	Perdue Georgetown	Allen Family Foods	City of Milton
BOD_5 (lb/d)	11.7	44.5	28.1	21.1
NH_3 (lb/d)	3.55	22.8	0.64	1.18
TN (lb/d)	14.6	321.2	226.9	18.1
TP (lb/d)	2.22	6.78	2.61	5.40
Enterococcus (#/d)	1.11e+09	5.20e+09	3.20e+09	2.15e+08

Baseline Loads for the Broadkill River Watershed

Parameter	WLA	LA	TMDL
TN (lb/d)	580.8	3707.0	4287.8
TP (lb/d)	17.0	157.8	174.8
Enterococcus (#/d)	9.7e+09	4.2e11	4.2e11

TABLE A2					
Broadkill River Baseline NPS Loads by Land Use and Watershed Group					
Parameter	**Urban**	**Agriculture**	**Pasture**	**Forest**	**Total**
Primehook Branch					
Area (acres)	1,679	9,267	235	3,642	14,823
TN (lb/d)	187.3	618.3	26.9	121.6	954.0
TP (lb/d)	5.34	33.79	11.53	0.77	51.44
Enterococcus (#/d)	3.6E+10	3.7E+10	6.5E+09	9.7E+09	8.8E+10
Ingram/Pemberton Branch					
Area (acres)	1,593	4,955	838	5,101	12,487
TN (lb/d)	201.7	373.8	106.4	172.5	854.4
TP (lb/d)	5.24	20.85	3.79	1.16	31.04
Enterococcus (#/d)	2.8E+10	2.3E+10	2.6E+10	1.6E+10	9.3E+10
Round Pole Branch					
Area (acres)	526	2,550	339	1,441	4,856
TN (lb/d)	57.8	171.2	38.9	48.1	316.1
TP (lb/d)	1.65	9.35	1.38	0.31	12.68
Enterococcus (#/d)	1.1E+10	1.0E+10	9.5E+09	3.8E+09	3.5E+10
Beaverdam Creek					
Area (acres)	803	2,881	192	1,516	5,392
TN (lb/d)	84.8	202.1	23.0	50.9	360.8
TP (lb/d)	2.41	11.13	0.82	0.33	14.68
Enterococcus (#/d)	1.9E+10	1.2E+10	5.6E+09	4.3E+09	4.1E+10
Old Mill Creek					
Area (acres)	3,694	4,502	180	1,292	9,668
TN (lb/d)	443.6	333.8	22.5	43.6	843.5
TP (lb/d)	12.30	18.59	0.80	0.29	31.98
Enterococcus (#/d)	8.6E+10	2.1E+10	5.5E+09	3.9E+09	1.2E+11
Broadkill River					
Area (acres)	1,307	3,838	145	1,565	6,855
TN (lb/d)	97.2	214.6	14.0	52.5	378.3
TP (lb/d)	3.68	11.45	0.49	0.34	15.96
Enterococcus (#/d)	2.6E+10	1.2E+10	3.3E+09	3.4E+09	4.4E+10

APPENDIX 4

BROADKILL RIVER HSPF INPUTS

(ACCUMULATION RATES AND LIMITS)

TABLE A3							
Broadkill River Watershed HSPF Accumulation Rates (lb/acre/day) - Calibration Run							
Pollutant	**Agriculture**	**Forest**	**Pasture/ Rangeland**	**Urban Pervious**	**Urban Impervious**	**Wetlands**	**Other**
BOD	10.0	5.0	7.0	15.0	0.2	5.0	10.0
Organic Nitrogen	2.00	1.00	1.40	3.00	0.03	1.00	2.00
Ammonia	0.500	0.030	0.100	0.070	0.010	0.030	0.070
Nitrite plus Nitrate	9.00	1.00	3.00	5.00	0.02	1.00	3.00
Organic Phosporus	0.270	0.130	0.190	0.400	0.004	0.130	0.270
Phosphate	0.0000	0.0000	0.0000	0.0000	0.0034	0.0000	0.0000
Enterococcus	8.00E+08	4.00E+08	6.00E+08	5.00E+08	3.00E+08	2.00E+07	6.00E+06

TABLE A4							
Broadkill River Watershed HSPF Accumulation Limits (lb/acre) - Calibration Run							
Pollutant	**Agriculture**	**Forest**	**Pasture/ Rangeland**	**Urban Pervious**	**Urban Impervious**	**Wetlands**	**Other**
BOD	100.0	50.0	70.0	150.0	2.1	50.0	100.0
Organic Nitrogen	19.80	9.90	13.80	29.70	0.42	9.90	19.80
Ammonia	5.000	0.300	1.000	0.700	1.000	0.300	0.700
Nitrite plus Nitrate	80.00	10.00	30.00	50.00	0.27	10.00	30.00
Organic Phosporus	2.700	1.350	1.890	4.040	0.057	1.350	2.700
Phosphate	0.0000	0.0000	0.0000	0.0000	0.0163	0.0000	0.0000
Enterococcus	7.20E+09	3.60E+09	5.40E+09	4.50E+09	2.70E+09	1.80E+08	5.40E+07

APPENDIX 5

BROADKILL RIVER POINT SOURCE INFORMATION

TABLE A5				
SAW Georgetown, Outfall 001, NPDES #0000141				
Effluent Type	Current Permit	Effluent Data		WLA
		Average	Maximum	
Flow (MGD)	0.33	0.30	0.32	0.33
BOD^5 (mg/L)	22.70	4.70	9.70	10.00
DO (mg/L) *	-	6.60	5.30	7.00
TN (mg/L)	-	5.60	17.20	7.00
TKN (mg/L)	7.30	3.10	10.00	3.00
NH_3 (mg/L)	-	1.40	5.90	1.00
$NO_2 + NO_3$ (mg/L)	-	2.50	7.20	4.00
TP (mg/L)	1.80	0.90	6.60	0.50
PO_4 (mg/L)	-	0.19	0.46	0.20
Entero (#/100mL)	-	10	44	100
Fecal (#/100mL)	200	31	160	-

* Effluent Data Concentration is Minimum not Maximum

TABLE A6				
Perdue Georgetown, Outfall 002, NPDES #0000469				
Effluent Type	Current Permit	Effluent Data		WLA
		Average	Maximum	
Flow (MGD)	2.00	1.38	1.65	2.00
BOD^5 (mg/L)	11.30	4.00	6.30	10.00
DO (mg/L) *	-	7.70	6.80	7.00
TN (mg/L)	-	24.80	60.30	7.00
TKN (mg/L)	7.50	1.90	3.40	3.00
NH_3 (mg/L)	15.00	3.10	11.20	1.00
$NO_2 + NO_3$ (mg/L)	-	22.90	56.90	4.00
TP (mg/L)	1.50	0.60	1.20	0.50
PO_4 (mg/L)	-	0.36	0.78	0.20
Entero (#/100mL)	-	5	16	100
Fecal (#/100mL)	-	7	16	-

* Effluent Data Concentration is Minimum not Maximum

TABLE A7				
Allen Family Foods, Outfall 001, NPDES #0000299				
Effluent Type	**Current Permit**	**Effluent Data**		**WLA**
		Average	**Maximum**	
Flow (MGD)	1.25	0.82	1.02	1.25
BOD^5 (mg/L)	16.00	3.90	9.40	10.00
DO (mg/L) *	-	-	-	7.00
TN (mg/L)	46.00	32.00	49.60	7.00
TKN (mg/L)	-	2.00	5.60	3.00
NH_3 (mg/L)	4.00	1.30	21.40	1.00
$NO_2 + NO_3$ (mg/L)	-	30.00	44.00	4.00
TP (mg/L)	8.00	0.47	1.70	0.50
PO_4 (mg/L)	-	0.19	0.70	0.20
Entero (#/100mL)	33	3	9	100
Fecal (#/100mL)	-	-	-	-

* Effluent Data Concentration is Minimum not Maximum

TABLE A8				
City of Milton, Outfall 001, NPDES #0021491				
Effluent Type	**Current Permit**	**Effluent Data**		**WLA**
		Average	**Maximum**	
Flow (MGD)	0.35	0.15	0.21	0.35
BOD^5 (mg/L)	15.00	12.30	35.00	15.00
DO (mg/L) *	-	-	-	7.00
TN (mg/L)	-	12.30	18.70	12.50
TKN (mg/L)	-	5.40	9.70	5.50
NH_3 (mg/L)	-	0.90	1.80	1.00
$NO_2 + NO_3$ (mg/L)	-	6.90	9.00	7.00
TP (mg/L)	-	4.10	5.40	4.50
PO_4 (mg/L)	-	-	-	3.50
Entero (#/100mL)	-	108	660	33
Fecal (#/100mL)	200	84	523	-

* Effluent Data Concentration is Minimum not Maximum