APPENDIX A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

Total Maximum Daily Load For Nutrients and Dissolved Oxygen for the Appoquinimink River

/S/

Jon M. Capacasa, Director
Water Protection Division

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Nutrient and Dissolved Oxygen TMDL Development for Appoquinimink River, Delaware

December 2003

U.S. Environmental Protection Agency
Region 3
1650 Arch Street
Philadelphia, Pennsylvania

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Executive Summary

The Appoquinimink River watershed drains approximately 47 square miles in New Castle County, Delaware, and is primarily agricultural with three residential/urban centers (Middletown, Odessa, and Townsend). The area is experiencing significant residential growth. The topography is generally characterized by flat to gently sloping land which is typical of the coastal plain. The Appoquinimink River system consists of three main tributaries, the Appoquinimink River main stem, Deep Creek, and Drawyer Creek. There are several shallow, man-made small lakes and ponds in the watershed (Wiggins Mill Pond, Noxontown Lake, Silver Lake, and Shallcross Lake). The Appoquinimink River is designated as a warm-water fishery and is subject to all water quality criteria specific to this designated use and those defined for general statewide water uses including aquatic life, water supply, and recreation. Due to their high nutrient concentrations and/or low dissolved oxygen levels, the Delaware Department of Natural Resources and Environmental Control (DNREC) identified and included in the state's 1996, 1998, and 2002 Section 303(d) lists of impaired waters several portions of the Appoquinimink River.

The Environmental Protection Agency Region III (EPA) establishes these Total Maximum Daily Loads (TMDLs) for the Appoquinimink River basin to address those stream segments impaired as a result of excess nutrients and low dissolved oxygen (DO). To address nutrient impairments, TMDLs have been established for total nitrogen (TN) and total phosphorus (TP) in order to attain and maintain applicable Water Quality Standards (WQS). There are presently no nutrient criteria defined by WQS for streams in the Appoquinimink River basin. Of the components of instream biological activity, only DO concentrations are included in water quality standards for stream segments of the Appoquinimink River basin. As a result, the nutrient TMDL endpoint is based on both the minimum and minimum daily average DO for the critical summer period characterized (June through September).

As part of the nutrient TMDLs, EPA has allocated specific amounts of TN and TP to nonpoint sources and point sources covered under storm water permits and flow, carbonaceous biochemical oxygen demand (CBOD), total kjeldahl nitrogen (TKN), and TP to the Middletown-Odessa-Townsend (MOT) WWTP located in the watershed. These allocations are necessary to restore and maintain applicable WQS for DO in the Appoquinimink River watershed.

TMDLs were determined for impaired segments and the subwatershed(s) contributing to them during the critical summer period (June through September). The total TMDL for each impaired segment is the combination of all TMDLs for contributing subwatersheds and for the MOT point source, where applicable. These watershed-based loads and the allocated load for the MOT WWTP enable the in-stream DO concentrations to meet criteria under all conditions. It should be noted that the WLAs for the storm water permits and the LAs for areas not covered by the storm water permits have been combined into a single WLA for each subwatershed (and impaired segment) and have not been presented separately. DNREC and New Castle County are

currently in the process of mapping storm water discharge locations that are covered by the permits, and as such, insufficient data are currently available to justify a more detailed allocation to the storm water permits. Once the mapping effort on behalf of DNREC and the county is complete, the TMDL can be refined to distribute the TMDL among the storm water permits (WLAs) and the nonpoint sources (LAs). The margin of safety (MOS) for this study was assumed implicit through conservative assumptions used in the modeling process.

The following tables summarize the TMDLs to address nutrient impairments for each stream segment of the Appoquinimink River basin included in the State's 303(d) list.

Table ES-1. TMDLs by contributing subwatershed for impaired waters of the Appoquinimink.

Segment Name	Segment ID	Contributing Subwatershed(s)	WLA TN (lbs/yr)	WLA TP (lbs/yr)
Appoquinimink River (Lower)	DE010-001-01	1	14,074	1,707
		2	6,737	896
		3	1,547	231
		4	7,075	862
		5	7,388	1,024
		6	5,498	742
		7	6,954	874
		8	10,594	1,367
		9	5,366	693
		10	8,814	1,230
		The total TMDL for this segment also includes the WLAs for the MOT WWTP (Table ES-2)		
Appoquinimink River (Upper)	DE010-001-02	2	6,737	896
		5	7,388	1,024
		6	5,498	742
		7	6,954	874
		8	10,594	1,367
		The total TMDL for this segment also includes the WLAs for the MOT WWTP (Table ES-2)		
Drawyer Creek	DE010-001-03	1	14,074	1,707
		9	5,366	693
		10	8,814	1,230
Wiggins Mill Pond to confluence with Noxontown Pond	DE010-002-01	5	7,388	1,024
Deep Creek to confluence with Silver Lake	DE010-002-02	7	6,954	874
Noxontown Pond	DE010-L01	5	7,388	1,024
		6	5,498	742
Silver Lake	DE010-L02	7	6,954	874
		8	10,594	1,367
Shallcross Lake	DE010-L03	10	8,814	1,230

Note: A map of the Appoquinimink River basin and its subwatersheds is presented in Section 4.0

Table ES-2. WLAs for the MOT WWTP NPDES discharge (DE0050547).

Parameter	WLA
Flow	0.5 mgd
CBOD-5 day	34.8 lbs/day (12,702 lbs/year)
Total Kjeldahl Nitrogen (TKN)	10.4 lbs/day (3,796 lbs/year)
Total Phosphorus (TP)	2.1 lbs/day (766.5 lbs/year)

The TMDL represents one allocation scenario. As implementation of the established TMDL proceeds, DNREC may find that the applicable water quality standard can be achieved through other combinations of point and nonpoint source allocations that are more feasible and/or cost effective. If that happens, DNREC is free to re-run the model to propose a revised TMDL with an alternative allocation scenario that will achieve water quality standards. It should be noted that, by transferring loadings from one source to another, the results of the model may change even if the total loading remains the same because the proximity and timing of difference sources impacts the river differently.

1.0 Introduction

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting their designated uses even though pollutant sources have implemented technology-based controls. A TMDL establishes the allowable load of a pollutant or other quantifiable parameter based on the relationship between pollutant sources and in-stream water quality. A TMDL provides the scientific basis for a state to establish water quality-based controls to reduce pollutant loads from both point and nonpoint sources and restore and maintain the quality of the state's water resources (USEPA, 1991).

Due to their high nutrient concentrations and/or low dissolved oxygen levels, the Delaware Department of Natural Resources and Environmental Control (DNREC) identified and included in the state’s 1996, 1998, and 2002 Section 303(d) lists of impaired waters several portions of the Appoquinimink River. This study will fulfill the requirements for nutrient and dissolved oxygen (DO) TMDLs for all waters in the Appoquinimink River basin included in the State’s 1996 and 1998 303(d) lists.

In 1996, the USEPA was sued under Section 303(d) of the CWA concerning the 303(d) list and TMDLs for the State of Delaware. Ths lawsuit maintained that Delaware had failed to fulfill the requirements of Section 303(d) and the EPA had failed to assume responsibilities not adequately performed by the State. A settlement in the lawsuit was reached and DNREC and EPA signed a Memorandum of Understanding (MOU) on July 25, 1997. Under the settlement, EPA agreed to complete TMDLs for all 1996 listed waters according to a 10-year schedule if the state failed to do so. Under the requirements of the suit settlement DNREC began this TMDL in order to compete the TMDL by December 30, 2002 but, because of various issues, requested EPA to complete the work. Because EPA is developing the TMDL the establishment date, in accordance with the suit settlement agreement, is December 15, 2003.

1.1 Background Information

The Appoquinimink River drains approximately 47 square miles in New Castle County, Delaware (Figure 1-1). Major tributaries in the basin include Drawyer Creek and Deep Creek. There are several small, shallow, man-made lakes and ponds in the watershed (Wiggins Mill Pond, Noxontown Lake (pond), Silver Lake, and Shallcross Lake). All tributaries mentioned are included within the listing for the mainstem of the Appoquinimink River on Delaware’s 303(d) list of impaired waters.

The Appoquinimink River watershed is primarily agricultural with three residential/urban centers (Middletown, Odessa, and Townsend). The area is experiencing considerable residential growth. The topography is generally characterized by flat to gently sloping land which is typical of the coastal plain.

The Appoquinimink River is designated as a warm-water fishery and is subject to all water

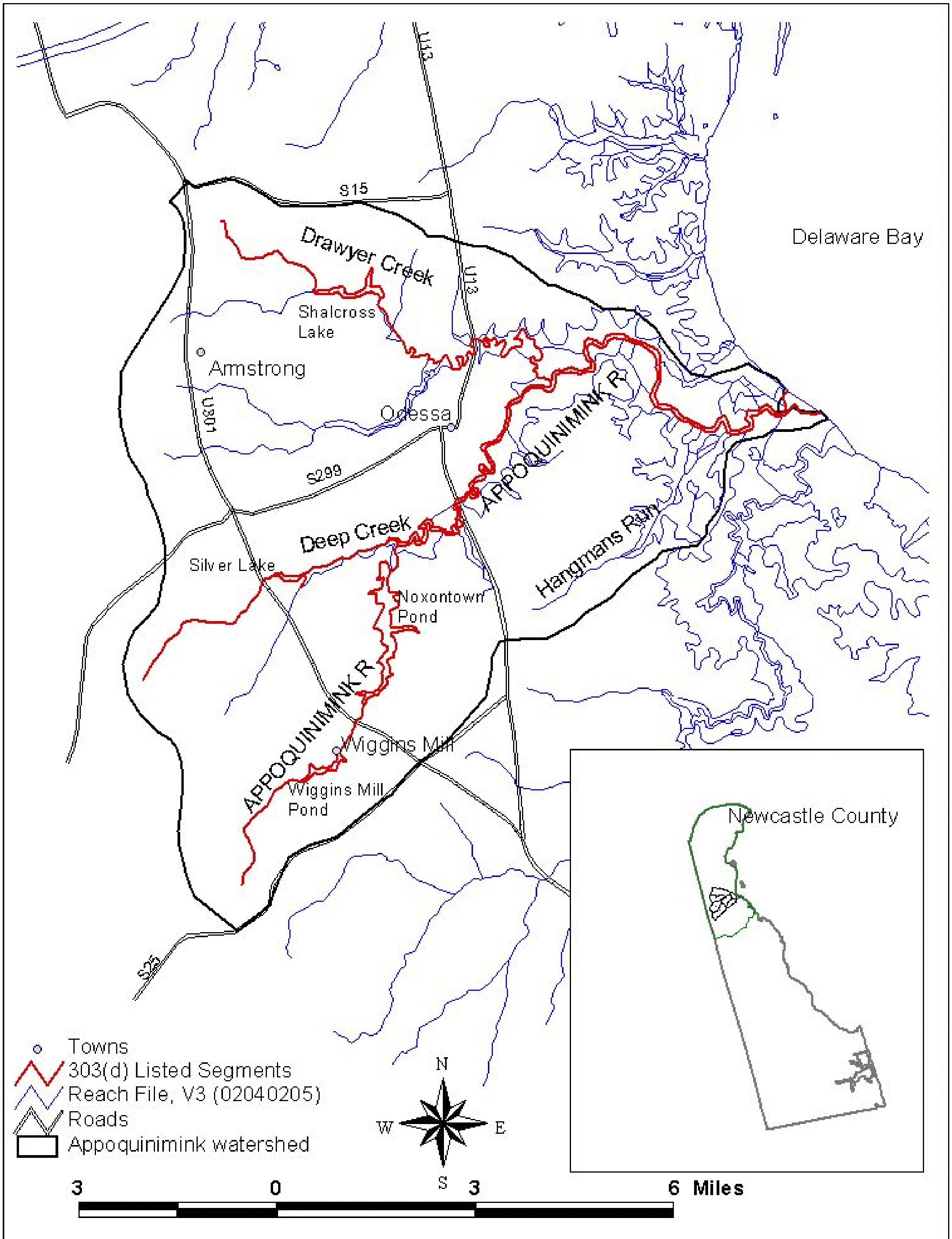

Figure 1-1. Appoquinimink River basin; stream segments on 1998 303(d) list are bold (red).

quality criteria specific to this designated use and those defined for general statewide water uses including aquatic life, water supply, and recreation. Several stream segments of the Appoquinimink River basin have been cited on the State's 303(d) list of impaired waters for failing to attain their applicable criteria.

The Appoquinimink River is tidal from the confluence with Delaware Bay to the dam at Noxontown Lake on the main stem, the dam at Silver Lake on Deep Creek, and the confluence with Drawyer Creek. Salinity intrusion from Delaware Bay typically reaches upstream past the Drawyer Creek confluence at river kilometer (Rkm) 8.5. The only non storm water point source in the watershed is the Middletown-Odessa-Townsend wastewater treatment plant (MOT WWTP) located at Rkm 10. Although the MOT WWTP primarily uses spray irrigation to dispose of its effluent, it is also permitted to discharge to the surface waters of Appoquinimink River.

1.2 Impairment Listing

TMDL development for this study was limited to nutrient and DO impairments in the Appoquinimink River basin. Eight stream segments in the Appoquinimink River basin were included in Delaware's 1996, 1998, and 2002 Section 303(d) lists due to nutrient and low DO impairments (see Table 1-1 and Figure 1-1). These include 2 segments of the Appoquinimink River mainstem as well as 3 tributary stream segments and 3 small lakes or ponds. Probable sources of nutrients have been identified as the municipal point source and nonpoint source runoff.

Table 1-1. Nutrient and DO impaired stream segments of the Appoquinimink River basin.

Segment Name	Segment ID	Size Affected	Pollutant and/or Stressor	Probable Sources	Year Listed
Appoquinimink River (Lower)	DE010-001-01	7.1 miles	Nutrients, DO	PS, NPS	1996
Appoquinimink River (Upper)	DE010-001-02	6.1 miles	Nutrients, DO	PS, NPS	1996
Drawyer Creek	DE010-001-03	8.2 miles	Nutrients, DO	NPS	1996
Wiggins Mill Pond to confluence with Noxontown Pond	DE010-002-01	3.4 miles	DO	NPS	1996
			Nutrients	NPS	2002
Deep Creek to confluence with Silver Lake	DE010-002-02	2.4 miles	DO	NPS	1996
			Nutrients	NPS	2002
Noxontown Pond	DE010-L01	158.6 acres	Nutrients	NPS	1998
Silver Lake	DE010-L02	38.7 acres	Nutrients	NPS	1996
Shallcross Lake	DE010-L03	43.1 acres	Nutrients	NPS	1996

1.3 Water Quality Standards

Section 10 of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, specifies the following designated uses for the waters of the Appoquinimink River basin: primary contact recreation; secondary contact recreation; fish, aquatic life, and wildlife; industrial water supply; and agricultural water supply (freshwater segments only).

The following sections of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, provide specific narrative and/or numeric criteria concerning the waters of the Appoquinimink River basin:

(1) Section 3: General guidelines regarding Department's Antidegradation policies
(2) Section 7: Narrative and numeric criteria for controlling nutrient enrichment in waters of the State
(3) Section 9: Specific narrative and numeric criteria for toxic substances
(4) Section 11: General water criteria for surface waters of the State.

Although there are no numeric criteria for nutrients in the waters of the Appoquinimink River basin, Section 7 of Delaware's Surface Water Quality Standards contains the following narrative criteria:

> *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 and human induced non-point 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 overenrichment. For tidal portions of stream basins of Indian River, Rehoboth Bay, and Little Assawoman Bay, controls needed to attain submerged aquatic vegetation growth season (approximately March 1 to October 31) average levels for dissolved inorganic nitrogen of 0.14 mg/L as N, for dissolved inorganic phosphorus of 0.01 mg/L as P, and for total suspended solids of 20 mg/L shall be instituted. The specific measures to be employed by existing NPDES facilities to meet the aforementioned criteria shall be as specified in Section 11.5(d) of these standards. Nutrient controls may include, but shall not be limited to, discharge limitations or institution of best management practices.*

In the absence of numeric nutrient criteria, DNREC has decided upon threshold levels of 3.0 mg/L for total nitrogen (TN), and 0.1 mg/L for total phosphorus (TP) in determining whether a stream should be placed on the State's 303(d) list of impaired waters.

Section 11 of the Standards contains numeric criteria for DO and the following water quality criteria are applicable to fresh and marine waters of the Appoquinimink River basin:

General Criteria for Dissolved Oxygen in Fresh Waters

(a) Average for the June-September period shall not be less than 5.5 mg/L.
(b) Minimum shall not be less than 4.0 mg/L.

(c) *In cases where natural conditions prevent attainment of these criteria, allowable reduction in dissolved oxygen as a result of human activities shall be determined through application of the requirements in Sections 3 and 5 of these Standards.*
(d) *The Department may mandate additional limitations on a site-specific basis in order to provide incremental protection for early stages of fish.*

General Criteria for Dissolved Oxygen in Marine Waters
(a) *Average for the June-September period shall not be less than 5.0 mg/L.*
(b) *Minimum shall not be less than 4.0 mg/L.*
(c) *In cases where natural conditions prevent attainment of these criteria, allowable reduction in dissolved oxygen as a result of human activities shall be determined through application of the requirements in Sections 3 and 5 of these Standards.*
(d) *The Department may mandate additional limitations on a site-specific basis in order to provide incremental protection for early stages of fish.*

According to Section 2 of the Standards, fresh waters are defined as waters of the state which contain natural levels of salinity of 5 parts per thousand (ppt) or less, and marine waters contain natural levels of salinity in excess of 5 ppt. The water quality standards for DO and nutrients are summarized in Table 1-2.

Table 1-2. Numeric water quality standards for Delaware.

Parameter	Comments	Criteria		Period
		Average (mg/L)	Minimum (mg/L)	
Dissolved Oxygen	Fresh waters (i.e., salinity less than 5.0 ppt)	5.5	4.0	Jun 1 to Sep 30
	Marine waters (i.e., salinity equal to or greater than 5.0 ppt)	5.0	4.0	Jun 1 to Sep 30
	Both fresh and marine waters	Not specified	4.0	Oct 1 to May 31
Ammonia Nitrogen	No numeric criteria; narrative statement for prevention of toxicity. EPA water quality criteria for ammonia nitrogen toxicity used for TMDL.	pH dependent		year round
Nitrate Nitrogen	Maximum contaminant level for public drinking water systems.	10 mg/L as N		year round
Total Nitrogen	Target for Appoquinimink River basin proposed by DNREC.	3.0 mg/L as N		year round
Total Phosphorus	Target for Appoquinimink River basin proposed by DNREC.	0.2 mg/L as P		year round

2.0 Source Assessment

Analyses were performed on historical water quality and streamflow data to determine critical flow conditions and relative loads to assess the impact of point and nonpoint sources on instream water quality. These analyses helped to assess nutrient and oxygen demanding sources in the Appoquinimink River watershed. Identification of critical flow conditions was an important step in determining the methodology used for TMDL development.

2.1 Data Sources

A wide range of information was reviewed for the Appoquinimink River watershed. The categories of data examined include physiographic data describing physical conditions of the watershed, environmental monitoring data identifying potential pollutant sources and contributions to the river and its tributaries, hydrologic flow data, and water quality monitoring data. Table 2-1 summarizes the various data types and data sources reviewed and collected.

Table 2-1. Sources of Data for the Appoquinimink River basin.

Data Category	Description	Data Source(s)
Watershed Physiographic Data	Land Use (National Land Cover Data)	USGS - MRLC
	Stream Reach Coverage (RF 1 and 3, and NHD)	USGS, US EPA BASINS
	Digital Elevation Model (30 meter resolution)	USGS - National Elevation Dataset (NED)
	Soils	NRCS/USGS STASGO
	Weather Information	National Climatic Data Center, National Weather Service
Hydrologic data	Stream Flow Data	USGS
Water Quality	Instream concentrations of nutrients and oxygen demanding substances as well as other parameters	EPA STORET

USGS - United States Geological Survey; BASINS - Better Assessment Science; STASGO - State Soil and Geographic Database; DNREC - Delaware Department of Natural Resources and Environmental Control; US EPA - United States Environmental Protection Agency; EPA STORET - STOrage and RETrieval System; RF 1 and 3 - Reach File 1 and Reach File 3; NHD - National Hydrography Dataset

Additionally, a number of technical reports describing past modeling efforts for the Appoquinimink River were reviewed. These include DNREC's *Technical Analysis for the Proposed Appoquinimink River TMDLs - October 2001* and Hydroqual's *The Appoquinimink River Watershed TMDL Model* (2001). The reader is referred to these reports for more detailed data summaries and analysis.

2.2 Nutrient and Oxygen Demanding Sources

A review of the historical data collected in the Appoquinimink River basin provided insight into the critical period for impact analysis. Once this condition was identified, the focus was directed to those sources having the most impact during such periods.

2.2.1 Identification of Critical Period

Nutrient and DO data have been collected by DNREC at multiple locations in the Appoquinimink River and its tributaries (see Figure 2-1). Concentrations of DO below the water quality standards have been observed at a number of stations, primarily during the summer months (i.e., June through September). Data and past modeling studies indicate that DO levels in the estuarine environment are influenced by contributions of nutrients and organic matter from the watershed (and ultimately the in-stream sediment) throughout the year. The impact from the loadings manifests itself during the summer period (DNREC, 2001). Therefore, the critical period can be influenced by a range of potential sources, including point and nonpoint sources.

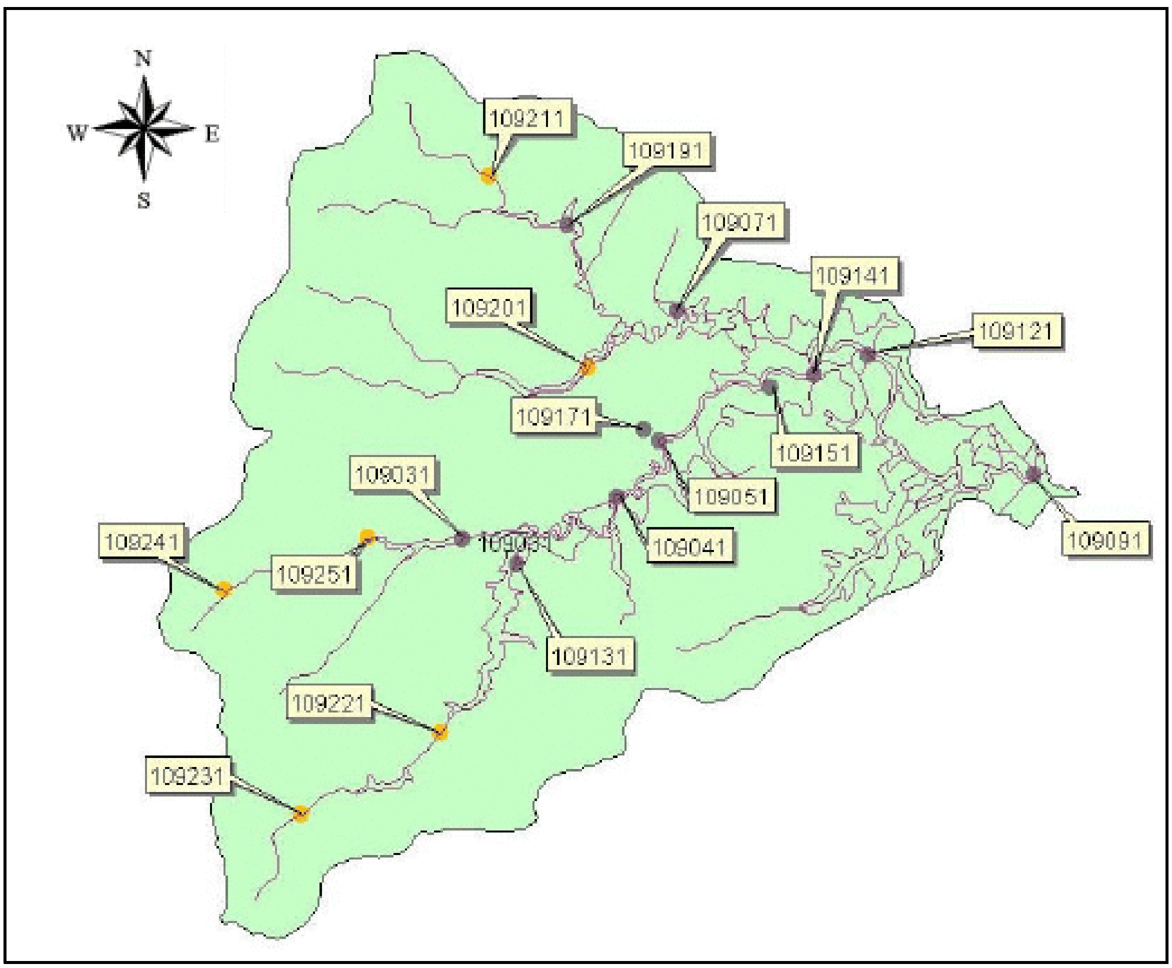

Figure 2-1. Monitoring stations in the Appoquinimink River basin.

2.2.2 Point Sources

Permitted point sources include discharges such as municipal waste water treatment plants, storm water systems, and industrial waste water facilities. The only non storm water point source discharger to the Appoquinimink River is the Middletown-Odessa-Townsend wastewater treatment plant (MOT WWTP, permit number DE0050547). The permitted and estimated characteristics of the MOT WWTP effluent are summarized in Table 2-2.

Table 2-2. Characteristics of MOT WWTP NPDES discharge (DE0050547).

Parameter	Permit Value	Estimated Value	Load
Flow	0.5 mgd		-
CBOD-5 day	34.8 lbs/day		34.8 lbs/day
Total Kjeldahl Nitrogen (TKN)	3,796 lbs/year		10.4 lbs/day
Total Phosphorus (TP)	2.1 lbs/day		2.1 lbs/day
Dissolved Oxygen (DO)		0.695 mg/L	2.9 lbs/day

EPA's stormwater permitting regulations require municipalities to obtain permit coverage for all storm water discharges from separate storm sewer systems (MS4s). Implementation of these regulations are phased such that large and medium sized municipalities were required to obtain storm water permit coverage in 1990 and small municipalities by March 2003. New Castle County has a general storm water permit which includes the municipalities of Middletown, Odessa, and Townsend. These municipalities cover less than 3 percent of the Appoquinimink watershed, but contain most of the watershed's population (4,500 people). The population is expected to expand within the near future. Although the watershed's economy is essentially agrarian, some light industry does exist in Middletown. The MS4 permit for New Castle county covers the major municipalities within the County and the Delaware Department of Transportation. The storm water loadings from the land segments covered by this permit required a waste load allocation (WLA).

2.2.3 Nonpoint Sources

In addition to point sources, nonpoint sources may also contribute to water quality impairments in the Appoquinimink watershed. Nonpoint sources represent contributions from diffuse, non-permitted sources. Typically, nonpoint sources are precipitation driven and occur as overland flow that carries pollutants into streams. They can impact a waterbody directly, e.g. through elevated concentrations during storm events and indirectly, e.g. through contribution to bottom sediments and ultimately sediment oxygen demand (SOD).

Land use information from the USGS Multi-Resolution Land Characterization (MRLC) completed in 1992 was available for the Appoquinimink watershed region and was used to evaluate potential nonpoint sources (as well as diffuse sources covered under the storm water permits). Landuse data for 2002 was obtained and used to supplement analysis of the 1992 data. Land use information for the Appoquinimink watershed is summarized in Table 2-3 (for both 1992 and 2002). The 1992 land use distribution for the Appoquinimink River watershed is shown in Figure 2-2.

Table 2-3. Landuse in the Appoquinimink River basin.

Landuse	1992		2002	
	mi^2	%	mi^2	%
Open Water	**1.47**	**3.19**	**1.83**	**3.97**
Low Intensity Residential	**0.85**	**1.84**	**6.06**	**13.13**
High Intensity Residential	**0.10**	**0.22**	**0.89**	**1.93**
High Intensity Commercial/ Industrial/ Transportation	**0.32**	**0.69**	**2.16**	**4.68**
Disturbed	**0.03**	**0.07**	**0.92**	**1.99**
Forest	**6.17**	**13.37**	**4.06**	**8.80**
Pasture/Hay	**8.41**	**18.22**	**1.60**	**3.47**
Row Crops	**23.53**	**50.99**	**23.74**	**51.44**
Other Grasses (Urban/recreational)	**0.01**	**0.02**	**0.34**	**0.74**
Wetlands	**5.26**	**11.40**	**4.55**	**9.86**
Total	**46.15**		**46.15**	

Note: The landuse datasets were obtained from different sources. Discrepancies between open water areas are attributable to a difference in the resolution of the datasets or possibly seasonal/hydrologic characteristics.

Based on the landuse data, it is clear that agricultural lands (row crops, in particular) cover a large portion of the watershed. Between 1992 and 2002, there was a significant increase in urban areas and a corresponding decrease in pasture/hay and forested areas. The 1997 Census of Agriculture identifies that the predominant crop types within New Castle County are soybeans, corn, and wheat. It also identifies that within the county, there are approximately 2,698 cattle and calves, 51 hogs and pigs, and 222 sheep and lambs (while chicken numbers are not available).

While a portion of the watershed is sewered, there are also areas that rely on septic systems for sewage disposal. Many of these areas fall outside denoted urban boundaries. Septic systems can contribute pollutants to waterbodies through a number of mechanisms usually associated with failure of the systems. Within New Castle County, there are approximately 12,000 septic tanks or cesspools (based on 1990 U.S. Census Bureau figures).

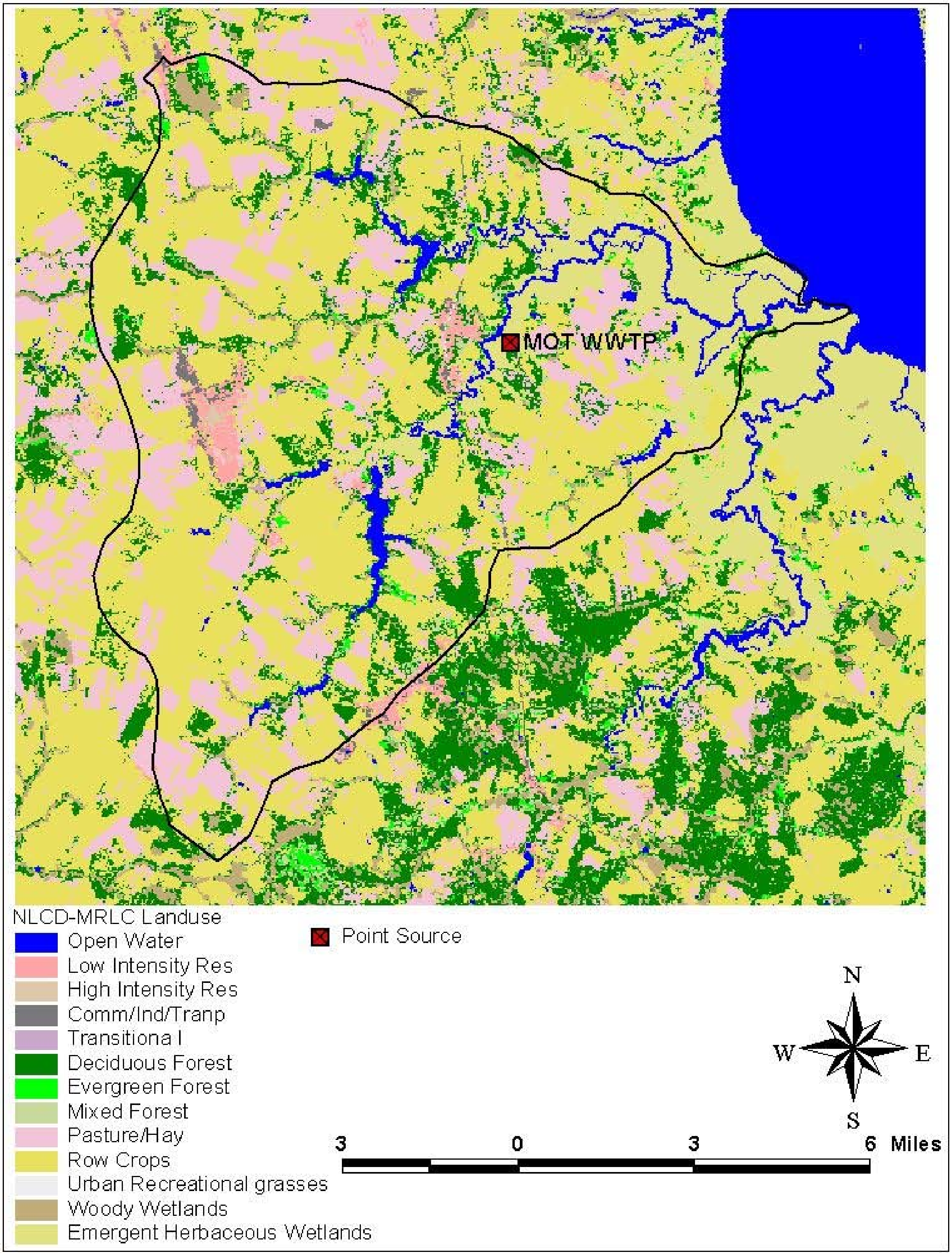

Figure 2-2. Land uses in the Appoquinimink River basin.

3.0 TMDL Endpoint Determination

The CWA requires states to adopt water quality standards to define the water goals for a waterbody by designating the use or uses to be made of the water, by setting criteria necessary to protect the uses and by protecting water quality through antidegradation provisions. These standards serve dual purposes: (1) they establish water quality goals for a specific waterbody, and (2) they serve as the regulatory basis for establishing water quality-based controls and strategies beyond the technology-based levels of treatment required by sections 301(b) and 306 of the CWA (USEPA, 1994).

Once the applicable use designation and water quality criteria are identified, the numeric water quality target or goal for the TMDL is determined. These targets represent a number where the applicable water quality is achieved and maintained in the waterbody. For the Appoquinimink River TMDLs, the target is to attain and maintain the applicable DO water quality criteria under critical summer conditions. The general water quality targets or endpoints for the Appoquinimink River basin TMDLs are identified in Table 3-1. The fresh water dissolved oxygen criteria was selected for the Appoquinimink River TMDL. The fresh water criteria was chosen because average summer salinity values on the Appoquinimink River were below 5.0 parts per thousand (ppt) upstream of its confluence with Drawer Creek while the minimum salinity values were below 5.0 ppt in the areas downstream of Drawer Creek. This methodology corresponds to DNREC's decision in the *Technical Analysis for the Proposed Appoquinimink River TMDLs* - October 2001.

Table 3-1. Summary of TMDL endpoints for Appoquinimink River basin.

Parameter	Comments	Target Limit		Period
		Average (mg/L)	Minimum (mg/L)	
Dissolved Oxygen	Fresh waters (i.e., salinity less than 5.0 ppt)	5.5	4.0	Jun 1 to Sep 30
	Marine waters (i.e., salinity equal to or greater than 5.0 ppt)	5.0	4.0	Jun 1 to Sep 30
	Both fresh and marine waters	5.5	4.0	Oct 1 to May 31
Ammonia Nitrogen	No numeric criteria; narrative statement for prevention of toxicity. EPA water quality criteria for ammonia nitrogen toxicity used for TMDL.	pH dependent		year round
Nitrate Nitrogen	Maximum contaminant level for public drinking water systems.	10 mg/L as N		year round

To meet the designated uses of the Appoquinimink River and its tributaries, water quality targets, or *endpoints*, must be met under all conditions. The selection of these endpoints considers the water quality standards prescribed by those designated uses (Section 1.3). Results of the analysis of water quality data collected by DNREC in the basin indicate that the water quality criteria for both the minimum DO and average DO, which EPA interprets as a daily average concentration, were not protected at a number of stations in the tidal Appoquinimink River.

These TMDLs have identified the pollutants and sources of pollutants that cause or contribute to the impairment of the DO criteria and allocate appropriate loadings to the various sources. Given our scientific knowledge regarding the interrelationship of nutrients, biochemical oxygen demand (BOD), and SOD and their impact on DO, it is necessary and appropriate to establish numeric targets for TN, TP, and CBOD based on applicable state criteria to support the attainment of the numeric DO criteria. Establishing numeric water quality endpoints or goals also provides the ability to measure progress toward attainment of the water quality criteria and to identify the amount or degree of deviation from the allowable pollutant load.

While the ultimate endpoint for this TMDL was to ensure that the water quality criteria for DO was maintained throughout the Appoquinimink River basin, it was necessary to determine if other applicable water quality criteria were met and maintained. Specifically, this applies to the numeric water quality criteria for nitrate nitrogen of 10 mg/L as N. The water quality standard for nitrate nitrogen was protected throughout the Appoquinimink River basin. Delaware does not have a numeric water quality criteria for ammonia nitrogen, however, the analysis indicates that ammonia nitrogen concentrations throughout the Appoquinimink River basin are consistent with the recommended EPA water quality criterion from Section 304(a) of the CWA.

Achieving these instream numeric water quality targets will ensure that the designated uses (aquatic life and human health) of waters in the Appoquinimink River basin are supported during critical conditions.

4.0 TMDL Methodology and Calculation

The following sections discuss the methodology used for TMDL development and results in terms of TMDLs and required load reductions for each stream segment listed on Delaware's 303(d) list as impaired due to nutrients. The selected methodology considers specific impacts and conditions determined necessary for accurate source representation and system response.

4.1 Methodology

Analysis of water quality data indicate that the Appoquinimink River is most susceptible to DO and aquatic life use impairments during the summer. More specifically, impairments occur during the summer as a result of multiple factors, including: SOD levels (impacted by land-based point and nonpoint source contributions), hydrodynamics (tidal influences), and oxygen's solubility based on temperature. To fully evaluate these factors and determine a TMDL for Appoquinimink River, a dynamic hydrodynamic and water quality model was utilized that included chemical and biological processes associated with nutrient enriched and eutrophic systems. An enhanced version of EPA's Water Quality Analysis and Simulation Program (WASP) model (Ambrose et al., 1993) which incorporated a predictive sediment diagenesis submodel was used for this TMDL analysis.

The computational framework for the Appoquiniminik River modeling effort included four components: (1) the Generalized Watershed Loading Functions (GWLF) watershed loading model, (2) the DYNHYD hydrodynamic model(WASP's hydrodynamic model), (3) the WASP water quality simulation model, and (4) the sediment diagenesis model. The inputs for the GWLF model, which are further described in Appendix A, included rainfall and land use data for subwatersheds representing the entire Appoquinimink River basin. Outputs from GWLF included flow rate, TN, and TP on a monthly basis. The outputs from GWLF were input to the DYNHYD and WASP models after conversion to daily values using rainfall data and a triangular hydrograph/pollutograph assumption. The DYNHYD and WASP models are based on an existing model developed and applied by DNREC (2001) for the Appoquinimink River (and described in Appendix B). Inputs for DYNHYD included river bathymetry, tidal forcing at the Delaware River boundary, and upstream inflows. Outputs from DYNHYD included tidal flows and water depths that were used by the WASP model to transport constituents throughout the Appoquinimink River system. The WASP model provides a generalized framework for simulating water quality and transport in surface waters and is based on a finite-segment approach. WASP is supported by the EPA's Center for Exposure and Assessment Modeling (CEAM) in Athens, Georgia. A more detailed description of the DYNHYD and WASP models can be found in Appendix B.

For this TMDL, several major updates have been implemented into the Appoquinimink water quality modeling framework previously developed by DNREC (2001). The major modifications to the modeling framework and system configuration are summarized in the following subsections.

4.1.1 Corrected Sediment-Water Column Connection

In the previous version of the Appoquinimink River model, the sediment compartment was isolated from the water column, resulting in no flux of nutrients from the sediment bed to the water column. Therefore, nutrients in the sediment were not affecting the DO concentrations in the water column in the previous model. This previous version of the WASP code was adequate when the model configuration did not include an active sediment layer. However, when an active sediment layer was included in the model, there was a lack of nutrient benthic fluxes because the original code was not written for an active sediment layer. This issue was resolved in the current effort by modifying the source code. The nutrient concentration in the water column is now responsive to the specified sediment nutrient flux. In the current model the in-stream sediment is a source of nutrients to the water column and does impact the DO concentrations.

4.1.2 Corrected Inconsistent CBODu/CBOD5 Ratio and Kd Values

In the previous version of the model, the carbonaceous biochemical oxygen demand (CBOD) deoxygenation rate (Kd) was set to 0.075/day, which corresponds to a CBODu/CBOD5 ratio of 3.19. However, in the boundary condition section, the CBODu/CBOD5 ratio was set as 1.58, which corresponds to a Kd decay rate of 0.2/day. This inconsistency was resolved through the recent calibration process, by using a Kd value of 0.10/day resulting in a corresponding CBODu/CBOD5 ratio of 2.54. By inputting the Kd value into the equation below, the CBODu/CBOD5 ratio can be determined. Assuming the instream CBOD deoxygenation rate (Kd) is a direct reflection of the wastewater characteristics (a reasonable assumption for highly treated effluents), the CBODu/CBOD5 ratio is related to Kd in the receiving water according to the following equation (Lung, 1998):

$$\frac{CBOD_u}{CBOD_5} = \frac{1}{1 - e^{-5Kd}}$$

and solving the above equation for Kd results in the following:

$$Kd = -\frac{\ln\left(1 - \frac{CBOD_5}{CBOD_u}\right)}{5}$$

4.1.3 Incorporated a Gaussian Temperature Function for Algal Growth Rate

In the standard WASP model, the temperature effect on algal growth rate is represented as a power function, which implies that a higher temperature results in a higher algal growth rate. This simplified assumption may not represent the conditions in many natural waterbodies. According to the observed data, the chlorophyll-*a* concentrations in the Appoquinimink River are relatively low in summer when temperature is high and the concentrations are significantly higher during fall when the temperature is lower. At the same time, there is no other evidence showing that this trend was caused by other factors. Therefore, it was assumed that temperature might be a prime factor responsible for this trend. To better represent this trend, the Gaussian temperature function, which has been considered to be more representative of real algal growth rate characteristics and is used in EFDC and other models (Park et al., 1995; HydroQual, 2001), was incorporated into the WASP model. This more accurately simulates the observed conditions in the watershed.

The formulation of the Gaussian temperature function is:

$$F(t) = \exp(-KTG1\,[T-TM1]^2) \quad \text{when } T <= TM1$$
$$F(t) = \exp(-KTG2\,[TM2-T]^2) \quad \text{when } T >= TM2$$

where, F(t) is the temperature correction function
T is the water temperature
KTG1 and KTG2 are the temperature correction coefficients
TM1 and TM2 are the lower and upper temperature bounds for optimal algal growth

4.1.4 Incorporation of a Diurnal DO Simulation Function Based on Phytoplankton Dynamics

Primary producers, such as phytoplankton, use nutrients during sun light hours for production and consume oxygen during nightfall when photosynthesis ceases. As a result these organisms can inflate DO concentrations during the day and lower DO concentrations through the night. As shown by the monitoring data, phytoplankton concentration can reach very high values in certain sections of the Appoquinimink River. It was therefore, necessary to include the impacts of primary production in the model. To account for the possible impact of the phytoplankton concentrations on DO, a diurnal DO simulation function was incorporated into the WASP framework. In addition, a simplified diurnal simulation module was added to the code to allow for a more accurate representation of DO fluctuation in the receiving water. In this simplified diurnal simulation module, the growth of phytoplankton occur during daylight hours and halt at night. The average solar radiation intensity was used to govern the algal dynamics during daylight hours, and a zero solar radiation intensity was used to restrict algal growth at night. The modified model is now capable of simulating time-variable DO with hourly resolution (or higher resolution as necessary), and estimating daily average, minimum, and maximum DO concentrations. To use the simplified diurnal simulation function, the light switch LGHTS were set to 6.0 to activate the relevant calculations. This addition to the model should better represent observed conditions.

4.1.5 Incorporation of a Predictive Sediment Diagenesis Module

The previous modeling report by DNREC (2001) indicated that sediment nutrient fluxes play a major role in the Appoquinimink's DO impairments. It also recommended that a dynamic sediment flux model be incorporated to properly balance watershed contributions throughout the year and fluxes to and from the sediment. To better account for the relationship between SOD and external load, a sediment diagenesis model was incorporated into WASP for this project and is based on the sediment flux modeling theory of DiToro (2001), as well as an implementation by Lung (2000). The sediment diagenesis model takes into account the CBOD and nutrients moving between the sediment and water column. The sediment layers allow an interaction between the sediment oxygen demand and the water column. The model also describes changes in aqueous methane, gaseous methane, ammonia, and gaseous nitrogen. This is accomplished by maintenance of the mass balance of CBOD and organic nitrogen.

4.1.6 Model Calibration and Validation

For WASP (and DYNHYD) modeling purposes, the Appoquinimink River system was divided into 47 segments from its confluence with the Delaware River to the headwaters of Drawyer Creek, Deep Creek, and Wiggins Mill Pond Branch (refer to Appendix B for more detailed information). Three small lakes or ponds were also included in the modeling framework (Shallcross Lake, Silver Lake, and Noxontown Pond). The DYNHYD and WASP modeling components were calibrated to flow and water quality conditions for the period May to July 1991. The model was validated using the period August to October 1991. The model calibration process involved modeling parameter adjustment, however the validation process simply involved application of the calibrated model parameters (without further adjustment). This calibration and validation approach enabled the dynamic sediment diagenesis model to generate results for the calibration period, which could then be used as a starting point for the validation condition. The DYNHYD model was run on a 5 second timestep and the WASP model was run on a 60 second timestep.

WASP model boundary conditions for the calibration and validation periods were generated using the GWLF watershed model (Appendix A), which was configured with meteorological data from the Wilmington New Castle County Airport and the 1992 MRLC landuse data. GWLF was run for the three-year period 1989 through 1991 using rainfall records from the airport. Flow and nutrient loads (TN and TP) were generated for subwatersheds used to represent the Appoquinimink watershed in GWLF and applied directly to respective WASP modeling segments for this entire time period. Although the WASP calibration and validation focused on 1991, it was necessary to simulate the two previous years, in order to stabilize the sediment diagenesis model. That is, rather than selecting arbitrary starting points for sediment-flux parameters, the model was run using predicted nutrient loads from the watershed over time to internally generate the sediment-flux parameters for the calibration condition.

The GWLF model generated TN and TP loads for delivery to the receiving waters in the watershed. These loads were, in turn, converted to nitrate-nitrite (NO2/NO3), ammonium (NH4), organic nitrogen, orthophosphate (OPO4), and organic phosphorus loads using ratios of: 0.670, 0.066, 0.264, 0.400, and 0.600, respectively. These ratios are consistent with those utilized in the 2001 DNREC analysis and were based on monitoring data. For application of these loads to the WASP model, the organic nutrient loads were additionally converted to CBOD loads. The following ratio was used: CBODu/organic nitrogen = 30.4. This ratio was initially determined based on the Redfield Ratio of 0.176 nitrogen(N)/carbon(C), and a carbon to oxygen ratio of 2.67 g O2/g C. This ratio was then refined for the waterbodies being evaluated through an iterative model calibration process. The relatively high CBODu/organic nitrogen ratio can be justified by the fact that in the watershed, organic nitrogen is relatively diminished (at low levels), corresponding to a higher C/N ratio (and CBODu/Org-N ratio).

For the calibration and validation periods a number of important assumptions were made regarding the boundary conditions from the Delaware River and the load being contributed by the MOT WWTP. Tidal contributions from the Delaware River varied depending on the time of year and were assumed to contribute 0.60 to 1.34 mg/L of NO2/NO3, 0.05 to 0.14 mg/L of NH3, 0.03 to 0.05 mg/L of OPO4, and 6.325 mg/L of CBODu. The MOT WWTP was assumed to contribute at levels based on 1991 discharge conditions. These conditions were used in the DNREC 2001 analysis and are as follows: 0.5 mgd, 0.0 mg/L of NO2/NO3, 10.0 mg/L of NH3, 0.845 mg/L of OPO4, and 19.5 mg/L of CBOD5 (55.4 mg/L of CBODu). This was done for the calibration and validation of the model since the calibration was to 1991 water quality data. However, the River was modeled with more current MOT data for the TMDL scenarios. In the various TMDL scenarios the pollutant and DO concentrations in the effluent were altered.

The calibration and validation plots for DO, chlorophyll-a, and nutrients (NH4, NO3, PO4, organic nitrogen, and organic phosphorus) are presented in Appendix C for the Appoquinimink River. Due to monitoring data limitations regarding time-variability, the plots present longitudinal profiles for the river (from the Delaware River to upstream of Wiggins Mill Pond) of minimum, mean, and maximum daily values of the constituents (over the calibration period and validation period separately). The model results are compared to mean, minimum, and maximum monitoring values at different locations for the calibration and validation periods (separately). It should be noted that the model results are reflective of predictions for every day during the calibration period (May through July) and validation period (August through October) while the monitoring data are only reflective of a few days during that period.

The goal of calibration and validation was to most accurately represent the observed range of constituent variability at all locations along the river's length.

4.2 TMDL Calculation

TMDLs were established for each individual segment listed on Delaware's 303(d) list. TMDLs consist of a point source wasteload allocation (WLA), a nonpoint source load allocation (LA), and a margin of safety (MOS). The TMDLs identify the sources of pollutants that cause or contribute to the impairment of the DO criteria and allocate appropriate loadings to the various sources. Given the scientific knowledge available, and utilizing the model processes that describe the interrelationship of nutrients, CBOD, SOD, and their impact on DO, it was determined necessary to prescribe WLAs and LAs for TN and TP (for land-based contributions) and CBOD, TP, and TKN (for the MOT WWTP).

The equation used for TMDLs and allocations to sources is:

$$TMDL = \sum WLA + \sum LA + MOS$$

The WLA portion of this equation is the total loading assigned to point sources. Federal regulations (40 CFR 130.7) require TMDLs to include individual WLAs for each point source. The LA portion is the loading assigned to nonpoint sources. According to federal regulations (40 CFR 130.2(g)), load allocations are best estimates of the nonpoint or background loading. These allocations may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint sources should be distinguished (EPA, 2001). The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis.

For this study, the MOS is assumed implicit through conservative assumptions used in the modeling process. These conservative assumptions include:

- There is a MOS with respect to the 4.0 mg/L minimum DO standard. That is, the TMDL conditions bring the minimum DO well above the required minimum of 4.0 mg/L while simultaneously closely meeting the 5.5 mg/L average.
- Losses of land-based nutrient and organics loads for the storms along the path to the receiving waters were not explicitly represented in the model.
- The model does not consider loss of organic matter from the sediment due to high flow conditions. Therefore, all organics that settle remain available for diagenesis processes. Thus, the predicted SOD may be somewhat higher than that in reality.

While the model achieves a reasonable level of accuracy, there is a certain amount of uncertainty associated with the model predictions. This uncertainty can be attributed to a number of factors, including:

- There are limited spatially and temporally representative water quality data.
- In generating boundary condition loads to the stream segments, it was assumed that long-term meteorological data for the Wilmington Airport is representative of conditions throughout the Appoquinimink watershed.
- The GWLF model does not explicitly simulate detailed nutrient generation and loading processes although it does provide reasonable trends.
- GWLF generates monthly nutrient load and flow, while the receiving water quality model requires higher temporal resolution to account for the time variability in water quality. The monthly load was distributed to daily values based on the rainfall distribution.
- GWLF only generates loads for TN and TP, while WASP requires loads for NH3, NO3/NO2, OPO4, CBOD, organic nitrogen, and organic phosphorus. Therefore, the TN and TP generated by the GWLF model were partitioned into the constituents used in WASP model based on the ratio previously used in 1998 TMDL and DNREC's recent modeling analysis.
- The receiving water quality model is a simplified representation of reality. It uses discrete computational segments to represent a continuous system, uses a lumped chlorophyll-a parameter to represent the entire population of algae, uses CBOD parameter CBOD to represent organic carbon, and does not explicitly account for the impact of groundwater (although groundwater contributions are represented in the GWLF model).
- Water quality monitoring data focused on evaluating the specific impacts of the tidal marshes were not available to support this study. As such, detailed processes associated with the marshes were not explicitly represented in the receiving water modeling framework (DYNHYD and WASP). Landuse data were available for the watershed, and thus the wetland areas (marshes) were represented as a distinct landuse category in the GWLF modeling framework. Because insufficient monitoring data were available to fully define the impact (in terms of a net gain or loss) of the wetlands, neither the detainment capacity nor loading processes were explicitly considered. That is, land-based constituent loads from the watershed, which in a good portion of the Appoquinimink River watershed pass through wetlands prior to feeding into the rivers (and tributaries), were not considered to be detained (and thus utilized) by the wetlands. At the same time, contributions of nutrients and organic matter from the wetlands themselves were also not explicitly represented. It was assumed that these factors would have a balancing effect on the overall loading to the river. Because the model was successfully calibrated through a comparison of predictions with in-stream monitoring data and did not indicate a major contributing source was being overlooked, the representation was deemed appropriate for TMDL analysis.

The TMDL development process involved the following steps:

1. The calibrated and validated model was run for a “baseline” condition. This condition was essentially the starting point for TMDL analysis. For the baseline condition, the MOT WWTP was set at its current permit limits which were based on EPA’s 1998 Appoquinimink TMDL WLA (as identified in Table 2-2), the Delaware Bay contributions were assumed to be consistent with those identified in Section 4.1.6, and the 1992 landuse scenario was used as the basis for generating flow and nutrient loads from the watershed to the receiving water models (DYNHYD and WASP). Although the 2002 landuse data were acquired and evaluated, the 1992 landuse data were used in the TMDL analysis. Using the 1992 landuse data likely results in a slightly different “baseline” loading than for 2002, however, this has no implications on the WLA and LA allocations (and total TMDL). The TMDL represents the assimilative capacity of the river and thus does not change due to the landuse distribution of the contributing watershed. The meteorological conditions that occurred during 1991 were assumed representative of typical conditions in the watershed. As identified in Section 4.4, this year was typical of most observed in the watershed and covered a range of hydrologic conditions. Dissolved oxygen concentrations predicted by the model for the period June through September were compared directly to Delaware’s DO criteria.
2. In the event that DO levels were not at or above the criteria, nutrient load reductions were required. The load reduction process involved reducing nutrient loads (specifically TN and TP) from the watershed until the DO criteria were met at all locations on impaired waters in the Appoquinimink River watershed.

4.3 TMDL Results and Allocations

TMDLs were developed for the Appoquinimink watershed based on Delaware’s DO criteria for fresh waters. Specifically, the minimum of the daily average DO concentrations predicted by the model during the June-September period (at every point along the impaired segments) was required to be at or above 5.5 mg/L. Additionally, the minimum of the daily minimum concentrations predicted by the model during the same period (at every point along the impaired segments) was required to be at or above 4.0 mg/L. Modeling results for impaired segments that show compliance with these criteria are presented in Appendix D. Note that each plot contains “baseline” conditions as described above and the successful compliance scenario (for which the TMDL allocations were based).

TMDLs are presented in Table 4-1 for impaired segments of the Appoquinimink River watershed. The TMDLs are presented by subwatershed contributing to the impaired segments (Figure 4-1). The total TMDL for each impaired segment is the combination of all TMDLs for contributing subwatersheds and for the MOT point source (Table 4-2), where applicable. These watershed-based loads and the allocated load for the MOT WWTP enable the in-stream DO concentrations to meet criteria under all conditions. It should be noted that the WLAs for the storm water permits and the LAs for areas not covered by storm water permits have been combined into a single WLA for each subwatershed (and impaired segment) and have not been presented separately. DNREC and New Castle County are currently in the process of mapping storm water discharge locations that are covered by the permits, and as such insufficient data are currently available to justify a more detailed allocation to storm water permit. Once the mapping effort on behalf of DNREC and the county is complete, the TMDL can be updated to distribute the TMDL among the storm water permits (WLAs) and the nonpoint sources (LAs). The WLA is assigned to New Castle County, Delaware Department of Transportation, Middletown, Odessa, and Townsend Township. The TMDL calls for a 60% reduction in nutrient loadings to the Appoquinimink River. When the TMDL was run using current land use data, without the best management practices included, a 56% reduction in nutrient loadings w required.

The TMDL represents one allocation scenario. As implementation of the established TMDL proceeds, DNREC may find that the applicable water quality standard can be achieved through other combinations of point and nonpoint source allocations that are more feasible and/or cost effective. If that happens, DNREC is free to re-run the model to propose a revised TMDL with an alternative allocation scenario that will achieve water quality standards. It should be noted that, by transferring loadings from one source to another, the results of the model may change even if the total loading remains the same because the proximity and timing of difference sources impacts the river differently.

Table 4-1. TMDLs and baseline loads by contributing subwatershed for impaired waters of the Appoquinimink.

Segment Name	Segment ID	Contributing Subwatershed(s)	Baseline TN (lbs/yr)	Baseline TP (lbs/yr)	WLA TN (lbs/yr)	WLA TP (lbs/yr)	% Reduced TN (lbs/yr)	% Reduced TP (lbs/yr)
Appoquinimink River (Lower)	DE010-001-01	1	35,185	4,267	14,074	1,707	60%	60%
		2	16,842	2,240	6,737	896	60%	60%
		3	3,866	579	1,547	231	60%	60%
		4	17,689	2,156	7,075	862	60%	60%
		5	18,471	2,560	7,388	1,024	60%	60%
		6	13,746	1,854	5,498	742	60%	60%
		7	17,386	2,184	6,954	874	60%	60%
		8	26,486	3,418	10,594	1,367	60%	60%
		9	13,416	1,734	5,366	693	60%	60%
		10	22,035	3,074	8,814	1,230	60%	60%
		The total TMDL for this segment also includes the WLAs for the MOT WWTP presented in Table 4-2.						
Appoquinimink River (Upper)	DE010-001-02	2	16,842	2,240	6,737	896	60%	60%
		5	18,471	2,560	7,388	1,024	60%	60%
		6	13,746	1,854	5,498	742	60%	60%
		7	17,386	2,184	6,954	874	60%	60%
		8	26,486	3,418	10,594	1,367	60%	60%
		The total TMDL for this segment also includes the WLAs for the MOT WWTP presented in Table 4-2.						
Drawyer Creek	DE010-001-03	1	35,185	4,267	14,074	1,707	60%	60%
		9	13,416	1,734	5,366	693	60%	60%
		10	22,035	3,074	8,814	1,230	60%	60%
Wiggins Mill Pond to confluence with Noxontown Pond	DE010-002-01	5	18,471	2,560	7,388	1,024	60%	60%
Deep Creek to confluence with Silver Lake	DE010-002-02	7	17,386	2,184	6,954	874	60%	60%
Noxontown Pond	DE010-L01	5	18,471	2,560	7,388	1,024	60%	60%
		6	13,746	1,854	5,498	742	60%	60%
Silver Lake	DE010-L02	7	17,386	2,184	6,954	874	60%	60%
		8	26,486	3,418	10,594	1,367	60%	60%
Shallcross Lake	DE010-L03	10	22,035	3,074	8,814	1,230	60%	60%

Table 4-2. WLAs for the MOT WWTP NPDES discharge (DE0050547).

Parameter	Permit Value	WLA	% Reduced
Flow	0.5 mgd	0.5 mgd	0%
CBOD-5 day	34.8 lbs/day	34.8 lbs/day (12,702 lbs/year)	0%
Total Kjeldahl Nitrogen (TKN)	3,796 lbs/year	10.4 lbs/day (3,796 lbs/year)	0%
Total Phosphorus (TP)	2.1 lbs/day	2.1 lbs/day (766.5 lbs/year)	0%

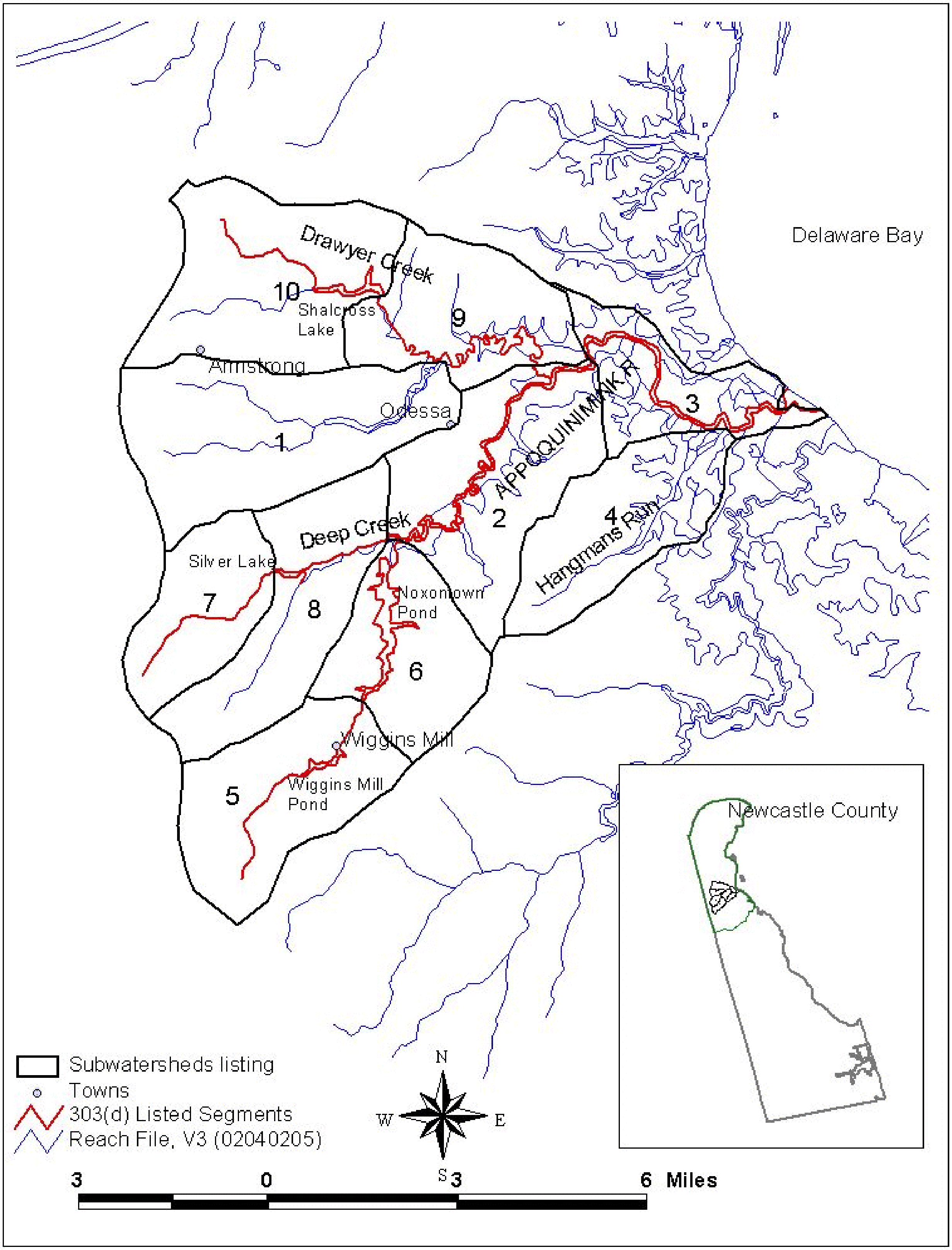

Figure 4-1. Map of Appoquinimink subwatersheds for summarizing TMDLs by impaired segment.

4.4 Consideration of Critical Conditions

Federal Regulations (40 CFR 130.7(c)(1)) require TMDLs to consider critical conditions for streamflow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality in waterbodies are protected during periods when they are most vulnerable. Critical conditions include combinations of environmental factors that result in attaining and maintaining the water quality criteria and have an acceptably low frequency of occurrence (USEPA, 2001).

TMDLs for the Appoquinimink River adequately address critical conditions through modeling for an entire year and using 1991 meteorological data, specifically. All conditions were considered through modeling for a full year, including the critical summer period when DO impairment is prevalent in the watershed. Because the receiving water model makes predictions at a sub-hourly timestep for the entire modeling period, it predicts constituent levels for low-flow as well as for storm events. More importantly, the model makes predictions for critical conditions overlooked by a steady-state analysis such as 7Q10 (e.g., by simulating relatively low-flow conditions that follow a storm event). A steady-state low-flow analysis assumes minimal land-based loading inputs, however, these inputs (which are typically contributed during storm events) become the most critical factor even during low flow events. Thus, the current modeling framework can be used to evaluate critical periods in more detail than a steady-state 7Q10 evaluation. The year 1991 was selected for modeling based on an analysis of available data. A statistical analysis was performed on USGS flow data in Morgan Creek (which was used as the reference watershed for the GWLF modeling effort and is assumed to be representative of conditions in the Appoquinimink watershed) since no data were available for the Appoquinimink River. The intention of the analysis was to compare annual volume totals at the gaging station for 1991 and the period 1980 through 2000. It is apparent from Figure 4-2 that the total volume for 1991 is very close to the long-term average annual volume.

In addition to the annual volumetric analysis, flow-duration curves for 1991 and the period 1980 through 2000 were compared. Figure 4-3 suggests that 1991 was representative of most flow conditions observed at the gage over a longer period of time, with the exception of extreme flood events and droughts. While the hydrologic regime of 1991 was consistent with average conditions throughout the past two decades, it also showed extreme depressions of dissolved oxygen in the monitoring data. This combination of factors suggested that 1991 meteorological conditions would be most representative and protective of conditions in the Appoquinimink River watershed.

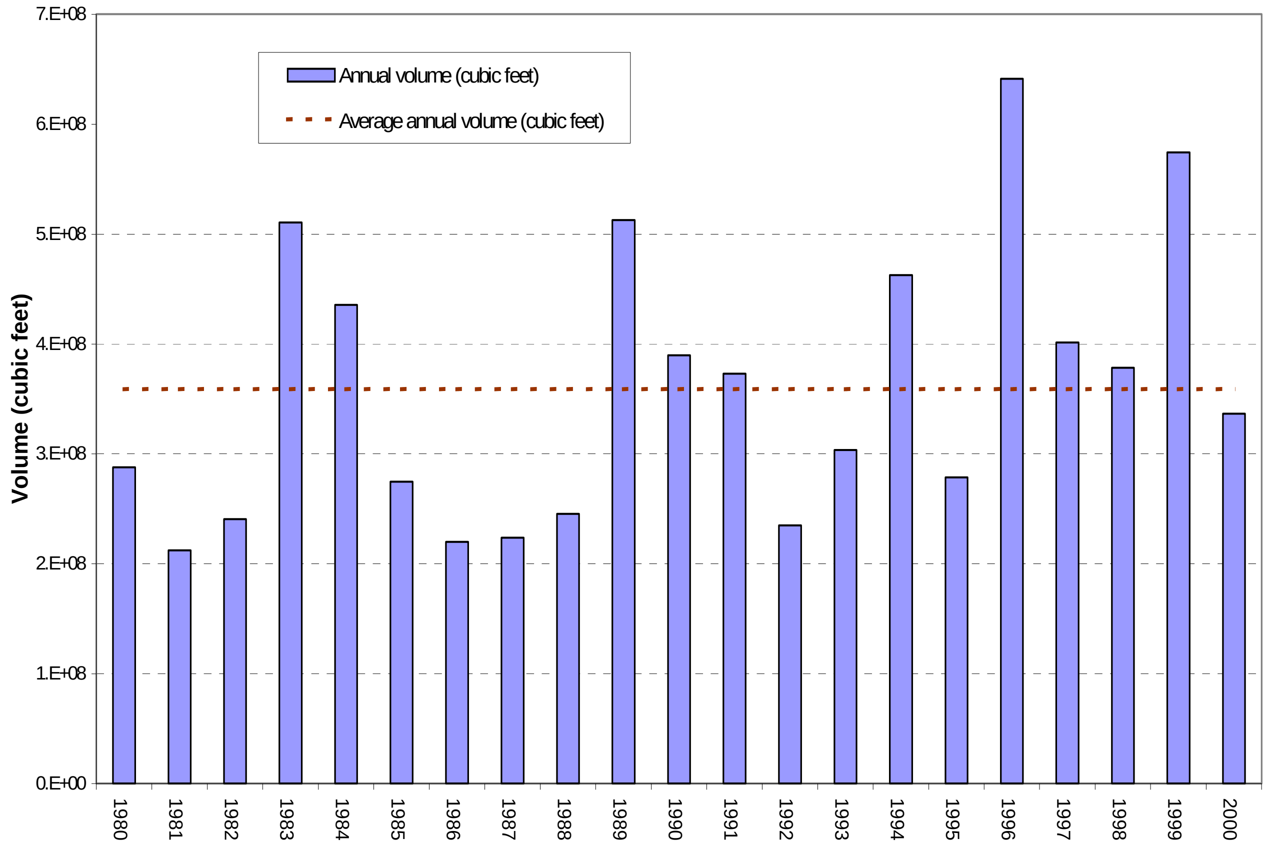

Figure 4-2. Volumetric analysis at the Morgan Creek USGS gage

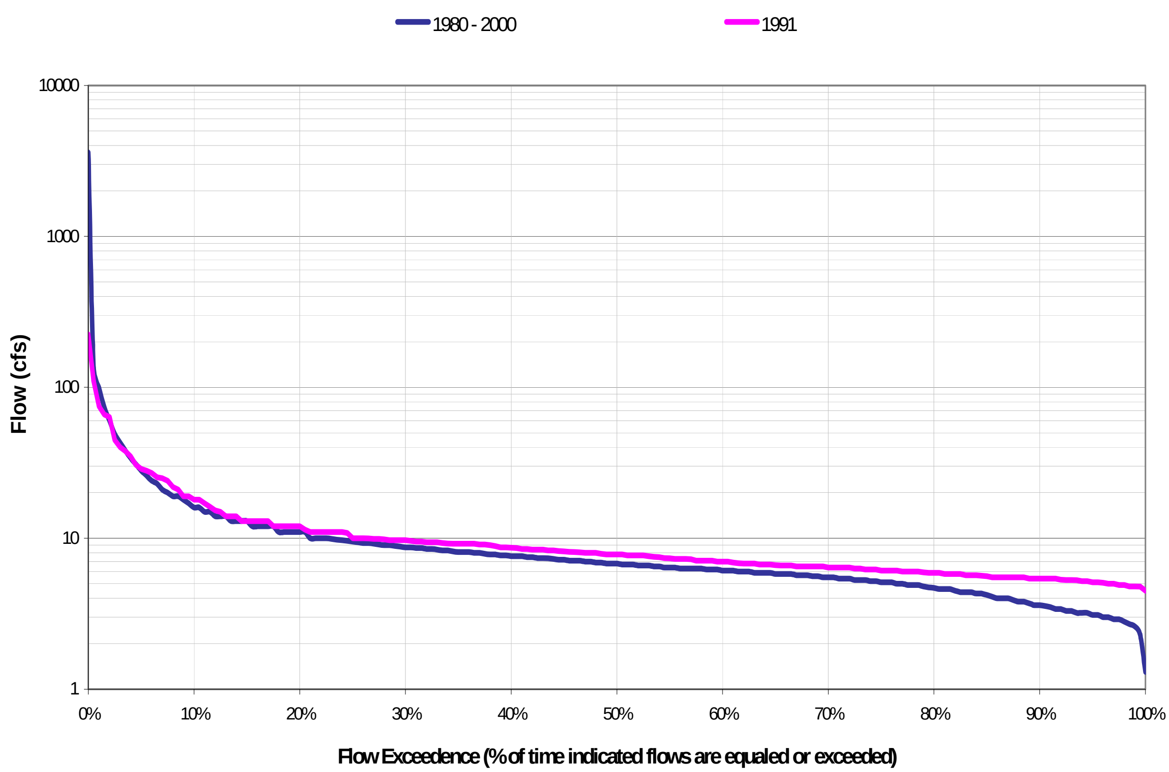

Figure 4-3. Flow-exceedance curve for the USGS gage on Morgan Creek

4.5 Consideration of Seasonal Variation

TMDLs for the Appoquinimink River adequately address seasonal variation directly through time-variable watershed and receiving water modeling. The linked modeling system simulates rainfall-runoff processes for the watershed throughout the year (for all seasons) as well as in-stream response. This approach provided insight into the time-variable nature of watershed loading and sediment diagenesis on DO levels in the Appoquinimink River and its tributaries. Rather than considering a single, extreme condition, this approach was comprehensive and represented a full seasonal analysis.

5.0 Reasonable Assurance and Implementation

Reasonable assurance indicates a high degree of confidence that each WLA and load allocation in a TMDL will be implemented. EPA expects the state to implement these TMDLs by ensuring that NPDES permit limits are consistent with the WLAs described herein. According to 40 CFR 122.44(d)(1)(vii)(B), the effluent limitations for a NPDES permit must be consistent with the assumptions and requirements of any available WLA for the discharge prepared by the state and approved by EPA. Furthermore, EPA has the authority to object to issuance of a NPDES permit that is inconsistent with the WLAs established for that point source. Additionally, according to 40 CFR 130.7(d)(2), approved TMDL loadings shall be incorporated into the state's current water quality management plans. These plans are used to direct implementation and draw upon the water quality assessments to identify priority point and nonpoint source water quality problems, consider alternative solutions, and recommend control measures. This provides further assurance that the pollutant allocations of the TMDLs will be implemented in the Appoquinimink River basin.

Development of TMDLs is only the beginning of the process for stream restoration and watershed management. Load allocations to point and nonpoint sources serve as targets for improvement, but success is determined by the level of effort put forth in making sure that those goals are achieved. Load reductions proposed by nutrient and dissolved oxygen TMDLs require specific watershed management measures to ensure successful implementation.

In terms of nonpoint sources, the load allocations are representative of expected pollutant loads during critical conditions from baseflow, atmospheric deposition, and traditional land-based sources. The analysis was performed using early 1990's landuse data and thus the baseline loads from the watershed are representative of conditions in the watershed at that time. The Appoquinimink River watershed has undergone significant change since the early 1990's. Many of the agricultural lands have been urbanized and a number of best management practices (BMPs) have been implemented. Based on the assumption that nutrient loadings are generally higher for agricultural areas than urban areas and that the BMPs are achieving nutrient load reductions, it is likely that current watershed nutrient loadings are less than those presented in the baseline condition. The BMP data was not sufficient to model in this TMDL. EPA expects that a portion of the reductions called for in the TMDL have already been achieved with these BMPs. A summary of current BMPs in the Appoquinimink River watershed and estimates of their corresponding load reductions are provided in Table 5-1 (based on personal communication with DNREC, November 2003).

Further implementation of BMPs in conjunction with waste load reductions from point sources should achieve the loading reduction goals established in the TMDLs. Further ground truthing will be performed to assess both the extent of existing BMPs, and to determine the most cost-effective and

Table 5-1. Summary of Current BMPs in the Appoquinimink River watershed and corresponding estimated nutrient load reductions (source: DNREC, 2003)

environmentally protective combination of BMPs required for meeting the nutrient reductions outlined in this report.

Category	System/acreage	Estimated TN reduction lbs/day	Estimated TP reduction lbs/day
Onsite Wastewater Disposal Systems			
Holding tank compliance	0		
Pump-out	459	2.5	1.0
Alternative systems			
Subtotal		*2.5*	*1.0*
Agriculture			
Nutrient relocation & alternative use			
Grassed waterways	2.5	0.26	0.01
Filter Strips	18	1.87	0.05
Riparian Buffers			
Grass Buffers	4.8	0.5	0.01
Forest Buffers			
Ponds	4	0.14	0
Wetlands	83	5.68	0.14
Grass Filter strips	14	0.58	0.01
Wildlife Habitat	14	0.58	0.01
Cover Crops	992	42.81	0.08
Subtotal		*52.81*	*0.30*
Stormwater			
Dry Infiltration Trench	0.3	0.00	0.00
Extended Detention Ponds	5	0.03	0.02
Filter Strips	3	0.1	0.00
Grass Swales	1.5	0.00	0.00
Retention wet ponds	21	0.31	0.14
Wet Ponds	16	*0.23*	0.11
Dry Ponds	2.1	*0.00*	0.00
Stormwater wetland	11.5	0.17	0.09
Wet In-Filter System	7.5	0.02	0.02
Infiltration systems	0.5	0.01	0.00
Subtotal		*0.87*	*0.38*
TOTAL		**56.18**	**1.68**
TMDL required reduction based on Model Baseline results		**304.3**	**39.6**
Estimated Progress Towards TMDL		**18.5%**	**4.2%**

To provide additional assurance that TMDLs are protective of the designated uses of the Appoquinimink River watershed, analysis was performed to ensure that WLAs for ammonia did not result in violations of water quality criteria. Delaware does not have a water quality standard for ammonia nitrogen, so the EPA national criterion for ammonia in fresh water was used (USEPA, 1998). The criteria maximum concentration (CMC or acute criteria) and criteria continuous concentration (CCC or chronic criteria) ammonia standards are calculated based on pH. The water quality sample data in the STORET database were used to calculate the mean, 75th percentile, and 90th percentile pH values for the Appoquinimink River watershed using all data for all stations for the months of July and August during the period 1970 through 1998. The corresponding 4-day CCC, 30-day CCC, and 1-hour CMC ammonia nitrogen criteria are shown in Table 5-2. The recent STORET data from 1990 to 1998 indicate the highest ammonia nitrogen concentration was 0.681 mg/L as N which is below the criteria listed in Table 5-2. Therefore, since the TMDL allocations will reduce the loading of ammonia from existing conditions, the ammonia toxicity criteria are expected to be protected within the Appoquinimink River basin.

Table 5-2. Ammonia nitrogen criteria for Appoquinimink River basin.

Statistic	pH (S.U.) Jul-Aug	Ammonia Nitrogen Criteria (mg/L as N)			
		30-day CCC	4-day CCC	1-hour CMC (salmonids present)	1-hour CMC (salmonids absent)
mean	7.52	2.238	4.476	12.89	19.30
75th percentile	7.80	1.661	3.322	8.11	12.14
90th percentile	8.35	0.732	1.464	2.86	4.28

The maximum concentration nitrite+nitrate nitrogen concentration reported in the STORET database for all stations in the Appoquinimink River basin is 6.57 mg/L as N. This is below the nitrate water quality standard of 10 mg/L as N, therefore, it is reasonable to expect the nitrate standard will be protected as a result of the TMDL allocations.

6.0 Public Participation

Public participation is a requirement of the TMDL process and is essential to its success. At a minimum, the public must be allowed at least 30 days to review and comment prior to establishing a TMDL. Also, EPA must provide a summary of all public comments and responses to those comments to indicate how the comments were considered in the final decision.

The draft of the *Nutrient and DO TMDL Development for Appoquinimink River, Delaware* was open for public comment from October 10, 2003 to November 18, 2003. On November 10, 2003, a public meeting was held in the Brick Mill Elementary School in Middletown, Delaware. The results of TMDL development were presented to the public at this meeting. Approximately 30 people attended the meeting. Comments received at the meeting were used in amending the TMDL to its final format.

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Appendix A: GWLF Model

The objective of this Appendix is to describe the watershed modeling approach used to support TMDL development for the Appoquinimink River.

GWLF Model

The watershed model for the Appoquinimink River watershed was developed using the GWLF model and the BasinSim 1.0 interface. The GWLF model, which was originally developed by Cornell University (Haith et al., 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each area is assumed to be homogeneous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are applied to the calculated erosion to determine sediment yield for each source area. Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Manured areas, as well as septic systems, also can be considered. Urban nutrient inputs are all assumed to be solid phase, and the model uses an exponential accumulation and washoff function for these loadings. Subsurface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the subsurface submodel considers only a single, lumped-parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent on land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et al. 1992).

For execution, the model requires three separate input files containing transport, nutrient, and weather-related data. The transport file (TRANSPRT.DAT) defines the necessary parameters for each source area to be considered (e.g., area size, curve number) as well as global parameters (e.g., initial storage, sediment delivery ratio, streambank erosion coefficient) that apply to all source areas. The nutrient file (NUTRIENT.DAT) specifies the various loading parameters for the different source areas identified (e.g., urban source area accumulation rates, manure concentrations). The weather file (WEATHER.DAT) contains daily average temperature and total precipitation values for each year simulated.

Model Setup

Watershed data needed to run the GWLF model were generated using GIS spatial coverages, streamflow data, local weather data, literature values, and other information. The Appoquinimink watershed was segmented into seven subwatersheds to represent nutrient loadings (Figure A-1). Three of the subwatersheds represent the three tributaries to Appoquinimink River, which are Drawyer Creek, Deep Creek and Hangman's Run. The tributary feeding into Drawyer Creek (Dove Nest Branch) was delineated to represent the loading coming from this subbasin into the Drawyer Creek sub-basin. The remaining three subbasins were delineated to represent the loadings alongside the Appoquinimink River. The impaired and reference subwatersheds were delineated based on USGS 7.5 minute digital topographic maps (24K RG - Digital Rastar Graphics), USGS Digital Elevation Model data, and the EPA RF3 stream coverage.

Nonpoint source pollution is rainfall driven, therefore precipitation data are necessary to drive the watershed model. Local rainfall and temperature data were used to simulate flow conditions in modeled watersheds. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations. The weather data collected at the Wilmington New Castle County Airport NCDC station (precipitation data and temperature data) were used to construct the weather file used in modeling. This station is approximately 19 miles away from the Appoquinimink

River. It has complete coverage of data starting from 1948 until 2000 (99% coverage). Table A-1 shows the weather stations used in the watershed model.

Table A-1. Meteorological Stations

Station ID	Station Name	Data Begin Date	Data End Date	Percent Coverage	Lat.	Long.	Elev.
DE 9595	Willmington New Castle County Airport	8/1/1948	12/31/2000	99	39.6728	-75.60083	74
DE 13781	Willmington New Castle County Airport	1/1/1948	12/24/2001	99	39.6728	-75.60083	74

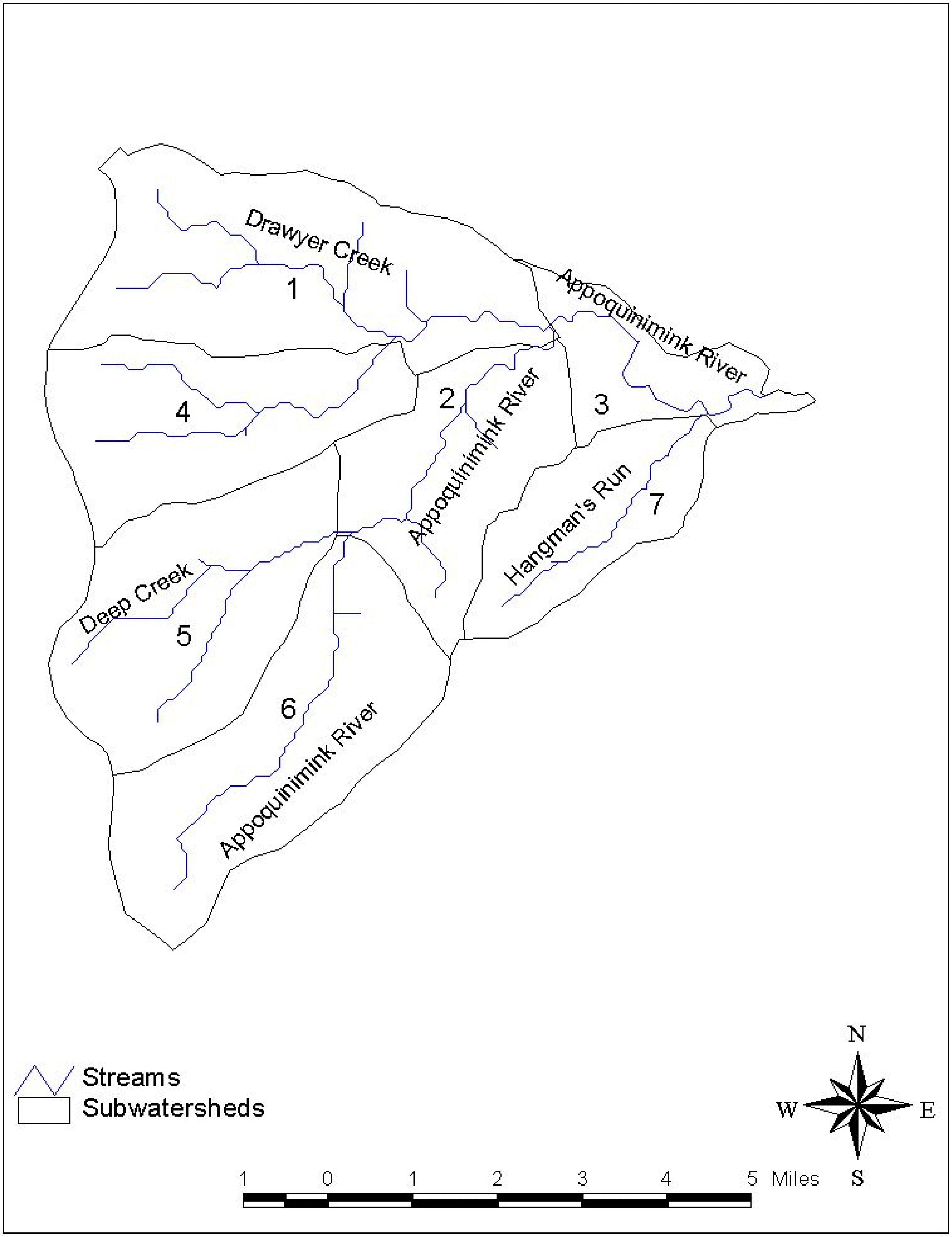


Figure A-1. Appoquinimink River subwatershed delineations.

Model Testing

Streamflow data are generally used to test or calibrate watershed hydrologic parameters for the GWLF model. There are no active U.S. Geological Survey (USGS) gages in the Appoquinimink River watershed, nor is there information available regarding historical stream flow data. Therefore a reference watershed, where data are available and which exhibits similar soil and landuse characteristics, was also modeled (drainage area to the USGS gage on Morgan Creek near Kennedyville, Maryland - Figure A-2). Once calibrated, the hydrology parameters from the reference watershed were applied to the Appoquinimink River watershed.

GWLF predicted overall water balances in the reference watershed. For the Morgan Creek watershed, weather data obtained from the NCDC meteorological station located at Willmington New Castle County Airport were used to model for a 10-year time period (1989 through 1999). The modeling period was selected based on the availability of weather and flow data that were collected during the same time period. It was assumed that a 10 year period would incorporate the seasonal variation in the model with a range of precipitation and stream flow conditions being represented.. Calibration plots for the entire 10-year period and for the 3-year period for which the river was modeled for the TMDL are presented in Figures A-3 and A-4. A total flow volume error percentage of less than 10 percent was achieved (4% error for the 10-year period and 1.5% error for the 3-year period). In general, the seasonal trends and peaks are captured reasonably well for the 10 year period in the reference watershed.

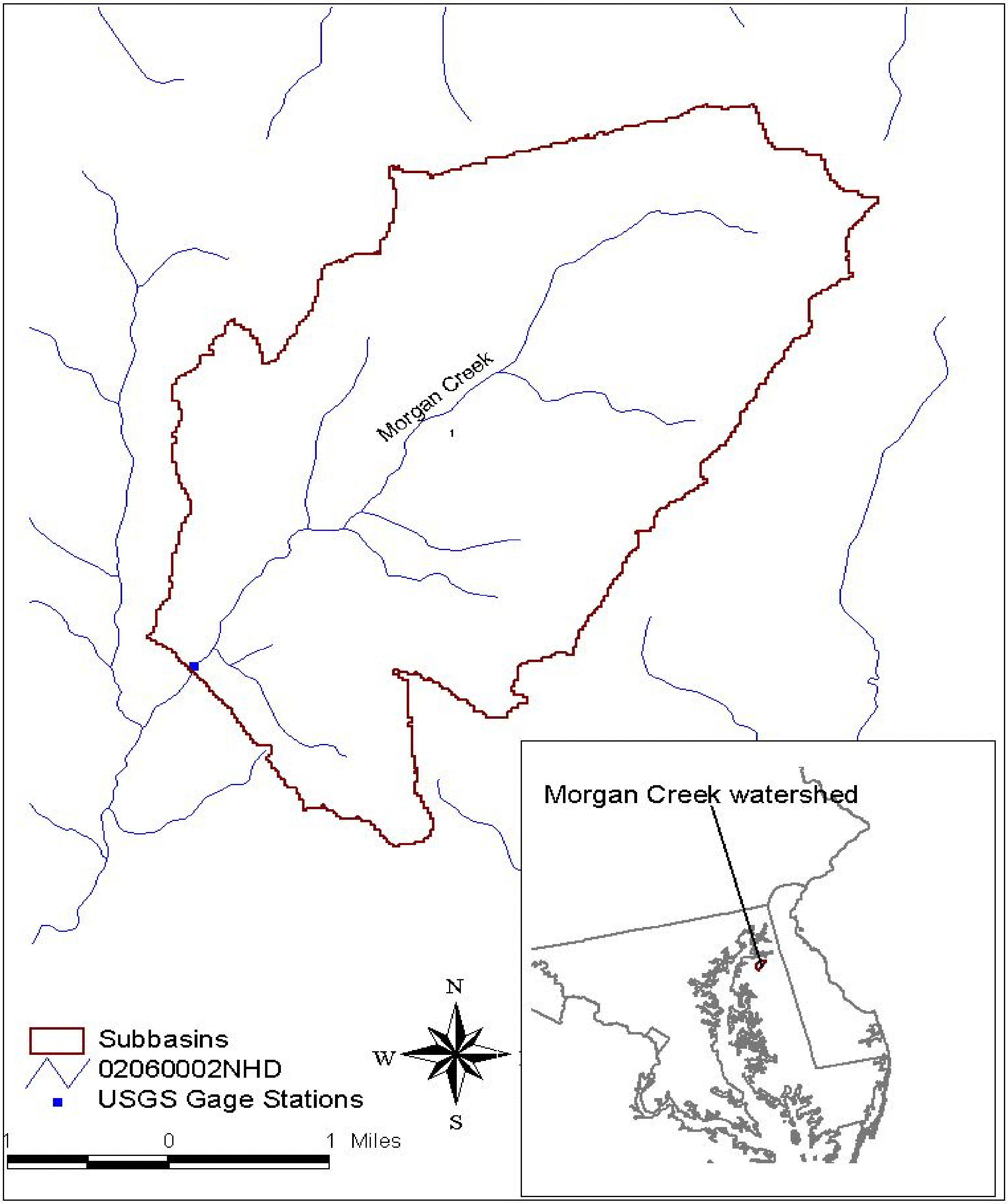


Figure A-2. Morgan Creek watershed

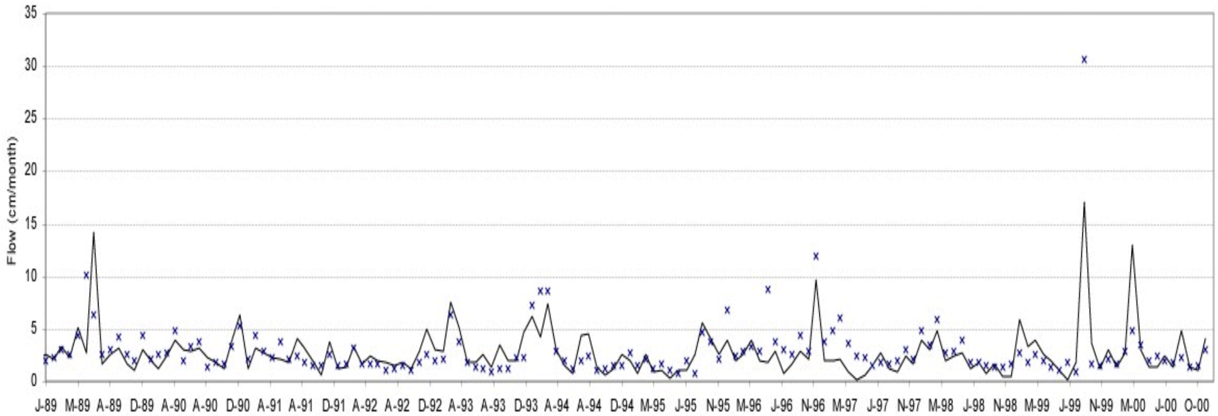


Figure A-3. Hydrology Calibration - Morgan Creek at USGS 01493500 (1/1/1989 - 12/31/1999)

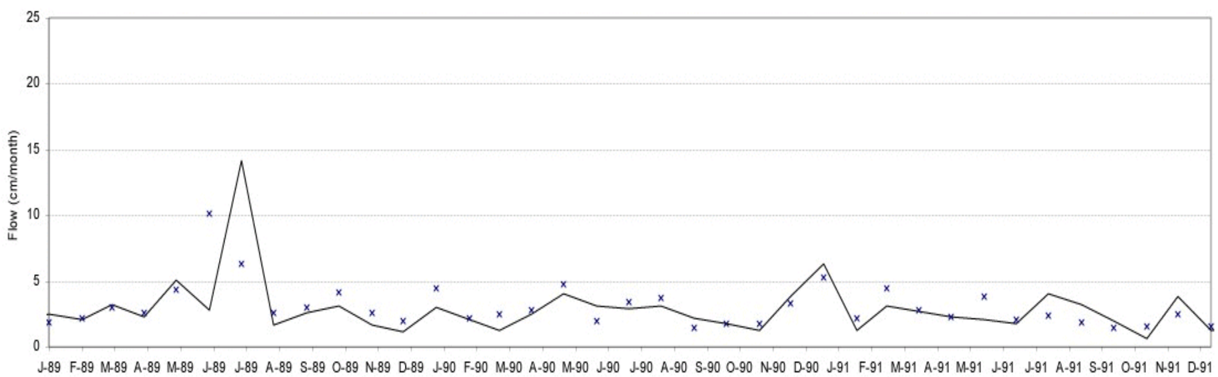


Figure A-4. Hydrology Calibration - Morgan Creek at USGS 01493500 (1/1/1989 - 12/31/1991)

Explanation of Important Model Parameters

In the GWLF model, the nonpoint source load calculation is affected by terrain conditions, such as the amount of agricultural land, land slope, soil erodibility, farming practices used in the area, and by background concentrations of nutrients (nitrogen and phosphorus) in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. Some of the more important parameters are summarized as follows:

Areal extent of different land use/cover categories: Land use information from the Multi-Resolution Land Characterization (MRLC) completed in 1992 was available for the impaired and reference watersheds. MRLC land use coverages were used to calculate the area of each land use category in impaired and reference watersheds, respectively. The breakup of the landuse in the impaired and reference watershed are given below in Tables A-2 and A-3. Note that this is a further subdivision of the landuse categories presented in the main TMDL report, where deciduous forest, evergreen forest, and mixed forest have been combined into the forest category, and where woody wetlands and emergent herbaceous wetlands have been combined into the wetlands category.

Curve number: This parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use and soils coverages. Soils data were obtained the State Soil Geographic (STATSGO) database for the respective watersheds, as developed by the Natural Resources Conservation Services (NRCS).

K factor: This factor relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land. The K factor and other Universal Soils Loss Equation (USLE) parameters were downloaded from the NRCS Natural Resources Inventory (NRI) database (1992). Average values for specific crops/land uses in each watershed county were used.

LS factor: This factor signifies the steepness and length of slopes in an area and directly affects the amount of soil erosion.

C factor: This factor is related to the amount of vegetative cover in an area. In agricultural areas, this factor is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

P factor: This factor is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

Sediment delivery ratio: This parameter specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size.

Unsaturated available water-holding capacity: This parameter relates to the amount of water that can be stored in the soil and affects runoff and infiltration.

Dissolved nitrogen in runoff: This parameter varies according to land use/cover type. Reasonable values have been established in the literature. This rate, reported in milligrams per liter, can be readjusted based on local conditions such as rates of fertilizer application and farm animal populations. The default values reported in literature were used.

Table A-2. Landuse in the Appoquinimink River Watershed (in square miles)

LANDUSE	Subbasin 1	Subbasin 2	Subbasin 3	Subbasin 4	Subbasin 5	Subbasin 6	Subbasin 7	TOTAL
Open Water	0.298	0.232	0.345	0.071	0.082	0.344	0.104	**1.474**
Low Intensity	0.064	0.148	0.000	0.222	0.291	0.127	0	**0.852**
High Intensity Residential	0.000	0.006	0.000	0.039	0.049	0.008	0	**0.102**
High Intensity Commercial/	0.064	0.043	0.007	0.137	0.037	0.026	0.007	**0.321**
Disturbed	0.000	0	0.000	0.008	0.02	0.000	0	**0.028**
Deciduous Forest	1.237	0.872	0.11	0.737	0.496	1.237	0.216	**4.906**
Evergreen Forest	0.088	0.059	0.027	0.031	0.054	0.093	0.036	**0.388**
Mixed Forest	0.162	0.167	0.009	0.092	0.104	0.278	0.06	**0.872**
Pasture/Hay	2.093	0.907	0.298	1.272	1.454	1.812	0.574	**8.41**
Row Crops	5.261	2.194	0.417	3.868	5.100	4.475	2.216	**23.532**
Other Grasses	0.000	0.008	0.000	0.005	0	0	0	**0.013**
Woody Wetlands	0.335	0.047	0.000	0.143	0.028	0.129	0.048	**0.729**
Emergent Herbaceous	0.503	1.121	1.820	0.049	0.080	0.087	0.872	**4.532**
Total	**10.11**	**5.80**	**3.03**	**6.68**	**7.79**	**8.62**	**4.13**	**46.16**

Table A-3. Landuse in the Morgan Creek Watershed (in square miles)

LANDUSE	Area
Open Water	0.12
Low Intensity Residential	0.09
Commercial/Industrial/Transportation	0.04
Deciduous Forest	0.42
Evergreen Forest	0.03
Mixed Forest	0.08
Pasture/Hay	4.36
Row Crops	6.66
Woody Wetlands	0.56
Emergent Herbaceous Wetlands	0.03
Total	**12.39**

Dissolved phosphorus in runoff: Similar to nitrogen, the value for this parameter varies according to land use/cover type, and reasonable values have been established in the literature. This rate, reported in milligrams per liter, can be readjusted based on local conditions such as rates of fertilizer application and farm animal populations. The default values reported in literature were used.

Nutrient concentrations in runoff over manured areas: These concentrations are user-specified concentrations for nitrogen and phosphorus that are assumed to be representative of surface water runoff leaving areas on which manure has been applied. As with the runoff rates described above, these concentrations are based on values obtained from the literature. They also can be adjusted based on local conditions such as rates of manure application or farm animal populations. The default values reported in literature were used.

Background nitrogen and phosphorus concentrations in soil: Because soil erosion results in the transport of nutrient-laden sediment to nearby surface water bodies, reasonable estimates of background concentrations in soil must be provided. This information was based on literature values that were adjusted locally depending on manure loading rates and farm animal populations.

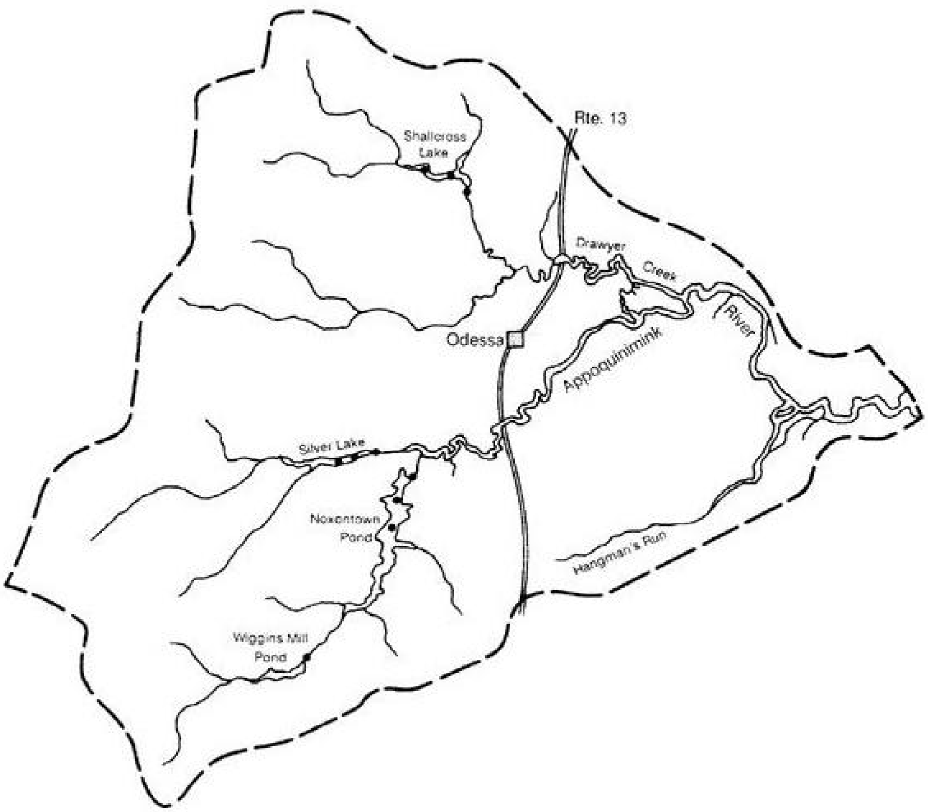
Nutrient buildup in nonurban areas: In GWLF, rates of buildup for both nitrogen and phosphorus have to be specified. These rates are estimated using published literature values and adjusted to local conditions.

Background nitrogen and phosphorus concentrations in groundwater: Subsurface concentrations of nutrients (primarily nitrogen and phosphorus) contribute to the nutrient loads in streams. Nutrient concentrations in groundwater were based on the results from a nationwide study of mean dissolved nutrients as measured in streamflow (as reported in Haith et al. 1992).

Other less important factors that can affect sediment and nutrient loads in a watershed also are included in the model. More detailed information about these parameters and those outlined above can be obtained from the GWLF User's Manual (Haith et al. 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

Appendix B: DNREC's Technical Analysis for the Proposed Appoquinimink River TMDLs - October 2001.

Technical Analysis for the Proposed Appoquinimink River TMDLs - October 2001



Prepared by
Watershed Assessment Section
Division of Water Resources
Delaware Department of Natural Resources and Environmental Control
820 Silver Lake Boulevard, Suite 220 Dover, DE 19904-2464

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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act (CWA) requires States to identify and establish a priority ranking for waters in which existing pollution controls are not sufficient to attain and maintain State water quality standards, establish Total Maximum Daily Loads (TMDLs) for those waters, and periodically submit the list of impaired waters (303(d) list) and TMDLs to the United States Environmental Protection Agency (EPA).

Due to their high nutrient concentrations and/or low dissolved oxygen levels, the Delaware Department of Natural Resources and Environmental Control (DNREC) has identified and included in the States 1996, 1998, and/or proposed 2000 303(d) lists the following segments of the Appoquinimink River and its tributaries and ponds as impaired:

- Lower Appoquinimink River (DE010-001-01)
- Upper Appoquinimink River (DE010-001-02)
- Drawyer Creek (DE010-001-03)
- Wiggins Mill Pond to confluence with Silver Lake (DE010-002-01)
- Deep Creek to confluence with Silver Lake (DE010-002-02)
- Noxontown Pond (DE010-L01)
- Silver Lake (DE010-L02)
- Shallcross Lake (DE010-L03)

A court-appointed Consent Decree (C.A> No. 960591, D. Del 1996) requires that the Appoquinimink TMDL be established by December, 2001.

The proposed Appoquinimink River TMDL is based on an assessment of the water quality condition of the Appoquinimink River and its tributaries and ponds during design conditions under various levels of point and nonpoint source loading levels. A calibrated and verified hydrodynamic water quality of the Appoquinimink River and its tributaries and ponds model was used as an assessment tool. The Appoquinimink River Model was developed using extensive hydrological and water quality data collected from 1991 through 1993 and from 1997 through 2000.

Considering the results of the assessment, DNREC has determined that in order to meet the State's water quality standards and targets, the point and nonpoint source nutrients loads (nitrogen and phosphorous) and oxygen consuming compounds (CBOD5) within the watershed should be reduced as described in Table ES-1. The proposed Appoquinimink River TMDL includes a Load Allocation (LA) for nonpoint sources and a Waste Load Allocation (WLA) for point source discharges. The margin of safety for the Appoquinimink River TMDL is considered to be implicit as the result of the consideration of conservative assumptions made during the TMDL analysis.

Table ES-1 Proposed TMDL Loads for the Appoquinimink Watershed

Source	Flow (mgd)	Total N (lb/d)	Total P (lb/d)	CBOD5 (lb/d)
Waste Load Allocation (WLA) for Point Source: MOT	0.5	10.4	2.1	34.8
Load Allocation (LA) for Nonpoint Sources	-	334.1	18.0	-
Proposed TMDL Total Loads	-	344.5	20.1	34.8

1. Introduction/Background

Under Section 303(d) of the Clean Water Act (CWA), States are required to identify and establish a priority ranking for waters in which existing pollution controls are not sufficient to attain and maintain State water quality standards, establish Total Maximum Daily Loads (TMDLs) for those waters, and periodically submit the list of impaired waters (303(d) list) and TMDLs to the United States Environmental Protection Agency (EPA). If a State fails to adequately meet the requirements of section 303(d), the CWA requires the EPA to establish a 303(d) list and/or determine TMDLs for that State.

In 1996, the EPA was sued under Section 303(d) of the CWA concerning the 303(d) list and TMDLs for the State of Delaware. The suit maintained that Delaware had failed to fulfill all of the requirements of Section 303(d) and the EPA had failed to assume the responsibilities not adequately preformed by the State. A settlement in the suit was reached and the Delaware Department of Natural Resources and Environmental Control (DNREC) and the EPA signed a Memorandum of Understanding (MOU) on July 25, 1997. Under the settlement, DNREC and the EPA agreed to complete TMDLs for all 1996 listed waters on a 10-year schedule.

In the Appoquinimink River watershed, a number of river segments, tributaries and ponds have been included on the State's Clean Water Action Section 303(d) List of Waters needing Total Maximum Daily Loads (Table 1-1, Figure 1-1). TMDLs need to be established for dissolved oxygen, nutrients (nitrogen and phosphorus) and bacteria concentrations.

The development of a TMDL for a particular water body typically requires the application of a receiving water model, which simulates the movement and transformation of pollutants through the water body. This can be used to predict water quality conditions under different pollutant loading scenarios to determine the loading scenario that will allow ambient conditions to meet water quality standards.

In 1998, EPA Region III, in cooperation with DNREC adopted a TMDL for the main stem of the Appoquinimink River (DE010-001-01, DE010-001-02) using a DYNHYD-WASP model. This TMDL expanded the Phase 1 TMDL developed by DNREC in 1992. The focus of the 1998 TMDL was to address water quality impairments due to low dissolved oxygen concentrations violating the daily standard of 5.5 mg/L. The TMDL called for reductions in phosphorus, carbon (carbonaceous biochemical oxygen demand [CBOD5]) and nitrogen [ammonia, and organic nitrogen] from both point and non-point sources.

TMDLs are required for the tributaries and ponds within the Appoquinimink River Watershed prior to December 2001, therefore, the 1998 DYNHYD-WASP model was expanded to include it's tributaries and ponds (DE010-001-03, DE010-002-01, DE010-002-02, DE010-L01, DE010-L02, DE010-L03). They include: Drawyer Creek, Deep Creek, Shallcross Lake, Silver Lake, Noxontown Lake and Wiggins Mill Pond (Figure 1-1). The expanded model (ARM1) will be built upon the TMDLs developed in 1998.

Table 1-1 Appoquinimink River Watershed Segments listed on the Proposed 2000 303(d) List

Waterbody ID (Total Size)	Watershed Name	Segment	Description	Size Affected	Pollutant(s) and/or Stressors	Probable Sources	Year Listed	Target Date for TMDL
DE010-001-01 (7.1 miles)	Appoquinimink River	Lower Appoquinimink River	Saline Tidal Reach, excluding Hangman's Run	7.1 miles	Nutrients, DO	PS, NPS	1996	Established 1998 (for Nutrients and DO)
					Bacteria, PCBs, Dioxins	NPS	2000	2006 (for Bacteria)
								2011 (for PCBs, Dioxin)
DE010-001-02 (6.1 miles)	Appoquinimink River	Upper Appoquinimink River	Freshwater Tidal Reach	6.1 miles	Nutrients, DO	PS, NPS	1996	Established 1998 (for Nutrients and DO)
					Bacteria	PS, NPS	2000	2006
					PCBs, Dioxins	NPS	2000	2011
DE010-001-03 (19.5 miles)	Appoquinimink River	Drawyer Creek	From the headwaters of Drawyer Creek to the confluence with the Appoquinimink River, including Shallcross Lake	8.2 miles	Bacteria, Nutrients, DO	NPS	1996	2001 (for Nutrients and DO)
								2006 (for Bacteria)
			Tributary of Drawyer Creek--from the confluence of the headwaters to the confluence with the mainstem	2.30 miles	Biology and Habitat	NPS	1998	2011
			Western tributary of the headwaters of Drawyer Creek to its confluence	2.20 miles	Habitat	NPS	1998	2011
DE010-001-03 (19.5 miles)	Appoquinimink River	Drawyer Creek	Tidal Portion		PCB,DDT	NPS	2000	2011
DE010-002-01 (3.4 miles)	Appoquinimink River	Wiggins Mill Pond to confluence with Silver Lake	From the headwaters of Wiggins Mill Pond to the confluence with Noxontown Pond	3.4 miles	Bacteria, DO	NPS	1996	2001 (for DO)
								2006 (for Bacteria)
					Nutrients	NPS	2000	2001
			From the confluence of the headwaters of Wiggins Mill Pond to the confluence with Noxontown Pond	1.62 miles	Biology	NPS	1998	2011

Waterbody ID (Total Size)	Watershed Name	Segment	Description	Size Affected	Pollutant(s) and/or Stressors	Probable Sources	Year Listed	Target Date for TMDL
DE010-002-02 (4.4 miles)	Appoquinimink River	Deep Creek to confluence with Silver Lake	From the headwaters of Deep Creek to confluence with Silver Lake, excluding Silver Lake	2.4 miles	DO	NPS	1996	2001
					Bacteria, Nutrients	NPS	2000	2001 (for Nutrients)
								2006 (for Bacteria)
			First western tributary after the headwaters of Silver Lake	1.98 miles	Biology	NPS	1998	2011
			Deep Creek.-- from the confluence of the headwaters to Appoquinimink River	1.84 miles	Biology	NPS	1998	2011
DE010-L01 (158.6 acres)	Appoquinimink River	Noxontown Pond	Pond southwest of Odessa	158.6 acres	Bacteria, Nutrients	NPS	1998	2001 (for Nutrients)
								2006 (for Bacteria)
DE010-L02 (38.7 acres)	Appoquinimink River	Silver Lake	Lake adjacent to Middletown, below Deep Creek	38.7 acres	Bacteria, Nutrients	NPS	1996	2001 (for Nutrients)
								2006 (for Bacteria)
					PCB, Dieldrin, DDT, Dioxin	NPS	2000	2011
DE010-L03 (43.1 acres)	Appoquinimink River	Shallcross Lake	Lake above Drawyer Creek	43.1 acres	Bacteria, Nutrients	NPS	1996	2001 (for Nutrients)
								2006 (for Bacteria)

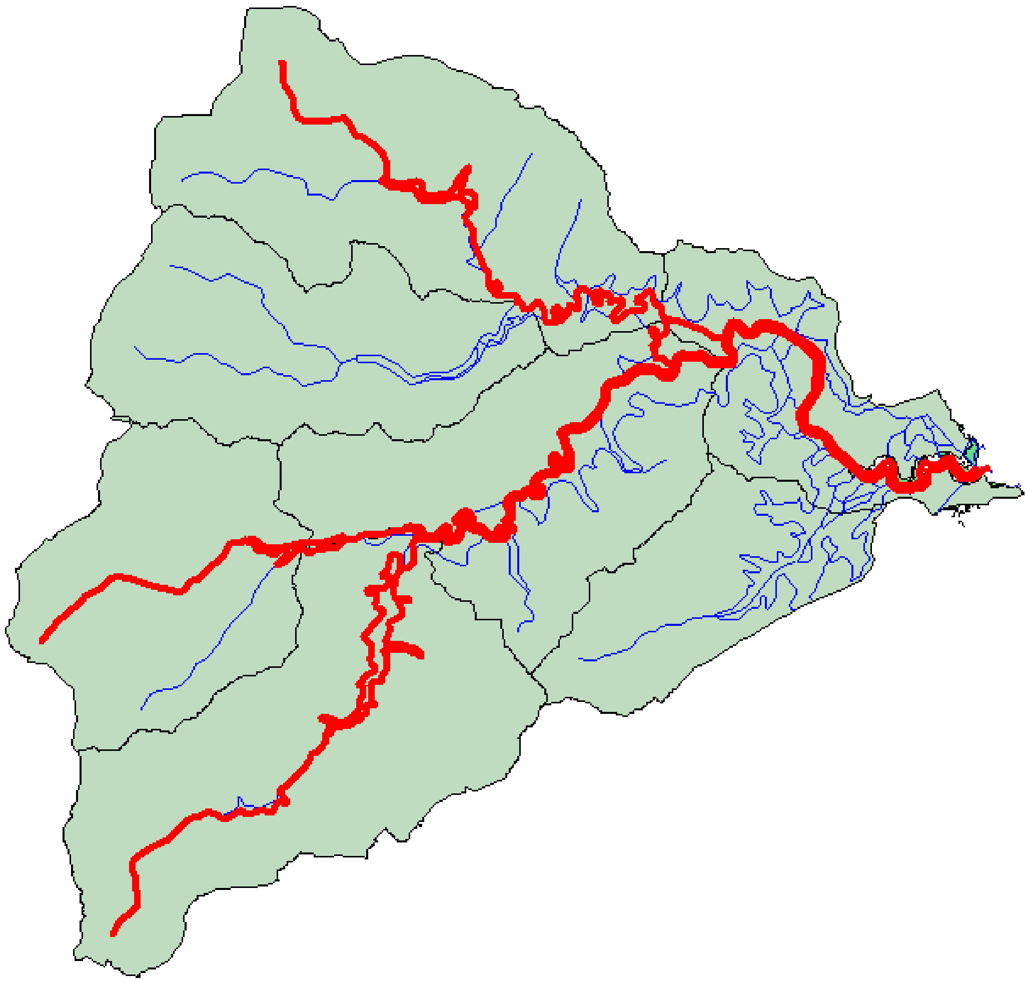


Figure 1-1 Segments within the Appoquinimink River Watershed included in the 1998 303(d) Listing

2. The Appoquinimink River Watershed

The Appoquinimink River watershed is located in the flat coastal plain of eastern Delaware (New Castle County). The watershed is approximately 47 square miles and can be described as primarily agricultural with three residential/urban centers: Middletown, Odessa and Townsend. The land is generally characterized as flat to gently sloping, which is typical of the coastal plain.

The Appoquinimink River system consists of three main branches. Moving south to north, it includes: the Appoquinimink River (Wiggins Mill Pond and Noxontown Lake); Deep Creek (Silver Lake); and Drawyer Creek (Shallcross Lake). The ponds and lakes included in the Appoquinimink River Watershed are typically shallow, man-made ponds maintained by dams.

The system is tidal up to the outlet dams of Noxontown Lake on the Appoquinimink River main stem, Silver Lake on Deep Creek, and the Drawyer Creek's confluence with the Appoquinimink River. The salinity from Delaware Bay typically extends past the Drawyer Creek - Appoquinimink confluence at river kilometer (Rkm) 8.5. The only point source within the system is the Middletown-Odessa-Townsend wastewater treatment plant (MOT WWTP) located at Rkm 10 which primarily uses spray irrigation to dispose of its effluent but may occasionally discharge into the surface waters of the Appoquinimink River.

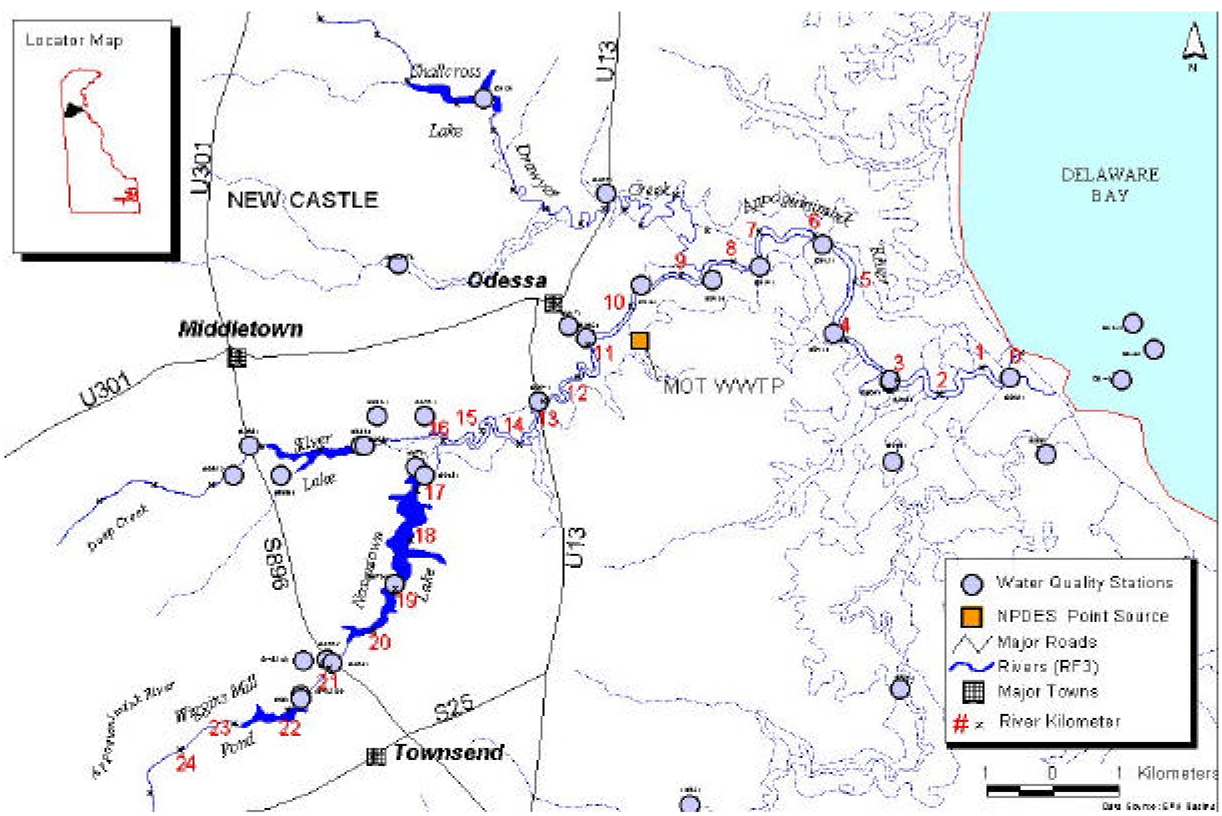


Figure 2-1 Study Area

2.1. Designated Uses

Section 10 of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, specifies the following designated uses for the waters of the Appoquinimink River watershed:

1. Primary Contact Recreation
2. Secondary Contact Recreation
3. Fish, Aquatic Life, and Wildlife
4. Industrial Water Supply
5. Agricultural Water Supply (freshwater segments)

2.2. Applicable Water Quality Standards

The following sections of the State of Delaware Surface Water Quality Standards, as amended August 11, 1999, provide specific narrative and/or numeric criteria concerning the waters of the Appoquinimink River Watershed:

1. Section 3: General guidelines regarding Department's Antidegradation policies
2. Section 7: Specific narrative and numeric criteria for controlling nutrient overenrichment in waters of the State
3. Section 9: Specific narrative and numeric criteria for toxic substances
4. Section 11: General water criteria for surface waters of the State

According to Section 11 and 7 of the Standards, the following water quality criteria are applicable to fresh and/or marine waters of the Appoquinimink River:

A. Disolved Oxygen (DO)

   a. 5.5 mg/L daily average (from June through September) for fresh waters. Fresh waters are defined as those having a salinity of less than 5 parts per thousand

   b. 5.0 mg/L daily average (from June through September) for marine waters. Marine waters are defined as those having a salinity of equal to or greater than 5 parts per thousand.

   c. 4.0 mg/L minimum at any time of both fresh and marine waters.

Based on the salinity data (Figure 2-2), all portions of the Appoquinimink River and it's tributaries are considered to be fresh water because the minimum salinity levels are less than 5 ppt.

B. Enteroccus Bacteria

   a. For fresh waters, the geometric average of representative samples should not exceed 100 colonies/100 mL.

C. Nutrients

a. Section 7 of the Standards uses a narrative statement for controlling nutrient overenrichment of the State's surface waters. It states; "*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. Thy 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 overenrichment.*"

In the absence of numeric nutrient criteria, DNREC has decided upon threshold levels of 3.0 mg/L for total nitrogen and 0.1 mg/L for total phosphorous in determining whether a stream should be included on the State's list of impaired waters (303(d) lists). These threshold levels are generally accepted by the scientific community to be an indication of overenriched waters.

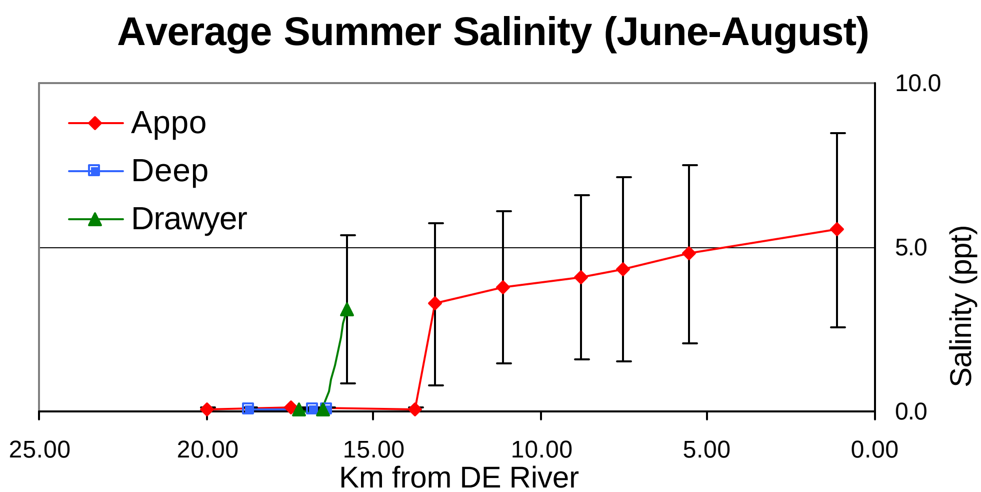


Figure 2-2 Summer Salinity within the Appoquinimink River Watershed ('97-'00 data)

3. Development of the Appoquinimink River WASP5 Model

HydroQual Inc. was contracted by the Delaware DNREC to expand, calibrate, and validate the ARM0 model to include the additional sections within the watershed listed on the 303(d) list (Section 1). The following sections are excerpts from their report, "The Appoquinimink River Watershed TMDL Model", delivered in June, 2001.

3.1. Previous modeling Study

The "TMDL Model Study for the Appoquinimink River, Delaware" was issued in May 1993 and included tidal hydrodynamics using DYNHYD5 (hydrodynamic submodel included in WASP5). The DYNHYD5 model of the Appoquinimink River was an advance over the earlier modeling study (Phase I TMDL, DNREC 1992), which simulated the movement of water in the estuary as steady state and tidally averaged conditions.

The Appoquinimink River was segmented into 27 nodes or junctions and 26 connecting channels. Figure 3-1 shows the WASP segmentation of the previous modeling study (ARM0). For each segment the surface area and average depth at (mean sea level) were determined for input to the DYNHYD5 hydrodynamic sub model. For each channel, the depth, length, cross-sectional area, downstream (positive flow) direction, and Manning's 'n' roughness coefficient were estimated. The channel geometries (depth and width) were estimated from data measured by the USGS at ten stations along the Appoquinimink River. The geometries for segments between the measured cross-sections were estimated by interpolation.

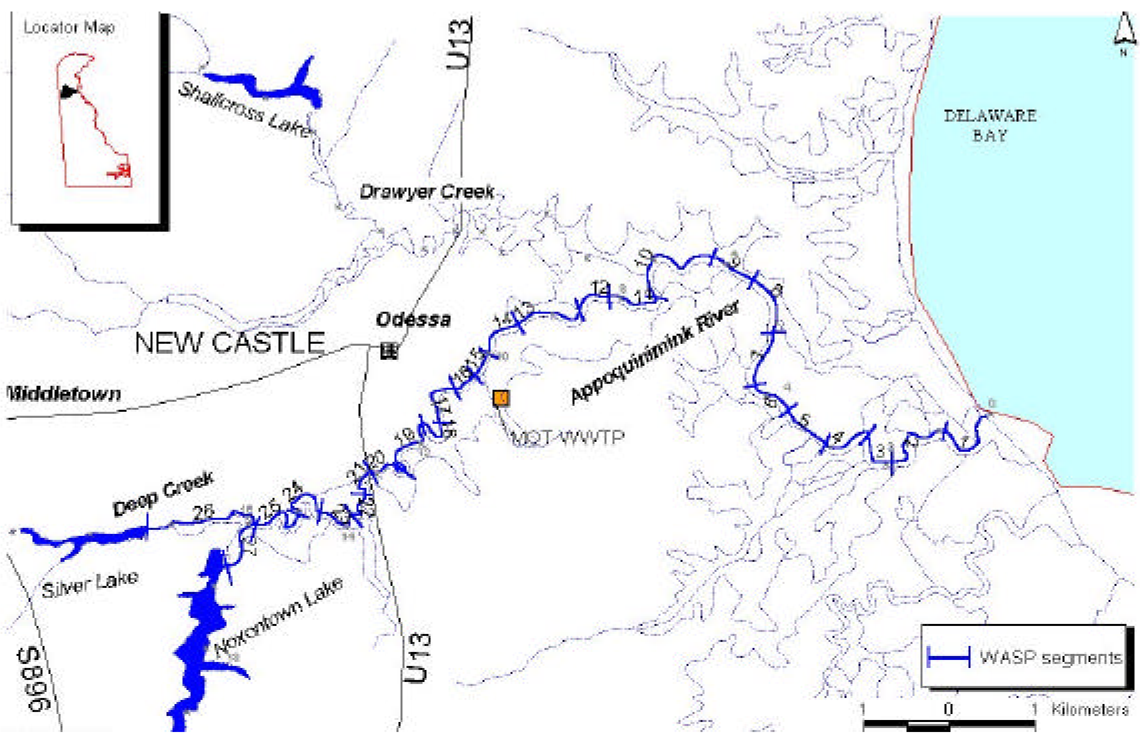


Figure 3-1 ARM0 WASP Segmentation

Boundary tides at the mouth of the Appoquinimink River were estimated from National Oceanic and Atmospheric Administration (NOAA) tide predictions using Reedy Point as the reference station. The times and heights of the high and low tides were then corrected to Liston Point which is about 3 miles south of the mouth of Appoquinimink River. The high and low tides over the period August 11 to October 19, 1991, were used as the boundary forcing condition in the model. Tributary flows in the model were set to constant values for the following locations for the August-October period.

Noxontown Pond	4.0 cfs	Model Junction 26
Silver Lake	4.0 cfs	Model Junction 27
Drawyer Creek	13.5 cfs	Model Junction 11

These flows were estimated based on the drainage area of each sub watershed and flows measured by a nearby USGS gage on Morgan Creek near Kennedyville, Maryland.

3.2. River Geometry

3.2.1 Hydrodynamic Data

3.2.1.1. Geometry

Expanding the existing Appoquinimink River Model (ARM0) to include upstream river reaches and lakes required additional data collection. Combined with the existing bathymetry and geometry data, the new data provided the basis for the expanded model grid. The river geometry data used to set up the new model framework came from four primary sources:

1) 1993 DYNHYD5 Model: Hydrodynamic model setup which included river geometry for the Appoquinimink River. The 1993 river geometry data was used as the basis for extending the existing hydrodynamic data. Depths, widths, flows and roughness coefficients values for the ARM0 were used to assign the values to the new tributaries.

2) RF3 files: United States Environmental Protection Agency (USEPA) - Reach File, Version 3 (RF3) data for rivers. RF3 data for rivers was used for the model segmentation. This data also provided the location and lengths of Drawyer Creek and Deep Creek.

3) USGS Topographic Maps: United States Geological Survey (USGS) 7.5 minute topographic map for elevation data and river length. The USGS topographic map of the area was used to estimate widths of Drawyer and Deep Creeks as well as the reaches of the Appoquinimink River upstream of the Noxontown Pond.

4) DNREC Survey - May 2000: DNREC collected geometry data during the Acoustic Doppler Current Profiler (ADCP) survey conducted at several sites along the Appoquinimink River on May 9, 2000. The lengths and widths collected during the ADCP survey were used in the hydrodynamic model setup (Table 3-1 , Table 3-2, Figure 3-2, Figure 3-3, Figure 3-4).

Table 3-1 Cross Sectional Data (5/9/2000)

Station	Width (m)	Depth (m)	DYNHYD Segment Number
1	94.35	4.6	2
2	74.78	4.1	6
3	97.32	2.72	8, 9
4	64.9	4.8	11
5	62.6	2.11	48
6	47.1	3.37	14
7	51.1	3.0	17

DNREC also provided geometry data for the 4 ponds/lakes located in the Appoquinimink River Watershed. These data are presented in Table 3-2 and were also used in the model segmentation setup.

Table 3-2 Physical Characteristics of the Ponds

Pond	Surface Area (acres)	Dam Height (ft)
Noxontown Pond	158.6	6
Shallcross Lake	43.3	8
Wiggins Mill Pond	21.2	15
Silver Lake	38.2	10

3.2.1.2. Flow Data

The 1993 DYNHYD5 model (ARM0) provided the flow data in the segments of the Appoquinimink River main stem. This flow output data was used to calibrate the expanded DYNHYD5 model (ARM1). The freshwater inflows, roughness coefficients and river geometry were adjusted to fit the 1993 flow data.

3.2.1.3. Tide Data

Tidal elevation data at the boundary was obtained from the 1993 DYNHYD5 model. Two periods of continuous data were available for the boundary:

1) August through October 1991 (~ 2 months)
2) May through July 1991 (~ 3 months)

The tidal elevation data at the Delaware River boundary is presented in Figure 3-5. During these two periods the tidal elevations, ranged from approximately -1 to 1 meter with a maximum tidal range of approximately 2 meters.

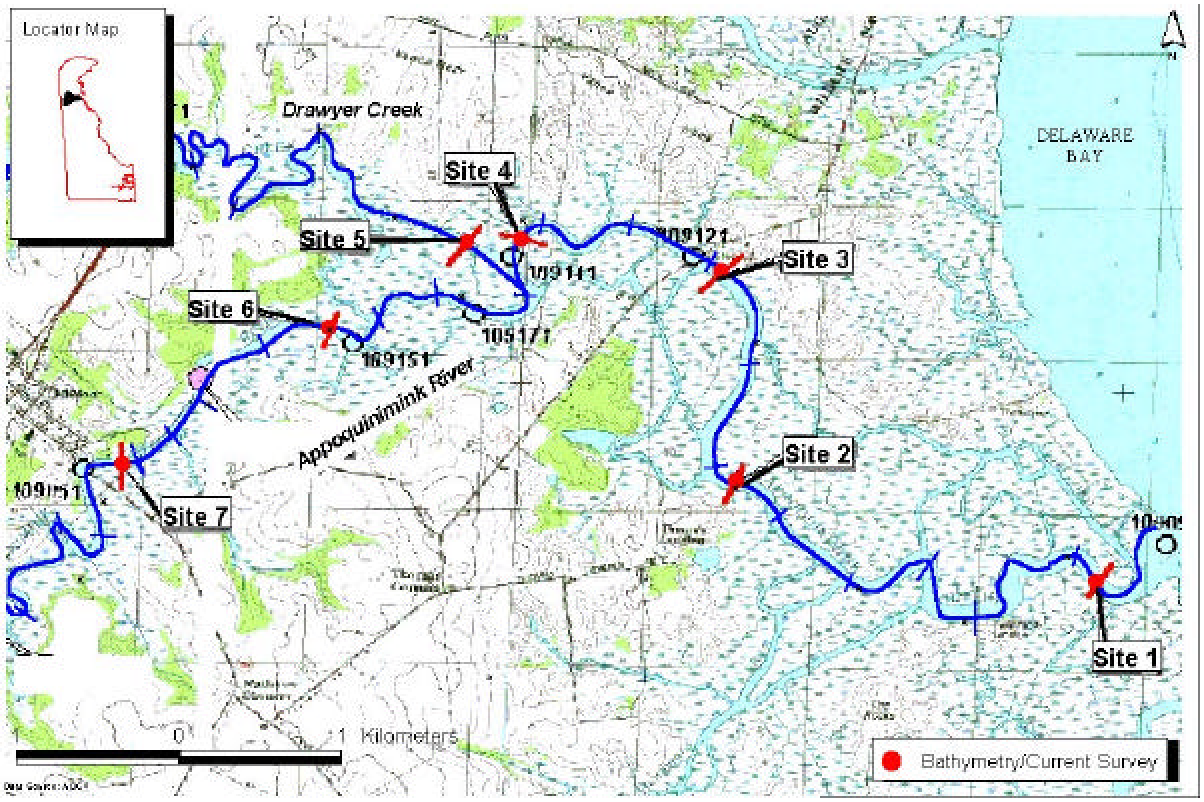


Figure 3-2 Bathymetry Survey (5/9/2000)

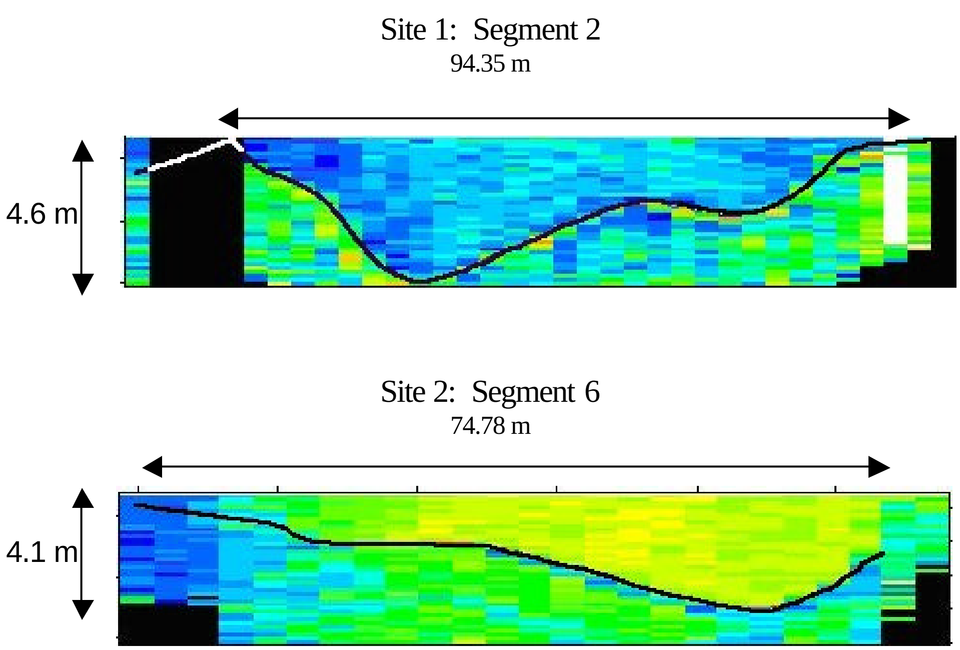


Figure 3-3 Cross Sectional Data –Sites 1 & 2 (ADCP Survey)

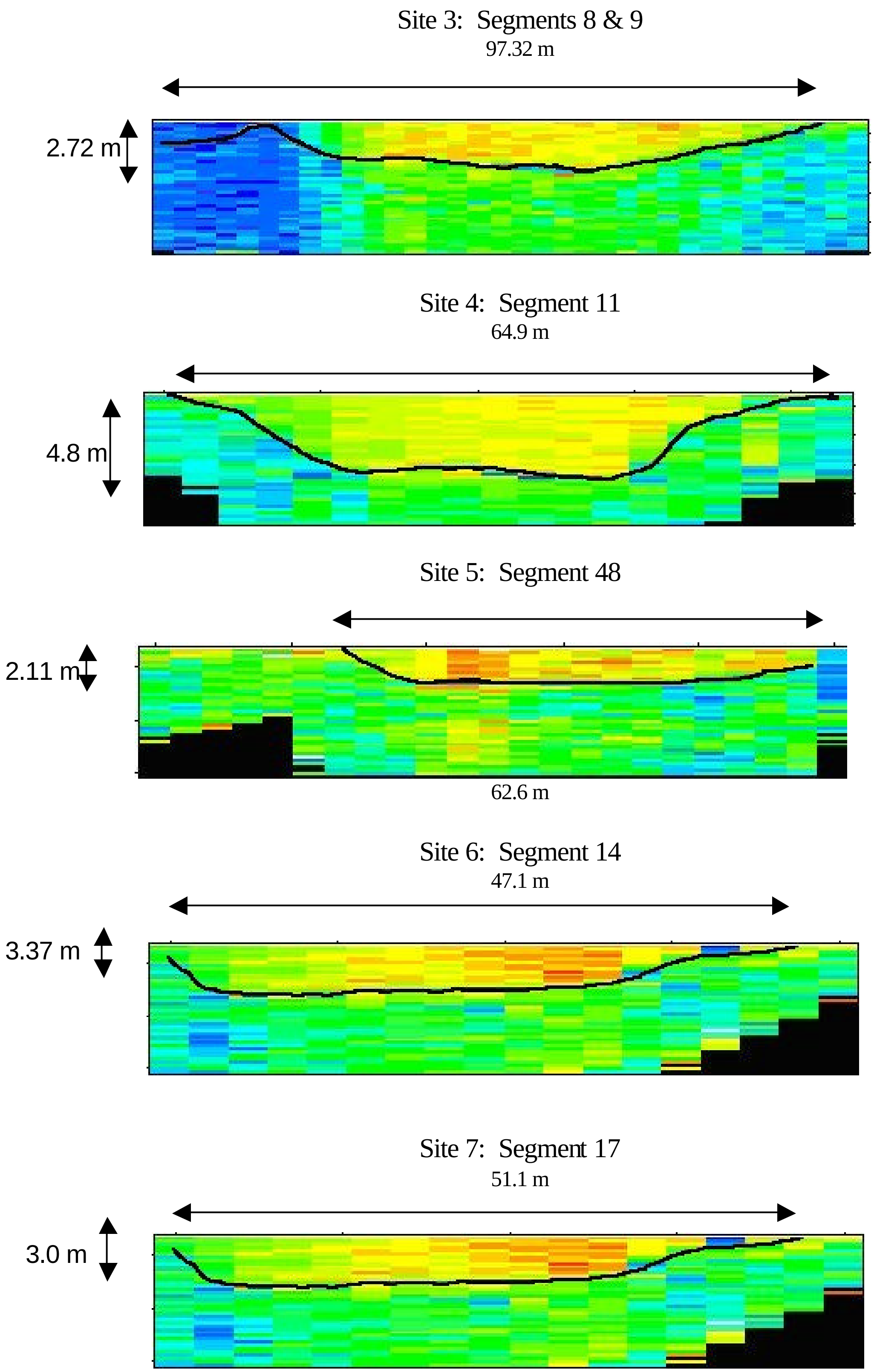
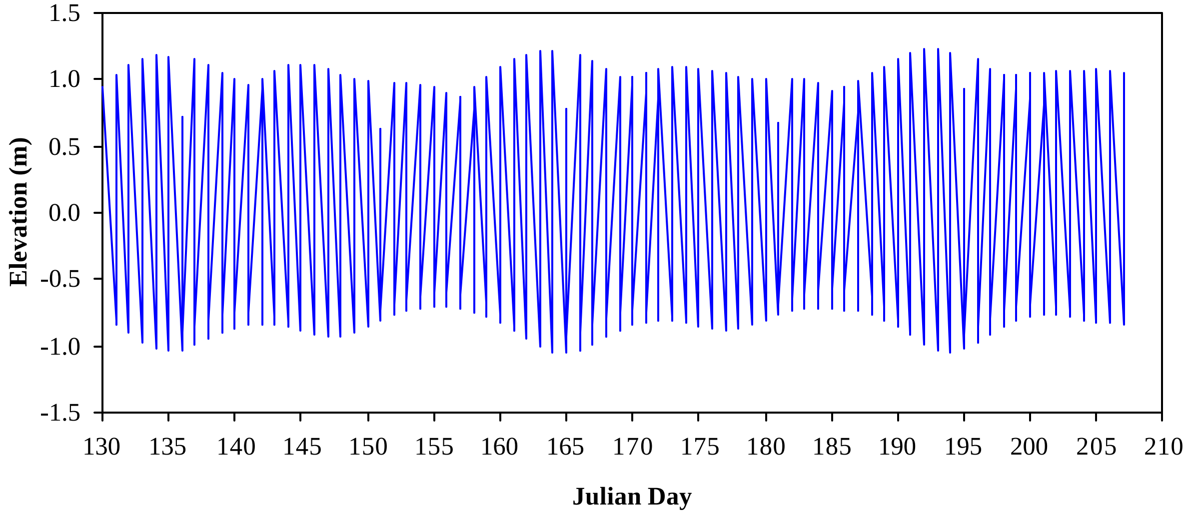


Figure 3-4 Cross Sectional Data – Sites 3-7 (ADCP Survey)



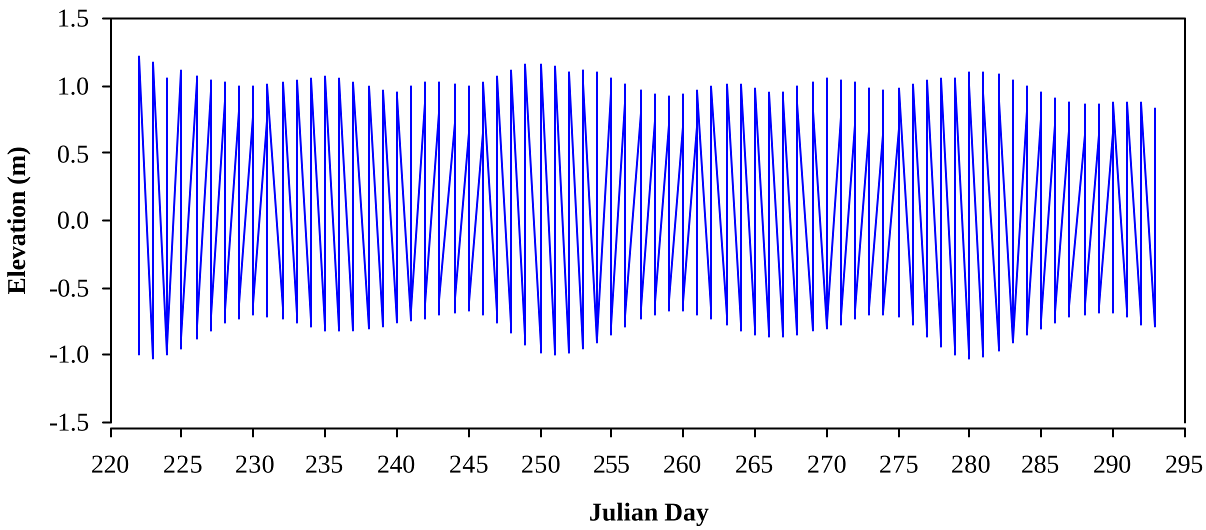


Figure 3-5 Tidal Elevation Data at the DE River Boundary (1991)

3.3. DYNHYD5 Model Framework

3.3.1 Theory

3.3.1.1. Modeling Program

The USEPA's DYNHYD5 hydrodynamic model was used to calculate water transport within the Appoquinimink River Watershed. DYNHYD5 is part of the WASP5 water quality-modeling program and solves the one-dimensional equations of continuity and momentum for a branching channel junction (link node) computational network.

The hydrodynamic model solves equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). The equation of motion, based on the conservation of momentum, predicts water velocities and flows. The equation of continuity, based on the conservation of volume, predicts water heights (heads) and volumes. This approach assumes that:

- Flow is predominantly one-dimensional,
- Coriolis and other accelerations normal to the direction of flow are negligible,
- Channels can be adequately represented by a constant top width with a variable hydraulic depth (i.e., "rectangular"),
- The wave length is significantly greater than the depth, and
- Bottom slopes are moderate.

Although no strict criteria are available for the latter two assumptions, most natural flow conditions in large rivers and estuaries would be acceptable. Dam break situations could not be simulated with DYNHYD5, nor could small mountain streams with steep slopes.

The DYNHYD model simulates the circulation patterns of water by solving two equations:

1) The equation of motion:

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} + a_{g,l} + a_f + a_{w,l}$$

where:

$\frac{\partial U}{\partial t}$ = the local inertia term, or the velocity rate of change with respect to time, [m/sec^2]

$U\frac{\partial U}{\partial x}$ = the Bernoulli acceleration, or the rate of momentum change by mass transfer; also defined as the convective inertial term from Newton's second law, [m/sec^2]

$a_{g,\lambda}$ = gravitational acceleration along with the λ axis of the channel, [m/sec^2]

a_f = frictional acceleration, [m/sec^2]

$a_{w,\lambda}$ = wind stress acceleration along axis of channel, [m/sec^2]

x = distance along axis of channel, [m]

t = time, [sec]

U = velocity along the axis of channel, [m/sec^2]

λ = longitudinal axis

2) The equation of continuity:

$$\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x}$$

where:

A = cross sectional area, [m^2]
Q = flow, [m^3/sec]

For rectangular channels of constant width (B):

$$\frac{\partial H}{\partial t} = -\frac{1}{B}\frac{\partial Q}{\partial x}$$

where:

B = width, [m]

H = water surface elavation, [m]

$\frac{\partial H}{\partial t}$ = rate of water surface elevation change with respect to time, [m/sec]

$\frac{1}{B}\frac{\partial Q}{\partial x}$ = rate of water volume change with respect to distance per unit width, [m/sec]

The equations of motion and continuity form the basis of the hydrodynamic model DYNHYD5. Their solution gives velocities (U) and heads (H) throughout the water body for the duration of the simulation. Because closed-form analytical solutions are unavailable, the solution of equations requires numerical integration on a computational network, where values of U and H are calculated at discrete points in space and time. The "link-node" network solves the equations of motion and continuity at alternating grid points. At each time step, the equation of motion is solved at the links while the equation of continuity is solved at the nodes, giving velocities for mass transport calculations and heads for pollutant concentration calculations respectively.

Picturing the links as channels conveying water and the nodes as junctions storing water allows a physical interpretation of this computational network to be envisioned. Each junction is a volumetric unit that acts as a receptacle for the water transported through its connecting channels. Taken together, the junctions account for all the water volume in the river or estuary. Parameters influencing the storage of water are defined within this junction network. Each channel is an idealized rectangular conveyor that transports water between two junctions, whose midpoints are at each end. Taken together, the channels account for all the water movement in the river or estuary. Parameters influencing the motion of water are defined within the channel network. The link-node computational network, then, can be viewed as the overlapping of two closely related physical networks of channels and junctions.

3.3.2 Model Geometry and Bathymetry

The segmentation for the expanded Appoquinimink River Watershed model (ARM1) is presented in Figure 3-6. The model is one-dimensional and consists of 51 junctions and 47 channels that average approximately one half mile in length.

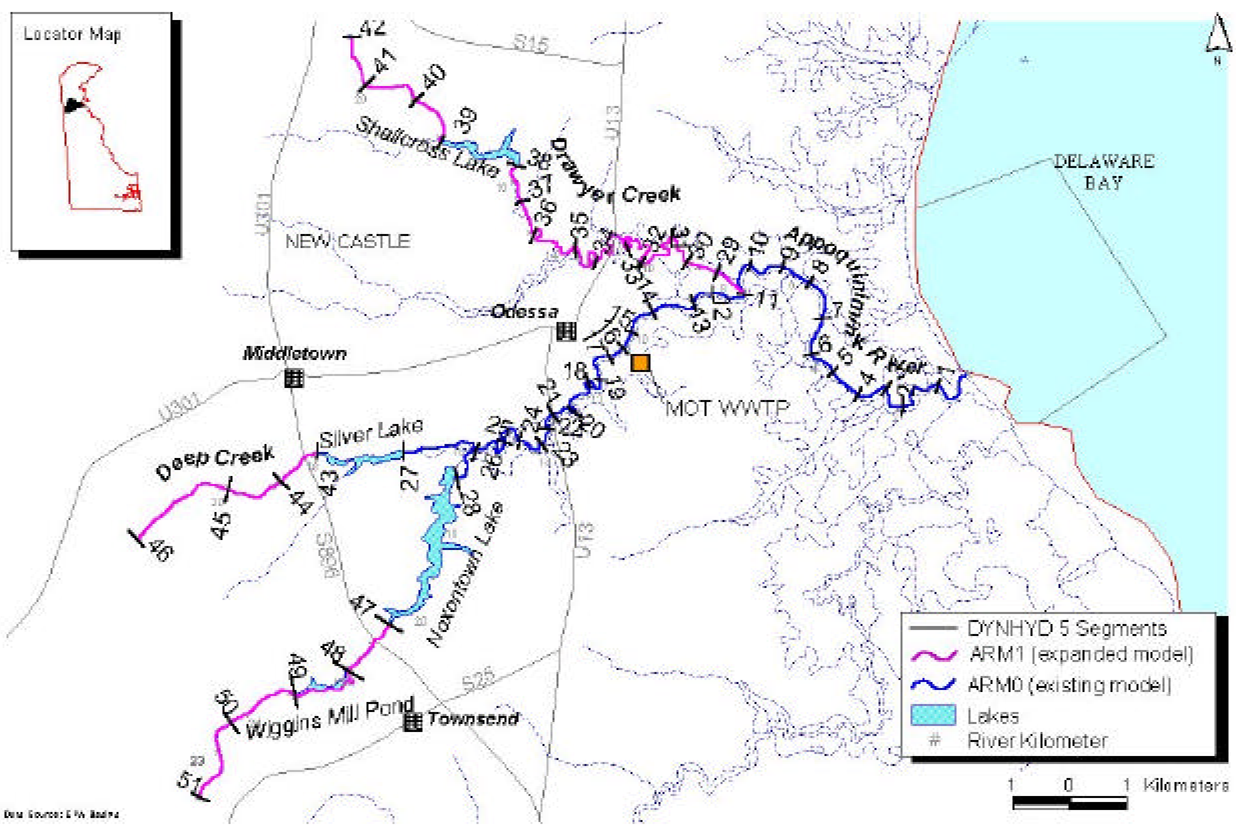


Figure 3-6 DYNHYD5 ARM1 Junctions

Four ponds were included in the expanded model grid: Noxontown Lake, Wiggins Mill Pond, Silver Lake and Shallcross Lake. Flow out of the ponds results from water flowing over the tops of the dams. With a dam forming a physical boundary to the free flow of water through the system, channel velocities are not propagated downstream of the ponds in the model framework. Only flows entering the pond are passed to the downstream model junction.

As previously mentioned, the data used to extend the hydrodynamic model of the Appoquinimink River was obtained from four data sources (1993 DYNHYD5 model, DNREC geometry, RF3 data and USGS topographic maps) and used in setting up the geometry (width, initial depth and elevation) for the DYNHYD5 model. None of the data sources alone provided the complete data set needed for the model grid. Therefore, best professional judgment was used to integrate the data sources into one picture of the river to resolve discrepancies and inconsistencies between and within the data sources, and to make estimates where data gaps existed.

Using the data as a guide, widths and depths were assigned for each model junction. Manning's 'n' which describes the bottom roughness, varied between 0.035 and 0.065. Increased roughness coefficients of 0.10 were used for three channels at the confluence of Drawyer Creek and the Appoquinimink River to improve the DYNHYD5 comparisons to the ARM0 model output. The roughness coefficients were adjusted based on the values of the coefficients of the previous modeling study (ARM0) geometry .

3.3.2.1. Model Forcing Data

Freshwater flows at the upstream boundaries and tide data at the downstream boundary were the primary forcing functions in the model. The water loss due to evaporation from the water surface and the addition of water due to precipitation falling directly on the water surface were assumed to be of second-order importance and not included in the model framework. The direct effect of wind on the water surface was also assumed to be of second-order importance. The river channel is relatively narrow and would, therefore, not be strongly impacted by winds. The effect of wind on Delaware Bay is reflected in the tidal data and, therefore, is included in the model indirectly through the tidal data used to drive the downstream boundary. A total of four boundary conditions are included in the model; the open tidal boundary at Delaware Bay and three upstream freshwater inputs (Drawyer Creek, Deep Creek and the Appoquinimink River).

3.3.2.2. Tidal Boundary

An open water boundary was located at the mouth of the river to Delaware Bay (junction 1), which is driven by the tidal conditions in the Delaware Bay.

Tidal information used in the ARM0 (1991 model setup) was used to drive the downstream model boundary. This data has been described in Section 3.2.1.3 and presented in Figure 3-5.

3.3.2.3. Fresh Water Flows

Flow enters the model through one of three possible mechanisms: upstream boundaries (Drawyer Creek, Deep Creek and upstream Appoquinimink River), tributaries, or direct runoff into a model junction. Three freshwater inputs were assigned at upstream boundary for Drawyer

Creek, Deep Creek and the Appoquinimink River (Table 3-3). These freshwater inputs are constant flows and are not affected by tidal conditions in the lower Appoquinimink River. The flows for the upstream boundaries were determined based on the ratio of the drainage area of each sub basin to the drainage area of the gagged sub basin. At each of the three upstream boundary locations, the following constant flows were assigned.

Table 3-3 Freshwater Inflows

Location	Junction	Inflows (cfs)
Drawyer Creek	42	13.5
Deep Creek	46	4.0
Appoquinimink River	51	4.0

3.3.2.4. Initial Conditions

Initial conditions were assigned to each model segment for each system being modeled based on the ARM0 initial conditions, these conditions included the initial mean velocities (m/s). An average initial velocity of 0.001 m/s was specified for all the channels.

3.4. DYNHYD5 Calibration/Validation

HydroQual was contracted to expand the existing TMDL model of the Appoquinimink River (ARM0) to upstream areas not included in the original model study area. These expanded areas include Drawyer Creek and Shallcross Lake, Deep Creek and Silver Lake, and the upstream Appoquinimink River including Wiggins Mill Pond and Noxontown Lake. This new expanded model is referred to as ARM1. Since new data was not available for this phase of the model expansion, additional calibration analyses could not be completed. In addition, since the existing TMDL for the main stem of the Appoquinimink River is based on the 1993 TetraTech model (ARM0), the expanded model (ARM1) primarily used the same base-line conditions, assumptions, and parameters to avoid any inconsistencies. Therefore, the expanded hydrodynamic model (ARM1) was calibrated to match the results of the 1993 adjusted model (ARM0). The same periods used to calibrate and validate the ARM0 model (calibration: August 10, 1991 to October 14, 1991 and validation: May 10, 1991 through July 25, 1991) were also used to calibrate and validate the ARM1 model. With additional upstream segments and new geometry data, the ARM1 model was calibrated primarily by performing adjustments to Manning's 'n' and refinements to the model geometry. This is the same approach used in the 1993 calibration efforts and included adjusting parameters to conform within the ranges used in the earlier modeling work (ARM0). Inconsistencies between the ARM0 model input channel lengths and widths, and junction surface areas were corrected in the ARM1 model with the channel lengths and widths used to calculate the new surface areas. In addition, the large boundary junction required in the original ARM0 model was not required in the ARM1 model and the correct surface area was used.

3.4.1 Calibration

The model was calibrated to the period from August 10 to October 14, 1991 with results presented for 6 segments (Figure 3-7). Roughness coefficients and river geometry were adjusted to match the 1993 modeling results.

The model output in segments 1, 5, 10, 15, 20, and 25 for the calibration period generated with the new expanded model (ARM1) show agreement with the model output previously generated with the 1993 model (ARM0). Cross-plots of ARM0 and ARM1 DYNHYD5 model output is presented in Figure 3-8 through Figure 3-10 for velocity, flow and depth at junctions 1, 5, 10, 15, 20 and 25 along with a line of perfect agreement (slope = 1). The new ARM1 DYNHYD5 model generally reproduces the ARM0 model output with slightly greater flood and ebb tide velocities and flows calculated with the ARM1 model at junctions 1, 5, 10, and 25. The ARM1/ARM0 agreement at junctions 15 and 20 for velocity and flow is very good. Calculated water depths from the ARM1 model also agree very well with the ARM0 results.

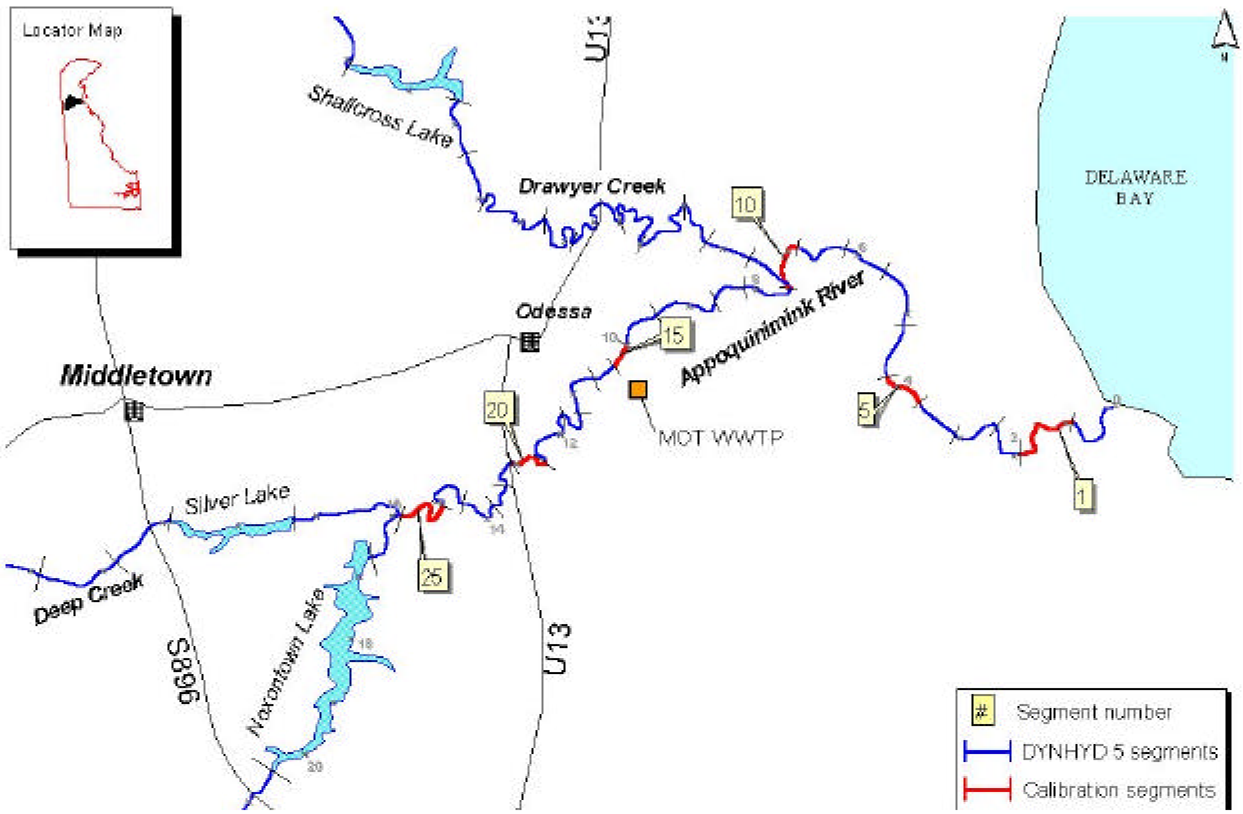


Figure 3-7 Appoquinimink River Watershed DYNHYD5 Calibration Segments

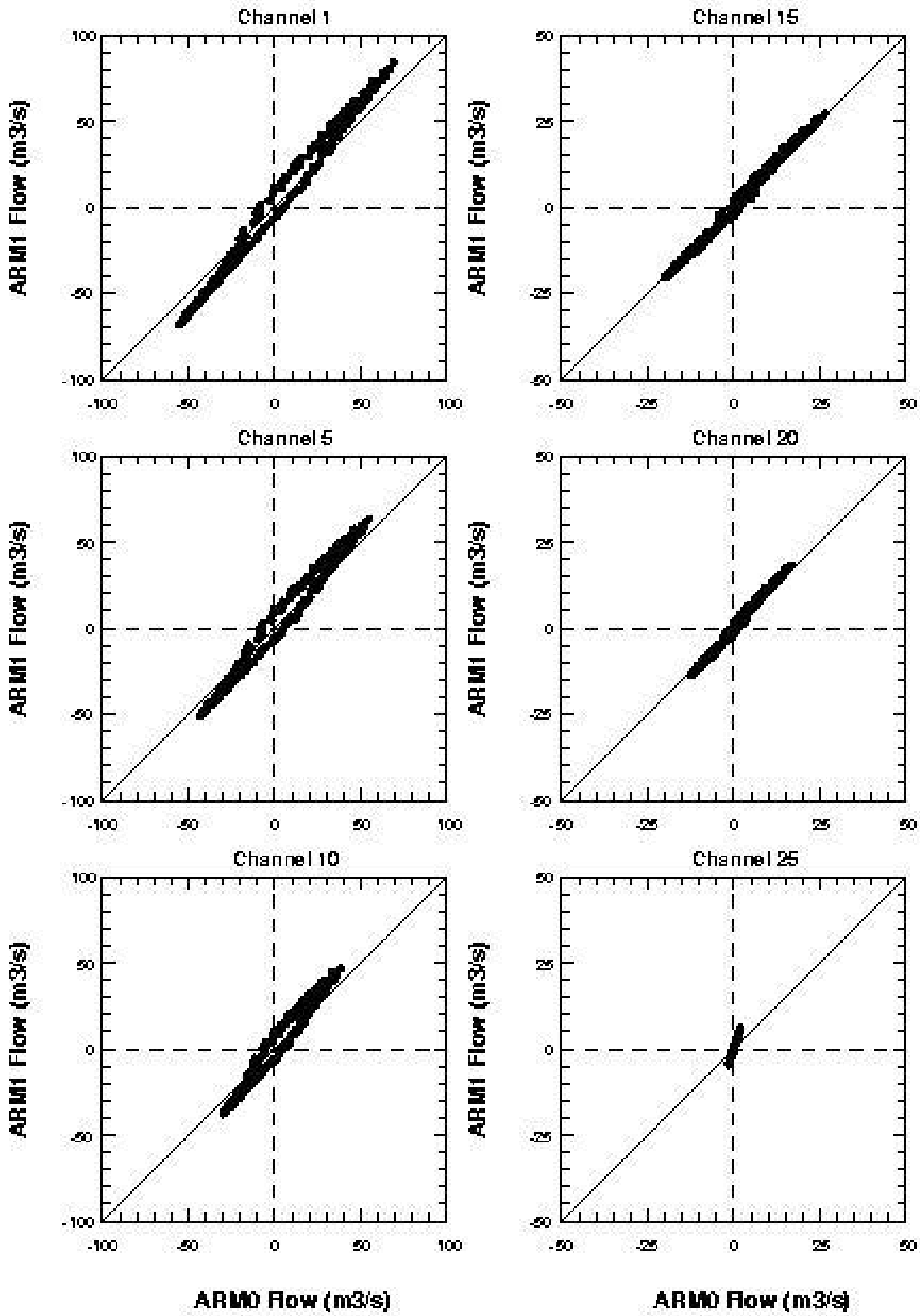


Figure 3-8 Appoquinimink River Model DYNHYD5 Calibration Flow Comparisons

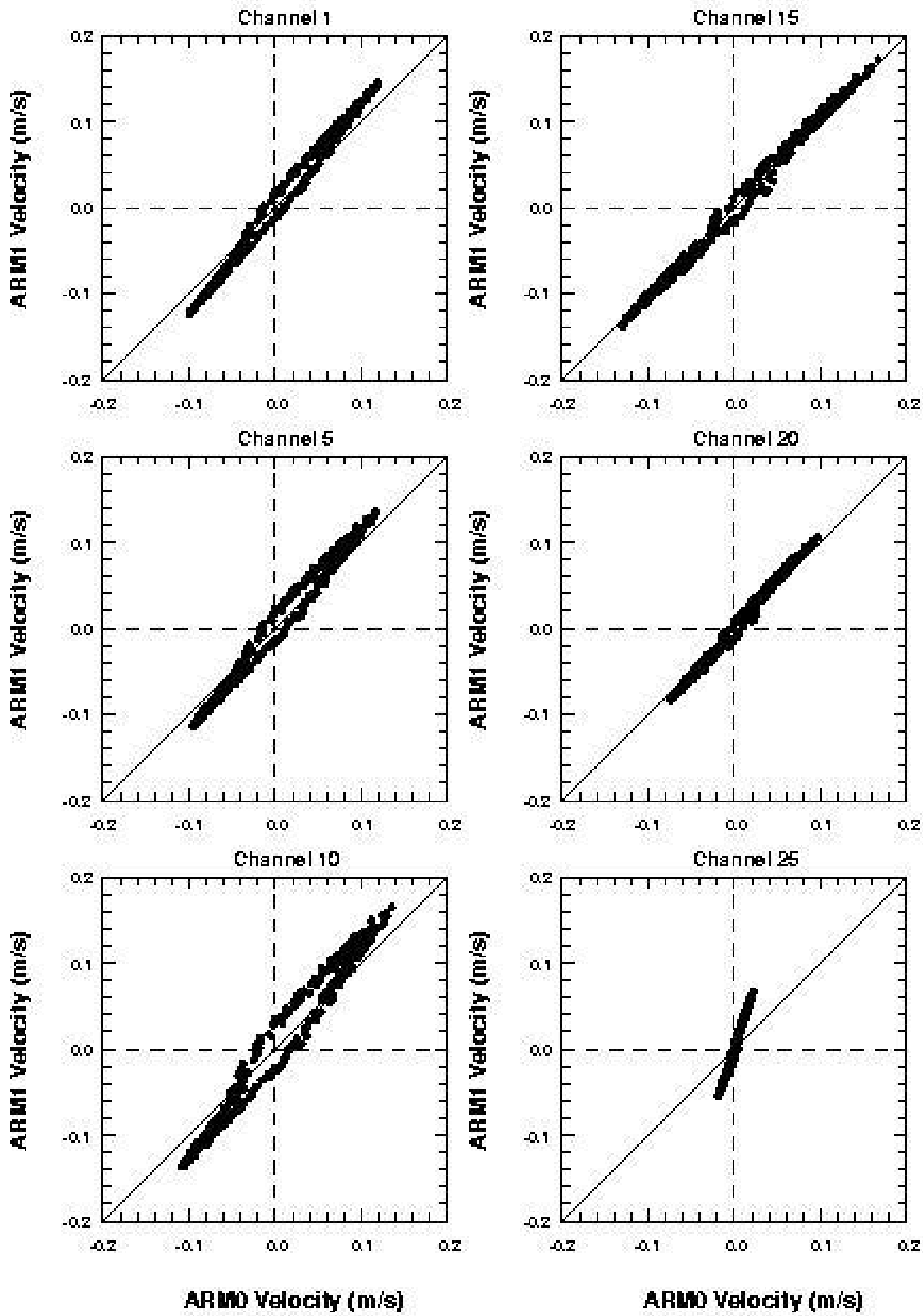


Figure 3-9 Appoquinimink River Model DYNHYD5 Calibration Velocity Comparisons

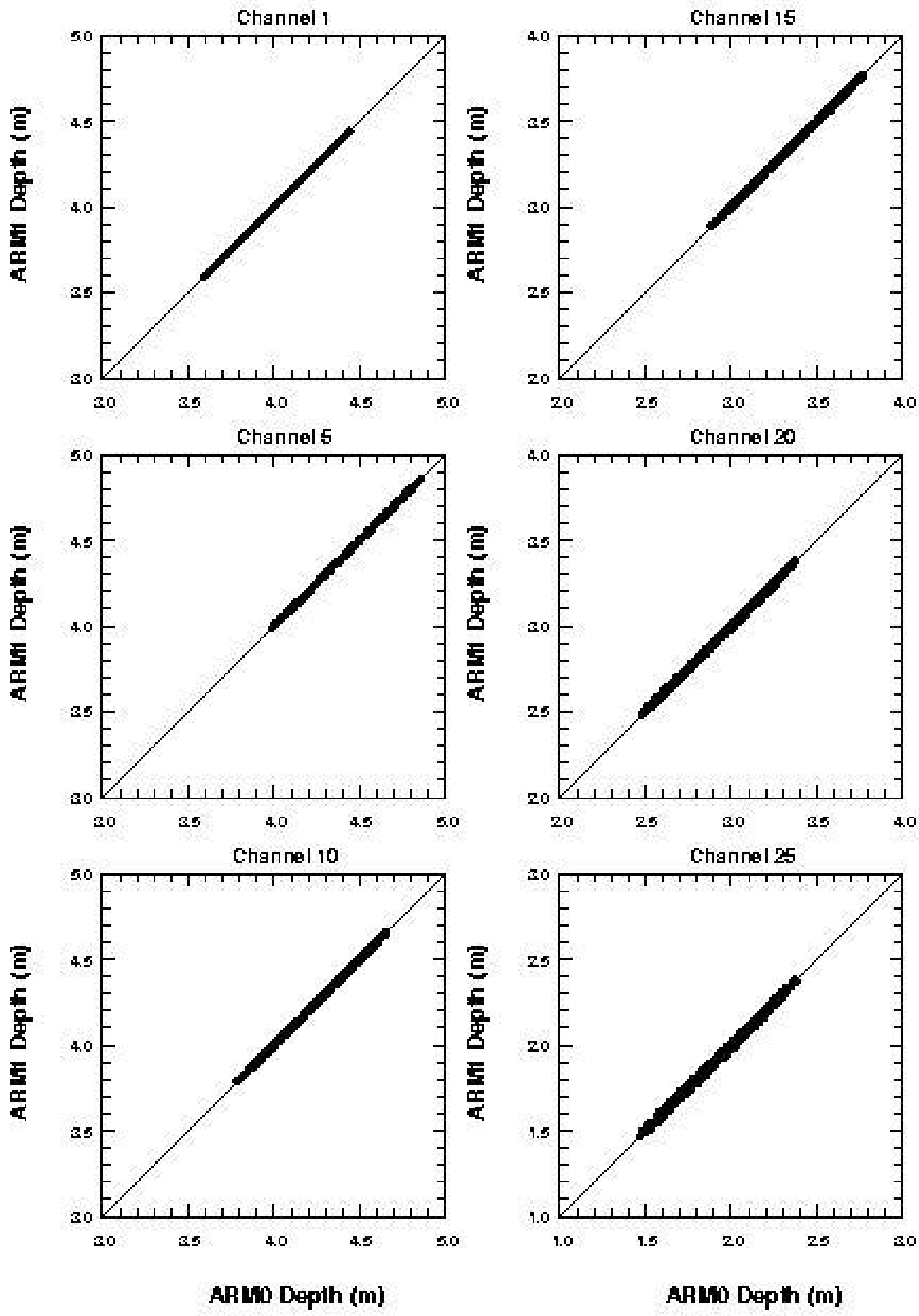


Figure 3-10 Appoquinimink River Model DYNHYD5 Calibration Depth Comparisons

3.4.2 Validation

Following calibration, the model was validated to the period between May 10 and July 25, 1991. As with the calibration period, flows, velocities and depths calculated by the ARM1 model over the validation period show agreement between the ARM1 and ARM0 models. Again the cross-plots of ARM0 and ARM1 DYNHYD5 model results are presented in Figure 3-11 through Figure 3-13 for velocity, flow and depth. The comparisons between the ARM1 and ARM0 model result in similar conclusions for the validation period as for the calibration period.

3.4.3 Tidally Averaged Transport

The tidally averaged transport from the ARM1 model during the calibration and validation period are presented in Figure 3-14 and Figure 3-15. In these figures the solid line represents the Appoquinimink River main stem, the dashed line represents Drawyer Creek and the dotted line represents Deep Creek. The tidally averaged flows ranged from 4 to 25 cfs with Drawyer Creek flow of approximately 14 cfs. Velocities ranged from approximately 5 to 45 cm/s with depths ranging from approximately 1 to 16 feet.

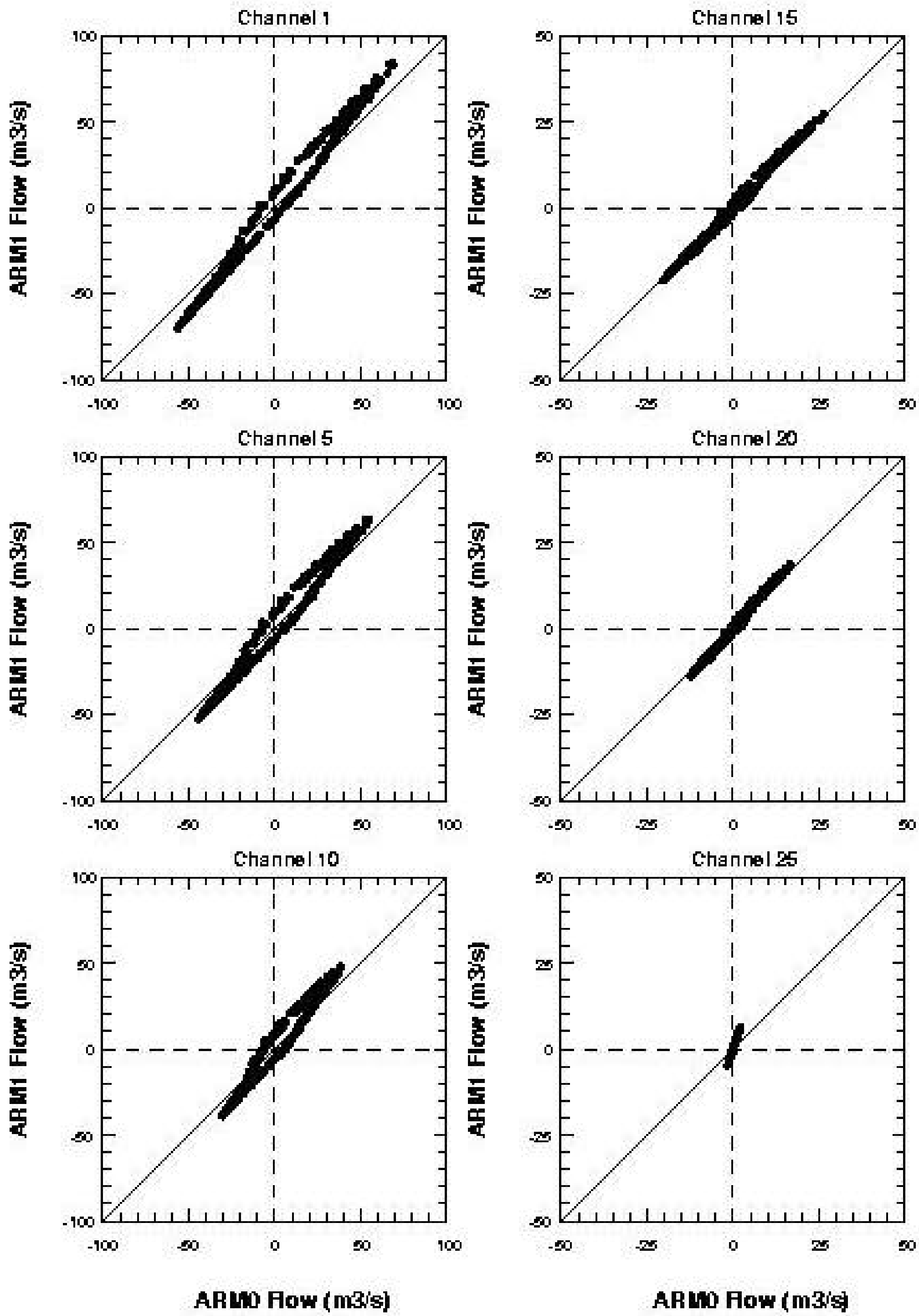


Figure 3-11 Appoquinimink River Model DYNHYD5 Verification Flow Comparisons

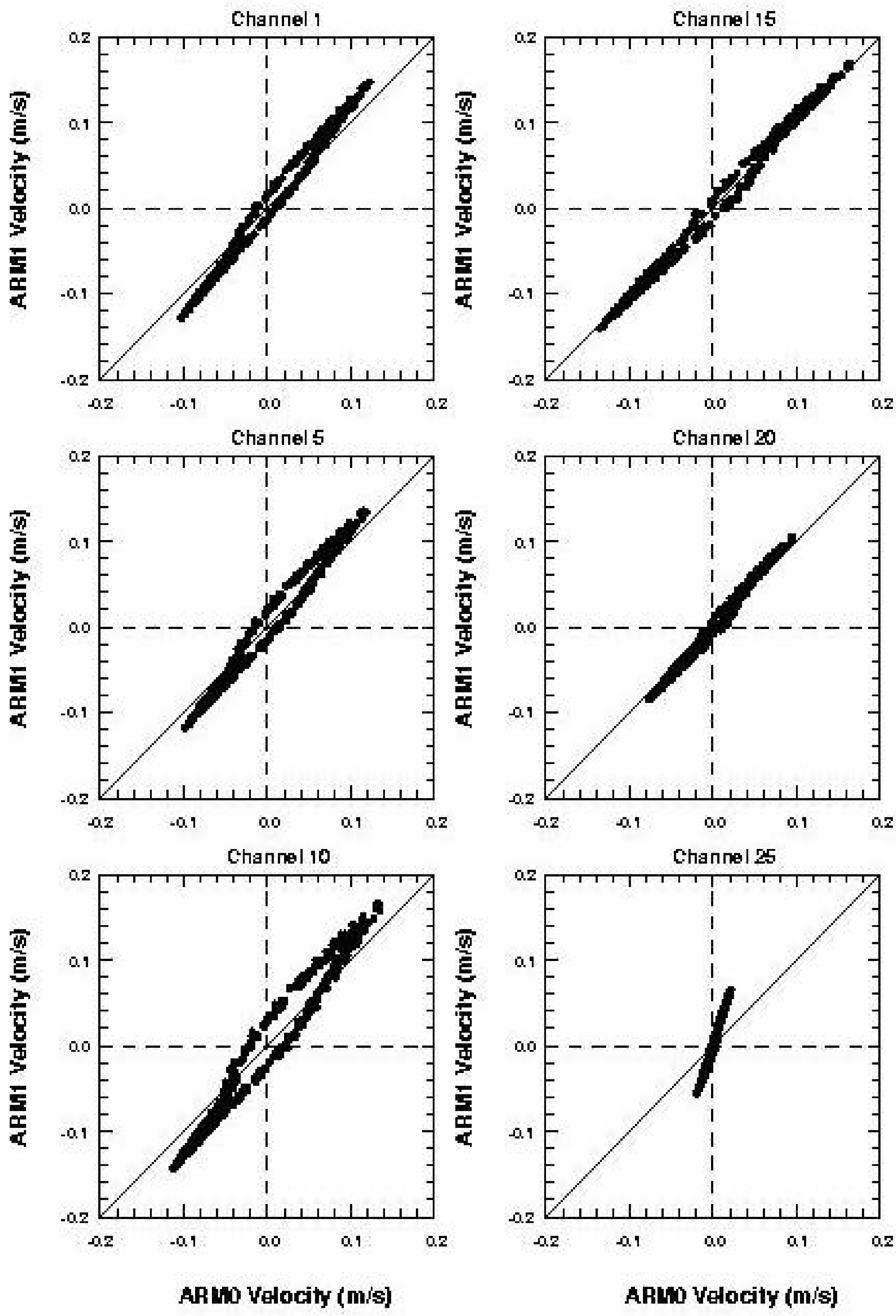


Figure 3-12 Appoquinimink River Model DYNHYD5 Verification Velocity Comparisons

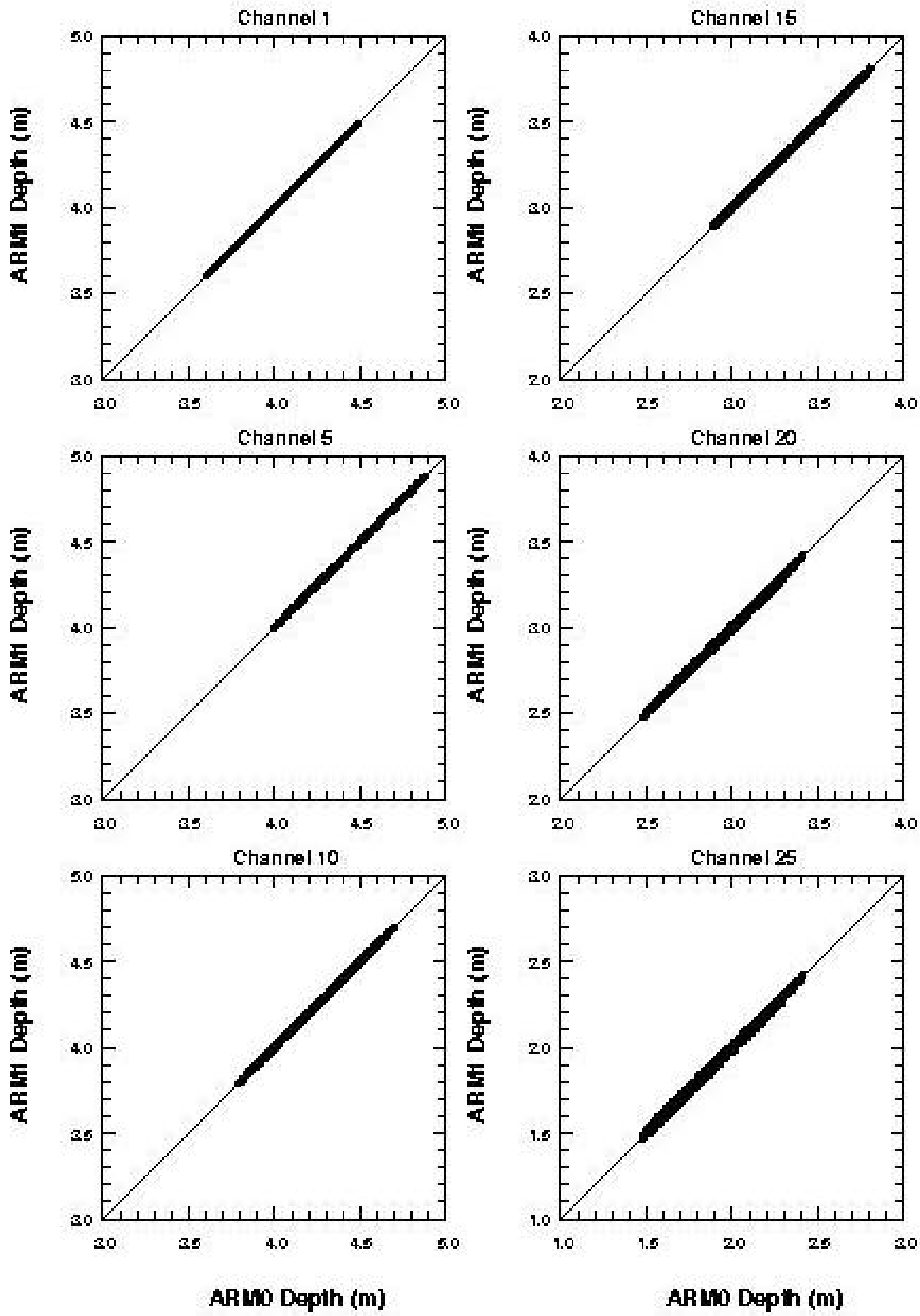


Figure 3-13 Appoquinimink River Model DYNHYD5 Verification Depth Comparisons

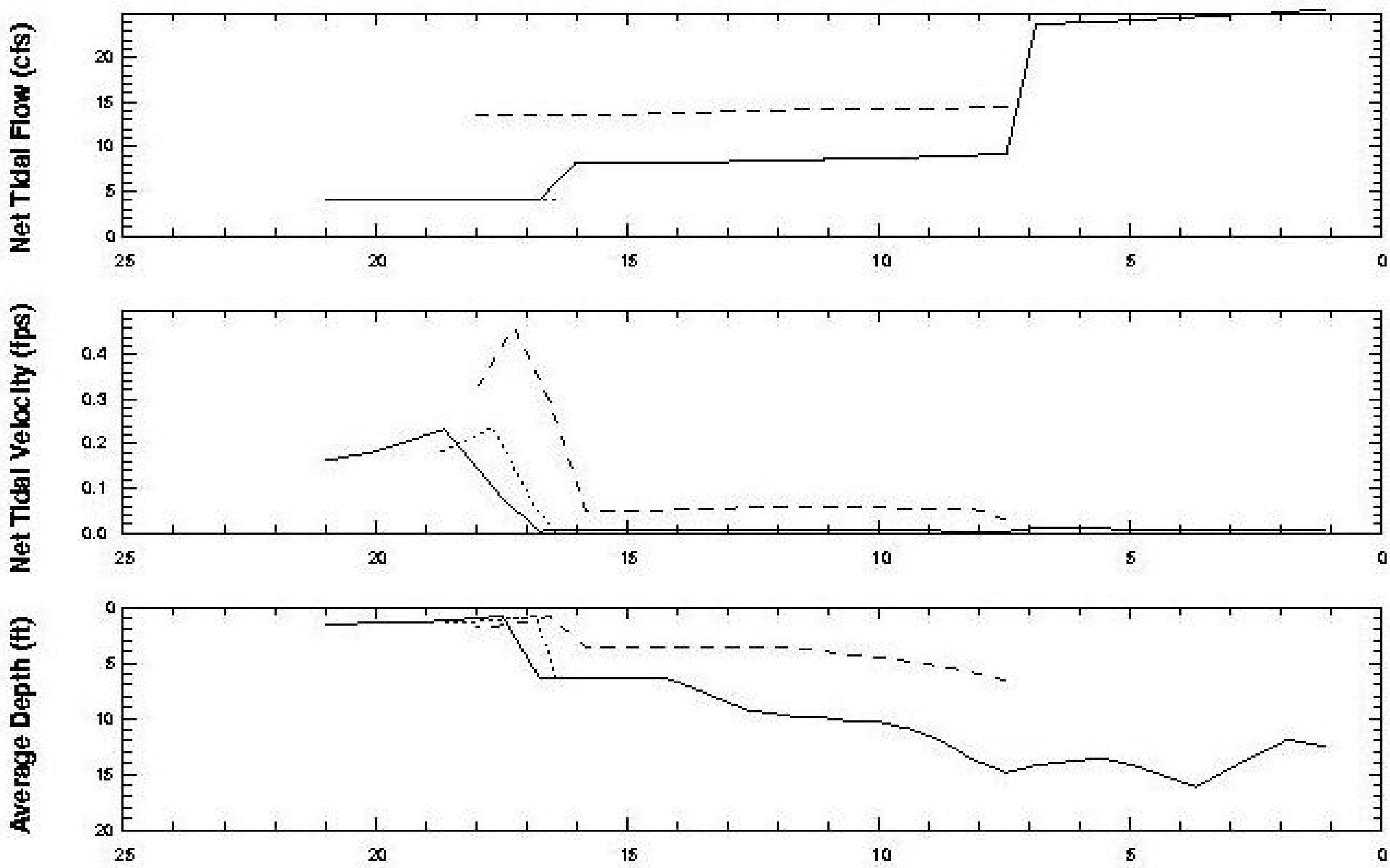


Figure 3-14 Appoquinimink River Model DYNHYD5 Model Calibration Output (ARM1)

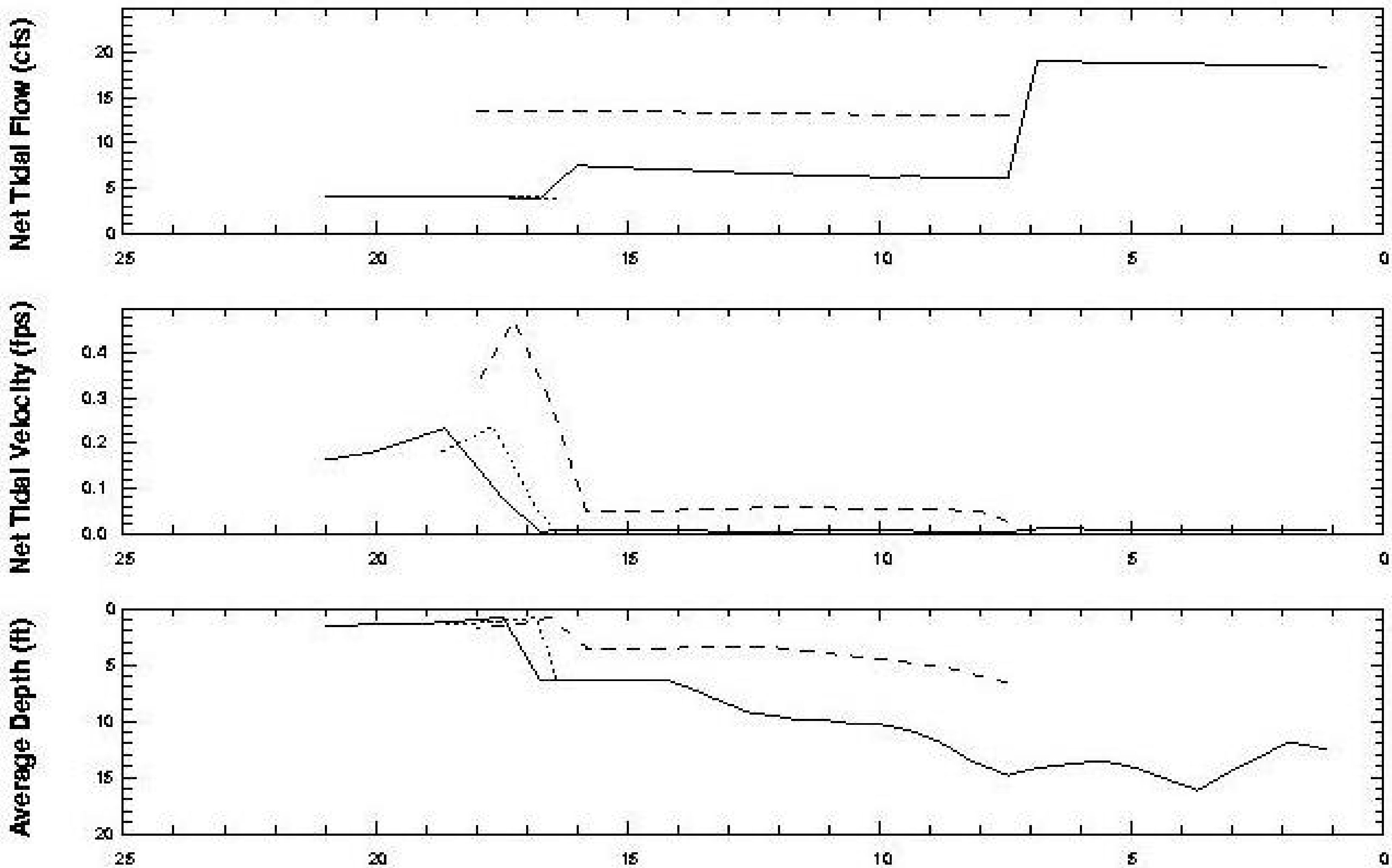


Figure 3-15 Appoquinimink River Model DYNHYD5 Model Validation Output (ARM1)

3.5. WASP5 Model Framework

3.5.1 Water Quality Modeling Framework (WASP-Eutro)

3.5.1.1. Background

The Water Quality Analysis Simulation Program5 (WASP5) is an enhancement of the original WASP (DiToro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). This model allows users to interpret and predict water quality responses to natural phenomena and man-made pollution. WASP5 is a dynamic compartmental modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in this program.

The WASP5 system consists of two standalone computer programs, DYNHYD5 and WASP5 that can be run in conjunction or separately. The hydrodynamic program, DYNHYD5, simulates the movement of water while the water quality program, WASP5, simulates the movement and interaction of pollutants within the water. For more information regarding DYNHYD5, please refer to Section 5.1.

WASP5 is a dynamic compartmental model that can be used to analyze a variety of water quality problems in such diverse water bodies as lakes, reservoirs, rivers, estuaries, and coastal waters. WASP5 is supplied with two kinetic sub-models to simulate two of the major classes of water quality problems: conventional pollutants (involving dissolved oxygen, biochemical oxygen demand (BOD), nutrients and eutrophication) and toxic pollutants (involving organic chemicals, metals, and sediment). The linkage of either sub-model with the WASP5 program results in the models EUTRO5 and TOXI5, respectively. The water quality model for the Appoquinimink River Watershed (ARM1) uses the EUTRO5 sub-model.

The equations solved by WASP5 are based on the principle of mass conservation. This principle requires that the mass of each water quality constituent being investigated must be accounted for. WASP5 traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time. To perform these mass balance computations, the user must supply WASP5 with input data defining seven important characteristics:

- Simulation and output control;
- Model segmentation;
- Advective and dispersive transport;
- Boundary conditions;
- Point and diffuse source waste loads;
- Kinetic parameters, constants, and time functions; and
- Initial conditions.

These input data, together with the general WASP5 mass balance equations and the specific chemical kinetics equations, uniquely define a special set of water quality equations. These are numerically integrated by WASP5 as the simulation proceeds in time. At user specified print intervals, WASP5 saves the values of all display variables for subsequent retrieval by the postprocessor program.

3.5.1.2. Theory and Equations

The water quality modeling framework used in this study and detailed in this report is based upon the principle of conservation of mass. The conservation of mass accounts for all of a material entering or leaving a body of water, transport of the material within the water body, and physical, chemical and biological transformations of the material. For an infinitesimal volume oriented along the axis of a three-dimensional coordinate system, a mathematical formulation for the conservation of mass may be written:

$$\frac{\partial c}{\partial t} = \underbrace{\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right)}_{\text{dispersive transport}} \underbrace{- U_x \frac{\partial c}{\partial x} - U_y \frac{\partial c}{\partial y} - U_z \frac{\partial c}{\partial z}}_{\text{advective transport}} \qquad (7\text{-}1)$$

where:

c = concentration of water quality variable [M/L^3];

t = time [T];

E = dispersion (mixing) coefficient due to tides and density and velocity gradients [L^2/T];

U = advective velocity [L/T];

S_L = external inputs of the variable c [M/L^3-T];

S_B = boundary loading rate (including upstream, downstream, benthic and atmospheric inputs) [M/L^3-T];

S_K = sources and sinks of the water quality variable, representing kinetic interactions [M/L^3-T];

x,y,z = longitudinal, lateral and vertical coordinates; and

M,L,T = units of mass, length and time, respectively.

The model framework used in this study is comprised of three components:

1) Transport due to advective freshwater flow and density-driven tidal currents and dispersion;
2) Kinetics which control the physical, chemical and biological reactions being modeled (sources and sinks); and
3) External inputs entering the system (point sources, non-point sources and boundary conditions).

The transport within the Appoquinimink River Watershed System is a complex process affected by freshwater inflows, temperature, wind, and offshore forcing from the coastal shelf via the Delaware Bay. This transport was determined by the hydrodynamic model previously presented in Section 6. The hourly average fluxes from this hydrodynamic model were used to drive the transport field of the water quality model.

The kinetics represent the rates of reaction among water quality variables and approximate the physical, chemical and biological processes occurring in the Appoquinimink River Watershed. The kinetic framework of the water quality model is presented in Figure 3-16.

External inputs of carbonaceous biochemical oxygen demand (CBOD), nutrients (nitrogen and phosphorus) and other model variables are from point sources, non-point sources and model boundary conditions.

The modeling framework used in this study utilized the following state-variables:

1 - Ammonia Nitrogen (NH_3);
2 - Nitrate (NO_3);
3 - Dissolved Inorganic Phosphorus (PO_4);
4 - Phytoplankton (PHYT);
5 - Carbonaceous Biochemical Oxygen Demand (CBOD);
6 - Dissolved Oxygen (DO);
7 - Organic Nitrogen (Org N); and
8 - Particulate Organic Phosphorus (Org P).

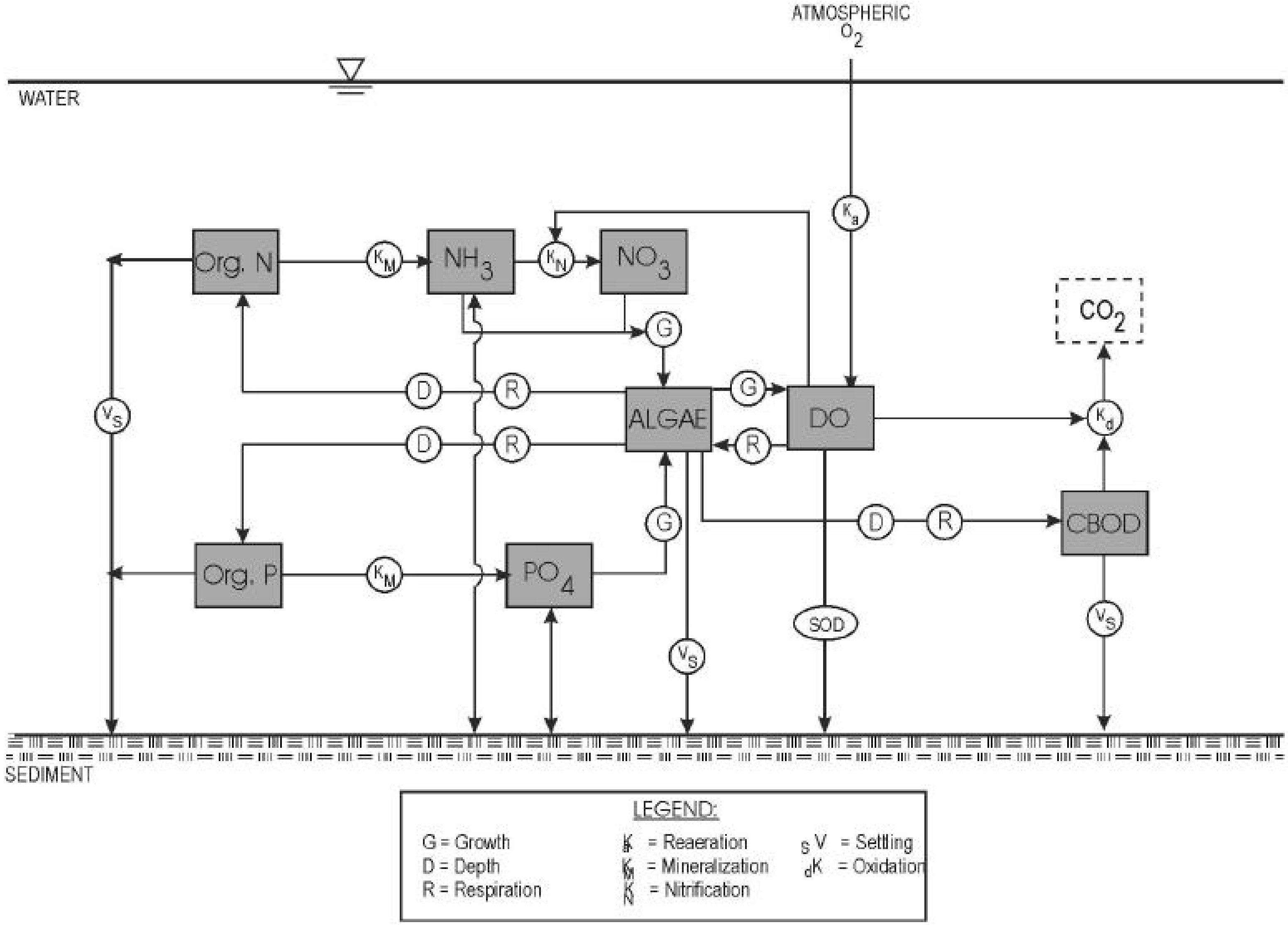


Figure 3-16 WASP-EUTRO5 Water Quality Model Kinetic Framework for the Appoquinimink River Watershed

3.5.2 Model Grid

The model segmentation for the Appoquinimink River Watershed water quality model is presented in Figure 7-2. The model is one-dimensional and consists of 47 water quality segments that average approximately one mile in length with one sediment segment for the entire model domain. The model segmentation is based on the DYNHYD5 model of the Appoquinimink River Watershed with the junctions used for water quality model segments. The original ARM0 water quality model improperly assigned the boundary condition segments in the model setup. It is necessary to assign the water quality boundary conditions one segment in from the DYNHYD5 boundary condition junctions. The proper assignment of water quality boundary condition segments was completed in the ARM1 WASP5 model. This improper assignment of boundary condition segments in the ARM0 model was noticed in the ARM1 model when the assigned boundary conditions were not properly affecting the internal model calculations.

3.6. WASP5 Model Calibration/Validation

The expanded WASP5 model (ARM1) calibration and validation results are compared to the results of the previous model (ARM0) and the data collected during the calibration period (August 11, 1991 to October 19, 1991) and validation period (May 10, 1991 to July 25, 1991). The model calibration and validation results for each parameter are presented in the following sections which show the data collected during each modeling period, the period average and range in model values calculated over that modeling period.

During this process it was noted that the WASP5 volumes used in the original ARM0 model did not correlate with the assigned lengths, widths and depths in the DYNHYD5 model. In order to be consistent between the DYNHYD5 and WASP5 models, re-calculated volumes were assigned in the new ARM1 WASP5 model based on the new DYNHYD5 model lengths, widths and depths.

3.6.1 Forcing Functions

Initial Conditions

Prior to the start of a model simulation, an initial condition was assigned to each segment for each of the eight systems (ON, NH_3, NO_x, OP, PO4, CBOD, DO, chl-a) being modeled. The initial conditions used for both modeling periods for the new model segments were based on the ARM0 model and expanded to the upstream reaches for Silver Lake, Noxontown Lake and Drawyer Creek.

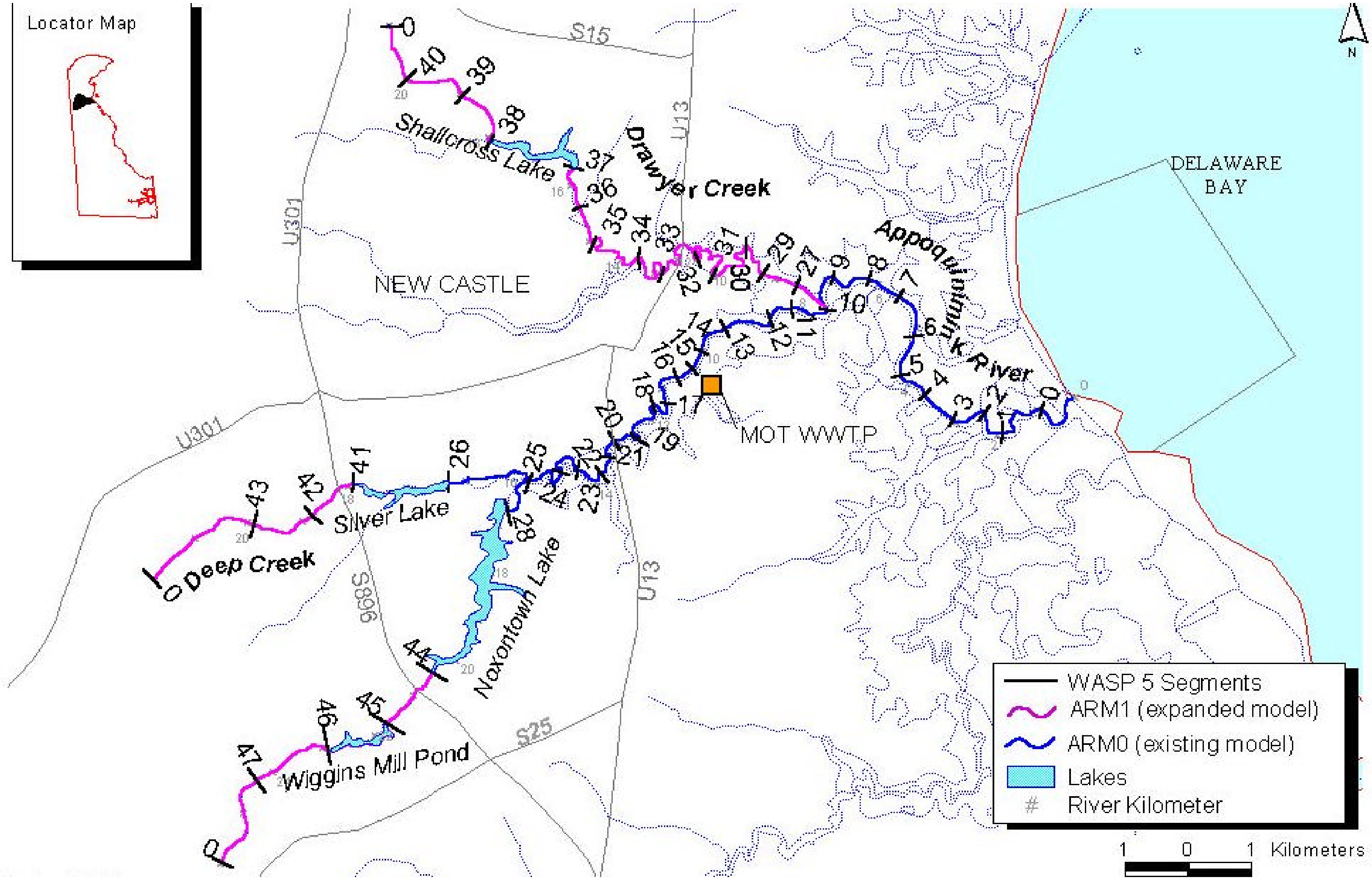


Figure 3-17 WASP5 ARM1 Segments, Appoquinimink River Watershed

Boundary Conditions

A total of four boundary conditions were accounted for in the model, including an open water boundary located at the Delaware Bay (segment 1) which is driven by the tidal conditions in the Bay. The three other boundaries are upstream freshwater inputs for Drawyer Creek (segment 40), Deep Creek (segment 43) and main stem Appoquinimink River (segment 47). The freshwater inputs are constant flows and are not affected by tidal conditions in the lower Appoquinimink River.

No data was available on the modeled periods for the new model segments. At the upstream boundary locations, the boundary conditions used in the ARM0 model were used for the boundary concentrations in the ARM1 model.

3.6.2 Pollutant Loading

Point Source Loads

One municipal point source is located in the Appoquinimink River Watershed, the Middletown-Odessa-Townsed WWTP, which discharges approximately 0.5 MGD. This point source, was previously included in the ARM0 model and the daily loading values used are listed in Table 3-4.

Table 3-4 Point Source Loads

Parameter	Load (kg/d)
NH_3	18.9
NO_3+NO_2	0
PO_4	1.6
Chl-a	0
$CBOD_5$	36.9
DO	1.3
ON	9.5
OP	4.8

Only daily average data was available to assign loads for the New Castle County WWTP and by using constant values, uncertainty in the actual daily load is incorporated into the model calculation.

3.6.3 Calibration Period

The model-data comparisons for the calibration period are presented in Figure 3-18. The data are shown as the filled symbols (average and range) and the average main stem Appoquinimink River model results during the calibration period are presented as a solid line with the shaded region representing the range calculated during the period. The data for the Drawyer Creek period average model output is presented as the dashed line while the dotted line represents the Deep Creek model output. Model (ARM1) and data comparisons are presented for organic nitrogen (Org N), ammonia nitrogen (NH_3), nitrite plus nitrate nitrogen (NO_2+NO_3), organic phosphorus (Org P), orthophosphate (PO_4), carbonaceous BOD (CBOD), dissolved oxygen (DO) and chlorophyll “a”. Overall the model reasonably reproduces the available field data in the Appoquinimink River main stem for all parameters. No data was available for Drawyer Creek and Deep Creek during the modeled time period making it impossible to compare the model results to the observed data.

Due to the improper boundary condition assignment and WASP5 volume inconsistencies between the DYNHYD5 model lengths, width and depths in the original ARM0 model, more weight was placed on reproducing the observed water quality data rather than the original ARM0 model output. An example of the ARM1 versus ARM0 model outputs is presented in Figure 3-19. The ARM0 model results are shown in blue and the ARM1 model results in red. Reasonable agreement between the ARM1 and ARM0 model outputs is obtained.

3.6.4 Validation Period

The results of the model validation are presented in Figure 3-20 and Figure 3-21 in the same format as the calibration figures. Again, the ARM1 model reasonably reproduces the observed data for the Appoquinimink River main stem. Data were not available for comparison in the expanded areas of the model.

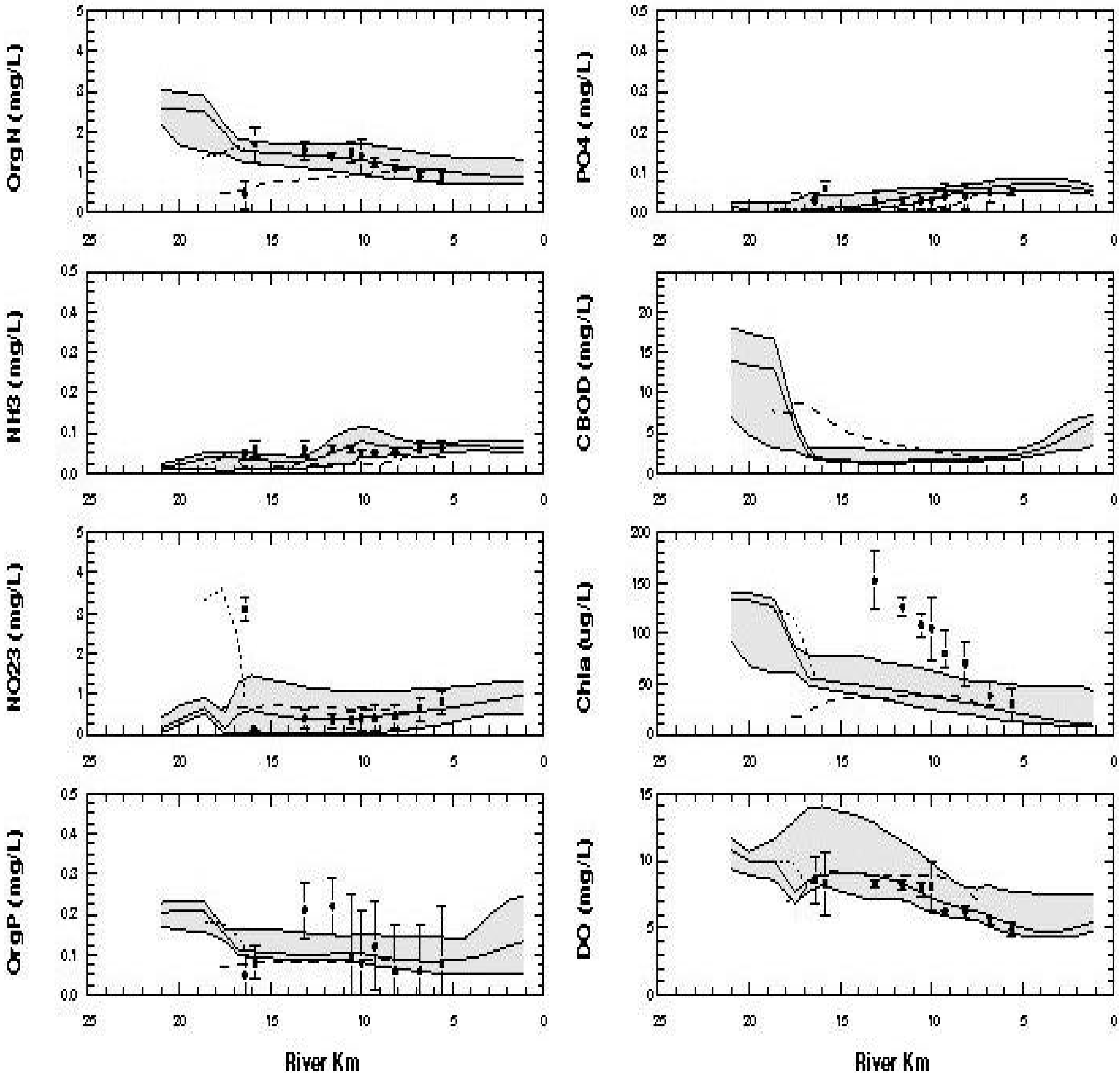
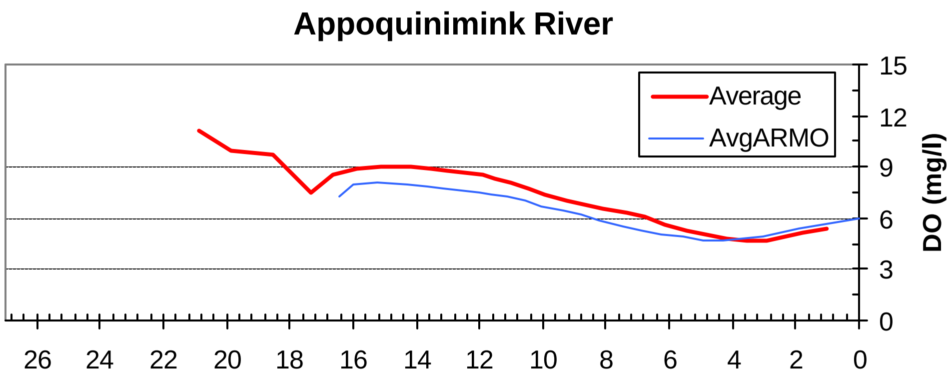
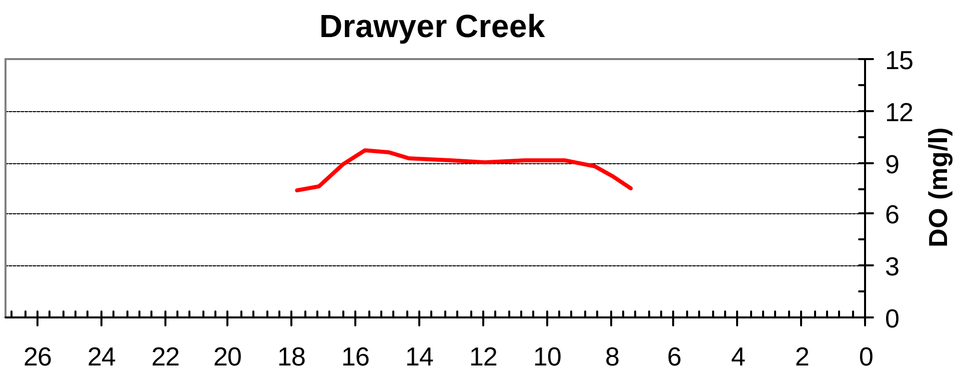


Figure 3-18 Appoquinimink River Model Calibration Output (ARM1)





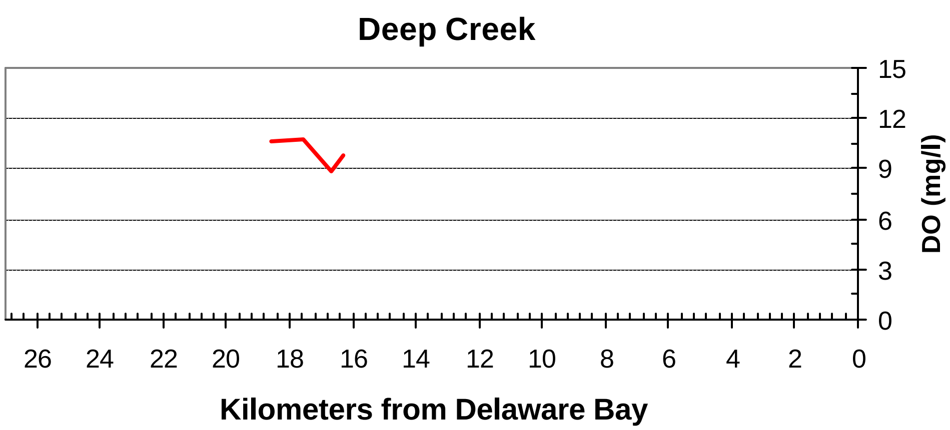


Figure 3-19 Average DO ARM0 Versus ARM1, Calibration Period

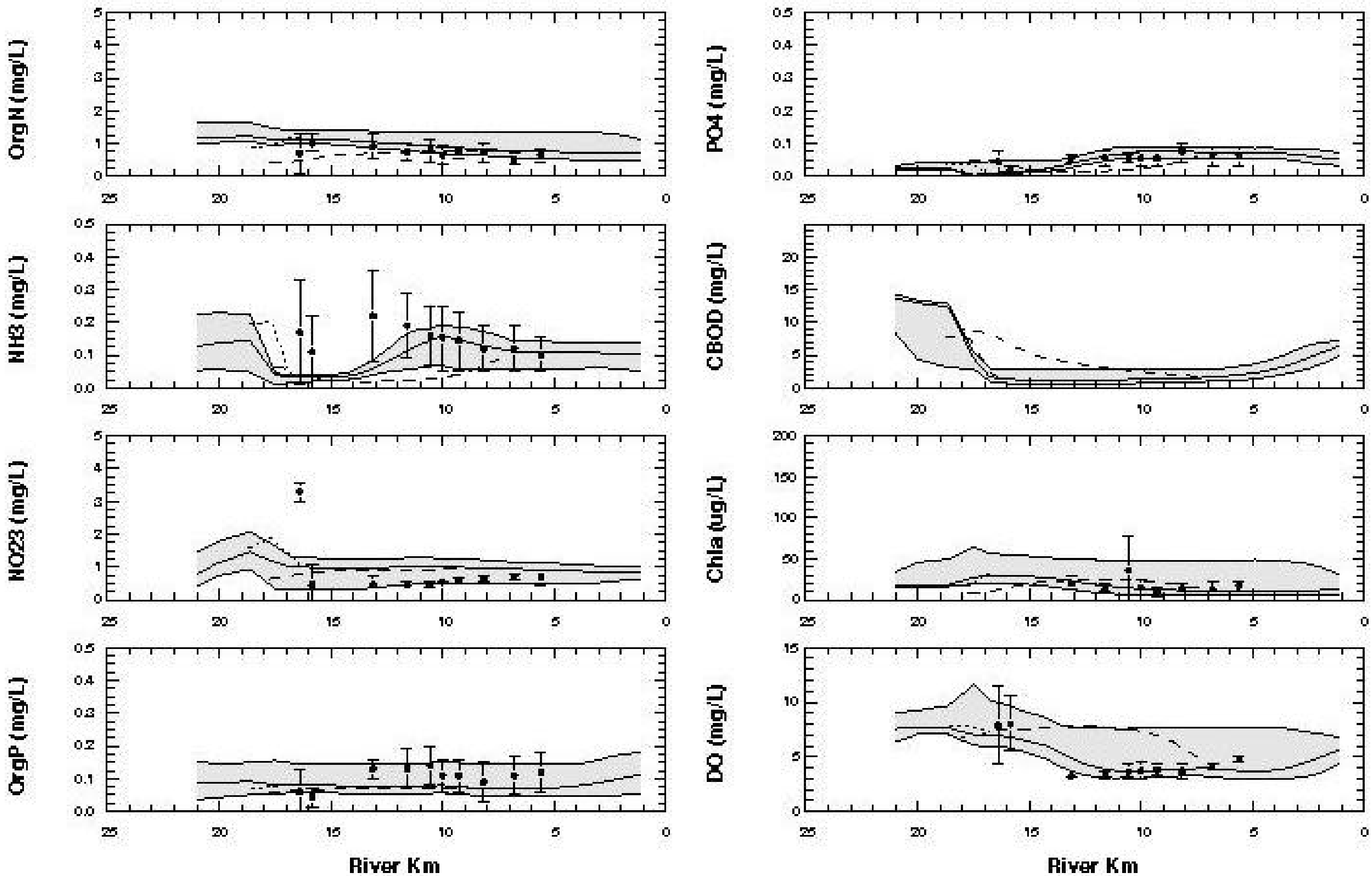


Figure 3-20 Appoquinimink River Model Verification Output (ARM1)

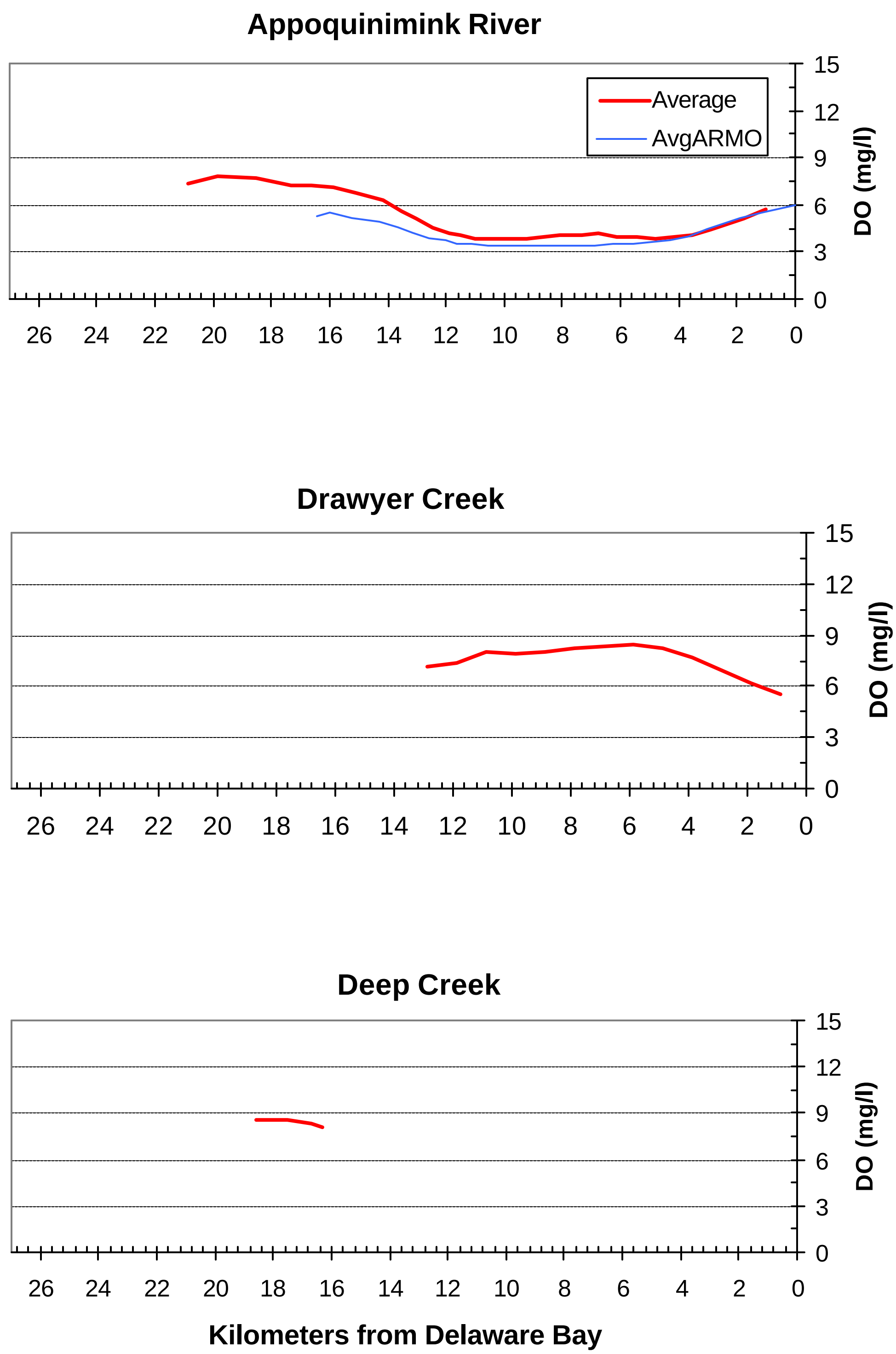


Figure 3-21 Average DO ARM0 Versus ARM1, Verification Period

4. Adjusting ARM1 to Reflect Current Conditions

Recent water quality data was compiled at a number of stations in the Appoquinimink River watershed. This data comes from 17 DNREC monitoring stations (Figure 4-1) as presented below.

- 109091 – Mouth of Appoquinimink River to Delaware Bay;
- 109121 – Appoquinimink River at Route 9 Bridge;
- 109141 – Appoquinimink River at mouth of East Branch Drawyer Creek;
- 109151 – Appoquinimink River above West Branch Drawyer Creek;
- 109051 – Appoquinimink River at Route 299 Bridge (Odessa);
- 109171 – Appoquinimink River west bank from MOT WWTP;
- 109041 – Appoquinimink River at Route 13 Bridge;
- 109131 – Noxontown Pond Overflow (Road 38);
- 109221 – Downstream from Wiggins Mill Pond at Route 71;
- 109231 – Upstream from Wiggins Mill Pond at Grears Corner Road;
- 109071 – Drawyer Creek at Route 13;
- 109191 – Shallcross Lake Overflow;
- 109211 – Drawyer Creek above Shallcross Lake at Cedar Lane Road;
- 109201 – Tributary to Drawyer Creek at Marl Pit Road;
- 109031 – Silver Lake Overflow;
- 109241 – Deep Creek at DE Route 15;
- 109251 – Deep Creek above Silver Lake at Route 71;

This recent data set was used to assess the model results in Drawyer Creek, Deep Creek and the upstream Appoquinimink River areas that were added into the ARM1 model (1991 data). In general, the recent Drawyer Creek data (Stations 109071, 109191 and 109211) for nutrients, chlorophyll-a, BOD and DO is reasonably represented by the ARM1 model. Differences can be due to a number of factors such as river flow, tidal forcing, NPS loads, meteorology, change in land use, pollution control strategies, etc.. The same conclusions can be drawn for Deep Creek (Stations 109031, 109241 and 109251) and the upstream Appoquinimink River (Stations 109131, 109221 and 109231) areas. Figure 4-2 illustrates the average values for the total N, total P, DO, and $CBOD_5$ values for the time period prior to 1997 versus the values obtained between 1997 through 2000. The red symbols indicate the concentrations at each station prior to 1997 and the blue symbols reflect the 1997 through 2000 concentrations. It is clear that the average total N concentrations have decreased while the average total P concentrations have increased between these two time periods. With the exception of one station, the average N values all fall below the 3.0 mg/L concentration (maximum target criteria). In contrast, over half of the stations report average total P values higher than 0.2 mg/L (maximum target criteria). The DO and $CBOD_5$ levels are relatively consistent. Figure 4-3 illustrates the ’97-‘00 data with the inclusion of the minimum and maximum values at each station. In addition, the symbols are color coded to indicate which segment they are located on: blue for the Appoquinimink River, pink for Deep Creek, green for Drawyer Creek and red for station 109201 located on a tributary off of Drawyer Creek. Although the minimum daily average standard for DO (5.5 mg/L) is met, the minimum (4 mg/L) is not. The daily averages for nutrients fall within the targets (1-3 mg N/L, 0.1-0.2mg P/L) but there are maximum values over 400% greater than those ranges. The highest concentrations of total P are in Drawyer Creek while the highest total N concentrations are found in Deep Creek. The lowest levels of DO are in the Appoquinimink River.

To better reflect the current conditions this data was incorporated into the ARM1 model. Prior to the integration of this new data, a sensitivity analysis was performed to evaluate the effect of changing the variables and parameters defined within the model. Table 4-1 reflects the effect of changing model parameters on the total N, total P, CBOD, Chl-a, and DO. The concentration changes listed reflect the average concentration change within all the waters modeled in the watershed. By evaluating the responses to changes in the parameters, e.g. increasing SOD causes DO to decline, it was determined that the inclusion of the 1997-2000 data would not harm the integrity of the ARM1 model while providing a better picture of the current conditions and a more meaningful baseline to simulate load reductions scenarios. Detailed graphs displaying each scenario are included in Appendix A.

Station 109201 (Marl Pit Rd.) data reflected a high P concentration that was not included in the ARM0 model. Because of its high P levels and drainage from the Middletown area in which significant development is occurring, the boundary condition flow and nutrient load for the Drawyer was adjusted to incorporate this tributary. A constant flow input (0.080 m^3/s) at section 34 was added and the flow at section 42 was reduced from 0.381 m^3/s to 0.301 m^3/s. The corresponding nutrient load was added into the NPS auxiliary input file.

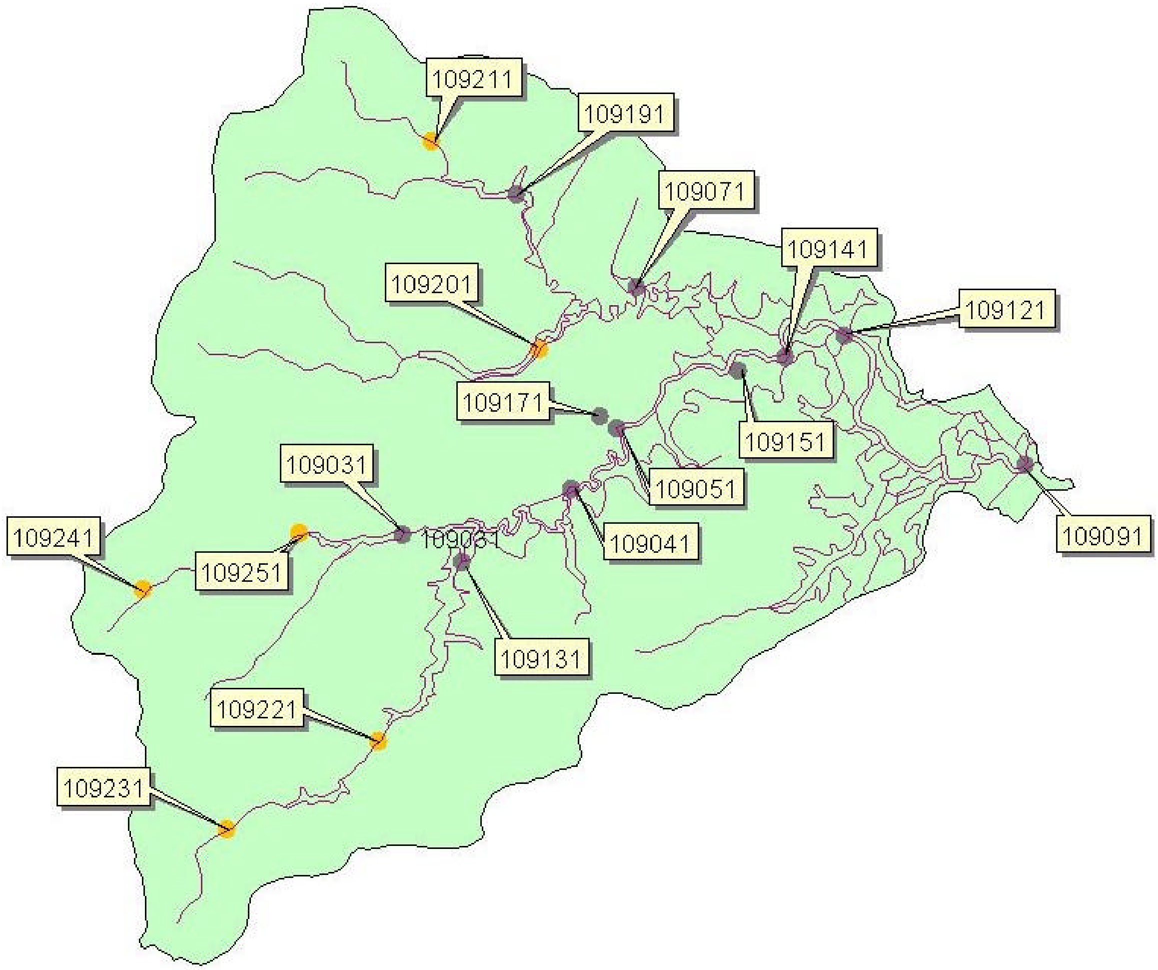


Figure 4-1 Monitoring Stations within the Appoquinimink River Watershed

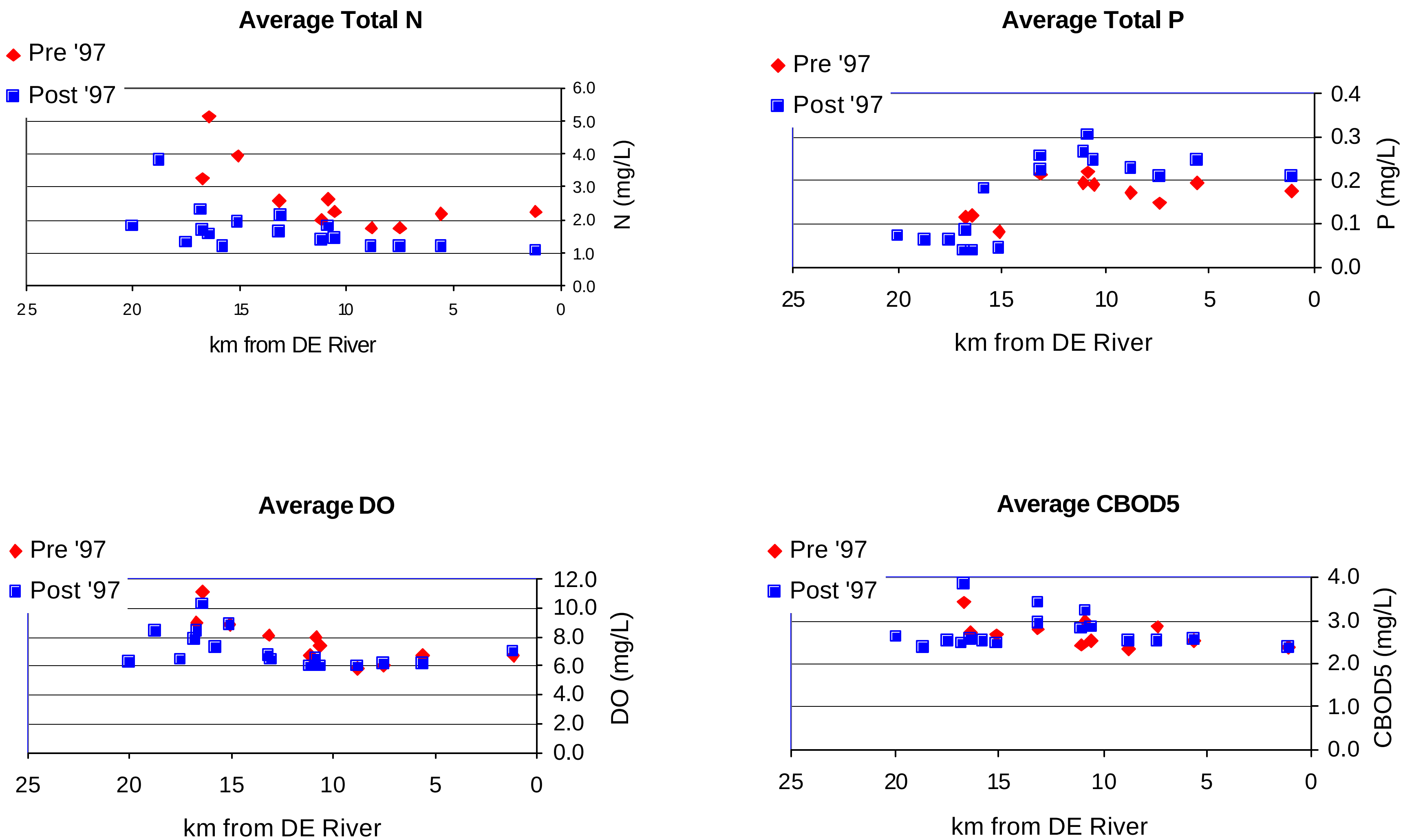


Figure 4-2 Comparison of Pre 1997 Data versus 1997-2000 Data for the Appoquinimink Watershed

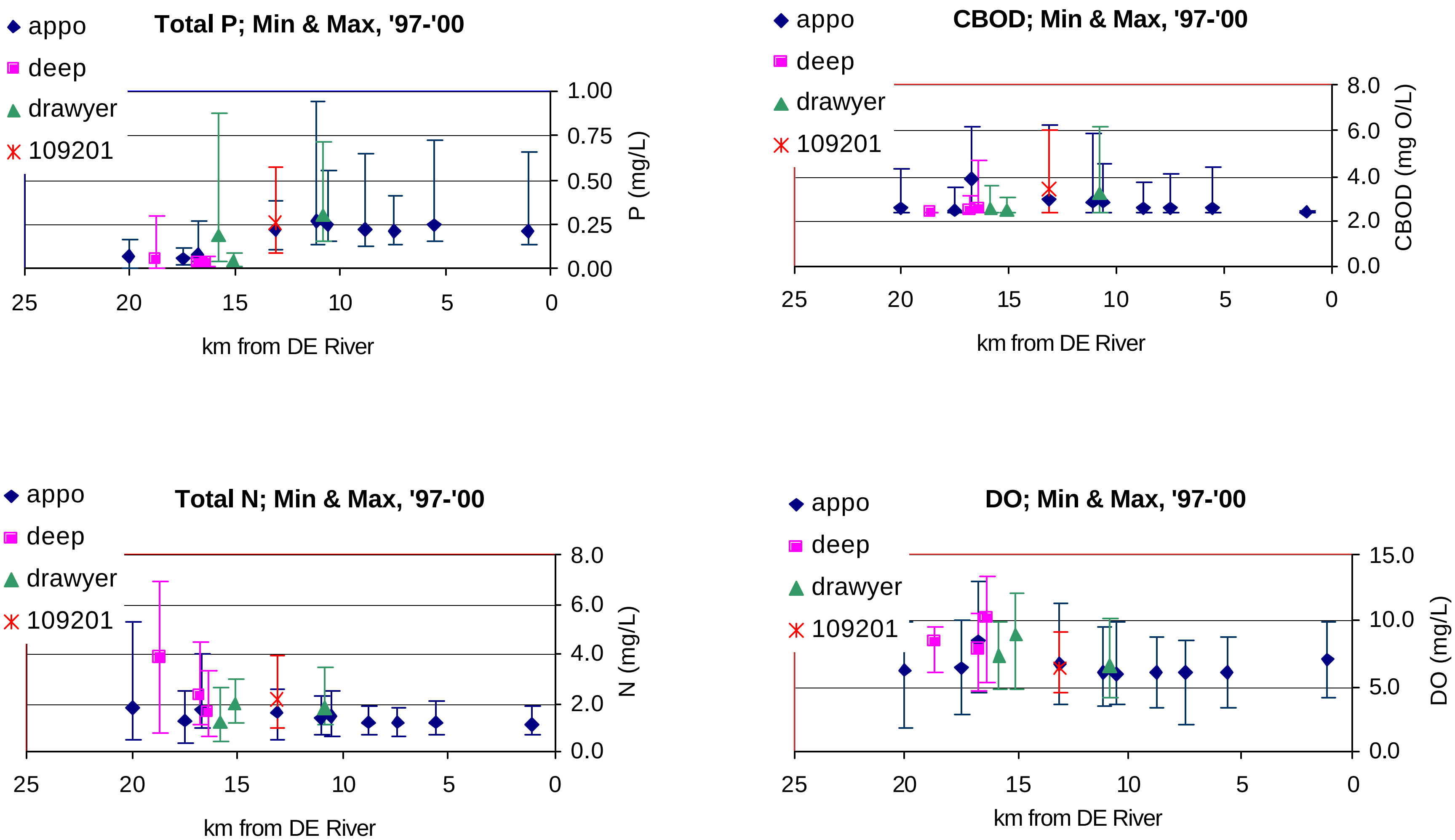


Figure 4-3 Max Min Values for the 1997-2000 Data

Table 4-1 Sensitivity Analysis Scenarios C1-C52

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C1	No PS MOT	4.04	-0.0500	-0.0087	-0.1071	-0.6361
C2	½ X FNH_4	3.83	0	0	0	0
C3	½ X SOD1D	4.52	-0.0003	0	-0.0162	0
C4	2X SOD1D	0.74	-0.0033	0	0.0945	0
C5	2X FNH_4	3.83	0	0	0	0
C6	½ X FPO_4	3.83	0	0	0	0
C7	2X FPO_4	3.83	0	0	0	0
C8	½ X SAL	3.90	0	0	-0.0014	0
C9	2X SAL	3.70	0.0001	0	0.0029	0
C10	½ X KESG	5.43	0.0754	0.0086	0.1107	9.0396
C11	2X KESG	2.99	-0.0410	-0.0032	-0.0907	-5.8927
C12	0 constant inflow			unstable		
C13	½ X constant inflow	3.83	0.0127	0.0019	-0.1267	0.2555

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C14	1½ X constant inflow	3.80	-0.0128	-0.0018	0.1293	0.2530
C15	2X constant inflow			unstable		
C16	½ X Flow, all segments	3.71	0.2225	0.0127	0.0724	3.6237
C17	2X Flow, all segments	3.85	-0.2363	-0.0168	-0.0994	-4.6343
C18	BC: ½ X NH3-N	3.85	-0.0222	0	-0.0003	0
C19	BC: 2X NH3-N	3.80	0.0457	0	0.0007	0
C20	Added MOT inflow	3.81	-0.0050	-0.0004	-0.0082	-0.0628
C21	C20 & BC: ½ X NOx-N	3.81	-0.0653	-0.0004	-0.0037	-0.0628
C22	C20 & BC: 2X NOx-N	3.82	0.1165	-0.0004	-0.0171	-0.0628
C23	C20 & BC: ½ X PO4	3.81	-0.0117	-0.0043	-0.0186	-0.7591
C24	C20 & BC: 2X PO4	3.82	0.0075	0.0074	0.0101	1.1404
C25	C20 & BC: ½ X Phyt	3.89	-0.0396	-0.0035	-0.0375	-2.6253
C26	C20 & BC: 2X Phyt	3.60	0.0614	0.0069	0.0466	4.7211

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C27	C20 & BC: ½ X CBOD	4.15	-0.0053	-0.0004	-1.3075	-0.0628
C28	C20 & BC: 2X CBOD	2.50	-0.0042	-0.0004	2.6614	-0.0628
C29	C20 & BC: ½ X Diss O2	2.67	-0.0043	-0.0004	0.0313	-0.0628
C30	C20 & BC: 10 mg/L Diss O2	4.00	-0.0055	-0.0004	-0.0292	-0.0628
C31	C20 & BC: ½ X Org-N	3.82	-0.1518	-0.0004	-0.0082	-0.0628
C32	C20 & BC: 2X Org-N	3.79	0.2829	-0.0004	-0.0081	-0.0628
C33	C20 & BC: ½ X Org-P	3.78	-0.0117	-0.0224	-0.0181	-0.7307
C34	C20 & BC: 2X Org-P	3.86	0.0086	0.0434	0.110	1.2355
C35	C20 & 7Q10, New permit MOT PS	3.95	-0.0340	-0.0063	-0.1747	-0.4657
C36	C35 & SOD values: EPA TMDL 1/98	4.76	-0.0340	-0.0063	-0.1925	-0.4657
C37	C36 & 15kg/day CBOD NPS	4.76	-0.0340	-0.0063	-0.1798	-0.4657
C38	C37 & EPA DO BC, DE river	4.90	-0.0340	-0.0063	-0.1821	-0.4657
C39	C38 & EPA initial DO conc	4.68	-0.0340	-0.0063	-0.1769	-0.4657

Scenario	Parameter Changed	Effect				
		Minimum DO mg/L	(average concentration change with respect to waspver4 run)			
			Total N mg/L	Total P mg/L	CBOD mg/L	Chl-a mg/L
C40	C39 & EPA '98 TMDL BC, DE River: NH3-N	4.60	0.0074	-0.0063	-0.1763	-0.4657
C41	C40 & EPA '98 TMDL BC, DE River: NOx-N	4.60	0.1032	-0.0063	-0.1816	-0.4657
C42	C41 & EPA '98 TMDL BC, DE River: PO4	4.62	0.1053	-0.0004	-0.1783	-0.2060
C43	C42 & EPA '98 TMDL BC, DE River: Phyt	4.30	0.1575	0.0054	-0.1416	3.7242
C44	C43 & EPA '98 TMDL BC, DE River: CBOD	2.83	0.1581	0.0054	2.0851	3.7242
C45	C44 & EPA '98 TMDL BC, DE River: Org-N	2.82	0.4229	0.0054	2.0857	3.7242
C46	C45 & EPA '98 TMDL BC, DE River: Org-P	2.83	0.4288	0.0455	2.0941	4.3146
C47	C46 & EPA '98 TMDL Group G	2.84	0.4268	0.0453	2.0907	4.1495
C48	C47 & EPA '98 TMDL initial NOx conc	2.84	0.4337	0.0453	2.0901	4.1495
C49	C48 & EPA '98 TMDL initial Phyt conc	3.11	0.3692	0.0390	2.0120	0.5417
C50	C49 & EPA '98 TMDL initial CBOD conc	2.87	0.3692	0.0390	2.3626	0.5417
C51	C50 & EPA '98 TMDL initial Org-N conc	2.87	0.3481	0.0390	2.3626	0.5417
C52	C51 & EPA '98 TMDL initial Org-P conc	2.87	0.3501	0.0432	2.3661	0.7371

5. Evaluation of Various Loading Scenarios and Proposed TMDL

The results of the water quality monitoring and modeling show that the State water quality standards and targets with regard to DO, total N and total P are not met in several segments of the Appoquinimink River and it's tributaries. Therefore, reduction of pollutant loads from point and/or nonpoint sources are necessary to achieve water quality standards and targets.

To determine the optimum load-reduction scenario, the ARM1 model was adjusted to the current conditions and used as a baseline to evaluate different reduction scenarios. Table 5-1 illustrates the incorporation of the current conditions into the ARM1 model in order to develop a baseline to evaluate possible load reduction scenarios. The final baseline deviates from the original ARM1 hydver4.inp in the following ways: the updated hydver4 includes a 0.5 mgd flow from the MOT, the flow is reduced from the headwater of the Drawyer (originally 0.380 m^3/s, new 0.301 m^3/s), and a 0.80 m^3/S flow now enters the Drawyer at section 34. Deviations from the original ARM1 waspver4.inp include the incorporation of boundary conditions reflecting the monitoring station data taken between 1997 and 2000 (SOD, chl-a, CBOD, DO, NH_3, NO_x, ON, OP, PO4, and temperature). The new boundary condition data was incorporated individually into the runs (D series) using C38 as an initial starting point (see Appendix B for detailed scenario results). In addition to the scenarios reported, the effect of the reduction scenarios using the ARM0 model as well as unreported scenarios were also evaluated.

The baseline scenario and final reduction scenario are illustrated in Figure 5-1. The solid lines represent the Average concentrations on Julian day 199 and the dotted lines represent the corresponding baseline concentrations in the Appoquinimink River, Drawyer Creek, and Deep Creek. The final scenario brings both the total P and total N nutrient levels into compliance with DNREC's target levels and meets the State water quality standard for DO. To achieve this the proposed TMDL holds the MOT nutrient and $CBOD_5$ discharge levels constant at the concentrations prescribed by the 1998 EPA TMDL. In addition, the non point source reductions include a 20% reduction in PO_4, OP, ON, NH_3, and NO_x along with an 18.4% decrease in SOD. Since the flux rates of nutrients and SOD is a function of pollutant loads received by the system, it is a reasonable assumption to relate the percentage of the rate change to the percentage of load change (similar mechanism was suggested by the Army Corps of Engineers for the Inland Bays Model). The algorithm for this change can be shown as:

$$\text{Adjusted Rate} = \text{Base Rate}\,(1 + PSR * PSF + NPSR * NPSF)$$

Where:

Base Rate = the nutrient and flux rates used in model calibration
PSR = percent change of point source load change. The PSR is positive when the load is increased and is negative when load is decreased
PSF = fraction of total load represented by point sources
NPSR = percent change of nonpoint source load change. The NPSR is positive when the load is increased and is negative when load is decreased
NPSF = fraction of total load represented by nonpoint sources

Table 5-1 Current Condition and Baseline Development Scenarios

Scenario	Scenario Description
D1	C38
D2	D1 with no NPS: auxilary
D3	D1 with no NPS: Appo, Deep & Drawyer
D4	D1 with no NPS
D5	D1 with no NPS or MOT
D6	D1 with no nutrient load from DE River
D7	D1 with no nutrient load or chl-a from DE River
D8	D1 with oxygen addition in NPS auxilary
D9	D1 with '98 EPA TMDL 7Q10 flows
D10	D1 with '97-'00 NH_3, NO_X, ON data for DE River BCs
D11	D10 with '97-'00 chl-a data for DE River BCs
D12	D11 with '97-'00 $CBOD_5$ data for DE River BCs
D13	D12 with '97-'00 OP & PO4 data for DE River BCs
D14	D13 with '97-'00 dissolved oxygen data for DE River BCs
D15	D14 with DE River BC: 10% nutrient load reduction, 10% increase in DO
D16	D14 with KESG=3.2 in segments 1-14 (secchi depth 24")
D17	D16 with DE River BC: 20% total load reduction & 20% increase in DO
D18	D17 with NPS: Appo, Deep, Drawyer 20% total load reduction
D19	D1 with '97-'00 data, all BCs
D20	D19 with no NPS: auxilary
D21	D19 with no NPS: Appo, Deep & Drawyer
D22	D19 with no MOT
D23	D19 with no NPS
D24	D19 with no NPS or MOT
D25	D19 with DE River BC: 10% nutrient load reduction, 10% increase in DO
D26	D19 with DE River BC: 10% increase in DO
D27	D19 with 25% NPS: Appo, Deep & Drawyer total load reduction
D28	D27 with 10% SOD reduction
D29	D19 with 25% NPS total load reduction & 10% SOD reduction
D30	D19 with 35% NPS total load reduction & 10% SOD reduction
D31	D29 with '98 EPA TMDL DE River DO BC
D32	D31 with 50% decrease in PO_4 & OP into the Drawyer
D33	D32 with DE River BC: 10% total load reduction
D34	D32 with '98 EPA TMDL DE River BCs
D35	D32 with 15% SOD decrease instead of 10% SOD decrease
D36	D32 with 25% SOD decrease instead of 10% SOD decrease
D37	D36 with '98 EPA TMDL 7Q10

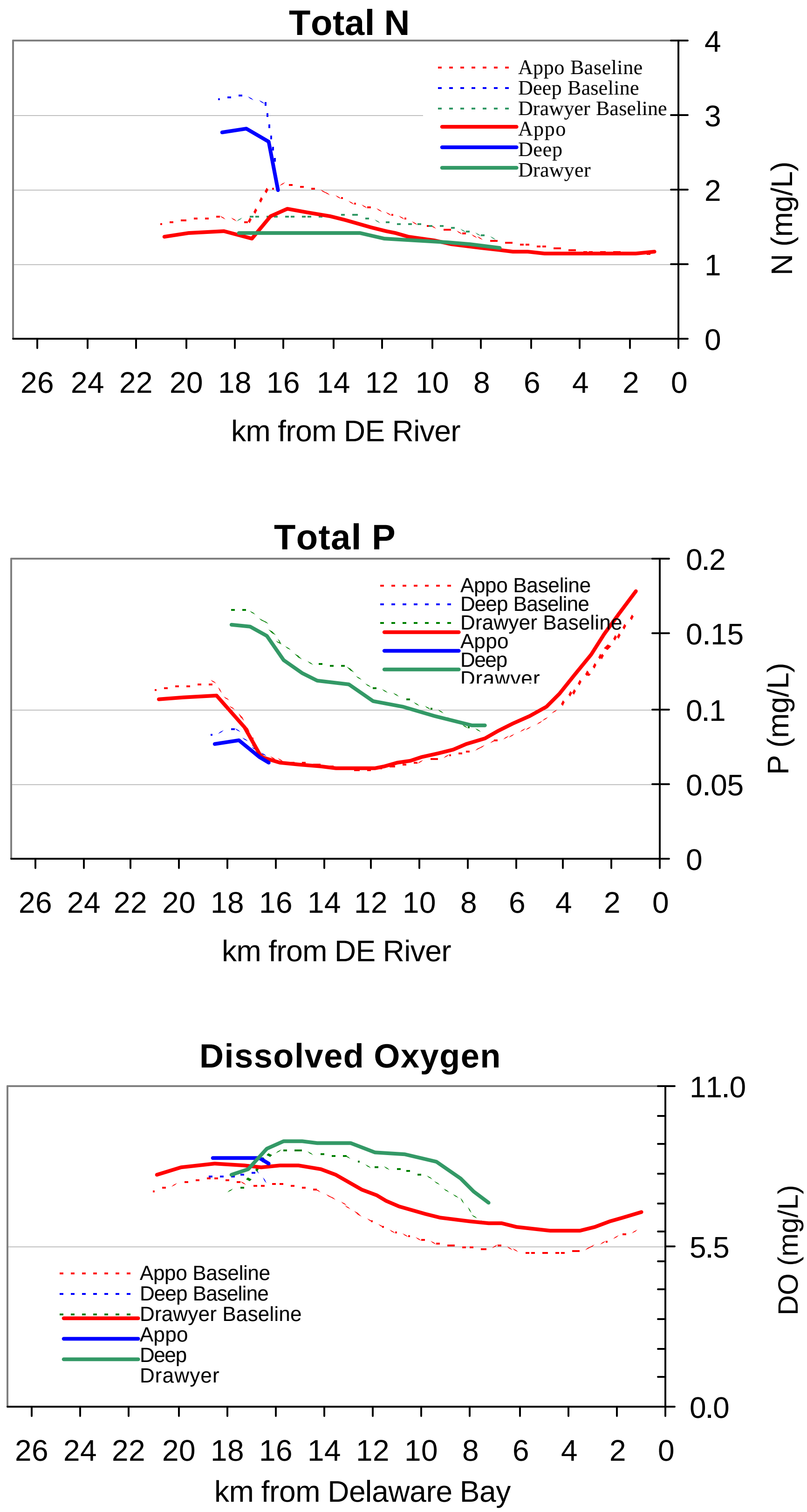


Figure 5-1 Base Line versus Final TMDL Reduction Scenario, Average Values on Day 199

Table 5-2 illustrates the proposed TMDL loads for the Appoquinimink River Watershed. The only point source (MOT) will be limited to a discharge of 10.4 lb total N per day, 2.1 lb. total P per day, and 34.8 lb $CBOD_5$ per day with a flow rate not to exceed 0.5 mgd. The proposed nonpoint source loads are 334.1 lb total N per day and 18.0 total P per day. The total TMDL loads are 344.5 lb total N per day, 20.1 lb total P per day, and 34.8 lb $CBOD_5$ per day.

Table 5-2 Proposed TMDL Loads for the Appoquinimink Watershed

Source	Flow (mgd)	Total N (lb/d)	Total P (lb/d)	CBOD5 (lb/d)
Waste Load Allocation (WLA) for Point Source: MOT	0.5	10.4	2.1	34.8
Load Allocation (LA) for Nonpoint Sources	-	334.1	18.0	-
Proposed TMDL Total Loads	-	344.5	20.1	34.8

6. Discussion of Regulatory Requirements for TMDLs

Federal regulations at 40 CFR Section 130 require that TMDLs must meet the following eight minimum regulatory requirements:

1. The TMDLs must be designed to achieve applicable water quality standards
2. The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources
3. The TMDLs must consider the impact of background pollutants
4. The TMDL must consider critical environmental conditions
5. The TMDLs must consider seasonal variations
6. The TMDLs must include a margin of safety
7. The TMDLs must have been subject to public participation
8. There should be a reasonable assurance that the TMDLs can be met

1. The Proposed Appoquinimink River Watershed TMDL is designed to achieve applicable water quality standards.

The model analysis indicates that after the proposed reductions are met, the minimum DO level in any portion of the Appoquinimink will not fall below the 5.5 mg/L standard.

With regard to nutrients, model analysis indicates that the target levels (1.0-3.0 mg/L total N, 0.1-0.2 mg/L total P) will be obtained after the proposed reductions are met.

2. The Proposed Appoquinimink River Watershed TMDL includes a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.

Table 5-2 lists the proposed WLA and LA for the Appoquinimink River Watershed. The total WLA is 10.4 lb/d total N, 2.1 lb/day total P, and 34.8 lb/d $CBOD_5$. The LA is 334.1 lb/d total N and 18.0 lb/d total P.

3. The proposed Appoquinimink River TMDL considers the impact of background pollutants.

The proposed TMDL is based upon a calibrated and verified hydrodynamic and water quality model of the Appoquinimink River and its tributaries, lakes, and ponds. The model was developed using an extensive water quality and hydrological database. The water quality and hydrological database included headwater streams representing background conditions for nutrients and other pollutants. Therefore, it can be concluded that the impact of background pollutants are considered in the proposed Appoquinimink River Watershed TMDL.

4. The proposed Appoquinimink River Watershed TMDL considers critical environmental conditions

The proposed TMDL was established based on the calculated 7Q10 (Section 3) and the ambient conditions on Julian day 199 when the ambient air and water temperatures are relatively high. The average salinity in the section of the Appoquinimink River between the confluence of the Delaware River and the intersection with Drawer Creek is above the salt water salinity standard of 5 ppt. but because the minimum is below the 5 ppt level, it is considered fresh water. The results of the water quality modeling analysis have shown that considering the above design conditions, State water quality standards and targets are still meet within the Appoquinimink River Watershed. Therefore, it can be concluded that consideration of critical environmental conditions was incorporated in the Appoquinimink River Watershed TMDL analysis.

5. The proposed Appoquinimink River Watershed TMDL considers seasonal variations.

The model used to represent the watershed was calibrated for the period of August 11 through October 14, 1991 and was validated for the period of May 10 through July 25, 1991. The above calibration and verification periods included different seasons with varying environmental conditions. Therefore, it can be concluded that consideration of seasonal variations was incorporated in the Appoquinimink River Watershed TMDL analysis.

6. The proposed Appoquinimink River Watershed TMDL considers a margin of Safety.

EPA's technical guidance allows consideration of a margin of safety as implicit or as explicit. An implicit margin of safety is when conservative assumptions are considered for model development and TMDL establishment. An explicit margin of safety is when a specified percentage of assimilative capacity is kept unassigned to account for uncertainties, lack of sufficient data, or future growth.

An implicit margin of safety has been considered for establishing the proposed Appoquinimink River Watershed TMDL. The ARM1 model is calibrated using conservative assumptions regarding reaction rates, pollutant loads, and other environmental conditions. Consideration of these conservative assumptions contributes to the implicit margin of safety. In addition, the proposed TMDL considers several critical conditions such as 7Q10 flows, high ambient and water temperatures, high salinity in segments up to the confluence with the Delaware river, and MOT discharges at maximum permitted levels. Since the possibility of occurrence of all these critical conditions at the same time is rare, the above consideration contributes to the implicit margin of safety. Therefore, it can be concluded that an implicit margin of safety has been considered for this TMDL analysis.

7.0 The proposed Appoquinimink River Watershed TMDL has been subject to public participation.

The EPA held a public hearing prior to the adoption of the 1998 TMDL covering the mainstem of the Appoquinimink river. During the adoption period of the '98 TMDL, DNREC and the public had an opportunity to present comments.

Another important public participation activity regarding this TMDL was the formation of the Appoquinimink Tributary Action Team last year. The Tributary Action Team, made up of concerned citizens and other affected parties within the watershed, has met several times and will assist the DNREC in developing pollution control strategies (PCS) to implement the requirements of the proposed Appoquinimink River Watershed TMDL.

In addition to the public participation and stakeholder involvement mentioned above, a public workshop and public hearing has been scheduled for December 5, 2001 to present the proposed Appoquinimink River Watershed TMDL to the general public and receive comments prior to formal adoption of the TMDL regulation.

8.0 There should be a reasonable assurance that the proposed Appoquinimink River Watershed TMDL can be met.

The proposed Appoquinimink River Watershed TMDL considers the reduction of nutrients and oxygen consuming pollutants (CBOD) from point and nonpoint sources. The magnitude of load reductions suggested by the proposed TMDL is in line with the current TMDL and is technically feasible and financially affordable. Following the adoption of the TMDL, the Appoquinimink River Tributary Action Team will assist the Department in developing a PCS to implement the requirements of the Appoquinimink River Watershed TMDL Regulation. The DNREC is planning to finalize and adopt the Appoquinimink River PCS within one year after formal adoption of the TMDL Regulation.

7. REFERENCES

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Appendix C: WASP Model Calibration and Validation Results

The objective of this Appendix is to present calibration and validation results for the WASP model of the Appoquinimink River. Calibration results (May through July, 1991) are presented on pages C-2 through C-5 and validation results (August through October, 1991) are presented on pages C-6 through C-9. The tables at the end of this section present the mean, minimum, and maximum 1991 water quality monitoring sample values (in that order) used in the calibration and validation (source: DNREC).

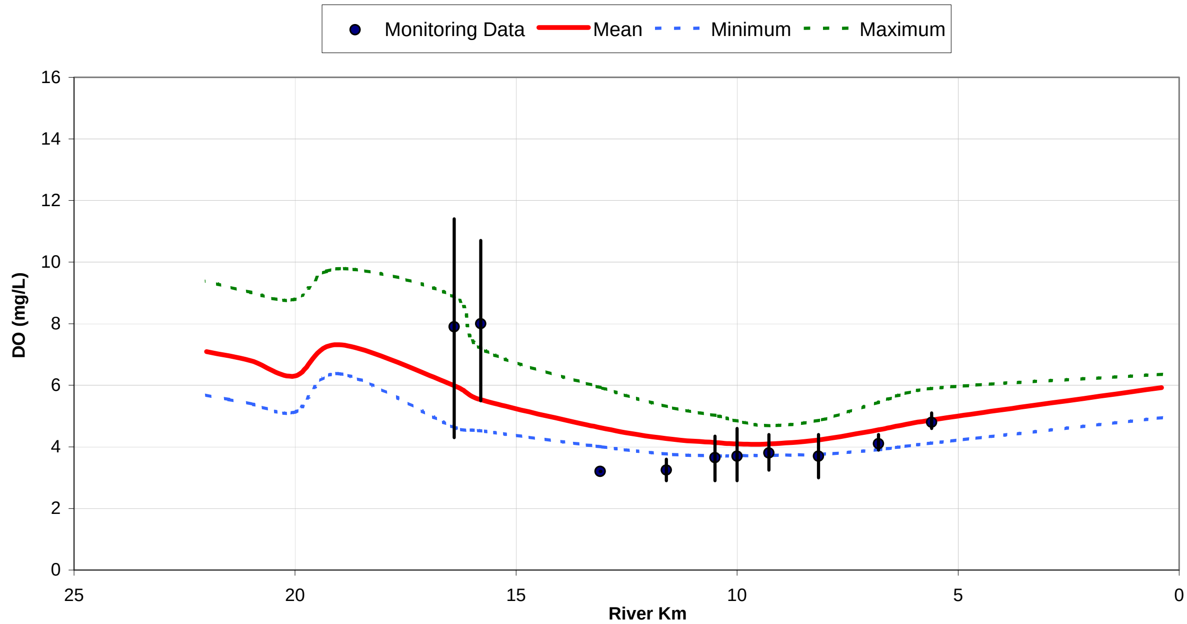


Figure C-1. Dissolved Oxygen Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

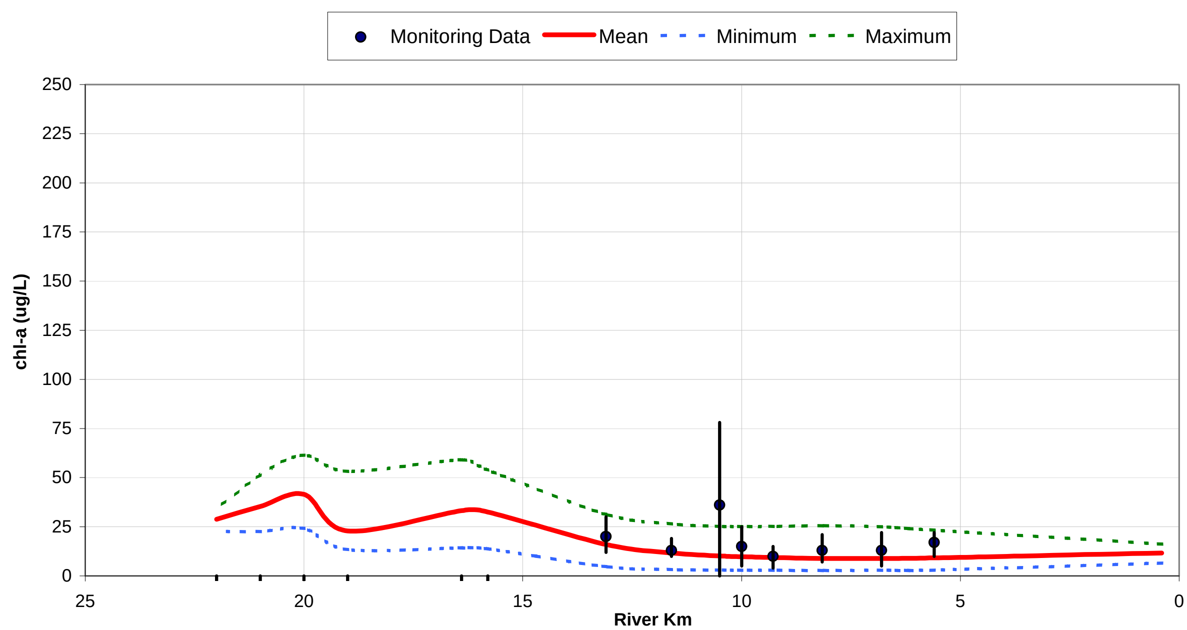


Figure C-2. Chlorophyll-a Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

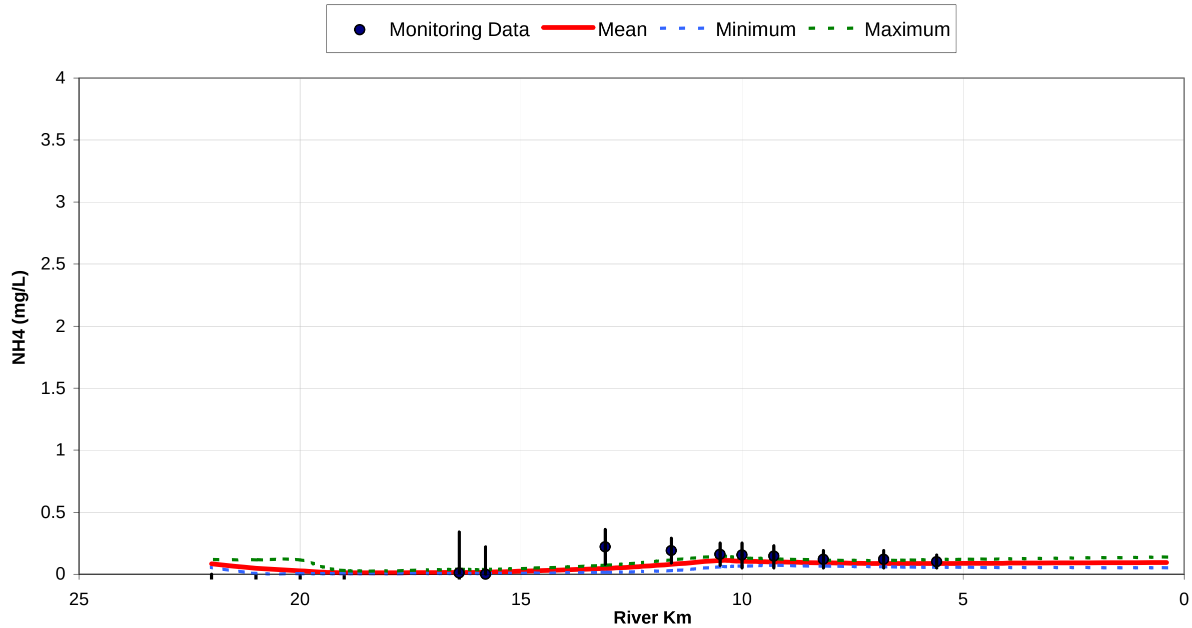


Figure C-3. NH4 Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

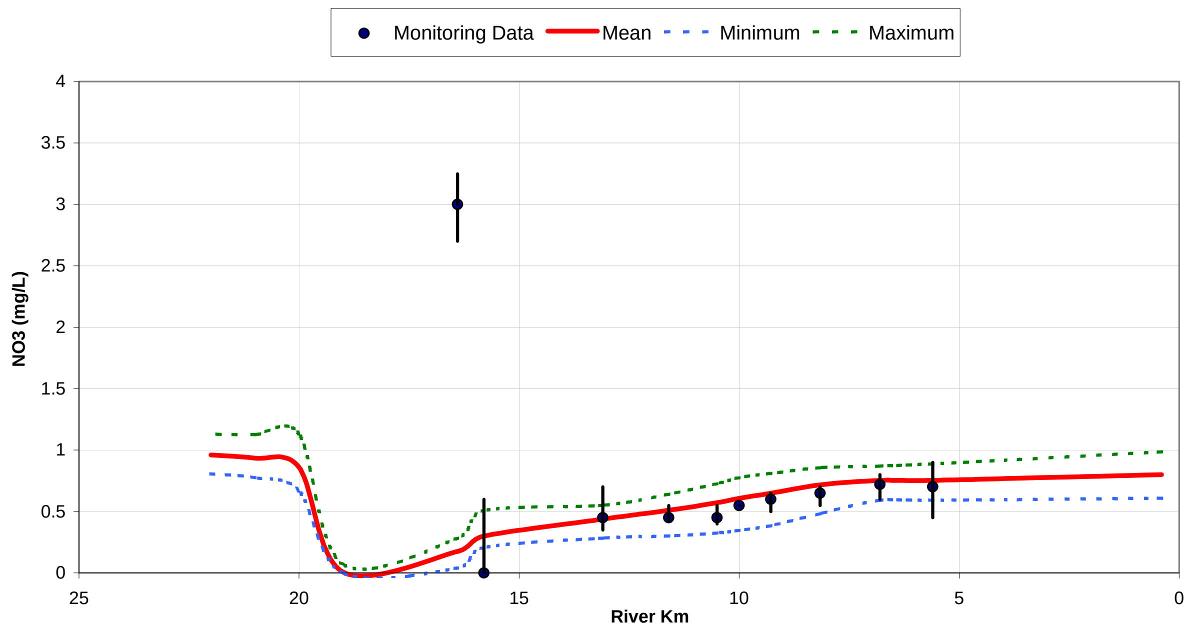


Figure C-4. NO3 Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

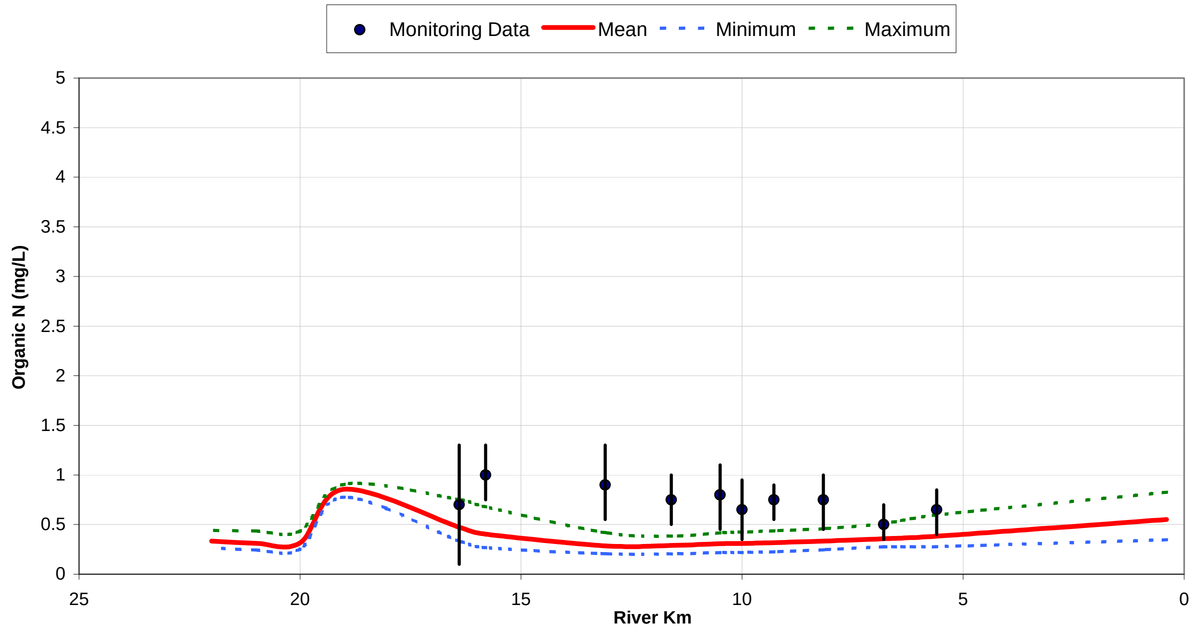


Figure C-5. Organic-N Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

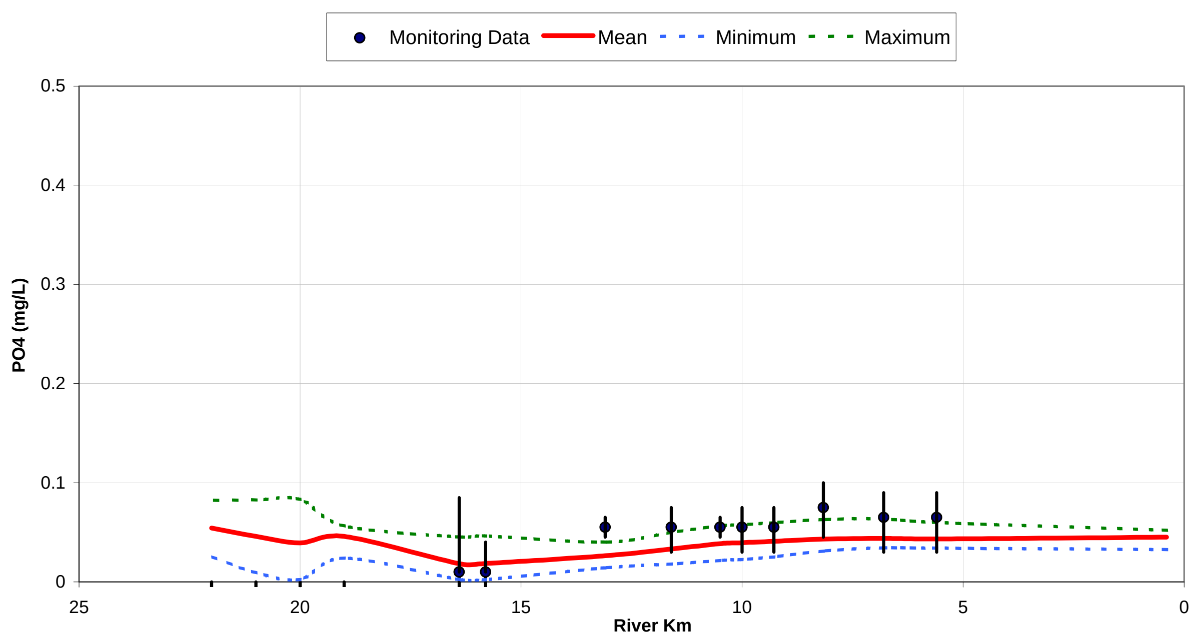


Figure C-6. PO4 Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

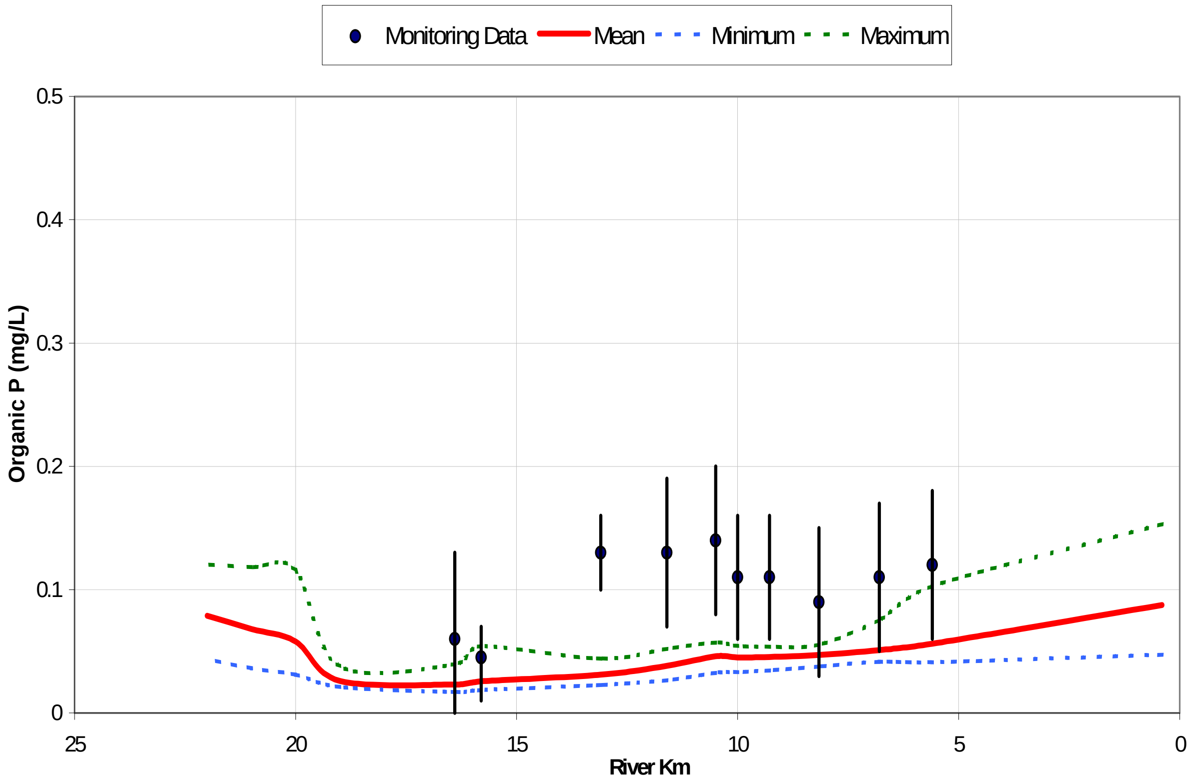


Figure C-7. Organic-P Calibration for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for May through July, 1991

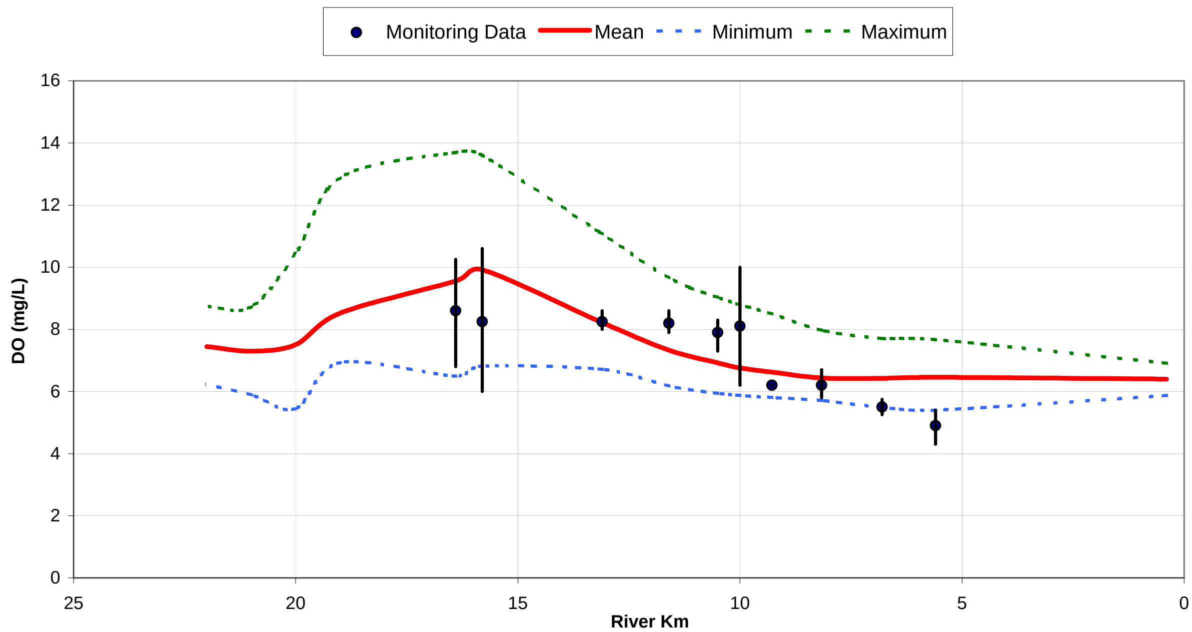


Figure C-8. Dissolved Oxygen Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

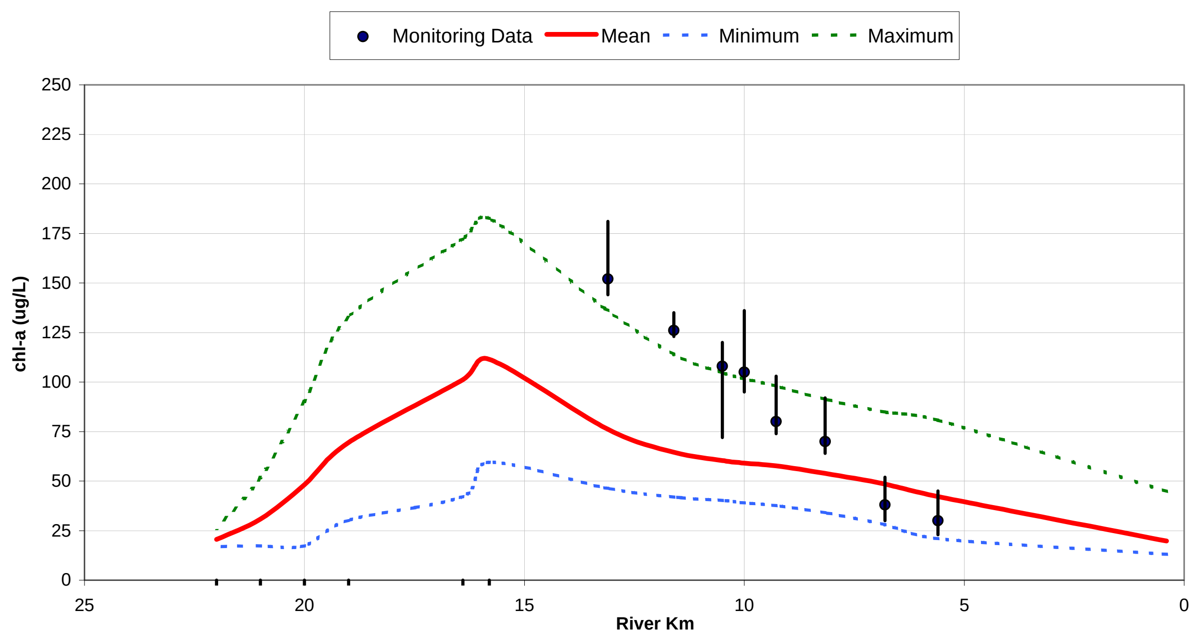


Figure C-9. Chlorophyll-a Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

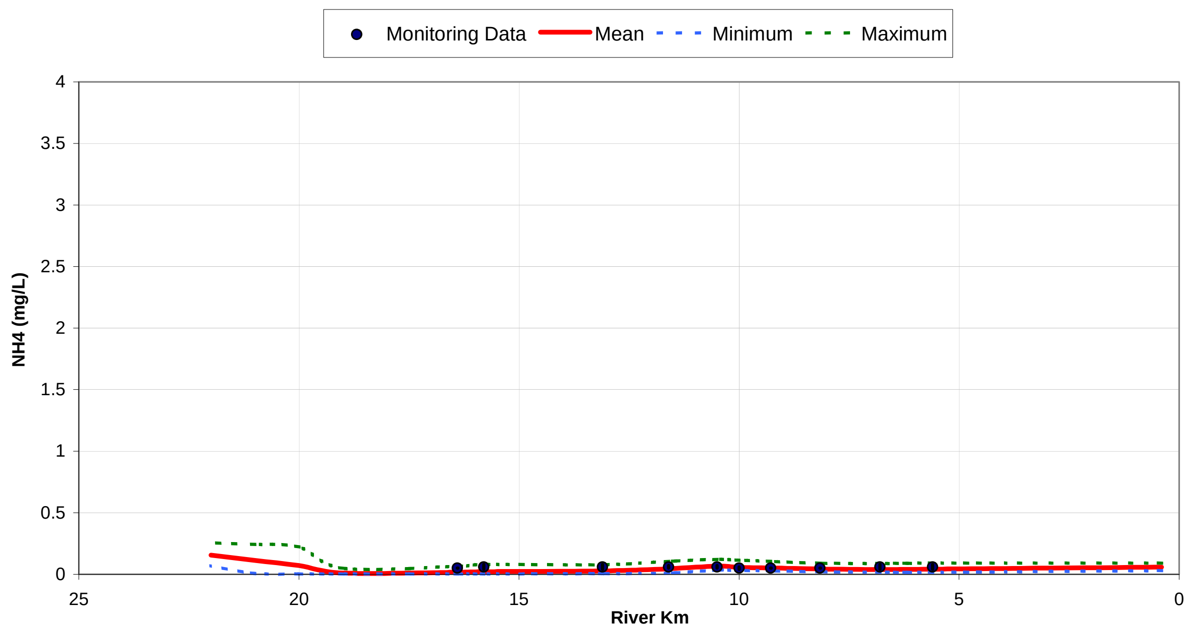


Figure C-10. NH4 Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

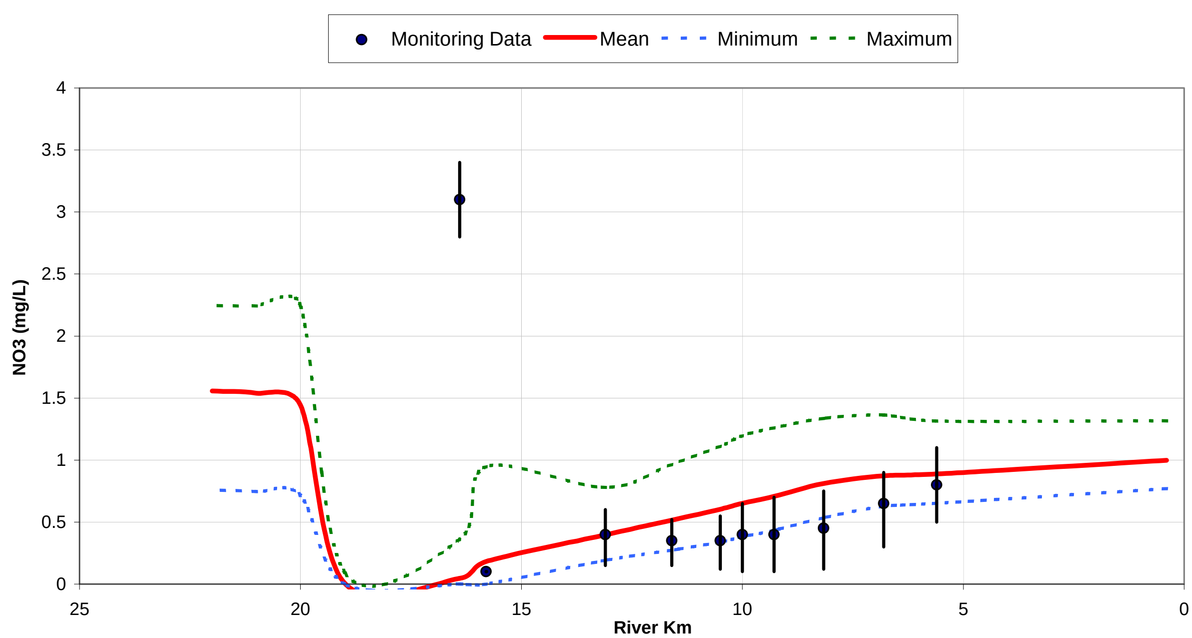


Figure C-11. NO3 Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

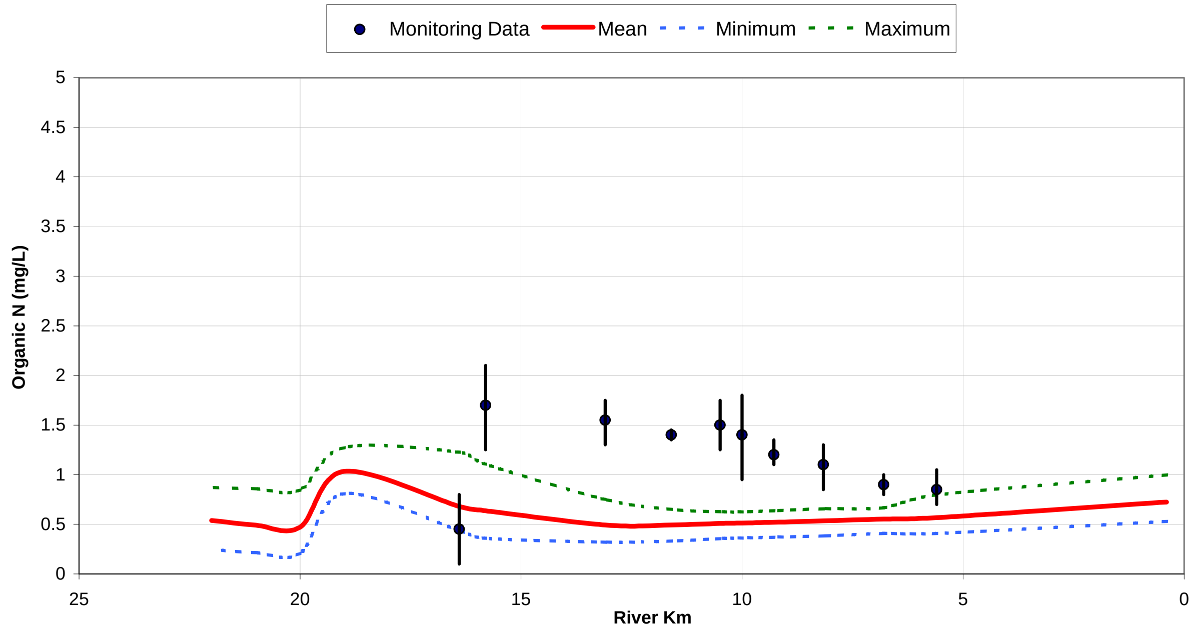


Figure C-12. Organic-N Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

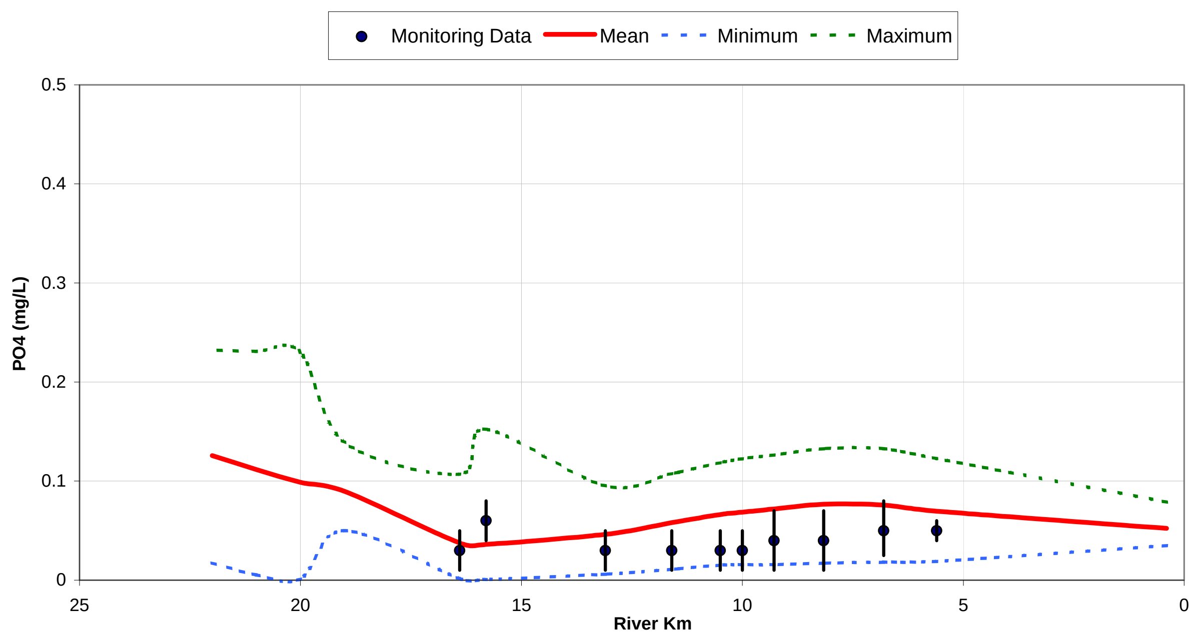


Figure C-13. PO4 Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

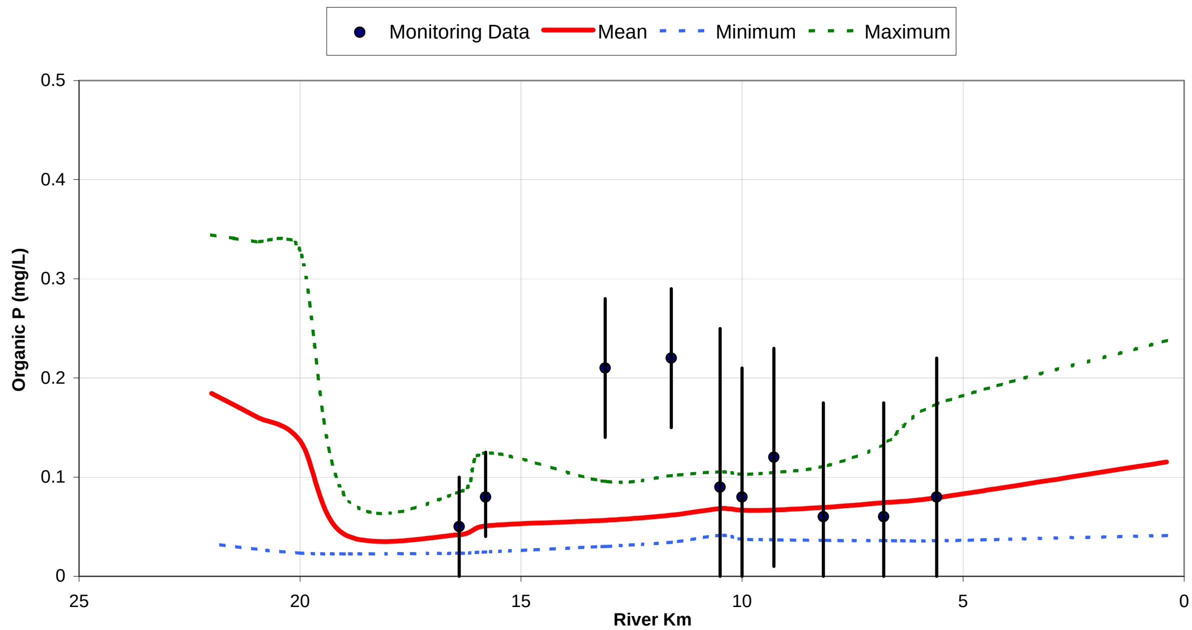


Figure C-14. Organic-P Validation for the Appoquinimink River: Minimum, Maximum, and Mean Concentrations for August through October, 1991

Table C-1. Dissolved Oxygen and Chlorophyll-a Data for the Appoquinimink River: May through July and August through October, 1991

		DO (mg/L)			Chlorophyll a (ug/L)		
Time Period	Distance from Downstream (km)	mean	min	max	mean	min	max
Aug-Oct	0.40	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00
Aug-Oct	5.60	4.90	4.30	5.40	30.00	12.00	45.00
Aug-Oct	6.80	5.50	5.25	5.75	38.00	28.00	52.00
Aug-Oct	8.16	6.20	5.80	6.70	70.00	47.00	92.00
Aug-Oct	9.28	6.20	6.20	6.20	80.00	65.00	103.00
Aug-Oct	10.00	8.10	6.20	10.00	105.00	72.00	136.00
Aug-Oct	10.56	7.90	7.30	8.30	108.00	95.00	120.00
Aug-Oct	11.60	8.20	7.90	8.60	126.00	118.00	135.00
Aug-Oct	13.12	8.25	8.00	8.60	152.00	124.00	181.00
Aug-Oct	15.84	8.25	6.00	10.60	-9.00	-9.00	-9.00
Aug-Oct	16.40	8.60	6.80	10.25	-9.00	-9.00	-9.00
May-July	0.40	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00
May-July	5.60	4.80	4.60	5.10	17.00	10.00	22.00
May-July	6.80	4.10	3.90	4.40	13.00	5.00	22.00
May-July	8.16	3.70	3.00	4.40	13.00	7.00	21.00
May-July	9.28	3.80	3.25	4.40	10.00	4.00	15.00
May-July	10.00	3.70	2.90	4.60	15.00	5.00	25.00
May-July	10.56	3.65	2.90	4.35	36.00	0.00	78.00
May-July	11.60	3.25	2.90	3.60	13.00	10.00	19.00
May-July	13.12	3.20	3.20	3.20	20.00	12.00	30.00
May-July	15.84	8.00	5.50	10.70	-9.00	-9.00	-9.00
May-July	16.40	7.90	4.30	11.40	-9.00	-9.00	-9.00

Table C-2. NH3-N, NO2-NO3-N, and Organic-N Data for the Appoquinimink River: May through July and August through October, 1991

		NH3-N (mg/L)			NO2-NO3-N (mg/L)			Organic-N (mg/L)		
Time Period	Distance from Downstream (km)	mean	min	max	mean	min	max	mean	min	max
Aug-Oct	0.40	-9.000	-9.000	-9.000	-9.00	-9.00	-9.00	-9.000	-9.000	-9.000
Aug-Oct	5.60	0.060	0.040	0.080	0.80	0.50	1.10	0.850	0.700	1.050
Aug-Oct	6.80	0.060	0.040	0.080	0.65	0.30	0.90	0.900	0.800	1.000
Aug-Oct	8.16	0.050	0.050	0.050	0.45	0.12	0.75	1.100	0.850	1.300
Aug-Oct	9.28	0.050	0.050	0.050	0.40	0.10	0.70	1.200	1.100	1.350
Aug-Oct	10.00	0.050	0.040	0.060	0.40	0.10	0.65	1.400	0.950	1.800
Aug-Oct	10.56	0.060	0.050	0.070	0.35	0.12	0.55	1.500	1.250	1.750
Aug-Oct	11.60	0.060	0.050	0.070	0.35	0.15	0.52	1.400	1.350	1.450
Aug-Oct	13.12	0.060	0.040	0.080	0.40	0.15	0.60	1.550	1.300	1.750
Aug-Oct	15.84	0.060	0.040	0.080	0.10	0.10	0.10	1.700	1.250	2.100
Aug-Oct	16.40	0.050	0.050	0.050	3.10	2.80	3.40	0.450	0.100	0.800
May-July	0.40	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00
May-July	5.60	0.100	0.050	0.155	0.70	0.45	0.90	0.650	0.400	0.850
May-July	6.80	0.120	0.050	0.190	0.72	0.60	0.80	0.500	0.350	0.700
May-July	8.16	0.120	0.050	0.190	0.65	0.55	0.70	0.750	0.450	1.000
May-July	9.28	0.145	0.050	0.230	0.60	0.50	0.65	0.750	0.550	0.900
May-July	10.00	0.155	0.050	0.250	0.55	0.55	0.55	0.650	0.350	0.950
May-July	10.56	0.160	0.070	0.250	0.45	0.40	0.55	0.800	0.450	1.100
May-July	11.60	0.190	0.090	0.290	0.45	0.42	0.55	0.750	0.500	1.000
May-July	13.12	0.220	0.080	0.360	0.45	0.35	0.70	0.900	0.550	1.300
May-July	15.84	0.110	0.000	0.220	0.45	0.00	1.05	1.000	0.750	1.300
May-July	16.40	0.170	0.010	0.330	3.30	3.00	3.55	0.700	0.100	1.300

Table C-3. PO4-P and Organic-P Data for the Appoquinimink River: May through July and August through October, 1991

		PO4-P (mg/L)			Organic-P (mg/L)		
Time Period	Distance from Downstream (km)	mean	min	max	mean	min	max
Aug-Oct	0.40	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
Aug-Oct	5.60	0.050	0.040	0.060	0.080	0.000	0.220
Aug-Oct	6.80	0.050	0.025	0.080	0.060	0.000	0.175
Aug-Oct	8.16	0.040	0.010	0.070	0.060	0.000	0.175
Aug-Oct	9.28	0.040	0.010	0.070	0.120	0.010	0.230
Aug-Oct	10.00	0.030	0.010	0.050	0.080	0.000	0.210
Aug-Oct	10.56	0.030	0.010	0.050	0.090	0.000	0.250
Aug-Oct	11.60	0.030	0.010	0.050	0.220	0.150	0.290
Aug-Oct	13.12	0.030	0.010	0.050	0.210	0.140	0.280
Aug-Oct	15.84	0.060	0.040	0.080	0.080	0.040	0.125
Aug-Oct	16.40	0.030	0.010	0.050	0.050	0.000	0.100
May-July	0.40	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00
May-July	5.60	0.065	0.030	0.090	0.120	0.060	0.180
May-July	6.80	0.065	0.030	0.090	0.110	0.050	0.170
May-July	8.16	0.075	0.045	0.100	0.090	0.030	0.150
May-July	9.28	0.055	0.030	0.075	0.110	0.060	0.160
May-July	10.00	0.055	0.030	0.075	0.110	0.060	0.160
May-July	10.56	0.055	0.045	0.065	0.140	0.080	0.200
May-July	11.60	0.055	0.030	0.075	0.130	0.070	0.190
May-July	13.12	0.055	0.045	0.065	0.130	0.100	0.160
May-July	15.84	0.025	0.010	0.030	0.045	0.010	0.070
May-July	16.40	0.045	0.010	0.075	0.060	0.000	0.130

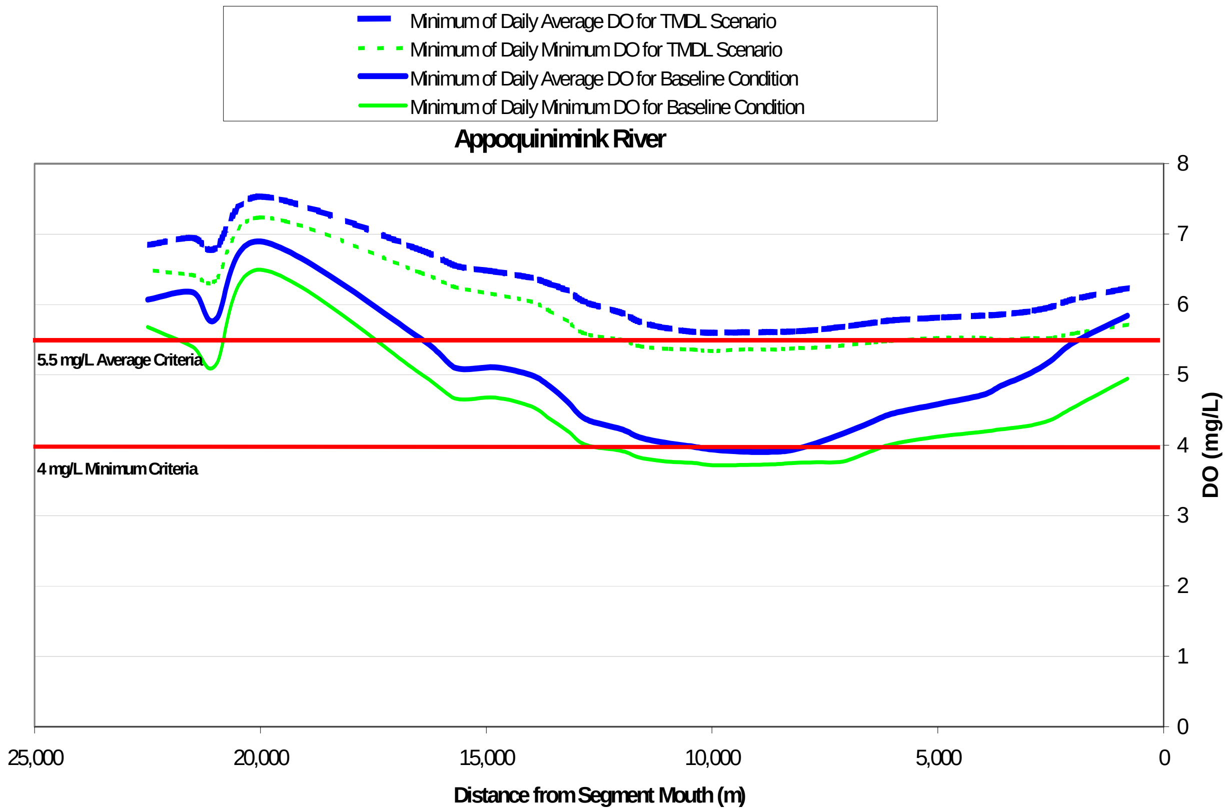
Table C-4 . Structural BMP Expected Pollutant Removal Efficiency

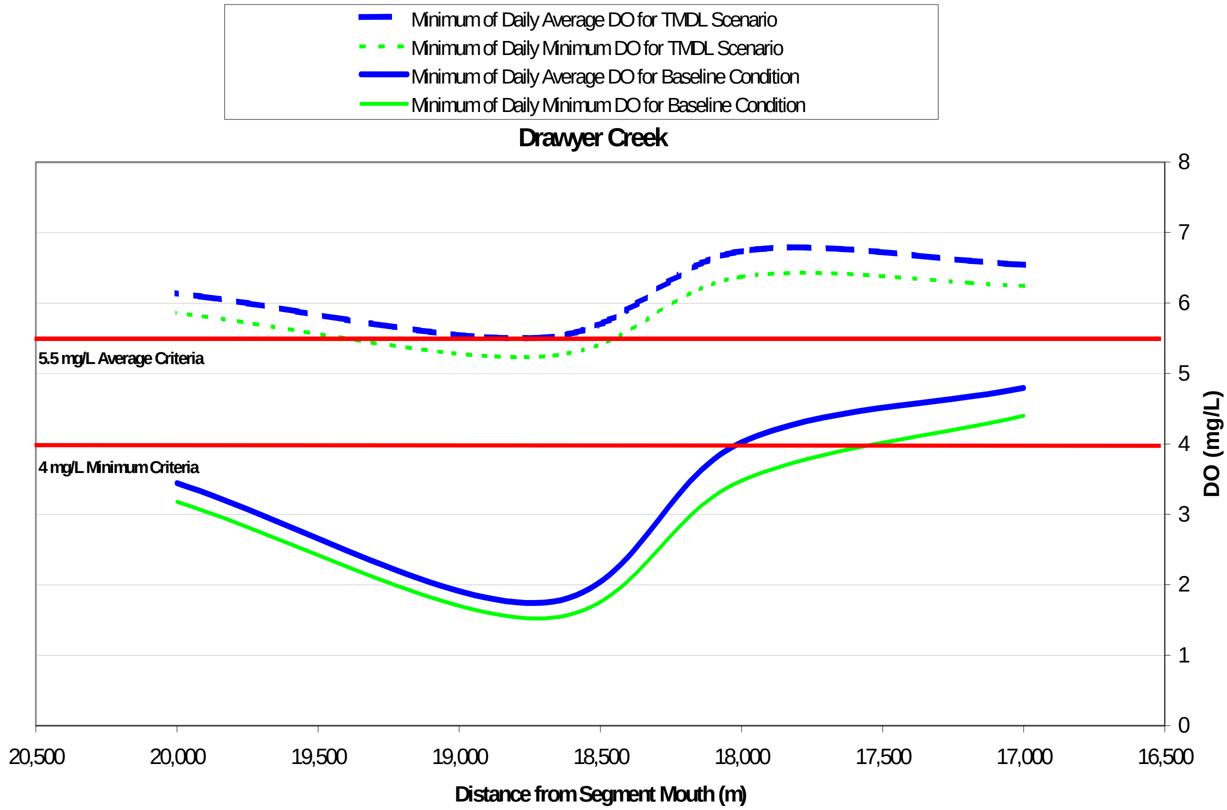
BMP Type	Typical Pollutant Removal (percent)*		
	Suspended Solids	Nitrogen	Phosphorous
Dry Detention Basin	30 - 65	15 - 45	15 - 45
Retention Basin	50 - 80	30 - 65	30 - 65
Constructed Wetlands	50 - 80	<30	15 - 45
Infiltration Basins	50 - 80	50 -80	50 -80
Infiltration Trenches/ Dry Wells	50 - 80	50 - 80	15 - 45
Porous Pavement	65 - 100	65 - 100	30 - 65
Grassed Swales	30 - 65	15 - 45	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80
Surface Sand Filters	50 - 80	<30	50 - 80
Other Media Filters	65 - 100	15 - 45	<30

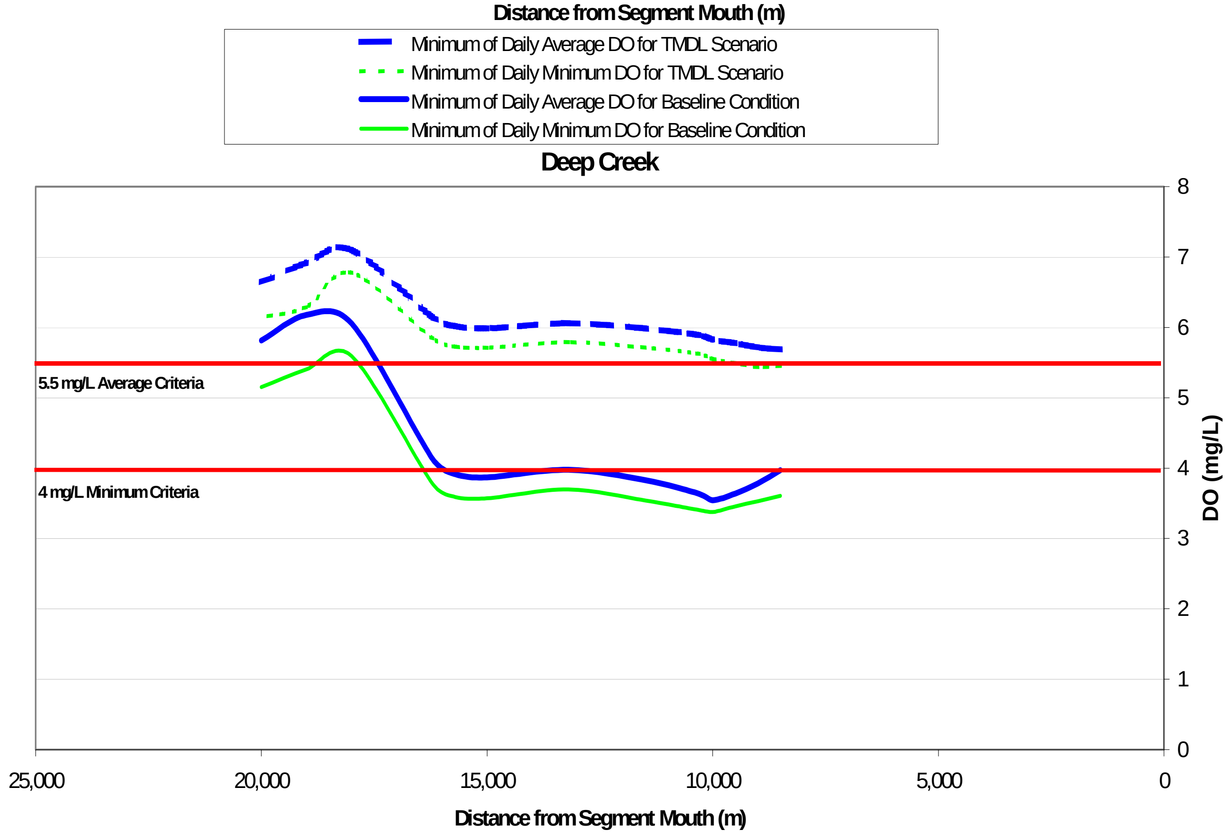
* Source, EPA, 1999. "Preliminary Data Summary of Urban Storm Water Best Management Practices" EPA # 821-R-99-012. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Appendix D: Dissolved Oxygen Modeling Results for Baseline and TMDL Scenarios

This Appendix presents modeling results for the baseline condition and a successful compliance scenario. The compliance scenario was used to identify TMDLs for the impaired waters in the Appoquinimink watershed. Plots on pages D-2 present modeling results for the Appoquinimink River and Deep Creek , respectively. The plot on page D-3 presents results for Drawyer Creek. The distances presented on the plot represent distances from the mouth of that particular segment.


Minimum of Daily Average DO for TMDL Scenario
Minimum of Daily Minimum DO for TMDL Scenario
Minimum of Daily Average DO for Baseline Condition
Minimum of Daily Minimum DO for Baseline Condition
Appoquinimink River
5.5 mg/L Average Criteria
4 mg/L Minimum Criteria
DO (mg/L)
Distance from Segment Mouth (m)
25,000
20,000
15,000
10,000
5,000
0
1
2
3
4
5
6
7
8


Minimum of Daily Average DO for TMDL Scenario
Minimum of Daily Minimum DO for TMDL Scenario
Minimum of Daily Average DO for Baseline Condition
Minimum of Daily Minimum DO for Baseline Condition
Drawyer Creek
5.5 mg/L Average Criteria
4 mg/L Minimum Criteria
DO (mg/L)
0
1
2
3
4
5
6
7
8
20,500
20,000
19,500
19,000
18,500
18,000
17,500
17,000
16,500
Distance from Segment Mouth (m)


Minimum of Daily Average DO for TMDL Scenario
Minimum of Daily Minimum DO for TMDL Scenario
Minimum of Daily Average DO for Baseline Condition
Minimum of Daily Minimum DO for Baseline Condition
Deep Creek
5.5 mg/L Average Criteria
4 mg/L Minimum Criteria
DO (mg/L)
0
1
2
3
4
5
6
7
8
25,000
20,000
15,000
10,000
5,000
0
Distance from Segment Mouth (m)

Appoquinimink TMDL Responsiveness Summary
Dec. 15, 2003

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-01	New Castle County was not provided with access to the model development process and was not provided with enough access to the model.	New Castle County was provided with the model on October 14, 2003, four days after the opening of the public comment period. Since the comment period was extended by one week, New Castle County had over 30 days to review the model. EPA provided assistance to New Castle County's contractor in operating the model.
Surles, Tracy	01-02	We see no reason why EPA did not have the TMDL and all supporting information ready for review by the public at the start of the 30-day comment period.	The TMDL was posted on the web at the start of the comment period. The model and Appendix B (DNREC's 2001 report) were not available on the web but were available upon request. The model was e-mailed to New Castle County on October 14, 2003. Since the comment period was extended by one week, New Castle County had over 30 days to review the model. Appendix B contained DNREC's 2001 report (the commentor mentioned they had commented upon this document) would have been furnished to the County upon request, however EPA was never contacted by the County in regards to the appendix even though it was contacted several times about the model.
Surles, Tracy	01-03	EPA has failed to provide important information for the public comment. EPA's approach left the public with little meaningful opportunity to comment on the accuracy of all of the modeling information.	EPA provided the public with over thirty days to review the TMDL and was available for contact after the release of the TMDL. New Castle County requested assistance from EPA on running the model. EPA provided this assistance quickly and in a professional manner.
Surles, Tracy	01-04	The Appoquinimink system is extensively influenced by marshes. EPA and DNREC should be aware of the several studies about the system and the previous technical information that was provided to DNREC during the public comment opportunity.	EPA is aware of the marsh systems associated with the Appoquinimink River. EPA believes that it was able to accurately characterize the stream system through the use of the models in the TMDL as evidenced in the calibration and validation process. Even though the model did not explicitly account for the marshes it still reflected the stream's conditions.

Appoquinimink TMDL Responsiveness Summary
Dec. 15, 2003

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-05	The TMDL fails to address the marshes either from a hydraulic or water quality perspective. The model cannot yield dependable results without addressing the marshes.	Water quality monitoring data focused on evaluating the specific impacts of the tidal marshes were not available to support this study. As such, detailed processes associated with the marshes were not explicitly represented in the receiving water modeling framework (DYNHYD and WASP). Landuse data were available for the watershed, and thus the wetland areas (marshes) were represented as a distinct landuse category in the GWLF modeling framework. Because insufficient monitoring data were available to fully define the impact (in terms of a net gain or loss) of the wetlands, neither the detainment capacity nor loading processes were explicitly considered. The comment assumes the TMDL fails to account for the contribution of nutrients to the watershed from adjacent marshes. It is well-documented, however, that wetlands perform a nutrient uptake function by detaining land-based loads prior to their reaching the river. In this case, there is no data specific to marshes in the Appoquinimink River watershed, either as to the contribution or nutrients from those marshes or as the impact of the nutrient uptake functions performed by those marshes. Accordingly, while the GWLF model included wetlands as a distinct land use category, specific data as to detention in the marshes of land-based constituent loads from the watershed, which in a good portion of the Appoquinimink River watershed pass through wetlands prior to feeding into the rivers (and tributaries), were not considered. At the same time, contributions of nutrients and organic matter from the wetlands themselves were also not explicitly represented. Because the model was successfully calibrated through a comparison of predictions with in-stream monitoring data and did not indicate a major contributing source was being overlooked, it is reasonable to assume that contributions from the marshes was balanced by the nutrient uptake function in terms of loading to the river.
Surles, Tracy	01-06	The net effect of forcing the model to fit observed data, while ignoring the marshes, results in incorrectly attributing the impacts of the marshes to other sources	Please see response 01-05.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-07	The sensitivity analysis clearly demonstrates that the system is sensitive to SOD. The model treats SOD as a constant sink of D.O. associated with the bottom area of the stream. Because the impact of the marshes can be, at least partially conceptualized as a periodic expansion of the inundated area that exerts SOD, this should have been a signal that the marshes could not be neglected.	Water quality monitoring data focused on evaluating the specific impacts of the tidal marshes (including the ability to lower DO in the river) were not available to support this study. The SOD was predicted using a sediment diagenesis model, and thus cannot physically be "inflated." The SOD was predicted based on a combination of factors, including loadings from the entire watershed and MOT and hydrologic regime.
Surles, Tracy	01-08	Because the DO standard for the river is not met due to the natural conditions, EPA should have done a use attainability analysis to identify the attainable D.O. level before doing a TMDL to achieve the standard.	To the extent the commenter argues that the TMDL is flawed because the applicable water quality standard is inherently deficient and could not be satisfied under any circumstance, the commenter's concerns are properly addressed to DNREC and not to this TMDL. TMDLs must, by law, be calculated to implement state water quality standards. This TMDL is an inappropriate forum for seeking a change in the state's water quality standards or the initiation of a use attainability analysis. Section 303(d)(1)(A) requires the State to identify waters for which technology-based limits are insufficient "to implement any water quality standard applicable to such waters." Section 303(d) is not an appropriate vehicle for disputing the appropriateness of specific State water quality standards. The appropriate vehicle for rectifying concerns regarding the appropriateness of a State water quality standard is EPA's authorities under Section 303(c). Under Delaware law implementing Section 303(c), water quality standards must be adopted as regulations through the state's normal notice-and-comment procedure. See Delaware WQS § §5.1, 5.2 (B-36-37). Any changes to a water quality standard must therefore also be adopted by the state through formal regulatory channels; in addition, any such changes must be approved by EPA. Id. Unless and until the the applicable water quality standard is changed pursuant to Section 303(c), it remains the only legally valid standard in place and the one that must be satisfied under Section 303(d). Nothing in the TMDL prevents DNREC from initiating a use attainability analysis.

Appoquinimink TMDL Responsiveness Summary
Dec. 15, 2003

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-09	Why did EPA choose to ignore the attainability question given EPA's 1994 case study on the Appoquinimink River?	The conclusions of the 1994 study call on the following; to define the load reductions necessary to meet the DO criteria; further characterize nonpoint source nutrient loads; monitor and model the SOD; and specify how the TMDL will be implemented. The new TMDL is based on a new model which accounts for SOD and nonpoint sources of nutrients. The model also identifies the nutrient reductions that are necessary to attain the criteria.
Surles, Tracy	01-10	The applicable DO standard depends on whether the river is considered fresh or marine. EPA should recommend to DNREC that it specify the application of the marine standard.	EPA chose to develop the TMDL using the freshwater criteria. This is consistent with previous TMDL decisions by the state and EPA and is supported by the water quality data. As stated in the Technical Analysis for the Proposed Appoquinimink River TMDLs - October 2001, "the average salinity in the section of the Appoquinimink River between the confluence with the Delaware River and the intersection with Drawer Creek is above the saltwater salinity value of 5 ppt, but because the minimum is below the 5 ppt level, it is considered fresh water." EPA used Delaware's interpretation of their criteria for the TMDL endpoint.
Surles, Tracy	01-11	DNREC's data from 1997-2000 shows an average summer salinity: indicative of marine conditions as far as 5 km upstream from the Delaware River. For these areas, the draft TMDLs are more stringent than necessary and likely unattainable.	The summer salinity data reviewed by EPA showed that the salinity concentrations associated with fresh water criteria were more appropriate for the Appoquinimink River. Please see comment 1-10 for additional information.
Surles, Tracy	01-12	The TMDLs are being designed to meet critical (7Q10) conditions, when by definition there is extremely low fresh water flow. Therefore, it would be appropriate for these TMDLs to be designed to meet the marine D.O. standard- which is more likely the correct and attainable standard than the more stringent fresh water standard, especially in the lower portion of the river.	The current Appoquinimk TMDL was not developed for the 7Q10 flow, but was developed using a dynamic model which takes into account various storm and flow data. Therefore, it is more appropriate to use the fresh water criteria since this represents the stream condition.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-13	The use of the 5.0 mg/L marine DO standard is further supported by the natural background conditions of the river. As explained in the County's March 13, 2002 letter to Hearing Officer Rod Thompson, historical data demonstrate that th 5.5 mg/L standard cannot be achieved under critical conditions because of naturally occurring and other background conditions that have not been factored into the model. The basic problem is that the BOD, nutrients and SOD produced by surrounding salt marshes significantly reduce DO to the point that the river cannot meet the 5.5 mg/L standard. The TMDLs do not reflect this.	The model shows that the reduction in loadings called for in the TMDL will allow the Appoquinimnk River to attain the DO criteria for fresh water systems. EPA applied the fresh water criteria which was used by the state and EPA in previous TMDLs and is an appropriate interpretation of the DO criteria.
Surles, Tracy	01-14	DNREC has not specified that the marine standards should apply in the lower portion of the river. We believe that good science supports such a conclusion. EPA should initiate a UAA to address this issue.	DNREC has interpreted Delaware's water quality standard as applying the freshwater criteria. As a general matter, EPA will defer to a State's interpretation of its own water quality standard regulations, so long as that interpretation falls within the range of reasonable interpretations. In this case, DNREC determined to apply the freshwater criteria. DNREC's interpretation falls within the range of reasonable interpretations and is accepted by EPA. To the extent the commenter argues that the TMDL is flawed because the applicable water quality standard is inherently deficient and could not be satisfied under any circumstance, see response to 01-08. (Data Supporting this Decision)
Surles, Tracy	01-15	The available STORET data supports this view. DO levels during the June- September time frame during 2000-2001 fell below the 5.5 mg/L standard a significant amount of the time. At station 109121 90% of the DO values were below 5.5 mg/L. Almost every station we looked at had a significant number of samples below the standard. These results are almost certainly attributable to the marsh impacts.	Marsh impacts maybe impacting the DO concentration in the Appoquinimink River as stated in these comments. However, the marsh impacts are not the only factor impacting the low DO values. The model demonstrates that by reducing the elevated nutrient load that is reaching the River the DO impairment can be removed. The DO impairment is being impacted by both flow and load issues. To the extent the commenter implies the River will not be able to maintain the applicable criteria because of marsh related issues without addressing the excess nutrient loading, the comment does not reflect all conditions to the stream.
Surles, Tracy	01-16	The TMDL should be developed for both the 5.5 mg/L and 5.0 mg/L potential water quality standards.	The regulations require the TMDL to be developed for the applicable criteria therefore, the TMDL was developed for the DO concentrations associated with the fresh water criteria, 5.5mg/L.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-17	The Clean Water Act does not authorize EPA to make allocation decisions which have land use implications but preserves the role of state and local authorities in these matters.	To the extent the commenter suggests that, through the TMDL, EPA is impinging on State and local government's sovereignty to make local land use decisions, the commenter is mistaken. The commenter mistakenly equates the water quality-based approach with a regulatory control function. TMDLs established pursuant to Section 303(d) of the Clean Water Act merely afford EPA and the States the authority to identify all sources of impairments of water quality standards (point source and nonpoint source). A variety of allocation scenarios may achieve the water quality standard for the Appoquinimink River. The TMDL provides a breakout of the total loads for to the point sources and nonpoint sources and represents one allocation scenario. DNREC retains significant discretion as to how to implement the TMDL. As implementation of the established TMDL proceeds, DNREC may find that the applicable water quality standard can be achieved through other combinations of point and nonpoint source allocations that are more feasible and/or cost effective. If that happens, DNREC is free to re-run the model to propose a revised TMDL with an alternative allocation scenario that will achieve water quality standards. These procedures should be followed even if the sum of the loads remains identical. By transferring the loadings from one source to another the results of the model may change. The proximity and timing of the different sources impacts the river differently.
Surles, Tracy	01-18	EPA should include a chart that shows the available loadings for the limited parameters as well as the percent allocation between point and nonpoint sources as well as any margin of safety and reserved growth loadings.	Table 4-1 presents the available loadings for nonpoint sources (in the WLA column) and Table 4-2 presents the available loadings for point sources. The Margin of Safety was implicit, and thus not explicitly quantified. Therefore, it was not presented in the tables. No assignment was made to reserved loadings for growth.
Surles, Tracy	01-19	EPA should expressly acknowledge in the TMDL that any other allocation scenario that meets the total loadings is allowable within DNREC's discretion.	See response to 01-17.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-20	The sensitivity analysis is grossly inadequate. It does not provide any meaningful insight into how the system reacts to alternate input scenarios.	Although the sensitivity of modeling parameters and source contributions were evaluated during the model calibration/validation and allocation efforts, respectively, a full sensitivity analysis (which is not a regulatory requirement) was not presented in the TMDL report. The model was made available to the public, so that the public would have the ability to make sensitivity runs as they see fit.
Surles, Tracy	01-21	We would like to have seen sensitivity runs using different pollutant concentrations from our MOT treatment plant.	While the commenter suggests that there should have been additional sensitivity runs, the commenter failed to propose any alternative allocation scenarios, other than the commenter's request in its letter dated September 2, 2003 (which was based on an August 2003 meeting between New Castle County and EPA) seeking an allocation scenario that would increase the effluent from the MOT plant by a factor of 5. At the commenter's request, EPA ran the model increasing the loading from the MOT plant by the values requested in the letter. The model predicted that these loadings (CBOD 104 lbs/day, TN 104 lbs/day, TP 83 lbs/day) from the MOT plant would cause a failure to achieve water quality standards, even if the storm water sources were reduced by the amount called for in the TMDL. Accordingly, a WLA was selected that did not require a reduction from the MOT plant. As stated in response to 01-17, the TMDL represents one allocation scenario, and DNREC remains free to re-run the model and propose a revised TMDL with a different allocation scenario.
Surles, Tracy	01-22	Why was an effluent DO value of 0.695 mg/L used for the MOT plant when it has not discharged at such a low level. A more appropriate level in the range of 5 to 7 mg/L should have been evaluated.	A DO value of 0.695 mg/L was used for the MOT discharge to be consistent with DNREC=s original DYNHYD-WASP model of the Appoquinimink River. This value was used as part of the 1998 TMDL, increasing the DO concentration in the effluent is not expected to impact the model results.
Surles, Tracy	01-23	EPA did not provide enough time for the public to access the model and run alternative allocations.	EPA did provide an adequate amount of time and assistance in the public comment period. Please see responses to comment 1.
Surles, Tracy	01-24	Why does the model not reflect seasonal nitrogen inputs to the Appoquinimink River from the emergent herbaceous wetlands which represent 9.82% of the land use in the watershed.	Emergent and Woody Wetlands were assumed to have no net load contribution due to their capacity to detain and/or utilize nutrient inputs (since these processes were not explicitly represented in the modeling framework). See response to 01-05.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-25	Routine, scientifically correct investigations, from 1995 to the present of the chemistries and fishes in the Appoquinimink by DNREC demonstrate that the aquatic life use is being protected throughout the Appoquinimink. This is despite the fact that DO's below the minimum criteria are routinely measured.	Section 303(d) requires that each state identify and develop TMDLs for those waters for which technology-based effluent limitations are not stringent enough to implement "any water quality standard applicable to such waters." Applicable water quality standards includes narrative criteria, numeric criteria, use designations and anti-degradation. All four parts of the water quality standard must be considered. In this case, although there may be studies showing that the Appoquinimink River supports aquatic life, the evidence also shows that the river fails to achieve the numeric criteria for DO. Waters which fail to attain their numeric criteria must be listed on the Section 303(d) List as impaired for TMDL development. The attainment of a healthy benthic community does not cancel out the violations to the DO criteria.
Surles, Tracy	01-26	Why is the wetlands tidally influenced reduction of DO concentrations not listed as a factor contributing to lower DO concentrations in the river? Why is an inflated SOD used to compensate for the lack of wetlands influenced reduction in DO?	Water quality monitoring data focused on evaluating the specific impacts of the tidal marshes (including the ability to lower DO in the river) were not available to support this study. The SOD was predicted using a sediment diagenesis model, and thus cannot physically be "inflated." The SOD was predicted based on a combination of factors, including loadings from the entire watershed and MOT and hydrologic regime.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-27	Please provide a numerical example of the conversion of monthly GWLF TN and TP outputs to daily values. Please explain how the model mathematically calculates the interaction between wetlands functions and rainfall related runoff events to the river's mainstem.	The conversion of monthly GWLF outputs to daily was performed as follows: Assuming: ~ there are 30 days in a month ~ the monthly load of constituent X is 1,000 lb/month ~ monthly average flow is 3 cms ~ during the month there are only two rainfall events of 6 inches and 8 inches, respectively, on day 7 and day 11. Therefore, the total rainfall during the month is 14 inches. For those days without rainfall, a baseflow was first assumed (0.1 cms), thus the total flow for the 28 days without rainfall was 0.1 x 28 = 2.8 cms (cms is used instead of cubic meters for simplicity). The total flows for the other two days was thus (3 x 30) - 2.8 = 87.2 cms. Assuming the flow is directly proportional to rainfall, the flow on day 7 is: (6 inch/14 inch) x 87.2 = 37.3 cms; and the flow on day 11 is: (8 inch/14 inch) x 87.2 = 49.9 cms. Due to the inherent uncertainty in these estimates, the fact that the resulting storm flows are attenuated with respect to the rainfall values, and the ultimate goal of predicting water quality trends over time in the river system due to storm flow and low flow conditions, these estimates were distributed over a multiple-day time period. This is a common practice in water quality modeling studies (such as in Deas and Orlob, 1999), where specific flow and water quality loads or concentrations for all individual storms are not monitored (and thus must be predicted). Based on the first estimate of the flow, the flow time series is distributed over time using a weighted moving average scheme, where the flow on day n is represented as: Sum w(i)*Flow(n-K) from i--k to k. Where: the weight vector w(i) is determined based on a triangular formula as w(-2)=0.1, w(-1)=0.2, w(0)=0.4, w(1)=0.2, and w(2)=0.1. As boundary condition, the Newflow(1) and Newflow(2) should be equal to the Flow(1) and Flow(2).

			By using this linear formula, the flow on day 3 is calculated as: Newflow(7)=0.1*flow(5)+0.2*flow(6)+0.4*flow(7)+0.2*flow(8)+0.1*flow(9)=0.1*0.1+0.2*0.1+0.4*37.3+0.2*0.1+0.1*0.1=0.01+0.02+14.9+0.02+0.01=14.96 cms Newflow(8)=0.1*flow(6)+0.2*flow(7)+0.4*flow(8)+0.2*flow(9)+0.1*flow(10)=0.01+7.46+0.04+0.02+0.01=7.54 cms Using this formula, the distributed time series can be obtained for each day of the month. Then, the total load of 1,000 lbs is distributed to each day based on the assumption that the load of each day is proportional to the flow on that day. There is no explicit hydrodynamic representation of the wetlands, however tidal influences are simulate.
Surles, Tracy	01-28	Will appendix B provided with the final document?	Appendix B was available during the comment period; it simply was not on the web site. Although it was not on the web site, New Castle County requested and received the model. Appendix B also could have been requested and would have been provided. New Castle County did not, however, request a copy of Appendix B during the comment period. The Appendix will be furnished to the commenter at this time.
Surles, Tracy	01-29	What is the source of SOD that is introducing nutrients to the water column? Would rainfall related runoff sediments be trapped in the surrounding wetlands? Under the BNR conditions for the MOT previously provided to EPA would not MOT effluent be viewed as an insignificant source?	The source of the SOD is the organic matter loading from the watershed and the internal organic matter loading from algae death. Some of the watershed contributions are expected to be trapped in the surrounding wetlands, however, no information was available to accurately quantify the influence of the wetlands. Therefore, the wetlands were not explicitly represented in the modeling framework. The entire watershed load generated by the GWLF model was input directly into the DYNHYD- WASP model as a conservative assumption. MOT effluent would not be viewed as an insignificant source under the BNR conditions provided since it is responsible for more than 1% of the nitrogen and phosphorous loadings.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-30	Why is the Gaussian temperature function considered to be more representative of real algal growth? We question whether the lack of algal growth in the summer is due to temperature and whether algae are limited by nutrients as claimed in the TMDL.	Algae, depending on species, typically grows the fastest when temperature is within the optimal range (given other condition are also optimal). When temperature is lower or higher than the optimal range, growth is generally reduced. This trend is well represented by the Gaussian function. Recent, advanced models use the Gaussian temperature function instead of the power function (Park et al, 1995; HydroQual, 2001). Algae growth is influenced by many factors, including temperature, nutrient levels, and light availability. Because no specific data were available regarding light availability, and because light availability was not expected to vary drastically between the calibration and validation periods, it was assumed that temperature and nutrient concentrations were the primary factors. Thus, the model reflected these influencing factors and successfully predicted chlorophyll a concentrations. Nutrient loads throughout the year (including summer and fall) were predicted by the GWLF model. Thus, variability in nutrient levels (combined with flow) contributed by the watershed to the river was explicitly represented in the modeling framework. General observations regarding wetland functions are insufficient to explain cholorophyll-a concentrations in the Appoquinimink system under the calibration and validation conditions. The model predicts algae based on a host of factors specific to the Appoquinimink River system under specific conditions.
Surles, Tracy	01-31	Please explain why the use of a Kd decay rate value of 0.10/day resolves the previous model inconsistencies. What is the source and explanation for the selected Kd rate and why is it applicable to this river?	Previously, the Kd value was set as 0.075/day, while the CBODu/CBOD5 ratio was set as 1.58. A Kd value of 0.075/day, however, is associated with a CBODu/CBOD5 ratio of approximately 3.2. In the current version of the model, Kd was set to 0.1/day (and CBODu/CBOD5 was set to 2.54). This Kd was set through calibration and based on the consideration that the sole point source along the river discharges secondary treatment effluent, while the remainder of contributions are from the watershed (land) itself. In Lung, 2001, it is stated that in a river where secondary treatment effluent discharges and other sources are nonpoint source, the Kd can be as low as 0.075/day. Using a significantly higher Kd value would likely overestimate the impact of CBOD.

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-32	Please include the phytoplankton monitoring data in the TMDL technical document.	The phytoplankton monitoring data are shown graphically on the plots in Appendix C of the TMDL report. A table has been added as per your request.
Surles, Tracy	01-33	Lacking a wetlands component in the model, does the sediment diagenesis model have to overcompensate the DO reduction associated with the sediment?	No, the sediment diagenesis model does not overcompensate the DO reduction associated with the sediment, because it only responds to the organic load coming into the river from the watershed and MOT. Some of the watershed contributions are expected to be trapped in the surrounding wetlands, however, no information was available to accurately quantify the influence of the wetlands. Therefore, the wetlands were not explicitly represented in the modeling framework. The entire watershed load generated by the GWLF model was input directly into the DYNHYD- WASP model as a conservative assumption.
Surles, Tracy	01-34	Please provide the monitoring data base and calculations that support the method by which the GWLF TN and TP outputs were converted to nitrate-nitrite, ammonium, organic nitrogen, orthophosphate and organic phosphorous loads.	Ratios among nutrient components (e.g., individual nitrogen components vs. total nitrogen) for boundary conditions in the existing DNREC model were used to convert the TN and TP outputs from the GWLF model into individual nutrient components. The ratios in the DNREC model were based on an analysis of water quality data. Although each modeling segment had been assigned a unique ratio in the DNREC model, the mean ratio of all segments was calculated and used to convert GWLF output into constituents for the WASP model. The final ratios used are presented on page 4-5 of the TMDL report.
Surles, Tracy	01-35	Please provide an explanation on how the CBODu/organic nitrogen, N/C and C/oxygen ratios were derived/selected.	The CBODu/organic nitrogen ratio (or C/N ratio) was determined through an iterative process, starting with the widely accepted Redfield Ratio, and then adjusting the initial value through calibration. The resulting CBODu/organic nitrogen ratio (or C/N) was twice as high as the Redfield ratio. This can be justified by the fact that the C:N ratio of overland organic matter can be as high as 4 to10 times the Redfield ratio (Lunsford, 2002). The ratio C/Oxygen=2.67 is a stoichiometry constant (Chapra, 1997).

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Dec. 15, 2003

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-36	Given that organic nitrogen represents 26.4% of TN generated by the GWLF, explain how it is reasonable to justify the high CBODu/organic nitrogen ratio by saying the organic nitrogen is relatively diminished.	When the report stated that "the organic nitrogen is relatively diminished", it meant that in comparison to carbon, nitrogen is relatively diminished (a small portion of organic matter is nitrogen). Although, organic nitrogen is a significant part of the total nitrogen load as mentioned in your comment it is not a significant portion of the total organic load which also includes organic carbon and phosphorous. This is consistent with the fact that the C:N ratio of the overland organic matter can be as high as 4 to10 times the Redfield ratio (Lunsford, 2002)
Surles, Tracy	01-37	For which dates during the calibration and validation period is monitoring data available?	Data are available for the following dates: 05/15/91, 06/20/91, 07/09/91, 08/12/91, 09/09/91, and 10/09/91. EPA has included this data in an appendix to the report.
Surles, Tracy	01-38	Why does the model not consider the loss of sediment due to high flow conditions?	The model is conservative in that it does not consider loss of sediment due to high flow conditions. This is part of the implicit Margin of Safety included in the loading.
Surles, Tracy	01-39	How does the model account for the oxygen depletion that occurs to the land-based flows as they pass through the marsh during the summer?	See response to 01-05.
Surles, Tracy	01-40	Why was GWLF trend: nutrient information used instead of instream water quality and flow measurements?	The GWLF model was used to predict watershed contributions over time, in order to generate inputs for the predictive sediment diagenesis model. In-stream measurements were used to test the model (through calibration and validation), however, they're insufficient to provide an accurate input time series for the sediment diagenesis model (because they are not reflective of a wide range of hydrologic conditions). The GWLF modeling framework also enables a source-based analysis and allocation to be made.
Surles, Tracy	01-41	If the model does not explicitly account for the impact of groundwater how can there be a base fresh water flow? In the absence of a net advective flow, the water below the dams would be saline. Why then is the fresh water average criteria used for judging the model attainment and developing the TMDL?	The text in the report will be clarified. Groundwater contributions of flow and nutrients were predicted by the GWLF model, however, an explicit groundwater model was not implemented. In the absence of net advective flow, the salinity of the water below the dams would be dependent on salinity levels in Delaware Bay. Please see responses to comment 3

Commentor	Letter ID	Comment	Response
Surles, Tracy	01-42	Please explain the enormous change in baseline TP between the 1998 model and the current draft TMDL.	The discrepancy between the 1998 and current model baseline TP values is attributed to two factors. First, the load used in the 1998 model was based on a low-flow condition, while the current model is based on variable hydrologic conditions (including all the actual storm events for the time period in addition to the low-flow conditions). Thus, the newly estimated load is expected to be significantly higher than the previous estimate. Second, the low phosphorus load estimated for the 1998 model was based on Ritter and Levin's method which uses an extremely high N:P ratio of approximately 57.0. The N:P ratio simulated by the GWLF model corresponds with the widely-accepted Redfield Ratio, which is less than 10.0. According to Wiseman, et al, 1999 (see reference list), the N:P load in watersheds should be close to the Redfield Ratio. Thus, this ratio was used as the basis for phosphorus predictions from the watershed.
Surles, Tracy	01-43	Please explicitly note that the TMDL does not limit the flow from the MOT plant.	The TMDL establishes a specific loading from the MOT facility. The permit for the MOT facility must reflect the loadings called for in the TMDL. If the permitting authority chooses to allow the flow from the facility to increase this would need to be compensated via a reduction in the discharge pollutant concentrations.
Surles, Tracy	01-44	Data are available for the particular sampling events, and the model produces output on a continuous basis, allowing direct comparison of the model with each data set. The TMDL compares averages of the model and data over several months. The model could be grossly in error on the high or low side of each sampling event. Even with the simplification several parameters in the calibration and verification sets don't agree with the model at all.	Data for the calibration and validation periods are not sufficient to perform an extremely detailed temporal and spatial calibration. Therefore, model calibration and validation results were evaluated through a comparison of the predicted and observed minimum, maximum, and average conditions during the period of interest (i.e., the time period used for evaluation of water quality criteria). The model results demonstrate that maximum and average concentrations, and in particular, minimum concentrations are predicted well. These minimum concentrations are the basis of the water quality criteria, and are thus the critical factor.

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Surles, Tracy	01-45	There appear to be several miscellaneous modeling problems. The DO upstream boundary concentrations were changes. For the calibration and validation periods, the boundary conditions were generated using the GWLF model. For the TMDL scenario, the DO concentration was assumed to be equivalent to 80% of the saturation level at a water temperature of 28 degree C. The effect of the above changes can best be evaluated by running the TMDL scenario with the input data in the calibration file. However this cannot be done at this time because the files provided to the County do not allow us to run the WASP model. The TMDL report does not provide details of the hydrodynamic calibration. From the input file, the May to July tidal data were recycled for the entire simulation period. Therefore it appears that the May to July tidal data have also been used for the validation period August to October. The validation seems to be questionable due to the use of tidal data of a different period.	In the calibration/validation periods, the DO boundary condition was set equal to the same values used in the previous DNREC model to maintain consistency (DO was not predicted by the GWLF model). These boundary conditions were not applicable to the TMDL run because when a nutrient/organic matter load reduction scheme is implemented, the DO concentration of the upstream incoming flow is expected to increase. Thus, 80% of the saturation level at a water temperature of 28 degree C was used as the boundary concentration in the TMDL case for DO. A more accurate set of tidal data may provide more confidence in the model validation, however, the quality of the validation is not expected to change significantly. Because the configuration and parameterization of the model is the same for both the calibration and validation period (i.e., no additional parameter adjustment was made for validation period), and the model predicted water quality well for the validation period using the recycled tidal data, it is reasonable to assume that the tidal data for the calibration period approximated conditions for the validation period reasonably well.
Stuhltrager, James	02-01	The Appoquinimink River TMDL is based on land use data form 1992. Because much of the pollutant loading to the River is contributed by nonpoint sources that are effected by land use, the TMDL may not accurately reflect current environmental conditions. As soon as more current land use data is available EPA should consider amending the TMDL to more accurately reflect current environmental conditions. r	The draft Appoquinimink TMDL was based on 1992 land use data as stated in your comments. However, the model was run using the 2002 land use data EPA received during the comment period. This did not significantly change the TMDL as mentioned in the report.

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Stuhltrager, James	02-02	A potential source of additional pollutants is the future growth that is projected to occur in the communities surrounding the Appoquinimink River. The proposal does not consider the forecasted increase in both point and nonpoint source contributions due to the county's growth. The Appoquinimink TMDL should develop methods to control these future impacts before they adversely affect the River.	The water quality standard for the Appoquinimink River may be achieved through a variety of allocation scenarios. The TMDL provides one such scenario, which neither requires a reduction in the current point source loading from the MOT nor provides a specific allocation to future growth. DNREC retains significant discretion in implementing the TMDL. As implementation of the established TMDL proceeds, DNREC may find that the applicable water quality standard can be achieved through other combinations of point and nonpoint source allocations that are more feasible and/or cost effective. If that happens, DNREC is free to re-run the model and to propose a revised TMDL with a different allocation scenario that will achieve water quality standards. See response to 01-17.
Stuhltrager, James	02-03	The proposed TMDL is silent as to the methods that will implement the necessary load allocations. By failing to include a plan for implementation, the TMDL may not attain the applicable WQSs.	An implementation plan is not one of the regulatory requirements of a TMDL. Section 5.0 of the TMDL report describes the best management practices that have been put in place.
Stuhltrager, James	02-04	In the absence of any enforceable point source reductions, the Appoquinimink River TMDL must identify the specific BMPs that will be implemented and the corresponding NPS reduction that can be expected from each.	Many of the nonpoint sources are actually associated with New Castle County's MS4 permit, therefore there is a regulatory program established to address these loads. The specific BMPs which will lead to the 60% reduction in storm water loadings should be identified in the implementation plan which should be developed by the state.
Stuhltrager, James	02-05	EPA has failed to establish separate WLAs for the various MS4s in accordance with EPA regulations and guidance.	In the TMDL all nonpoint sources were placed in the WLA for the MS4 permit. The remaining loads from nonpoint sources will be placed in the WLA for the MS4 at this time the state and county are mapping out the storm sewer lines. Once this work has been completed the loadings from storm water will be further segregated.
Stuhltrager, James	02-06	The proposed TMDL does not include an adequate MOS. The MOS does not include foreseeable factors that should be considered in the proposal. It is recommended that EPA use an explicit MOS.	The TMDL uses an implicit MOS and conservative assumptions to account for uncertainties in the model. The conservative assumptions are identified in the TMDL report.

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Commentor	Letter ID	Comment	Response
Worall, Courtney	03-01	If the deadline for the TMDL is extended, I highly recommend holding another public meeting to explain the new data and what changes, if any that results in.	The deadline for the TMDL is not being extend.
Worall, Courtney	03-02	Please provide data regarding the implementability of the 60% reduction in nonpoint source load allocations.	EPA does not have data on the implementability of the 60% reduction in stormwater loads to the Appoquinimink. EPA has provided information in the TMDL on common best management practices for stromwater management and the possible load reductions expected with these measures.
Worall, Courtney	03-03	The point source load allocation should remain as presented in the draft TMDL.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL.
Worall, Courtney	03-04	EPA should segrerate the storm water point sources from the nonpoint sources and assign discrete allocations after DNREC and the county complete their mapping effort. EPA should allow the public and the permitees to work together to determine how this segregation should take place.	The forest and agricultural loads that were placed in the WLA of the MS4 permit in the TMDL due to the resolution of the model and the data available. Future work between the state and county should be able to refine these loadings.

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Commentor	Letter ID	Comment	Response
Myoda, Sam	04-01	DNRECs Division of Water Resources is concerned with the nonpoint source loading rates generated by the GWLF model and the inability to adequately calibrate and verify the resulting water quality predictions due to the lack of a comprehensive data set. In 1997, additional monitoring stations were added to provide a comprehensive coverage within the watershed. DWR believes that it is more appropriate to use a post 1997 data set so that the model may be adequately calibrated and verified. In addition the use of the more recent data set would better reflect the current conditions in the watershed, eliminating the need ro adjust the proposed load reductions to reflect those reductions that have occurred since 1991.	Although a comprehensive water quality data set for the headwaters of the Appoquinimink River watershed was not available to perform a detailed calibration of the GWLF model, constituent loadings predicted by the model were validated through comparison of the WASP model predictions to monitoring data. The WASP model used GWLF model results as inputs. Thus, in order for the WASP model to accurately predict nutrient, DO, and algae levels, it was necessary for the GWLF loadings to be reasonably accurate. Because the WASP model results correlated well with monitoring data, the GWLF loadings can be assumed to be reasonable. Additional monitoring data in the headwaters would support refining the GWLF model calibration, however it's possible that load estimates would not differ from the current predictions. At the time the updated model was calibrated, only the MRLC landuse coverage (early 1990s) was available, therefore the 1991 time period was used for model calibration. Additionally, calibration of the receiving water model (WASP) focused on adjusting kinetic parameters that likely would not change significantly from the early 1990s to current conditions. The in-stream processes and relationships are not expected to change with changes to terrestrial land uses. Thus, the actual calibration year is not necessarily a critical factor. The primary changes would come in the land- based contributions (i.e., predictions from the GWLF model). Because the GWLF model is a dynamic, predictive watershed model that is source/landuse-based, it can readily be updated to reflect current conditions without the need for a full calibration. That is, the landuse distribution in the model can be updated to reflect current conditions, and new loadings can be predicted and applied to the receiving water model (without necessarily the need for recalibration.

Commentor	Letter ID	Comment	Response
Myoda, Sam	04-02	The GWLF output calculated the annual phosphorous load to be substantially higher than Ritter and Levin's rates. DWR monitored the outflows at Silver Lake and Noxontown Lake to determine actual nonpoint source loads to the upper boundary of the tidal river to serve as a basis for Ritter and Levin's calculations. This discrepancy needs to be addressed.	The discrepancy is attributed to two factors. First, the load used in the 1998 model was based on a low-flow condition, while the current model is based on variable hydrologic conditions (including all the actual storm events for the time period in addition to the low-flow conditions). Thus, the newly estimated load is expected to be significantly higher than the previous estimate. Second, the low phosphorus load estimated for the 1998 model was based on Ritter and Levin=s method which uses an extremely high N:P ratio of approximately 57.0. The N:P ratio simulated by the GWLF model corresponds with the widely-accepted Redfield Ratio, which is less than 10.0. According to Wiseman, et al, 1999 (see reference list), the N:P load in watersheds should be close to the Redfield Ratio. The Redfield Ratio is based on terrestrial sources which are the sources being recreated in the model and therefore the Redfield Ratio was deemed appropriate. Thus, this ratio was used as the basis for phosphorus predictions from the watershed.
Myoda, Sam	04-03	DWR's Surface Water Discharges section issues NPDES permits based on 7Q10 flow conditions. The dynamic model looks at a seasonal average and may overlook the critical periods. The steady state model used in the 1998 TMDL is more consistent with the 7Q10 and critical time period approach. DWR supports the EPA in recognizing that the point source waste loads will be maintained at their existing level.	The model used for TMDL development does not look at seasonal average conditions. It makes predictions at a sub-hourly timestep for the entire modeling period. Therefore, it predicts constituent levels for low-flow as well as for storm events. More importantly, the model makes predictions for critical conditions overlooked by a 7Q10 analysis (e.g., relatively low- flow conditions that follow a storm event). A 7Q10 analysis assumes minimal land-based loading inputs, however, these inputs (which are typically contributed during storm events) become the most critical factor even during low flow events, such as the 7Q10. Thus, the current modeling framework can be used to evaluate critical periods in more detail than a steady-state 7Q10 evaluation.
Myoda, Sam	04-04	At this time neither EPA nor DWR has sufficient data to determine the portion of water that is captured by the storm water system. DWR supports EPA in combining the WLAs for the storm water permits and the Las for the areas not covered by the storm water permits until adequate dat is obtained ro justify a discrete allocation to the storm water permits.	The forest and agricultural loads that were placed in the WLA of the MS4 permit in the draft TMDL can now be found in the LA. The remainder of the storm water loading has been lumped into one gross WLA for the MS4. EPA believes that the state, stakeholders, and permittees should further segregate this loading when the storm sewer mapping data set becomes available.

Commentor	Letter ID	Comment	Response
Myoda, Sam	04-05	The adjusted CBODu/CBOD5 ratio is significantly higher than monitoring data values.	There were no CBODu/CBOD5 data available during the study. Only CBOD20 was measured, as indicated in the dataset. The CBODu/CBOD5 ratio in the current version of the model was determined based on the CBOD decay rate of 0.1/day. In general, a high CBODu/CBOD5 ratio is associated with a low CBOD decay rate, which indicates that the organic matter in the water is relatively well stabilized and would impose less impact on the DO concentration. See Comment 1-31 for additional discussion on the CBOD rate.
Myoda, Sam	04-06	SOD is one of the major drivers affecting the DO levels in the Appoquinimink River, using this approach, and with a CBODu/CBOD5 ratio that DWR considers too high, the SOD values may also be too high, resulting in reductions that are greater than necessary to ensure State Water Quality Standards are met.	No in-situ SOD data were available for directly calibrating the sediment diagenesis model during the study. However, the predictive sediment diagenesis model was indirectly calibrated and validated through a comparison of the simulated DO, NH3 and PO4 concentrations with monitoring data. If the SOD, NH3 and PO4 fluxes simulated by the sediment diagenesis model were incorrect, then the water column DO, NH3 and PO4 would not have matched the monitoring data. Since model predictions for these constituents correlated well with monitoring data, this is not the case. The CBODu/CBOD5 does not have a significant impact on the predicted SOD value because the major source of organic matter that generates SOD is from the watershed (land-based) loading (where the CBODu/CBOD5 ratio does not play any role). Thus, the proposed reduction to meet the State WQS was not caused by the high CBODu/CBOD5 ratio.
Myoda, Sam	04-07	Total nitrogen is not considered only Total TKN. DWR would ask that EPA to consider a WLA for nitrogen that exists as nitrate and nitrite.	The WLA assigned for the MOT WWTP NPDES discharge (DE0050547) included only TKN, in order to be consistent with its current permit.
Bryan, Frank & Rhoda	05-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL
Murray, Joseph	06-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL.

Commentor	Letter ID	Comment	Response
Love, Susan	07-01	No reductions are called for in the load from the MOT wastewater treatment plant. The plant is currently in violation of its permit and trying to reduce its buffer requirements order to accept more flow per day. It is unclear how the load reduction of 60% will be accomplished. While it is understood that nonpoint source pollution is a major factor in the impairment of the Appoquinimink River, clean water quality gains can be made immediately by reducing the allowable nutrient contributions of the MOT plant.	Your comments regarding the performance of the MOT facility will be forwarded to DNREC and EPA's enforcement branch. As stated in your comments the TMDL calls for a 60% reduction from land based sources yet does not require a reduction in the MOT effluent. The TMDL model found that Appoquinimink was more sensitive to reductions in land based sources of nutrients. These sources represented over 90% of the nutrient load and must be reduced for the River to attain the applicable criteria.
Lang, Bryan&Rebecca	08-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL
Whiteside, Warren	09-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL
Mulholland, Chuck	10-01	We have learned of that New Castle County has approached EPA to increase their discharge in the Appoquinimink River from 0.5 mgd to 2.5 mgd without any prior advisory from our local government. We believe that a reduction from a single point source, the waterfarm, would more easily attain the water quality we seek to attain.	New Castle County did propose that the WLA from the MOT plant include an increase in its current loading . EPA ran the model with the increased WLA to the MOT plant and predicted that this increase in the loading from the MOT plant would cause a failure to achieve water quality standards. Thus, the allocation scenario selected for the TMDL provides for no change from the current loading from the MOT plant. The TMDL model found that Appoquinimink was more sensitive to reductions in land based sources of nutrients. These sources represented over 90% of the nutrient load and must be reduced for the River to attain the applicable criteria. According to the model, the River would be unable to attain the applicable criteria even if the MOT facility was removed. It should be noted that the TMDL provides only one allocation scenario. DNREC retains significant discretion in implementing the TMDL. As implementation of the established TMDL proceeds, DNREC may find that the applicable water quality standard can be achieved through other combinations of point and nonpoint source allocations that are more feasible and/or cost effective. If that happens, DNREC is free to re-run the model and to propose a revised TMDL with a different allocation scenario that will achieve water quality standards. See response to 01-17.

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Commentor	Letter ID	Comment	Response
Waxman, Harry	11-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL. The WLA was not increased for the MOT facility.
Chandler, David	12-01	Do not increase the WLA for New Castle County Water Farm #1.	The point source allocation in the final TMDL is the same as what appeared in the draft TMDL. The WLA was not increased for the MOT facility.
Baker, Bob	13-01	As a result of the "Hawes Case", the EPA and the State of Delaware should stop the process of developing TMDLs. The Court found that the agreement with the State of Oregon was null and void and that the state should stop imposing and implementing TMDLs on nonpoint source waters.	To the extent the commenter is arguing that the Clean Water Act does not authorize EPA to establish TMDLs where the sources of the pollutant loadings are nonpoint sources, the commenter is incorrect. In Pronsolino v. Nastri, 291 F.3d 1123 (9th Cir. 2002), cert. denied, 123 S.Ct. 2573 (2003), the U.S. Court of Appeals for the Ninth Circuit held that the Clean Water Act authorizes EPA to establish TMDLs for waters that are impaired by nonpoint sources.