United States Environmental Protection Agency | Office Of Water (WH-553) | EPA841-F-93-007 August 1993 Number 9

EPA

TMDL Case Study

Appoquinimink River, Delaware

Key Feature: A phased TMDL for phosphorus on a tidal freshwater river reach

Project Name: Appoquinimink River
Location: EPA Region III/New Castle County, Delaware
Scope/Size: River, watershed 30,200 acres
Land Type: Flat plains
Type of Activity: Agriculture, urban
Pollutants: Phosphorus (algae)
TMDL Development: Phased, PS/NPS
Data Sources: Local, STORET
Data Mechanisms: WASP4 model
Monitoring Plan: Yes
Control Measures: NPDES permit, BMPs

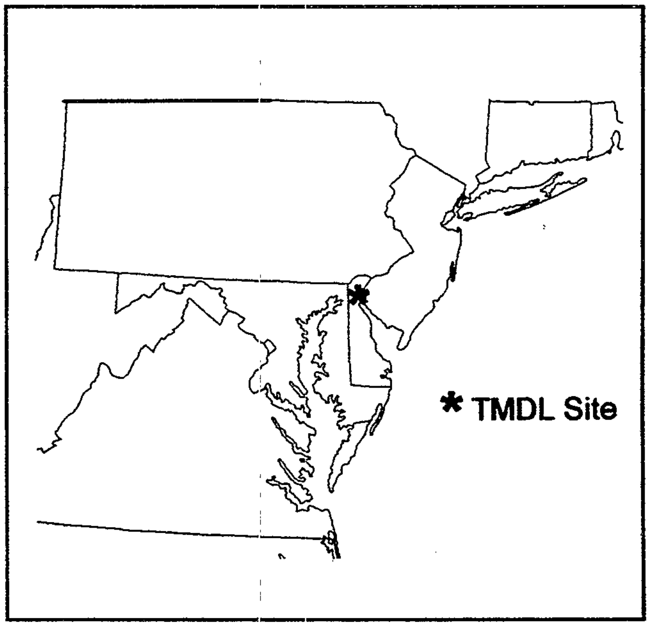

FIGURE 1. Location of the Appoquinimink River watershed

Summary: The Appoquinimink River watershed is located in eastern Delaware (Figure 1). Delaware's Department of Natural Resources and Environmental Control (DNREC) chose the tidal freshwater segment of the Appoquinimink River as the site of its first total maximum daily load (TMDL) because intensive monitoring indicated the criteria for dissolved oxygen (DO) were being violated; an NPDES permit decision was pending for the only point source discharger to the river, the Middletown-Odessa-Townsend wastewater treatment plant, making the TMDL relatively simple; and information on nonpoint source loadings was available. DNREC used available ambient water quality data and existing point and nonpoint source loading data to conduct the initial assessment and characterization of the Appoquinimink's water quality problems. In addition, the EUTRO4 version of EPA's WASP4 water quality model was used to analyze the DO and nutrient economy of the river. Phosphorus overenrichment was determined to be the ultimate cause of excursions of applicable DO criteria. To avoid exacerbating the problem, DNREC developed a total maximum daily load (TMDL) for phosphorus whose first phase (1) limits point source loads at existing levels to prevent increasing the frequency DO standard violations; (2) further characterizes nonpoint source nutrient loads and their impact on river water quality; (3) describes the water quality monitoring and modeling studies necessary to determine the second-phase TMDL; and (4) plans and schedules activities that will lead to the adoption and implementation of the Phase II TMDL (DNREC, 1992). The Phase I TMDL of 18,947 lb/yr was calculated as the sum of the point source allocation (6,862 lb/yr) and the background/nonpoint source allocation (12,085 lb/yr). These allocations reflect a reasonable margin of safety to prevent further water quality degradation until the TMDL can be refined in Phase II to meet water quality standards.

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BACKGROUND

The Appoquinimink River watershed is located in the flat coastal plain of eastern Delaware (Figure 1). The river's headwaters and major tributaries drain agricultural lands and feed four major impoundments: Shallcross Lake, Silver Lake, Noxontown Pond, and Wiggins Mill Pond.

In its natural state, the 30,200-acre watershed is dominated by oak, hickory, pine, southern floodplain forest, and southern mixed forest (Omernik, 1987). Forestlands make up 15 percent of its area. The wetlands that cover another 9 percent represent the only large marsh system in Delaware that is essentially undisturbed by human activity. These wetlands are highly valued as waterfowl, shorebird, and wildlife habitat and as a spawning and nursery area for fish and aquatic life. About 61 percent of the watershed is actively cultivated to produce corn, soybeans, small grains, and specialty crops such as potatoes and tomatoes. There are 130 farms in the watershed, each averaging 150 acres of cropland.

The tidal freshwater segment of the Appoquinimink is bounded by the head of tide at Noxontown Pond and Silver Lake (river mile 10.2) at the upstream end and by Drawyer Creek's confluence with the Appoquinimink River (river mile 5.0) at the downstream end. At the upstream end, the river flows at approximately 30 cubic feet per second. Salinity within this 5-mile reach generally remains below 5 parts per thousand. Under the definitions provided in the State of Delaware Surface Water Quality Standards (DNREC, 1990), this salinity level classifies the reach as freshwater.

Aquults make up the majority of soils in the watershed, with Matapeake-Sassafras Association constituting approximately 83 percent of the area. These soils are mainly limited by the risk of erosion unless close-growing plant cover is maintained. They are deep, well-drained, and medium- to coarse-textured. Except for the degree of slope and the hazard of erosion in some areas, the major soils have few limitations for farm and nonfarm use. Slopes range from nearly level in the uplands to steep near the stream channels.

The remainder of the basin consists of Tidal Marsh Association soils that exist within the marshlands along the Delaware River and protrude inland along the Appoquinimink and its tidal tributaries. Marsh vegetation covers most of these soils. Tidal marsh cannot be used for crops or pasture, but it is used as wildlife habitat and for some recreational purposes.

Middletown, Odessa, and Townsend cover approximately 11 percent of the Appoquinimink watershed, and most of the watershed's population (4,500 people) is located in these towns. 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 only point source discharger to the Appoquinimink River is the Middletown-Odessa-Townsend wastewater treatment plant (MOT WWTP).

The designated uses of the tidal freshwater portion of the Appoquinimink are: primary contact recreation; secondary contact recreation; fish, aquatic life, and wildlife; industrial water supply; and agricultural water supply. The 1986 report of the Rural Clean Water Program's Appoquinimink River Basin Project stated that recreational uses such as swimming have been sharply curtailed because of water quality constraints, especially the excessive algal growth and DO deficit that have resulted from phosphorus loadings (Water Resources Agency, 1986).

The reach is impaired by low DO levels. For freshwater systems, section 11.1 of the Standards requires a representative daily (24-hour) average DO concentration of 5.5 mg/L from June through September and an instantaneous minimum DO concentration of 4.0 mg/L.

Although there are no numerical standards for nutrient concentrations, section 7 of the Water Quality Standards does recognize that nutrient overenrichment is a significant problem in some of Delaware's surface waters. For this reason, it is DNREC's policy to minimize nutrient input to surface waters from any controllable source, establishing the types of, and need for, nutrient controls on a site-specific basis. Nutrient controls may include, but are not limited to, effluent limits on point sources or the institution of best management practices (BMPs) for nonpoint sources.

ASSESSING AND CHARACTERIZING THE PROBLEM

Targeting and Prioritizing

DNREC chose the Appoquinimink River as the site of its first TMDL because it was identified as being water quality limited and requiring a TMDL; a wastewater management decision was pending at the MOT WWTP; a single point source made the TMDL relatively simple; and information on nonpoint source loadings was available.

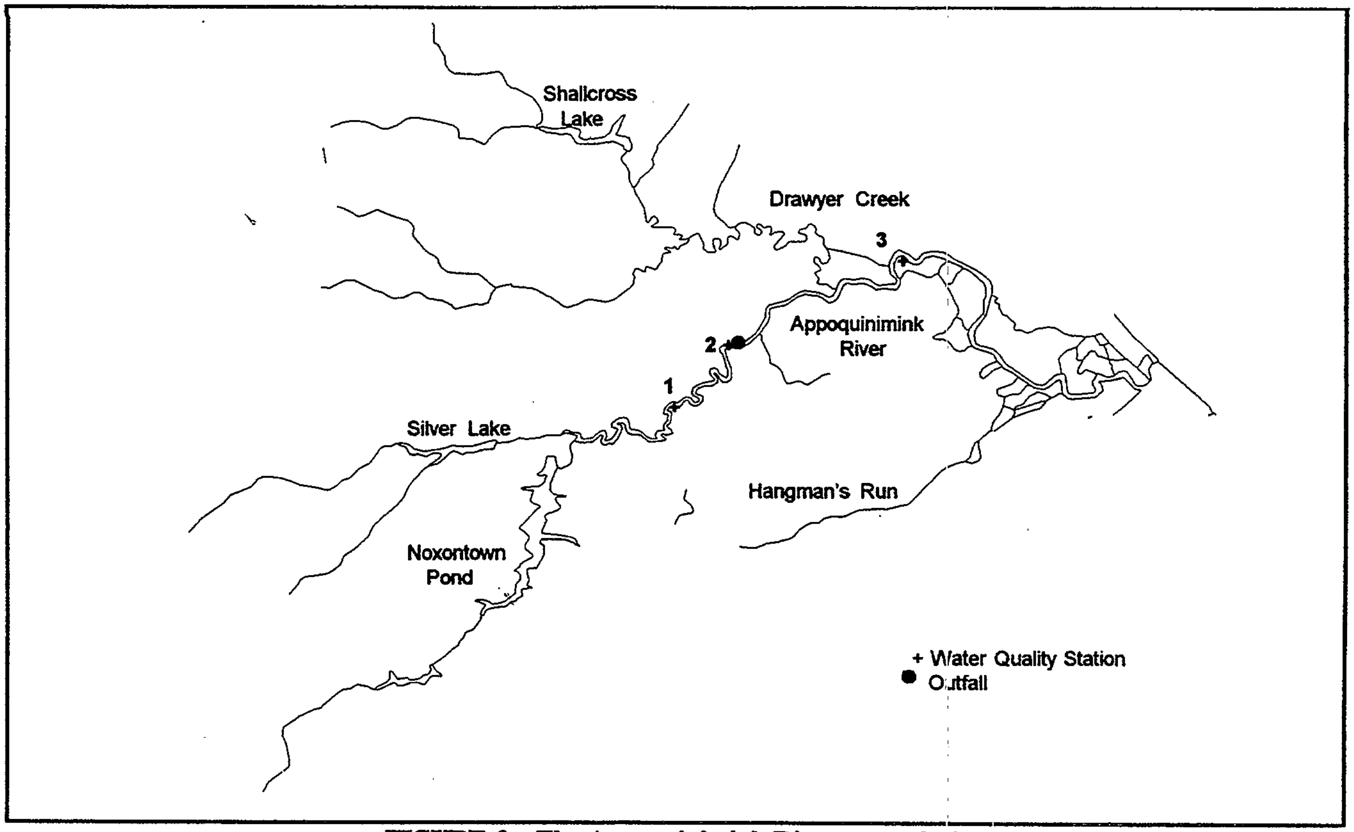

FIGURE 2. The Appoquinimink River watershed

Monitoring and Data Bases

DNREC used available ambient water quality data and existing point and nonpoint source loading data to conduct an initial assessment and characterization of water quality problems in the Appoquinimink River.

Most of the ambient data came from intensive water quality surveys that were conducted for New Castle County from September through October 1990 to assess the human health and environmental impacts that might be caused by increasing the MOT WWTP discharge. DNREC's ambient water quality monitoring program data from 1985 through 1990 were retrieved from EPA's STORET data base to supplement the intensive survey data. STORET data on nitrate nitrogen (NO_3-N) and soluble orthophosphorus (SOP) concentrations were particularly important because the intensive survey failed to quantify them. The value for NO_3-N is provided in Table 1, which summarizes the available water quality data. Only one sample of SOP (0.04 mg/L) was available from March of 1990 at river mile 6.0, while levels measured at the upstream boundary of the reach were below the detection limit of 0.02 mg/L. No data on chlorophyll-*a* concentrations were available.

As part of the intensive surveys, water quality samples were collected during high and low slack tide conditions at stations located at the upstream boundaries, at river mile 7.95 (Route 13 bridge), at river mile 6.4 (Route 299 bridge at Odessa) just upstream of the existing discharge, and at river mile 3.2 below the downstream boundary of this reach (Figure 2). A contractor collected data on DO, temperature, 5-day biological oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), SOP, salinity, and pH. A diel DO profile was also developed at the river mile 6.4 station, just above the treatment plant discharge.

The diel DO data collected during October 1990 indicated violations of the daily average criterion of 5.5 mg/L. Periodic grab samples collected from 1985 to 1990 also indicated several violations of the minimum criterion of 4.0 mg/L. To more completely characterize the factors contributing to these violations of the DO standard, DNREC prepared a plan to intensively monitor the Appoquinimink and its major tributaries. The plan includes synoptic water quality surveys of the tidal river and major tributaries; measurement of tributary flows and nutrient concentrations to estimate nutrient loads;

TABLE 1. Applicable water quality standards (DNREC, 1990) and the results of intensive water quality surveys conducted for New Castle County on the Appoquinimink River, Delaware, from river mile 5.0 to river mile 10.2 during September and October 1990 (DNREC, 1992)

Parameter	Applicable Water Quality Standard	Intensive Survey for New Castle County, mg/L	
Dissolved oxygen	5.5 mg/L daily average 4.0 mg/L instantaneous minimum (both apply to freshwater systems)	Diel Station	4.2 - 6.1 (5.2 mg/L 24-hour avg at an avg water temperature of 21.5°C
Total phosphorus	None	Diel Station Upstream Boundary Downstream Boundary	0.18 - 0.25 < 0.10 < 0.10
Soluble orthophosphorus	None	All stations	Less than detection (0.05 mg/L)
Total Kjeldahl nitrogen	None	Diel station	0.35 - 1.14
Ammonia-nitrogen	None	Diel station	0.18 - 0.33
Nitrate-nitrogen	None	Diel station	1.37 (std dev 0.9)[a]

[a] Data from EPA's STORET database for the State of Delaware (1985-1990); not available from the intensive surveys.

analyses of sediment nutrient content; and diel monitoring of DO, temperature, and salinity at selected stations in the tidal river for periods of several consecutive days. The plan also provides for a data base to calibrate a water quality model of the Appoquinimink. This plan was submitted to EPA Region III for review and approval as part of DNREC's Ambient Surface Water Quality Monitoring program.

Monitoring began in November 1991 and is still under way. The additional data will allow DNREC to calibrate the WASP4 model to a higher order of complexity, making the model more predictive. Previous modeling efforts that were conducted at lower levels of complexity only mimic river responses. With the more sophisticated model, the effects of combinations of various BMPs and point source reductions can be predicted. When modeling is complete, DNREC will identify appropriate pollution reduction controls and their impacts on water quality.

TMDL DEVELOPMENT

Determining the Pollutants of Concern

The EUTRO4 version of EPA's WASP4 water quality model was used to analyze the DO and nutrient economy of the Appoquinimink River so that the cause of the DO criteria violations could be determined. The WASP model runs were steady-state, tidally averaged simulations of a one-dimensional channel to represent the tidal freshwater portion of the Appoquinimink River. Model simulations were run using the Full Linear DO Balance (Level 3 order of complexity), as defined in the WASP4 user's manual. Key processes modeled included carbonaceous biological oxygen demand (CBOD), oxidation, nitrification, reaeration, and sediment oxygen demand (SOD). Although they were considered important, algal photosynthesis and respiration rates were not modeled as part of this initial effort because there were no chlorophyll-*a* data. Instead, algal photosynthesis and respiration rates were estimated using screening-level analyses (discussed below) that involved evaluating available STORET data.

The diel variation of DO concentrations (1.8 mg/L) that was noted during the intensive water quality surveys suggested that phytoplankton productivity and respiration were occurring at significant rates. It was therefore important to determine whether nitrogen or phosphorus was limiting algal growth. Analysis of STORET data yielded a nitrogen/phosphorus ratio of 40 with a standard deviation of 23, indicating that phosphorus is more likely to be limiting phytoplankton growth (Thomann and Mueller, 1987).

DNREC postulated that most of the phosphorus available for biological uptake is being used for phytoplankton growth and that additional loadings of phosphorus would contribute to increased phytoplankton productivity. In streams with heavy algal growth, differences in algal catabolism during light and dark periods can result in wide diurnal variations in DO.

Excessive algal biomass production and subsequent die-off and sedimentation of organic matter can contribute to higher-than-normal SOD that causes DO levels to fall below criteria. To prevent more frequent violations of the DO standard, DNREC decided to establish an initial TMDL that capped existing phosphorus loads to the reach until a more refined TMDL that ensures compliance with the standard can be established.

Point Source Wasteload Allocation

Because most of the phosphorus from the treatment plant would be bioavailable as SOP, it is likely that eutrophic conditions would result throughout the reach and possibly in downstream waters if limits were not set. At the time of the Phase I TMDL analysis, the MOT WWTP was permitted and operating at 0.5 mgd with effluent BOD_5 at 15 mg/L. The permit conditions were assumed in the modeling analysis of BOD, with values for effluent nitrogen concentrations assumed to be 10.0 mg/L of ammonia-nitrogen and 5.0 mg/L of organic-nitrogen, as reported for similar treatment facilities by Thomann and Mueller (1987).

Using 24-hour composite samples, DNREC analyzed effluent phosphorus concentrations (TP and SOP) on a weekly basis from February 6, 1991, through April 3, 1991. Concentrations of TP in the effluent ranged from 2.61 to 4.88 mg/L, and concentrations of SOP ranged from 2.18 to 4.88 mg/L. These concentrations were multiplied by the measured daily discharge to estimate actual phosphorus wasteloads from the treatment plant, as presented in Table 2.

The point source load limit was established by statistical analysis of the effluent phosphorus load measurements. The data were statistically analyzed to define a monthly average load limit at a 95 percent confidence level. The monthly average phosphorus load was determined to be 14.57 lb/day, with a standard deviation of 2.57 lb/day. The 95th percentile value of a normal distribution with a mean of 14.57 and standard deviation of 2.57 is 18.8 lb/day. This translates into equivalent loads of 572 lb/month and 6862 lb/yr. This allocation was incorporated into the NPDES permit as final effluent limits for MOT WWTP. These caps go into effect May 9, 1994. No interim limits have been set for phosphorus while the plant works to meet compliance.

Nonpoint Source and Background Load Allocation

Ambient water quality measurements showed that background concentrations of TP in the tidal portion of the Appoquinimink are below 0.1 mg/L.

Rural Clean Water Program studies that were conducted from 1980 through 1986 measured nonpoint source loading rates of phosphorus and nitrogen in the Appoquinimink's Wiggins Mill subwatershed. These studies provided data on loads based on the following agricultural seasons: fallow season, 151 days from November through March; planting season, 61 days from April through May; and growing season, 153 days from June through October. There were a total of seven data points for each season.

Using a log-transformed distribution of the seasonal data, a Monte Carlo simulation program entitled PC-MC was run to generate annual loads by repeated random sampling of the seasonal distributions. A total of 2,000 annual load simulations were run to develop an entire distribution of annual loads based on random sampling of the seasonal load distribution. The median annual phosphorus load for the Wiggins Mill sub-basin was determined to be 1,760 lb/yr. This value was extrapolated to the entire watershed tributary to the tidal freshwater segment of the Appoquinimink by multiplying by the ratio of watershed area (14,900 acres/2,170 acres) to yield an annual nonpoint source phosphorus load limit of 12,085 lb/yr.

DNREC decided that although these readily available estimates were adequate to use for the first phase of the Appoquinimink TMDL, they were not appropriate to use for developing the final TMDL. Land use patterns and the widespread implementation of BMPs since the last studies were conducted in 1986 have certainly altered nonpoint source loading rates. The validity of extrapolating the Wiggins Mill loading rates to the rest of the Appoquinimink watershed is also questionable, because of differences in land use patterns, soils, and geologic-hydrologic conditions among the subwatersheds. Additional studies to characterize nonpoint source nutrient loads to the reach and to assess the effect of Noxontown Pond, Silver Lake, and Shallcross Lake on the nonpoint source loads actually delivered to the reach were therefore proposed as part of the Phase I TMDL.

The Margin of Safety

TMDLs should reflect a margin of safety based on the uncertainty or variability in the data, the point and nonpoint source load estimates, and/or the modeling analyses.

The point source phosphorus loads were well defined based on the recent effluent monitoring. The nonpoint source phosphorus load measurements were more variable, and therefore had a greater level of uncertainty associated with their estimates. Selecting the 95th percentile value of the estimated load distribution, as was selected for the point source loads, allowed nonpoint source phosphorus loads equivalent to those that occurred prior to implementation of BMPs during the

TABLE 2. Summary of measured phosphorus loads in Middletown-Odessa-Townsend effluent

Date	Flow (mgd)	Effluent Concentration (mg/L) Total Phosphorus	Soluble OrthoPhosphorus	Mass Loads (lbs/day) Total Phosphorus	Soluble OrthoPhosphorus
6 FEB 91	0.550	3.89	2.81	17.84	12.89
13 FEB 91	0.530	2.90	2.24	12.82	9.90
20 FEB 91	0.517	3.05	2.49	13.15	10.74
27 FEB 91	0.509	3.08	2.18	13.07	9.25
6 MAR 91	0.418	2.74	2.61	9.55	9.10
14 MAR 91	0.505	2.73	2.47	11.50	10.40
20 MAR 91	0.529	2.61	2.40	11.51	10.59
27 MAR 91	0.551	4.43	2.90	20.36	13.33
3 APR 91	0.523	4.88	2.67	21.29	11.65

Rural Clean Water Program project. Limiting nonpoint source loads to the median value (equivalent to the 50th percentile value) of the estimated distribution yields a phosphorus load that is approximately 30 percent less than the pre-BMP loads, and is representative of the nonpoint source loads measured after implementation of BMPs during the Rural Clean Water Program. DNREC therefore believes that selection of the median value of the estimated nonpoint source load distribution provides a reasonable margin of safety from a water quality perspective.

IMPLEMENTATION OF POLLUTION CONTROLS

Point Sources

New Castle County identified and explored several potential pollution control options for the MOT WWTP. The principal options were land application (i.e., spray irrigation) of the treated effluent and relocation of the discharge to the Delaware River. Land treatment proved to be both more environmentally responsible and less costly.

Relocating the discharge to the Delaware River was rejected because, even if DNREC could obtain a permit to cross miles of wetlands, costs would be exorbitant.

Spray irrigation at a site other than one adjacent to the plant was also rejected because it would require additional infrastructure change. However, spray-irrigating to adjacent land would take advantage of the existing infrastructure (i.e., pumps).

DNREC has implemented the point source phosphorus wasteload allocation by incorporating it into MOT WWTP's NPDES permit effluent limits. The NPDES permit, which was issued in November 1992, capped phosphorus loads at 6862 lb/yr. Effluent discharge was limited to 0.5 mgd, except for the first 18 months when the plant can discharge up to 0.65 mgd to accommodate current growth while a method of compliance is evaluated and installed. There are no current plans to expand the stream discharge, although spray irrigation may expand up to 1.2 mgd for a total discharge of 1.7 mgd.

Nonpoint Sources

The Rural Clean Water Program report for the Appoquinimink River identified 14 BMPs potentially applicable to the Appoquinimink watershed. The BMPs included permanent vegetative cover; animal waste control systems; stripcropping systems; terrace systems; diversions; grazing land protection; waterways; cropland protective cover; conservation tillage systems; stream protection; permanent vegetative cover on critical areas; sediment retention, erosion control structures, or water control structures; fertilizer management; and pesticide management. Most of these BMPs were implemented to some degree during the Rural Clean Water Program study prior to the TMDL analyses. Continuation, expansion, and refinement of these practices throughout the Appoquinimink watershed are potential control measures for agricultural areas. Other BMPs, such as erosion and sediment controls, may become necessary to control runoff and nutrient loads from developing areas. DNREC will coordinate with New Castle County, New Castle County Water Resources Agency, and New Castle County Conservation District in establishing additional BMPs for nonpoint sources, if necessary.

FOLLOW-UP FOR THE NEXT PHASE

Table 3 presents the proposed schedule of activities that will support completion of the TMDL.

Public Hearing

Before sending the preliminary TMDL to EPA Region III for approval, DNREC published a Hearing Notice in the *News Journal* and the *Delaware State News* to obtain written and oral comments on the first-phase TMDL from interested parties. A report on the development of the preliminary TMDL (DNREC, 1992) was made available to the public in Dover, New Castle, and Georgetown, Delaware. The TMDL hearing was held in conjunction with the hearing to consider comments on the New Castle County Department of Public Works' application for reissuance of the NPDES permit for the MOT WWTP (NPDES Permit No. DE 0050547). As stated previously, the purpose of the permit was to establish effluent limitations, monitoring requirements, and other terms and conditions needed to protect the designated uses of the Appoquinimink River.

Nonpoint Sources

The studies to estimate existing nonpoint source loads for the entire Appoquinimink watershed were completed by the end of 1992. DNREC monitored the overflows of Silver Lake and Noxontown Lake in order to determine actual nonpoint source loads to the upper boundary of the tidal river. DNREC also funded a cooperative study between the University of Delaware, the Water Resources Agency for New Castle County, and the New Castle County Soil and Water Conservation District.

These studies are documented in *Nutrient Budgets for the Appoquinimink Watershed* (Ritter and Levin, 1992), which outlines the nonpoint source nitrogen and phosphorus budgets that were developed using the unit loading rate method, and also details land uses that were determined from 1989 aerial photographs, national wetlands inventory maps, and parcel base maps. The nutrient budget study concluded that Noxontown Pond may remove from 60 to 70 percent of the nitrogen and 30 to 50 percent of the phosphorus from nonpoint sources; that Silver Lake may remove from 30 to 50 percent of the nitrogen and 50 to 70 percent of the phosphorus; and that Shallcross Lake is probably removing some nitrogen and phosphorus in the Drawyer Creek watershed.

The researchers also found that (1) cropland is the largest land use in the Appoquinimink watershed and contributes over 75 percent of the nitrogen and phosphorus loads from nonpoint sources; (2) the nitrogen load from nonpoint sources is much greater than the nitrogen load being discharged by the MOT WWTP; (3) if land use changes from cropland to urban-high density development with central sewer in the future, nitrogen loads from nonpoint sources would decrease and phosphorus loads would remain at present day levels; (4) the nitrogen contribution from septic tanks is greater than the nitrogen load from the WWTP; (5) the MOT WWTP phosphorus load constitutes approximately 32 percent of the phosphorus load in the Appoquinimink watershed; (6) nitrogen loads may be able to be reduced by lowering nitrogen fertilizer application rates, but crop yields would also be reduced; and (7) phosphorus loads may be able to be reduced by constructing ponds and filter strips in critical areas. The loading rates determined by this study are being applied in the water quality modeling study of the Appoquinimink River as described below to better define the impact of nonpoint source nutrient loads on the water quality of the Appoquinimink and to provide a basis for refining the established TMDL.

Water Quality Model Calibration and Application

EPA's WASP4 model was applied and tentatively calibrated to simulate the observed nutrient and DO concentrations in the Appoquinimink River as part of the first-phase TMDL. The initial modeling study helped identify the major sinks of DO and indicated impacts of point source loads on ambient nutrient concentrations.

Because of limitations in the existing data base, the full eutrophication version of the WASP4 model was not

TABLE 3. The proposed schedule of activities to support development of the final phase of the Appoquinimink phosphorus TMDL

Scheduled Activity	Start Date	Completion Date
Public Hearing: Phase I TMDL and NPDES Permit	August 11, 1992	–
Nonpoint Source Nutrient Budget Study	July 15, 1992	September 30, 1992
Intensive Water Quality Monitoring	October 1, 1991	ongoing
Water Quality Modeling Study and TMDL Determination	October 1, 1992	August 1, 1993
Identification of Feasible Point and Nonpoint Source Wasteload Allocation Options	March 1, 1993	August 1, 1993
Preparation of Phase II TMDL Document	August 1, 1993	December 31, 1993

implemented. As a consequence, a predictive relationship between nutrient loads, algal productivity, and DO concentrations could not be precisely determined. The latest modeling study used the information obtained from the nonpoint source nutrientload study and the intensive water quality monitoring study to calibrate the EUTRO4 version of WASP for the Appoquinimink. The calibrated model was applied to project DO levels under a variety of point and nonpoint source nutrient loading scenarios.

The original plan was to develop cost and confidence curves for different pollution control scenarios. However, the modeling study found that even the most aggressive pollution control scenario—which consisted of total removal of point source loads; 50 percent removal of nonpoint source phosphorus and nitrogen loads; and 50 percent removal of SOD, ammonia, and phosphorus flux of sediments—provided only a marginal difference in DO levels, indicating that the system is driven by SOD.

Given this information, the Phase II TMDL will:

- define the phosphorus load reductions necessary to meet DO criteria;
- require additional characterization of nonpoint source nutrient loads;
- require continued monitoring and modeling, address the SOD issue; and
- specify how the TMDL will be implemented.

There are essentially two methods to address SOD. The short-term solution is to dredge and fill the mucky bottom, alleviating the oxygen sink. The long-term solution is to limit phosphorus loads, preventing the proliferation of algae whose death and sedimentation cause the SOD and allowing the current SOD to gradually decrease over time.

A lack of SOD data will make the long-term solution difficult to quantify within the context of a TMDL. However, over the next several years DNREC will begin planning and conducting SOD measurements so this information can be available for future watershed studies. These results have demonstrated that sediment can significantly impact the quality of water systems along Delaware's coast, and DNREC plans to conduct future TMDL studies accordingly.

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This case study was prepared by Tetra Tech, Inc., Fairfax, Virginia, in conjunction with EPA's Office of Wetlands, Oceans and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.