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Watershed Water Quality Attainment Using TMDL—A Delaware USA Review

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ABSTRACT: The impaired waters of the watershed streams and/or tributaries, etc., in the USA would be included in the Section 303(d) List of the Clean Water Act (CWA), and a Total Maximum Daily Load (TMDL) needs to be developed and promulgated under the regulatory requirements of 40 CFR Part 130—Water Quality Planning and Management. The 40 CFR Part 130 Section 130.7—Total Maximum Daily Loads (TMDL) And Individual Water Quality-Based Effluent Limitations, establishes the contaminant discharge limitations toward a sustainable-attainment of the state and federal set watershed water quality standards. A TMDL analysis was accomplished using a hydrodynamic and water quality model Generalized Environmental Modeling System for Surface waters (GEMSS), to verify the effectiveness of prescribed point and nonpoint source load reductions to meet the TMDL objectives. A new and improved GEMSS model, a union of 1-dimensional streams and the 3-dimensional river and bays, was used to project water quality conditions as a result of point and nonpoint source load reductions. The point and nonpoint source nutrient reduction loads prescribed in the 1998 TMDL analysis of the State of Delaware's Indian River, Indian River Bay, and Rehoboth Bay, were applied to the entire watershed and water quality effects were examined. Modeled nutrient concentrations were compared to water quality standards and nutrient target values. The results of the model runs showed that implementation of the load reductions required by the 1998 TMDL Regulation to the entire watershed would result in achieving all applicable water quality standards and target values.

INTRODUCTION

The Section 303(d) of the United States Clean Water Act (CWA) requires the listing of impaired waters of various watersheds in the country. An impaired stream means the stream does not meet one or more of its designated uses, i.e., supporting aquatic life, swimming, wading, drinking water supply use, fish consumption, etc. Under the regulatory requirement of 40 CFR Part 130 (Water Quality Planning and Management) Section 130.7 [Total Maximum Daily Loads (TMDLs) And Individual Water Quality Based Effluent Limitations], these impaired waters would be controlled and monitored to meet the designated use of these waters and associated surface water quality standards.

The 40 CFR Section 130.7 include: identification of water quality limited sections of the watersheds that require Wasteload Allocations (WLAs), Load allocations (Las), and TMDLs, and priority setting for these loads; establishment of water quality monitoring, modeling, data analysis, and the list of applicable contaminants; submission of the state's identified watershed segments WLAs/Las/TMDLs for USEPA approval; adoption of the USEPA approved contaminant loads into the state's Water Quality Management (WQM) plans and the National Pollutant Discharge Elimination System (NPDES) permits; involvement of the public review, affected or contaminant dischargers, associated other agencies and local governments in the process; and providing the clear procedures in the state Continuing Planning Process (CPP). These regulatory requirements are available in the 40 CFR Part 130.7 (a) through (d) (USEPA 2007).

The State of Delaware water quality standards program was developed based on the following nine (9) categories of designated uses of the water bodies: public water supply; secondary contact recreation (wading); agricultural water supply; industrial water supply; fish aquatic life and wildlife; ERES waters (waters of exceptional recreational of ecological significance); primary contact recreation (swimming); cold water fish; and harvestable shellfish waters. This study included Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay of Delaware. The designated usages of these waters are the following: industrial water supply, primary contact recreation, secondary contact recreation, and fish, aquatic life & wildlife (and portions for agricultural

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water supply, and ERES waters) (State of Delaware 2004).

The Inland Bays of Sussex County in the State of Delaware was included in the CWA Section 303(d) list based on eutrophication in the waters due to high concentration of nutrients (nitrogen and phosphorus). The symptoms of nutrient over-enrichment are excessive macro-algae growth (sea lettuce and other species), phytoplankton blooms (some are potentially toxic), large daily swings in dissolved oxygen levels, loss of Submerged Aquatic Vegetation (SAV), and fish kills. Thus, a TMDL evaluation and promulgation was required to bring the Inland Bays water quality to the attainment of designated water quality. This TMDL analysis included the waters of: estuarine portions of the Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay. In addition, the contaminant or nutrient contributions by both point and nonpoint sources were evaluated. The following address the elements of this TMDL analyses.

The State of Delaware Department of Natural Resources and Environmental Control (DNREC), in the Year 1998, adopted a TMDL for control of 'nitrogen and phosphorous' for the estuarine portions of the Indian River, Indian River Bay, and Rehoboth Bay, and the USEPA promulgated a TMDL for 'temperature' in the Indian River. The 1998 TMDL Regulation, which required significant reduction of nutrient loads from point and nonpoint sources, did not include the other contiguous Little Assawoman Bay or the freshwater streams and ponds, which were on the State's 303(d) list of impaired waters. In this study, the efficacy of the load reductions called for by the 1998 TMDL Regulation for meeting water quality standards in the impaired waters was examined. In addition, the TMDLs for Little Assawoman were established.

A hydrodynamic and water quality model called the Generalized Environmental Modeling Surface Water System (GEMSS) (Kolluru, 2000) was used to verify the effectiveness of prescribed point and nonpoint source load reductions to meet the Total Maximum Daily Loads (TMDLs) objectives of Delaware's Inland Bays (Figure 1). The model was originally developed in 1998 for the Delaware Department of Natural Resources and Environmental Control (DNREC) as part of the Inland Bays Flushing Study (ENTRIX, 2001b) without inclusion of the contiguous Little Assawoman Bay. The goal of the Flushing Study was to estimate water quality improvements resulting from proposed methods to increase ocean exchange with the Inland Bays. The Flushing Study model has been expanded and enhanced by connecting Rehoboth Bay and Indian River to Little Assawoman Bay via the Little Assawoman Canal, as well as by including the streams and ponds connected to the bays and the Indian River that are also on the State's 303(d) list of impaired water bodies (DNREC, 2002). The resulting new model, a union of 1-dimensional (1-D) streams and the 3-dimensional (3-D) river and bays, was then used to project water quality conditions because of point and nonpoint source load reductions.

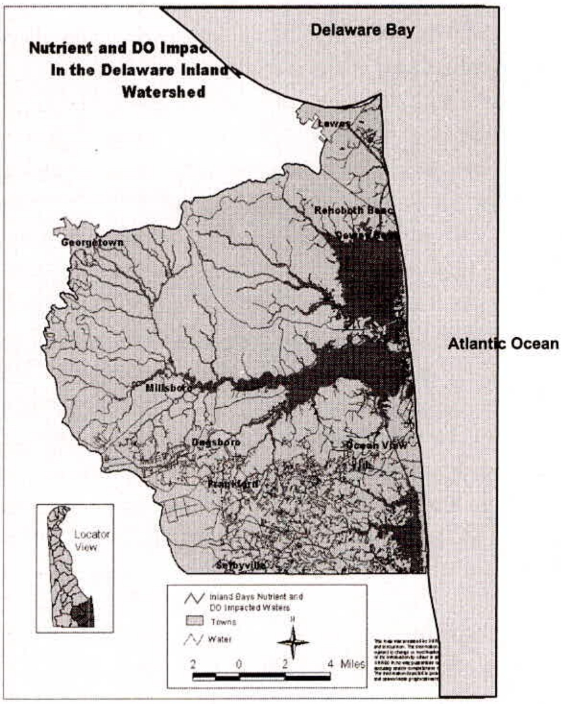

Fig. 1: Map of the Delaware Inland Bays and Associated Streams

Therefore, DNREC in 1998 adopted a TMDL Regulation for nitrogen and phosphorous for the estuarine portions of the Indian River, Indian River Bay, and Rehoboth Bay (DNREC, 1998). The 1998 TMDL Regulation, which required significant reduction of nutrient loads from point and nonpoint sources, did not include the Little Assawoman Bay or the freshwater streams and ponds which were on the State's 303(d) list of impaired waters. For this analysis, an examination was made of the efficacy of the load reductions called for by the 1998 TMDL Regulation for meeting water quality standards in the remaining impaired waters. In addition, the TMDLs for Little Assawoman were established.

METHODOLOGY

The GEMSS model was configured to project water quality that would result if the recommended 1998

TMDL point and nonpoint source load reductions were applied to the entire Inland Bays watershed. Modeled concentrations were compared to water quality standards and nutrient target values. According to Delaware's surface water quality standards (DNREC, 1999), for production of SAV beds during growth season (March 1 to October 31), Dissolved Inorganic Nitrogen (DIN) must average 0.14 mg/L as N or below, and average Dissolved Inorganic Phosphorus (DIP) must not exceed 0.01 mg/L as P in tidal portions of the Inland Bays. Furthermore, the State Water Quality Standards require that average dissolved oxygen concentrations are not to be below 5 mg/L, and daily minimum values must not be below 4 mg/L for these tidal waters. For freshwater streams and ponds, the State water quality standard for DO is 5.5 mg/l as daily average and 4.0 mg/l as daily minimum. Furthermore, in the streams and ponds, modeled nutrient concentrations were compared to target values for Total Nitrogen (TN) and Total Phosphorus (TP).

The point and nonpoint source nutrient reduction loads prescribed in the 1998 TMDL analysis of the Indian River, Indian River Bay, and Rehoboth Bay (DNREC, 1998), were applied to the entire watershed and water quality effects were examined. Nutrients, chlorophyll *a*, and dissolved oxygen levels averaged over the critical time period in the streams and ponds within the Inland Bays watershed were compared to target values. Similarly, nutrients and dissolved oxygen concentrations in the tidal portions of the Inland Bays (including Little Assawoman Bay) averaged during the critical time period were compared against standards while chlorophyll *a* was compared against its target values. The results of the model runs (as will be described later in this report) showed that implementation of the load reductions required by the 1998 TMDL Regulation to the entire watershed would result in achieving all applicable water quality standards and target values.

Study Area

The interlocked Delaware Inland Bay System includes two main water bodies: Indian River Bay and Rehoboth Bay. The Delaware Inland Bays are located in the southeastern part of the State of Delaware in Sussex County. The Indian River Bay is connected to the Atlantic Ocean on the east via the Indian River Inlet and to Little Assawoman Bay to the south via the Little Assawoman Canal. Rehoboth Bay is connected to Delaware Bay to the north via the Lewes-Rehoboth Canal and to Indian River Bay to the south. The western portion of Indian River Bay, referred to as the Indian River, terminates at Millsboro Dam.

The drainage area of the system is 55,647 ha (137,506 acres), of which 14,339 ha (35,432 acres) are upstream of the impoundment at Millsboro. The basin contains one long-term stream gauging station (USGS Station #01484500) on the Stockley Branch. Mean flow for the period of record (43 years) is 0.196 cms (6.92 cfs). Employing the runoff at Stockley to characterize the remainder of the basin indicates a long-term basin mean flow of 8.03 cms (283.6 cfs).

Surface area and volume of the bay system are 7.31×10^7 m^2 (8.74×10^7 yd^2) and 1.21×10^8 m^3 (1.58×10^8 yd^3), respectively. Mean depth is 1.66 m (5.45 ft), which characterizes most of the system. Near the inlet, local mean depth exceeds 10 m (33 ft). Mean tide range at the inlet is 1.25 m (4.10 ft). The tidal prism is 51×10^6 m^3 (67×10^6 yd^3). The system is well mixed from surface to bottom and is saline virtually throughout its tidal cycle. Median salinity is 22.7 ppt and 95% of observations exceed 4.3 ppt. The lowest salinities occur immediately downstream of the Millsboro Dam during periods of high runoff. Residence time of the system, determined as volume divided by freshwater flow rate, is approximately 174 days. An alternate way to characterize residence time (total volume divided by tidal prism divided by the tidal period) yields a much shorter value: 1.2 days (ENTRIX, 2001b). Except near headwaters and in constricted areas in which the tide is dampened, tidal flushing is more effective than runoff in the determination of volumetric flows and mass transport throughout the system.

Water Quality Standards and Target Values

The model was configured to project water quality that would result if the recommended load reductions under the 1998 TMDL Regulations were applied to the entire Inland Bays watershed. Comparisons were made between applicable standards/target values (Table 1) and modeled concentrations of DIP, DIN, chlorophyll *a*, and DO in the tidal portions of the system. Table 1 also lists criteria for bacteria (for information only and no analyses were reviewed in this paper).

To determine our benchmarks, Delaware's surface water quality standards were used. Though not a standard, chlorophyll *a* was compared against a target value of 20 μg/L. In the streams and ponds, modeled nutrient and chlorophyll *a* concentrations were compared to target values for Total Nitrogen (TN) and Total Phosphorus (TP).

Table 1: Applicable Water Quality Standards and Target Values for Delaware Inland Bays Watershed

Water Body	*Water Quality Standard*				*Water Quality Target Values*		
	DO (mg/l)	*DIN-N (mg/l)*	*DIP-P (mg/l)*	*Enterococcus Bacteria (colonies/100 ml)*	*Total N (mg/l)*	*Total P (mg/l)*	*Chl-a (µg/l)*
Tidal portions (Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay)	5.0 average June–Sept.	0.14	0.01	10 (geometric mean)	1.0	0.1	20
Fresh water systems including streams and ponds	5.5* average June–Sept.	–	–	100 (geometric mean)	3.0	0.2	50

*The Lewes-Rehoboth Canal has a 3.0 mg/L standard for DO.

Load Reductions and Waste Load Allocations

To reach these water quality goals, reductions assessed in the 1998 TMDL Regulation (DNREC, 1998) were applied to the entire watershed. These include reductions in point source and nonpoint source nutrient loads (both from runoff and atmospheric loading), and sediment oxygen demand.

In the 1998 TMDL Report (DNREC, 1998), the recommended scenario requires nonpoint source nutrient load reductions ranged between 40% to 85%, depending on location. This TMDL scenario includes:

- 85% reduction of nonpoint source nitrogen loads from tributaries in the upper Indian River.
- 65% reduction of nonpoint source phosphorus from tributaries in the upper Indian River.
- 40% reduction of nonpoint source nitrogen from tributaries outside the upper Indian River.
- 40% reduction of nonpoint source phosphorus from tributaries outside the upper Indian River.
- 20% reduction in atmospheric nitrogen deposition rates.
- 100% reduction of nitrogen and phosphorus in all point sources.

For this analysis, the remaining areas of the watershed that were not included in the 1998 TMDL report (e.g. tributaries to Little Assawoman) were treated as low reduction areas with 40% reductions of N and P applied.

Nonpoint Sources

The 1998 report divides the tributaries into 12 major branches, including five describing the upper Indian River. Using the GEMSS model's designation of streams and branches, the upper Indian River is comprised of: Swan Creek, Millsboro Pond/Cow Bridge, Millsboro Pond/Mirey Branch, Millsboro Pond/Long Drain Ditch, Millsboro Pond/Sunset Branch, Iron Creek, Pepper Creek, and Vines Creek.

As described in the Enhancement and Expansion of Hydrodynamic and Water Quality Modeling System Report (ENTRIX, 2004), the nonpoint source loads of nitrogen and phosphorus were estimated through the US Geological Survey's (USGS) Hydrological Simulation Program—FORTRAN (HSPF) model (Gutiérrez-Magness and Raffensperger, 2003). The model examined the nature of land-use in the watersheds and the conditions of manure/fertilizer application to derive estimates of nutrient runoff. In drainage areas where the USGS model produced highly unrealistic results, the nonpoint source load was back calculated using the water quality measurements taken along the stream.

Point Sources

The 1998 TMDL report lists 13 active NPDES point sources that were discharging during the time of the study (1988–1990). Point source waste load allocations were applied in this model to nine permitted facilities that were discharging during this study's modeling period (1998–2000). These facilities each must reduce their nitrogen and phosphorus loads 100%.

It should be noted that of the thirteen (13) point sources, nine were active during the 1998–2000 time period used for model input, and some of these facilities are currently no longer permitted dischargers.

Atmospheric Deposition

Atmospheric nitrogen deposition was applied to the Inland Bays model. According to the 1998 TMDL (DNREC, 1998), the atmospheric nitrogen loads were applied uniformly to the open surfaces of the Indian River, Indian River Bay, and Rehoboth Bay. In this model, the load was also uniformly applied to Little Assawoman Bay. Based upon the time series of nitrogen atmospheric loadings provided in a report by Joseph Scudlark for the Center of Inland Bays (Scudlark, 2002), data was collected at the long-term NADP/AIRMoN station DE02 at Cape Henlopen, and station IR located on the Indian River approximately

14 miles southwest. Measurements were made for NH_4^+ and NO_3^-. The model calculated a total nitrogen load using these values multiplied by the associated rainfall intensity to calculate areal loads. To best estimate the loads across the surfaces of the Inland Bays, a non-linear interpolation method was applied to the depositional data at the two stations. The average load rate during wet weather was based upon time varying data from which yielded loads averaging 765 kg/d. Atmospheric loads of phosphorus were considered insignificant, as the 1998 TDML study cited monitoring data at Cape Henlopen yielded no detectable levels of atmospheric deposition.

TMDL Modeling

The GEMSS model was constructed using inputs from 1998 through 2000, the time period with the greatest spatial and temporal coverage of recent field measurements available for the Inland Bays. Model inputs were compiled for bathymetry, freshwater flows, point source discharges, tidal elevations and currents, atmospheric deposition, and sediment fluxes. Water quality data were gathered from a variety of sources including DNREC's seasonal water quality measurements (residing in EPA's STORET database), measurements taken by DNREC's Pfiesteria Study, the Citizen's Monitoring Group, the University of Delaware's (UD's) CISNet database, ENTRIX's water quality measurements taken in 1998–1999 for the Indian River Power Plant (ENTRIX, 2001a), stormwater monitoring, and special surveys conducted by DNREC and UD for additional tide and current data. Estimates of nonpoint source nutrient runoff was provided by the USGS from the HSPF Model (Gutiérrez-Magness and Raffensperger, 2003). The consolidated 1-D non-tidal and 3-D tidal models were calibrated using 1999, the year with greatest spatial and temporal coverage of data. Calibrations were performed for tidal elevations, water temperatures, salinity, and water quality. The model was then verified for the year 2000. Extensive error analysis conducted for the hydrodynamic model showed good model calibration. Model predicted water quality concentrations at selected 50 stations in the Inland Bays for all the years show reasonable comparison with the available limited forcing data (time varying loads) for the model.

Derivation of the Critical (Design) Conditions

A critical condition is defined as a time when water quality parameters of concern simultaneously tend to assume more environmentally harmful values than other time periods for extended periods of time. TMDLs must be established so that water quality standards are maintained even during these critical (design) conditions.

To identify the critical condition for the Inland Bays, the three years that formed the foundation of the GEMSS Inland Bays Model (1998, 1999 and 2000) were examined to determine which year, if any, provided the critical year. With conditions left "as is" before TMDL load reductions were applied, the model was run for each of these years. Since summer time is generally a critical time period, minimums, maximums, and averages at each river, bay, and major stream branch were examined from June 1–September 30. The results of the analysis upon the tidal regions showed that there was no single year that was clearly the "worst year." The DO values were lowest in 1998. For nitrogen, 2000 was the critical year resulting in highest concentrations. For phosphorus, 2000 experienced the highest values of all the years in the upper Indian River, but 1998 had the highest values overall throughout all the regions. The highest chlorophyll *a* values were seen in 1999. Lacking a single critical year, it was decided to use the averages over the three summers as the critical (design) condition for the TMDL analysis.

Current Conditions—The Base Case

The calibrated GEMSS model was used as the foundation of the TMDL analysis. This Base Case is representative of current conditions, since there have been no significant changes to the Inland Bays since the 1998–2000 time period upon which the model was built. Load reductions were applied to the Base Case to estimate future conditions after TMDL implementation.

For analysis of the tidal areas of the Inland Bays were divided into regions (Figure 2), and three-year summertime average water quality conditions were taken. For the free flowing streams, 1-D stream contouring is used to display the three-year summertime average water quality conditions along the main stems of the streams (Figure 3). A single summertime average value was used for each parameter within the ponds.

Summertime averages for specific regions and streams were calculated as follows. The minimum, maximum, and average values within every 3-D grid cell were obtained from the three model years (1998, 1999 and 2000) pooled together over the period of June 1–September 30. The 3 year summertime average values are shown for DO, nitrogen, phosphorus, and chlorophyll *a* in Figure 4.

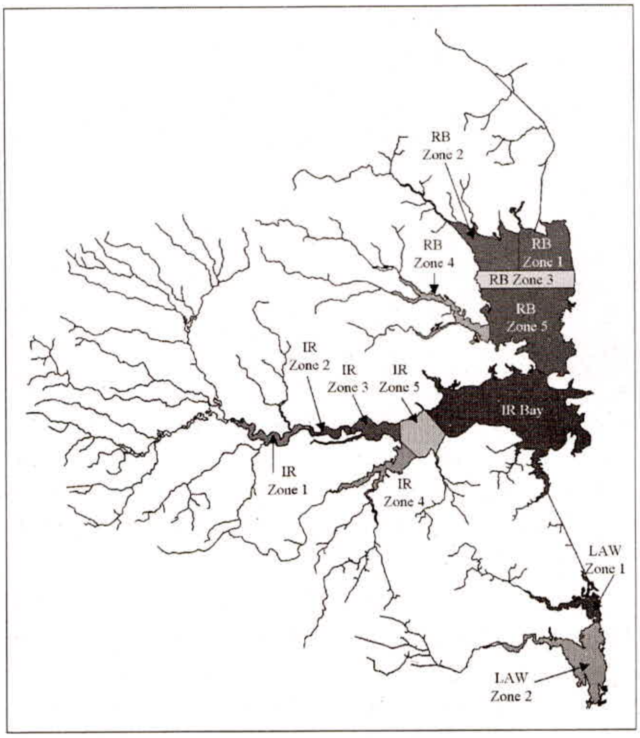

Fig. 2: TMDL Analysis Regions—3-D Model Zones

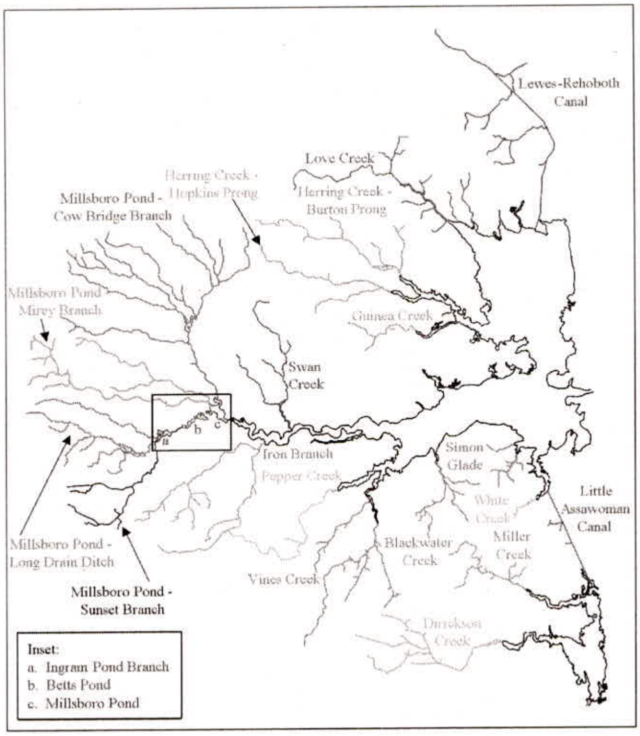

Fig. 3: TMDL Analysis Regions—1-D Model Zones

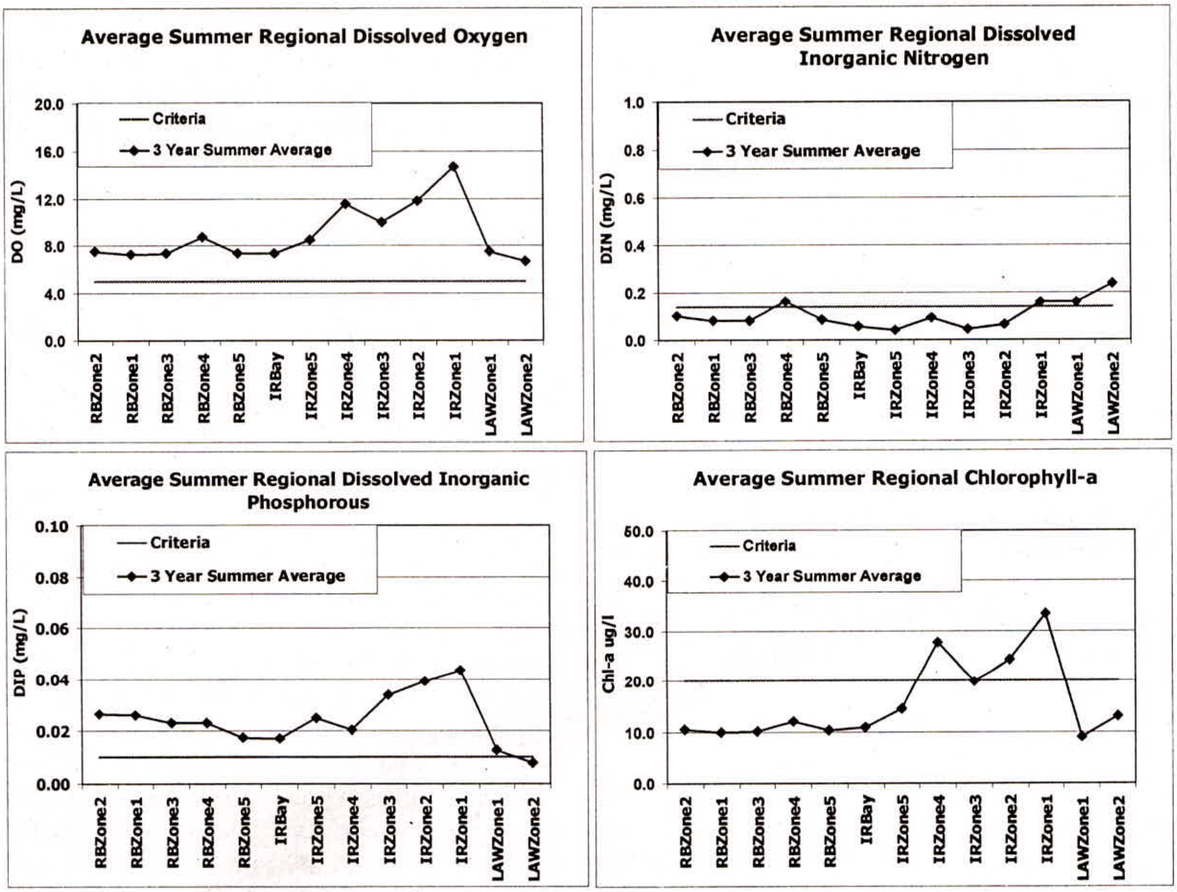

Fig. 4: Base Case—Summertime Averages for Rivers and Bays

Nitrogen and phosphorus load estimates were calculated for streams (Table 2) and point-sources (Table 3) based upon summertime and annual average flow rates and concentrations.

Table 2: Base Case Nonpoint Source Nitrogen and Phosphorus Loads

Receiving Water	*Stream Branch*	*Total Nitrogen Annual Average Load (kg/d)*	*Total Phosphorus Annual Average Load (kg/d)*
Rehoboth Bay	Lewes-Rehoboth Main Canal	55.1	8.8
	Love Creek	323.8	13.9
	Herring Creek—Hopkins Prong	85.7	3.3
	Herring Creek—Burton Prong	60.6	1.6
	Guinea Creek	175.9	8.4
Indian River	Swan Creek	198.2	4.1
	Millsboro Pond/Cow Bridge	477.5	5.1
	Millsboro Pond/Mirey Branch	230.8	2.3
	Millsboro Pond/Long Drain Ditch	192.7	2.0
	Millsboro Pond/Sunset Branch	238.9	1.7
	Iron Creek	437.2	5.9
	Pepper Creek	215.5	4.3
	Vines Creek	203.9	10.9
	Blackwater Creek	290.8	1.9
	White Creek	204.5	1.3
	Collins Creek	79.8	2.5
Little Assawoman Bay	Miller Creek	109.0	1.6
	Dirickson Creek	160.6	20.8
All	Total	3740.4	100.3

TMDL Analysis

The TMDL analysis was comprised of validating the efficacy of the 1998 TMDL, as well as generating the TMDL for the areas in the Inland Bays not included in the 1998 TMDL Regulation including the tributaries of Little Assawoman Bay. Load reductions were applied to the calibrated Base Case. The TMDL Scenario was then run and compared to water quality criteria and target values.

Under the guidelines of the 1998 report, more stringent load reductions were assigned to the upper Inland Bays compared to the rest of the system. Nonpoint source load reductions upon all forms of nitrogen and phosphorus in the 1-D model stream and pond segments were applied. All point source nutrient loads were reduced to zero, and the atmospheric deposition of nitrogen was reduced to 20%.

Table 3: Base Case Point Source Nitrogen and Phosphorus Loads

Point Source Name	*Total Nitrogen Annual Average Load (kg/d)*	*Total Phosphorus Annual Average Load (kg/d)*
Georgetown Sewage Treatment Plant (STP)	16.3	0.8
Rehoboth Beach STP	109.2	9.1
Lewes STP	34.0	7.2
Vlassic Foods, Inc.	2.8	0.89
Colonial Estates	1.3	0.1
Townsend Inc.	85.3	25.2
Bayshore Mobile Home Park	0.1	0.01
Millsboro STP	32.3	1.1
Total	281.3	44.2

Sediment nutrient load rates were reduced to reflect the natural response to load reductions in the overlying water column. The sediment nutrient flux reductions were applied to both the tidal and non-tidal sections of the model. Sediment nitrogen and phosphorus were reduced following the reduction scheme of the nonpoint source loads such that 60% reductions in N & P sediment fluxes were applied to the input stations in central and eastern Indian River, Rehoboth Bay, and Little Assawoman Bay. 85% N/65% P reductions were applied to the sediment flux station in the upper Indian River by Millsboro (ENTRIX, 2004).

In addition, the Sediment Oxygen Demand (SOD) flux was also reduced in order to reflect the positive effect nutrient reductions will have upon sediment sinks of DO. Using the nutrient TMDL reduction values for N and P as a basis, a 65% reduction of SOD was applied to the upper Indian River, while a 40% reduction of SOD was applied to all other areas.

RESULTS

After application of the adjustments described above, the results of this Scenario demonstrated the effectiveness of the TMDL reductions upon point and nonpoint sources to achieve water quality goals throughout the Inland Bays. The results are found in Figures 5 and 6. Tables 4 and 5 show the TMDLs for nitrogen and phosphorus resulting from the prescribed point and nonpoint source reductions upon the main stream branches of the Inland Bays and reduction of atmospheric deposition. Since the 1998 TMDL yielded different estimates of loads, new TMDL values have been generated. Despite the increased estimation of the nutrient loads in the tributaries, water quality standards are met using the 1998 TMDL recommendations.

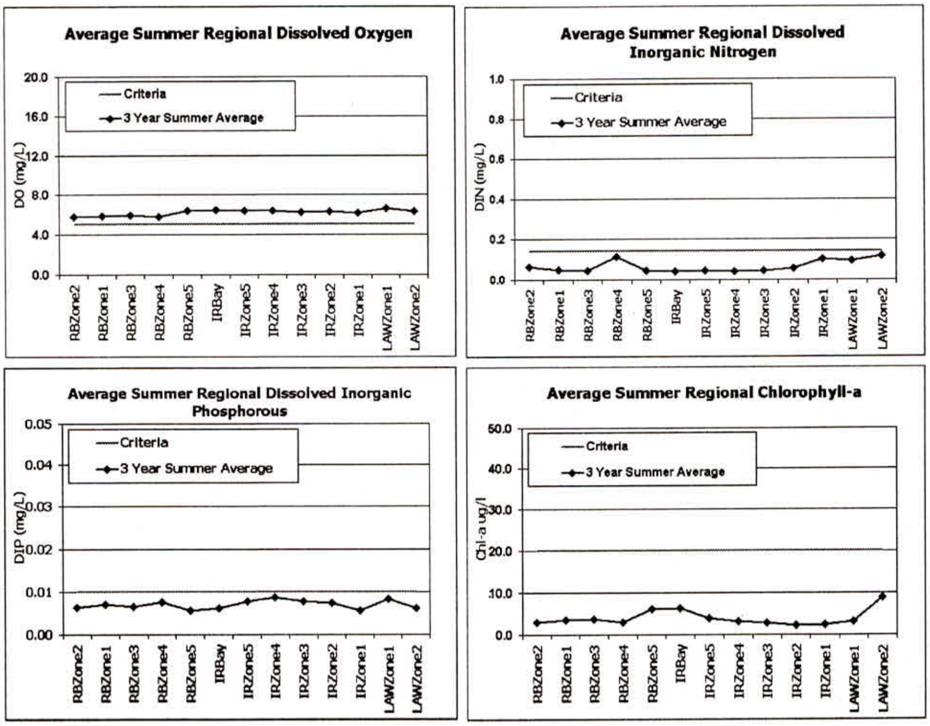

Fig. 5: TMDL Scenario—Summertime Averages for Rivers and Bays

Table 4: Proposed TMDLs for the Inland Bays Summary

Source	*Base Case (1998–2000)*		*TMDL Scenario (for a normal rainfall year)*	
	Nitrogen Load (kg/d)	*Phosphorus Load (kg/d)*	*Nitrogen Load (kg/d)*	*Phosphorus Load (kg/d)*
Point Sources	281.3	44.2	0	0
Nonpoint Source	3740.4	100.3	1256.7	51.1
Atmospheric Nitrogen Deposition	765	N/A	612	N/A

Table 5: Inland Bays TMDLs for Nitrogen and Phosphorus Loads

Receiving Water	*Stream Branch*	*Total Nitrogen Annual Average Load (kg/d)*	*Total Phosphorus Annual Average Load (kg/d)*
Rehoboth Bay	Lewes-Rehoboth Main Canal	33.0	5.3
	Love Creek	194.3	8.3
	Herring Creek—Hopkins Prong	51.4	2.0
	Herring Creek—Burton Prong	36.4	1.0
	Guinea Creek	105.5	5.0
Indian River	Swan Creek	29.7	1.4
	Millsboro Pond/Cow Bridge	71.6	1.8
	Millsboro Pond/Mirey Branch	34.6	0.8
	Millsboro Pond/Long Drain Ditch	28.9	0.7
	Millsboro Pond/Sunset Branch	35.8	0.6
	Iron Creek	65.6	2.1
	Pepper Creek	32.3	1.5
	Vines Creek	30.6	3.8
	Blackwater Creek	174.5	1.1
	White Creek	122.7	0.8
	Collins Creek	47.9	1.5
Little Assawoman Bay	Miller Creek	65.4	0.9
	Dirickson Creek	96.4	12.5
All	Total	1256.7	51.1

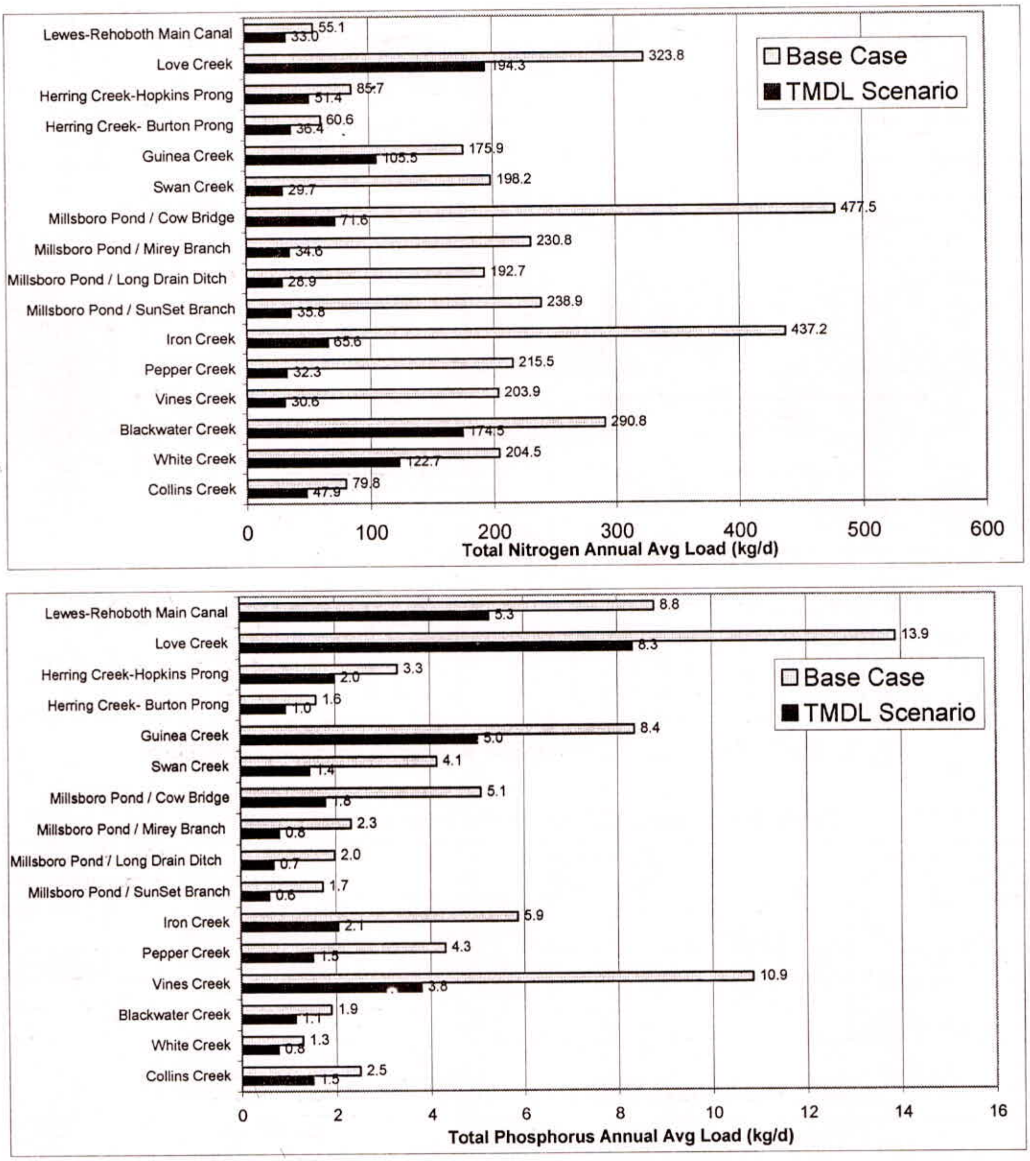

Fig. 6: TMDL Values for Indian River and Rehoboth Bay Drainage Areas

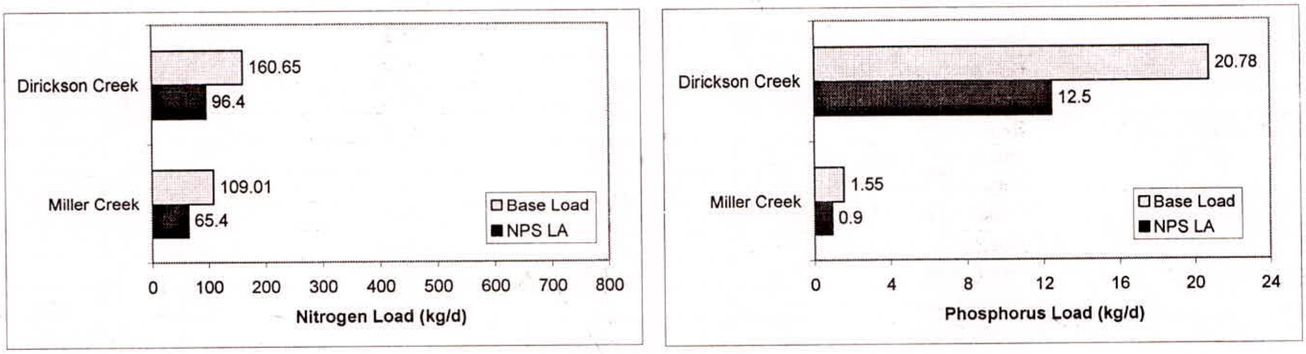

Fig. 7: Load Allocations for Little Assawoman Bay

Based upon the application of the load reductions upon the Little Assawoman drainage area, TMDLs for this area have been established. These are described for nitrogen and phosphorus in Figure 7. TMDLs are listed for the two main tributaries to Little Assawoman Bay: Dirickson Creek and Miller Creek. The nitrogen TMDLs are 96.4 kg/d and 65.4 kg/d for Dirickson Creek and Miller Creek respectively. For phosphorus

TMDLs, the values are 12.5 kg/d and 0.9 kg/d for Dirickson Creek and Miller Creek respectively. There are no point sources in Little Assawoman Bay requiring a TMDL.

CONCLUSIONS

An improved GEMSS model with the union of 1-dimensional streams and the 3-dimensional river and bays, was used to project watershed quality conditions.

The effectiveness of the TMDL reductions prescribed in the 1998 TMDL Report were examined by predicting the resulting water quality improvements within the rivers, bays, streams, and ponds of the Inland Bays upon attainment of the recommended point and nonpoint source load reductions. Examinations were made into changes in concentration of DO, nitrogen, phosphorus, and chlorophyll *a* compared to the State's water quality criteria or target values.

The TMDL scenario was run with several assumptions used make to realistic predictions of future conditions after the prescribed TMDL reductions have been established. TMDLs for applicable segments of the Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay drainage area were established. The efficacy of the 1998 TMDL had been confirmed. Therefore, it was been determined that the prescribed TMDLs are sufficient to attain the necessary water quality objectives within the Delaware Inland Bays.

Thus, the applicable requirements of the US CWA and 40 CFR Section 130.7 were met and the TMDLs and LAs were established.

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