Progress Report of the Baywide Nutrient Reduction Reevaluation

Chesapeake Bay Program

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February 1992

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FOREWORD

The Chesapeake Bay Program is the ongoing Bay restoration program conducted jointly by the District of Columbia, Virginia, Pennsylvania, Maryland, the Chesapeake Bay Commission, the U.S. Environmental Protection Agency, and other federal agencies.

In 1987, the parties to the original Chesapeake Bay Agreement of 1983 signed a new Chesapeake Bay Agreement. The 1987 Chesapeake Bay Agreement set a specific goal—to achieve at least a 40 percent reduction of nitrogen and phosphorus entering the mainstem Chesapeake Bay by the year 2000. The agreement also included a provision that the goal be reevaluated in 1991 to determine whether it is, indeed, the reduction needed.

The ecological balances in the Bay are extremely complex and are affected by many factors. Nutrient enrichment is just one of the important factors contributing to imbalances in the Bay's delicate ecology. The purpose of this progress report is to give an overview of the problem caused by excess nutrients in the Bay, to explain the status of the ongoing Nutrient Reduction Reevaluation, and to report progress to date. Remarkable progress is being made in reducing nutrient discharges within the Chesapeake Bay basin. This has been reflected in positive trends in water quality and in the return of underwater grasses to some of the Bay's shorelines. Strides have been made in pollution control in both the public and private sectors.

A number of tools are being used to determine the validity of the goal and the effects the nutrient reduction will have on the Bay's water quality: (1) computer models are being used to guide the reevaluation; (2) research, monitoring and detailed studies of the habitat requirements of the Bay's living resources (plant and animal life) are being conducted; (3) engineering studies of control options for managing point and nonpoint source pollution are underway.

Although this progress report's findings are preliminary, trends and generalizations of nutrient loads, water quality, and habitat improvements are becoming evident. Most of the background studies for the Nutrient Reduction Reevaluation have been drafted. To date, seven model runs have been completed for use in this report. Many additional computer model runs and refinements of the model will be necessary before results can be synthesized into final recommendations.

This reevaluation has been supported by many Chesapeake Bay Program participants who have worked since the original Baywide Nutrient Reduction Strategy was prepared in 1988. This report was prepared by a Reevaluation Workgroup whose members are noted on the next page. We look forward to presenting our final report later this year.

Robert Perciasepe
Chairman
Nutrient Reevaluation Workgroup

CSC.LR18.12/91

ACKNOWLEDGMENTS

THE NUTRIENT REEVALUATION WORKGROUP:

Robert Perciasepe
Reevaluation Workgroup Chairperson, Maryland Secretary of the Environment

Lou Bercheni
Pennsylvania Department of Environmental Resources

Edwina Coder
Chairperson Citizens Advisory Committee

James Collier
Chairperson Modeling Subcommittee, District of Columbia Consumer and Regulatory Affairs

James Cox
Chairperson Nutrient Reduction Task Force, Virginia Department of Conservation and Recreation

Michael Haire
Maryland Department of the Environment

Verna E. Harrison
Chairperson Living Resources Subcommittee, Maryland Department of Natural Resources

Michael Hirshfield
Citizens Advisory Committee representative, Chesapeake Bay Foundation

Veronica Kasi
Pennsylvania Department of Environmental Resources

Kenneth Laden
District of Columbia Department of Public Works, Office of Policy & Planning

Joseph Mihursky
Chairperson Scientific and Technical Advisory Committee

Larry Minock
Virginia Council on the Environment

Alan Pollock
Virginia State Water Control Board

Rosemary Roswell
Chairperson Nonpoint Source Subcommittee, Maryland Department of Agriculture

Charles S. Spooner
U.S. Environmental Protection Agency Chesapeake Bay Program Office

Ann Pesiri Swanson
Chesapeake Bay Commission

Cameron Wiegand and James Shell
Local Government Advisory Committee representative, Montgomery County

Lee Zeni
Chairperson Monitoring Subcommittee, Interstate Commission on the Potomac River Basin

The Nutrient Reevaluation Workgroup coordinated its efforts with many other Chesapeake Bay Program participants including the Modeling Subcommittee, the Nutrient Reduction Task Force, the Living Resources Subcommittee, the U.S. Army Corps of Engineers—Baltimore District and Waterways Experiment Station. This effort benefited from the services of a number of respected consultants and public agencies including Computer Sciences Corporation and their consultant Dr. Robert V. Thomann, Aqua-Terra, Hydroqual, the U.S. Environmental Protection Agency, and the Model Evaluation Group.

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THE PROBLEM AND THE STRATEGY

Identifying the Problem

In the mid-1900s, scientists, government officials and concerned citizens realized that the Chesapeake Bay was in trouble. Studies completed in the 1970s substantiated that increases in agricultural development, population growth, and sewage treatment plant flows were causing the Bay to become nutrient enriched (Figure 1). This condition involves a chain reaction. High levels of nutrients (primarily phosphorus and nitrogen) flow into the Bay's waters causing excessive algal growth. When the algae die and fall to the Bay's bottom, they are decomposed by bacteria which deplete the water's oxygen supply, particularly near the bottom where much of the Bay's aquatic life lives.

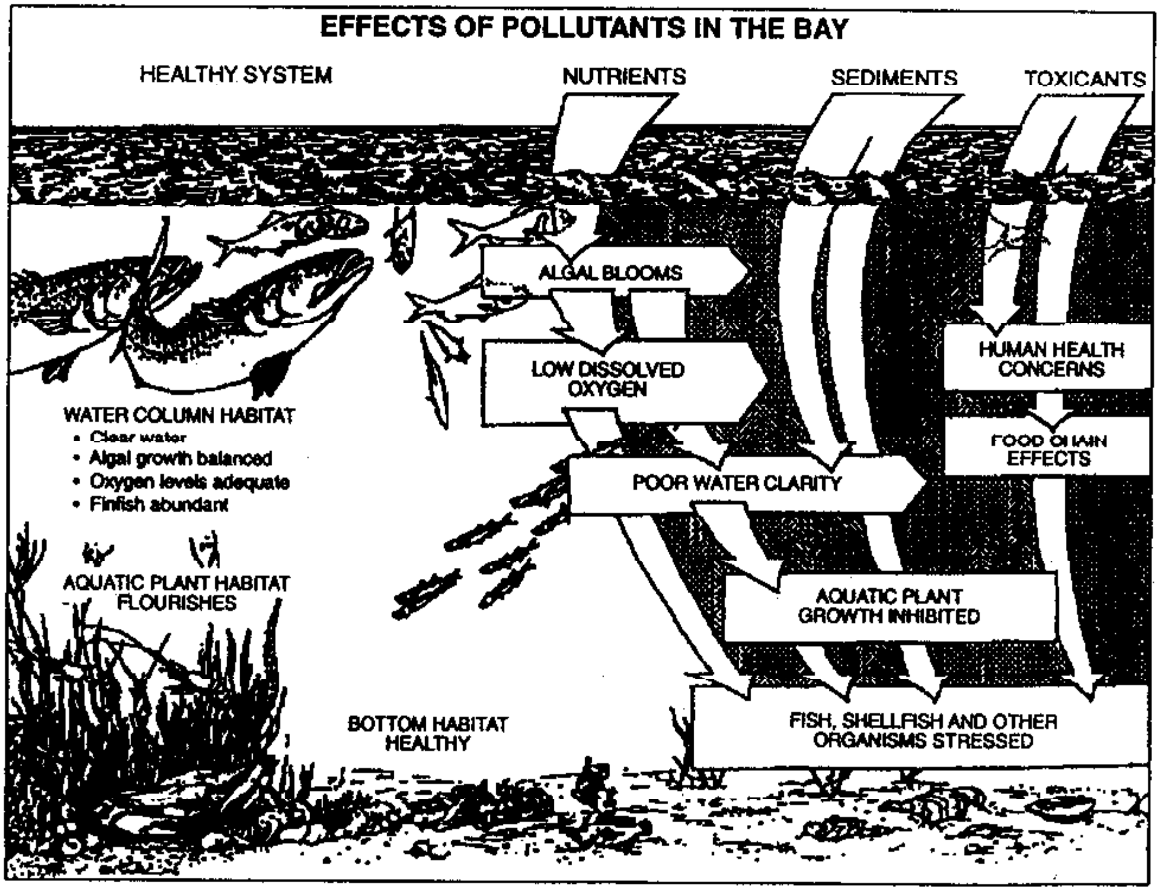


Figure 1. Effects of pollutants in the Bay (Source: Maryland Department of the Environment)

Although problems other than nutrient enrichment existed in the Bay (e.g., toxics and overfishing), their extent was unclear. Nutrient enrichment, however, was relatively well understood. It was also understood that no individual category of nutrient sources was to blame for the excess nutrients and that no single state bordering the Bay could solve the problem by itself—meeting the challenge would involve a regional effort (Figure 2).

Through a series of formal agreements in 1983 and 1987, the jurisdictions bordering the Bay—Pennsylvania, Maryland, District of Columbia, and Virginia—along with the Chesapeake Bay Commission and the U.S. Environmental Protection Agency (EPA), agreed to develop a cooperative strategy to deal with nutrient enrichment and other Bay ecological problems.

Chesapeake Bay Watershed

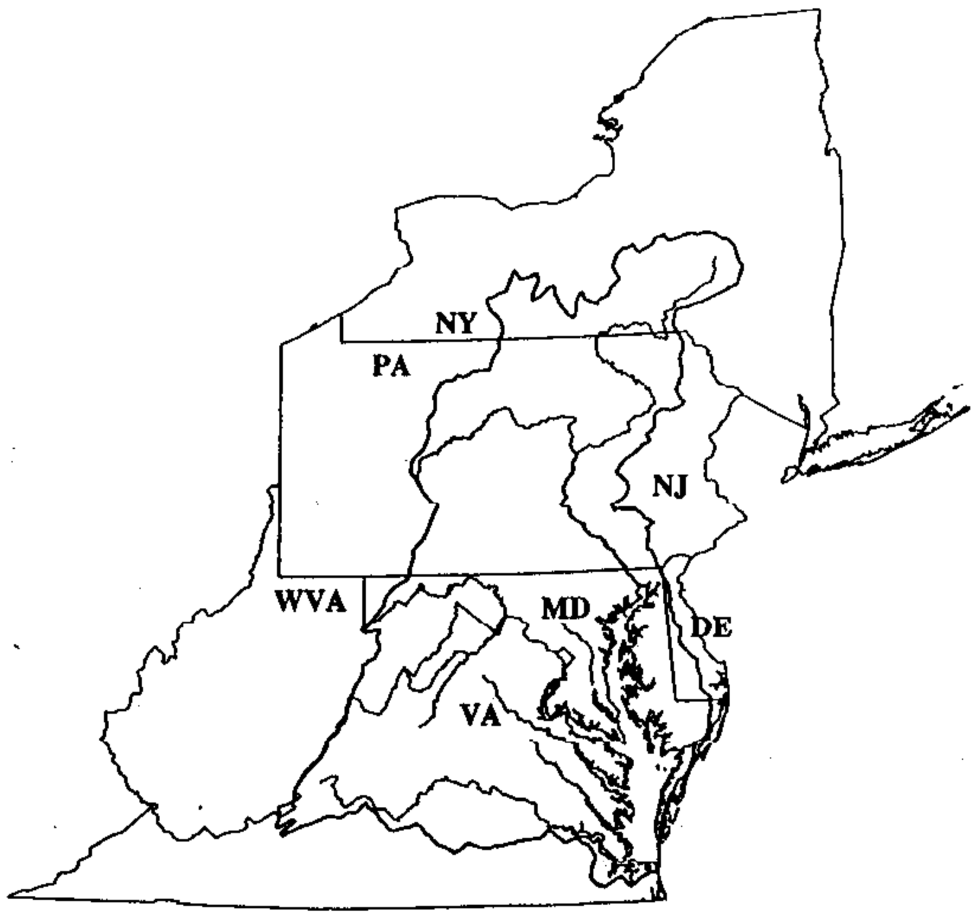


Figure 2. The Chesapeake Bay is the largest estuary in the contiguous United States. The Bay itself is part of an interconnected system which includes the mouths of many rivers draining parts of New York, Pennsylvania, West Virginia, Maryland, Delaware, Virginia and the District of Columbia. The Bay and all of its tidal tributaries comprise the Chesapeake Bay ecosystem. (Text Source: Chesapeake Bay: Introduction to an Ecosystem; Graphic Source: Chesapeake Bay Barometer, December 1991 issue, Chesapeake Bay Program)

The Chesapeake Bay Agreements

Much of the success of the Chesapeake Bay Program has resulted from the cooperative strategies developed by the participating jurisdictions and the EPA. Fundamental to this cooperative spirit has been the convening of two major Chesapeake Bay conferences and the signing of two landmark Chesapeake Bay Agreements.

1983 Agreement

The major environmental problems of the Chesapeake Bay and its tributaries were investigated in a comprehensive study initiated in 1975 by the EPA at the direction of Congress. In September 1983, final research findings and recommended remedial strategies were published identifying ten areas of environmental concern.[1,2] Three specific concerns were targeted for concentrated examination: nutrient enrichment, toxic substances, and the decline in submerged aquatic vegetation.

The Chesapeake Bay Agreement of December 1983[3], signed by Maryland, Virginia, Pennsylvania, the District of Columbia, the Chesapeake Bay Commission and the EPA, established the major elements of a cooperative structure to develop and coordinate a comprehensive Bay restoration and protection program. These elements included the Chesapeake Executive Council, the Implementation Committee, and the EPA Chesapeake Bay Program Office.

1987 Agreement

In December 1987, the signatories to the 1983 Agreement signed a new Bay Agreement.[4] It significantly expanded the original pact by listing specific goals, objectives, and commitments in six categories including water quality. The water quality goal is to "reduce and control point and nonpoint sources of pollution to attain the water quality condition necessary to support the living resources of the Bay."

The agreement specifically required the signatory jurisdictions:

"By July 1988, to develop, adopt, and begin implementation of a basinwide strategy to equitably achieve by the year 2000 at least a 40% reduction of nitrogen and phosphorus entering the mainstem of the Chesapeake Bay. The strategy should be based on agreed upon 1985 point source loads and on nonpoint loads in an average rainfall year," and, "by December 1991, to reevaluate the 40 percent reduction target based on the results of modeling, research, monitoring and other information available at that time."

The Baywide Nutrient Reduction Strategy

During the period between the 1983 and 1987 Chesapeake Bay Agreements, the Bay Program developed a relatively simple mathematical model that was used to devise a strategy for reducing the amount of nitrogen and phosphorus entering the Bay. This model evaluated the water quality response of the Bay to a variety of nutrient reduction scenarios. The model's results predicted that if nutrient loads were reduced 40%, nutrient enrichment would be reduced sufficiently to stop the depletion of dissolved oxygen (particularly in the deep, central region of the Bay), thereby encouraging the recovery of the Bay's living resources to earlier, higher population levels.

In July 1988, the Chesapeake Executive Council adopted the Baywide Nutrient Reduction Strategy to implement the agreement's goal. The strategy:

1. documented the estimate of the 1985 "baseline" loading conditions and set the year 2000 loading goals for nitrogen and phosphorus;

2. described the information needed over the next several years to more accurately measure progress and to refine the Baywide Nutrient Reduction Strategy to meet the year 2000 target; and,

3. defined the following phases:

   Phase I: From the baseline loading year of 1985 to the 1988 adoption of the Baywide Nutrient Reduction Strategy—during this period, significant nutrient reductions occurred. These reductions need to be accounted for in assessing the 40% reduction goal.

   Phase II: From 1988 to the 1991 Reevaluation—this phase allowed the jurisdictions to project progress to the time when the reevaluation was to occur.

   Phase III: From 1991 to the year 2000—this period follows any mid-course adjustments resulting from the 1991 Reevaluation.

PROGRESS TO DATE

Progress, for the purposes of this report, is documented for Phases I and II of the Baywide Nutrient Reduction Strategy commencing with the baseline year 1985 through the onset of the Nutrient Reduction Reevaluation. The nutrient loads are inventoried, point and nonpoint source reductions since 1985 are noted, and recently observed water quality trends are assessed.

Nutrient Load Inventories

Nutrients that enter the Chesapeake Bay originate from point sources (e.g., municipal and industrial wastewater discharge), nonpoint sources (e.g., cropland, animal wastes, urban and suburban runoff), and from atmospheric deposition (airborne contaminants). These sources span so vast an area that it is difficult to collect comprehensive data throughout the watershed. Therefore, a computer simulation of sources was used as the common mechanism for estimating both the 1985 base load, and the load reductions that are feasible by the year 2000.

The 40% nutrient reduction is computed on loads estimated for a base year, chosen to be 1985. In 1987, when the Baywide Nutrient Reduction Strategy was devised, considerable uncertainty surrounded loading estimates. Work was begun almost immediately to collect data and inventory point and nonpoint source loadings to determine a more precise benchmark as the starting point for reductions. Updated point source loadings were provided by the four jurisdictions: Maryland, Virginia, Pennsylvania, and the District of Columbia. The 1991 version of the Chesapeake Bay Watershed Model was used to revise an estimate of the average nonpoint source loads of 1985.

The 1985 base nonpoint source load estimate for this reevaluation is derived from the output of the Watershed Model averaged for the period 1984-87, which represents a range of river flow conditions. An average of four years is used because nonpoint source nutrient loads are largely a function of natural variations in runoff and river flow. This period was thought to approximate long-term average conditions. Figures 3a and 3b show the distribution of sources presently being considered in the reevaluation. Nonpoint sources continue to be dominant sources of both nutrients, but point sources are also significant. Atmospheric deposition (both wet and dry) is shown as a contribution to water surfaces, but is otherwise considered in this report to be a contribution to nonpoint source loads. Further work is needed to determine what portion of the sources shown as nonpoint sources can actually be attributed to atmospheric deposition.

The goal as stated in the Agreement was to reduce nutrient loads to the Bay by 40%. The original Baywide Nutrient Reduction Strategy defined "controllable loads" as the basis for this reduction. As a result, the Baywide Nutrient Reduction Strategy seeks a 40% reduction in controllable loads in the states party to the Chesapeake Bay Agreement. The "controllable" loads were originally defined as the nutrient loads that were not natural background loads. Controllable loads include point source and nonpoint source, and are all man-made. They were

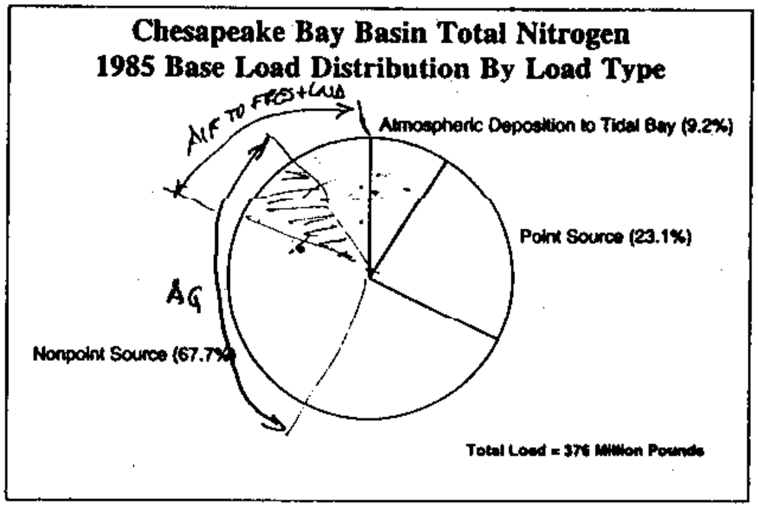
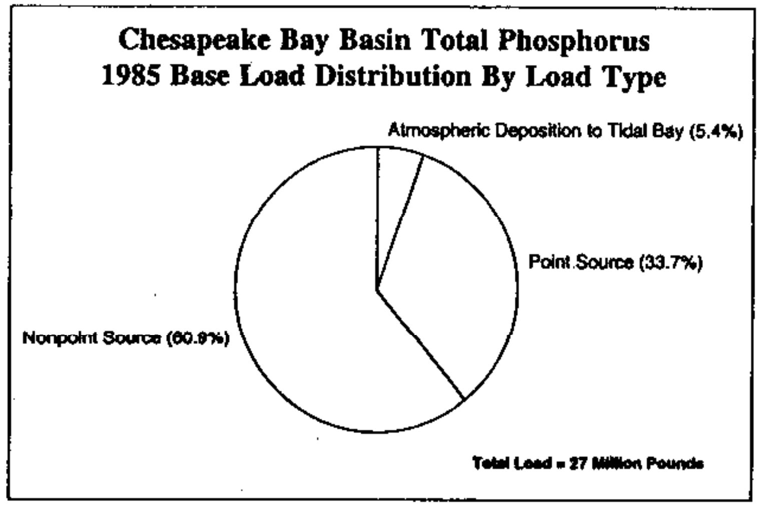


Figure 3a. Chesapeake Bay Basin Total Nitrogen 1985 Base Load Distribution By Load Type (Source: 1991 Watershed Model) <—

Figure 3b. Chesapeake Bay Basin Total Phosphorus 1985 Base Load Distribution By Load Type (Source: 1991 Watershed Model) —>



computed as the difference between the 1985 base load and the load estimated under 100% forest cover in the Bay watershed. In developing the original Baywide Nutrient Reduction Strategy, each jurisdiction estimated its point source and nonpoint source loads. Different approaches were used. Now, however, controllable loads are calculated using uniform assumptions and are shown in Tables 1a and 1b for nitrogen and phosphorus, respectively, for each participating jurisdiction and for the total area of the Chesapeake Bay watershed.[5] Importantly, 80% of the nitrogen (Table 1a, A15+A22) and 86% of the phosphorus (Table 1b, A15+A22) come from point and nonpoint sources in the states that are party to the Chesapeake Bay Agreement.

These nutrient loads are displayed by the states in which they originate in Figure 4a and 4b and in Tables 1a and 1b.

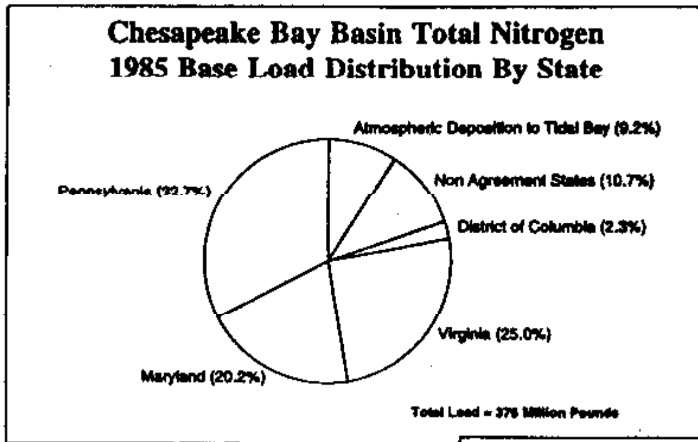


Figure 4a. Chesapeake Bay Basin Total Nitrogen 1985 Base Load Distribution By State (Source: 1991 Watershed Model) <—

Figure 4b. Chesapeake Bay Basin Total Phosphorus 1985 Base Load Distribution By State (Source: 1991 Watershed Model)

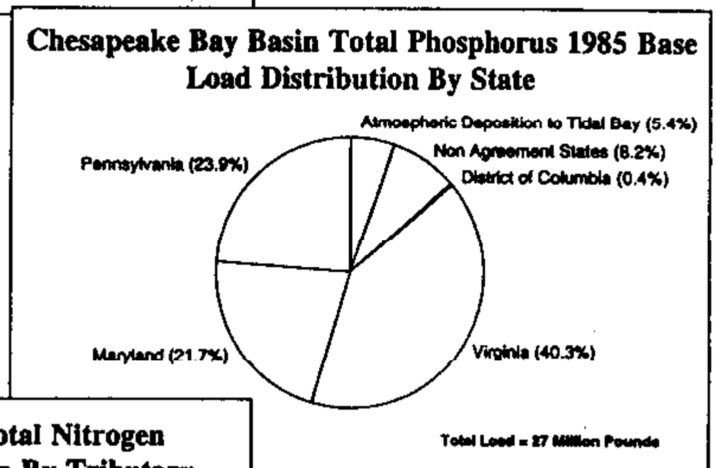


Figure 5a. Chesapeake Bay Basin Total Nitrogen 1985 Base Load Distribution By Tributary (Source: 1991 Watershed Model)

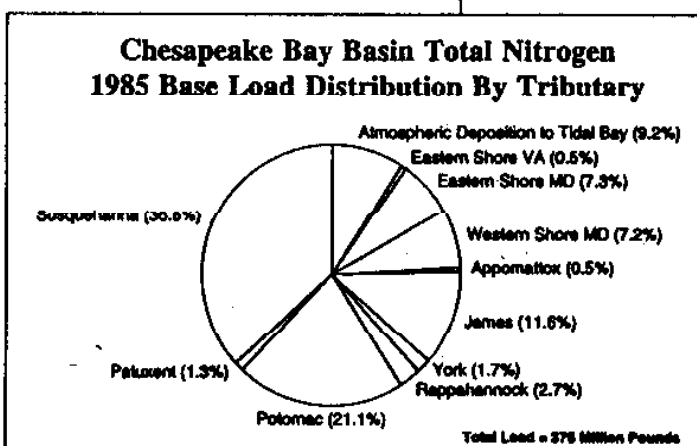
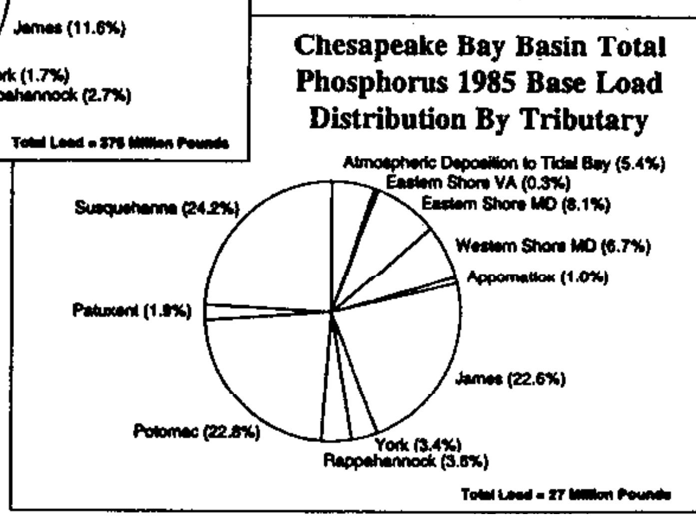


Figure 5b. Chesapeake Bay Basin Total Phosphorus 1985 Base Load Distribution By Tributary (Source: 1991 Watershed Model)



These loads are also displayed to show the tributaries that convey them to the Bay as in Figure 5a and 5b and Table 2a and 2b.

These new estimates of controllable nitrogen loads have been reduced 9% from 1988 estimates while controllable phosphorus loads have been reestimated to be 9% higher than in 1988.[5]

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Table 1a. Nitrogen Loading to Chesapeake Bay — 1985 Base Load and Controllable Fraction (million lbs./yr)[1]

Jurisdiction	Nutrient Source[2]	1985 Base Load[3]	Forest Background Load[4]	Controllable Load[5]	Controllable Load as a % of Base Load	Y Axis
Pennsylvania	Nonpoint	112.4	73.8	38.6	34	1
	Point	10.5	0.0	10.5	100	2
	SUBTOTAL	122.9	73.8	49.1	40	3
Maryland	Nonpoint	45.5	25.2	20.3	45	4
	Point	30.5	0.0	30.5	100	5
	SUBTOTAL	76.0	25.2	50.8	67	6
Virginia	Nonpoint	59.5	27.2	32.3	54	7
	Point	34.4	0.0	34.4	100	8
	SUBTOTAL	93.9	27.2	66.7	71	9
District of Columbia	Nonpoint	0.3	0.1	0.2	67	10
	Point	8.5	0.0	8.5	100	11
	SUBTOTAL	8.8	0.1	8.7	99	12
Bay Agreement Participants	Nonpoint	217.7	126.3	91.4	42	13
	Point	83.9	0.0	83.9	100	14
	TOTAL	301.6	126.3	175.3	58	15
Other States in the Watershed (NY, WV & DE)	Nonpoint	37.3	8.7	28.6	77	16
	Point	2.8	0.0	2.8	100	17
	TOTAL	40.1	8.7	31.4	78	18
Watershed Total	Nonpoint	255.0	135.0	120.0	47	19
	Point	86.7	0.0	86.7	100	20
	Atmospheric Deposition[6]	34.6	34.6	0.0	0	21
	TOTAL	376.3	169.6	206.7	55	22
X Axis		A	B	C	D	

Source: 1991 Watershed Model Note: Shaded column shows loads that were the basis for the calculation of the 40% reduction. X/Y Axis references text percentage sources.

1. This table is preliminary and subject to revision in the final report.
2. Nonpoint source loads include atmospheric deposition to the land. Point source loads are reported as delivered to tidal waters.
3. 1985 Base Load is 1984-87 averaged output from the Watershed Model plus point source load discharged below fall line.
4. Forest Background Load simulated all land uses converted to forest. (See Technical Appendix: Simulation Forest Reference No. 1 and 2A) Includes atmospheric deposition on the land, rivers and lakes that may be possible to control. Reductions seen in sources originating in other states in the watershed (lines 16-18) are attributed to their removal during transport in more natural (all forested) riverine systems.
5. Controllable Load is Base Load minus Forest Background Load.
6. Deposition to tidal waters only. Technical studies show that a large majority of this load is attributable to man's activities, but that fraction is not estimated here.

Table 1b. Phosphorus Loading to Chesapeake Bay — 1985 Base Load and Controllable Fraction (million lbs./yr)[1]

Jurisdiction	Nutrient Source[2]	1985 Base Load[3]	Forest Background Load[4]	Controllable Load[5]	Controllable Load as a % of Base Load	Y Axis
Pennsylvania	Nonpoint	4.88	0.96	[redacted]	80	1
	Point	1.64	0.0	[redacted]	100	2
	SUBTOTAL	6.52	0.96	[redacted]	85	3
Maryland	Nonpoint	3.70	1.33	[redacted]	64	4
	Point	2.20	0.0	[redacted]	100	5
	SUBTOTAL	5.90	1.33	[redacted]	77	6
Virginia	Nonpoint	6.20	2.01	[redacted]	68	7
	Point	4.78	0.0	[redacted]	100	8
	SUBTOTAL	10.98	2.01	[redacted]	82	9
District of Columbia	Nonpoint	0.019	0.002	[redacted]	89	10
	Point	0.107	0.000	[redacted]	100	11
	SUBTOTAL	0.126	0.002	[redacted]	98	12
Bay Agreement Participants	Nonpoint	14.80	4.30	[redacted]	71	13
	Point	8.73	0.0	[redacted]	100	14
	TOTAL	23.53	4.30	[redacted]	82	15
Other States in the Watershed (NY, WV & DE)	Nonpoint	1.82	0.08	1.74	97	16
	Point	0.43	0.0	0.43	100	17
	TOTAL	2.25	0.08	2.17	96	18
Watershed Total	Nonpoint	16.62	4.38	12.24	73	19
	Point	9.16	0.0	9.16	100	20
	Atmospheric Deposition[6]	1.47	1.47	0.0	0	21
	TOTAL	27.25	5.85	21.4	78	22
X Axis		A	B	C	D	

Source: 1991 Watershed Model Note: Shaded column shows loads that were the basis for the calculation of the 40% reduction. X/Y Axis references text percentage sources.

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5. Controllable Load is Base Load minus Forest Background Load.
6. Deposition to tidal waters only. Technical studies show that a large majority of this load is attributable to man's activities, but that fraction is not estimated here.

Table 2a. Total Nitrogen Loading to Chesapeake Bay by Major Tributary (in millions lbs/yr)[1]

River Basin	Nutrient Source[2]	1985 Base Load[3]	Forest Background Load[4]	Controllable Load[5]	Controllable Load as a % of Base Load	Y Axis
Susquehanna	Nonpoint	126.3	89.5	[illegible]	29	1
	Point	12.4	2.6	[illegible]	79	2
	SUBTOTAL	138.7	92.1	[illegible]	34	3
Patuxent	Nonpoint	3.6	1.29	[illegible]	64	4
	Point	1.4	0.0	[illegible]	100	5
	SUBTOTAL	5.0	1.29	[illegible]	74	6
Potomac	Nonpoint	53.0	38.0	15.0	28	7
	Point	26.6	0.2	[illegible]	99	8
	SUBTOTAL	79.6	38.2	[illegible]	52	9
Rappahannock	Nonpoint	9.7	2.4	[illegible]	75	10
	Point	0.4	0.0	[illegible]	100	11
	SUBTOTAL	10.1	2.4	[illegible]	76	12
York	Nonpoint	5.1	1.6	[illegible]	69	13
	Point	1.3	0.0	[illegible]	100	14
	SUBTOTAL	6.4	1.6	[illegible]	75	15
James	Nonpoint	21.0	8.88	[illegible]	58	16
	Point	22.8	0.02	[illegible]	99	17
	SUBTOTAL	43.8	8.9	[illegible]	80	18
Appomattox	Nonpoint	1.9	0.5	[illegible]	74	19
	Point	0.0	0.0	[illegible]	—	20
	SUBTOTAL	1.9	0.5	[illegible]	74	21
Western Shore Maryland	Nonpoint	6.6	2.2	[illegible]	67	22
	Point	20.5	0.0	20.5	100	23
	SUBTOTAL	27.1	2.2	[illegible]	92	24
Eastern Shore Maryland	Nonpoint	26.7	12.31	[illegible]	54	25
	Point	0.9	0.09	[illegible]	90	26
	SUBTOTAL	27.6	12.40	15.20	55	27
Eastern Shore Virginia	Nonpoint	1.4	1.4	[illegible]	0	28
	Point	0.3	0.00	[illegible]	100	29
	SUBTOTAL	1.7	1.4	[illegible]	18	30
Watershed Total	Nonpoint	255.3	158.08	[illegible]	38	31
	Point	86.6	2.91	[illegible]	97	32
	Atmospheric Deposition[6]	34.6	34.6	[illegible]	0	33
	TOTAL	376.5	195.59	[illegible]	48	34
X Axis		A	B	C	D	

Source: 1991 Watershed Model Note: Shaded column shows loads that were the basis for the calculation of the 40% reduction. X/Y Axis references text percentage sources.

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4. Forest Background Load simulated all land uses converted to forest. (See Technical Appendix: Simulation Forest Ref. No. 1 and 2A) Includes atmospheric deposition on the land, rivers and lakes that may be possible to control.
5. Controllable Load is Base Load minus Forest Background Load.
6. Deposition to tidal waters only. Technical studies show that a large majority of this load is attributable to man's activities, but that fraction is not estimated here.

Table 2b. Total Phosphorus Loading to Chesapeake Bay by Major Tributary (in millions lbs/yr)[1]

River Basin	Nutrient Source[2]	1985 Base Load[3]	Forest Background Load[4]	Controllable Load[5]	Controllable Load as a % of Base Load	Y Axis
Susquehanna	Nonpoint	4.79	0.94	[illegible]	80	1
	Point	1.80	0.17	[illegible]	91	2
	SUBTOTAL	6.59	1.11	[illegible]	83	3
Patuxent	Nonpoint	0.30	0.03	[illegible]	90	4
	Point	0.21	0.00	[illegible]	100	5
	SUBTOTAL	0.51	0.03	[illegible]	94	6
Potomac	Nonpoint	4.93	2.63	[illegible]	47	7
	Point	1.28	0.07	[illegible]	95	8
	SUBTOTAL	6.21	2.70	[illegible]	57	9
Rappahannock	Nonpoint	0.83	0.08	[illegible]	90	10
	Point	0.16	0.00	[illegible]	100	11
	SUBTOTAL	0.99	0.08	[illegible]	92	12
York	Nonpoint	0.51	0.07	[illegible]	86	13
	Point	0.43	0.00	[illegible]	100	14
	SUBTOTAL	0.94	0.07	[illegible]	93	15
James	Nonpoint	2.51	0.89	[illegible]	65	16
	Point	3.64	0.01	[illegible]	100	17
	SUBTOTAL	6.15	0.90	[illegible]	85	18
Appomattox	Nonpoint	0.28	0.02	[illegible]	93	19
	Point	0.0	0.0	[illegible]	—	20
	SUBTOTAL	0.28	0.02	[illegible]	93	21
Western Shore Maryland	Nonpoint	0.53	0.03	[illegible]	94	22
	Point	1.29	0.00	[illegible]	100	23
	SUBTOTAL	1.82	0.03	[illegible]	98	24
Eastern Shore Maryland	Nonpoint	1.88	0.46	[illegible]	76	25
	Point	0.34	0.04	[illegible]	88	26
	SUBTOTAL	2.22	0.50	[illegible]	77	27
Eastern Shore Virginia	Nonpoint	0.082	0.08	[illegible]	2	28
	Point	0.003	0.0	[illegible]	—	29
	SUBTOTAL	0.085	0.08	[illegible]	6	30
Watershed Total	Nonpoint	16.64	5.23	[illegible]	69	31
	Point	9.15	0.29	[illegible]	97	32
	Atmospheric Deposition[6]	1.47	1.47	[illegible]	0	33
	TOTAL	27.26	6.99	[illegible]	74	34
X Axis		A	B	C	D	

Source: 1991 Watershed Model Note: Shaded column shows loads that were the basis for the calculation of the 40% reduction. X/Y Axis references text percentage sources.

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4. Forest Background Load simulated all land uses converted to forest. (See Technical Appendix: Simulation Forest Ref. No. 1 and 2A) Includes atmospheric deposition on the land, rivers and lakes that may be possible to control.
5. Controllable Load is Base Load minus Forest Background Load.
6. Deposition to tidal waters only. Technical studies show that a large majority of this load is attributable to man's activities, but that fraction is not estimated here.

Progress In Chesapeake Bay Nutrient Control

Point Source Nutrient Reductions

Point sources account for 23% of the nitrogen (Table 1a, A20+A22) and 34% of the phosphorus (Table 1b, A20+A22) entering the Bay; municipal wastewater discharges contribute the majority of these loads. Three critical elements of the Chesapeake Bay Program's point source control strategy are responsible for these reductions:

1. prohibiting the sale of detergents containing phosphorus, and other pollution prevention actions;
2. upgrading wastewater treatment plants; and,
3. improving compliance with permit requirements.

A phosphorus ban limits the amount of phosphorus used in detergents and other cleaning products to trace amounts. Because the ban reduces the amount of phosphorus coming into wastewater treatment plants, it further reduces the amount of phosphorus discharged into the Bay by secondary treatment plants (which do not contain phosphorus removal systems). At advanced treatment plants which are required to remove phosphorus to a specified level, the phosphorus ban reduces operating costs for sludge disposal and chemical precipitants.

In Maryland the ban was implemented in late 1985 as part of Phase I of the nutrient reduction program. The state has experienced a 30% decrease in influent phosphorus concentrations and a 16% decrease in discharged municipal phosphorus loads. At the twenty-one advanced treatment plants in the state required to remove phosphorus, sludge production has been reduced by 28 dry tons/day, with an annual savings of $4.4 million realized because of the reduced need for chemical precipitants.[9]

The District of Columbia operates the watershed's largest wastewater treatment plant, Blue Plains. The District implemented its ban in 1986 and has experienced a 26% decrease in influent phosphorus concentrations, a 30% decrease in chemical usage[10] and a 14% decrease in sludge volume providing an annual savings of $6.5 million (representing about 10% of the Blue Plains operating budget).

The Virginia ban was initiated in 1988. Since that time, municipal treatment plants in Virginia have experienced a 34% decrease in influent and a 50% decrease in effluent phosphorus concentrations. As a result, the phosphorus loads from municipal wastewater treatment plants decreased by 46% between 1985 and 1989 despite a 13% increase in wastewater requiring treatment.[11]

Pennsylvania implemented a phosphorus ban within the Susquehanna River basin in 1990, and benefits are expected to be similar to those of the other jurisdictions.

The ban on phosphates used in laundry detergents eliminated between one-quarter and one-third the total amount of phosphorus entering municipal treatment plants.

Nitrogen reduction progress has recently begun to keep pace with the goals established in the Baywide Nutrient Reduction Strategy.* Improved pollution prevention by industry and improved wastewater treatment is now reducing this load, where in the past nitrogen discharges have risen with an increase in sewage flow stemming from population growth (Figure 6a). Phase III of the Baywide Nutrient Reduction Strategy has scheduled an increased emphasis on nitrogen removal from point sources.

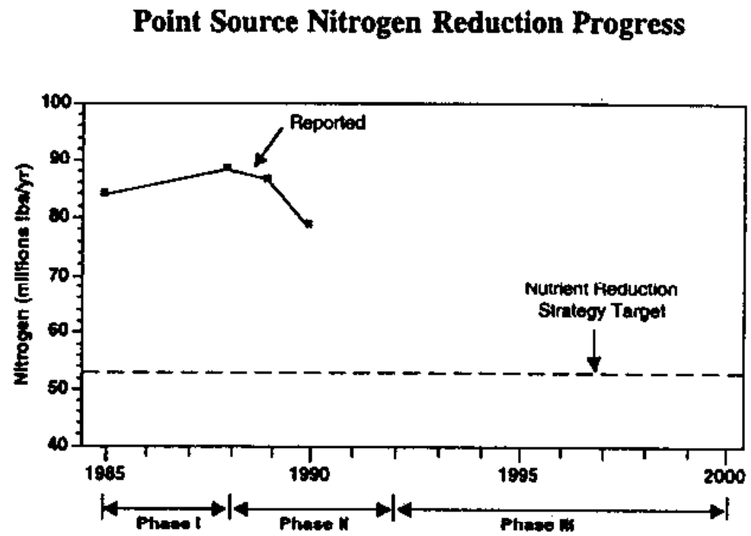

Figure 6a. Point Source Nitrogen Reduction Progress (Source: see references 7, 8)

Phosphorus discharges have been reduced at a faster pace than predicted in the Baywide Nutrient Reduction Strategy. Annual discharges have dropped about 3 million pounds, a reduction of 40% of the 1985 load (Figure 6b). This is the year 2000 goal set in the 1988 Baywide Nutrient Reduction Strategy.

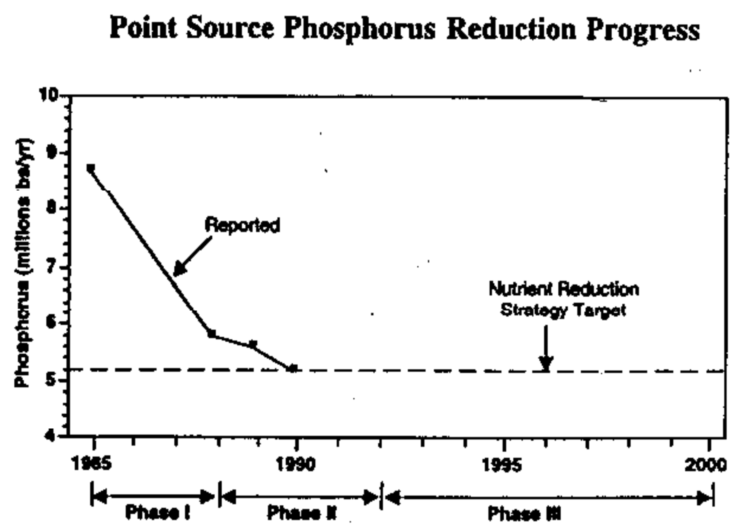

Figure 6b. Point Source Phosphorus Reduction Progress (Source: see references 7, 8)

The upgrading of wastewater treatment plants has strengthened controls on phosphorus. It has also begun to have a similar effect on nitrogen. A technology known as biological nutrient removal (BNR) has been extensively studied in the basin and is now in use among the treatment technologies for reducing point sources of both nitrogen and phosphorus.[12]

Furthermore, compliance has improved with permitted discharge limits as shown in Figure 7. The EPA and the states track the rate of non-compliance and have found that since 1989 (when the Chesapeake Executive Council made compliance a priority) the rate of non-compliance has been steadily declining.[13]

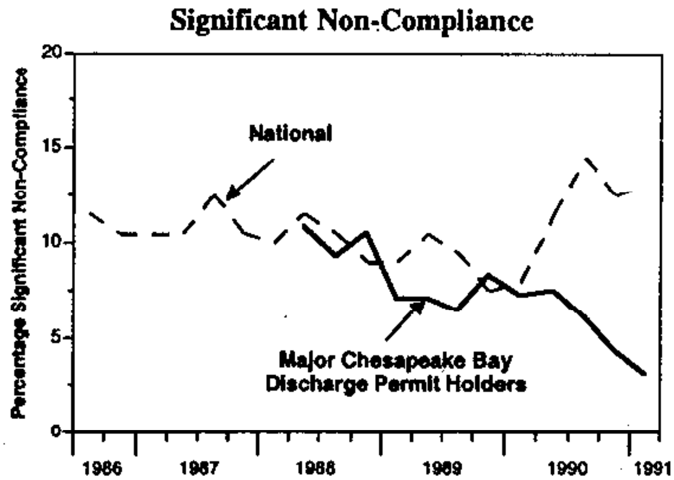

Figure 7. Significant Non-Compliance (Source: Chesapeake Bay Quarterly Noncompliance Report, Fourth Quarter 1991)

Nonpoint Source Nutrient Reductions

The Chesapeake Bay nonpoint source control program is responsible for reducing the 218 million pounds of nitrogen (Table 1a, A13) and 15 million pounds of phosphorus (Table 1b, A13) that enter the Bay annually from nonpoint sources in its watershed. Programs to accomplish this task were begun in the first phase of the Baywide Nutrient Reduction Strategy's implementation and will play an increasingly large role in the future. These jurisdiction-specific programs have focused on research, technical assistance, education, and financial assistance for implementation. They also are widely thought to have inspired voluntary source reductions that cannot be measured. These programs have been further improved through intensive management reviews.

The Chesapeake Bay Program's nonpoint source control portion of the Baywide Nutrient Reduction Strategy emphasized controls on agriculture (including cropland fertilization and waste from livestock), paved surfaces, and construction in urban areas. Whereas the Baywide Nutrient Reduction Strategy began as a modification to traditional measures for controlling soil erosion, it has grown to a level where it now incorporates many other control measures. The most important additional control measure is the practice of nutrient management[14,15] in which animal wastes and fertilizers are applied to farmland in amounts carefully calculated to meet the needs of the crops. This practice replaces the use of outdated guidelines which promoted overuse and, consequently, runoff or leaching of nutrients.

Controllable Nonpoint Source Estimates

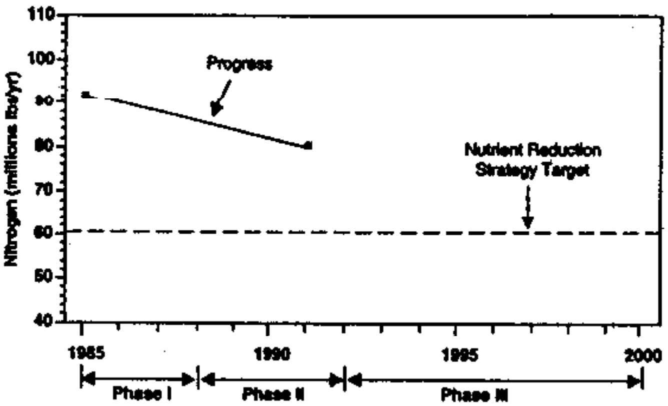

Figure 8a. Nonpoint Source Nitrogen Reduction Progress. Note: Lower level reflects a revised estimate of 1985 nitrogen loads. (Source: see reference 5, Watershed Model)

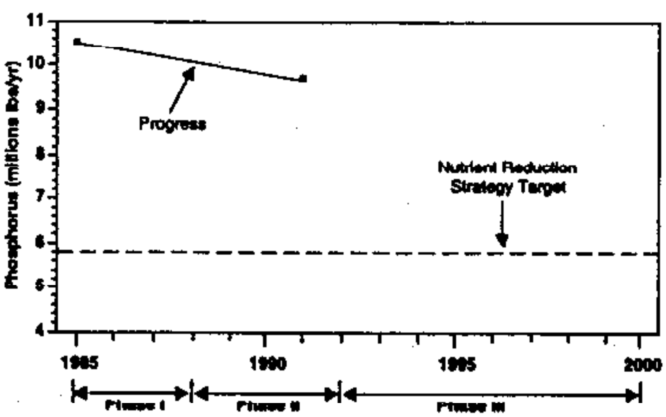

Figure 8b. Nonpoint Source Phosphorus Reduction Progress. Note: Higher level reflects a revised estimate of 1985 phosphorus loads. (Source: see reference 5, Watershed Model)

Documenting nutrient loadings from nonpoint sources and progress made in reducing those loads is much more difficult than for point sources. Since it is not possible to monitor every nonpoint source, appropriate methods must be developed to estimate nonpoint source loads and the reductions achieved by the state's control programs. Recognizing that the initial estimation methods used for the Baywide Nutrient Reduction Strategy needed to be more accurate, the Nonpoint Source Subcommittee has been actively working on improving the load estimation methods since the Baywide Nutrient Reduction Strategy was developed in 1988. The Chesapeake Bay Watershed Model has been developed and is being applied in the reevaluation to provide a means to refine estimates of nonpoint source nutrient loads and the reductions due to different types of control programs.

The first step in the reevaluation of the Baywide Nutrient Reduction Strategy was to check the 1985 base year loading estimates published in 1988. The Watershed Model estimates for the reevaluation compare favorably with the 1988 estimates. Controllable nonpoint source nitrogen was overestimated by approximately 9% and controllable nonpoint source phosphorus was underestimated by approximately 6% in the Baywide Nutrient Reduction Strategy.

By incorporating this type of program tracking information into the Bay Watershed Model, nutrient loading reductions can be estimated. Figure 8 depicts this progress toward achieving the states' nonpoint source nutrient reduction goals. Implementation of nonpoint source control programs has resulted in a 12% and 8% reduction in controllable nonpoint source nitrogen and phosphorus respectively. These rates of progress compare favorably to the progress that was projected at the end of Phase II (1991) for the Baywide Nutrient Reduction Strategy (12% reduction in nitrogen and 11% reduction in phosphorus).

Figures 8a and 8b illustrate the revised base load estimates and the nonpoint source nutrient reduction progress through 1990. As the figures indicate, although progress on nonpoint source loading reductions are reasonably close to the Baywide Nutrient Reduction Strategy projections, rates of load reductions will need to be accelerated in Phase III of the Baywide Nutrient Reduction Strategy's implementation.

Portions of these decreases are reduction in nitrogen loads to ground water. Because nitrogen in ground water is released very slowly, the benefits to Bay water quality may not be seen for many years.

The programs implementing the Baywide Nutrient Reduction Strategy have not invested heavily in the control of nutrients from forests, since forests represent the least polluting land use in the watershed. They also planned no action in reducing the amounts of nutrient pollution from atmospheric sources to the Bay and its watershed, even though they were known to be a significant source of nitrogen. But investigations during the first two phases of the strategy's implementation as well as the passage of the Clean Air Act Amendments in 1990[16] have revealed that it may indeed be possible to reduce atmospheric sources of pollutants. Such a reduction would reduce the nitrogen delivered by both rainfall and dust to water and land thereby reducing the demands on other control programs.

This progress does not include nutrient reductions in states that are not parties to the Chesapeake Bay Agreement—Delaware, New York, and West Virginia. Further information will be needed to characterize any load reductions that may have been made in these states.

The largest nonpoint source of nitrogen and phosphorus loads continues to be farmland. It has been the focus of nutrient reduction strategies in the past and will need to continue to be targeted in the future.

Water Quality Trends and Characterization

The previous section discussed the progress made in reducing the point and nonpoint sources that were the focus of attention in the first two phases of the Baywide Nutrient Reduction Strategy. An analytical effort has been conducted along with the assessment of load reductions to measure the impact that reduced nutrient loads had on water quality. Findings from trend analyses of 1984-1991 Bay water quality monitoring data confirm the significant progress made in reducing phosphorus from nonpoint source and municipal point source loads, as well as the need for further progress towards reducing nitrogen loadings. These trends are as follows:

Nitrogen Trends

- A 2% increase in total nitrogen was observed in the mainstem Bay. (Figure 9a.)[17]
- Nitrogen concentrations increased significantly in the upper mainstem (from the Susquehanna Flats to the mouth of the Patuxent River).
- Nitrogen concentrations increased significantly in the upper reaches of several tributaries (Potomac, Rappahannock, York, Gunpowder, Northeast, Sassafras, Chester and Choptank).
- Nitrogen concentrations increased significantly in the lower section of the James River.

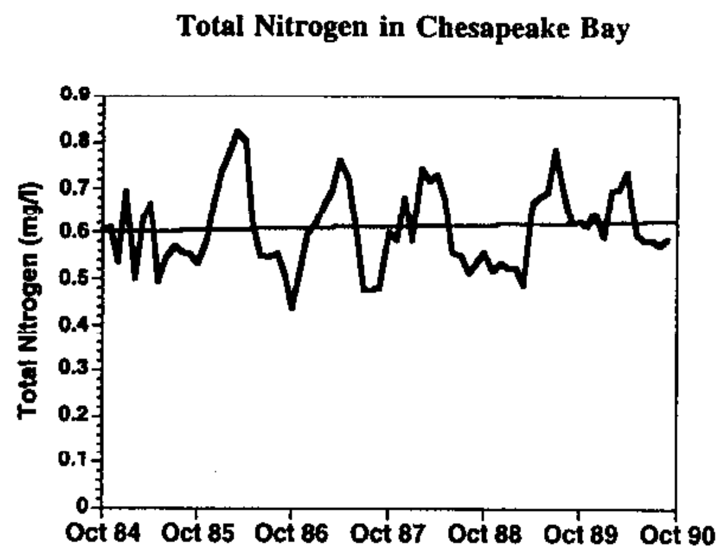

Figure 9a. Total Nitrogen in Chesapeake Bay (Source : See reference 17)

Phosphorus Trends

- A 19% decrease in total phosphorus was observed during a six-year period in the mainstem Bay. (Figure 9b).[17]
- Significant downward trends in phosphorus concentrations were observed in the upper middle mainstem (between the Bay Bridge and the mouth of the Patuxent River) and the lower mainstem (Mobjack Bay south to the mouth of Bay).
- Phosphorus concentrations declined in several tributaries as a result of reductions in point source loadings (Patuxent and James, and less recently in the Potomac).

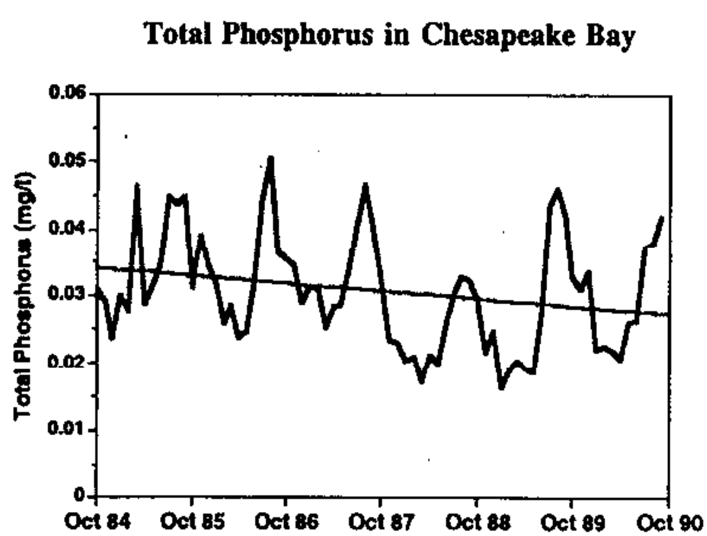

Figure 9b. Total Phosphorus in Chesapeake Bay (Source: See reference 18)

Dissolved Oxygen Trends

Oxygen in the Bay's waters, like oxygen in the air, is critical for the survival of its living resources. Aquatic life in the Bay must breathe dissolved oxygen to live. Thus, the levels of dissolved oxygen found in the Chesapeake are an important indicator of the Bay's water quality.

The amount of oxygen that water can hold in solution is affected by both temperature and salinity. The colder and less saline the water, the more oxygen it can hold. To compensate for variations in water temperature and salinity, the analysis was performed on the dissolved oxygen deficit—the difference between the amount of oxygen that could be present theoretically and the amount of oxygen that is actually present. The dissolved oxygen deficit is the measure by which dissolved oxygen conditions can be improved.

Dissolved oxygen data were analyzed for long and short-term trends.[19] The analysis attempted to detect trends over a forty-year period, 1950 through 1990, during which time large natural variations in environmental conditions occurred that affected dissolved oxygen. (Gaps in the data prior to 1984 may also affect the results of the analysis).

- The volume of anoxic/hypoxic water in the mainstem has fluctuated widely over the last four decades, often reflecting patterns of freshwater inflow.
- The volume of anoxic waters has increased since 1950, based on available data.
- No distinct trends have occurred in the dissolved oxygen deficit since 1984.

In summary, the six and a half years of baywide nitrogen, phosphorus and dissolved oxygen data described here represent a minimum time period over which to test whether significant trends exist in an estuary. More subtle trends may be occurring that will require several more years of monitoring to become detectable. The trends summarized here are analyzed in the Water Quality Characterization Report.[20]

Water Quality Characterization

Through a detailed, baywide characterization of water quality conditions, new insights into water quality patterns have emerged:

- Numerous areas in the Bay's tributaries, as well as previously identified areas in the mainstem Bay, are impacted by low dissolved oxygen. These tributaries include the Patapsco, Magothy, Severn, South, West, Rhode, Patuxent, Potomac, Anacostia, Rappahannock, York, Chester, and Little Choptank rivers, as well as Eastern Bay.
- Water column transparency in many tributary areas indicate habitat conditions unsuitable for survival and growth of submerged aquatic vegetation.

- Although some regions of the tributaries and mainstem and some time periods have shown indications of both phosphorus and nitrogen limitation of algal growth, a greater potential for phosphorus limitation has appeared in the majority of regions and time periods.

As the Chesapeake Bay Program plans to address basin-specific nutrient loading reduction targets, these specific water quality characterizations can guide nutrient reduction programs to areas of greatest need.

Living Resources Characterization

Characterizations of the current status of twenty seven indicator species and two biological communities in the Bay basins indicate that a number of key living resources in Chesapeake Bay are below historical or potential resource levels.[21] These basin-specific characterizations of living resources will be useful in targeting nutrient reductions within specific tributaries as jurisdictions prepare more detailed nutrient reduction plans.

THE REEVALUATION

In 1989, the Implementation Committee formed the Nutrient Reevaluation Workgroup to assemble the results of modeling, research, monitoring and other information and then integrate them with social and economic factors. The workgroup joined forces with a number of respected consultants, public agencies and other Bay Program participants to complete the Nutrient Reevaluation.

The workgroup also directed the compilation of eight reports that quantified point and nonpoint source loads, characterized water quality and living resource populations, and investigated the effectiveness and costs of various nutrient control technologies. These reports synthesized the results of monitoring, research and modeling efforts and described the baseline 1985 loads from which the reductions were calculated. A project management timeline was developed to keep this process on track (Figure 10).

The Nutrient Reevaluation: Project Management Timeline

1991 ——>		1992 and beyond ——>	
Interpret Progress and Characterize Current Conditions	Complete Background Management Studies	Assess Alternative Management Options	Update Nutrient Reduction Strategies

• Nutrient Load Inventories[5]
• Point Source Reductions[7]
• Nonpoint Source Reductions[6]
• Water Quality Characterizations[20]
• Water Quality Trends[17, 18, 19, 20]
• Living Resources Characterization[21]
	• Refined Water Quality Objectives for Living Resources Habitats[16, 18, 19]
	• Model Refinements
	  • Watershed Model
	  • Water Quality Model
	• Assessment of Technology Effectiveness[6]
	• Assessments of Cost Effectiveness[8]
		• Baywide Water Quality Projections
		• Baywide Living Resources Habitat Quality Projections
		• Pollution Control Guidelines
		  - Effectiveness
		  - Implementability
		  - Cost
		  - Equity
		• Assess Additional Controls That May Be Needed
		• Conduct Public Information and Reviews
		• Outline Further Technical Studies
			• Jurisdictional Tributary Water Quality Improvements
			• Tributary Living Resources Habitat Quality Improvements
			• Plan Additional Controls as Needed
			  - Conduct Public Information and Reviews
			  - Program Further Technical Studies

Figure 10. Source: Reevaluation Workgroup

Major Objectives of the Reevaluation

Based on the 1987 Agreement and the Baywide Nutrient Reduction Strategy, the workgroup formulated the following major objectives of the reevaluation process:

1. ***Reevaluate the appropriateness of the 40% nutrient reduction commitment based on available monitoring, modeling and research information.***

   The 40% nutrient (nitrogen and phosphorus) reduction goal was established on the assumption that it would eliminate anoxia and prevent reintroduction of nutrients from the sediments to the water. The 3-D Model is being used to determine the adequacy of this reduction goal.

2. ***Refine nutrient reduction commitments as appropriate, based upon a careful evaluation of the cost effectiveness, implementability, and living resources benefits.***

   The Nutrient Reevaluation has investigated the cost effectiveness and implementability of various point and nonpoint source controls to meet the 40% (or an adjusted) nutrient reduction goal and related living resource benefits. The states will use this information along with experiences gained in implementing Phases I and II of the Baywide Nutrient Reduction Strategy to refine their strategies in the tributaries.

3. ***Provide a refined overall baywide nutrient reduction commitment including basin-specific nutrient reduction targets.***

   The 1987 Agreement calls for an equitable achievement of the 40% nutrient reduction goal by the year 2000 (the original goal called for across-the-board reductions without any targeting). The 3-D Model will be used to determine equitable targeted loadings, identifying the maximum allowable nitrogen and phosphorus loads from each tributary to meet the 40% or adjusted reduction goal.

4. ***Based on the work and analysis completed, provide guidance to the signatories with regard to living resources, water quality and nutrient load characterization to aid in revising the basin strategies most effectively.***

Once equitable targeted loadings have been agreed upon, the states will use available data, as appropriate, to determine the best mix of point and nonpoint source controls to meet the identified tributary loadings.

The Baywide Nutrient Reduction Strategy developed by the Nutrient Reevaluation Workgroup has focused on the following process:

1. setting appropriate water quality and living resource objectives;
2. establishing levels of key physical and chemical water quality parameters necessary to support those objectives;

3. evaluating the effectiveness and feasibility of pollution control options to achieve the desired water quality;

4. estimating the cost of the various options; and,

5. recommending changes to the Baywide Nutrient Reduction Strategy that can best reach the program's reconsidered objectives.

This approach is being used to review and restate water quality and living resource objectives. The approach is also being used to examine the effectiveness and implementability of the Baywide Nutrient Reduction Strategy in an engineering context, cost efficiency in the economic context, and equitability in the social and political context. To date, the first four steps of the process are well underway.

Water Quality and Living Resource Objectives

The Bay Program's highest priority is to restore the Bay's living resources. Among the ways this will be accomplished is through water quality improvements to be achieved through nutrient reductions. These reductions will increase dissolved oxygen and improve water clarity. Submerged aquatic vegetation (SAV) provides critical habitat for many of the Bay's organisms, but requires relatively clear water to grow and photosynthesize.

While the importance of water quality and dissolved oxygen to the Bay's living resources has been known for some time, more precise measures were necessary to set objective goals. The Bay Program's application of the findings from research and monitoring have produced a more refined picture of the water quality needs of living resources. Efforts to develop quantitative restoration goals are underway through the Living Resources Subcommittee, with an initial focus on key fish species and SAV.

An initial task of the reevaluation was to characterize the living resource status in the mainstem Bay and each major tributary. In the Baywide Nutrient Reduction Strategy, only the Bay's mainstem living resources were considered. In current work, the status of twenty-seven indicator species and two biological communities were compared with historical or potential resource levels.[21]

The Living Resources Subcommittee has prepared and is proposing quantifiable physical and chemical parameters to be used as planning goals. They include:

1. the formation of dissolved oxygen habitat requirements which will protect living resource habitats throughout the Chesapeake Bay.[22] In the original Baywide Nutrient Reduction Strategy, only a general goal of eliminating anoxia in the deep portions of the Bay's mainstem was considered. Recently, considerable work has been done to synthesize living resources habitat requirements and to incorporate them in target concentrations of dissolved oxygen which are both physically reasonable and biologically justifiable. However, it should be recognized that these levels of dissolved oxygen might not be attainable at all places and all times under any scenario of water quality

improvement. In some deep areas of the Bay, where mixing with surface waters does not occur for long periods of time in summer, dissolved oxygen may reach 1.0 mg/l or below for extended periods even under pristine conditions. Levels of dissolved oxygen in the proposed restoration goal will provide sufficient oxygen to support the survival, growth, and reproduction of fish and invertebrates in the Chesapeake Bay by maximizing, to the greatest spatial and temporal extent possible, the following dissolved oxygen concentrations:

- dissolved oxygen concentrations of at least 1 mg/l at all times throughout the Chesapeake Bay;
- dissolved oxygen concentrations below 3 mg/l should not occur for longer than 12 hours with the interval between excursions of this oxygen-depleted water being at least 48 hours throughout the Chesapeake Bay including subpycnocline waters;
- dissolved oxygen monthly mean concentrations of at least 5 mg/l at all times throughout the Chesapeake Bay with the exception of subpycnocline waters;
- dissolved oxygen concentrations at or above 5 mg/l at all times and in all locations of the Chesapeake Bay's spawning rivers with the exception of subpycnocline waters.
- maintaining the existing minimum concentration of dissolved oxygen in areas of the mainstem Bay and tributaries where dissolved concentrations are above those stated in items above.

2. water quality-based habitat requirements for submerged aquatic vegetation habitat restoration.[23] This important resource was not explicitly considered in the Baywide Nutrient Reduction Strategy. Preliminary quantitative growing season requirements have been established for four salinity zones for light attenuation, suspended solids, chlorophyll, dissolved nitrogen and dissolved phosphorus. (See the Technical Appendix for details).

These two categories of habitat requirements can be compared to existing conditions and, in instances where projections are possible, be compared to future conditions using computer models discussed in the next section.

Shallow areas of the Bay and tidal tributaries, which contain the most critical habitat, are the areas in which the computer models are the least helpful in predicting future water quality and habitat conditions.

Areas that will benefit most from improved water quality measured by the dissolved oxygen and submerged aquatic vegetation requirements noted here are shown in the technical appendix. Modeling discussions which follow give needed perspective to future investments in water quality, however because they forecast benefits to the mainstem of the Bay and not to the major tributaries to the Bay, they underestimate the benefits nutrient reduction programs are likely to have on habitat restoration.

State nutrient reduction strategies should attempt, in the future, to better describe the benefits to tributary habitats.

Modeling Efforts

The Role of Models in the Baywide Nutrient Reduction Strategy

Mathematical models that compute pollution generation and its chemical and biological effects on the Bay's water quality are being used to assess the effectiveness and feasibility of pollution reduction alternatives. To perform this analysis, the Reevaluation Workgroup used refined versions of the models that guided the preparation of the 1988 Baywide Nutrient Reduction Strategy.

The models used are simply mathematical representations of pollution transportation and biological and chemical reactions seen in the real world. Models are constructed for two basic reasons:

1. to provide tools for predicting the effects of pollution abatement controls on future water quality; and,

2. to improve the understanding of the key physical, chemical and biological processes that determine water quality.

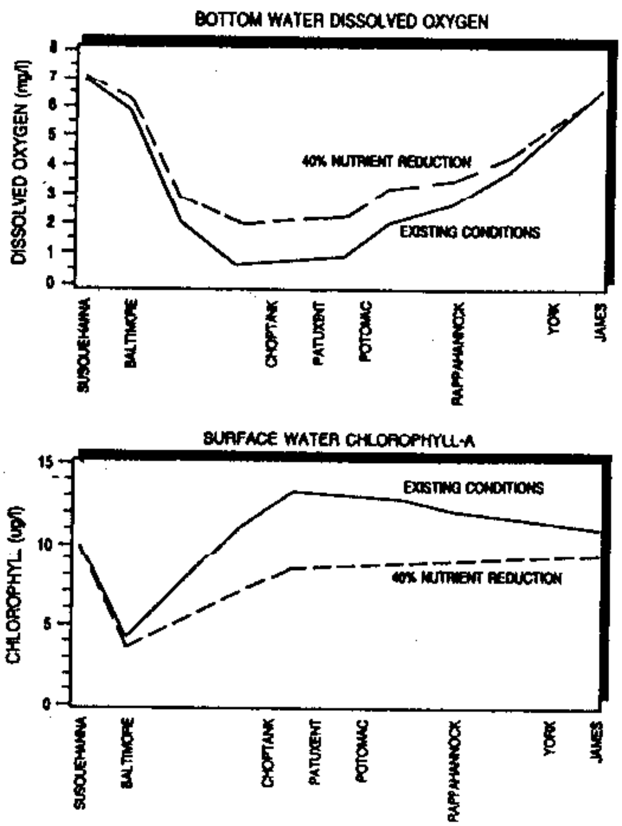

Figure 11. Simulated Water Quality from the Steady State Model (Source: see reference 6)

Mathematical models do not make water quality management decisions. They serve as aids in the systematic analysis of such complex bodies of water as the Chesapeake Bay, thereby contributing credible technical justification to the decision process.

Previous Chesapeake Bay Modeling Efforts

In 1987, two computer models of the Bay were completed by the Chesapeake Bay Program. The first was the Chesapeake Bay Watershed model which predicted the delivery of nutrients to the estuary from point and nonpoint sources above the fall line and from nonpoint sources below the fall line. The second was the Chesapeake Bay Steady-State Model which simulated Bay water quality. The results of these models showed that a 40% reduction of nitrogen and phosphorus point source and controllable nonpoint source loadings would eliminate anoxia and maintain average dissolved oxygen concentrations above 2.0 mg/l in the mainstem of the Bay and substantially reduce algae in the Bay measured as chlorophyll *a*. This result was the basis of the 40% nitrogen and phosphorus reduction goal contained in the 1987 Chesapeake Bay Agreement. The simplistic output of this model is contrasted to 1985 conditions in Figure 11.

The signatories to the 1987 Chesapeake Bay Agreement recognized that the early Watershed and Steady-State Models had their limitations. The Watershed Model was unable to adequately consider important best management practices (BMPs) which control nonpoint source pollution and could not simulate instream sediment-nutrient interactions. The Steady-State Model could not simulate the impacts of wet and dry year sequences—an important factor in the delivery of nutrients to the Bay. Also in the Steady-State Model, the Bay was divided into coarse lateral segments which limited its utility in understanding and evaluating strategies to improve nearshore habitats. Although this model accounted for sediment nutrient fluxes and oxygen demand on water quality conditions, the fluxes could only be modified by external manipulation, an awkward and imprecise process. Without a model-generated sediment response, it was not possible to evaluate how long it would take the Bay to respond to reduced nutrient loadings. Realizing the limitations of these models, the signatories called for this Nutrient Reevaluation, using refined versions of the two models, planned when the original goal was established.

Refinements to the Chesapeake Bay Models

The Watershed Model refinements include an improved and updated 1985 inventory of land uses and pollution sources, as well as the region's weather patterns to compute the tributary river flows and nutrient loads delivered to the Bay from the entire watershed, which includes New York, West Virginia, Pennsylvania, Virginia, the District of Columbia, Delaware, and Maryland. Other refinements to this model include more advanced capabilities for simulating agricultural fertilizer use and reductions due to nutrient management, and algorithms for instream sediment transport that more accurately simulate nutrients which are transported with sediment in rivers.

A 3-Dimensional Time-Variable Model was created to replace the Steady-State Model used in 1988. This model, known as the "3-D Model," links two features—the hydrodynamic component and the water quality component. The hydrodynamic component predicts the velocities, salinities, and temperature of waters in the tidal portion of the Bay, including its tributaries. The water quality component predicts the important aspects of water quality in the tidal Bay. These water quality predictions include such things as the concentrations of nitrogen, phosphorus, and dissolved oxygen. This model is time-varying in that it simulates water quality from a succession of naturally changing tributary river flows, allowing a ten-year pattern to be analyzed instead of a single two-month summer-averaged condition. Another important feature of the water quality component is its ability to link nutrients in the water column to those in the sediment on the Bay's bottom. This is accomplished through a sediment sub-model that predicts nitrogen and phosphorus fluxes and sediment oxygen demand based on the organic material that settles from the water column to the sediment layer.

The Watershed Model and the hydrodynamic portion of the 3-D Model are combined to produce input for the water quality portion of the 3-D Model (Figure 12).

Chesapeake Bay Models

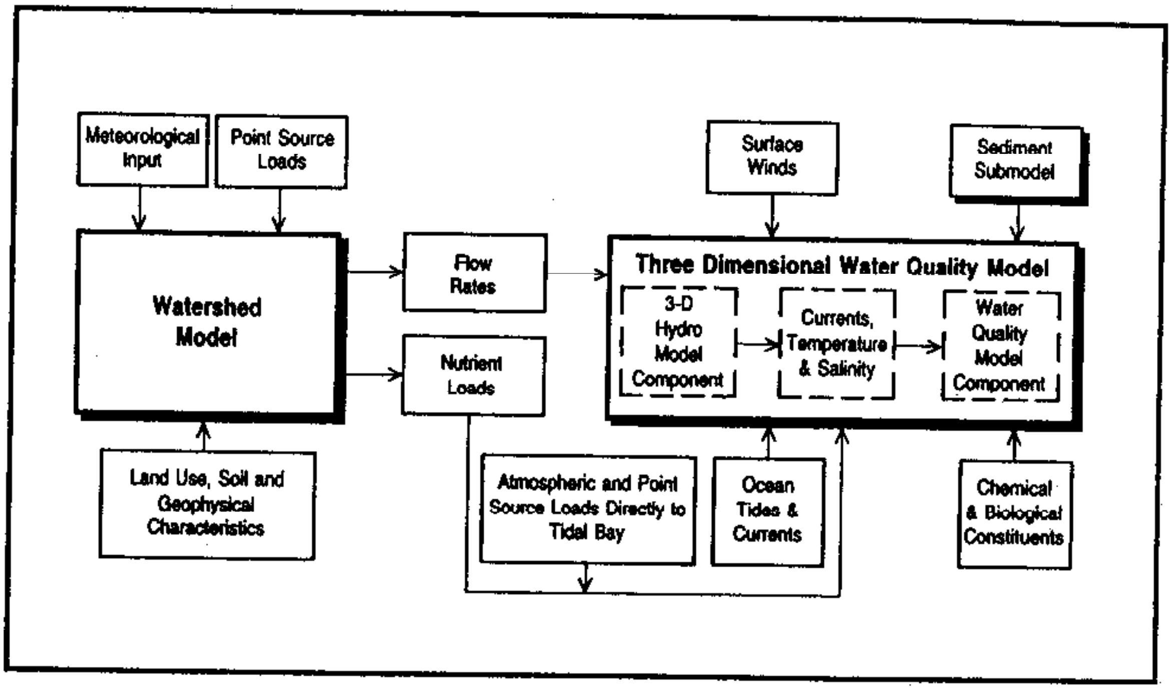

Figure 12. Model Structure (Source: Adapted from Modeling of the Chesapeake Bay, CRC Publication No. 131)

These models were developed to address the following management issues:

- What impact do nutrient loads from point and nonpoint sources delivered by the Bay's major tributaries have on the Chesapeake's water quality?
- How do these impacts change with reductions or increases in these sources?
- How are these impacts distributed across the Bay's habitats?
- How much of the nutrient loads to the Bay is natural and how much is related to man-made sources, and to what extent can loads be controlled?
- How long will it take the water quality in the Bay to improve once nutrient controls are fully implemented?

Seven model runs have been completed that begin to answer these questions. These runs are described in greater detail in the Technical Appendix. They include a simulation of base case conditions that establish the starting point for measuring the impacts of various nutrient levels on the Bay. From this base, a "no action" run simulated a 20% increase in nutrient loads to test whether further degradation would result from the absence of effective controls. Once this was confirmed, various reductions, some extreme in their assumptions, were simulated to establish the bounds of water quality improvement that can be expected from simulations. Figure 13 shows that the changes in the nutrient loads that were simulated ranged from an increase of 20% in both nutrients to decreases of up to 90%. The detailed assumptions about these model runs are contained in the Technical Appendix.

These models have been used to date to project overall changes in dissolved oxygen levels in the Bay. These projections give a more complete picture of the changes in dissolved oxygen than was possible in 1988 using the Steady-State Model.

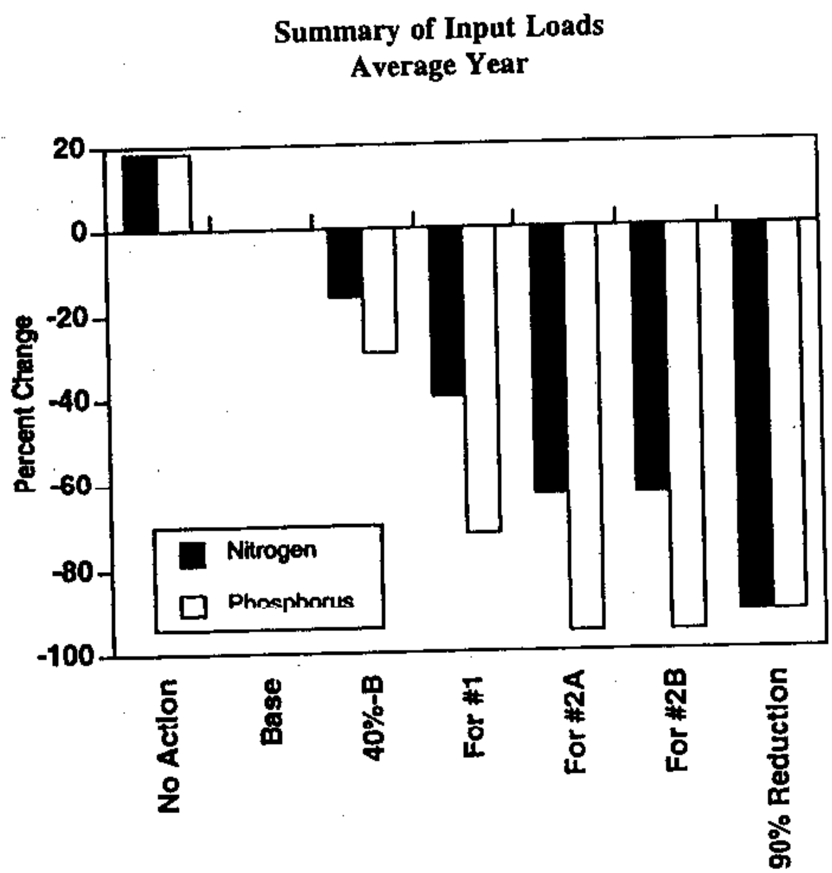

Figure 13. Summary of Simulated Nutrient Loads. (Source: Dr. Robert V. Thomann, 1991)

Figure 14 shows change as "anoxic volume days," an index of the volume of Bay waters with low dissolved oxygen simulated to occur during the June to October season. In the future, model projections will also be related to the habitat requirements presented in the first section of the Technical Appendix to this report.

The projections of future water quality confirm the utility of the models in predicting the effects of pollution controls. The analysis of these projections has also confirmed the 3-D model's use in its secondary function, that of understanding the complex interactions that occur in the Bay itself. These simulations have revealed the importance of the nutrients contained in ocean waters that flow in and out of the Bay through tidal action. When nutrients are reduced in the Bay, they are reduced in ocean waters that come from the Bay and which are conveyed back into the Bay by the tidal action. Changes to the 3-D model are underway to better simulate the fact that adjacent ocean water will be affected by changes in the Bay's water quality.

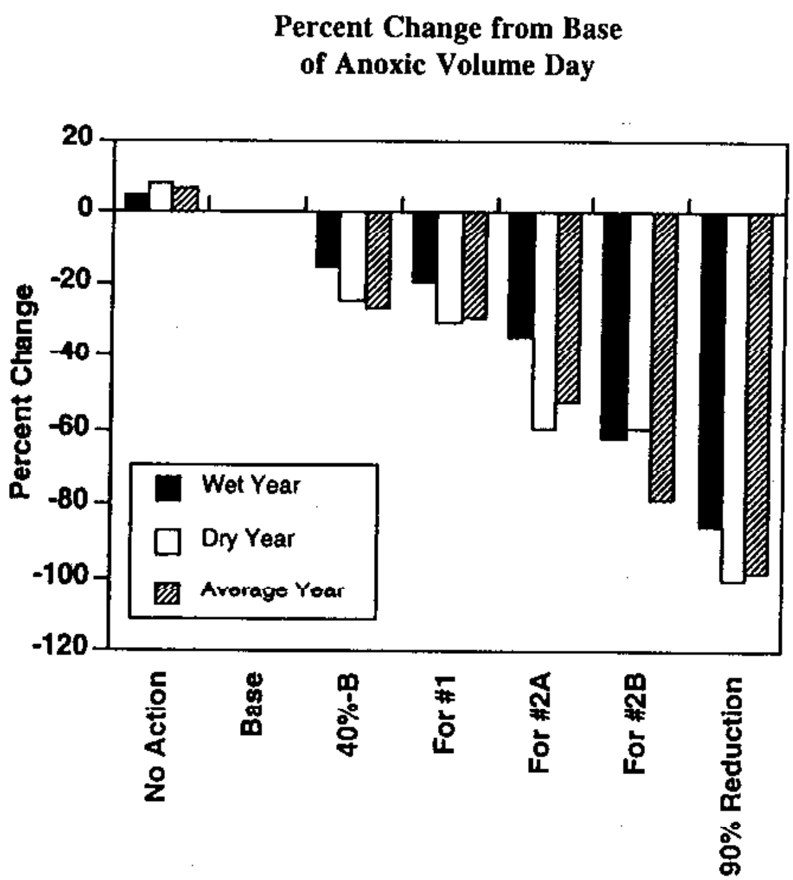

Figure 14. Summary of Simulated Dissolved Oxygen Levels. (Source: Dr. Robert V. Thomann, 1991)

Although the 3-D Model is being continuously refined, several preliminary observations can be made:

- The simulation of the Chesapeake Bay Program's goal of a 40% reduction in controllable nitrogen and phosphorus will result in a reduction in total nitrogen (18% reduction) and in total phosphorus (29% reduction) loads. The relatively smaller nitrogen reduction is attributable to the impacts of atmospheric deposition of nitrogen.

- Simulations named "Forest Reference" appear to simulate conditions beyond those that can be achieved by any control programs.[24,25]

- The simulation named "90% Reduction" probably approximates the condition of the Chesapeake Bay before it was burdened by the nutrient emissions of modern society. From this simulation it is apparent that anoxia did not exist in the Bay under undeveloped conditions in dry years.

Technology Effectiveness and the Costs of Nutrient Load Reductions

The cause and effect relationships that can be quantified through the use of models provide only a portion of the perspective needed to consider the effectiveness of the Baywide Nutrient Reduction Strategy's management plans. A review of the costs and efficiency of nutrient pollution control technologies was undertaken to ensure that the feasibility of these controls is considered part of the overall picture.[26]

Point Source Control Technologies

Point source nutrient removal technologies were reviewed.[27,28,29,30,31] The reviews included performance data from full scale, conventional wastewater treatment plants operating in the Bay's watershed along with performance data from both full scale and pilot advanced nutrient removal plants constructed and operated under the 1988 Baywide Nutrient Reduction Strategy. Expected effluent levels for phosphorus and nitrogen removal were developed for two averaging periods—long-term (annual averages) and short-term (monthly averages) commonly used in regulatory controls. From the results of these analyses, the costs and performance of these technologies were agreed upon.

Nonpoint Source Control Technologies

Management investigations have been undertaken to determine the costs and effectiveness of nonpoint source nutrient control measures, so that they can be applied more effectively in the future.[32,33,34,35,36,37] These investigations.

- quantified the long, useful lives of appropriately installed and maintained BMPs;
- helped develop consistent methodologies for estimating groundwater nutrient contributions to the Bay;
- examined the effectiveness of voluntary nonpoint source implementation.[38]

Cost Effectiveness

Cost effectiveness is defined as the cost per pound of nutrients removed per year. The nutrient removal effectiveness and relative costs of point and nonpoint source technologies were extensively studied[26] in the reevaluation process. A method was developed for using this information in conjunction with the Chesapeake Bay Watershed Model. This method will use relative cost comparisons of nutrient reduction scenarios, helping to form cost effective strategies for point and nonpoint source nutrient reductions.

FINDINGS & FUTURE ACTIVITIES

Findings

The information summarized in this report represents a major advance in our understanding of the causes and results of nutrient enrichment in the Chesapeake Bay and the actions needed to improve the Bay's condition. This effort could not have been achieved without the coordinated efforts of managers, scientists and citizens.

Additional work remains in finalizing the numerous technical reports that are the foundation of the reevaluation and in using the complex mathematical models of the Bay and its watershed to test various nutrient reduction alternatives. Nevertheless, the work accomplished to date permits us to issue the following preliminary findings:

Nutrient Loadings and Controls:

- Revised nutrient loading estimates for point sources of nutrients are close to the 1987 estimates.
- Nutrient loading estimates for basinwide nonpoint sources were revised using the Watershed Model. 1991 Watershed Model runs indicate that nonpoint sources, including atmospheric deposition to the watershed, contribute approximately 77% of the nitrogen and 66% of the phosphorus on an average basis.
- Bay wide, agricultural sources are dominant, followed by forest and urban sources.
- The "controllable" fraction of nutrient loads from the Bay Agreement states is approximately 47% for nitrogen and 70% for phosphorus. This controllable fraction can be increased to 55% and 78% respectively, by considering loads from states not party to the Bay Agreement. The percentage for nitrogen would increase further if the large atmospheric deposition loads were considered to be controllable.
- We are ahead of schedule in meeting the 40% point source reduction target for phosphorus and are starting to make progress in nitrogen removal.
- Preliminary results show the nonpoint source progress is reasonably close to originally projected rates. Rates of nonpoint source nutrient load reduction will need to be accelerated following the completion of the reevaluation at the end of Phase II. Added emphasis on nonpoint source controls is vital to the restoration of the Bay.

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- A combination of several best management practices, referred to as a "Resource Management System" is the most effective means of reducing nutrient loading from nonpoint sources. Results of the watershed model and cost studies show that nutrient management is the single most effective measure for inclusion in these resource management systems.

- Biological Nutrient Removal has been shown to be an effective alternative to traditional point source technologies in some circumstances. However, chemical addition technologies may still be required to meet point source nutrient reduction objectives in some situations.

Status and Trends in the Bay's Condition:

- Trends in the Bay's nutrient concentrations since 1984 show significant decreases in phosphorus levels in the mainstem and several tributaries and slight increases in nitrogen in the upper mainstem and some tributaries.

- Water quality impacts related to nutrient enrichment, such as low dissolved oxygen, are evident and have now been quantified in numerous tributaries to the Bay as well as the mainstem.

- Living resource based water quality goals have been developed that will assist in the interpretation of existing water quality impacts and projected improvements under various management scenarios. Status and trends for key living resources have been assembled for the Bay's major basins that confirm the need for restoration actions.

Projections from Preliminary Model Results:

- Simulations of nutrient loading increases of 20% (projected growth with no additional nutrient controls) result in approximately a 15 to 20% increase in the extent and duration of Bay waters with dissolved oxygen levels less than 1 mg/l.

- Preliminary model runs show that a 40% reduction of the revised estimates of controllable nutrient loads results in up to a 25% reduction in the extent and duration of Bay waters with dissolved oxygen levels less than 1 mg/l.

- Nutrient reductions using maximum technological controls could reduce by between 30% - 45% the extent and duration of Bay waters with dissolved oxygen levels less than 1 mg/l.

- The shallow areas of the Bay and tidal tributaries which contain the most critical habitats are the areas in which the computer models are the least helpful in predicting future water quality and habitat conditions. Future models should be refined to make these projections.

Future Activities

Preliminary findings of the reevaluation are presented above. In the first half of 1992, additional technical work will refine these findings and comments received on this progress report will be incorporated. The final report, containing recommendations, is scheduled to be presented to the Executive Council in August, 1992. Following approval of the final report on the reevaluation, the Bay Agreement jurisdictions will be responsible for developing implementation plans to meet the revised nutrient reduction goals. These jurisdiction-specific and basin-specific plans are scheduled to be drafted by December, 1993.

The nature of the refinements to the preliminary findings presented here will be to:

- confirm the 40% reduction goal or provide a revised basin-wide nutrient reduction goal and specific nutrient load reduction targets for major basins to most effectively achieve improvements in the Bay's condition;
- further examine the relative benefits of nitrogen and phosphorus controls;
- examine, through the use of models, the reduced atmospheric deposition expected to result from air quality controls that will be necessary to comply with the Clean Air Act. Additional modeling will be necessary to determine the extent to which these controls will reduce sources of nutrients important to the Chesapeake Bay.
- estimate the value of nutrient reduction alternatives using a broader suite of water quality parameters that have relevance to living resource habitats;
- thoroughly consider the implementability and cost of the recommended nutrient load reduction targets.

These factors will be evaluated with additional runs of the mathematical models and more detailed analysis and synthesis of information compiled in the reports prepared as part of the reevaluation.

The Baywide Nutrient Reduction Strategy and the state implementation plans it contains will have to be reviewed and updated as necessary to reflect this reevaluation.

Information compiled during the reevaluation will provide valuable guidance to the jurisdictions in developing their plans. This information, as described in previous section of this report , will include detailed nutrient loading estimates, evaluations of water quality and living resources status and trends in the mainstem and tributaries, and an accounting of available technologies and costs for point and nonpoint source nutrient controls.

The process outlined above will extend the goals and principles of the 1987 Chesapeake Bay Agreement while ensuring that the nutrient reduction plans of the signatories are realistic and will lead to significant progress in restoring the Chesapeake Bay by the year 2000.

TECHNICAL APPENDIX

This appendix describes in detail the development and use to date of the proposed living resource habitat requirements, the simulation of future Bay water quality using the Watershed and 3-D models, and the detailed assessments of technologies and costs that have been prepared as a part of the reevaluation process.

Water Quality and Living Resource Objectives

Reduced quantities of nutrients will lead to greater water clarity essential to the return of submerged aquatic vegetation which forms important habitat and elevates levels of dissolved oxygen required to support fish populations. While the importance of water clarity to submerged aquatic vegetation has been generally known for some time, more precise relationships were needed to set goals.

Research undertaken by the Bay Program provided an understanding of the relationships between nutrient concentrations, total suspended solids, water quality, and the survival of submerged aquatic vegetation, as well as the health and survival of other Bay living resources. This knowledge will allow planning goals for nutrient concentrations to be formally adopted by the Program as the foundation of the restoration plan for these resources.

Our understanding of living resource habitat needs has progressed; priorities can now be assigned to programs that first address areas of critical local concern, and can then be used to address larger regional concerns. Two sets of habitat requirements are used in this assessment—the first is for submerged aquatic vegetation (SAV), and the second is for dissolved oxygen.

Submerged Aquatic Vegetation

The survival and growth of the Bay's SAV are significant concerns that need to be addressed in restoration and protection plans for each of the Bay's major tributaries. Extensive studies have shown that the presence of SAV corresponds to a set of water quality parameters such as light attenuation, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen and dissolved inorganic phosphorus (Table A1).

These habitat requirements are based on zones of salinity and apply to areas delineated as existing habitat or as areas for potential SAV regrowth.[23] Figures A1 and A2 show areas in which the SAV habitat requirements—dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP)—are and are not being met. These are the areas of greatest need for SAV habitat restoration.

The dissolved inorganic nitrogen habitat requirements were not achieved in about half of the Bay, including the upper central mainstem (see Figure A1). Portions of several tributaries including the Patapsco, Magothy, middle Patuxent, middle York, lower James, Chester, Choptank, Nanticoke and Wicomico rivers also failed to meet this parameter.

Chesapeake Bay SAV Habitat Requirements

Salinity Regime	SAV HABITAT REQUIREMENTS FOR ONE METER RESTORATION: Light Attenuation Coefficient (m^{-1})[2]	Total Suspended Solids (mg/l)	Chlorophyll *a* (µg/l)	Dissolved Inorganic Nitrogen (mg/l)	Dissolved Inorganic Phosphorus (mg/l)	Critical Life Period(s)[3]	SAV HABITAT REQUIREMENTS FOR TWO METER RESTORATION: Light Attenuation Coefficient (m^{-1})[2]	Critical Life Period(s)[3]
Tidal Fresh	<2	<15	<15	—	<0.02	April-October	<0.8	April-October
Oligohaline	<2	<15	<15	—	<0.02	April-October	<0.8	April October
Mesohaline	<1.5	<15	<15	<0.15	<0.01	April-October	<0.8	April-October
Polyhaline	<1.5	<15	<15	<0.15	<0.02	March-November	<0.8	March-November

1. The Chesapeake Bay SAV habitat requirements are applied as median values over the April-October critical life period of tidal fresh, oligohaline, and mesohaline salinity regimes. For the polyhaline salinity regime, the SAV habitat requirements are applied as median values from the combined March-May and September-November data.
2. Tidal fresh = <0.5 ppt; oligohaline = 0.5-5 ppt; mesohaline = >5-18 ppt; and polyhaline = >18 ppt.
3. For determination of Secchi depth habitat requirements, apply the conversion factor Secchi depth = 1.45/light attenuation coefficient.

Table A1. Chesapeake Bay SAV Habitat Requirements, (Source: SAV Technical Synthesis, U.S. EPA Chesapeake Bay Program Office, Annapolis, Maryland)

The dissolved inorganic phosphorus habitat requirements were met throughout most of the mainstem bay. This achievement is shown in Figure A2. Portions of a number of major tributaries including the Patapsco, Patuxent, upper Potomac, upper York, James, Choptank, Nanticoke and Wicomico rivers failed this measure of habitat quality.

In recognition of the critical role SAV plays in the Chesapeake Bay ecosystem, water quality restoration priorities are being considered which will set priorities to first protect existing SAV resources, then expand existing SAV distribution, and finally restore SAV to areas currently unvegetated but containing potential SAV habitat. Analyses are underway to refine this analysis so that these priorities can be further used in the tributary strategies of the states.

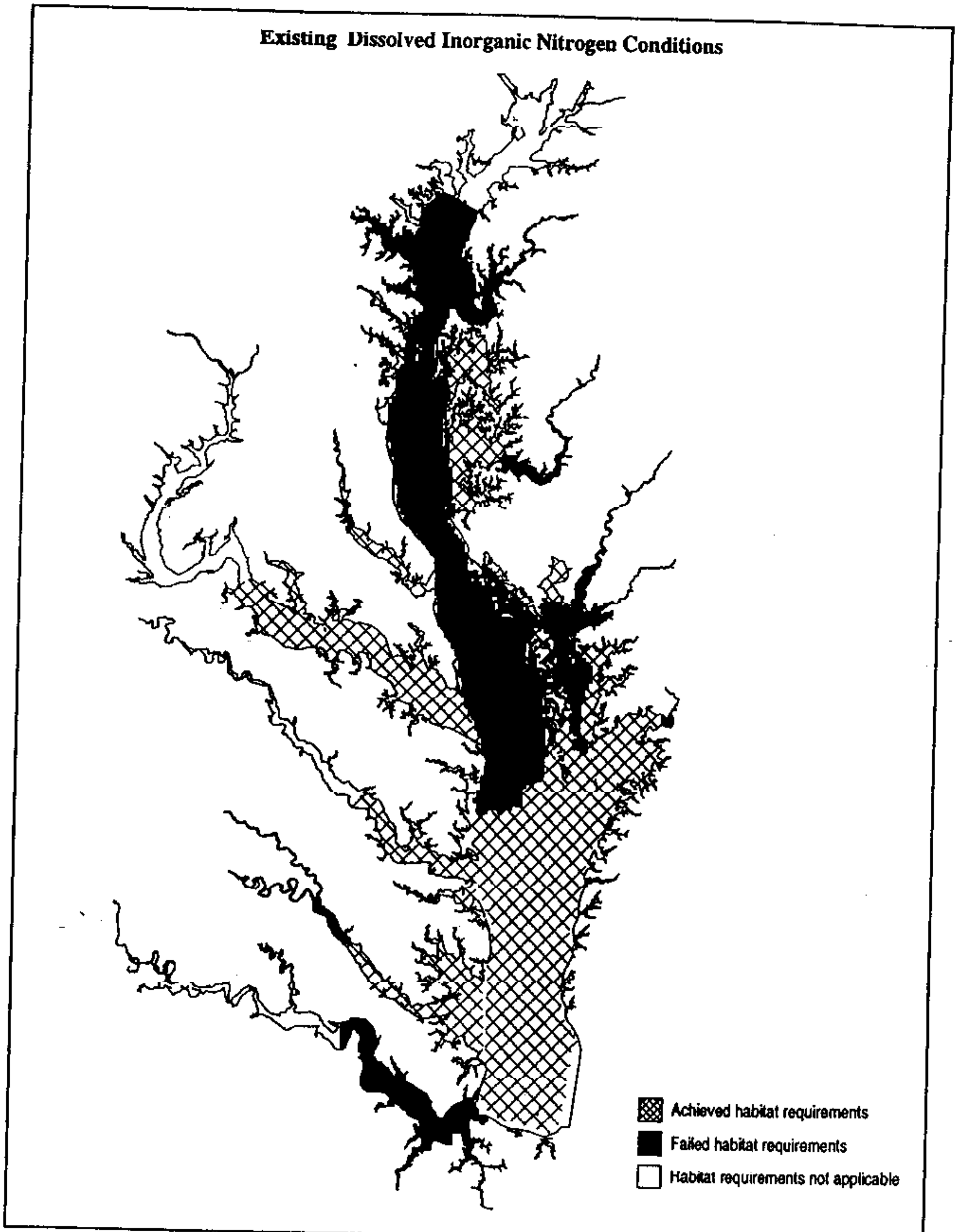

Figure A1. Simulated existing dissolved inorganic nitrogen conditions presented as achievement of the proposed dissolved inorganic nitrogen submerged aquatic vegetation habitat requirements. (Source: Chesapeake Bay Water Quality Monitoring Data Base)

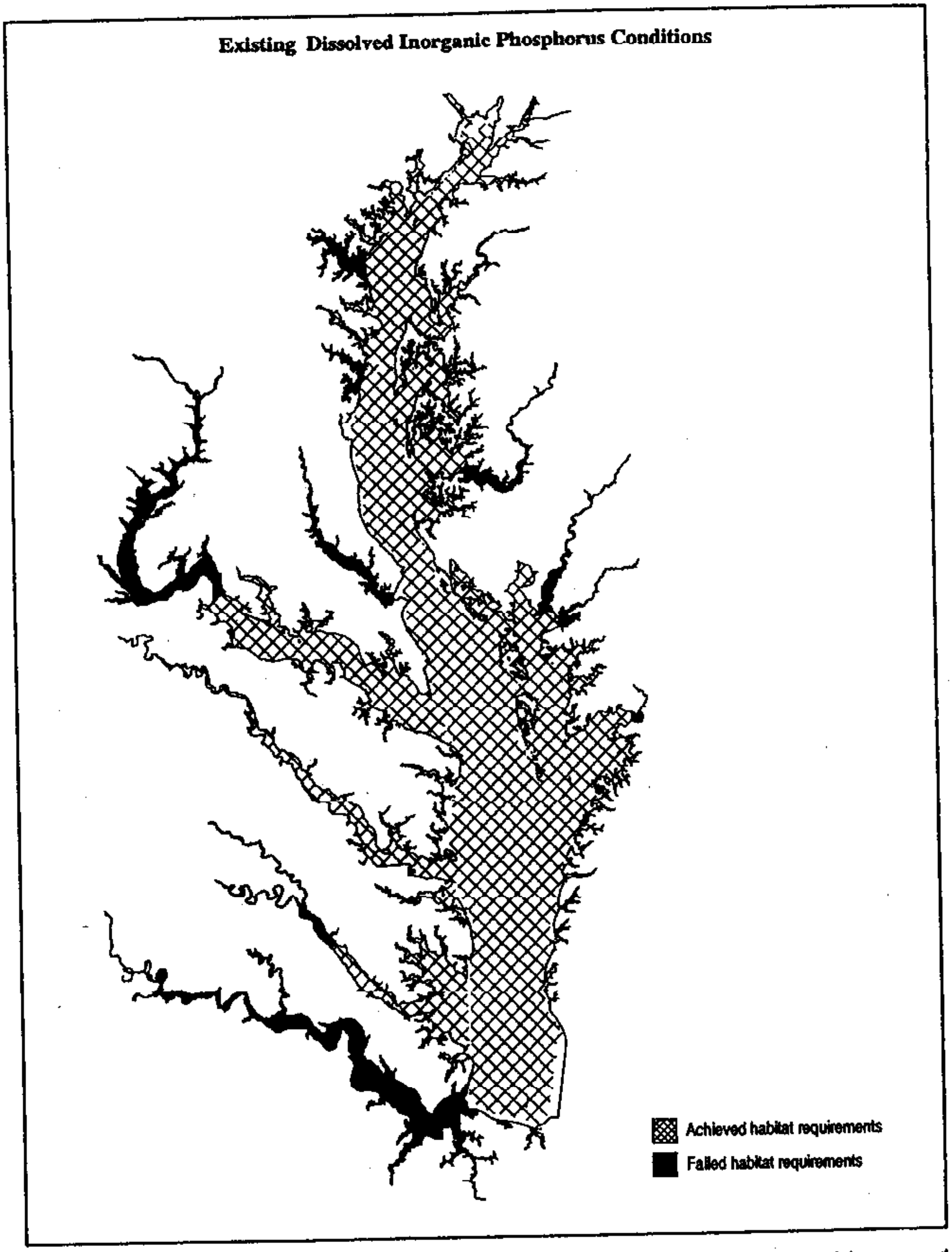

Figure A2. Simulated existing dissolved inorganic phosphorus conditions presented as achievement of the proposed dissolved inorganic phosphorus submerged aquatic vegetation requirements. (Source: Chesapeake Bay Water Quality Monitoring Data Base)

Dissolved Oxygen

Dissolved oxygen habitat requirements constitute the second set of living resource requirements important to the reevaluation. Dissolved oxygen requirements were derived through analysis of dissolved oxygen tolerance information collected for over forty three Chesapeake Bay species[22] in order to identify areas of greatest need for living resource habitat restoration. Dissolved oxygen habitat requirements have been translated to apply to a seasonal time scale for direct comparison with model-forecasted dissolved oxygen for alternative nutrient reduction programs. These habitat requirements, together presented as a proposed dissolved oxygen restoration goal, should assure species survival as well as protect sensitive life stages.

Figure A3 shows the achievement or non-achievement of the dissolved oxygen goal throughout the Chesapeake Bay is exceeded most frequently in the mainstem and in the lower tributaries between the Bay Bridge and the Rappahannock River. Areas north of the mouth of the Patuxent to north of Baltimore suffer depressed oxygen levels over 50% of the time. Areas further north of this zone experienced depressed oxygen as well, although less frequently.

Based on this comparison of living resource habitat needs and existing conditions, dissolved oxygen improvements should be targeted towards the areas identified in figure A4 beginning in the lower tributaries, moving out to the surface waters of the mainstem and eventually down into the deep trough.

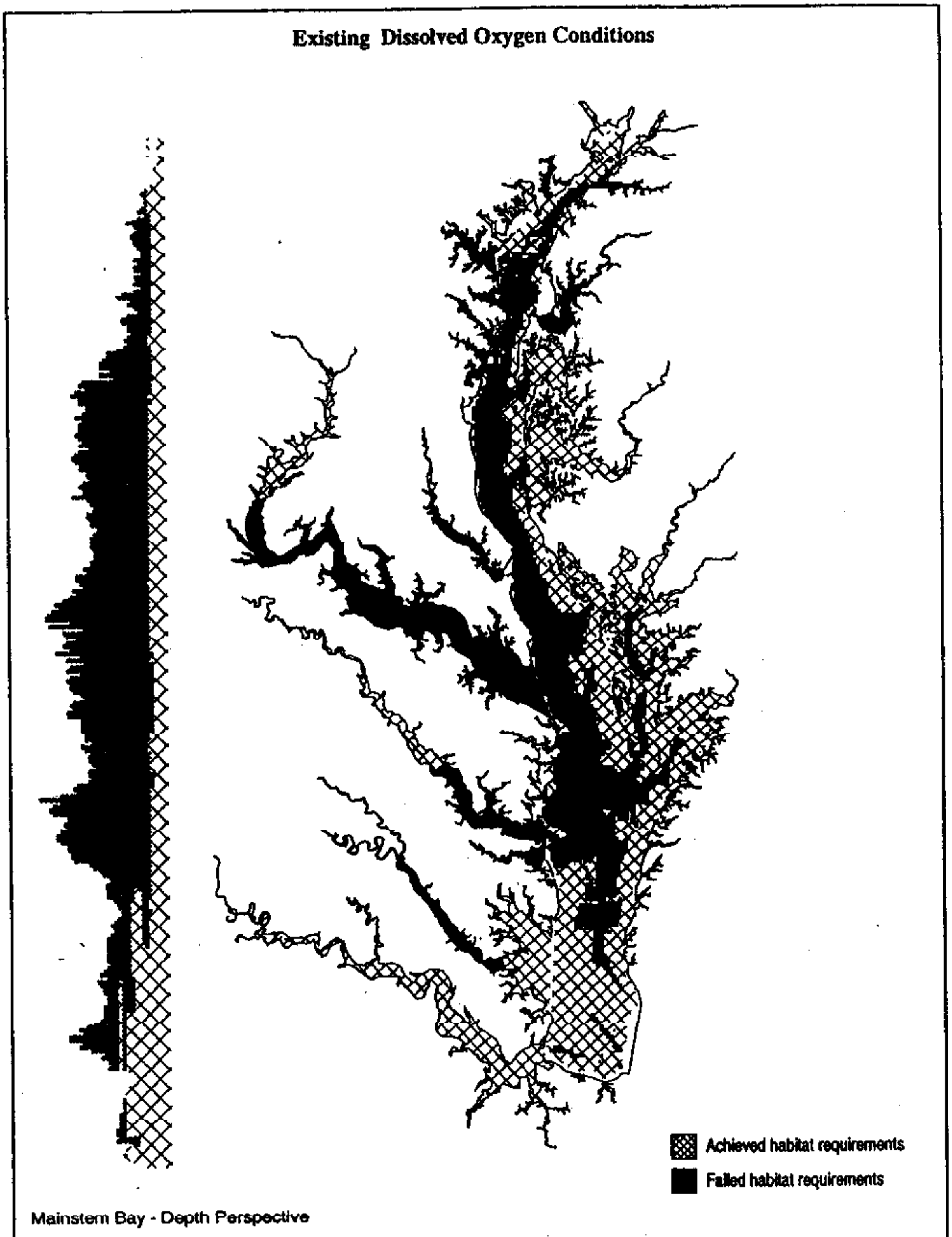

Figure A3. Simulated existing dissolved oxygen conditions presented as attainment of the proposed dissolved oxygen restoration goal 90% of the time. (Source: Chesapeake Bay Water Quality Monitoring Data Base)

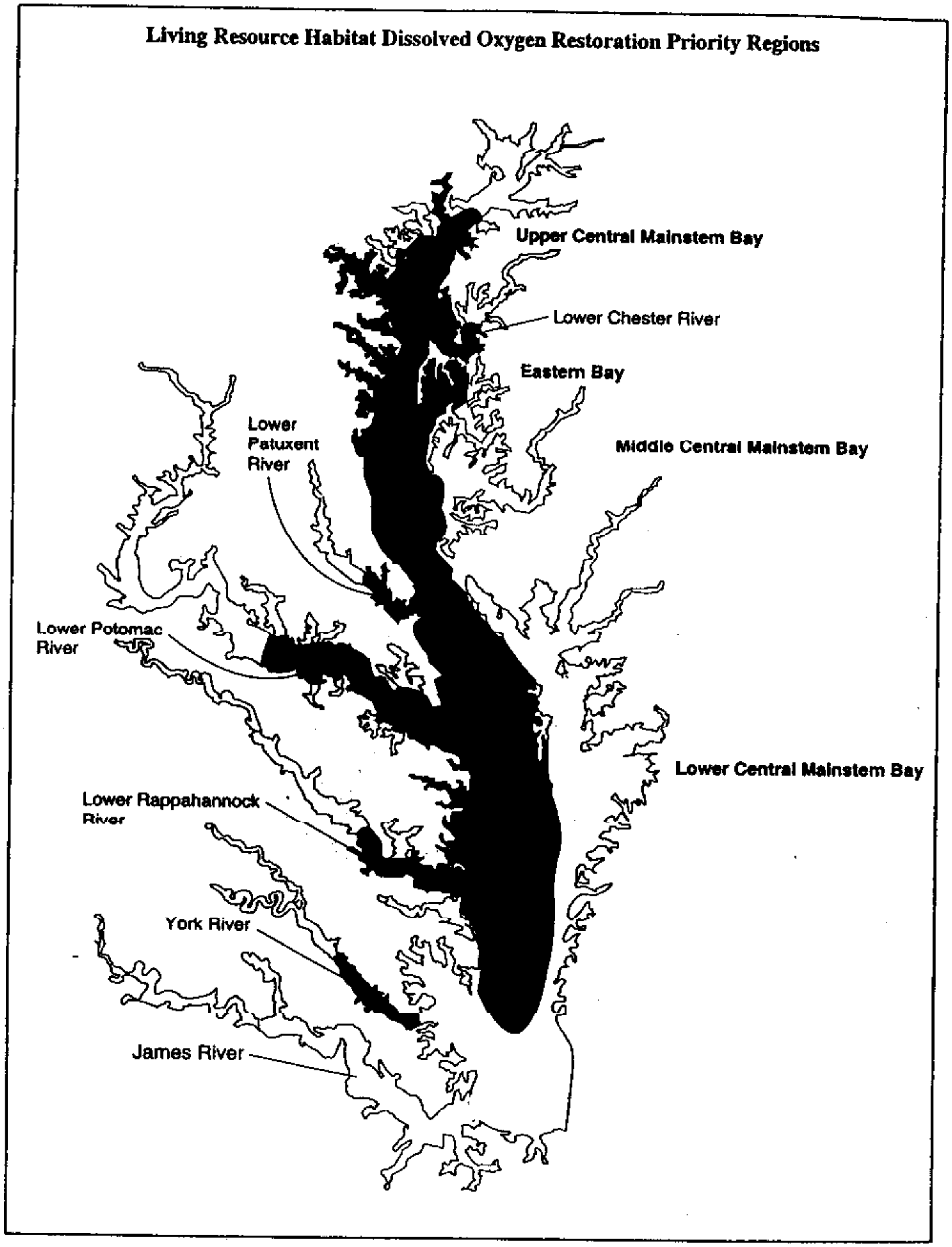

Figure A4. Priority regions for dissolved oxygen restoration identification based on percent achievement of the goal matched with key living resource habitats. (Source: Chesapeake Bay Program Office).

The Bay Program now has:

- The tools necessary to establish basin-specific water quality restoration priorities based on the needs of the Bay's living resources and a more in-depth understanding of the water quality standards for critical SAV habitats. When this information is translated into planning targets, it will be a useful tool in refining the Baywide Nutrient Reduction Strategy.

- The perspective to gauge the significance of dissolved oxygen levels projected by the Chesapeake Bay Water Quality Model as the Bay Program considers control programs to guide subsequent state tributary plans.

Model Refinements

The refinement of the Steady-State Eutrophication Model into a more detailed time-variable model of water quality in the Chesapeake Bay was the milestone foreseen in the 1987 Chesapeake Bay Agreement when it called for a reevaluation of the nutrient reduction goal.

The 3-D Model linkage to the Watershed Model was undertaken to coincide with this refinement. Valuable insights can also be obtained from analyzing predictions of the Watershed Model independent of the 3-D Model.

The set of linked Chesapeake Bay models has been subjected to rigorous review by the Modeling Evaluation Workgroup. This group has concluded that the models are valid and can be used for planning purposes related to the cleanup of the Chesapeake Bay. The Modeling Subcommittee of the Chesapeake Bay Program has also endorsed the use of these models.

As a result of the extensive development work, these linked models can now be used to investigate variations in the main Bay water quality under nutrient loadings different from those used in the calibration. A group of loading simulations have been made. The purposes of these initial simulations were to:

1. confirm the models' credibility over a range of loadings to ensure its satisfactory performance;

2. provide a preliminary assessment of the adequacy of the Baywide Nutrient Reduction Strategy; and,

3. investigate whether alternative nutrient management programs might be more effective in restoring Bay water quality.

Updating the Watershed Model

The current Chesapeake Bay Watershed Model[39] is a refinement to a watershed model used to generate nutrient loadings for input to the Steady-State Bay

Eutrophication Model. The Watershed Model requires inputs of meteorological conditions, land-use patterns and other watershed characteristics to estimate nutrient loadings and streamflow contributed to the tidal waters from the watershed.

From the segmentation scheme of the original model, ten major tributary basins with sixty-three model segments were retained (Figure A5). The 1978 base year for landuse data was revised and updated to reflect 1985. Improvements to the portion of the model dealing with agricultural land uses were made to include more advanced capabilities for simulating agricultural fertilizer use and reductions due to nutrient management. The model algorithms for instream sediment transport were refined to more accurately simulate nutrients associated with sediment transported in the rivers. Finally, the model calibration period was extended through 1987 to take advantage of additional water quality data collected on the major rivers.

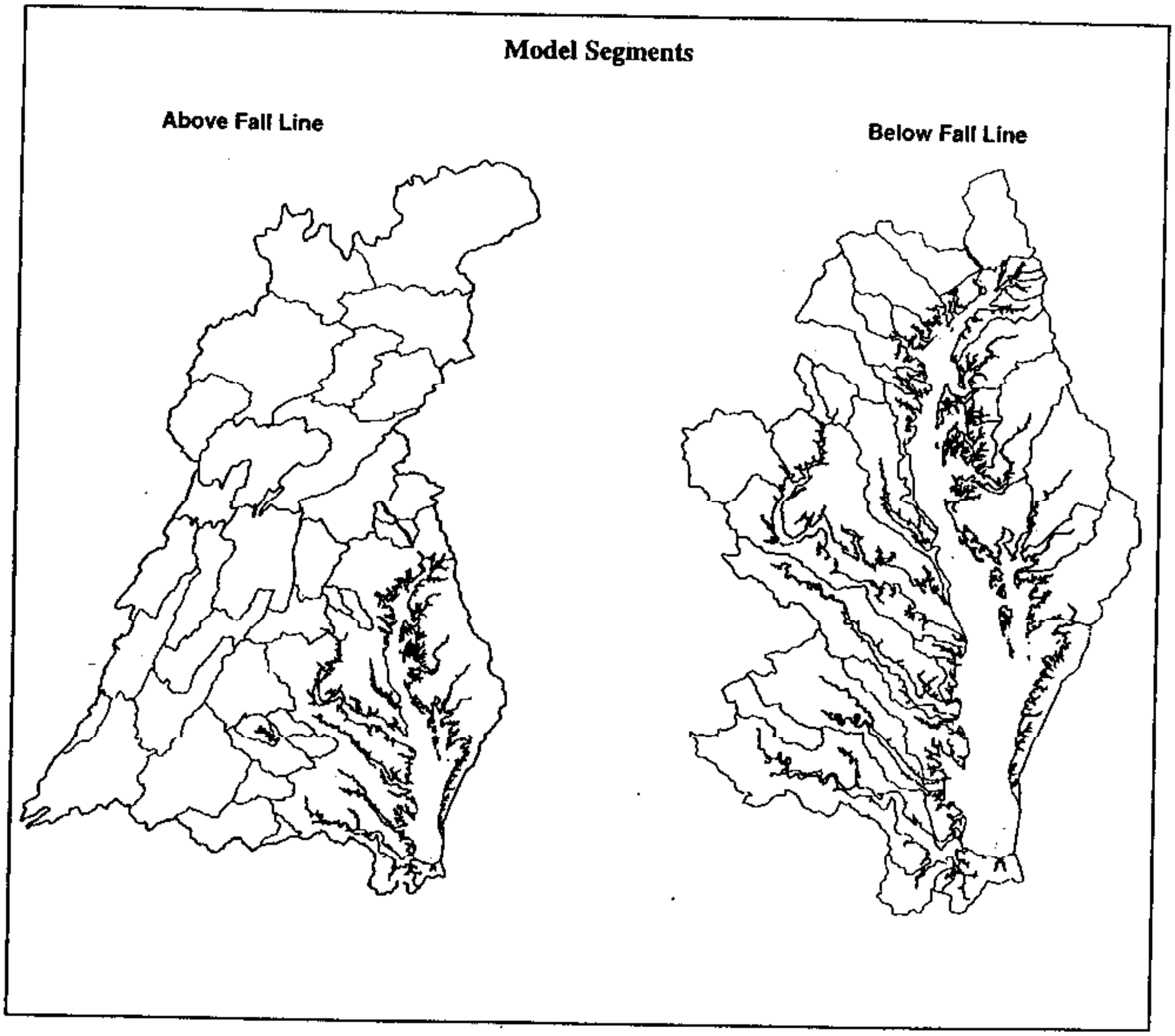

Figure A5. Model Segments. (Source: Chesapeake Bay Program Office)

The precision of the Watershed Model calibration is seen in how well the predicted nutrient loads correspond with loads derived from monitored water quality. Figure A6 shows the comparison for loads from the Conowingo Dam on the Susquehanna River. The dotted line shows loads taken from a regression equation that relates flows and loads. The solid line shows the predictions of the Watershed Model.

Despite these substantial improvements, the Watershed Model does not have sufficient resolution to target control measures at the sub-basin level. Additional refinements need to be undertaken on the major sub-basins to provide information for watershed-specific management decisions.

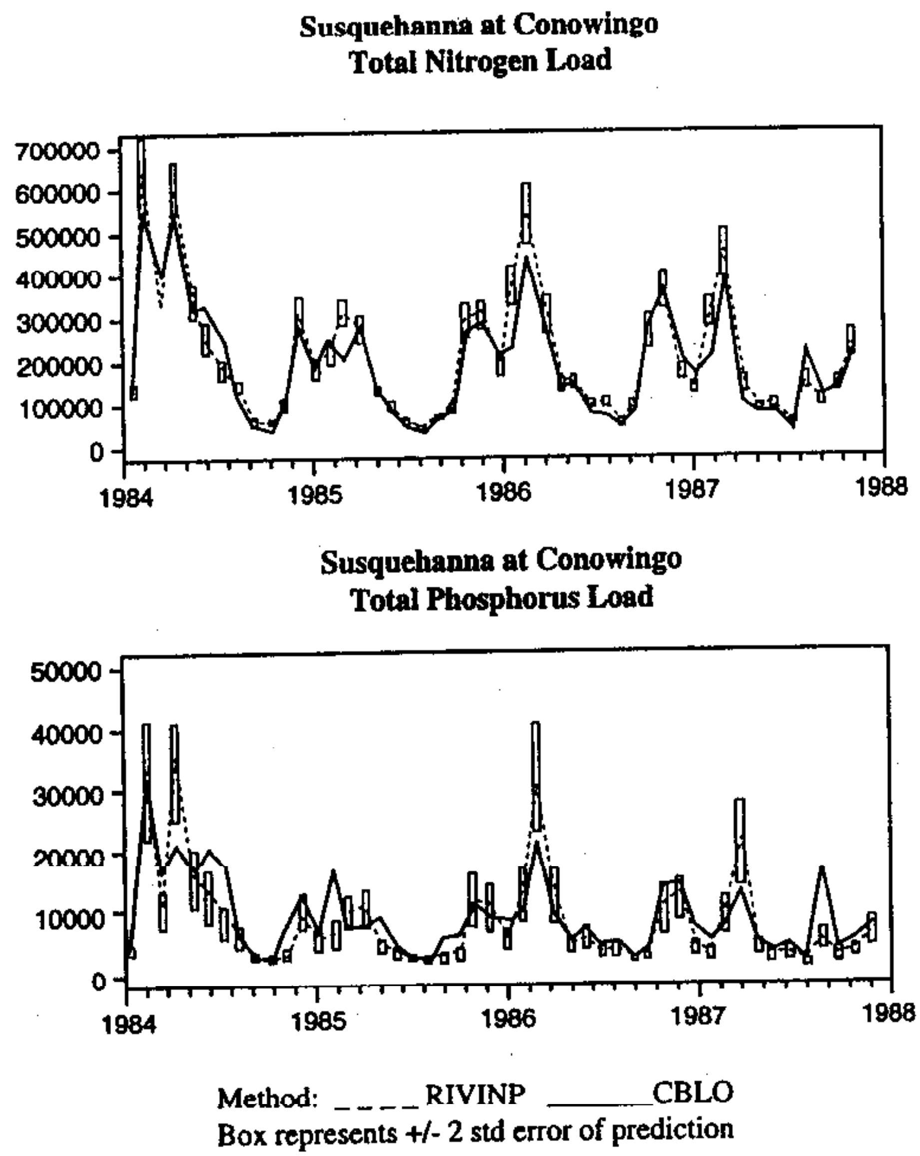

Figure A6. Susquehanna at Conowingo. Total Nitrogen and Total Phosphorus Loads. (Source: Maryland Department of the Environment)

Creating the 3-D Water Quality Model

The Chesapeake Bay Water Quality Model (3-D Model) predicts the water quality response of the Bay to changes in nutrient loadings due to pollution control efforts. The model is composed of two components:

The Hydrodynamic Component

Water quality in the Chesapeake Bay is very dependent on physical processes such as flow and circulation patterns, mixing and dispersion, water temperature, and salinity distribution. As an example, the degree of stratification due to the vertical salinity distribution is a major factor contributing to low dissolved oxygen in the bottom waters of the Bay. To properly represent these physical processes in the water quality component, it was essential to develop a hydrodynamic component. The development of a hydrodynamic component was initiated during modeling efforts prior to 1988, but the time frame did not allow its successful completion.

The hydrodynamic component of the tidal Chesapeake Bay is represented by 3948 computational cells, 734 horizontal cells, and between 2 to 15 vertical layers. Grid resolution is approximately 10 km longitudinally, 3 km laterally, and 1.52 m vertically (Figure A7). The hydrodynamic component requires input of flow rates at the fall line, wind distribution throughout the tidal Bay, and tidal heights and salinities at the ocean boundary. The output from the component model is currents, temperature, and salinity at each of these cells. The hydrodynamic component was calibrated and validated using data from 1980, 1983 and 1984 through 1986.

The Water Quality Component

The water quality component uses the same segmentation scheme as the hydrodynamic component (see Figure A7), and requires information from both the Watershed Model and the hydrodynamic component. The water quality component solves mathematical equations that represent the physical, chemical, and biological interactions among twenty two primary water quality parameters. This model component was validated using monitoring data collected from 1984 through 1986.

Measures of nutrient fluxes to the water column from the sediment layer are obtained through a sediment sub-model which interacts continuously with the water quality component. Through settling, the sediment receives particulate organic matter (carbon, nitrogen, phosphorus and silica) from the water column. The particulate matter is converted to soluble end products through mineralization. The difference between the concentrations of the nutrients in the sediment and in the water column determines the magnitude and direction of the fluxes.

Chesapeake Bay Hydrodynamic and Water Quality Model Grid

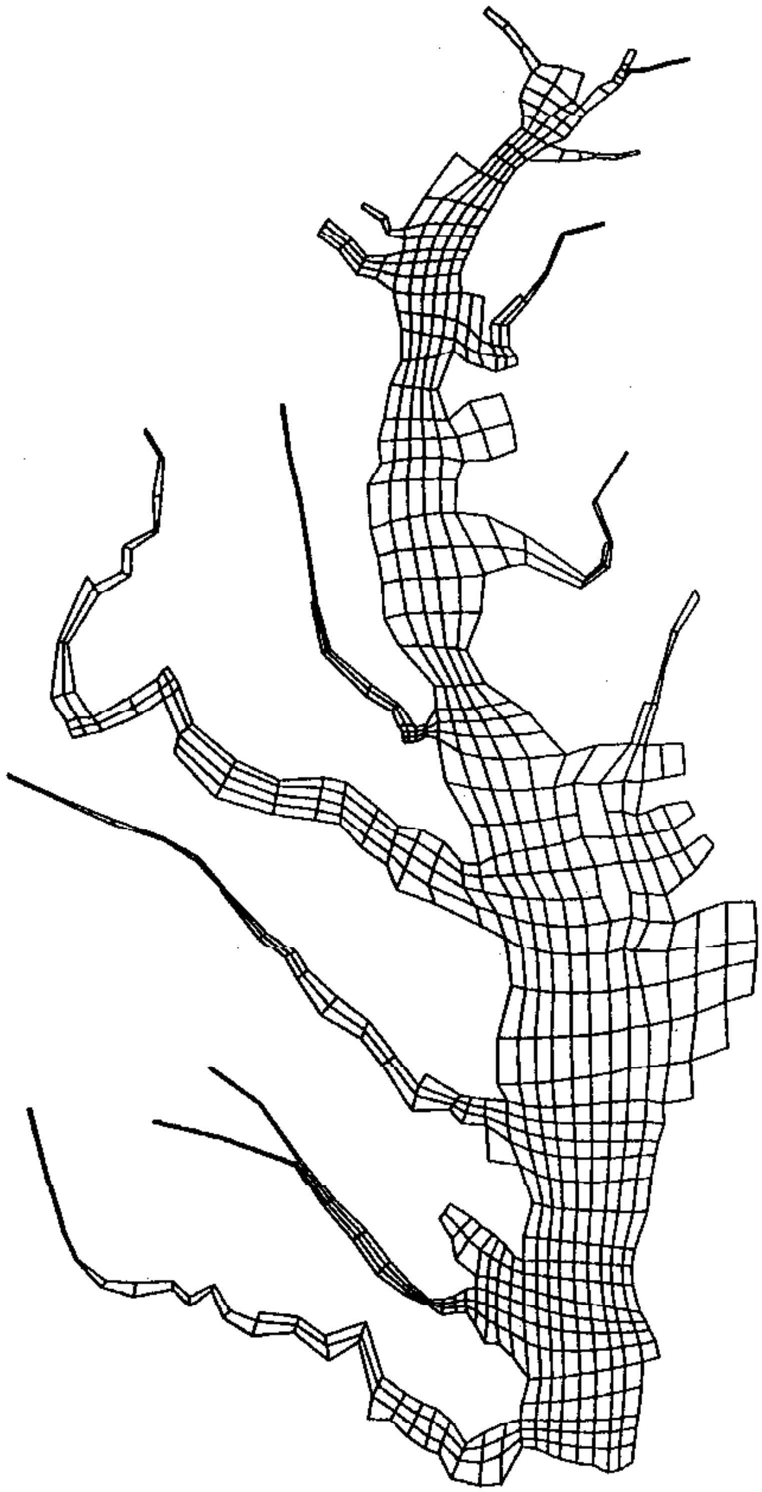

Figure A7. Chesapeake Bay Hydrodynamic and Water Quality Model Grid. (Source: U.S. Army Corps of Engineers)

Simulating Future Water Quality

The simulations are constructed under a series of common assumptions that provide a basis for comparing the relative response between different nutrient loading patterns. These assumptions are summarized as follows:

1. The change in nutrient loading to the Bay is assumed to occur instantly and to continue at the new level.

2. The model is run for ten years at the new loading rate with a consistent pattern of changing hydrologic conditions. For each simulation, a ten year hydrologic sequence representing the Bay hydrology from 1979 to 1988 was constructed from hydrologies typical of wet, average, and dry years. A wet year was represented by 1984 hydrology, an average year by 1986 hydrology, and a dry year by 1985 hydrology. The river flows delivering nutrients to the Bay during the decade ending in 1988 were simulated by assembling a sequence of wet, average, and dry hydrologies to approximate what actually occurred. The hydrology sequence for the scenarios is shown in Table A2.

Year	Condition
1979	Wet
1980	Dry
1981	Dry
1982	Average
1983	Average
1984	Wet
1985	Dry
1986	Average
1987	Average
1988	Dry

Table A2. Hydrology Sequence Used in the Ten Year Simulation. (Source: Modeling Subcommittee)

3. Ocean boundary nutrient concentrations were initially set at observed 1984-1986 values, and they had a significant impact on the Bay's phosphorus levels. Later runs reduced ocean boundary concentrations by amounts expected from reduced phosphorus discharges in the Chesapeake Bay watershed. The final version of the 3-D Model will have ocean boundary concentrations which will be adjusted internally within the model run in response to load reduction scenarios. Methods of computing this interaction continue to be refined.

4. Each scenario is evaluated based on the ninth year of the ten year simulation. Though this year does not represent the hydrologic conditions used to establish the baseline load reductions (determined by the Watershed Model), it is the year within the 3-D Model simulation period that is most like the long term average flow.

Description of Preliminary Scenarios and Nutrient Loadings

To date, a total of seven sensitivity runs have been made using the preliminary calibrated model of the Bay. The scenarios were chosen to provide initial results for a range of loading conditions, not all of which are technologically achievable. Several sensitivity runs were included to test the behavior of the model under a wide range of load changes. Others were included to provide estimates of base case, forest, and controllable loads. For all scenarios, the ten year hydrology sequence previously discussed was applied. The first five years of the simulation equilibrate the sediment to the sensitivity run loads. Analysis is focused on the last five years of the sensitivity run. Special emphasis is given to the ninth year in this report because it was near average conditions. Also, ocean boundary conditions representative of 1984-1986 observed conditions were used for all scenarios except numbers 3, 6 and 7 which test the lower ocean concentrations expected to result from reduced Bay nutrient discharges. The scenarios are described in Table A3.

Scenario Number	Name	Description
1	No action	120% of base case loads simulating the continuing growth of pollution sources.
2	Base case	1984-1986 loads serving as the program's starting point.
3	40% -B Reduction	60% of the load difference between base case and Forest Ref. #1
4	Forest Ref. #1	All forest in signatory states
5	Forest Ref. #2A	All forest in all states, no atmospheric input to the tidal Bay
6	Forest Ref. #2B	Same as Forest Ref. #2A but reduced ocean nutrients levels
7	90% Reduction	Approximately 90% reduction of base case loads, no atmospheric input to the tidal Bay

Table A3. Completed Scenario Runs. (Source: Modeling Subcommittee)

Figure A8 shows the relative nitrogen and phosphorus loads in each of these simulations. The percent load reductions shown in this figure are different from the reductions implied by some of the names assigned to the simulation because the hydrology simulated in the ninth year was not identical to hydrology used to define the conditions of the simulation.

The nitrogen and phosphorus loading changes for each of these seven simulations are shown in the figure below. The loads shown are input loads that originate from the air and land. These include loadings from tributaries at the fall line, point and nonpoint sources originating below the fall line, and atmospheric sources.

The model brings in other sources such as those that enter the water column from the sediments and the loads that intrude into the Bay from the ocean. These loads are important, and they vary as a function of reductions in loads from the land and air. The sediment and ocean loads will be depicted in later reports.

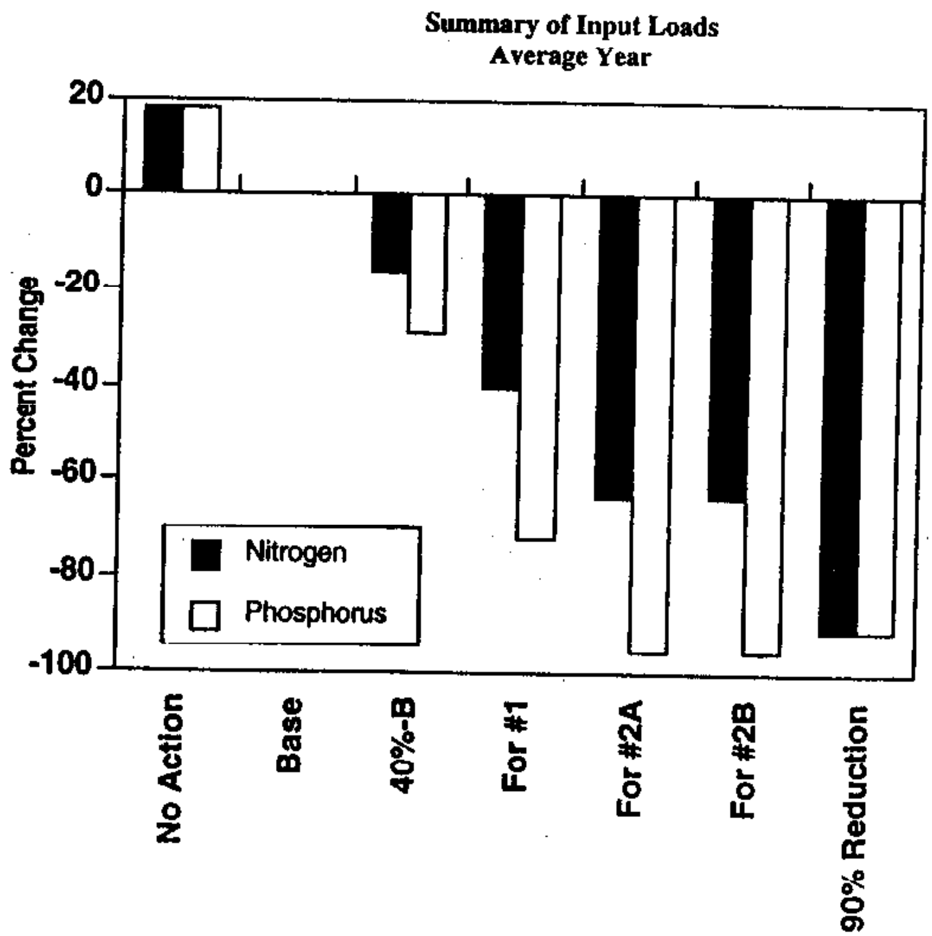

Figure A8. Average Year of Simulation - Input Loads Only. (Source: Dr. Robert V. Thomann, 1991)

Some observations about these simulations include:

- The 40% reduction scenario (the current nutrient reduction goal) will result in a relatively small decrease in nitrogen loading (18%). Phosphorus reduction will be higher (29%). The reason for the small nitrogen decrease is the relatively high nitrogen loading attributed to atmospheric deposition.

- The 90% load reduction simulation approximates natural background nitrogen loading for all basin states. [24]

Other observations include:

- The relative contribution of the ocean boundary loads is significant and becomes more important as upstream loads of phosphorus and nitrogen are simulated to decrease.

- The nitrogen and phosphorus load from the non-signatory states can be calculated from the information contained in Table 1a and 1b (see Chapter 2). Without considering atmospheric deposition which originates both within and outside of the watershed, non-signatory states contribute about 11% of the total nitrogen load and 8% of the total phosphorus load. This is 18% of the controllable nitrogen and 11% of the controllable phosphorus discharged in the states that are party to the Chesapeake Bay Agreement.

- Direct atmospheric deposition of nitrogen to Bay surface waters (34.6 million lbs/year), is quite large. Successful implementation of the 40% nitrogen reduction goal will remove 70.1 million lbs/year of nitrogen from land-based sources. This reduction is only twice as large as the nutrient load deposited from the atmosphere to tidal waters.

Summary of Simulated Water Quality Responses

There are several possible measures to evaluate the simulated responses of the main Bay to the loading reductions. The emphasis in this review will be on the dissolved oxygen (DO) response.

Measuring other indices of dissolved oxygen responses also provide useful ways to interpret progress. The length of time that the Bay has DO less than 1 mg/l, and the volume over which this condition is experienced can be expressed as anoxic volume-days. This measure is expressed as a percent of change from the base case.

Figure A9 shows the response for the second measure, the percent change in anoxic volume-days projected through the simulations. In the "no action" alternative, the volume-days below 1 mg/l would increase by about 8% while the 40% Reduction simulation reduces the anoxic volume-days by between 15 and 25%. Note that the 90% reduction scenario nearly eliminates the anoxic volume-days, indicating that at no time or place was the DO calculated to be below 1 mg/l. This figure is presented with a range of hydrologic conditions, showing the variations in control effectiveness that are experienced under different conditions. In general, the percent reduction in anoxic volume for these simulations is less than the percent reduction in nitrogen and phosphorus loading. This is believed to be due to the influence of phosphorus release from sediment.

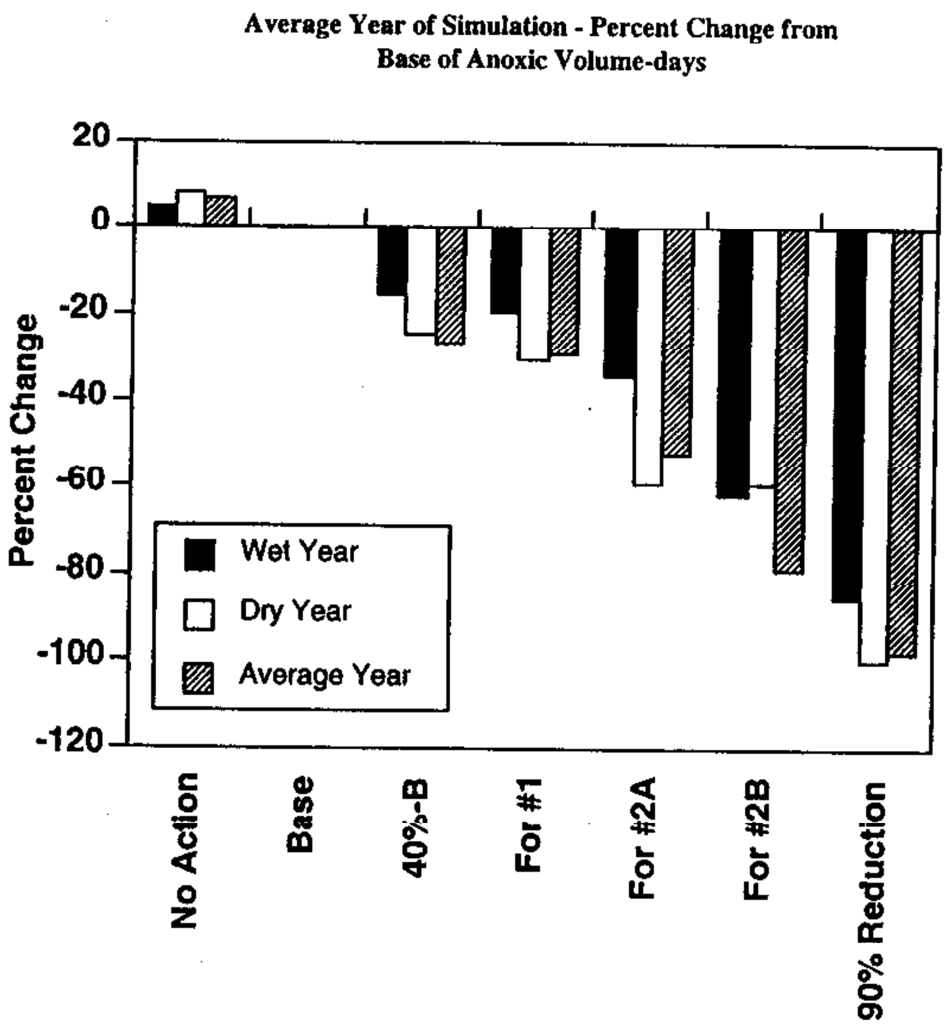

Figure A9. (Source: Dr. Robert V. Thomann, 1991)

The preliminary conclusions emerging from the analyses of these simulations are:

1. If nutrient loads were allowed to increase by 20% over current levels (the "no action" case) the overall extent and duration of poor DO are expected to deteriorate and water quality would be further degraded.
2. Under the 90% load reductions scenario (which approximates natural background nutrient loads typical of colonial times), anoxia probably did not exist to any substantial degree.
3. A 40% reduction of controllable loads provides a modest 15 to 26% improvement over current anoxic volume-days, but a substantial improvement over the "no action" case.
4. For greater improvements in DO, additional load reductions will be necessary.
5. Such additional load reductions might include application of increased technological control on point and nonpoint nutrient sources, reductions in atmospheric nitrogen deposition, and reductions of nutrient loads in non-signatory states.

Technology Effectiveness and Cost for Nutrient Load Reductions

Point Source Control Technology

A special assessment reviewed available point source nutrient removal technologies including performance data from full-scale, conventional wastewater treatment plants operating in the region and from both full scale and pilot advanced nutrient removal plants constructed and operated under the Baywide Nutrient Reduction Strategy. Expected effluent levels for phosphorus and nitrogen removal were developed for two averaging periods: long-term (annual averages) and short-term (monthly averages) commonly used in regulatory controls[12]. The results of these analyses have been agreement on the costs and performance of these technologies.

Nonpoint Source Control Technology

Management investigations have been undertaken which lead us to better understand the costs and effectiveness of nonpoint source nutrient control measures so that we can better apply them in the future. They have:

- confirmed the long useful lives of BMPs;
- developed consistent methodologies for groundwater nutrient contributions to the Bay; and,
- examined the effectiveness of voluntary nonpoint source implementation.

Cost effectiveness is defined as the ratio of the cost per pound of nutrient removed per year. The nutrient removal effectiveness and relative costs of point and nonpoint source technologies were also extensively studied in the reevaluation process. A method was developed for using this information in conjunction with the Chesapeake Bay Watershed Model. The method will allow relative cost comparisons of nutrient reduction scenarios to determine cost effective strategies for point and nonpoint source nutrient reduction.

Process and Approach

Point Source Control Costs

The focus of the analysis was on the financial cost effectiveness of upgrading municipal wastewater treatment plants for nutrient removal since this represented the largest source of nutrients among the point sources. The bases for the cost estimates were extensive studies undertaken as the original Baywide Nutrient Reduction Strategy was being prepared.[27,28,29,30,31]

- For nitrogen removal retrofits, the selection of chemical addition (methanol) or biological nitrogen removal without the use of chemicals will depend on site-specific constraints. Therefore, despite the cost effectiveness of biological nitrogen removal, it cannot be concluded that nitrogen removal without the use of chemicals should be the technology of choice for retrofitting all municipal treatment plants.
- Seasonal nitrogen removal may be more cost effective than annual removal. Costs can significantly increase for annual removal because at lower temperatures biological processes require longer wastewater retention times. Longer retention times require larger reactor tank sizes thereby increasing costs.
- Biological Phosphorus Removal (BPR) can be a cost effective alternative for phosphorus removal (Figure A10). It has potential for cost savings in chemical use and sludge handling. However, plants that implement BPR technologies may require chemical phosphorus removal facilities to comply with permits mandating effluent requirements below 1.0 mg/l.

Nonpoint Source Control Costs

The reevaluation focused on the financial cost effectiveness of agricultural and urban Best Management Practices (BMPs).

Watershed Model runs were used to determine the aggregate nutrient reduction for each control scenario. Nutrient reductions for each scenario were calculated as the difference between the loads generated by a particular scenario and the "base case" model run.

The cost effectiveness of individual nonpoint source control practices should not be judged only on their individual performance, but rather as combinations of BMPs aggregated into "Resource Management Systems" that together reduce the pollutant loads.[33] Different BMPs remove different proportions of nitrogen and phosphorus, and some are more effective in some settings than others. Controls, for instance, that work on the principle of retaining storm flows to reduce soil erosion and phosphorus pollution may shunt nitrogen to the ground water where it will eventually be transported into the Bay. For this reason, the aggregate performance and cost of an entire system must be examined before its combined merits can be fully assessed. The Watershed Model provides a mechanism for doing this.

A cost effective Resource Management System, however, must be comprised of efficient and low cost components. Preliminary cost effectiveness ratios for point and nonpoint source nutrient reduction controls are summarized for use in assembling these systems (see Figure A10). The relative costs and performance of resource management systems make them powerful tools in guiding future nutrient reduction programs.

Nutrient Control Costs for Nitrogen and Phosphorus Removal

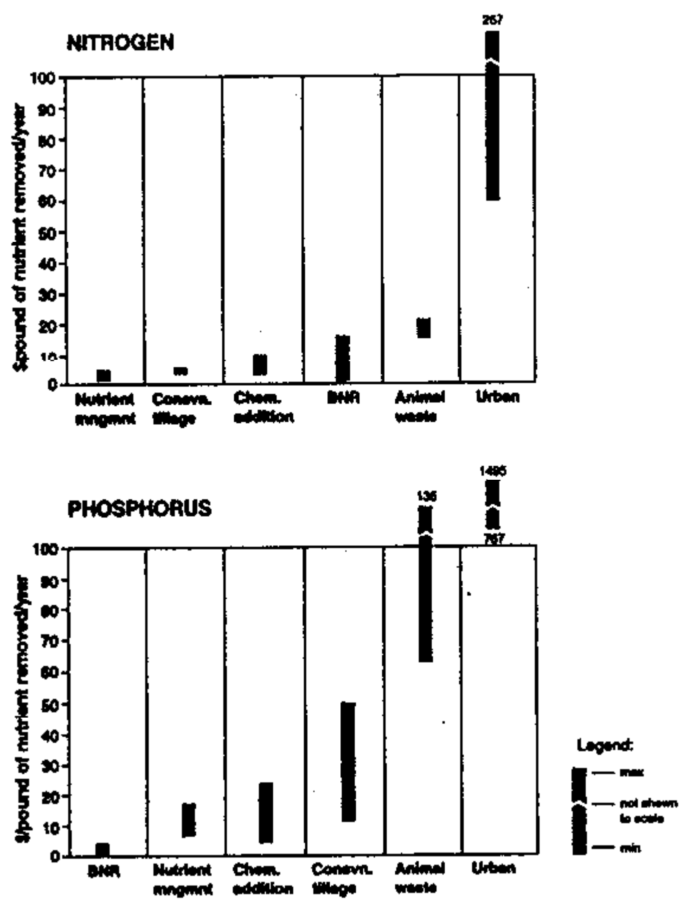

Figure A10. Comparative Nutrient Control Costs for Nitrogen and Phosphorus Removal Per Year. (Source: see reference 26)

- Results of the Watershed Model show nutrient management to be the most cost effective control technology . Other technologies in combination with in-field BMPs such as conservation tillage and winter cover crops are cost effective management alternatives for nutrient reduction.

- Winter cover crops are very effective in removing excess nitrates during the cold season.

- Conversion of highly erodible land to permanent vegetation is cost effective since vegetation can considerably reduce sediment erosion, runoff, and nutrient loads entering the water.

- Animal waste has been identified as a significant contributor of nutrient loads to the Bay. Although the cost is high, animal waste management systems should be considered important components of "Resource Management Systems." More emphasis should be given to reducing these costs.

- Preliminary results show urban BMPs to be the least cost effective nutrient control technology, however some urban BMPs have other important functions which were not addressed in this report.[37]

The analysis of technology effectiveness and costs of nutrient removal provides the basis upon which the most cost effective nutrient controls can be selected. It cannot be used to predict the absolute cost of implementation of nutrient removal programs. Those costs will depend on factors such as local/state/federal government cost share programs, schedule of implementation, and other factors, in addition to site-specific conditions which can significantly affect costs and the application of nutrient removal technologies.[26] The potential economic benefits of nutrient reduction programs have been demonstrated. These benefits were not evaluated but may need to be factored into an implementation plan.

GLOSSARY

Algae: Any of a group of aquatic plants, including phytoplankton and seaweeds, ranging from microscopic to several meters in size.

Anoxia: Total absence of dissolved oxygen in water.

Anoxia Volume-Day: A unit that represents a cubic meter of water which has a daily mean dissolved oxygen concentration less than 1.0 mg/l. Used as a metric of annual anoxia in the Bay when the anoxic volume of each day of the June to October season is summed.

Atmospheric Deposition: The accretion of chemicals including nitrogen and phosphorus attached to dust materials during dry weather or as part of raindrops during wet weather, which deposit onto the land or water surfaces from the air.

Baseline Loading: The mass of nutrients (measured in pounds or kilograms) which is delivered to the Bay from the basin, under the conditions of population, land use, and point sources in 1985. Nonpoint sources considered a part of baseline loading were computed as the average of loads washed from the land surface by storms and river flows monitored in 1984 through 1987.

Best Management Practices (BMPs): Pollution control techniques developed by farmers, scientists and administrators for managing nonpoint source nutrient discharges into the Bay and its tributaries. BMPs cover two broad areas of management: constructing facilities to contain nutrients, and employing farming practices that decrease the use and/or runoff of fertilizers and manure.

Biological Nutrient Removal (BNR): Wastewater treatment processes that (1) create specific biological environments which enhance phosphorus removal; and, (2) utilize chemical energy drawn from the wastewater itself to remove nitrogen.

Biochemical Oxygen Demand (BOD): A measure of the quantity of dissolved oxygen removed from water by the metabolism of microorganisms. Excessive BOD results in oxygen-poor water.

Blooms: Excessive growth of plankton in concentrations sufficiently dense to cause discoloration of water and reduced light penetration.

Characterization: The process of bringing together a number of information sources to synthesize overall patterns or make a statement of current conditions.

Chesapeake Bay Program: The ongoing restoration and protection program for the Chesapeake Bay conducted through the cooperation of Pennsylvania, Maryland, Virginia, the District of Columbia, federal agencies, and the Chesapeake Bay Commission consisting of legislators, the governors and citizens from the three states. The Chesapeake Bay Program was established with the historic signing of the 1983 Chesapeake Bay Agreement.

Chesapeake Executive Council: Composed of the governors of Pennsylvania, Maryland, and Virginia, the mayor of the District of Columbia, the chairperson of the Chesapeake Bay Commission, and the Administrator of the U.S. Environmental Protection Agency. The Council establishes the policy direction for the restoration and protection of the Chesapeake Bay and its living resources.

Chlorophyll: Green pigment in plants that is essential for photosynthesis. One type of the pigment (chlorophyll *a*) is commonly used as a measure of phytoplankton abundance.

Compliance: Conformance to the rules and regulations regarding wastewater discharges into the Bay and its tributaries.

Conservation Tillage: In agriculture, the utilization of a tillage system appropriate for the soil properties, climate, and farming system that is also compatible with the goals of reduced soil erosion and effective nutrient application.

Control Program: The methods used to reduce nutrient releases from both point sources and nonpoint sources into the Bay and its tributaries.

Controllable: Those sources of nutrients that arise or result from the impact of human activities and are not attributable to background loads. "Controllable" does not imply that these loads are scheduled for control or that they can all be managed, only that they can be controlled given the technologies available. When the term was defined in the Nutrient Reduction Strategy arising from the 1987 Chesapeake Bay Agreement, neither atmospheric sources of nitrogen nor land-based sources outside of Chesapeake Bay Program states were considered in this definition though they may be amenable to control.

Conventional Pollutants: Pollutants typically discharged by municipal sewage treatment plants and a number of industries. The category includes wastes with a high biochemical oxygen demand (BOD), total suspended solids, fecal coliform, pH, and grease and oil.

Dissolved Oxygen (DO): Concentration of oxygen in water, commonly employed as a measure of water quality. Low levels adversely affect aquatic life. Most finfish cannot survive when DO falls below 3 mg/l for a sustained period of time.

Ecosystem: An ecological community consisting of living organisms and their physical and chemical environment.

Effluent: Discharge or emission of a liquid or gas into the environment.

Estuary: A semi-enclosed body of water, connected to the open sea, in which sea water is measurably diluted with fresh water from inland sources.

Fall Line: Area in a tributary where tidal waters meet free-flowing fresh water, often called the "head of tide." In the Chesapeake Bay watershed, the fall line marks the boundary between older, resistant rocks of the Piedmont and younger sediments of the Coastal Plain. This is a transition zone at which water quality is most easily related to the rate of river flow.

Forest Background Loads: The mass of nutrients (measured in pounds or kilograms) which would be delivered to the Bay from the basin if the basin were entirely covered in forest. The forest background loads provide a metric to establish controllable loads.

Ground Water: Subsurface water saturating soil or porous rock which often returns, with its nitrogen loads, to surface streams during dry periods.

Habitat Requirements: The habitat and water quality restoration goals necessary to promote life in and on the Bay.

Hydrodynamic: The motion of the Bay's water, brought about by wind, tide, and density differences. The 3-D Model contains a Hydrodynamic Component which simulates this motion.

Hypoxia: Low levels of dissolved oxygen in water, defined as less than 2 mg/l.

Implementation Committee (IC): Composed of representatives from the signatories to the 1983 Chesapeake Bay Agreement as well as from other federal agencies, the IC is responsible for implementing the policy decisions and technical studies of the Chesapeake Executive Council and for coordinating the restoration and protection activities under the 1987 Chesapeake Bay Agreement.

Light Attenuation: A measure of how quickly light disappears with increasing depth in the water. Low light attenuation means increased levels of light penetrate further down in the water column; also see water clarity.

Living Resources: The plant and animal life of the Chesapeake Bay.

Loading: Quantity of contaminants, nutrients, or other substances introduced to a water body.

Mainstem: The deep mid-channel forming the longitudinal axis of the Bay from the Susquehanna Flats to the Virginia capes. It does not include lower reaches of the Bay's tributaries.

Marine: Pertaining to the ocean or sea.

Mesohaline: Water of medium salinity—5 to 18 parts per thousand.

Meteorological Conditions: Atmospheric phenomena, such as precipitation, wind, and temperature which ultimately drive the surface and ground water flow of water and nutrients.

Model: A simplified mathematical representation of reality. Water quality modeling is used to study Chesapeake Bay processes and project effects of varying environmental conditions or management actions.

Monitoring: Observing, tracking or measuring some aspect of the environment to establish base line conditions and short or long-term trends.

Nitrogen: A nutrient essential for life. May be organic or inorganic (ammonia, nitrate, nitrite). Elemental nitrogen constitutes 78 percent of the atmosphere by volume.

Nonpoint Source Pollution: Toxicants, other contaminants, nutrients, or soil entering a water body from sources other than discrete discharges such as pipes. Includes pollution on the land which originates as atmospheric deposition as well as farm and urban runoff.

NPDES Permits: National Pollutant Discharge Elimination System Permits to discharge treated wastewaters to the waters of the United States issued by either the EPA or the state.

Nutrient Enrichment: Nutrient enrichment increases primary productivity in a water body, resulting eventually in depletion of dissolved oxygen essential to aquatic life (also called eutrophication).

Nutrient Flux: The rate of transfer of nutrients across a surface, usually the sediment/water column interface.

Nutrients: Chemicals required for growth and reproduction of plants. Excessive levels of the nutrients nitrogen and phosphorus can lead to excessive algae growth.

Ocean Boundary: The interface between the Bay and the ocean. In the 3-D Model, it represents the spatial limit of the model's extent.

Oligohaline: Water of low salinity—0.5 to 5.0 parts per thousand.

Phosphorus: A nutrient essential for life found in both organic and inorganic forms.

Phytoplankton: Microscopic plants that live in water such as algae.

Point Source Pollution: Contamination from waste effluent discharged into a water body through pipes or conduits.

Polyhaline: Water with a salinity of 18 to 30 parts per thousand, generally the highest concentrations found in the Bay.

Runoff: Drainage of precipitation over the soil or a non-porous surface (e.g., asphalt) to a stream, river, or other receiving body of water.

Salinity: Amount, by weight, of dissolved salts in 1,000 units of water (reported as parts per thousand).

Sediments: The loose solids, (e.g. soil from erosion or runoff), that settle to the bottom of the Bay or its tributaries and which can be sources of nitrogen and phosphorus.

Signatories: Representatives of Pennsylvania, Maryland and Virginia, the District of Columbia, the Chesapeake Bay Commission, and the U.S. Environmental Protection Agency who signed the Chesapeake Bay Agreements of 1983 and 1987 and are directing the Bay restoration and protection program.

Significant Noncompliance (SNC): Includes instances of NPDES permit violations (e.g. monthly average permit limits) or violation of administrative or judicial orders that meet certain screening criteria for frequency and duration. Permit holders on SNC lists are targeted first for enforcement actions.

Stratification: In Chesapeake Bay, the layering of fresh water over salt water due to differences in relative density and temperature.

Submerged Aquatic Vegetation (SAV): Vegetation that grows underwater along the fringes and in the shallows of the Bay.

Subpycnocline Water: The Bay's water column is separated by a natural boundary, the pycnocline, into a fresher less dense surface layer and a more dense saltier lower layer ("subpycnocline water") where dissolved oxygen is lower or absent especially during the summer.

Tributary: A stream or river which joins and feeds into a larger stream, river or other body of water.

Turbidity: Reduction of water clarity caused by suspended sediments and organics in the water.

Wastewater Treatment: Processes to remove pollutants, commonly categorized as primary, secondary, and advanced levels of treatment.

Water Clarity: A general term which describes the transparency of water in an aquatic system. Water clarity is reduced with increased amounts of particulate materials (e.g., suspended sediments) in the water column; also see light attenuation.

Water Column: A vertical extent of water reaching from the surface to the bottom substrate of a water body.

Water quality: Status or condition of a water body in terms of defined variables characterizing the "health" of the water.

Watershed: Area drained by a river system or other water body.

Zooplankton: Animal plankton of widely varying size that drift or swim weakly in the water. They consume the primary producers and are a second link in the food chain or food web.

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