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Chesapeake Bay Program Office

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Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability

October 2003

Foreword

In April 2003, the U.S. Environmental Protection Agency (EPA) Region III issued guidance entitled *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries* (*Regional Criteria Guidance*). The development of the *Regional Criteria Guidance* was the realization of a key commitment in the *Chesapeake 2000* agreement. In that agreement, the signatories (the states of Pennsylvania, Maryland and Virginia; the District of Columbia; the Chesapeake Bay commission and the EPA) committed to, "by 2001, define the water quality conditions necessary to protect aquatic living resources." New York Delaware and West Virginia agreed to the same commitment through a separate six-state memorandum of understanding with the EPA.

The EPA, in the *Regional Criteria Guidance*, defined the water quality conditions called for in the *Chesapeake 2000* agreement through the development of Chesapeake Bay-specific water quality criteria for dissolved oxygen, water clarity and chlorophyll *a*. The EPA also identified and described five habitats, or designated uses, that provide the context in which the EPA Region III derived adequately protective Chesapeake Bay water quality criteria for dissolved oxygen, water clarity and chlorophyll *a*. Collectively, the three water quality conditions provide the best and most direct measures of the effects of too much nutrient and sediment pollution on the Bay's aquatic living resources—fish, crabs, oysters, their prey species and underwater bay grasses. These criteria were developed as part of a larger effort to restore Chesapeake Bay water quality.

The *Technical Support Document for the Identification of Chesapeake Bay Designated Uses and Attainability* (*Technical Support Document*) was developed by the EPA and its watershed partners to be a companion document to the *Regional Criteria Guidance*. Because it describes the development and geographical extent of the designated uses to which the water quality criteria may apply, the *Technical Support Document* serves as a resource to the states to assist them in the development and adoption of refined water quality standards. Specifically, the EPA developed the

Technical Support Document to help states in conducting use attainability analyses (UAA) which they may conduct as part of their water quality standards development and adoption processes.

The *Technical Support Document* is not law or regulation; it is guidance that states in the Chesapeake Bay watershed may consider in the development and adoption of revised water quality standards.

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Executive Summary

In May 2003, the U.S. Environmental Protection Agency (EPA) Region III issued guidance entitled *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries* (*Regional Criteria Guidance*). The EPA developed this guidance to achieve and maintain the water quality conditions necessary to protect aquatic living resources of the Chesapeake Bay and its tidal tributaries. The *Regional Criteria Guidance* is intended to assist the Chesapeake Bay jurisdictions—Maryland, Virginia, Delaware and the District of Columbia—in adopting revised water quality standards to address nutrient and sediment-based pollution in the Chesapeake Bay and its tidal tributaries. Part of the jurisdictions' water quality standards development process may be to conduct use attainability analyses (UAAs). The EPA developed the *Technical Support Document for Identifying Chesapeake Bay Designated Uses and Attainability* (*Technical Support Document*) to assist states in developing their individual UAAs.

The UAA process is traditionally conducted by individual states. However, the multi-stakeholder body that guided the development of the water quality criteria for the Chesapeake Bay, the Water Quality Steering Committee, determined that providing UAA-related information on a watershed-wide scale would help promote coordination and consistency across all jurisdictions. To that end, the *Technical Support Document* provides a compilation of the basinwide analyses assimilated collaboratively by the affected jurisdictions. The *Technical Support Document* is not a regulation or a mandatory requirement. Rather, the EPA encourages the jurisdictions to use the information in this document and, when appropriate, to perform additional analyses tailored to each jurisdiction during their respective water quality standards development processes.

In providing technical background information for the Bay jurisdictions to use in their own UAAs, the *Technical Support Document* explains and documents why it appears that the current designated uses for aquatic life protection cannot be attained in all parts of the Chesapeake Bay and its tidal tributaries. The *Technical Support Document* provides scientific data showing that natural and human-caused conditions that cannot be remedied are the basis for the nonattainment and proposes refined designated uses for the states to consider during their upcoming water quality standards development and adoption processes. The document also provides scientific data indicating that the refined designated uses are viable in many areas of the Chesapeake Bay and its tidal tributaries and documents that the refined designated uses protect existing aquatic life uses. Finally, the document briefly summarizes economic analyses performed by the Chesapeake Bay Program, including estimates of the cost of implementing three of the four levels of control scenarios.

REGULATORY BACKGROUND

The Water Quality Standards Regulation (40 CFR 131.3) defines a UAA as ". . . a structured scientific assessment of the factors affecting the attainment of a use which may include physical, chemical, biological, and economic factors. . . ." (40 CFR 131.10[g]). The Water Quality Standards Regulation requires a state to conduct a UAA when it designates uses that do not include those specified in Section 101(1)(2) of the Federal Water Pollution Control Act .[1] A state must also conduct a UAA when it wishes to remove a specified designated use of the Federal Water Pollution Control Act or adopt subcategories of those specified uses that require less stringent criteria.

When conducting a UAA, a state must demonstrate that attaining the designated use is not feasible due to one or more of six factors specified in Section 131.10(g) of the Water Quality Standards Regulation. These factors are:

1. Naturally occurring pollutant concentrations prevent the attainment of the use;
2. Natural, ephemeral, intermittent, or low-flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of a sufficient volume of effluent without violating state water conservation requirements to enable uses to be met;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modifications in a way that would result in the attainment of the use;
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles and the like, unrelated to chemical water quality, preclude attainment of aquatic life protection uses; and

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[1] Section 101(a)(2) of the Federal Water Pollution Control Act states that "...it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983."

6. Controls more stringent than those required by sections 301(b)(1)(A) and (B) and 306 of the Act would result in substantial and widespread economic and social impacts.

The Water Quality Standards Regulation also specifies that any change in designated uses must show that the existing uses are still being protected. The EPA's 1983 *Water Quality Standards Handbook* provides two definitions for an existing use. First, an existing use can be defined as fishing, swimming or other uses that have actually occurred since November 28, 1975. The second definition of an existing use is that the water quality of a water body is suitable to allow the use to be attained—unless there are physical problems, such as substrate or flow, that prevent use attainment. The Water Quality Standards Regulation, in turn, requires state anti-degradation policies to protect existing water quality. Therefore, any recommendations regarding refined designated uses for the Chesapeake Bay and its tidal tributaries must ensure that existing aquatic life uses continue to be protected.

DOCUMENTING WHY CURRENT DESIGNATED USES MAY NOT BE ATTAINABLE

The determination documented in the *Technical Support Document* that current designated uses in the Chesapeake Bay and its tidal tributaries may not be attainable is based on two of the six factors noted above—natural and human-caused conditions that cannot be remedied. Output from model-simulated scenarios as well the paleoecological record of the Chesapeake Bay ecosystem both provide evidence that these two conditions prevent attainment of current designated uses.

To understand the feasibility of attaining current designated uses in the Chesapeake Bay and its tidal tributaries, the Chesapeake Bay Program developed three watershed modeling scenarios: 'all-forest,' 'pristine' and 'everything, everywhere by everyone,' or the E3 scenario. The 'all-forest' and 'pristine' scenarios represent the Chesapeake Bay Program's best effort to simulate water quality conditions prior to European settlement and, in so doing, help characterize existing, naturally occurring pollutant concentrations that prevent attainment of current designated uses. To represent human-caused conditions that cannot be remedied and to determine the upper boundaries of the watershed's technological capability for reducing nutrient and sediment pollution, the Chesapeake Bay Program also developed the E3 scenario, which the watershed partners consider physically implausible.

Figure 1 illustrates the results of these three model scenarios, which show that significant portions of the deep channel and deep waters of the Chesapeake Bay and its tidal tributaries cannot meet a dissolved oxygen concentration of 5 mg/l. For the pristine scenario, on a baywide basis for all tidal-water segments that have deep-channel and deep-water areas, attainment is not achieved for portions (i.e., approximately 3 percent and 1 percent, respectively) of these areas during the summer months. For the E3 scenario, 59 percent, 23 percent and 2 percent

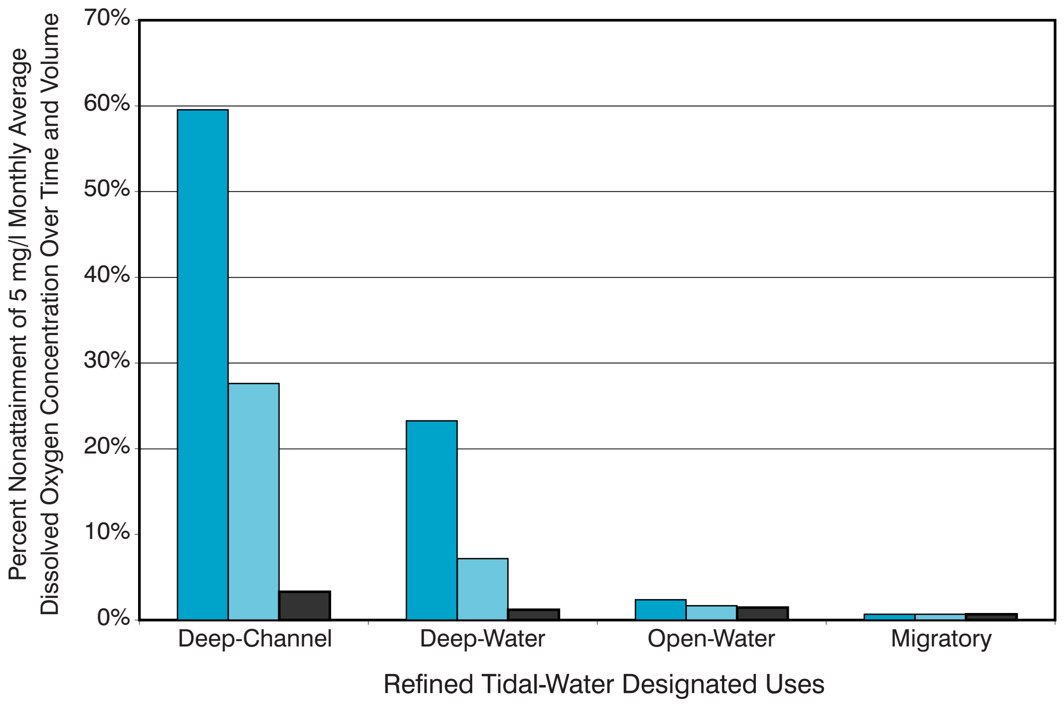

Figure 1. Percent nonattainment of a 5 mg/l monthly average dissolved oxygen concentration over the June through September period for the E3 (physically implausible) (🟦), all-forest (▨) and pristine (■) model scenarios by the refined tidal-water designated uses.

non-attainment are exhibited in the deep-channel, deep-water and open-water areas, respectively, even after implementation of nutrient reduction measures that represent limits of technology.

In addition to modeled information, the Chesapeake Bay Program has evidence from the paleoecological record of the Chesapeake Bay ecosystem to support the concept that natural conditions prevent attainment of current designated uses. An evaluation of this information suggests that the main channel of the Chesapeake Bay most likely experienced oxygen depletion before large-scale post-colonial land clearance took place, due to natural factors such as climate-driven variability in freshwater inflow.

DEVELOPMENT OF THE REFINED DESIGNATED USES

Current designated uses for the Chesapeake Bay and its tidal tributaries do not fully reflect natural conditions and are too broad in their definition of use to support the adoption of more habitat-specific aquatic life water quality criteria. The current uses also change across jurisdictional borders within the same water body. Therefore, in refining the tidal-water designated uses, the six Bay watershed states and the District of Columbia considered five principal factors:

- Habitats used in common by sets of species and during particular life stages should be delineated as separate designated uses;
- Natural variations in water quality should be accounted for by the designated uses;
- Seasonal uses of different habitats should be factored into the designated uses;
- The Chesapeake Bay criteria for dissolved oxygen, water clarity and chlorophyll *a* should be tailored to support each designated use; and
- The refined designated uses applied to the Chesapeake Bay and its tidal tributary waters will support the federal Clean Water Act goals and state goals for uses existing in these waters since 1975.

The five refined designated uses reflect the habitats of an array of recreationally, commercially and ecologically important species and biological communities. The vertical and horizontal breadth of the designated use boundaries are based on a combination of natural factors, historical records, physical features, hydrology, bathymetry and other scientific considerations (Figure 2).

The *migratory fish spawning and nursery designated use* protects migratory and resident tidal freshwater fish during the late winter to late spring spawning and nursery season in tidal freshwater to low-salinity habitats. Located primarily in the upper reaches of many Bay tidal rivers and creeks and the upper mainstem Chesapeake Bay, this use will benefit several species including striped bass, perch, shad, herring, sturgeon and largemouth bass.

The *shallow-water bay grass designated use* protects underwater bay grasses and the many fish and crab species that depend on the vegetated shallow-water habitat provided by underwater grass beds.

The *open-water fish and shellfish designated use* focuses on surface water habitats in tidal creeks, rivers, embayments and the mainstem Chesapeake Bay and protects diverse populations of sport fish, including striped bass, bluefish, mackerel and sea trout, as well as important bait fish such as menhaden and silversides.

The *deep-water seasonal fish and shellfish designated use* protects animals inhabiting the deeper transitional water-column and bottom habitats between the well-mixed surface waters and the very deep channels. This use protects many bottom-feeding fish, crabs and oysters, and other important species such as the bay anchovy.

The *deep-channel seasonal refuge designated use* protects bottom sediment-dwelling worms and small clams that bottom-feeding fish and crabs consume. Low to occasional no dissolved oxygen conditions occur in this habitat zone during the summer.

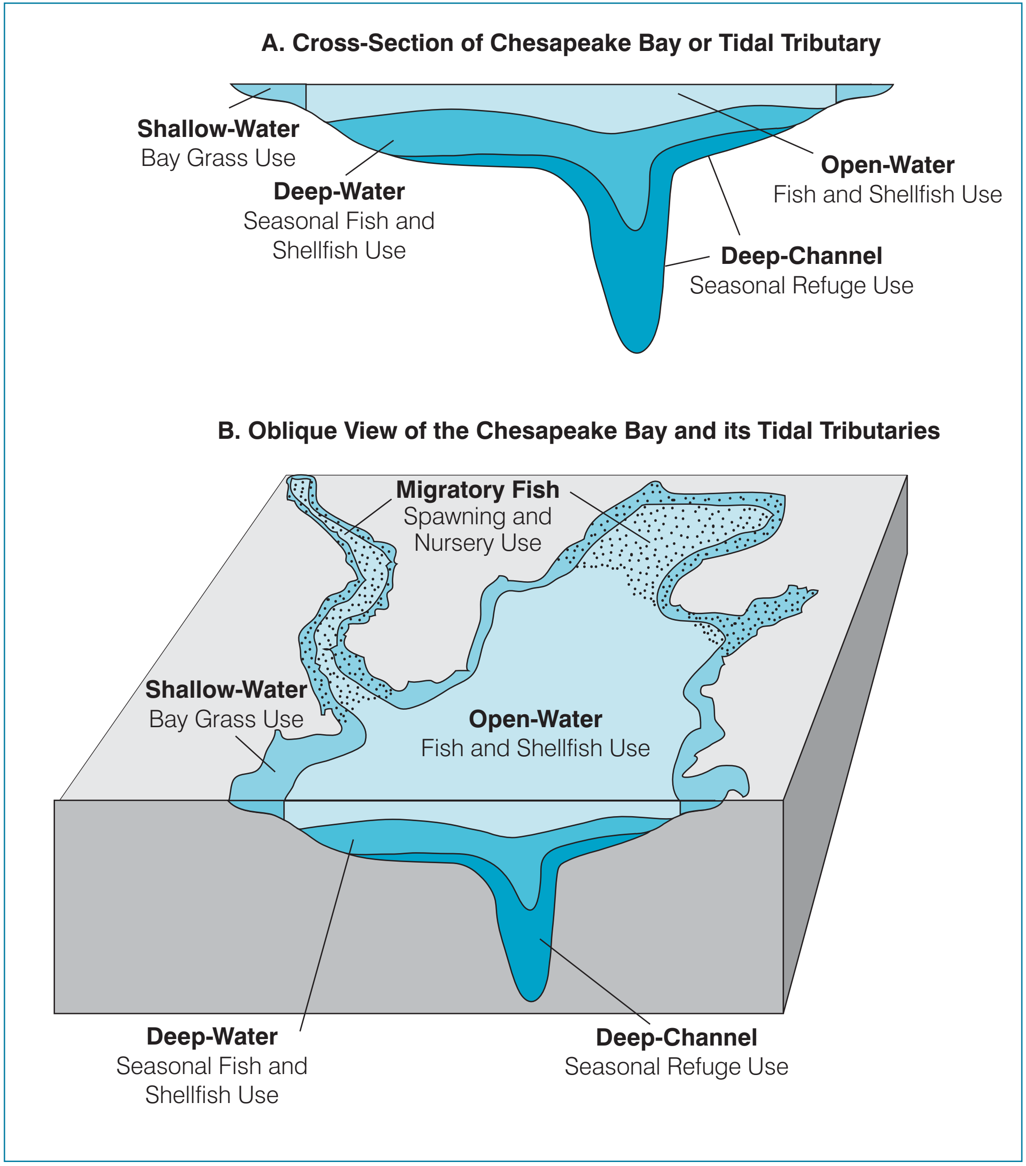

Figure 2. Conceptual illustration of the five Chesapeake Bay tidal-water designated use zones.

ATTAINABILITY OF REFINED DESIGNATED USES

The Chesapeake Bay Program assessed attainability for the refined designated uses based on dissolved oxygen for the migratory and spawning, open-water, deep-water and deep-channel designated uses. Attainability for the shallow-water designated use was assessed based on historic and recent data on the existence of underwater bay grass acreage. The Chesapeake Bay Program did not assess attainability for the chlorophyll *a* criteria, which applies to the open-water designated use, because this criteria is expressed in narrative terms and does not provide a numeric value around which to perform attainability analyses.

For the refined designated uses to which the dissolved oxygen criteria applies, the Chesapeake Bay Program evaluated attainability by comparing the modeled water quality response to a series of technology-based nutrient reduction scenarios. This series of scenarios was developed to represent the watershed's nutrient and sediment reduction potential in terms of the types, extent of implementation and performance of best management practices (BMPs), wastewater treatment technologies and storm water controls.[2] These scenarios range from Tier 1, which represents the current level of implementation plus regulatory requirements implemented through 2010, to a theoretical limit-of-technology scenario referred to as the E3 scenario ('everything, everywhere by everybody'). Tier 2 and Tier 3 are intermediate scenarios between Tier 1 and the E3 scenario. It is important to note that these tiers are artificial constructs of technological levels of effort and do not represent actual programs that the jurisdictions will eventually implement to meet the water quality standards. Rather, the Chesapeake Bay Program developed the tiers as an assessment tool to determine potential load reductions achievable by various levels of technological effort, and to model water quality responses to controls.

The Chesapeake Bay Program used the Chesapeake Bay Watershed and Water Quality Models to determine the water quality response to the pollutant reductions in each scenario (Table 1) and then compared these modeled water quality observations within the five refined designated uses to determine the spatial and temporal extent of nonattainment with the respective dissolved oxygen criteria. Specifically, comparison of model results for dissolved oxygen were made to a monthly average dissolved oxygen concentration of 6 mg/l for the migratory and spawning use, 5 mg/l for the open-water use, 3 mg/l for the deep-water use and 1 mg/l for the deep-channel use.

Table 1. Summary of pollutant loadings that result from applying the load reductions associated with each scenario across all nutrient and sediment sources (except shoreline erosion) in the watershed.

Pollutant	2000 Progress	2010 Tier 1	2010 Tier 2	2010 Tier 3	2010 E3
Nitrogen	284.8	260.9	221.3	180.8	116.4
Phosphorus	19.12	18.96	16.41	13.38	10.10
Sediment	5.044	4.644	4.144	3.625	2.953

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[2] Sediment reduction is only reflected in the scenarios as that incidental to nutrient removal.

MIGRATORY AND SPAWNING DESIGNATED USE

Current monitoring data and Chesapeake Bay Water Quality Model outputs indicate that the migratory and spawning designated use is essentially being attained in the Chesapeake Bay and its tidal tributaries for dissolved oxygen. The few segments that are not fully attaining the dissolved oxygen criterion would fully attain this use in the Tier 1 scenario (lowest level of control technologies).

OPEN-WATER, DEEP-WATER AND DEEP-CHANNEL DESIGNATED USES

Table 2 provides the results of the attainability analysis for dissolved oxygen for the open-water (including shallow-water)[3], deep-water and deep-channel designated uses, by Chesapeake Bay Program segment. As Table 2 illustrates, current monitoring data (presented under the 'observed' column) indicate that the open-water designated use is seldom fully attained. However, at Tier 3, attainment for about 60 percent of the segments is achieved for this refined designated use. In most cases where nonattainment is indicated for open-water at Tier 3, it is less than 2 percent nonattainment, and often, less than 1 percent. For the deep-water designated use for dissolved oxygen criteria, almost no attainment is achieved based on current monitoring data and only some degree of attainment is seen at reduction levels equivalent to Tier 2. At the reduction levels represented by the E3 scenario, attainment is achieved for all segments of the Chesapeake Bay except for one (middle central Chesapeake Bay, CB4MH). Table 2 illustrates that, under observed conditions, the proposed dissolved oxygen criteria are not attained for the deep-channel designated use. With increasing load reductions, however, 100 percent attainment is achieved at the E3 scenario, and, at the levels of reduction represented by Tier 3, percent nonattainment is primarily less than 2 percent.

SHALLOW-WATER BAY GRASS DESIGNATED USE

Attainability for the shallow-water bay grass designated use is based on historic and recent data on the distribution of underwater bay grasses. Detailed analyses using this data—including historical aerial photographs—were undertaken to map the distribution and depth of historical underwater bay grass beds in the Chesapeake Bay and its tidal tributaries. These analyses led to the adoption of the single best year method that considers historical underwater bay grass distributions from the 1930s through the early 1970s as well as more recent distributions since 1978 to present. Using this method, the Chesapeake Bay Program and its watershed partners established a baywide underwater bay grass restoration goal of 185,000 acres. Because of limitations associated with mapping underwater bay grasses using historical photography, the estimate of past underwater bay grass distributions is conservative. Therefore, the restoration goal is conservative as well and considered attainable.

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[3] Because the dissolved oxygen criteria is the same for the open-water as for the shallow-water use, attainability for the shallow-water designated use is presented under the open-water designated use in Table 2.

Table 2. Percent nonattainment of monthly averaged 5, 3 and 1 mg/l dissolved oxygen concentrations applied to open-water, deep-water and deep-channel designated uses, respectively.

	Model Scenarios					
Chesapeake Bay Program Segment	**DU**	**Observed**	**Tier 1**	**Tier 2**	**Tier 3**	**E 3**
Northern Chesapeake Bay(CB1TF)	OW	A	A	A	A	A
Upper Chesapeake Bay (CB2OH)	OW	1.92	0.68	0.43	0.17	A
Upper Central Chesapeake Bay (CB3MH)	OW	A	A	A	A	A
	DW	4.18	2.24	1.61	0.73	A
	DC	13.52	7.21	5.03	1.84	A
Middle Central Chesapeake Bay (CB4MH)	OW	0.05	A	A	A	A
	DW	19.64	14.28	12.05	8.51	0.69
	DC	45.19	28.94	18.81	3.93	A
Lower Central Chesapeake Bay (CB5MH)	OW	A	A	A	A	A
	DW	6.16	3.75	2.58	1.08	A
	DC	13.79	6.00	2.59	0.15	A
Western Lower Chesapeake Bay (CB6PH)	OW	5.87	3.68	2.71	1.30	0.01
	DW	0.36	A	A	A	A
Eastern Lower Chesapeake Bay (CB7PH)	OW	4.55	2.81	1.82	0.74	A
	DW	A	A	A	A	A
Mouth of Chesapeake Bay (CB8PH)	OW	A	A	A	A	A
Upper Patuxent River (PAXTF)	OW	A	A	A	A	0.38
Middle Patuxent River (PAXOH)	OW	9.79	1.84	1.62	0.86	A
Lower Patuxent River (PAXMH)	OW	7.40	1.69	1.04	0.01	A
	DW	5.52	0.82	0.50	0.07	A
Upper Potomac River (POTTF)	OW	A	A	A	A	A
Middle Potomac (POTOH)	OW	2.10	1.08	0.63	0.31	0.01
Lower Potomac (POTMH)	OW	0.78	A	A	A	A
	DW	6.90	4.53	3.11	1.12	A
	DC	18.89	8.64	5.07	0.19	A
Upper Rappahannock River (RPPTF)	OW	A	A	A	A	A
Middle Rappahannock River (RPPOH)	OW	A	A	A	A	A
Lower Rappahannock River (RPPOH)	OW	0.44	0.10	A	A	A
	DW	5.58	1.09	0.01	A	A
	DC	6.39	3.38	1.65	A	A
Piankatank River (PIAMH)	OW	0.12	A	A	A	A
Upper Mattaponi River (MPNTF)	OW	33.26	25.87	27.23	33.73	52.14
Lower Mattaponi River (MPNOH)	OW	46.88	28.95	31.86	28.99	48.11
Upper Pamunkey River (PMKTF)	OW	62.25	42.07	30.35	32.94	54.50

continued

Table 2. Percent nonattainment of monthly averaged 5, 3 and 1 mg/l dissolved oxygen concentrations applied to open-water, deep-water and deep-channel designated uses, respectively *(cont.)*.

		Model Scenarios				
Chesapeake Bay Program Segment	**DU**	**Observed**	**Tier 1**	**Tier 2**	**Tier 3**	**E 3**
Lower Pamunkey (PMKOH)	OW	42.15	12.66	13.86	10.32	11.39
Middle York River (YRKMH)	OW	18.08	3.31	2.32	0.42	A
Lower York River (YRKPH)	OW	1.48	A	A	A	A
	DW	0.01	A	A	A	A
Mobjack Bay (MOBPH)	OW	2.30	1.60	1.10	0.34	A
Upper James River (JMSTF)	OW	0.66	A	A	A	A
Middle James River (JMSOH)	OW	A	A	A	A	A
Lower James River (JMSMH)	OW	A	A	A	A	A
Mouth of the James River (JMSPH)	OW	A	A	A	A	A
Eastern Bay (EASMH)	OW	A	A	A	A	A
	DW	3.26	2.00	0.90	0.36	A
	DC	20.23	11.26	6.49	0.67	A
Middle Choptank River (CHOOH)	OW	0.14	A	A	A	A
Lower Choptank River (CHOMH2)	OW	2.27	1.78	1.51	1.08	0.43
Mouth of the Choptank River (CHOMH1)	OW	0.33	A	A	A	A
Tangier Sound (TANMH)	OW	0.15	0.06	0.05	0.36	0.22
Lower Pocomoke River (POCMH)	OW	A	A	A	A	A

A = Applicable dissolved oxygen criteria fully attained; analysis based on monthly averaged dissolved oxygen concentrations 5 mg/l, 3 mg/l and 1 mg/l for open-water, deep-water and deep-channel designated uses.

DU = designated use; OW—open-water; DW—deep-water; DC–deep-channel.

CONFIRMATION THAT EXISTING USES ARE MET

In establishing the refined designated uses, the Chesapeake Bay Program took explicit steps in developing the requirements and boundaries to ensure that existing aquatic life uses would continue to be protected as the EPA Water Quality Standards Regulation require. For some refined designated uses—the migratory fish spawning and nursery, the deep-water and the deep-channel—the application of new dissolved oxygen criteria will result in improvements to existing water quality conditions. The refined open-water fish and shellfish designated use dissolved oxygen criteria will provide an equal level of protection as the current state water quality standards afford to the same tidal waters. Likewise, the refined shallow-water bay grass designated use also ensures protection of existing underwater bay grass-related uses because the single best year method is based on historical (1930s through the early 1970s) and more recent (1978–present) underwater bay grass distributions.

ECONOMIC ANALYSES

The *Technical Support Document* summarizes three types of economic analyses that the Chesapeake Bay Program performed in conjunction with developing revised water quality criteria, designated uses and boundaries for those uses in the Chesapeake Bay and its tidal waters. One analysis was undertaken to estimate the costs of implementing the hypothetical control scenarios (represented by the Tier 1-3 scenarios). Screening-level analyses are the second type of analysis summarized. These analyses were conducted to rule out areas that would not experience substantial and widespread economic and social impacts if states implemented controls more stringent than those required by sections 301 and 306 of the Clean Water Act. The results of analyses to model regional economic impacts is the third type of analysis summarized in the *Technical Support Document.*

A separate document entitled *Economic Analyses and Impacts of Nutrient and Sediment Reduction Actions in the Chesapeake Bay Watershed* (*Economic Analyses*) presents detailed descriptions of these three types of analysis and the attendant findings.

Table 3 summarizes the results of the cost analyses described in detail in the *Economic Analyses* document. Captured in the table are the total capital and annual costs (annualized capital plus annual operation and maintenance [O&M] costs) associated with the tier scenarios. The cost analysis and other economic analyses provide information related to evaluating impacts from the implementation of the nutrient reduction measures defined in the tier scenarios. However, the Chesapeake Bay Program did not use these analyses to delineate boundaries for the refined designated uses. Although this information may be useful to them in developing their own UAAs, states will need to conduct more rigorous economic analyses than the analyses performed by the Chesapeake Bay Program.

Table 3. Estimated cumulative costs and pollutant loading reductions associated with the Tier 1–3 scenarios and the E3 scenario.

Tier	Total Nitrogen Reduction from Levels in 2000 (millions pounds per year)[1]	Total Capital Costs (in millions 2001 dollars)[2]	Total Annual Costs (in millions 2001 dollars)[2]
Tier 1	23.9	$1,391	$196
Tier 2	63.5	$3,593	$553
Tier 3	104.0	$7,713	$1,125
E3[3]	168.4	Not estimated	Not estimated

1. Loadings based on Phase 4.3 of the Chesapeake Bay Program's Watershed Model.
2. Costs include those paid by private-sector businesses and households in addition to those paid by public entities that provide cost-share funding for nutrient reduction controls and BMPs.
3. The E3 scenario represents a theoretical limit-of-technology control scenario that provides a maximum loadings reduction estimate.

Acknowledgments

This *Technical Support Document for Identifying Chesapeake Bay Designated Uses and Attainability* was developed through the collaborative efforts, collective knowledge and applied expertise of the Chesapeake Bay Program Water Quality Steering Committee's Use Attainability Analysis Workgroup; the Chesapeake Bay Program's Modeling, and Monitoring and Assessment subcommittees; the Chesapeake Bay Program's Nutrient Subcommittee workgroups: the Agricultural Nutrient Reduction Workgroup, the Forestry Workgroup, the Point Source Workgroup, the Urban Storm Water Workgroup, the Tributary Strategy Workgroup and the Sediment Workgroup.

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chapter i

Introduction

BACKGROUND

In 1987, the governors of Maryland, Virginia and Pennsylvania; the Mayor of the District of Columbia, the U.S. Environmental Protection Agency (EPA) administrator and the chair of the Chesapeake Bay Commission signed the Chesapeake Bay Agreement. This historic agreement stated that a 40 percent reduction in nutrients entering the Chesapeake Bay would be necessary to restore its health (Chesapeake Executive Council 1987). The goal targeted a 40 percent reduction of controllable nutrient loads from point and nonpoint sources from 1985 levels by the year 2000. The partners to the Chesapeake Bay Agreement committed that once achieved, these levels of reduced nutrient loads would continue to be maintained into the future.

In spite of the widespread implementation of best management practices (BMPs) and enhanced treatment technologies across the Chesapeake Bay watershed, nutrient- and sediment-related water quality problems have persisted. Figure I-1 illustrates the listed nutrient- and/or sediment-impaired waterbodies in the Chesapeake Bay watershed. Maryland's portion of the Chesapeake Bay and its tidal tributaries were listed on its 1996 and 1998 Clean Water Act (CWA) Section 303(d) lists of impaired waters. In May 1999, EPA Region III included Virginia's portion of the Chesapeake Bay and portions of several tidal tributaries on Virginia's 1998 CWA Section 303(d) list. Delaware listed its tidally influenced portions of the Chesapeake Bay waters on their 1996 and 1998 lists, and the District of Columbia listed its Chesapeake Bay waters in 1998. Streams and rivers also are listed for nutrient and/or sediment in the nontidal portions of the Chesapeake Bay watershed in all seven Chesapeake Bay watershed jurisdictions, including West Virginia, Pennsylvania, and New York.

The new *Chesapeake 2000* agreement was developed in response to a comprehensive assessment of the Chesapeake Bay's restoration needs and delineated an ambitious list of new restoration commitments (Chesapeake Executive Council 2000). The significant focus on restoration of Chesapeake Bay water quality resulted from the listing of most of the Chesapeake Bay and its tidal tributaries on the 303(d) list of impaired waters. Subsequently, the governors of Delaware, New York and West Virginia signed a Memorandum of Understanding with Maryland, Virginia,

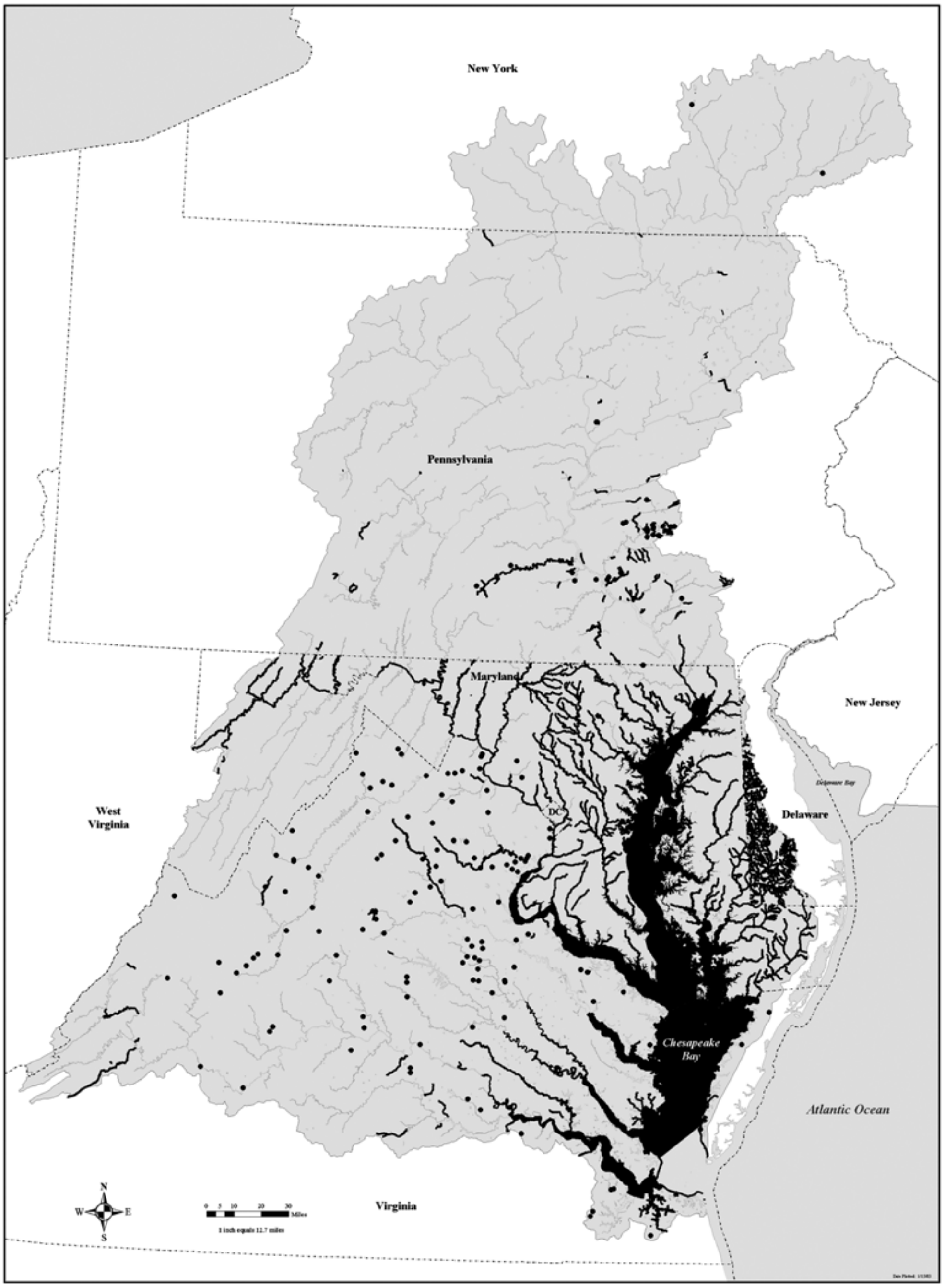

Figure I-1. Nutrient, sediment and dissolved oxygen impaired waterbodies in the Chesapeake Bay watershed from the 1998 303(d) list illustrated as points (•), linear (–) or area (solid black) events.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

Pennsylvania, the District of Columbia and the EPA committing to implement the Water Quality Protection and Restoration section of the agreement (Chesapeake Bay Watershed Partners 2001).

Chesapeake 2000 specifies a goal to remove the Chesapeake Bay and its tidal tributaries from the list of impaired waterbodies for nutrients and sediments by 2010. Thus, the development of a total maximum daily load (TMDL) for the entire Chesapeake Bay was delayed until 2011, anticipating that the Chesapeake Bay Program partners can cooperatively achieve water quality standards by that time, making a baywide TMDL unnecessary.

Chesapeake 2000 lists the following specific commitments as steps to achieve its water quality goal of eliminating nutrient- and sediment-related impairments from tidal waters:

1. By 2001, define water quality conditions (i.e., criteria) necessary to protect aquatic living resources and then assign load reductions for nitrogen, phosphorus and sediment to each major tributary;
2. By 2002, complete a public process to develop and begin implementing revised Tributary Strategies to achieve and maintain the assigned loading goals; and
3. By 2003, jurisdictions with tidal waters will use their best efforts to adopt new or revised water quality standards consistent with the defined water quality conditions.

Although the above commitments still stand, the schedule has changed. The current schedule that all seven watershed jurisdictions and the EPA agreed to calls for:

- Final definitions of water quality conditions (i.e., criteria) by April 2003;
- Development of new and revised tributary strategies by April 2004; and
- Adoption of new and revised state water quality standards by 2005.

To implement and coordinate these actions, the Chesapeake Bay Program formed the Chesapeake Bay Water Quality Steering Committee, composed of senior managers from the EPA, state environmental quality, natural resource management, and agricultural agencies, the Chesapeake Bay Commission, interstate river basin commissions, the environmental community and wastewater treatment operators. Under the Water Quality Steering Committee, a Use Attainability Analysis (UAA) Workgroup was convened to collaboratively assess the attainability of the refined designated uses for the Chesapeake Bay and its tidal tributaries.

TECHNICAL SUPPORT DOCUMENT

This document provides the Chesapeake Bay jurisdictions[4] with information to assist them in adopting water quality standards to protect aquatic life in the Chesapeake

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[4] The jurisdictions that will develop and adopt revised water quality standards in response to this effort are those with Chesapeake Bay and tidal tributary waters listed as state waters: Maryland, Virginia, Delaware and the District of Columbia.

Bay and its tidal tributaries against nutrient and sediment enrichment impairments. Part of the jurisdictions' water quality standards development process may be to conduct use attainability analyses. The *Technical Support Document* may be used to assist states in developing their individual UAAs and state-specific documents. While a UAA is traditionally a process conducted independently by a state, the multi-stakeholder Water Quality Steering Committee decided to provide information on a watershed-wide scale to promote coordination and consistency across all jurisdictions.

OBJECTIVES

The EPA developed the *Technical Support Document* to:

- Document why it appears that the current designated uses for protecting aquatic life cannot be attained in all parts of the Chesapeake Bay and its tidal tributaries due to irremediable natural and human-caused conditions;
- Document the rationale and scientific basis for the refined designated uses for the Chesapeake Bay and its tidal tributaries;
- Document that the refined designated uses are potentially attainable; and
- Provide technical background information for the four Chesapeake Bay jurisdictions with tidal waters to use in developing their own jurisdiction-specific UAAs.

STRUCTURE AND CONTENT

Chapter II provides background information regarding Chesapeake Bay tidal-water quality problems caused by excess nutrients and sediments. *Chapter III* demonstrates that two factors–natural conditions and irremediable, human-generated conditions–provide sufficient evidence that the current designated uses cannot be met in certain portions of the Chesapeake Bay and its tidal tributaries.

Chapter IV provides information that jurisdictions may use in adopting refined tidal-water designated uses based on the habitat quality needs of the plants and animals that inhabit the different Chesapeake Bay tidal-water habitats and the Bay and its tidal rivers' natural physical processes and features. The refined designated uses are subcategories of current aquatic life protection uses, protected by new Chesapeake Bay regional criteria for dissolved oxygen and, where appropriate, chlorophyll *a* and water clarity (U.S. EPA 2003a). This chapter also presents the scientific basis underlying the geographic and temporal extent ('boundaries') of the refined designated uses and documents that the refined designated uses protect uses existing since November 1975, as required by the EPA Water Quality Standards regulation.

Assessments of the technological attainability of the refined designated uses—migratory spawning and nursery habitat, open-water habitat, deep-water habitat and deep-channel habitat—were conducted by comparing model-simulated water quality responses (measured as dissolved oxygen criteria attainment) of four level-of-effort scenarios (or tiers) to the nutrient and sediment reductions accomplished at each level. The water quality responses are summarized in *Chapter V* in a series of 'attainability tables,' that show which Chesapeake Bay tidal waters achieve attainment for dissolved oxygen for each of the recommended refined designated uses. Attainability of the shallow-water habitat designated use is assessed by examining the historical and recent distributions of underwater bay grasses.

Chapter VI provides an overview of the estimated costs for each set of tiered levels of implementation scenarios. This information is used also to conduct economic impact analyses, which also are described in Chapter VI. The objective is to provide the jurisdictions with preliminary estimates of the types of potential impacts that could occur as a result of implementing the tier scenarios throughout the watershed. However, it may be necessary for states to perform more comprehensive analyses for their own state-specific UAAs. At the basinwide level, economic impacts were not considered in determining the boundaries of designated uses. Rather, it will be up to the individual jurisdictions conducting their own UAAs to determine where there may be substantial and widespread social and economic impacts and to adjust their final use boundary delineations as a result. The present economic information and methodologies are intended only to assist the states with that decision.

The *Technical Support Document* is a compilation of basinwide guidance on UAA-related analyses and was assembled collaboratively by the relevant jurisdictions; it does not represent a regulation or a set of mandatory requirements. The EPA encourages jurisdictions to use the information in this document and, when appropriate, to perform additional analyses relevant to their respective water quality standards development process. The general descriptions provided here may not apply to all circumstances. Interested parties may raise questions and objections about the substance of the *Technical Support Document* and its specific applications. The EPA and other decision-makers retain the discretion to adopt approaches that differ from those described in this document, where appropriate.

The *Technical Support Document* does not include a determination as to whether the refined designated uses are attainable in specific areas; such decisions belong to the states. Instead it provides information based on scientific data to show that revisions of the current designated uses may be justified and that the refined designated uses are viable in many areas of the Chesapeake Bay and its tidal tributaries.

It should be noted that the *Technical Support Document* presents information that is current at the time of publication, and its analyses are works in progress. The EPA expects Chesapeake Bay jurisdictions with Bay tidal waters to continue related analyses and to seek assistance from the EPA and their Chesapeake Bay Program partners during their tributary strategy development and water quality standards adoption processes.

Resource constraints prevented a full evaluation of many issues such as local cost and impact assessments, physical implementation constraints for technologies and potential cap load impacts. However, the EPA anticipates that the four jurisdictions with Chesapeake Bay tidal waters will explore such issues in greater detail, where appropriate, during their respective water quality standards development processes.

APPROACH TO REFINING TIDAL-WATER DESIGNATED USES

The *Chesapeake 2000* agreement and the subsequent six-state, District of Columbia and EPA memoranda of understanding challenged the Chesapeake Bay watershed jurisdictions to "define the water quality conditions necessary to protect aquatic living resources" and to have the jurisdictions with tidal waters "use their best efforts to adopt new or revised water quality standards consistent with the defined water quality conditions." Against this backdrop of a renewed commitment to restore Chesapeake Bay water quality, the Chesapeake Bay Program partners determined that the current underlying tidal-water designated uses must be refined to better reflect desired Chesapeake Bay water quality conditions.

The federal water quality standards regulation establishes that states must specify appropriate water uses to be achieved and protected. Current designated uses applied to the waters of the Chesapeake Bay and its tidal tributaries do not fully reflect natural conditions and are too broad in their definition of 'use' to support the adoption of more habitat-specific aquatic life criteria. Furthermore, they change across jurisdictional borders in the same body of water.

Under the federal water quality standards regulation, states may adopt subcategories of uses, seasonal uses and may remove uses under certain conditions (including natural, physical and socio-economic conditions). If a state wishes to remove or establish a subcategory of a designated use that requires less stringent water quality criteria, it must conduct a use attainability study. States must also demonstrate that all water uses present on or after November 28, 1975, will always be protected. With publication of the *Technical Support Document*, the EPA encourages states to consider refining and subcategorizing their general aquatic life protection use applied to Chesapeake Bay tidal waters, found in current state water quality standards.

The EPA, in close collaboration with the Chesapeake Bay Water Quality Steering Committee, published new Chesapeake Bay regional water quality criteria for dissolved oxygen, water clarity and chlorophyll *a* (U.S. EPA 2003a). Portions of the Chesapeake Bay criteria are either equal, more, or less stringent than the current dissolved oxygen criteria adopted by the Chesapeake Bay jurisdictions in their water quality standards. Each jurisdiction that currently lists Chesapeake Bay tidal waters as state waters (Maryland, Virginia, Delaware and the District of Columbia) is responsible for submitting its own UAA to justify changes to state water quality standards for the Chesapeake Bay tidal waters. This *Technical Support Document* provides the jurisdictions with key information for conducting their own UAAs.

DETERMINING ATTAINMENT OF CURRENT DESIGNATED USES IS NOT FEASIBLE

The EPA Water Quality Standards Regulation (40 CFR 131.3) defines a UAA as:

> *A structured scientific assessment of the factors affecting the attainment of a use which may include physical, chemical, biological and economic factors as described in Section 131.10(g).*

A UAA is *required,* according to Section 131.10 (j) of the EPA Water Quality Standards Regulation, when:

1. The state designates or has designated uses that do not include the uses specified in Section 101(a)(2) of the Act; or
2. The state wishes to remove a designated use that is specified in Section 101(a)(2) of the Act or to adopt subcategories of uses specified in Section 101(a)(2) that require less stringent criteria.[5]

In conducting a UAA, a state must be able to demonstrate that attaining the designated use is not feasible due to one or more of the six factors in Section 131.10(g) listed below:

1. Naturally occurring pollutant concentrations prevent the attainment of the use;
2. Natural, ephemeral, intermittent or low-flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of a sufficient volume of effluent without violating state water conservation requirements to enable uses to be met;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use;
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles and the like, unrelated to chemical water quality, preclude attainment of aquatic life protection uses; and
6. Controls more stringent than those required by sections 301(b)(1)(A) and (B) and Section 306 of the Act would result in substantial and widespread economic and social impacts.

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[5] Section 101(a)(2) Federal Water Pollution Control Act states that "...it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983."

The *Technical Support Document* focuses on the current designated uses in Chesapeake Bay tidal waters for the protection of aquatic life.[6] Chapter III provides scientific information that the states may use in determining whether current tidal-water designated uses in Maryland, Virginia, Delaware and the District of Columbia, with corresponding dissolved oxygen criteria of 4 mg/l and 5 mg/l, are not achievable in all portions of the Chesapeake Bay and tidal tributaries.

Factors 1 and 3, above, are applied in demonstrating why it appears that the current uses may not be met in certain portions of the Chesapeake Bay and its tidal tributaries. States may rely on one or more of the factors to demonstrate that attaining the current designated use is not feasible. Factors 4 and 5 concerning unalterable hydrologic modifications and natural physical conditions that would preclude attainment may also explain why the current designated uses are unattainable in certain tidal-water habitats of the Chesapeake Bay. The *Technical Support Document* does not explore these two factors in as great of detail as factors 1 and 3; however, the jurisdictions may choose any of the preceding six factors in conducting their state-specific UAAs.

JUSTIFYING THE REFINED TIDAL-WATER DESIGNATED USES

A UAA is not required to justify application of the refined designated uses, particularly for areas in which the uses (criteria) will be more stringent than current ones. The Chesapeake Bay Program's Water Quality Steering Committee decided, however, that it was as important to document attainability of the more protective refined designated uses as it was to justify changes to current designated uses.

Due to the shortcomings of current designated uses applied to the Chesapeake Bay and its tidal tributaries, the Chesapeake Bay Program watershed partners concluded that the underlying tidal-water designated uses need to be refined to reflect a greater understanding of the complex Chesapeake Bay system and the needs of its living resources. Specifically, the partners recommend that the following five refined aquatic life designated uses be applied to the appropriate habitats in the Chesapeake Bay and its tidal tributaries:

- Migratory fish spawning and nursery;
- Open-water fish and shellfish;
- Deep-water seasonal fish and shellfish;
- Deep-channel seasonal refuge; and
- Shallow-water bay grass.

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[6] Specifically, all state waters in Maryland are protected for Use I or water contact recreation and protection of aquatic life. All state waters in Virginia are designated for the following uses: " . . . recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish." Delaware state waters are designated for protection of "fish, aquatic life and wildlife" with similar provisions for "protection and propagation of fish, shellfish and wildlife" in District of Columbia's waters.

The first four designated use subcategories were derived chiefly to address seasonally distinct habitats and living resource communities with widely varying dissolved oxygen requirements. The shallow-water bay grass designated use would occur seasonally in conjunction with the part of the year-round open-water use habitat for waters that border the land along the tidal portions of the Chesapeake Bay and its tributaries. It is intended to protect underwater bay grasses where the water clarity criteria will apply.

The same factors used to show why it appears the current designated uses are unattainable can also be applied in the development of the refined designated uses. Factors 1 (natural conditions) and 3 (irremediable human-generated conditions) were used to determine appropriate boundaries for the refined designated uses. The Chesapeake Bay Program partners also took into consideration factors 4 and 5 as part of the analysis for delineating the boundaries for the refined designated uses. The monitoring data and model-simulated outputs described in Chapter IV show that there are certain hydrologic and physical features that exist in the Chesapeake Bay tidal waters today—some natural and some man-made, such as the shipping channels—which directly influence the horizontal as well as vertical extent of the designated use boundaries.

ASSESSING ATTAINABILITY OF THE REFINED TIDAL-WATER DESIGNATED USES

The question of whether the refined designated uses are attainable is a challenging one. There is no precise approach or existing guidance for answering this question. The challenge is particularly daunting for an area as large and complex as the Chesapeake Bay and its watershed, with its heterogeneous habitats and its vulnerability to pollutants from point and nonpoint sources. The concept of attainability encompasses technological, economic and even political and legal perspectives. The *Technical Support Document* addresses these viewpoints to a limited extent. The states ultimately need to make their final determinations by applying information tailored to their respective jurisdictions. This document specifically addresses technological attainability of the migratory spawning and nursery, open-water, deep-water, deep-channel (based on dissolved oxygen criteria attainment) and shallow-water designated uses (based on past and recently observed underwater bay grass distributions). Because the Chesapeake Bay chlorophyll *a* criteria were published in narrative form, attainability of the open-water designated use was not assessed for this parameter.

From a legal perspective, ‘existing uses’ are, by definition, attainable. By regulation, they must be protected by designated uses in water quality standards (40 CFR 131.10[g], 131.10[h][1] and 131.10[i]). Further, at a minimum, uses are considered attainable if they can be achieved by implementing effluent limits (referred to as best available technology or BAT) required under sections 301(b) and 306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices (40 CFR 131.10[d] and 131.10[h][2]).

Once a use is designated (as in the case of the Chesapeake Bay), it is presumed to be attainable and may not be removed unless the state conducts a UAA and can demonstrate that attaining the designated use is not feasible based on one of the six use removal factors (40 CFR 131.10[g][1][6]). If a state conducts a UAA and demonstrates that one or more of the six use removal factors are met for a particular designated use, the state may remove the use. However, the state may not remove an existing use and must revise water quality standards to reflect uses actually attained (40 CFR 131.10[i]). In addition, designated uses not satisfying any of the six use removal factors may not be removed.

As 40 CFR 131.2 states:

> *. . . water quality standards should, wherever attainable, provide water quality for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water and take into consideration their use and value of public water supplies, propagation of fish, shellfish, and wildlife, recreation in and on the water . . .*

If the use removal factors are cited to remove a designated use, the state must adopt an 'appropriate' use or uses in place of the one removed (40 CFR 131.10[a]). Attainable uses are appropriate uses and may be expressed as subcategories of use. Because the use removal factors are designed to determine whether to remove a designated use when it is not attainable, they serve the purpose equally effectively when considering whether a use is attainable and should be designated.

The Chesapeake Bay Program partners have devised a valuable tool for exploring attainability from a technological perspective–a range of level-of-effort scenarios that represent degrees of nutrient and sediment load reduction through simulated implementation of best management practices and wastewater treatment upgrades. These scenarios begin with Tier 1, which represents the current level of implementation in the watershed, including regulatory requirements implemented through the year 2010, up to a scenario representing 'limits of technology' referred to as the E3 scenario or 'everything, everywhere by everybody,' which is acknowledged to be physically implausible. Tier 2 and Tier 3 scenarios also were developed to represent intermediate levels between the Tier 1 and E3 scenarios.

Each tier represents a nitrogen, phosphorus and sediment load reduction determined by the technologies and levels of implementation assigned to it.[7] These tiers are artificial constructs of technological levels of effort and *do not represent actual programs that the jurisdictions will eventually implement to meet the water quality standards*. These tiers are an assessment tool to determine potential load reductions achievable by various levels of technological effort and were modeled to determine water quality responses. Chapter V provides the results of the water quality model

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[7] Sediment reduction is only estimated where it is incidental to implementation of BMPs directed toward nutrient loading reductions.

analyses for dissolved oxygen by tier, presented in a series of ‘attainability tables,’ that estimate the level of attainment achieved within the designated use boundaries. These analyses shows that most segments of the Chesapeake Bay and its tidal tributaries realize attainment at the E3 levels. This attainment is also true for Tier 3 where, if nonattainment does exist, it is generally at levels less than one percent, except for Chesapeake Bay Program segment CB4MH or Middle Central Chesapeake Bay (see Table V-6) where 8.51 percent nonattainment in deep-water remains.

Chesapeake Bay Program partners have used the E3 scenario to represent human-caused conditions that cannot be remedied. The partners agree that reductions at E3 levels are not achievable and that the load reductions represented by Tier 3 are technologically achievable. Therefore, if a proposed use can be attained at load reductions equal to or greater than Tier 3, but less than the E3 scenario, that use should be designated. The jurisdictions may still, through their own analyses, show that irremediable human-caused conditions prevent use attainment, or explain why the uses cannot be attained based on substantial and widespread economic or social impacts, or other factors in 40 CFR 131.10(g). However, the analyses published in this *Technical Support Document* show that the refined designated uses can potentially be attained in the Chesapeake Bay and its tidal tributaries.

Chapter V also addresses the attainability of the shallow-water designated use. Restoration of underwater bay grasses to areas supporting “the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats” is ultimately the best measure of attaining the shallow-water bay grass designated use. This document provides the states with two means by which to determine the return of water clarity conditions necessary to support restoration of underwater bay grasses and, therefore, attainment of the shallow-water designated use.

CONSIDERATION OF ECONOMIC AND SOCIAL IMPACTS

The sixth factor to consider when conducting a UAA listed under Section 131.10(g) (“Controls more stringent than those required by Sections 301[b] and 306 of the Act would result in substantial and widespread economic and social impact”) also has been addressed to a limited extent in the *Technical Support Document*. The information presented in Chapter III justifying why current designated uses cannot be met does not require reliance on the substantial and widespread economic and social impact factors as part of the justification to change the uses. Furthermore, the Chesapeake Bay Program partners delineated the use boundaries for the Chesapeake Bay and its tidal tributaries based on estuarine living resources and their habitats, not on economic impact information.

Conversely, it is logical to ask if the designated uses are affordable. The *Technical Support Document* does not attempt to provide conclusions on affordability because the Chesapeake Bay Program partners judged it premature to specify thresholds for substantial and widespread economic and social impacts. On a regional, state or large watershed scale, economic impacts can be mitigated by cost-share, loans or new federal or state funding programs. Cost and economic analyses to show impacts that would preclude attainment of these refined uses must be more comprehensive and rigorous than the present analyses.

JURISDICTION WATER QUALITY STANDARDS AND TRIBUTARY STRATEGY DEVELOPMENT PROCESS

Upon publication of the *Regional Criteria Guidance*, the Chesapeake Bay tidal-water jurisdictions of Maryland, Virginia, Delaware and the District of Columbia began their respective water quality standards development and adoption processes. At the same time, all Chesapeake Bay watershed jurisdictions, including Pennsylvania, West Virginia and New York collaboratively allocated caps on nutrient and sediment loads necessary to meet these anticipated water quality standards (i.e., Chesapeake Bay regional criteria and refined designated uses) (U.S. EPA 2003b). States are scheduled to adopt water quality standards by 2005. Local watershed load reduction action plans (referred to as 'tributary strategies'), based on achieving the *Chesapeake 2000* nutrient and sediment cap load allocations, will be completed by April 2004. The development of tributary strategies will provide area-specific information that jurisdictions can use in their water quality standards adoption process. To promote consistency, jurisdictions will need to work cooperatively during their tributary strategy development and water quality standards adoption processes, particularly where tributary basins include more than one state in the Chesapeake Bay watershed, such as the Potomac River basin.

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chapter ii

The Chesapeake Bay and Its Watershed

BACKGROUND

The Chesapeake Bay is the nation's largest estuary and one of its most valuable natural treasures. Even after centuries of intensive use, the Chesapeake Bay remains a highly productive natural resource. It supplies millions of pounds of seafood, functions as a major hub for shipping and commerce, provides habitat for an extensive array of wildlife and offers a variety of recreational opportunities for residents and visitors. The Chesapeake Bay supports 348 species of finfish, 173 species of shellfish and more than 2,700 plant species. It is home to 29 species of waterfowl and is a major resting ground along the Atlantic Migratory Bird Flyway. Every year, 1 million waterfowl winter in the Chesapeake Bay's basin.

The Chesapeake Bay proper is approximately 200 miles long, stretching from Havre de Grace, Maryland, to Norfolk, Virginia. It varies in width from about 3.4 miles near Aberdeen, Maryland, to 35 miles at its widest point, near the mouth of the Potomac River. Including its tidal tributaries, the Chesapeake Bay encompasses approximately 11,684 miles of shoreline.

On average, the Chesapeake Bay holds more than 15 trillion gallons of water. Although the Bay's length and width are dramatic, the average depth is only about 21 feet. The Bay is shaped like a shallow tray, except for a few deep troughs believed to be remnants of the ancient Susquehanna River. The troughs, which in some areas are maintained by dredging, form a deep channel along much of its length. This channel allows passage of large commercial vessels. Because it is so shallow, the Chesapeake Bay is far more sensitive to temperature fluctuations and wind than the open ocean.

The Chesapeake Bay is an estuary, where freshwater and saltwater mix. About half of the Bay's water volume consists of saltwater from the Atlantic Ocean. The other half drains into the Bay from an enormous 64,000-square-mile drainage basin or watershed. Ninety percent of this freshwater is delivered from five major rivers: the Susquehanna (which is responsible for about 50 percent), Potomac, James, Rappahannock and York rivers.

The distribution and stability of such an estuarine ecosystem depends on three important physical characteristics of the water: salinity, temperature and circulation. Salinity is a key factor influencing the Bay's morphology. Seawater from the Atlantic Ocean enters the mouth of the Chesapeake Bay; salinity is highest at that point and gradually decreases farther north. Saltwater is more dense than freshwater, thus salinity increases at greater depths while freshwater tends to remain at the surface. Salinity levels within the Chesapeake Bay vary widely, both seasonally and from year to year, depending on the volume of incoming freshwater.

Temperature dramatically changes the rate of chemical and biological reactions within the water. Because the Chesapeake Bay is so shallow, its capacity to store heat over time is relatively small. As a result, water temperature fluctuates throughout the year, ranging from 34° to 84° Fahrenheit (2° to 52° Celsius). These changes in water temperature influence the cycles in which plants and animals feed, reproduce, move locally or migrate. The temperature profile of the Chesapeake Bay is fairly predictable.

The circulation of water transports plankton, fish eggs, shellfish larvae, sediment, dissolved oxygen, minerals and nutrients throughout the Chesapeake Bay. Circulation is driven primarily by the movements of freshwater from the north and saltwater from the south. Circulation causes nutrients and sediments to be mixed and resuspended. This mixing creates a zone of maximum turbidity that, due to the amount of available nutrients, fish and other organisms often use as nursery areas.

Salinity, temperature and circulation dictate the physical characteristics of water. The warmer, lighter freshwater flows seaward over a layer of saltier and denser water flowing upstream. The opposing movement of these two flows forms saltwater fronts or gradients that move up and down the Chesapeake Bay in response to the input of freshwater. These fronts are characterized by intensive mixing. A layer separating water of different densities, known as a pycnocline, is formed. This stratification varies within seasons, depending on river flow.

In autumn, the fresher surface waters cool faster than deeper waters and sink. Vertical mixing of the two layers occurs rapidly. In the process nutrients are moved up from the bottom, making them available to phytoplankton and other surface organisms. This turnover also distributes much-needed dissolved oxygen to deeper waters. In winter, water temperature and salinity are relatively constant from the surface to the bottom. During spring and summer, surface and shallow waters are warmer than deeper waters with the coldest water found at the bottom. This layering of warmer waters over deeper waters is often broken down by turbulence.

The water's chemical composition also helps determine the distribution and abundance of plant and animal life in the Chesapeake Bay. The Bay's waters contain organic and inorganic materials, including dissolved gases, nutrients, inorganic salts, trace elements, heavy metals and other chemicals.

Dissolved oxygen is essential for most aquatic animals. The amount of available oxygen is affected by salinity and temperature. Cold water can hold more dissolved oxygen than warmer water, and freshwater holds more than saltwater. Thus, concentrations of dissolved oxygen vary, in part, with both location and time. Oxygen is transferred from the atmosphere into surface waters by diffusion and the aerating action of the wind. It also is released by aquatic plants in the process of photosynthesis. Since photosynthesis requires light, the production of oxygen by rooted aquatic plants is limited to waters that are usually no more than six feet deep. Surface water is nearly saturated with oxygen most of the year, while deep bottom waters range from saturated to anoxic (without oxygen).

In winter respiration levels of organisms are relatively low. Vertical mixing is good, and there is little salinity or temperature stratification. As a result, dissolved oxygen is plentiful throughout the water column. During the spring and summer, increased levels of animal and microbial respiration and greater stratification may reduce vertical mixing, resulting in low levels of dissolved oxygen in deep water. In fact, deep parts of some tributaries like the Patuxent, Potomac and Rappahannock rivers and the Chesapeake Bay's mainstem can become anoxic in summer. In the autumn when surface waters cool, vertical mixing occurs and the deeper waters are re-oxygenated.

CHESAPEAKE BAY WATERSHED

The Chesapeake Bay receives about half its water volume from the Atlantic Ocean. The rest drains into the Bay from its 64,000-square-mile drainage basin or watershed. Runoff from this enormous watershed flows into an estuary with a surface area of 4,500 square miles resulting in a land-to-water ratio of 14 to 1. This ratio is one of the key factors in explaining why the drainage area has such a significant influence on water quality. The watershed includes parts of six states—New York, Pennsylvania, West Virginia, Delaware, Maryland and Virginia—and the entire District of Columbia (Figure II-1). Threading through the Chesapeake Bay watershed are more than 100,000 streams and rivers that eventually flow into the Bay.

Although the Chesapeake Bay lies entirely within the Atlantic Coastal Plain, its watershed includes parts of the Piedmont and Appalachian provinces. The waters that flow into the Bay have different chemical identities, depending on the geology where they originate. In turn, the nature of the Bay itself depends on the characteristics and relative volumes of these contributing waters.

The Atlantic Coastal Plain is a flat, lowland area with a maximum elevation of about 300 feet. It is supported by a bed of crystalline rock, covered with southeasterly dipping wedge-shaped layers of relatively unconsolidated sand, clay and gravel. Water passing through this loosely compacted mixture dissolves many of the minerals. The most soluble elements are iron, calcium and magnesium. The coastal plain extends from the edge of the continental shelf, to the east, to a fall line that ranges from 15 to 90 miles west of the Chesapeake Bay. This fall line forms the boundary between the Piedmont Plateau and the coastal plain. Waterfalls and rapids clearly mark this line, which is close to Interstate Highway 95. Here, the elevation

Figure II-1. The Chesapeake Bay watershed crosses the boundaries of six states—Maryland, Virginia, Delaware, Pennsylvania, New York and West Virginia—and the District of Columbia.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

rises to 1,100 feet. Cities such as Fredericksburg and Richmond in Virginia, Baltimore in Maryland, and Washington, D.C., developed along the fall line taking advantage of the potential water power generated by the falls. Since colonial ships could not sail past the fall line, cargo was transferred to canals or overland shipping. Cities along the fall line became important areas for commerce.

The Piedmont Plateau extends from the fall line in the east to the Appalachian Mountains in the west. This area is divided into two geologically distinct regions by Parrs Ridge, which traverses Carroll, Howard and Montgomery counties in Maryland and adjacent counties in Pennsylvania.

Several types of dense crystalline rock, including slates, schists, marble and granite, compose the eastern side. This variety results in a very diverse topography. Rocks of the Piedmont tend to be impermeable, and water from the eastern side is low in the calcium and magnesium salts.

The western side of the Piedmont consists of sandstones, shales and siltstones, layered over by limestone. This limestone bedrock contributes calcium and magnesium to its water, making it 'hard.' Waters from the western side of Parrs Ridge flow into the Potomac River, one of the Chesapeake Bay's largest tributaries.

The Appalachian Province covers the western and northern part of the watershed and is rich in coal and natural gas deposits. Sandstone, siltstone, shale and limestone form the bedrock. Water from this province flows to the Chesapeake Bay mainly via the Susquehanna River.

The hospitable climate, lush vegetation and natural beauty of the Chesapeake Bay watershed have attracted people for thousands of years. Hunters and gatherers first arrived about 10,000 years ago. Native Americans began cultivating crops and settling in villages throughout the area around a thousand years ago. Arriving less than 500 years ago, Europeans and later Africans (brought forcibly to the region beginning in 1619) struggled to transform forests into farmland during the colonial era between 1607 and 1775.

Since then, social, political, economic, and technological developments in metallurgy, steam power, internal combustion engines, chemical engineering and, most recently, electronics, have enabled people to transform regional environments in dramatic ways. Excessive forest clearing and poor land management have increased erosion, sending tons of sediment downstream. As a result, communities that once served as important ports are now landlocked, and elsewhere, the construction of sea walls and breakwaters has interfered with the natural flow of sand, causing beaches to erode too rapidly.

The changes brought about during hundreds of years of forest clearing and urban development have resulted in the following breakdown of current landuse in the watershed: 58 percent forest, 23 percent agriculture, 9 percent urban/suburban and 10 percent mixed open (herbaceous lands that are not agricultural such as golf courses or institutional grounds).

Today, nearly 16 million people live in the Chesapeake Bay watershed. Table II-1 provides a demographic summary of this population. Each resident lives just a few minutes from one of the more than 100,000 rivers, streams and creeks that drain into the Chesapeake Bay. Each tributary can be considered a pipeline from individual communities into the Chesapeake Bay and its rivers. Because materials on land are easily washed into streams and rivers, individual actions on the land ultimately affect the quality of Chesapeake Bay. These activities even include the use of automobiles, fertilizers, pesticides, toilets, water and electricity.

Table II-1. Chesapeake Bay watershed demographics

Race (%)	Educational Attainment (%)	Housing Location (%)	Means of Sewage Disposal (%)	Source of Water (%)	Transportation to Work (%)
White . . 78.1	No High School Diploma . . 23.1	Urban . . 71.7	Public 74.1	Public . . . 77.6	Drive Alone . . . 70.3
Black . . 18.5	High School Diploma 47.7	Rural . . . 27.4	Septic 24.6	Well 20.8	Car Pool 15
Asian . . . 2.3	Associate Degree 5.3	Farm 0.9	Other 1.3	Other 1.6	Public Trans. . . . 6.4
American Indian . . . 0.3	Bachelor Degree 14.4	Other 1			Bike/Walk 4.5
Other 1	Graduate Degree 9.5				Work Home 3.2

Source: 1990 U.S. Census.

CHESAPEAKE BAY TIDAL-WATER QUALITY PROBLEMS

Water quality problems in the Chesapeake Bay and its tidal tributaries are illustrated by the following environmental indicators which reveal the effects of excessive nutrients and sediments in the water column.

A significant proportion of living resource habitats are currently unsuitable due to low dissolved oxygen concentration during the summer months (Figure II-2). In 2001, half of the Chesapeake Bay's deeper waters had reduced dissolved oxygen

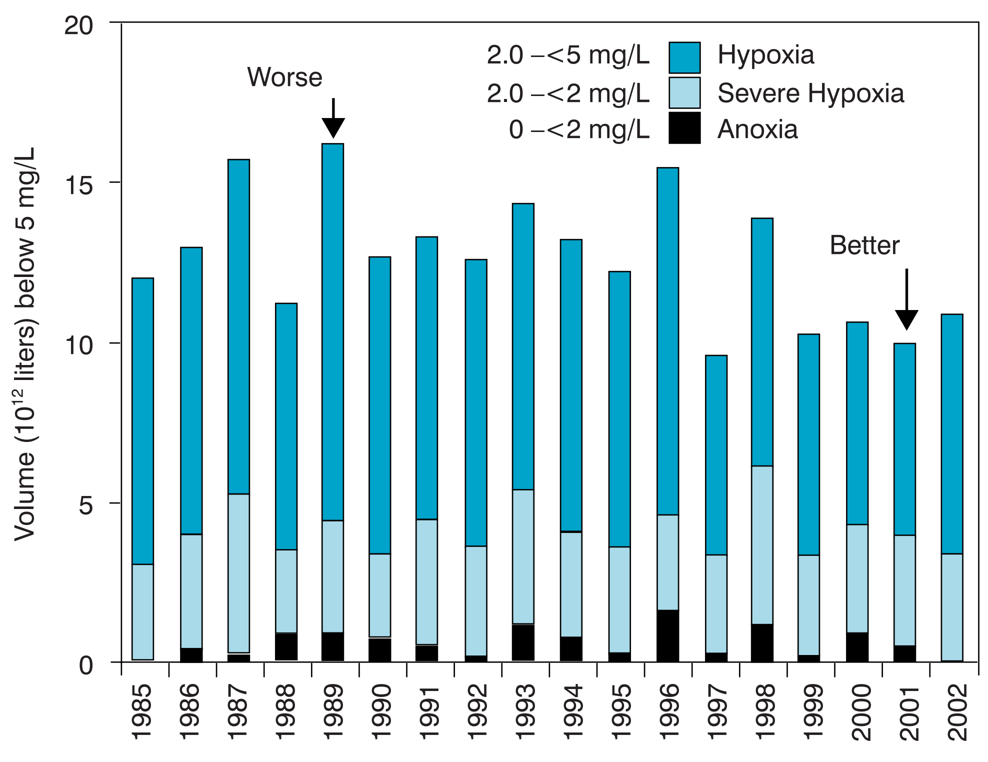


Figure II-2. Volume of the mainstem Chesapeake Bay lower layer waters with reduced dissolved oxygen concentrations–June through September average 1985-2002.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

concentrations, a condition known as hypoxia. Hypoxic conditions stress aquatic life and severely hypoxic waters may be lethal to aquatic plants and animals. If bottom waters become completely without oxygen or anoxic, nutrients tied up in sediments are released into the overlying waters, further fueling algal growth. Recent indications show an improving trend in dissolved oxygen since 1985, the year the Chesapeake Bay Program's complete data collection efforts were initiated.

Chlorophyll *a* is an indicator of algal biomass. Algae serve as a crucial link in the food chain; they reduce water clarity, and, left uneaten, fuel the loss of dissolved oxygen from tidal waters. Measured as chlorophyll *a*, algae are the first to respond to changes in nutrient levels. Recent trends in the Middle, Wicomico and Manokin rivers show improvements in the level of algal biomass. Most areas show no significant change, although the Rappahannock River, Tangier Sound and the mouth of the James River show degrading trends in terms of chlorophyll *a* (Figure II-3).

Water clarity is degrading in many parts of the basin (Figure II-4). Water clarity criteria are not attained in many shallow-water designated use habitats. In portions of the upper Chesapeake Bay, in the Elk and Middle rivers, in upper regions of the Choptank River, in Piscataway and Mattawoman creeks, and in the South Branch Elizabeth River, water clarity is improving.

CAUSES OF CHESAPEAKE BAY WATER QUALITY PROBLEMS

The Chesapeake Bay is part of an extremely productive and complex ecosystem that consists not only of the Bay and its tributaries, but of the plant, animal and human life they support. Through a significant investment in scientific research and coordinated monitoring and modeling programs, the Chesapeake Bay Program partners have gained deep understanding of how human activities affect the Bay's ecology and have led to declines in water quality. Using modeling tools such as the Chesapeake Bay Watershed Model and the Water Quality Model, the partners have learned a great deal about this unique resource by allowing for, among other things, the calculation and projection of changes in loads and the resultant responses in water quality. These models provide an estimate of management actions (such as air controls and point source controls) which will reduce nutrient or sediment loads to the tidal waters and lead to attainment of the Chesapeake Bay dissolved oxygen, water clarity and chlorophyll *a* criteria.

HUMAN POPULATION INCREASE

The relentless encroachment of the human population threatens the ecological balance of the Chesapeake Bay. Population in the Chesapeake Bay watershed has doubled since the 1950s with population levels projected to reach almost 18 million people by 2020 (Figure II-5). Each individual directly affects the Chesapeake Bay by adding waste, consuming resources, and changing the character of the land, water and air that surround it.

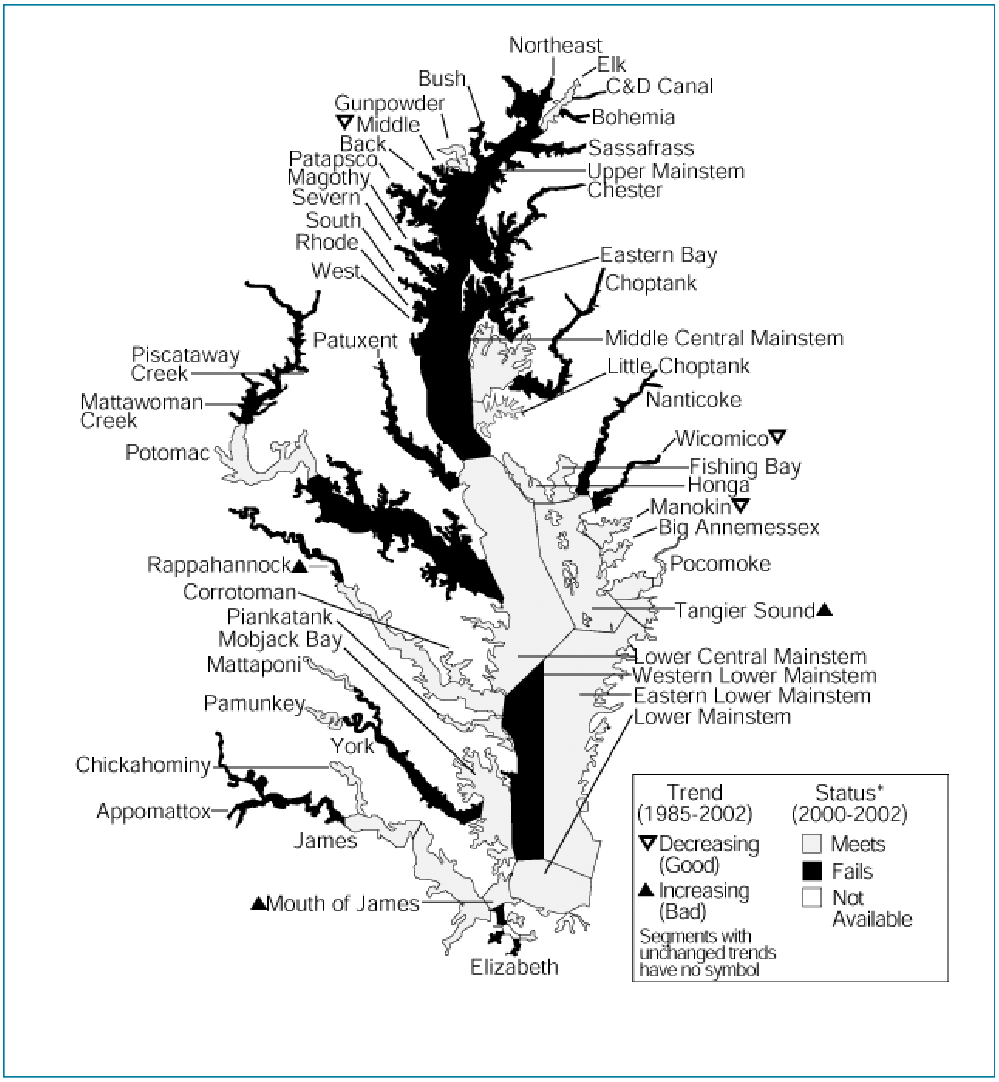


Figure II-3. Status and trends in summer Chesapeake Bay and tidal tributary chlorophyll *a* concentrations relative to concentrations characteristic of mesotrophic conditions.

* 'Meets' means equal to or less than and 'fails' means above the following chlorophyll *a* concentrations during the July through September timeframe:
25 ug/l tidal freshwaters
25 ug/l oligohaline waters
20 ug/l mesohaline waters
15 ug/l polyhaline waters.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

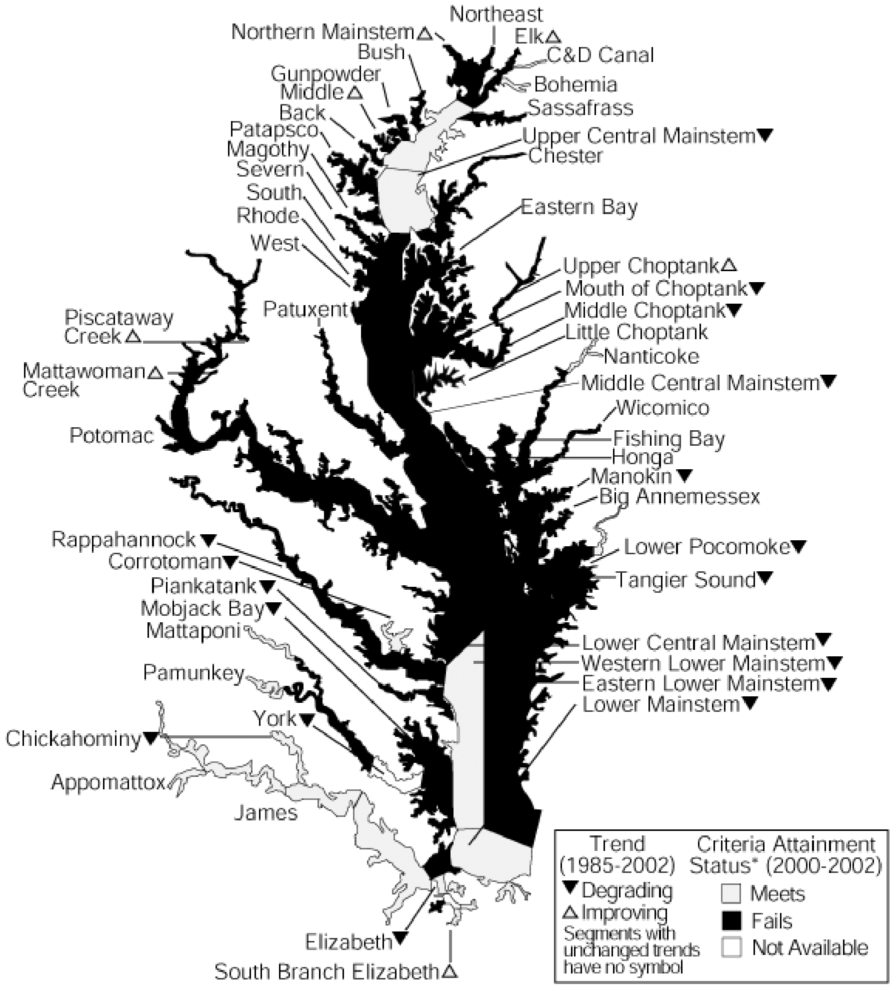


Figure II-4. Status and trends in underwater bay grass growing season water clarity in Chesapeake Bay and tidal tributaries.

* 'Meets' equals nonexceedance; 'fails' equals exceedance of the water clarity criteria during underwater bay grasses growing season applied in locations and depths where such grasses have occurred since the 1930s (however, if the single best year of underwater bay grasses, measured 2000–2002, achieves the acreage goal for a segment, there is no need to meet the clarity criteria). Application depths were based on: single best year percent of total potential habitat is >=20% or percent of total potential habitat is 10–19.9% and underwater bay grasses are persistent (1978–2000).

NOTE: The criteria attainment status covers the entire segment only for purposes of illustration. The water clarity criteria apply with the shallow-water designated use habitat which can extend as far out as the 2-meter depth contour depending on the segment.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

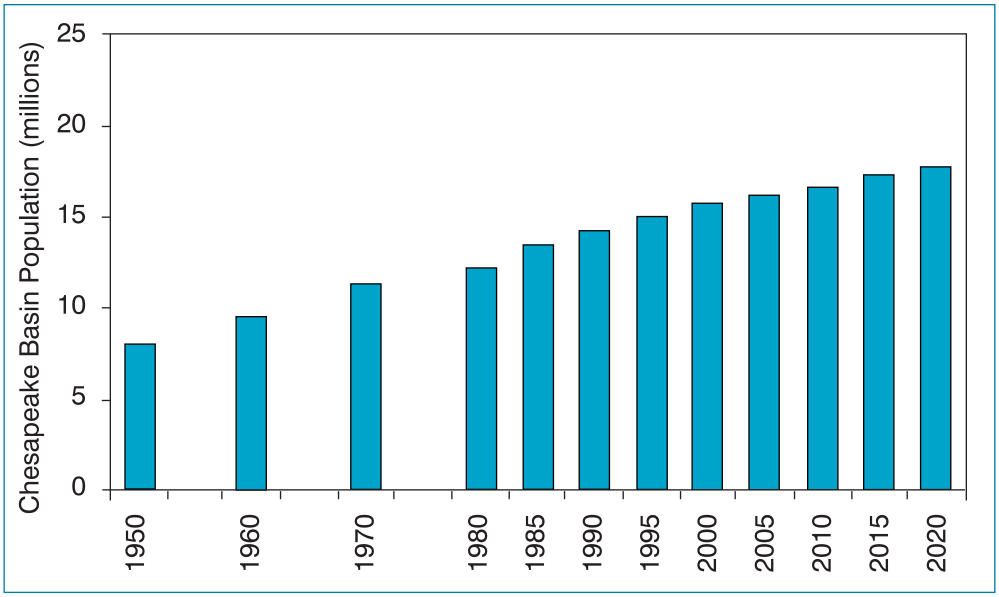


Figure II-5. Chesapeake Bay watershed human population trends since 1950 and projected through 2020.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

LOSS OF HABITAT

Historically, habitat provided by oyster bars, underwater bay grasses, wetlands and forests enabled the Chesapeake Bay ecosystem to recycle nutrients and sediments efficiently, resulting in one of the most productive ecosystems in the world. Dramatic loss of these habitats has not only led to declines in the creatures that rely on them for food and shelter; their loss also has reduced the ecosystem's capacity to fully utilize nutrients and sediments leading to poor water quality in the Chesapeake Bay and its tidal tributaries. Restoration, conservation, and preservation of the habitat provided by oysters, underwater bay grasses, wetlands and forests are critical for restoring living resources and for improving Chesapeake Bay water quality.

In addition to the aquatic reef habitat they provide, oysters are voracious feeders, and each is capable of filtering up to 50 gallons of water per day. It is estimated that at their peak abundance, the total population of oysters in the Chesapeake Bay could filter an amount of water equal to all the water in the Chesapeake Bay in three days. Today, due to decreased abundance, it takes a year for these animals to filter the same volume of water. Oyster harvests in the Chesapeake Bay have declined due to over-harvesting, disease, pollution and loss of oyster reef habitat. Two diseases, discovered in the 1950s and caused by the parasites MSX and Dermo, have been a major cause of the oyster's decline during recent times (Figure II-6).

Underwater bay grasses are important because they produce oxygen, provide food for a variety of animals (especially waterfowl), serve as shelter and nursery areas for many fish and shellfish, reduce wave action and shoreline erosion, absorb nutrients such as phosphorus and nitrogen and trap sediments. Although underwater bay

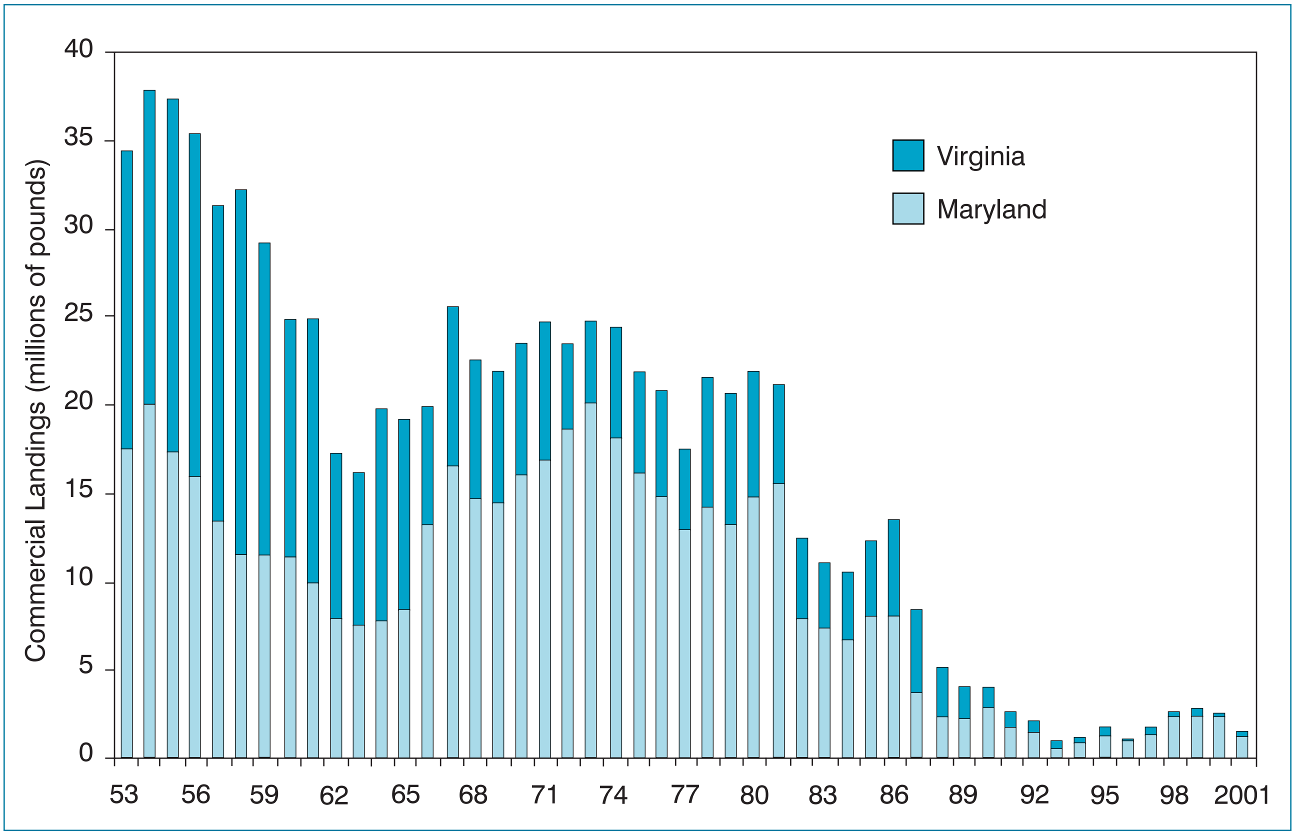


Figure II-6. Trends in Maryland and Virginia commercial harvest landings of oysters 1953–2001.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

grasses increased from a low point of 37,000 acres in 1984 to 85,000 acres in 2001, the Chesapeake Bay Program watershed partners have adopted a new restoration goal of 185,000 acres (Figure II-7).

Wetlands and forests (especially those buffering streambanks and shorelines) provide critical habitat and also act as natural filters to minimize sediment loads and absorb nutrients. Approximately 1.5 million acres of wetlands remain in the Chesapeake Bay watershed, less than half of the wetlands that were here during colonial times. Forests that once covered 90 to 95 percent of the watershed now cover only 58 percent (Figure II-8).

EXCESS NUTRIENTS

Nutrients are essential; they provide crucial ingredients to help living things grow. However, there is a delicate balance between what is needed for organisms to thrive, and what is excessively harmful. The amount of nutrients that would naturally enter the Chesapeake Bay has been adversely multiplied by anthropogenic sources over the course of history. Runoff from fertilizers applied to agriculture and lawns, sewage and industrial discharges, automobile emissions and power generation, are all sources that create excessive amounts of nutrient pollution delivered to the Chesapeake Bay and

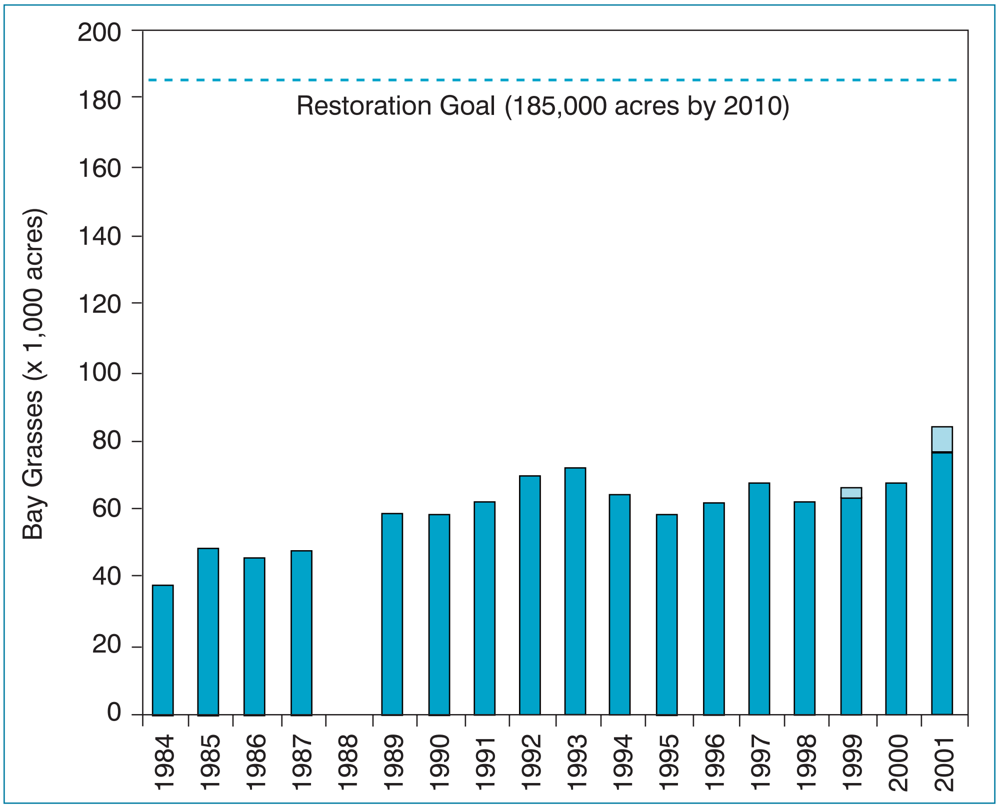


Figure II-7. Trends in the acreages of Chesapeake Bay and tidal tributary underwater bay grasses compared to the new 185,000 acre restoration goal. Light blue area of bar includes estimated additional acreage when flight restrictions or weather conditions prevented collection of a complete set of aerial photographs.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

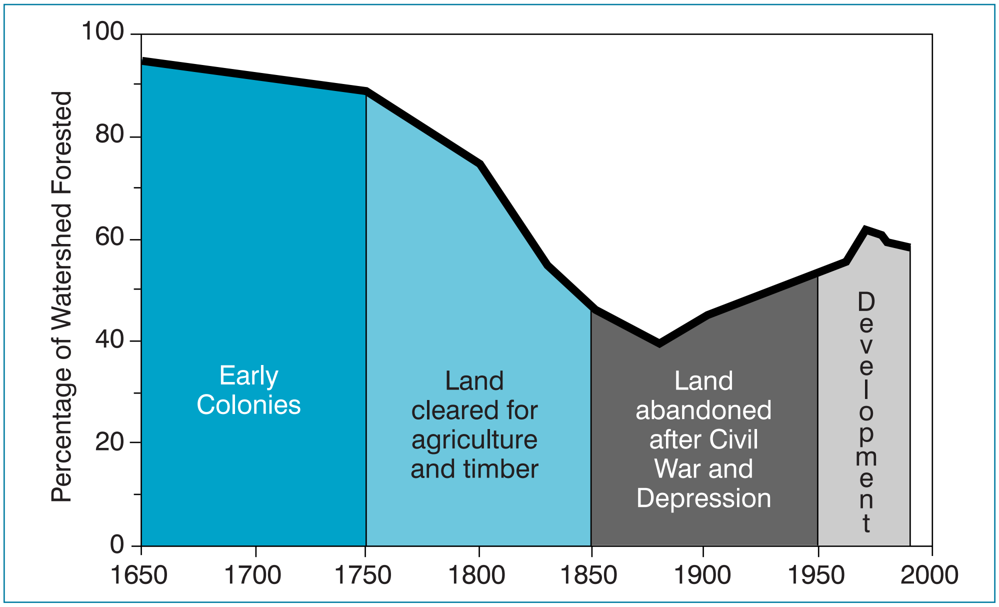


Figure II-8. Trends in Chesapeake Bay basin forests expressed as percentage of the watershed that was forested since 1650.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

its tidal tributaries. These anthropogenic sources of nutrients, together with a decline in the Chesapeake Bay's own natural capacity to assimilate these pollutants due to loss of habitats and living resources, have created overwhelming stresses.

Excess amounts of nitrogen and phosphorus cause rapid growth of phytoplankton, creating dense algal populations or blooms. These blooms become so dense that they reduce the amount of sunlight available to underwater bay grasses. Without sufficient light, these underwater plants cannot photosynthesize and produce the food they need to survive. Algae also may grow directly on the surface of underwater bay grasses, further blocking light. Another hazard of nutrient-enriched algal blooms comes after the algae die. As the algal blooms decay, oxygen is consumed via bacterial decomposition which can lead to dangerously low oxygen levels available for aquatic organisms. Known as eutrophication, this nutrient over-enrichment, ultimately leading to low dissolved oxygen levels in ambient waters, is a widespread problem throughout the tidal waters.

EXCESS SEDIMENTS

The surrounding watershed and the tidal waters of the Chesapeake Bay and its tidal tributaries transport huge quantities of sediments. Although sediments are a natural part of the Chesapeake Bay ecosystem, accumulation of excessive amounts is undesirable. As sediments settle to the bottom of the Chesapeake Bay, they can smother bottom-dwelling plants and animals, such as oysters and clams. Sediments suspended in the water column cause the water to become cloudy, decreasing the light available for underwater bay grasses. Sediment-related water quality problems, however, tend to be more of a localized problem.

Individual sediment particles have a large surface area, and many molecules easily adsorb or attach to them. As a result, sediments can act as chemical sinks by adsorbing nutrients and other pollutants. Thus, areas of high sediment deposition sometimes have high concentrations of nutrients which may later be released. Reducing sediment loads to the Chesapeake Bay and its tidal tributaries is critical for restoring water quality.

SOURCES OF NUTRIENT LOADS TO THE CHESAPEAKE BAY TIDAL WATERS

When accounting for all the nutrients that enter the Chesapeake Bay from its watershed, the two largest anthropogenic contributors of both nitrogen and phosphorus are nonpoint source runoff from agriculture and point sources. Forests are a natural source of nutrients, but relative to anthropogenic sources, are a relatively small percentage of the total nutrient load entering the Chesapeake Bay. The largest source of sediments in the Bay is agriculture, followed by forest, urban runoff and mixed open lands. Figures II-9 through II-14 provide a breakdown of the nitrogen, phosphorus, and sediment loads delivered to the Chesapeake Bay and its tidal tributaries as well as estimated reductions achieved in these loads from 1985 to 2000 from each source. These loads do not include atmosphere deposition directly to tidal waters—see "Atmospheric Sources" below.

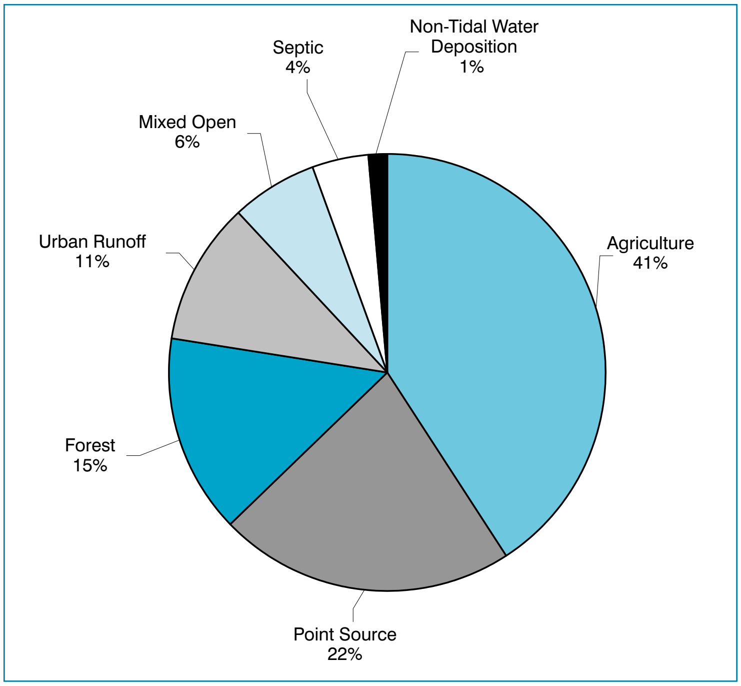


Figure II-9. Chesapeake Bay Watershed Model-estimated nitrogen loads by source delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion. A total of 285 million pounds/year were delivered to the tidal waters based on the Watershed Model's 2000 Progress scenario.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

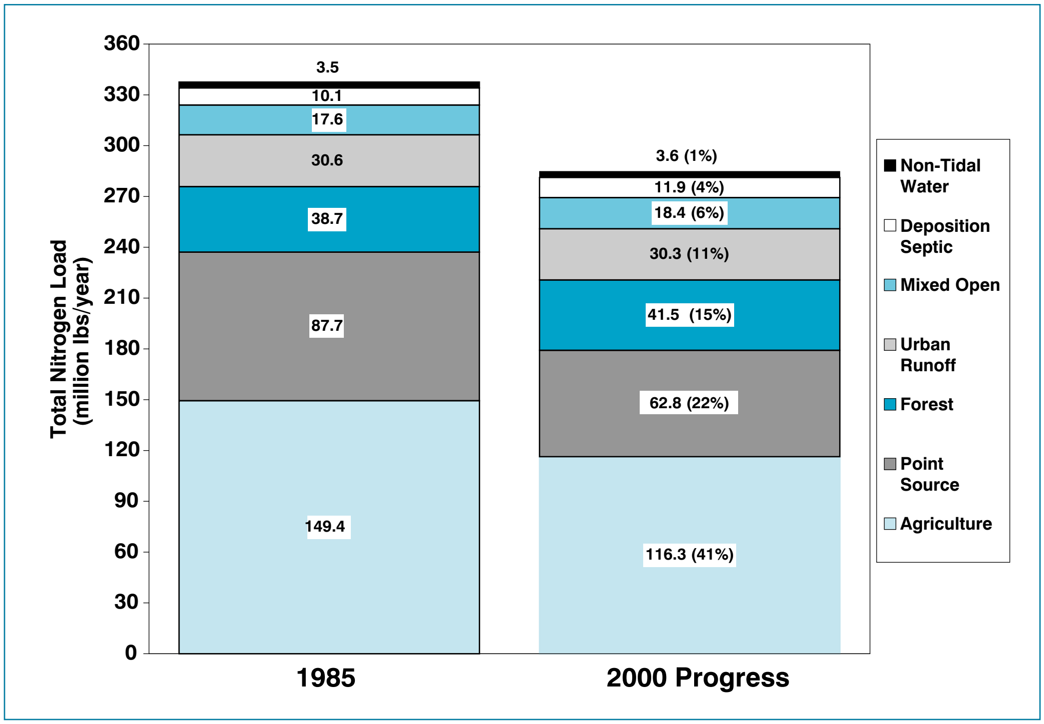
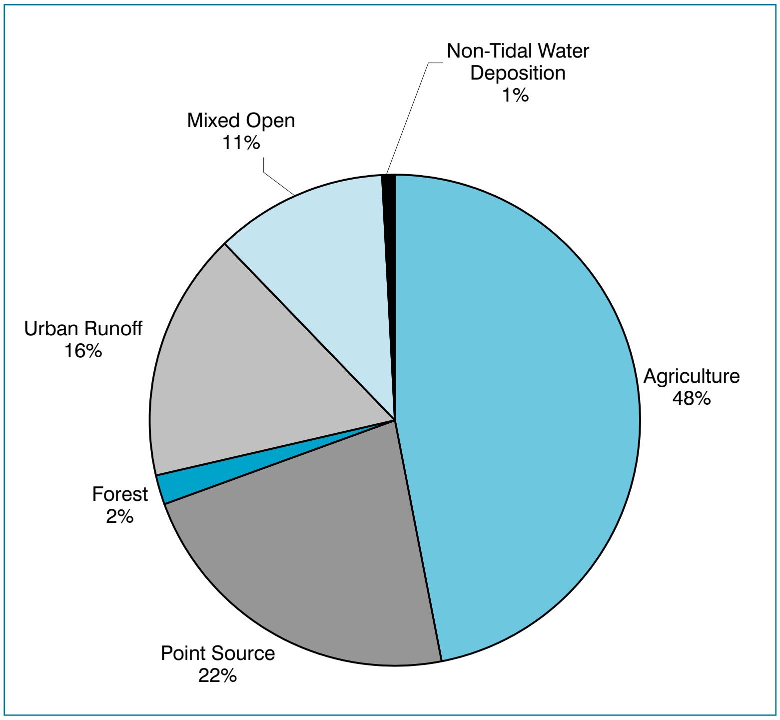


Figure II-10. 1985 and 2000 Chesapeake Bay Watershed Model-estimated nitrogen loads by source delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

Figure II-11. Chesapeake Bay Watershed Model-estimated phosphorus loads by source delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion. A total of 19.1 million pounds/year were delivered to the tidal waters based on the Watershed Model's 2000 Progress scenario.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.



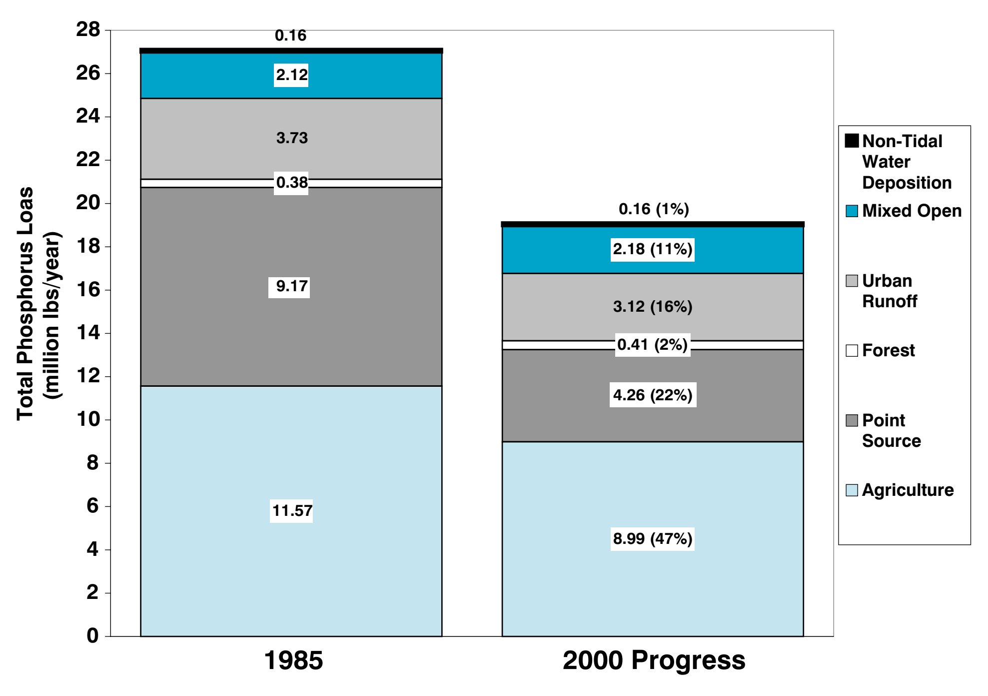


Figure II-12. 1985 and 2000 Chesapeake Bay Watershed Model-estimated phosphorus loads by source delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

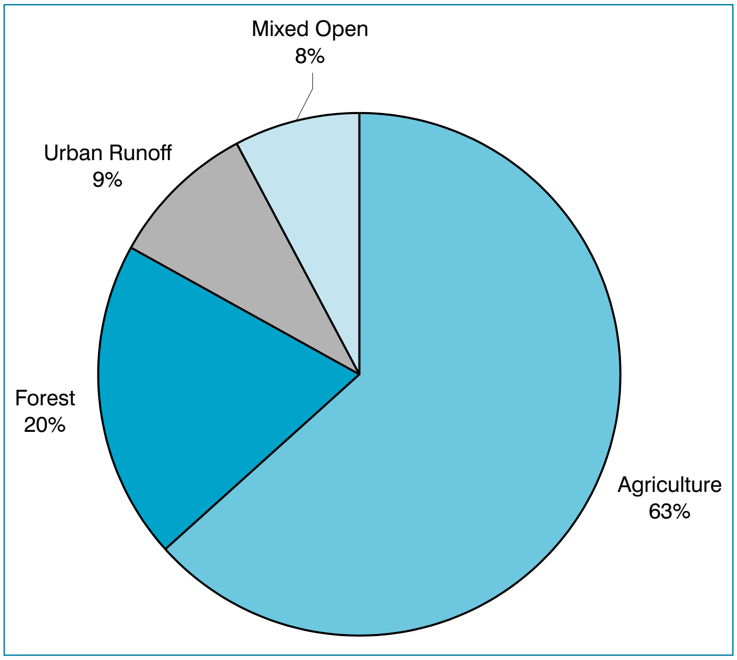


Figure II-13. Chesapeake Bay Watershed Model-estimated sediment loads by source delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion. A total of 5.04 million pounds/year were delivered to the tidal waters based on the Watershed Model's 2000 Progress scenario.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

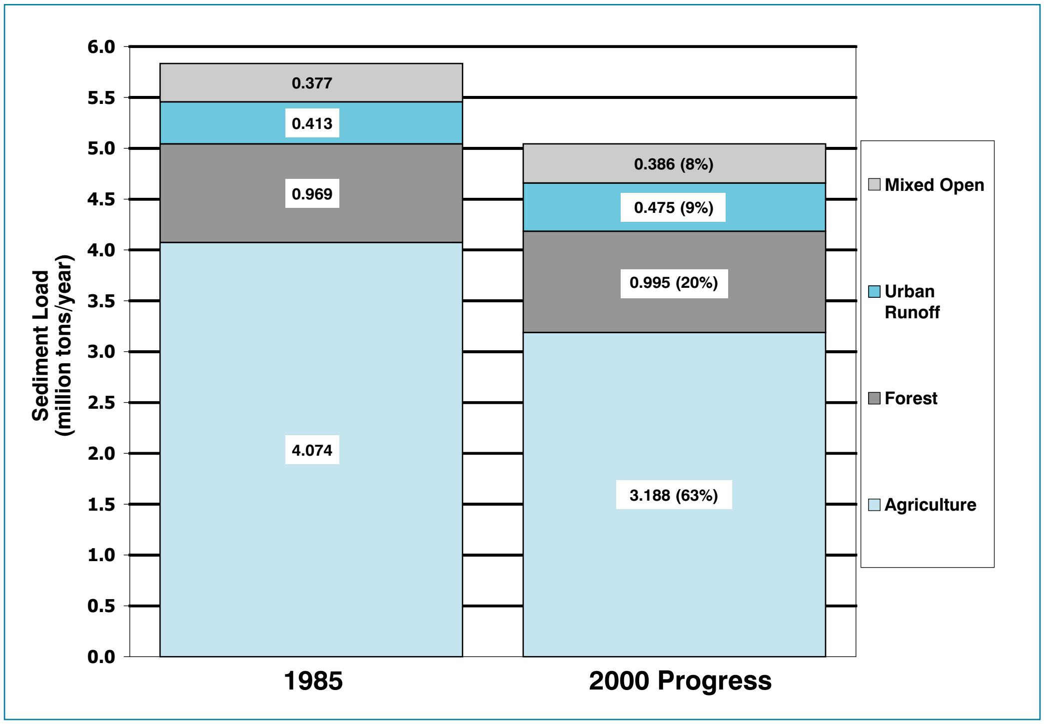


Figure II-14. 1985 and 2000 Chesapeake Bay Watershed Model-estimated sediment loads delivered to the Chesapeake Bay and its tidal tributaries excluding direct atmospheric deposition to tidal waters and shoreline erosion.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

NONPOINT SOURCES

Nonpoint source pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. Rainfall or melted snow moving over and through the ground is one such source. As the runoff moves, it picks up and carries away natural and anthropogenic pollutants, some of which are deposited into the Chesapeake Bay and its tidal tributaries. Animal manure or chemical fertilizers applied to lawns, gardens and farm fields can wash off the land into streams and rivers or seep into the ground where they can be delivered to streams via groundwater.

Nonpoint source pollution in the Chesapeake Bay watershed emanates from six sources: agriculture, forest, urban, mixed open, septic and atmospheric deposition. As noted earlier, agriculture accounts for the largest percentage of nonpoint source nitrogen pollution.

Agricultural runoff includes nutrients from chemical fertilizers and animal manure applied to land, as well as eroded soil particles and organic matter. Improper storage of animal wastes and mortality can result in additional nutrients being leaked into the groundwater or carried off in rainwater. Animals pastured near streams and other water bodies also contribute to the nutrient load delivered to the tributaries of the Chesapeake Bay.

Septic systems leak nutrients into the groundwater since most systems currently do not incorporate technologies to remove nitrogen from the wastewater they treat then discharge. Such systems are a source of nitrogen to the watershed not only from the treated effluent, but from systems that are not functioning properly due to age, neglect in operation and maintenance, or improper siting and installation.

Increases in nutrient runoff from urban areas are expected to occur in the future due to increasing development of forested and agricultural lands. Nitrogen loads from septic systems are expected to increase as population increases, however, if people continue to move away from the urban and suburban areas that are currently serviced by public sewer facilities, projected loads may be even higher. Runoff from farms is generally declining as farmers adopt nutrient management and runoff control techniques, but also because the overall amount of farmland is declining.

POINT SOURCES

A point source is an outfall pipe associated with a point of entry, such as the end of a pipe, where nutrients enter waterways. Industrial sites and wastewater treatment plants are examples of point sources. As of 2000, point sources were estimated to account for 22 percent of the total load of nitrogen and phosphorus to the Chesapeake Bay and its tidal tributaries. The Chesapeake Bay Program, working with its partner states and jurisdictions, assimilated a database on all of the point sources with significant contributions of nutrients to the watershed. (Sediments are not currently counted as a component of point source effluents.) The point source database consists of facilities located in all the states and jurisdictions in the Chesapeake Bay watershed (Table II-2). These point sources are divided into four principal categories.

- Significant municipal facilities, which are generally municipal wastewater treatment plants that discharge flows of equal to or greater than 0.5 millions of gallons per day (MGD). More specifically, significant municipal facilities are defined slightly differently for each jurisdiction. For Virginia, these facilities are those that have a design flow of 0.5 MGD or greater, and all facilities located below the fall line, regardless of flow. For Maryland, significant facilities are those having a current flow of 0.5 MGD or greater. For Pennsylvania, significant facilities are those having average annual 1985 flows of 0.4 MGD or greater. For Delaware, West Virginia, and New York, the Chesapeake Bay Program selected as significant municipal facilities those in the EPA Permit Compliance System database with current flows of 0.5 MGD or greater.
- Significant industrial facilities have been identified as those that discharge the equivalent or greater amounts of nutrients as compared to a municipal wastewater treatment facility's discharge of 0.5 MGD. These discharge loads would roughly be equivalent to those of municipalities with flows of 0.5 MGD or greater, or a total nitrogen load of 75 pounds per day, and a phosphorus load of 25 pounds per day or greater (based on a municipal facility effluent discharge of 2.5 mg/l total phosphorus and 18 mg/l total nitrogen).
- Nonsignificant municipal facilities are those that are generally smaller than discharge flows of 0.5 MGD. Only nonsignificant municipal facilities in Maryland and Virginia are included in the database due to the availability of data. While there are approximately 185 nonsignificant municipal facilities across the Chesapeake Bay watershed, the flow and corresponding nutrient loads from these facilities are less than 5 percent of the total for all point sources.
- Combined sewer overflow loads only for the District of Colombia are included in the database because it is the only location for which the Chesapeake Bay Program has nutrient load data. Certainly other combined sewer overflows exist in the watershed, however, to date these have not been quantified in terms of nitrogen and phosphorus load discharges.

Table II-2. Summary of point source facilities within the Chesapeake Bay watershed.

Point Source Category	Description	Number of Facilities	Total 2000 Flow (MGD)
Significant Municipals*	Generally > 0.5 MGD	304	1,554.4
Significant Industrials	Discharge loads generally > 75 lb/day TN & 25 lb/day TP	49	524.7
Non-significant Municipals	Generally < 0.5 MGD	185	10.8
Combined Sewer Overflows	Only for Blue Plains	1	7.6
Total		**540**	**2,097.5**

*Including the six Virginia plants to be built by 2010.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

Today, 83 of the 304 significant municipal wastewater treatment plants and many industrial facilities as well, are using nutrient removal technology (NRT). By 2010, that number is likely to increase to 156. Exponential advances in the development of NRT in recent years, along with performance levels beyond what was traditionally expected, have clearly shown the potential for this technology to achieve much lower levels of nitrogen in discharges than the traditionally accepted performance levels. It must be recognized that the enhanced performance seen to date is partly due to the fact that some treatment plants are operating below their design capacity, and this level of nutrient reduction may be difficult to maintain as flows increase. To date, 12 of the 49 significant industrial nutrient dischargers located in the Chesapeake Bay watershed are practicing some form of nutrient removal, and that number is expected to increase to 16 by 2010.

The nutrient load discharged from municipal point sources is directly linked to population. Because of the implementation of NRT to date, these point sources collectively have achieved a 53 percent reduction in phosphorus loads and a 28 percent reduction in nitrogen loads since 1985, despite the 15 percent increase in population since then. But because the watershed's population is expected to increase by an additional 14 percent by 2010, it will be increasingly more challenging to achieve nutrient reductions from point sources. Figures II-15 and II-16 illustrate the nitrogen and phosphorus loads, respectively, from point sources in the

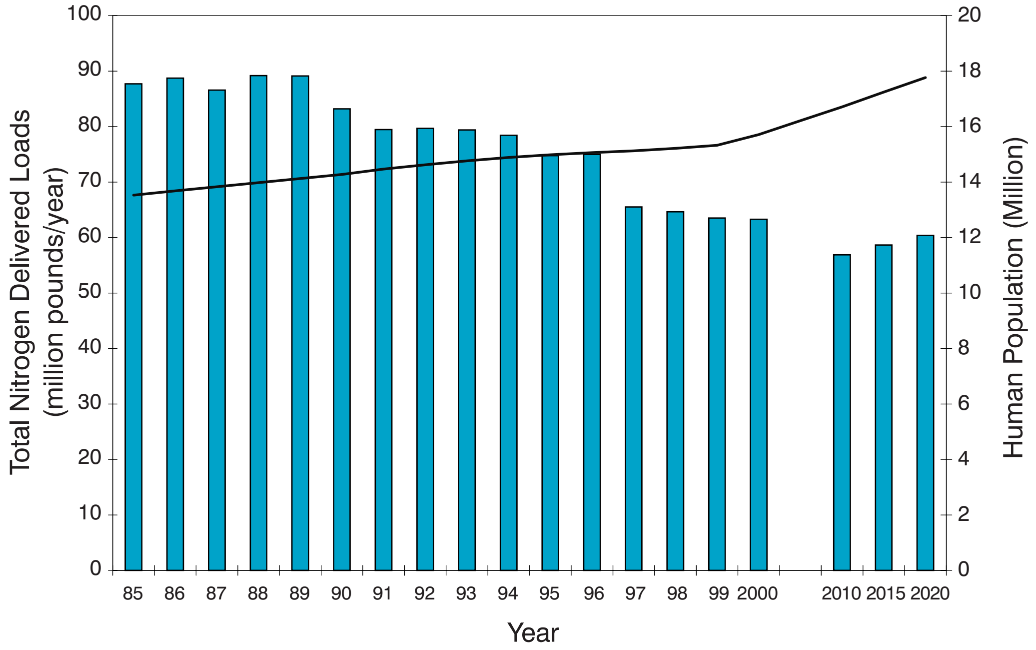


Figure II-15. Total nitrogen loads delivered to the Chesapeake Bay and its tidal tributaries from all point source facilities in the watershed (■) compared with human population trends (▬) in the Chesapeake Bay watershed projected through 2020.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

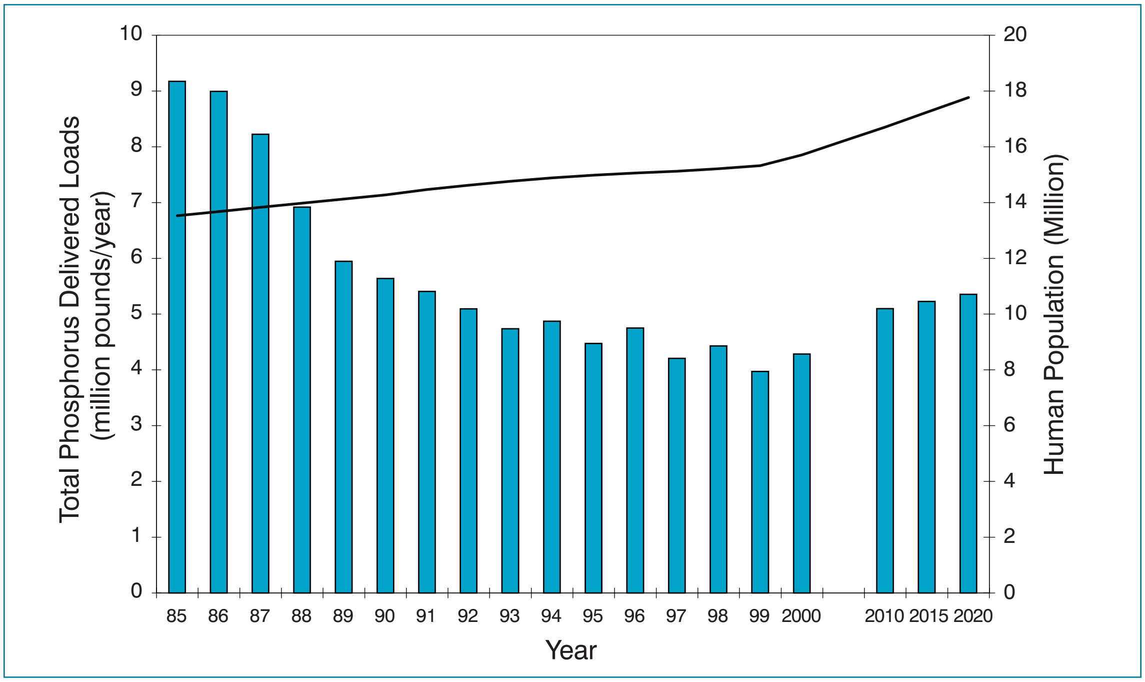


Figure II-16. Total phosphorus loads delivered to the Chesapeake Bay and its tidal tributaries from all point source facilities in the watershed (▮) compared with human population trends (▬) in the Chesapeake Bay watershed projected through 2020.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

past, present and for future projections based on NRT implementation plans by 2010, and for the year 2020 if no more facilities than currently planned implement NRT. Significant progress has been made since 1985 in achieving reductions, but population growth will diminish these successes unless NRT is implemented in more of the facilities, while simultaneously reaching far greater performance levels.

ATMOSPHERIC SOURCES

The sources of nitrogen emissions which contribute to atmospheric nitrogen deposition to the Chesapeake Bay and its watershed are primarily fossil fuels combustion (e.g., electric power generation, on-road vehicles, and industry) which emit nitrogen oxides (NO_x) and agricultural activities (such as commercial fertilizers and animal manure), which release ammonia into the air. Much of the atmospheric nitrogen that deposits to the watershed and makes it way to the tidal waters originates from states located in the nitrogen (NO_x and ammonia) airsheds (Figure II-17). The NO_x airshed is roughly 1,081,600 km^2 in size and the ammonia airshed is roughly 688,000 km^2 in size.

Atmospheric nutrient pollution that falls directly on the water is displayed as a separate category and accounts for 8 percent of the total nitrogen load. Ultimately,

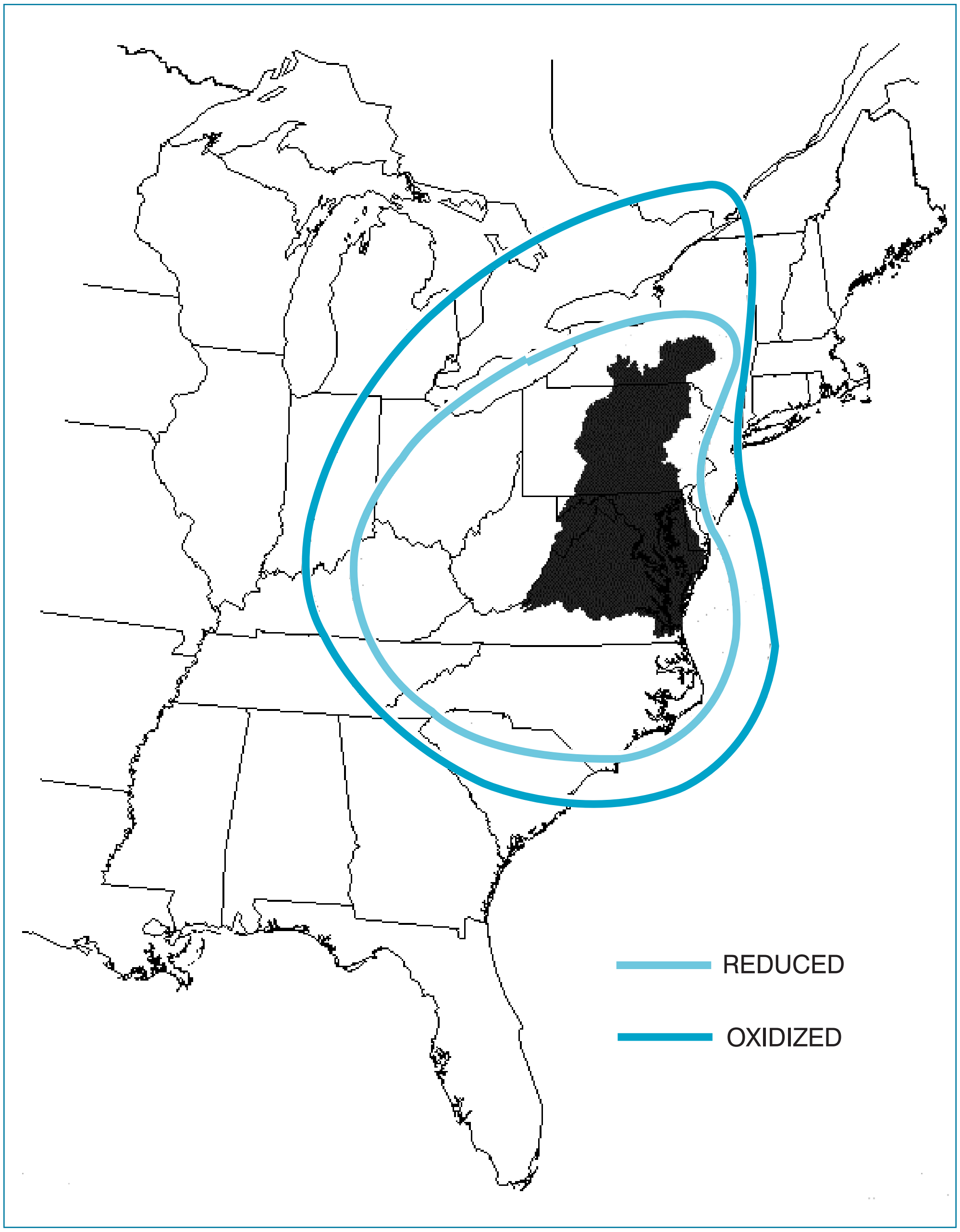


Figure II-17. Principal nitrogen airsheds for the Chesapeake Bay.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net/air/air.htm.

atmospheric nitrogen emissions can be viewed as a nonpoint source when they are deposited on the land and reach the Chesapeake Bay as runoff. Atmospheric nitrogen that falls on the land accounts for an additional 24 percent of the total nitrogen load and is included as part of the agriculture, forest and urban and mixed open sources in Figures II-9 and II-10.

ANTHROPOGENIC SOURCE INPUTS

Table II-3 was developed by estimating the relative nitrogen and phosphorus source contributions from the perspective of anthropogenic inputs–atmospheric emissions, chemical fertilizers and manure. This table includes atmospheric deposition directly to tidal waters (20 million pounds), thus totaling a model-estimated 305 million pounds/year of nitrogen delivered to the Chesapeake Bay and its tidal waters instead of 285 million pounds/year as portrayed in Figures II-9 and II-10. As also shown in Table II-3, the combined atmospheric deposition directly to non-tidal and tidal surface waters is 8 percent (7 percent plus 1 percent) of the total load.

Table II-3 provides estimates based solely on proportions of anthropogenic inputs. There are three key inputs to the land surfaces–atmospheric deposition, chemical fertilizer applications, and manure applications–from which the relative contribution in delivered nitrogen loads is depicted based on their relative proportions. There are natural sources of nitrogen loads to Chesapeake Bay tidal waters that cannot be extracted and are, therefore, included in these source contributions.

Table II-3. Chesapeake Bay Airshed and Watershed Model-estimated 2000 Progress scenario sources of nitrogen and phosphorus loads (million pounds/year) delivered to the Chesapeake Bay and its tidal tributaries based on anthropogenic inputs of atmospheric deposition, chemical fertilizers, manure, point sources and septics, excluding shoreline erosion.

Source Loading Category	Total Nitrogen 2000 Progress	Total Nitrogen (% of Total) 2000 Progress	Total Phosphorus 2000 Progress	Total Phosphorus (% of Total) 2000 Progress
Atmospheric Deposition to Land	75,003,697	25%	5,900,372	29%
Atmospheric Deposition to Non-Tidal Water	3,559,840	1%	162,471	1%
Atmospheric Deposition to Tidal Water	20,467,458	7%	1,550,081	7%
Chemical Fertilizer Applications to Agricultural Land	49,353,664	16%	3,456,104	17%
Chemical Fertilizer Applications to Urban Land	18,146,154	6%	0	0%
Chemical Fertilizer Applications to Mixed Open Land	9,872,122	3%	0	0%
Manure Applications to Agricultural Land	46,048,616	15%	4,646,036	22%
Animal Feeding Operation Runoff	8,026,157	3%	696,297	3%
Point Source	62,841,812	21%	4,257,314	21%
Septic	11,904,029	4%	0	0%
Bay-Wide Total	**305,223,54**	**100%**	**20,668,675**	**100%**

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

chapter iii

Why Attaining the Current Tidal-Water Designated Uses Appears Not to be Feasible

BACKGROUND

Many natural biological, physical and chemical processes and interactions influence water quality conditions and physical habitats in the Chesapeake Bay and its tidal tributaries. In addition, the watershed and estuary have changed dramatically, and in many ways, irreversibly, over the last four centuries as the population has grown to nearly 16 million people. The current state designated uses cannot be met in the deeper waters of the Chesapeake Bay mainstem and portions of the major lower tributaries due to natural and human-caused conditions that cannot be remedied. The current dissolved oxygen criteria adopted by Maryland and Virginia into their water quality standards—≥5 mg/l at all times and ≥4 mg/l minimum/≥5 mg/l daily average, respectively—are unlikely to be achieved in deeper Chesapeake Bay tidal waters during the summer season where physical processes (such as water-column stratification and water circulation) and bottom bathymetry-related barriers prevent the replenishment with oxygenated waters.

As described below, a combination of natural and human-caused conditions prevents attainment of the dissolved oxygen concentrations necessary to meet the states' current aquatic life designated uses in portions of the Chesapeake Bay and its tidal tributaries. It should be noted that any of the six designated use removal factors specified in the EPA Water Quality Standards regulations (40 CFR 131.10[g]) and described in Chapter I can be employed, where appropriate, to justify changing a designated use. This chapter relies on two of those factors, but that reliance does not prevent the states from using one or more additional factors in justifying refinements to their tidal-water designated uses.

The model simulation of all-forested and pristine watersheds and findings from scientific paleoecological records indicate that dissolved oxygen levels less than 5 mg/l are a natural condition in some deeper waters of the Chesapeake Bay and its tidal tributaries during the summer. Furthermore, even where natural conditions could support a dissolved oxygen concentration of 5 mg/l, model simulations show that areas exist where current state standards are unlikely to be met due to irremediable human-caused conditions.

NATURAL CONDITIONS THAT MAY PREVENT ATTAINMENT OF CURRENT DESIGNATED USES

Evidence from the paleoecological record of the Chesapeake Bay Watershed and Water Quality models' simulations of a pristine and all-forested Chesapeake Bay system indicates that natural conditions alone may prevent attainment of current uses. In the absence of monitoring data from periods before human settlement occurred, these findings and simulations provide the best available descriptions and estimates of the Bay's tidal-water quality under natural conditions.

PALEOECOLOGICAL RECORD OF NATURAL CONDITIONS

Dissolved oxygen levels vary naturally in lakes, estuaries and oceans over temporal and spatial scales due to many different biological, chemical and physical processes. In estuaries such as the Chesapeake Bay, freshwater inflow that influences water-column stratification; nutrient input and cycling; physical processes such as density-driven circulation; and tides, winds, water temperature and bacterial activity are among the most important factors. These processes can lead to large natural seasonal and interannual variability in oxygen levels in many parts of the Chesapeake Bay and its tidal tributaries.

Superimposed on this natural dissolved oxygen variability is a progressive increase in the intensity and frequency of hypoxia and anoxia over the past 100 to 150 years, most notably since the 1960s. This human-induced eutrophication is evident both from instrumental data and geochemical and faunal/floral 'proxies' of dissolved oxygen conditions obtained from the sedimentary record.

The instrumental record, while incomplete prior to the inception of the multi-agency Chesapeake Bay Monitoring Program in 1984, suggests that as early as the 1930s (Newcombe and Horne 1938) and especially since the 1960s (Taft et al. 1980), summer oxygen depletion has been recorded in the Chesapeake Bay. Officer et al. (1984), Malone (1992), Harding and Perry (1997) and Hagy (2002) provide useful discussions of the instrumental record of dissolved oxygen and related parameters such as chlorophyll *a* across this multi-decadal data record.

At issue is whether, and to what degree, dissolved oxygen reductions are a naturally occurring phenomenon in the Chesapeake Bay. Long sediment core records (17 meters to greater than 21 meters in length) indicate that the Chesapeake Bay formed about 7,500 years ago (Cronin et al. 2000; Colman et al. 2002) when the rising sea level after the final stage of Pleistocene deglaciation flooded the Susquehanna channel. The modern estuarine circulation and salinity regime probably began in the mid- to late Holocene epoch, about 4,000-5,000 years ago (in the regional climate of the early Holocene, Chesapeake Bay's salinity differed from that of the late Holocene). This theory is based on the appearance of 'pre-colonial' benthic foraminiferal, ostracode and dinoflagellate assemblages. It is against this mid- to late Holocene baseline that the post-European settlement and modern dissolved oxygen regime of the Chesapeake Bay can be viewed.

During the past decade, studies of the Chesapeake Bay's late Holocene dissolved oxygen record have been carried out using several proxies of past dissolved oxygen conditions, which are preserved in sediment cores that have been dated using the most advanced geochronological methods. These studies, using various indicators of past dissolved oxygen conditions, are reviewed in Cronin and Vann (2003) and provide information that puts the monitoring record of the modern Chesapeake Bay into a long-term perspective and permits an evaluation of natural variability in the context of restoration targets. The following types of measurements of oxygen-sensitive chemical and biological indicators have been used: nitrogen isotopes (Bratton et al. 2003); biogenic silica and diatom communities (Cooper and Brush 1991; Cooper 1995; Colman and Bratton 2003); molybdenum and other metals (Adelson et al. 2000; Zheng et al. 2003); lipid biomarkers; acid volatile sulfur (AVS)/chromium reducible sulfur (CRS) ratios; total nitrogen and total organic carbon (Zimmerman and Canuel 2000); elemental analyses (Cornwell et al. 1996) and paleoecological reconstructions based on dinoflagellate cysts (Willard et al. 2003); and benthic foraminiferal assemblages (Karlsen et al. 2000). Although space precludes a comprehensive review of these studies, and the time period studied and level of quantification vary, several major themes emerge, summarized below.

First, the 20th century sedimentary record confirms the limited monitoring record of dissolved oxygen, documenting that there has been a progressive decrease in dissolved oxygen levels, including the periods of extensive anoxia in the deep-channel region of the Chesapeake Bay that have been prominent during the past 40 years. Most studies provide strong evidence that there was a greater frequency or duration of seasonal anoxia beginning in the late 1930s and 1940s and again around 1970, reaching unprecedented frequencies or duration in the past few decades in the mesohaline Chesapeake Bay and the lower reaches of several tidal tributaries (Zimmerman and Canuel 2000; Hagy 2002). Clear evidence of these low dissolved oxygen conditions has been found in all geochemical and paleoecological indicators studied principally through their great impact on benthic and phytoplankton (both diatom and dinoflagellate) communities.

Second, extensive late 18th and 19th century land clearance also led to oxygen reduction and hypoxia, which exceeded levels characteristic of the previous 2,000 years. Best estimates for deep-channel mid-bay seasonal oxygen minima from 1750 to around 1950 are 0.3 to 1.4-2.8 mg/l and are based on a shift to dinoflagellate cyst assemblages of species tolerant of low dissolved oxygen conditions. This shift is characterized by a four- to fivefold increase in the flux of biogenic silica, a greater than twofold (5-10 milliliter^{-1}) increase in nitrogen isotope ratios ($_{15}$N) and periods of common (though not dominant) *Ammonia parkinsoniana*, a facultative anaerobic foraminifer. These patterns are likely the result of increased sediment influx and nitrogen and phosphorous runoff due to extensive land clearance and agriculture.

Third, before the 17th century, dissolved oxygen proxy data suggest that dissolved oxygen levels in the deep channel of the Chesapeake Bay varied over decadal and interannual time scales. Although it is difficult to quantify the extremes, dissolved oxygen probably fell to 3 to 6 mg/l, but rarely if ever fell below 1.4 to 2.8 mg/l. These paleo-dissolved oxygen reconstructions are consistent with the Chesapeake Bay's natural tendency to experience seasonal oxygen reductions due to its bathymetry, freshwater-driven salinity stratification, high primary productivity and organic matter and nutrient regeneration (Boicourt 1992; Malone 1992; Boynton et al. 1995).

In summary, the main channel of the Chesapeake Bay most likely experienced reductions in dissolved oxygen before large-scale post-colonial land clearance took place, due to natural factors such as climate-driven variability in freshwater inflow (Table III-1). However, this progressive decline in summer oxygen minima, beginning in the 18th century and accelerating during the second half of the 20th century, is superimposed on interannual and decadal patterns of dissolved oxygen variability. Human activity during the post-colonial period has caused the trend towards hypoxia and most recently (especially after the 1960s) anoxia in the main channel of the Chesapeake Bay and some of its larger tidal tributaries. The impact of these patterns has been observed in large-scale changes in benthos and phytoplankton communities, which are manifestations of habitat loss and degradation.

WATER QUALITY CONDITIONS UNDER ALL-FORESTED AND PRISTINE WATERSHEDS

The natural relationships between processes on the land and in the water have been altered to such a degree that it is now difficult to discern natural conditions in this complex estuarine ecosystem. A 'natural' system is often considered to be the state prior to European settlement, although pre-contact Native American activities had an effect on the watershed and the Chesapeake Bay ecosystem as well. Pristine estuarine ecosystems no longer exist from which to reference water quality conditions since human-induced changes now affect even the most remote regions of the planet.

Given the research and monitoring data limitations for measuring natural water quality conditions, the Chesapeake Bay Program developed a paired set of model scenarios that represent its best effort to simulate water quality conditions prior to European settlement. By using the same model simulation tools to estimate pre-settlement water quality conditions as those used in other aspects of the attainability analyses presented in the *Technical Support Document*, reasonable comparisons can be made among estimated nutrient and sediment loading results and resulting simulated tidal-water quality responses.

The 'all-forest' scenario is a model simulation of what nutrient and sediment loads might occur if the entire Chesapeake Bay watershed was forested and atmospheric

Table III-1. Synthesis of five scientific experts' individual and collective findings on the history of anoxia and hypoxic conditions in Chesapeake Bay tidal waters.

Chesapeake Bay Dissolved Oxygen Criteria Team member Dr. Thomas Cronin, of the U.S. Geological Survey (USGS), surveyed five scientists[8] who have studied the history of anoxia and hypoxia in the Chesapeake Bay over decadal and centennial time scales, using geochemical and biological proxies from sediment cores and instrumental and historical records. The consensus of the five scientists is that the Chesapeake Bay was seasonally anoxic between 1900 and 1960. The seasonal anoxia was extensive in the deep channel and probably lasted several months. Similarly, between 1600 and 1900, the near-unanimous consensus is that the Chesapeake Bay was seasonally anoxic for probably weeks to months in the deep channel. One researcher had reservations about his group's earlier conclusion on definitive evidence of anoxia prior to 1900, but cannot exclude the possibility of anoxia during this period. Anoxia during the 1900–1960 period was probably geographically less extensive in the Chesapeake Bay and perhaps occurred less frequently (i.e., not every year) than after the 1960s. In addition to the geochemical and faunal proxies of past trends in oxygen depletion, experts cite the Sale and Skinner (1917) instrumental documentation of hypoxia and probable anoxia in the lower Potomac River in 1912.

For the period prior to European colonization (approximately 1600 AD), the consensus is that the deep channel of the Bay may have been briefly hypoxic (less than 2 mg/l), especially during relatively wet periods (which did occur, based on the paleo-climate record). Anoxia probably occurred only during exceptional conditions. It should be noted that the late 16th century and much of the 17th century were extremely dry periods, not conducive to oxygen depletion.

In sum, hypoxia, and probably periodic spatially limited anoxia, occurred in the Chesapeake Bay prior to the large-scale application of fertilizer, but since the 1960s oxygen depletion has become much more severe.

These experts also unanimously believe that restoring the Chesapeake Bay to mid-20th century, pre-1960 conditions might be possible but very difficult (one expert suggested an 80 percent nitrogen reduction was necessary), in light of remnant nutrients in sediment in the Chesapeake Bay and behind dams, likely increased precipitation as the climate changes, population growth and other factors. Most researchers believe that restoring the Chesapeake Bay to conditions prior to 1900 is either impossible, or not realistic, simply due to the fact that the temporal variability (year-to-year and decadal) in 'naturally occurring' hypoxia renders a single target dissolved oxygen level impossible to define.

Source: U.S. EPA 2003.

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[8] T. M. Cronin (USGS, Reston, Virginia), S. Cooper (Bryn Athyn College), J. F. Bratton (USGS, Woods Hole, Massachusetts), A. Zimmerman (Pennsylvania State University), G. Helz (University of Maryland, College Park).

deposition reduced to 10 percent of the current loading rates. The storage of nutrients in the soil is still somewhat elevated under this scenario, and the nitrogen delivered to the Bay's tidal waters is actually greater than the atmospheric inputs to the watershed, owing to a 'draw-down' of nutrients in the soil. Shoreline erosion loading rates are maintained at current levels.

The 'pristine' scenario is a model simulation of what may have occurred under pre-settlement conditions. Atmospheric deposition is reduced to 10 percent of the current loading rates as in the all-forest scenario, but the soil storage of nutrients is also reduced, so that there is no 'draw-down' of nutrients during the simulation. In addition, steps were taken to restrict the conversion of particulate organic nitrogen to solution organic nitrogen. Shoreline erosion was set to only 10 percent of current levels to account for the pre-settlement presence of vast underwater grass beds and intertidal oyster bar breakwaters. Unlike most model simulations, no fertilizer applications to agricultural land, implementation of best management practices, septic loads or discharges from point sources are shown in either the all-forest or pristine scenarios.

STRENGTHS AND LIMITATIONS OF THE ALL-FOREST AND PRISTINE SCENARIOS

It is extremely difficult to determine the accuracy of the predictions at one-tenth the calibrated nitrogen loads for both the Chesapeake Bay Watershed and Water Quality models. Overall, the extremes of the all-forest and pristine scenarios push all three Chesapeake Bay models, including the Bay airshed model, to their limits since they are calibrated to relatively current conditions.

The biological filtering capacities of a pristine Chesapeake Bay ecosystem are not factored into the current Bay models. One of these processes involved the vast extent of filter feeders, such as oysters, that consumed water-borne nutrients. In addition, oyster reefs provided habitat for an enormous range of other animals such as worms, snails, sea squirts, sponges, small crabs, and fishes, all of which are important components of the estuarine food web.

Existing reservoirs, dams, and shipping channels are present in the all-forest and pristine scenario landscapes and tidal waters because the Chesapeake Bay Watershed and Water Quality models were calibrated with these human alterations in place. As described in Chapter IV, these physical alterations can directly influence Chesapeake Bay tidal-water quality conditions.

MODEL-SIMULATED NATURAL DISSOLVED OXYGEN CONDITIONS

By anticipating these limitations when characterizing pre-European settlement effects on watershed loadings and tidal-water quality conditions, the paired all-forest and pristine scenarios present the best quantitative estimate of where and when "naturally occurring pollutant concentrations prevent the attainment of the use"

(40 CFR 131.10[g]). The range of nutrient and sediment loads from these two scenarios yields the watershed partners' current best estimated range of "naturally occurring pollutant concentrations" and resulting Chesapeake Bay tidal-water quality conditions. Like all model results, the loads and water quality responses are most useful when compared to other scenarios. In this case, adequate comparisons can be made between the all-forest scenario results and those containing established levels of anthropogenic effects.

Figure III-1 illustrates the results of outputs from three scenarios of the Chesapeake Bay Water Quality Model–the pristine, all-forest, and E3 scenarios. The outputs provide the percent nonattainment of a 5 mg/l monthly average dissolved oxygen concentrations over 10 years of hydrology for the deep-channel, deep-water, open-water and migratory designated uses as discussed in Chapter IV. These dissolved oxygen concentrations are displayed over time (June 1 through September 30) and volume of each respective designated use. Given the integration of the Chesapeake Bay Water Quality Model with water quality monitoring data, the outputs are currently generated as monthly averages although the water quality model operates on hourly time scales (Table III-2).

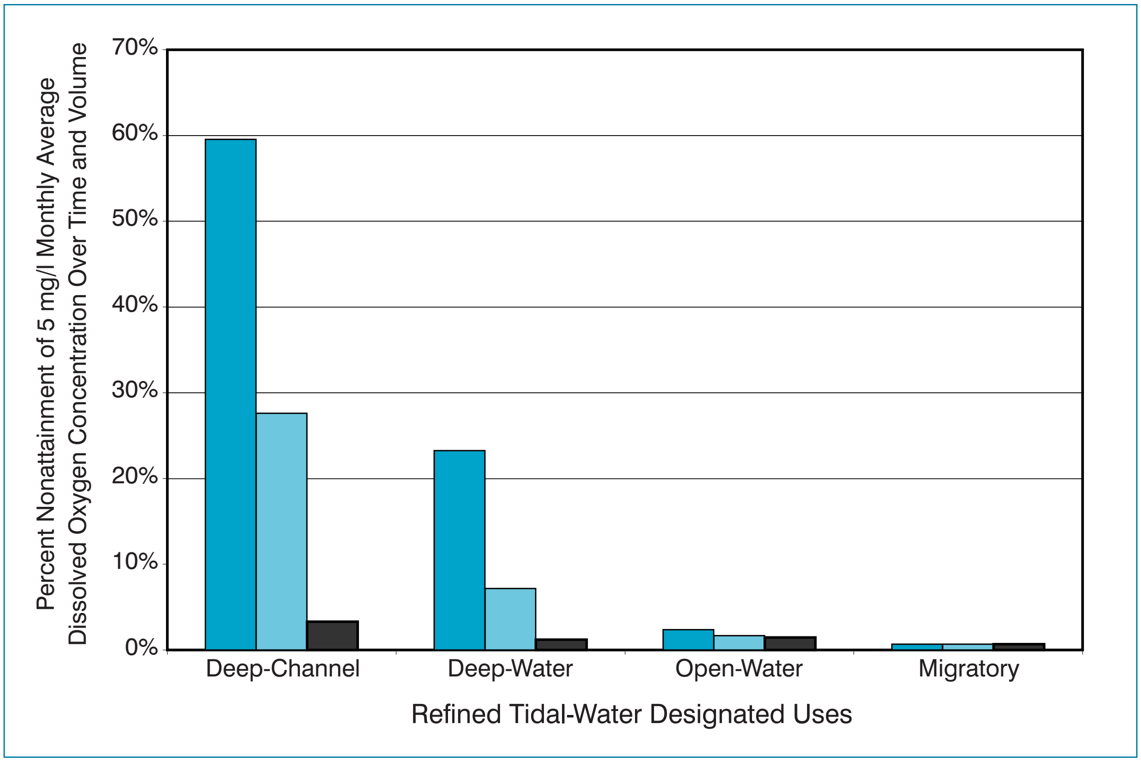

Figure III-1. Percent nonattainment of a 5 mg/l monthly average dissolved oxygen concentration over the June through September period for the E3 (physically implausible) (■), all-forest (□) and pristine (■) model scenarios by the refined tidal-water designated uses.

Table III-2. Chesapeake Bay Watershed and Water Quality models.

The watershed and airshed models are loading models. As such, they provide an estimate of management actions through air controls, agricultural best management practices, or point source controls which will reduce nutrient or sediment loads to the Chesapeake. The advantage of using loading models is that the full simulation through different hydrologies of wet, dry, and average periods can be simulated on existing or hypothetical landuse patterns. All of the Chesapeake Bay Program models used in the attainability analyses simulate the 10-year period of 1985 to 1994 (Linker et al. 2000).

Chesapeake Bay Watershed Model

The Chesapeake Bay Watershed Model is designed to simulate nutrient and sediment loads delivered to the Chesapeake Bay under different management scenarios (Donigian et al. 1994; Linker et al. 1996; Linker 1996). The simulation is an overall mass balance of nitrogen and phosphorus in the basin, so that the ultimate fate of the input nutrients is incorporation into crop or forest plant material, incorporation into soil, or loss through river runoff. The Chesapeake Bay Watershed Model has been in continuous operation within the Chesapeake Bay Program since 1982, and has had many upgrades and refinements since that time. The current version of the Watershed Model, Phase 4.3, is a comprehensive package for the simulation of watershed hydrology, nutrient and sediment export from pervious and impervious landuses and the transport of these loads in rivers and reservoirs.

Chesapeake Bay Water Quality Model

The complex movement of water within the Chesapeake Bay, particularly the density-driven vertical estuarine stratification, is simulated with a Chesapeake Bay hydrodynamic model of more than 13,000 cells (Wang and Johnson 2000). The Water Quality Model is linked to the hydrodynamic model and uses complex nonlinear equations describing 26 state variables of relevance to the simulation of dissolved oxygen, water clarity and chlorophyll *a* (Cerco 1993, 1995a, 1995b, 2000; Thomann et al. 1994; Cerco and Meyers 2000). Coupled with the Water Quality Model are simulations of settling organic material sediment and its subsequent decay and flux of inorganic nutrients from the sediment (Di Toro 2001), as well as a coupled simulation of underwater bay grasses in the shallows (Cerco and Moore 2001).

Integration of Monitoring and Modeling for Criteria Assessment

The observed data is used to assess criteria attainment during a ‘base’ period corresponding to the years of calibration for the Chesapeake Bay Water Quality Model, 1985–1994. The Chesapeake Bay Water Quality Model is used in scenario mode to determine the effect of changes in nutrient and sediment loads on water quality concentrations. A modified 1985–1994 observed data set is generated for each scenario using both the model and the observations. The same criteria attainment assessment process applied to the observed data is then applied to this ‘scenario’ data to determine likely criteria attainment under modified loading scenarios. For a full discussion of this procedure, see *A Comparison of Chesapeake Bay Estuary Model Calibration with 1985–1994 Observed Data and Method of Application to Water Quality Criteria* (Linker et al. 2002).

Under existing state water quality standards (see Chapter IV), the current dissolved oxygen criteria for Chesapeake Bay tidal waters in Maryland is “greater than or equal to 5 mg/l at all times,” and in Virginia the Chesapeake Bay tidal-water criteria are “greater than or equal to 4 mg/l minimum, and greater than or equal to 5 mg/l daily average [see Table IV-1].” The analysis illustrated here for monthly average dissolved oxygen concentrations is less stringent of an averaging period than the current criteria in the states’ water quality standards, given the monthly model output limitation.

Results from the all-forest and pristine scenarios indicate that water quality in those portions of the Chesapeake Bay that currently have deep-water and deep-channel designated uses are unlikely to meet existing Maryland and Virginia state dissolved oxygen water quality standards under natural conditions. Baywide, between 3 percent (pristine) and 28 percent (all-forest) of the volume and time over the summer months of the 10-year simulation period would likely not attain the current designated uses in the deep channel (Figure III-1). The current designated uses would likely not be attained up to 7 percent of the volume and time during the summer months under natural conditions in the deep-water habitats.

An examination of all-forest and pristine scenario results on a segment-by-segment scale documents similar findings. Table III-3 provides model-simulated results for the summer months–June through September–which have the lowest ambient dissolved oxygen concentrations. Results are presented for the 35 major Chesapeake Bay Program segments. In the upper, middle and lower central Chesapeake Bay, lower Potomac River, lower Rappahannock River and Eastern Bay segments there are natural barriers (e.g., water-column stratification, bottom bathymetry) preventing replenishment of dissolved oxygen to the deeper portions of the tidal waters under the all-forest scenario. For these segments under the all-forest scenario, nonattainment of the current state-adopted dissolved oxygen criteria assessed by the refined deep-water and deep-channel designated use habitats ranged up to 41 percent of the possible volume and time during the summer over the 10-year simulation period (Table III-3). Nonattainment values were down in the range of 4 percent to 5 percent under the pristine scenario.

These all-forest and pristine scenario findings are consistent with the conclusions reached through analysis of the *Paleoecological Records of Natural Conditions* described above.

Table III-3. Percent nonattainment of 5 mg/l monthly averaged dissolved oxygen concentrations over the June through September period from the E3, all-forest and pristine model scenarios for the 35 major Chesapeake Bay Program segments by the refined tidal-water designated uses.

Chesapeake Bay Program Segment	Refined Tidal-Water Designated Use	Scenario		
		E3	All-Forest	Pristine
Northern Chesapeake Bay (CB1TF)	MIG	A	A	A
	OW	A	A	A
Upper Chesapeake Bay (CB2OH)	MIG	A	A	A
	OW	A	A	A
Upper Central Chesapeake Bay (CB3MH)	MIG	A	A	A
	OW	A	A	A
	DW	6	A	A
	DC	44	10	A
Middle Central Chesapeake Bay (CB4MH)	OW	A	A	A
	DW	25	2	A
	DC	81	41	4
Upper Central Chesapeake Bay (CB5MH)	OW	A	A	A
	DW	8	1	A
	DC	54	28	4
Western Lower Chesapeake Bay (CB6PH)	OW	A	A	A
	DW	4	A	A
Eastern Lower Chesapeake Bay (CB7PH)	OW	A	A	A
	DW	1	A	A
Mouth of Chesapeake Bay (CB8PH)	OW	A	A	A
Upper Patuxent River (PAXTF)	MIG	A	A	A
	OW	A	5	5
Middle Patuxent River (PAXOH)	MIG	A	A	A
	OW	A	A	A
Lower Patuxent River (PAXMH)	MIG	A	A	A
	OW	A	A	A
	DW	9	A	A
Upper Potomac River (POTTF)	MIG	A	A	A
	OW	A	A	A
Middle Potomac River (POTOH)	MIG	A	A	A
	OW	A	A	A
Lower Potomac River (POTMH)	MIG	A	A	A
	OW	A	A	A
	DW	8	A	A
	DC	50	11	A
Upper Rappahannock River (RPPTF)	MIG	A	A	A
	OW	A	A	A
Middle Rappahannock River (RPPOH)	MIG	A	A	A
	OW	A	A	A

continued

Table III-3. Percent nonattainment of 5 mg/l monthly averaged dissolved oxygen concentrations over the June through September period from the E3, all-forest and pristine model scenarios for the 35 major Chesapeake Bay Program segments by the refined tidal-water designated uses *(cont.)*.

Chesapeake Bay Program Segment	Refined Tidal-Water Designated Use	Scenario E3	Scenario All-Forest	Scenario Pristine
Lower Rappahannock River (RPPMH)	MIG	A	A	A
	OW	A	A	A
	DW	6	A	A
	DC	39	11	A
Piankatank River (PIAMH)	OW	A	A	A
Upper Mattaponi River (MPNTF)	MIG	A	A	A
	OW	25	45	54
Lower Mattaponi River (MPNOH)	MIG	A	A	A
	OW	48	56	59
Upper Pamunkey River (PMKTF)	MIG	A	A	A
	OW	13	50	62
Lower Pamunkey River (PMKOH)	MIG	A	A	A
Middle York River (YRKMH)	MIG	A	A	A
	OW	A	A	A
Lower York River (YRKPH)	OW	A	A	A
	DW	2	A	A
Mobjack Bay (MOBPH)	OW	A	A	A
Upper James River (JMSTF)	MIG	A	A	A
	OW	A	A	A
Middle James River (JMSOH)	MIG	A	A	A
	OW	A	A	A
Lower James River (JMSMH)	MIG	A	A	A
	OW	A	A	A
Mouth of the James River (JMSPH)	OW	A	A	A
Eastern Bay (EASMH)	MIG	A	A	A
	OW	A	A	A
	DW	10	A	A
	DC	61	22	A
Middle Choptank River (CHOOH)	MIG	A	A	A
	OW	A	A	A
Lower Choptank River (CHOMH2)	MIG	A	A	A
	OW	A	A	A
Mouth of the Choptank River (CHOMH1)	MIG	A	A	A
	OW	A	A	A
Tangier Sound (TANMH)	OW	A	A	A
Lower Pocomoke River (POCMH)	OW	A	A	A

A = Applicable dissolved oxygen criteria fully attained; analysis based on monthly averaged dissolved oxygen concentrations 5 mg/l, 3 mg/l and 1 mg/l for open-water, deep-water and deep-channel designated uses.
DU = designated use; OW = open-water; DW = deep-water; DC = deep-channel.

HUMAN-CAUSED CONDITIONS THAT CANNOT BE REMEDIED WHICH APPEAR TO PREVENT ATTAINMENT OF CURRENT DESIGNATED USES

Beyond natural conditions, some human-related conditions and alterations of the watershed and tidal-water habitats must be considered in determining attainability of the current designated uses. To conduct this component of the UAA, where and when "human-caused conditions or source of pollution prevent the attainment of the use and cannot be remedied" (CFR 131.10[g]) must be defined.

The Chesapeake Bay Program developed a series of level-of-effort scenarios as a tool for assessing the Chesapeake Bay watershed's potential for nutrient and sediment reductions (Appendix A). These scenarios range from a Tier 1 level, which will be in place by 2010 under current voluntary and regulatory programs, up to the fourth, 'everything, everywhere by everybody,' or the E3 scenario. Each scenario was based on 2010 projections of landuses, human population, agricultural animal populations, point source flows and septic systems.

Reduction actions defined in the E3 scenario were simulated using the Chesapeake Bay Program's Phase 4.3 Watershed Model and the EPA's Regional Acid Deposition Model (RADM), resulting in estimated airshed and watershed loads for nitrogen, phosphorus and sediment. The loading inputs from the airshed and watershed models were then fed into the Chesapeake Bay Water Quality Model to simulate the resulting dissolved oxygen concentrations.

The E3 scenario represents the limits of technology as known at the time of this analysis (Table III-4) and is acknowledged not to be physically plausible in all cases (Table III-5). This analysis assumes that any nutrient or sediment reductions *equal to or beyond* the levels defined through the E3 scenario can be considered to represent human-caused conditions that cannot be remedied and can be used for justifying why current designated uses cannot be met.

It is not possible to determine definitively human-caused conditions that cannot be remedied. However, the E3 scenario represents the Chesapeake Bay Program partners' best effort to capture those conditions by removing as much subjectivity as possible in developing the scenario. Reported E3 scenario loading results from the Chesapeake Bay watershed's land area, as a whole, represent theoretical minimum loads equal to or beyond which it would be extremely difficult, if not impossible, in many cases to achieve at this time. However, the reported E3 scenario-simulated water quality response can be improved if opportunities for further controls on shoreline erosion are incorporated.

It appears unlikely that current state water quality standards for dissolved oxygen can be achieved in significant portions of the Chesapeake Bay and tidal tributaries' deep-water and deep-channel habitats (see Table III-3). As approximated by a 5 mg/l monthly average dissolved oxygen concentration, the existing state dissolved oxygen

Table III-4. E3 scenario description.

The defined levels for technology and best management practices implementation in the 'everything, everywhere by everybody,' or the E3 scenario, are theoretical. There are no cost and few physical limitations applied to implementing BMPs for point and nonpoint sources. In addition, the E3 scenario includes new technologies, management practices and programs that are not currently part of Bay watershed jurisdictional pollutant control strategies. Appendix A details the assumptions and methodologies used in developing each technology and BMP-based implementation level in the three tier and E3 scenarios for all nutrient and sediment source categories.

Agricultural Nonpoint Source Controls

In the E3 scenario, it was assumed that the load from every available acre of the relevant land area was being controlled by a full suite of existing or innovative practices for most applied BMPs. In addition, management programs converted landuses from those with high-yielding nutrient and sediment loads to those with lower loads without regard to the economic viability of such changes. Every acre of cropland is conservation-tilled. Applications of fertilizers are set so that the crops do not receive more than 98 percent of their need, well below current recommended nutrient management rates. All other components of farm plans are fully implemented and the cropland is planted in cover crops to maximize nutrient reduction benefits.

The E3 scenario designates 100-foot riparian forest buffers on all unbuffered stream miles in the Chesapeake Bay watershed. A total of 25,000 acres of cropland are restored to wetlands. A quarter of the crop and hay areas not converted to riparian forest buffers or restored to wetlands are retired to grass conditions. The E3 scenario assumes there is rotational grazing on all pasture land and that all unbuffered streams through pastures are fully protected through both riparian buffers and fencing to exclude animals. The waste in animal feeding operations is controlled to a degree that there is no runoff. Another quarter of crop acreage in the Chesapeake Bay basin is replaced with long-term grasses that serve as a carbon bank and could be converted to energy through combustion.

Urban/Suburban Nonpoint Source Controls

To minimize storm water runoff from urban and suburban areas in the E3 scenario, all land projected to be developed in the next decade is employing environmental site design or low-impact development practices. In addition, all existing urban areas are retrofitted with a suite of practices to significantly reduce nutrient and sediment loads. Fifty-foot riparian forest buffers are placed along all currently unbuffered urban stream miles, while 100-foot buffers are found on all herbaceous lands that are not in agriculture. Also, all urban and nonagricultural grass acres do not receive nutrient applications from chemical fertilizers.

The E3 scenario calls for a 30 percent reduction in projected urban growth in Pennsylvania, Maryland, Virginia and the District of Columbia over the next decade to conform to commitments of the *Chesapeake 2000* agreement. Specifically for this model scenario, more urban areas are built up rather than out, and 30 percent of the forests are protected from development.

Point Source Controls

In the E3 scenario, all significant municipal dischargers maintain annual averaged effluent concentrations of 3 mg/l total nitrogen and 0.1 mg/l total phosphorus. All new septic systems employ denitrification technologies and are maintained through regular pumping to meet edge-of-septic-field nitrogen loadings that are one-quarter of typical loads. In addition, E3 atmospheric deposition assumes emission controls on utilities, industry and mobile sources beyond what the Clean Air Act requires.

Table III-5. E3 scenario possible over- and underestimations of attainable load reductions.

Physical Limitations

In all appropriate circumstances, BMP implementation levels in the E3 scenario were applied to all relevant landuse areas or current limits of technology. In many cases and to remove the subjectivity in determining human-caused conditions that cannot be remedied, there were no physical limitations to employing the practices or programs.

For many BMPs, the E3 implementation levels could not physically be achieved. For example, space may not be available for 50-foot riparian buffers in urban areas or certain developed lands may not allow for retrofitting with practices that attain pollutant reduction efficiencies used in the E3 scenario. In addition, certain crop types cannot be conservation-tilled and it may be physically impossible to completely eliminate runoff from animal feeding operations.

It is also unlikely that every homeowner and farmer would efficiently apply fertilizers so that only the needs of the vegetation are met and that waterfront property owners would plant 50-foot buffers even if it were physically possible. As a whole, ‘feasible’ participation levels are not built into the E3 scenario. All of these instances are examples of where the E3 scenario may overestimate reductions.

Underestimations of Load Reductions Attainable under the E3 Scenario

By contrast, some BMP implementation levels physically could be even higher than those currently defined in the E3 scenario. For example, it is physically possible that more than 25,000 acres of cropland and hay in Chesapeake Bay watershed could be restored to wetlands. This limitation on wetland acres restored in the E3 scenario for Pennsylvania, Maryland and Virginia was used to reflect the *Chesapeake 2000* goal.

As another example, 25 percent of cropland was replaced with long-term grasses that serve as a carbon bank and could be converted to energy through combustion. Benefits of a carbon sequestration program, in terms of lower pollutant loads, would increase as more agricultural land is converted. Conversion of more than 25 percent of cropland is physically possible. In addition, the 30 percent reduction in urban sprawl over a decade could be set at a higher level. This rate was employed in the E3 scenario to adhere to a *Chesapeake 2000* goal.

The E3 scenario only includes shoreline erosion controls at current levels due to a current inability to define a ‘maximum’ limit that would not be entirely subjective. It has been demonstrated through modeling efforts that additional controls of shoreline erosion can significantly improve tidal-water quality. In general, much opportunity exists for reducing sediment and nutrient loads from eroding shorelines that is not reflected in the E3 scenario water quality model results.

If greater BMP implementation levels than those designated in the E3 scenario could be physically achieved for any BMPs, pollutant loadings would decrease and there would be corresponding improved responses in water quality. For the most part, however, the E3 scenario did not consider real physical limitations to BMP implementation or participation levels.

criteria protecting the current designated uses could not be attained in these habitats even after implementation of technologies and management practices at levels defined in the E3 scenario (see Figure III-1).

FINDINGS AND CONCLUSIONS

The combined results of the E3, all-forest and pristine scenarios (see Figure III-1 and Table III-3) along with the scientific conclusions from the paleoecological record, strongly indicate that current state aquatic life designated uses cannot be achieved in the Chesapeake Bay's and tidal tributaries' deep-water and deep-channel habitats where natural physical processes and bottom bathymetry-related barriers prevent oxygen replenishment (see Chapter IV). Natural conditions, as well as human-caused conditions that cannot be remedied, would result in even higher levels of nonattainment of the states' existing 4 mg/l daily minimum and 5 mg/l daily averaged dissolved oxygen criteria than illustrated in Figure III-1 and summarized in Table III-3, given the application of a 5 mg/l monthly average dissolved oxygen concentration for this analysis.

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chapter iv

Refined Designated Uses for the Chesapeake Bay and Tidal Tributaries

BACKGROUND

RENEWED COMMITMENT TO RESTORE CHESAPEAKE BAY WATER QUALITY

The *Chesapeake 2000* agreement and the subsequent six-state, District of Columbia and EPA memoranda of understanding challenged the Bay watershed jurisdictions to, "by 2010, correct the nutrient- and sediment-related problems in the Chesapeake Bay and its tidal tributaries sufficiently to remove the Bay and the tidal portions of its tributaries from the list of impaired waters under the Clean Water Act." (Chesapeake Executive Council 2000; Chesapeake Bay Watershed Partners 2001.)

These agreements included commitments to "define the water quality conditions necessary to protect aquatic living resources" and to have the jurisdictions with tidal waters "use their best efforts to adopt new or revised water quality standards consistent with the defined water quality conditions." Against this backdrop of a renewed commitment to restore Bay water quality (in part through the adoption of a consistent set of Chesapeake Bay water quality criteria as state standards), the Chesapeake Bay watershed partners recognized that the underlying tidal-water designated uses must be refined to better reflect desired Bay water quality conditions.

CURRENT STATE TIDAL-WATER DESIGNATED USES

Virginia, Maryland, Delaware and the District of Columbia have identified parts of the Chesapeake Bay and its tidal tributaries as 'state waters.' The current designated uses for these state waters are for the protection of aquatic life (Table IV-1; figures IV-1 through IV-4). The accompanying current criteria addressing nutrient and sediment enrichment impairments are limited to different dissolved oxygen concentrations, which apply separately to each jurisdiction's tidal waters.

Table IV-1. Summary of current designated uses for states' Chesapeake Bay and tidal tributary waters.

State	Current Designated Use for Chesapeake Bay and Tidal Tributary Waters
Maryland	• Use II (shellfish harvesting waters)—Chesapeake Bay proper • Use I (water contact recreation, protection of aquatic life)—All surface waters
Virginia	• Class II (estuarine waters) for tidal water—Coastal zone to fall line—Primary and secondary contact recreation, fish and shellfish consumption, aquatic life and wildlife "All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish."
Delaware	• Broad Creek, Nanticoke River—Industrial water supply, primary contact recreation, secondary contact recreation, fish and aquatic life and wildlife, agriculture water supply with additional classification as "waters of exceptional recreational and ecological significance" (ERES waters).
District of Columbia	• Potomac River Class A (primary contact recreation), B (primary contact recreation and aesthetics), C (protection and propagation of fish, shellfish, and wildlife), D (consumption of fish and shellfish) and E (navigation).

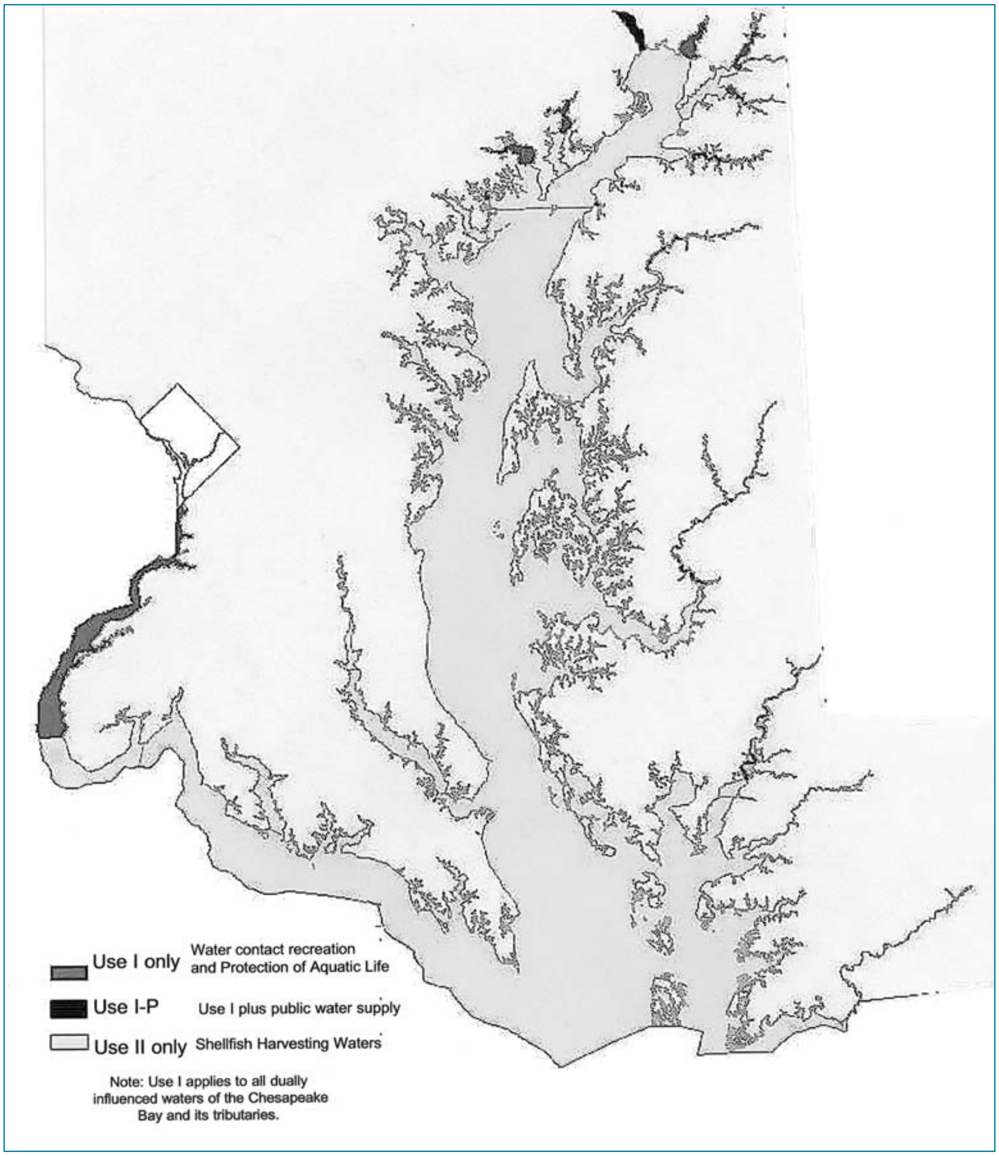
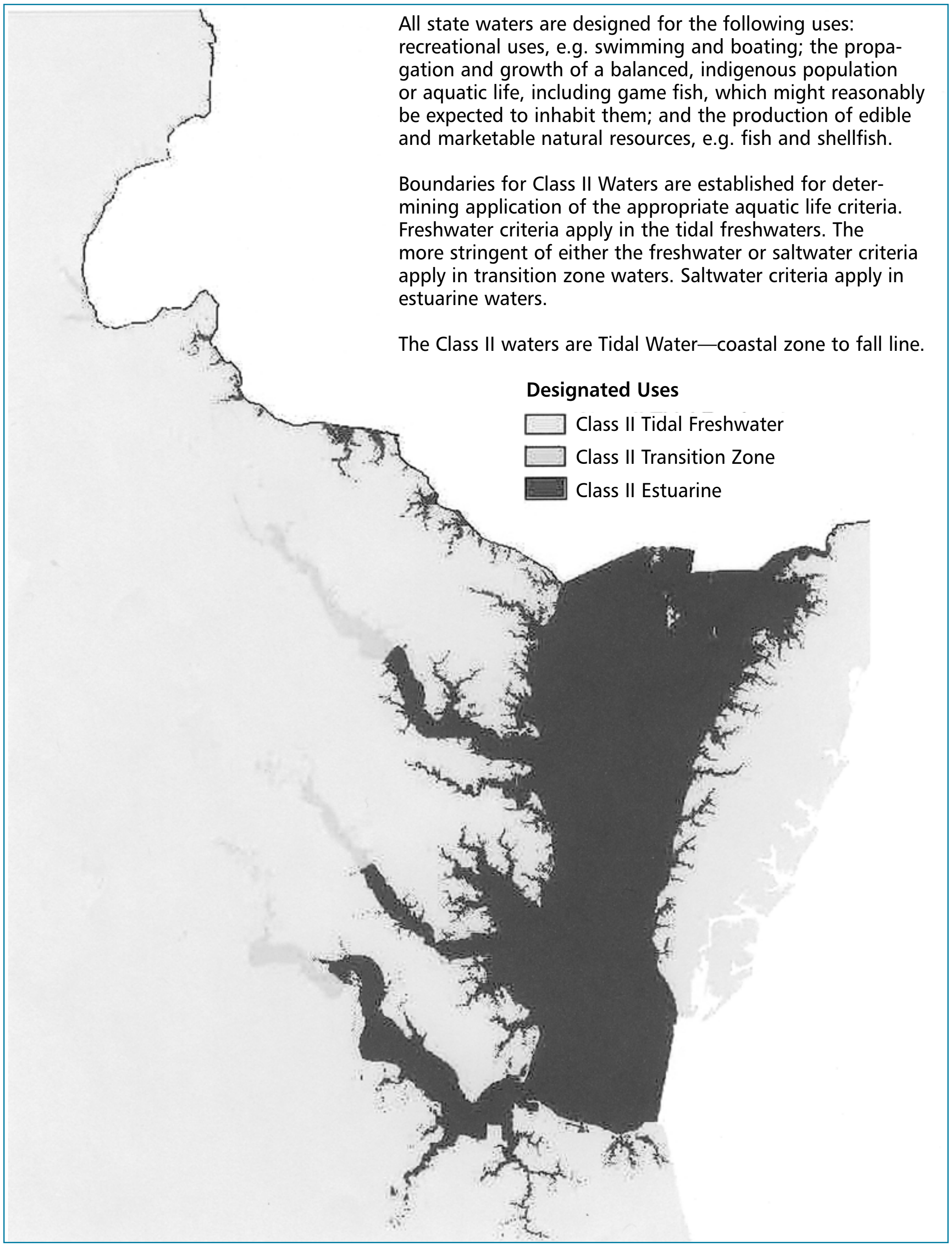


Figure IV-1. Current designated uses for Chesapeake Bay and tidal tributary waters located in Maryland.

Source: Code of Maryland Regulations 26.08.02 for water quality dated November 1, 1993.



All state waters are designed for the following uses: recreational uses, e.g. swimming and boating; the propagation and growth of a balanced, indigenous population or aquatic life, including game fish, which might reasonably be expected to inhabit them; and the production of edible and marketable natural resources, e.g. fish and shellfish.

Boundaries for Class II Waters are established for determining application of the appropriate aquatic life criteria. Freshwater criteria apply in the tidal freshwaters. The more stringent of either the freshwater or saltwater criteria apply in transition zone waters. Saltwater criteria apply in estuarine waters.

The Class II waters are Tidal Water—coastal zone to fall line.

Figure IV-2. Current designated uses for Chesapeake Bay and tidal tributary waters located in Virginia.

Source: Virginia State Water Control Board Regulation 9 VAC 25-260-5-et. seq. Water Quality Standards dated December 10, 1997.

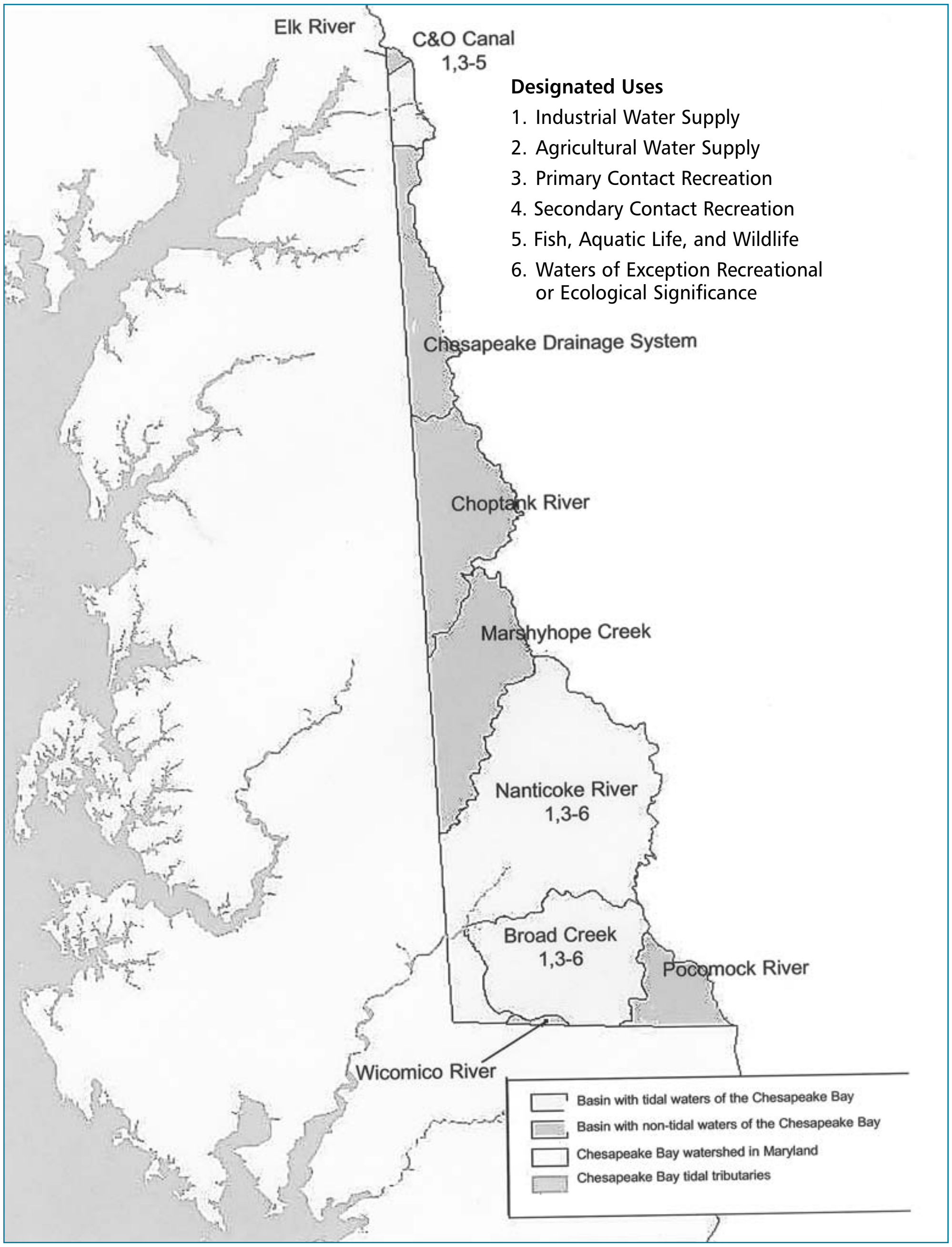


Figure IV-3. Current designated uses for Chesapeake Bay tidal tributary waters located in Delaware.

Source: State of Delaware Water Quality Regulations.

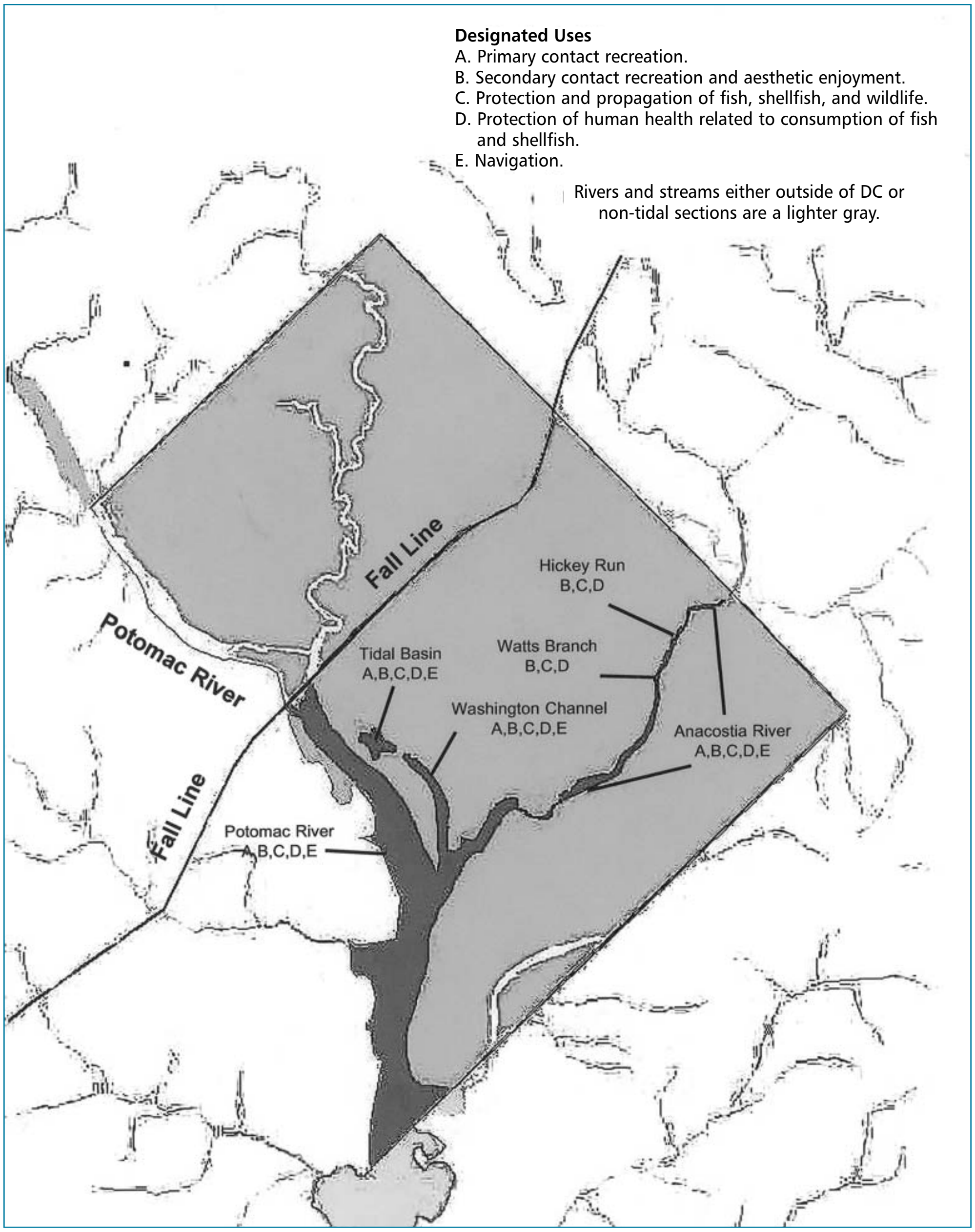


Figure IV-4. Current designated uses for Chesapeake Bay tidal tributary waters located in the District of Columbia.

Source: District of Columbia Department of Consumer and Regulatory Affairs Notice of Final Rulemaking.

REFINING TIDAL-WATER DESIGNATED USES

The Chesapeake Bay Program watershed partners determined that the underlying tidal-water designated uses must be refined to better reflect the desired and attainable Chesapeake Bay water quality conditions called for in the *Chesapeake 2000* agreement. In refining the current tidal-water designated uses, the six Chesapeake Bay watershed states and the District of Columbia took into account five principal considerations:

- Habitats used in common by sets of species and during particular life stages should be delineated as separate designated uses;
- Natural variations in water quality should be accounted for by the designated uses;
- Seasonal uses of different habitats should be factored into the designated uses;
- The Chesapeake Bay criteria for dissolved oxygen, water clarity and chlorophyll *a* should be tailored to support each designated use; and
- The refined designated uses applied to the Chesapeake Bay and its tidal tributary waters will support the federal Clean Water Act goals and state goals for uses existing in these water since 1975.

The Chesapeake Bay watershed partners are proposing five *refined subcategories* of the current broad aquatic life designated uses contained in the existing state water quality standards of the four jurisdictions bordering directly on Chesapeake Bay and its tidal tributaries. Figure IV-5 illustrates the conceptual framework of the refined tidal-water designated uses; Table IV-2 provides general descriptions of the five designated uses and the aquatic communities they were established to protect.[9] Four of the refined designated uses were derived largely to address seasonally distinct habitats and living resource communities with widely varying dissolved oxygen requirements:

- Migratory fish spawning and nursery;
- Open-water fish and shellfish;
- Deep-water seasonal fish and shellfish; and
- Deep-channel seasonal refuge.

The fifth refined designated use, the shallow-water bay grass designated use, occurs seasonally in conjunction with that part of the year-round open-water use which borders the land along the tidal portions of the Chesapeake Bay and its tributaries (Figure IV-5).

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[9] Note that for brevity, these refined designated uses may be referred to as migratory spawning and nursery, shallow-water, open-water, deep-water and deep-channel.

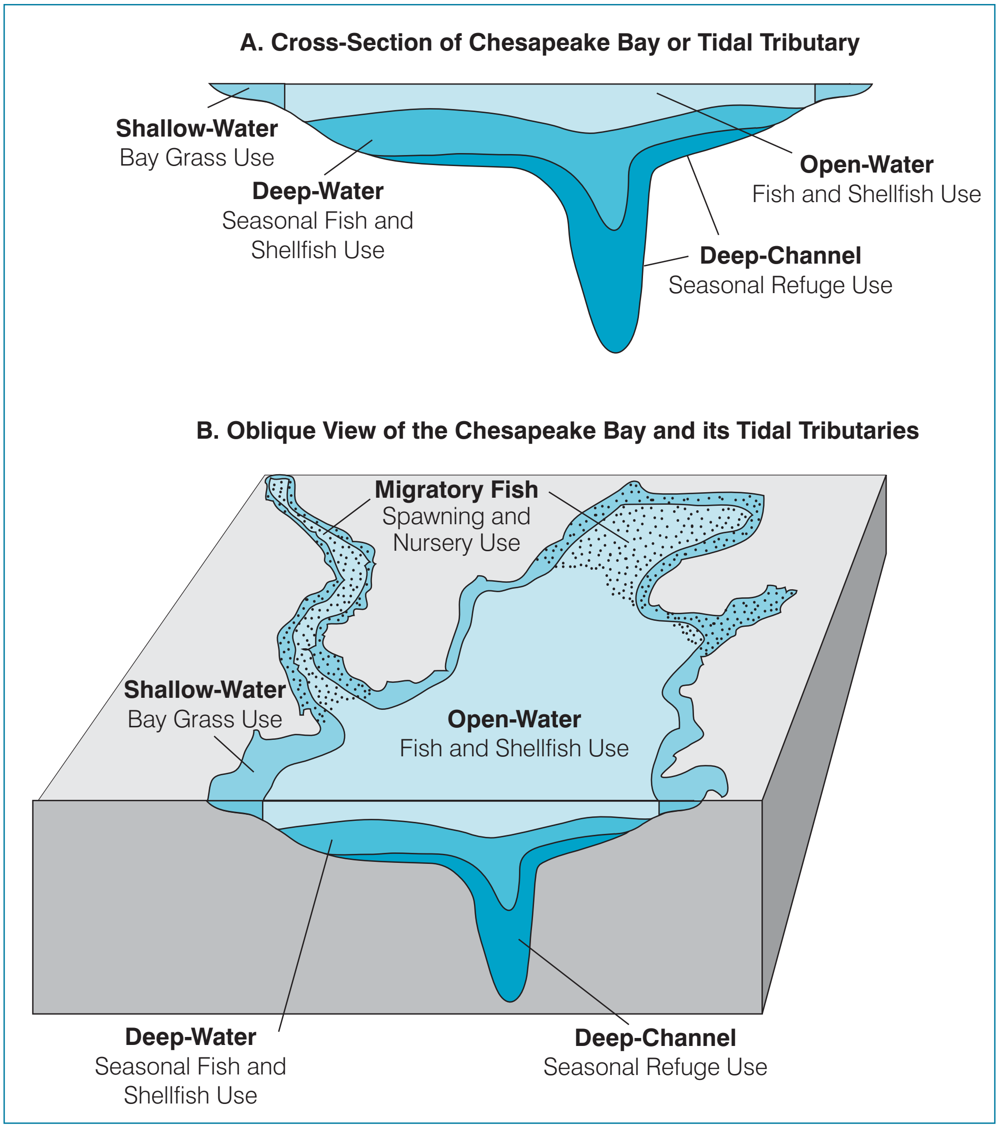

Figure IV-5. Conceptual illustration of the five Chesapeake Bay tidal-water designated use zones.

LIVING RESOURCE-BASED REFINED DESIGNATED USES AND PROTECTIVE CRITERIA

The five refined designated uses were derived to reflect the habitats of an array of recreationally, commercially and ecologically important species. The supporting prey communities were given full consideration along with the ‘target species’ in defining the designated uses.

Two extensive syntheses of habitat requirements for important target species and communities in the Chesapeake Bay and its tidal tributaries formed the basis from which these refined designated uses were conceived and developed (Chesapeake Bay

Table IV-2. General descriptions of the five proposed Chesapeake Bay tidal-water designated uses.

Migratory Fish Spawning and Nursery Designated Use: Aims to protect migratory finfish during the late winter/spring spawning and nursery season in tidal freshwater to low-salinity habitats. This habitat zone is primarily found in the upper reaches of many Bay tidal rivers and creeks and the upper mainstem Chesapeake Bay and will benefit several species, including striped bass, perch, shad, herring and sturgeon.

Shallow-Water Designated Use: Designed to protect underwater bay grasses and the many fish and crab species that depend on the shallow-water habitat provided by underwater bay grass beds.

Open-Water Fish and Shellfish Designated Use: Aims to improve water quality in the surface water habitats within tidal creeks, rivers, embayments and the mainstem Chesapeake Bay year-round. This use protects diverse populations of sport fish including striped bass, bluefish, mackerel and sea trout, bait fish such as menhaden and silversides, as well as the listed shortnose sturgeon.

Deep-Water Seasonal Fish and Shellfish Designated Use: Aims to protect living resources inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months. This use protects many bottom-feeding fish, crabs and oysters, as well as other important species, including the bay anchovy.

Deep-Channel Seasonal Refuge Designated Use: Designed to protect bottom sediment-dwelling worms and small clams that act as food for bottom-feeding fish and crabs in the very deep channel in summer. The deep-channel designated use recognizes that low dissolved oxygen conditions prevail in the deepest portions of this habitat zone and will naturally have very low to no oxygen during the summer.

Living Resource Task Force 1987; Funderburk et al. 1991). Only when coupled with analyses of the extensive Chesapeake Bay Monitoring Program's water quality, biological and living resource databases, now spanning 19 years, could the refined tidal-water designated uses described below be documented and delineated across all tidal-water habitats without constraints by jurisdictional borders.

The five tidal-water designated uses, in turn, provided the context for deriving dissolved oxygen, water clarity and chlorophyll *a* water quality criteria for the Chesapeake Bay and its tidal tributaries. These criteria, derived to protect each of the five refined designated uses, were based on effects data from a wide array of biological communities to capture the range of sensitivity of the thousands of aquatic species inhabiting the Chesapeake Bay and tidal tributary estuarine habitats (U.S. EPA 2003). Table IV-3 shows the proposed refined designated uses by Chesapeake Bay Program segment.

Table IV-3. Recommended tidal-water designated uses by Chesapeake Bay Program segment.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Migratory Spawning and Nursery (Feb. 1– May 31)	Open-Water (Year-Round)	Deep-Water (June 1– Sept. 30)	Deep-Channel (June 1– Sept. 30)	Shallow-Water (April 1– Oct. 30)
Northern Chesapeake Bay	CB1TF	x	x			x
Upper Chesapeake Bay	CB2OH	x	x			x
Upper Central Chesapeake Bay	CB3MH	x	x	x	x	x
Middle Central Chesapeake Bay	CB4MH	x	x	x	x	
Lower Central Chesapeake Bay	CB5MH		x	x	x	x
Western Lower Chesapeake Bay	CB6PH		x	x		x
Eastern Lower Chesapeake Bay	CB7PH		x	x		x
Mouth of the Chesapeake Bay	CB8PH		x			x
Bush River	BSHOH	x	x			x
Gunpowder River	GUNOH	x	x			x
Middle River	MIDOH	x	x			x
Back River	BACOH	x	x			x
Patapsco River	PATMH	x	x	x		x
Magothy River	MAGMH	x	x			x
Severn River	SEVMH	x	x			x
South River	SOUMH	x	x			x
Rhode River	RHDMH	x	x			x
West River	WSTMH	x	x			x
Upper Patuxent River	PAXTF	x	x			x
Western Branch (Patuxent River)	WBRTF	x	x			x
Middle Patuxent River	PAXOH	x	x			x
Lower Patuxent River	PAXMH	x	x	x		x
Upper Potomac River	POTTF	x	x			x
Anacostia River	ANATF	x	x			x
Piscataway Creek	PISTF	x	x			x
Mattawoman Creek	MATTF	x	x			x
Middle Potomac River	POTOH	x	x			x
Lower Potomac River	POTMH	x	x	x	x	x
Upper Rappahannock River	RPPTF	x	x			x
Middle Rappahannock River	RPPOH	x	x			x
Lower Rappahannock River	RPPMH	x	x	x	x	x
Corrotoman River	CRRMH	x	x			x
Piankatank River	PIAMH	x	x			x
Upper Mattaponi River	MPNTF	x	x			x
Lower Mattaponi River	MPNOH	x	x			x
Upper Pamunkey River	PMKTF	x	x			x
Lower Pamunkey River	PMKOH	x	x			x
Middle York River	YRKMH	x	x			x
Lower York River	YRKPH		x	x		x

continued

Table IV-3. Recommended tidal-water designated uses by Chesapeake Bay Program segment *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Migratory Spawning and Nursery (Feb. 1– May 31)	Open-Water (Year-Round)	Deep-Water (June 1– Sept. 30)	Deep-Channel (June 1– Sept. 30)	Shallow-Water (April 1– Oct. 30)
Mobjack Bay	MOBPH		x	x		x
Upper James River	JMSTF	x	x			x
Appomattox River	APPTF	x	x			x
Middle James River	JMSOH	x	x			x
Chickahominy River	CHKOH	x	x			x
Lower James River	JMSMH	x	x			x
Mouth of the James River	JMSPH		x			x
Western Branch Elizabeth River	WBEMH		x			
Southern Branch Elizabeth River	SBEMH		x			
Eastern Branch Elizabeth River	EBEMH		x			
Mouth to mid-Elizabeth River	ELIMH		x			
Lafayette River	LAFMH		x			
Mouth of the Elizabeth River	ELIPH		x	x	x	
Lynnhaven River	LYNPH		x			x
Northeast River	NORTF	x	x			x
C&D Canal	C&DOH	x	x			x
Bohemia River	BOHOH	x	x			x
Elk River	ELKOH	x	x			x
Sassafras River	SASOH	x	x			x
Upper Chester River	CHSTF	x	x			x
Middle Chester River	CHSOH	x	x			x
Lower Chester River	CHSMH	x	x	x	x	x
Eastern Bay	EASMH		x	x	x	x
Upper Choptank River	CHOTF	x	x			
Middle Choptank River	CHOOH	x	x			x
Lower Choptank River	CHOMH2	x	x			x
Mouth of the Choptank River	CHOMH1	x	x			x
Little Choptank River	LCHMH		x			x
Honga River	HNGMH		x			x
Fishing Bay	FSBMH	x	x			x
Upper Nanticoke River	NANTF	x	x			x
Middle Nanticoke River	NANOH	x	x			x
Lower Nanticoke River	NANMH	x	x			x
Wicomico River	WICMH	x	x			x
Manokin River	MANMH	x	x			x
Big Annemessex River	BIGMH	x	x			x
Upper Pocomoke River	POCTF	x	x			
Middle Pocomoke River	POCOH	x	x			x
Lower Pocomoke River	POCMH	x	x			x
Tangier Sound	TANMH		x			x

CHESAPEAKE BAY TIDAL-WATER DESIGNATED USES

The migratory fish spawning and nursery designated use is described first, given its unique seasonal role in protecting the spawning and nursery grounds of Chesapeake Bay and East Coast anadromous fish species. The shallow-water bay grass designated use is then described, as it protects the vegetated shallow-water habitats that are so critical to many individual estuarine species and living resource communities. Next, the open-water, deep-water and deep-channel designated uses are described as a series of year-round and seasonal subcategory designated uses formed around unique habitats defined largely by natural conditions (e.g., stratification of the water column, water circulation patterns) and physical barriers (Bay and tidal-water bottom bathymetry) in the tidal waters.

The watershed states with tidally influenced Chesapeake Bay waters (Maryland, Virginia and Delaware) and the District of Columbia ultimately are responsible for defining and adopting the designated uses into their state water quality standards. These uses will be adopted as subcategories of current state tidal-water designated uses, which are designed to protect aquatic life. The formal process for refining designated uses will meet the requirements of the Clean Water Act and any applicable jurisdiction-specific environmental laws or regulations.

The adopted designated uses will protect existing aquatic and human uses of the tidal waters that have been present since 1975. These designations go beyond minimum requirements (131.10[d] and [h][2]) and satisfy all requirements for meeting Clean Water Act goals (131.10 [a]), downstream waters maintenance and protection (131.10[b]) and for subcategorization as allowed by 131.10(g). The specific use definitions and the spatial application of the final designated uses will undergo public review through the four jurisdictions' respective regulatory adoption processes prior to EPA approval of the states' water quality standards.

MIGRATORY FISH SPAWNING AND NURSERY DESIGNATED USE

Waters with this designated use shall support the survival, growth and propagation of balanced indigenous populations of ecologically, recreationally and commercially important anadromous, semi-anadromous and tidal freshwater resident fish species inhabiting spawning and nursery grounds from February 1 through May 31 (Table IV-4).

Designated Use Rationale

Based on a commitment within the *1987 Chesapeake Bay Agreement* (Chesapeake Executive Council 1987), a list of target anadromous and semi-anadromous species was identified, including striped bass, American shad, hickory shad, alewife, blueback herring, white perch and yellow perch, based on their commercial, recreational and ecological value and "the threat to sustained production due to population

Table IV-4. Migratory fish spawning and nursery designated use summary.

Applicable Criteria: *Dissolved Oxygen:*	
	6.0 mg/l 7-day mean (only tidal habitats with 0–0.5 ppt salinity) 5.0 mg/l instantaneous minimum
Application:	February 1 through May 31
Designated Use:	This designated use supports the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important anadromous, semi-anadromous and tidal freshwater resident fish species inhabiting spawning and nursery grounds.
Designated Use Boundary:	The boundaries of this use extend from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats. The use extends horizontally from the shoreline of the body of water to the adjacent shoreline, and extends down through the water column to the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

decline or serious habitat degradation" (Chesapeake Bay Living Resources Task Force 1987). These species form a representative subset of species comprising a "balanced, indigenous population." Other ecologically important anadromous and semi-anadromous fish species also will be protected under this designated use.

Chesapeake Bay tidal waters support spawning and nursery areas that are important not only to Bay fishery populations, but also to populations that inhabit the entire East Coast, such as striped bass. The eggs, larvae and early juveniles of anadromous and semi-anadromous species often have more sensitive habitat quality requirements than other species and life stages (Funderburk et al. 1991; Jordan et al. 1992). These same habitats are critical spawning and nursery grounds for tidal freshwater resident fish species from February 1 to May 31 (U.S. EPA 2003). Thus, the combined migratory and tidal freshwater resident fish spawning and nursery habitats were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries.

Designated Use Boundary Delineation

The boundaries of the migratory fish spawning and nursery designated use were delineated from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats (Figure IV-6).

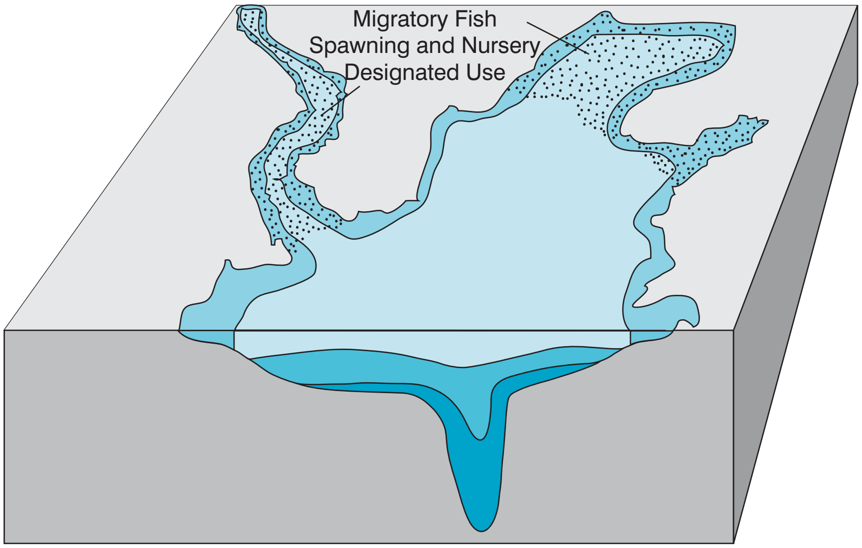

Figure IV-6. Illustration of the boundaries of the migratory fish spawning and nursery designated use.

Critical Support Communities—Food and Shelter

In this designated use, spawning adults and the resulting larvae and early juvenile fish depend on phytoplankton, zooplankton, bottom-dwelling worms and clams and forage fish as prey (Funderburk et al. 1991). The presence of underwater bay grasses in the shallows of the designated use habitat provides essential shelter for young juveniles as well as many prey species.

Seasonal Use Application

The migratory fish spawning and nursery designated use applies from February 1 through May 31. The defined season for applying this use is based on a composite of the full range of spawning and nursery periods of all the target anadromous and semi-anadromous species.

Striped bass and juveniles of other migratory spawners are passively dispersed as eggs and larvae and move farther downstream as they grow. Most juveniles do not leave the boundaries of their respective spawning and nursery areas. Adult yellow perch migrate from downstream to their spawning areas in the lower-salinity upper reaches of the tidal tributaries from mid-February through March (Richkus and Stroup 1987; Tsai and Gibson 1971). By early June, young-of-the-year juvenile striped bass begin to move shoreward, spending the summer and early fall in shoal waters less than six feet deep (Setzler-Hamilton et al. 1981). As juveniles grow, they move progressively downriver (Boreman and Klauda 1988; Dey 1981; Setzler-Hamilton et al. 1981). The February 1 beginning date reflects the initiation of the yellow perch spawning season; the May 31 end date reflects when the eggs and larvae have finished their transition to the juvenile life stage for all the target anadromous and semi-anadromous species.

Applicable Chesapeake Bay Water Quality Criteria[10]

The migratory fish spawning and nursery designated use is seasonally defined and occurs in conjunction with the year-round open-water designated uses and the seasonal shallow-water designated uses (see Figure IV-5). The migratory fish spawning and nursery designated use provides for the protection of the early life stages of anadromous, semi-anadromous and resident tidal-fresh species through the application of dissolved oxygen criteria derived for that purpose (U.S. EPA 2003). From February 1 through May 31, the migratory fish spawning and nursery dissolved oxygen criteria ensure protection of the egg, larval and early juvenile life stages (Table IV-4). Free-flowing streams and rivers, where several of the target species (e.g., shad, river herring) migrate for spawning, are protected through other existing state water quality standards.

The open-water fish and shellfish designated use dissolved oxygen criteria were derived to be protective of juvenile and adult life stages of anadromous and semi-anadromous species after May 31 (see Table IV-6; U.S. EPA 2003). The overlapping nature of these discrete designated uses will thus ensure that water quality conditions protective of different species' life stages are present in those designated use habitats. See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the individual dissolved oxygen criteria and criteria implementation procedures.

SHALLOW-WATER BAY GRASS DESIGNATED USE

Waters with this designated use support the survival, growth and propagation of rooted, underwater bay grasses necessary for the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats (Table IV-5).

Designated Use Rationale

The shallow-water bay grass designated use protects a wide variety of species, such as largemouth bass and pickerel, which inhabit vegetated tidal-fresh and low-salinity habitats; juvenile speckled sea trout in vegetated higher salinity areas; and blue crabs that inhabit vegetated shallow-water habitats covering the full range of salinities encountered in the Chesapeake Bay and its tidal tributaries. Underwater bay grasses,

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[10] Maryland, Virginia, Delaware and the District of Columbia currently have water quality standards in place that address pH conditions within the migratory fish spawning and nursery habitats.

Table IV-5. Shallow-water bay grass designated use summary.

Applicable Criteria:	*Water Clarity:* 13 percent ambient light through water (tidal habitats with 0–5 ppt salinity) 22 percent ambient light through water (tidal habitats with greater than 5 ppt salinity)
Application:	April 1 through October 31 for tidal-fresh, oligohaline and mesohaline habitats (0–18 ppt salinity); March 1 through May 31 and September 1 through November 30 for polyhaline habitats (>18 ppt salinity)
Designated Use:	Waters with this designated use support the survival, growth and propagation of rooted underwater bay grasses necessary for the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats.
Designated Use Boundary:	Tidally influenced waters from the intertidal zone out to a Chesapeake Bay Program segment-specific depth contour that varies from 0.5 to 2 meters.

Source for the Applicable Criteria: U.S. EPA 2003.

the critical community that the designated use protects, provide the shelter and food that make shallow-water habitats so unique and integral to the productivity of the Chesapeake Bay ecosystem. Many Chesapeake Bay species depend on vegetated shallow-water habitats at some point during their life cycle (Funderburk et al. 1991). Given the unique nature of this habitat and its critical importance to the Chesapeake Bay ecosystem, shallow waters were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries.

The shallow-water bay grass designated use is intended specifically to delineate the habitats where the water clarity criteria would apply. The open-water fish and shellfish designated use and the accompanying dissolved oxygen criteria will fully protect the biological communities inhabiting shallow-water habitats. The open-water designated use extends into the intertidal zone and protects shallow-water organisms beyond underwater bay grasses. The seasonal shallow-water bay grass designated use, similar to the migratory fish spawning and nursery use, actually occurs in conjunction with the year-round open-water designated use (see Figure IV-5) and provides specific protection for underwater bay grasses through the application of water clarity criteria.

Designated Use Boundary Delineation

The shallow-water bay grass designated use covers tidally influenced waters, from the intertidal zone out to a Chesapeake Bay Program segment-specific depth contour

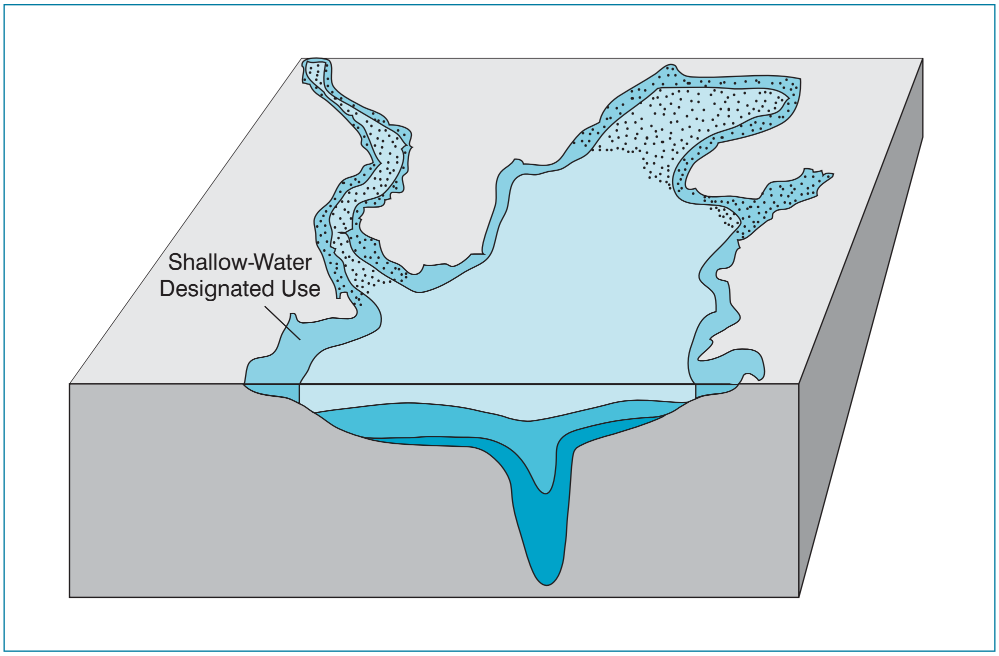

Figure IV-7. Illustration of the boundaries of the shallow-water bay grass designated use.

that varies from 0.5 to 2 meters (Figure IV-7). The segment-specific depths were based on rules described in detail in "Shallow-Water Bay Grass Designated Use Boundaries" (see page 105) along with two other approaches to defining shallow-water use boundaries.

Critical Support Communities—Food and Shelter

Phytoplankton, zooplankton, forage fish and bottom-dwelling worms and clams feed many fish, crab and mollusk species that inhabit shallow-water habitats for part or all of their life stages (Funderburk et al. 1991). Water quality criteria necessary to fully support the shallow-water designated use must provide for the survival, growth and successful propagation of prey communities in sufficient quantities.

Applicable Bay Water Quality Criteria

The shallow-water bay grass designated use is a seasonal use designation that occurs in conjunction with the year-round open-water use and the seasonal migratory spawning and nursery designated uses (see Figure IV-5). The shallow-water bay grass designated use boundary delineates where specific levels of water clarity must be restored to support restoration of underwater bay grasses. The applicable salinity regime-based water clarity criteria apply during the appropriate underwater bay grass growing season: April 1 through October 31 for tidal-fresh, oligohaline and mesohaline habitats and March 1 through May 31 and September 1 through November 30 for polyhaline habitats (see Table IV-5; U.S. EPA 2003).

Underlying the seasonal shallow-water bay grass designated use is the year-round open-water fish and shellfish designated use to support grass living resource communities inhabiting these shallow-water areas (see Table IV-6; U.S. EPA 2003). The open-water fish and shellfish dissolved oxygen criteria apply into the shallows to the intertidal zone. Therefore, nonvegetated shallow-water habitats and the living resource communities that depend on those habitats will receive protection under the open-water designated use. See chapters 3, 4 and 6, respectively, in U.S. EPA 2003 for more details on the individual dissolved oxygen criteria, water clarity criteria and criteria implementation guidelines.

OPEN-WATER FISH AND SHELLFISH DESIGNATED USE

Waters with this designated use support the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting open-water habitats (Table IV-6).

Designated Use Rationale

The natural temperature and salinity stratification of open waters influences dissolved oxygen concentrations and, thus, the distribution of Chesapeake Bay species. Surface mixed-layer waters with higher oxygen levels located above the pycnocline support a different community of species than deeper waters from late spring to early fall. Several well-known species that inhabit these open waters are menhaden, striped bass and bluefish. Their habitat requirements and prey needs differ from those of species and communities inhabiting deeper water habitats during the summer months. See the deep-water “Designated Use Rationale” on page 74 for more detailed documentation.

Clear evidence from the Chesapeake Bay as well as other estuarine and coastal systems, including Long Island Sound (Howell and Simpson 1994), Albemarle-Pamlico Sound (Eby 2001) and the Gulf of Mexico (Craig et al. 2001), indicates that the fish and other organisms inhabiting open-water habitats will use deeper within-pycnocline and below-pycnocline habitats, given suitable dissolved oxygen conditions. It is the lack of sufficient oxygen, not the presence of stratification, that limits the use of these deeper habitats. Therefore, the open-water designated use applies to transitional pycnocline and bottom mixed-layer below-pycnocline habitats where these below-pycnocline and pycnocline waters are sufficiently reoxygenated by oceanic or riverine waters.

During their first winter of life, members of five important Chesapeake Bay species—white perch, striped bass, Atlantic croaker, shortnose sturgeon and Atlantic sturgeon—are constrained to oligohaline and mesohaline regions (< 20 ppt) in the upper Chesapeake Bay mainstem, and seek out warmer temperatures that occur in deeper channel waters below the thermocline. From October through May, the deep-channel habitats in the upper Bay adjacent to shallower summer and fall habitats should be considered important nursery habitats for young-of-the-year juvenile white

Table IV-6. Open-water fish and shellfish designated use summary.

Applicable Criteria:	*Dissolved Oxygen* 5.5 mg/l 30-day mean (tidal habitats with 0–0.5 ppt salinity) 5.0 mg/l 30-day mean (tidal habitats with greater than 0.5 ppt salinity) 4.0 mg/l 7-day mean 3.2 mg/l instantaneous minimum *Chlorophyll* a*:* Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences–such as reduced water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions–or otherwise render tidal waters unsuitable for designated uses.
Application:	Year-round: open-water designated use and dissolved oxygen criteria. March 1 through May 31 and July 1 through September 30: chlorophyll *a* criteria.
Designated Use:	Waters with this designated use support the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting open-water habitats.
Designated Use Boundary:	From June 1 through September 30 the open-water designated use includes tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline. If a pycnocline is present and, in combination with bottom bathymetry and water-column circulation patterns, presents a barrier to oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column only as far as the measured upper boundary of the pycnocline. If a pycnocline is present but other physical circulation patterns (such as influx of oxygen rich oceanic bottom waters) provide for oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column to the bottom water-sediment interface. From October 1 through May 31, the open-water designated use includes all tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline, extending down through the water column to the bottom water-sediment interface.

Source for the Applicable Criteria: U.S. EPA 2003.

perch, striped bass, and Atlantic croaker (Pothoven et al. 1997) as well as Atlantic and shortnose sturgeon (Miller et al. 1997; Secor et al. 2000; Welsh et al. 2000).

During the coldest months, the interaction between temperatures and salinity tolerances may result in a ‘habitat squeeze’ or bottleneck, forcing juveniles into deep-channel habitats seeking preferred temperatures. Unpublished data from the Maryland Environmental Service indicate that a thermocline, separating the warmer deep waters from colder overlaying waters, typically occurs at a 10-to 20-meter depth in the deep channel from October through February. Therefore, from fall through late spring when the open-water designated use applies to these natural channel habitats, it also protects indigenous populations of important fish species that depend on deep-channel habitats for overwintering.

Based on these natural conditions and their influence on oxygen levels and the seasonal distributions of Chesapeake Bay species, open waters were delineated as a refined tidal-water designated use in the Chesapeake Bay.

Designated Use Boundary Delineation

From June 1 through September 30 the open-water designated use includes tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline (Figure IV-8). If a pycnocline is present and, in combination with bottom bathymetry and water-column circulation patterns, presents a barrier to oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column only as far as the measured upper boundary of the pycnocline

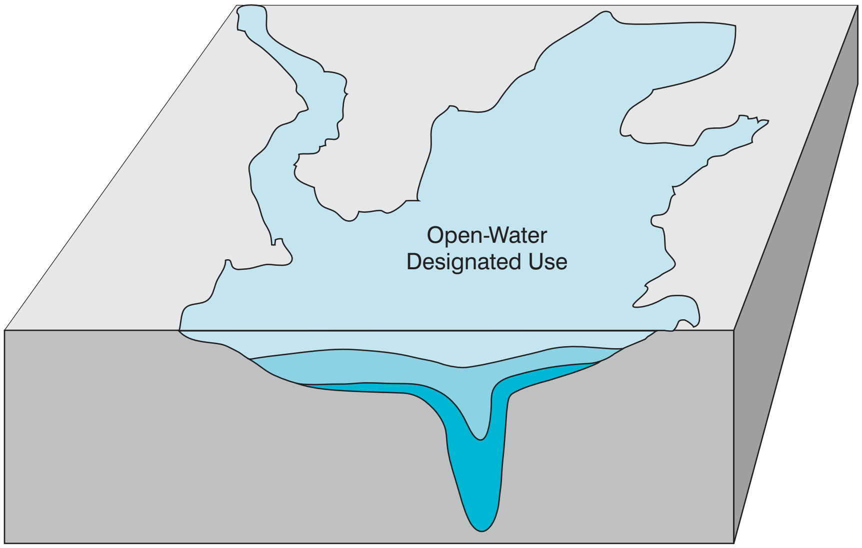

Figure IV-8. Illustration of the boundaries of the open-water fish and shellfish designated use.

(Figure IV-9). If a pycnocline is present but other physical circulation patterns (such as influx of oxygen rich oceanic bottom waters) provide for oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down through the water column to the bottom water-sediment interface.

From October 1 through May 31, the boundaries of the open-water designated use includes all tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline, extending down through the water column to the bottom water-sediment interface.

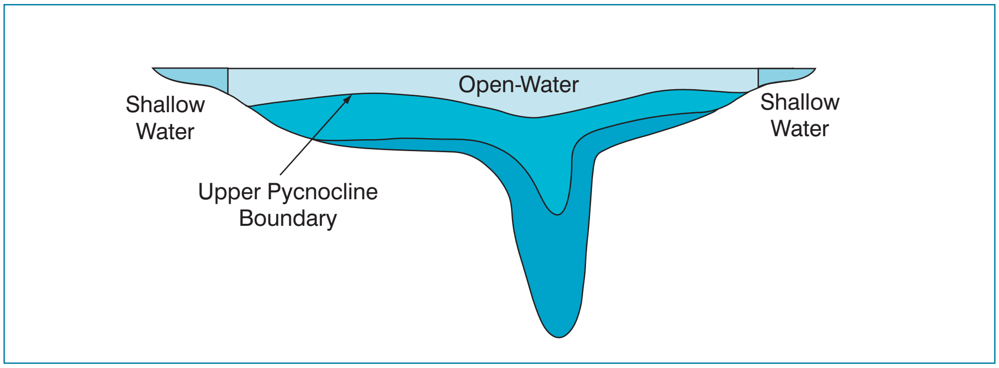

Figure IV-9. Illustration of the vertical boundaries for the refined open-water fish and shellfish designated use.

Critical Support Communities—Food and Shelter

Water column-dwelling phytoplankton, zooplankton and forage fish constitute the major prey for other species in the Chesapeake Bay's open waters (Funderburk et al. 1991). Water quality criteria to support the open-water designated use fully must provide for the survival, growth and successful propagation of quality prey communities in sufficient quantities.

Applicable Bay Water Quality Criteria

The open-water dissolved oxygen criteria apply year-round (see Table IV-6). The applicable salinity regime-based chlorophyll *a* criteria apply only in spring (March 1 through May 31) and summer (July 1 through September 30) to the open-water designated use habitats. See chapters 3 and 5, respectively, in U.S. EPA (2003) for more details on the individual dissolved oxygen and chlorophyll *a* criteria and chapter 6 for detailed criteria implementation procedures.

DEEP-WATER SEASONAL FISH AND SHELLFISH DESIGNATED USE

Waters with this designated use protect the survival, growth and propagation of balanced, indigenous populations of important fish and shellfish species inhabiting deep-water habitats (Table IV-7).

Table IV-7. Deep-water seasonal fish and shellfish designated use summary.

Applicable Criteria:	*Dissolved Oxygen:* 3 mg liter^{-1} 30-day mean 2.3 mg liter^{-1} 1-day mean 1.7 mg liter^{-1} instantaneous minimum
Application:	June 1 through September 30
Designated Use:	Waters with this designated use protect the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally, and commercially important fish and shellfish species inhabiting deep-water habitats.
Designated Use Boundary:	Tidally influenced waters located between the measured depths of the upper and lower boundaries of the pycnocline in areas where the measured pycnocline, in combination with bottom bathymetry and water circulation patterns, presents a barrier to oxygen replenishment of deeper waters. In some areas where a lower boundary of the pycnocline is not calculated, the deep-water designated use extends from the measured depth of the upper boundary of the pycnocline down through the water column to the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

Designated Use Rationale

In an eutrophic system such as the Chesapeake Bay, excess organic matter settles to the bottom, where it fuels microbial activity (e.g., Malone et al. 1986; Tuttle et al. 1987). With more fuel, more oxygen is consumed and, where replenishment with oxygen-saturated waters is restricted, the water becomes more severely oxygen-depleted. There is evidence that hypoxic and anoxic conditions existed in the deeper waters of the Chesapeake Bay prior to European settlement (Cooper and Brush 1991). These same data indicate that anthropogenic activity has increased the extent, frequency and severity of oxygen depletion in the Chesapeake Bay (Zimmerman and Canuel 2000; Hagy 2002).

Many parts of the Chesapeake Bay become, on a seasonal basis, vertically stratified because of depth-related density differences in the water column, caused primarily by variations in salinity and, to a lesser degree, temperature. Warmer, freshwater from the rivers floats on top of the cooler, denser saltwater at the bottom that enters the Bay from the ocean. The gravitational force of the downriver flow of freshwater causes a wedge of deeper, saltier water to move up the Bay and upriver. Vertically, at some point in the water column, a zone of maximum density difference is reached, which inhibits or prevents the exchange between water above and below it. This region is called the pycnocline. In the summer months, respiration by organisms living below the pycnocline can deplete concentrations of dissolved oxygen.

Because waters in and below the pycnocline are isolated from well-mixed surface waters, dissolved oxygen concentrations can decrease until they are stressful or lethal to higher organisms.

The formation of the pycnocline is a natural process. In areas where stratification is common, the pycnocline generally forms at about the same depth range, but is subject to seasonal and annual variations in depth due to river flow, temperature and salinity patterns. It is generally shallower at the mouths of rivers and the Chesapeake Bay and deeper at the heads of rivers. The effect of the pycnocline also is not the same everywhere in the Chesapeake Bay and is influenced by local characteristics such as bathymetry, vertical and horizontal water circulation patterns, and proximity to the ocean and major river fall-lines. In some parts of the Bay and its tidal rivers, these factors create a more complex stratification pattern: a second pycnocline is formed lower in the water column, dividing it into three layers. If a region is contained by the pycnocline above and by bottom bathymetry laterally, it is even more isolated from oxygen-replenishing waters.

Bay anchovy is a target species whose egg and larval life stages are spent in pycnocline waters (Keister et al. 2000; Rilling and Houde 1999; MacGregor and Houde 1996). Blue crabs, oysters, softshell clams, hard clams, spot, croaker, flounder and catfish inhabit the near-bottom waters in the deep-water habitats (Funderburk et al. 1991). The oxygen requirements of these species differ from those of species inhabiting shallow-water, open-water and deep-channel habitats. Their feeding patterns and distribution of eggs and larvae are greatly influenced by natural features of the water column such as the pycnocline.

Deep waters were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries based on the unique nature of the pycnocline region as an important living resource habitat and the transitional nature of its water quality conditions.

Designated Use Boundary Delineation

The deep-water designated use includes the tidally influenced waters between the measured upper and lower boundaries of the pycnocline where, in combination with bottom bathymetry and water circulation patterns, the pycnocline limits oxygen replenishment of deeper waters (Figure IV-10). In some areas where a lower boundary of the pycnocline is not calculated, the deep-water designated use extends from the measured depth of the upper boundary of the pycnocline down through the water column to the bottom sediment-water interface.

Critical Support Communities—Food and Shelter

Bottom-dwelling worms and clams and reef-dwelling forage fish are important food sources for the fish and crabs in deep-water habitats (Funderburk et al. 1991). Water quality criteria to support the deep-water designated use must provide for the survival, growth and successful propagation of quality prey communities in sufficient quantities.

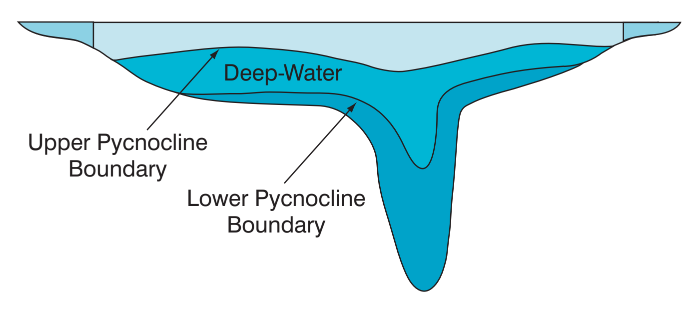

Figure IV-10. Illustration of the vertical boundaries for the refined deep-water designated use.

Seasonal Use Application

The deep-water seasonal fish and shellfish designated use applies from June 1 through September 30. By June, a combination of natural water-column stratification and increased biological oxygen consumption driven by higher water temperatures prevents the Chesapeake Bay's deep waters from retaining high concentrations of dissolved oxygen. These natural conditions generally persist into September. From October 1 through May 31 the open-water fish and shellfish designated use applies to these same waters.

Applicable Bay Water Quality Criteria

The deep-water dissolved oxygen criteria apply from June 1 through September 30 (see Table IV-7). See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the deep-water dissolved oxygen criteria and criteria implementation procedures.

DEEP-CHANNEL SEASONAL REFUGE DESIGNATED USE

Waters with this designated use must protect the survival of balanced, indigenous populations of ecologically important benthic infaunal and epifaunal worms and clams, which provide food for bottom-feeding fish and crabs (Table IV-8).

Designated Use Rationale

In the Chesapeake Bay, researchers have determined the oxygen minimum to be in the below-pycnocline waters throughout the deep trough in the mainstem Chesapeake Bay in the late spring to early fall (Smith et al. 1992). Isolated from aerated surface waters, low dissolved oxygen concentrations in this region are due to excess oxygen consumption from bacterial breakdown of organic material over oxygen additions from ocean waters flowing in from far down-Bay. North of this region, the

Table IV-8. Deep-channel seasonal refuge designated use summary.

Applicable Criteria:	*Dissolved Oxygen:* 1.0 mg/l instantaneous minimum
Application:	June 1 through September 30
Designated Use:	Waters with this designated use must protect the survival of balanced, indigenous populations of ecologically important benthic infaunal and epifaunal worms and clams, which provide food for bottom-feeding fish and crabs.
Designated Use Boundary:	Deep-channel designated use waters are defined as tidally influenced waters at depths greater than the measured lower boundary of the pycnocline in areas where, in combination with bottom bathymetry and water circulation patterns, the pycnocline presents a barrier to oxygen replenishment of deeper waters. The deep-channel designated use is defined laterally by bathymetry of the trough and vertically by the lower boundary of the pycnocline above, and below, at the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

trough quickly becomes shallow and bottom waters are oxygenated as they mix with aerated waters in the shoals. Below-pycnocline waters to the south are reoxygenated through mixing with oxygenated oceanic waters entering the Chesapeake Bay mouth.

These deep channels are sinks for excess organic material which, in the process of decaying, increase oxygen consumption. They are isolated from surface and oceanic sources of oxygen replenishment. Vertical stratification and gravitational and horizontal circulation often cause severe, sudden oxygen depletion beginning just below the lower boundary of the pycnocline and extending to the bottom (Smith et al. 1992). Given the physical nature of the deep trough leading to naturally severe oxygen depletion during the summer, the deep-channel was delineated as a refined tidal-water designated use for Chesapeake Bay.

Designated Use Boundary Delineation

Deep-channel designated use waters are defined as tidally influenced waters at depths greater than the measured lower boundary of the pycnocline in areas where the pycnocline, in combination with bottom bathymetry and water circulation patterns, presents a barrier to oxygen replenishment of deeper waters (Figure IV-11). The deep-channel designated use is defined laterally by bathymetry of the trough and vertically by the lower boundary of the pycnocline above, and below, at the bottom sediment-water interface.

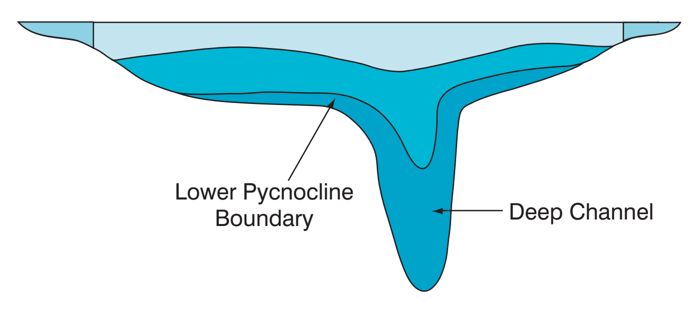

Figure IV-11. Illustration of the vertical boundaries of the refined deep-channel seasonal refuge designated use.

Critical Support Communities—Food and Shelter

Bottom-dwelling worms and clams are the principal food source of bottom-feeding fish and crabs in the deep-channel (Funderburk et al. 1991). Water quality criteria for the deep-channel designated use must provide for the survival of these prey communities.

Seasonal Use Application

The deep-channel designated use applies from June 1 through September 30. By June, a combination of natural water-column stratification and increased water temperature prevents the Chesapeake Bay's deep-channel waters from retaining high concentrations of dissolved oxygen. These natural conditions generally persist through September. From October 1 through May 31 the open-water designated use applies to these same habitats.

Applicable Bay Water Quality Criteria

The deep-channel dissolved oxygen criteria apply from June 1 through September 30 (see Table IV-8). See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the deep-channel dissolved oxygen criteria and criteria implementation procedures.

CHESAPEAKE BAY TIDAL-WATER DESIGNATED USE BOUNDARIES

Correct application of the Chesapeake Bay water quality criteria depends on the accurate delineation of the five tidal-water designated uses. Each of the designated uses has different dissolved oxygen criteria derived to match the respective level of protection required by different living resource communities. In case of the shallow-water bay grass designated use, the location of the boundaries is critical to providing sufficient suitable habitat for the restoration of the desired number of acres of underwater bay grasses.

The vertical depth and horizontal breadth of the designated use boundaries are based on a combination of factors: natural water-column stratification, bottom bathymetric features and circulation patterns, among other considerations. It is important to note that these boundaries have been developed without consideration of attainability from the perspective of potentially widespread social and economic impacts. The states may find they need to adjust these boundaries according to such impacts (131.19[g][6]), which may prevent attainment of the designated use, and must justify these adjustments during their water quality standards adoption processes. The technology-based attainability of these refined tidal-water designated uses and their boundaries is documented in Chapter V.

Four of the six factors defined in 40 CFR 101.10(g) justify deriving the boundaries described in this chapter for the refined tidal-water designated uses:

- Natural, ephemeral, intermittent or low-flow conditions or water levels (e.g., application of a 10-year water quality data record (1985-1994) reflecting a wide range of watershed hydrologic and tidal bay hydrodynamic conditions);
- Dams, diversion or other types of hydrologic modifications (e.g., dredged shipping channels);
- Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles and the like (e.g., water-column stratification, bottom bathymetry); and
- Naturally occurring pollutant concentrations (see Chapter III).

MIGRATORY FISH SPAWNING AND NURSERY DESIGNATED USE BOUNDARIES

The boundaries of the migratory fish spawning and nursery designated use were delineated from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats (Figure IV-12). Free-flowing streams and rivers, where several of the target species (e.g., shad and river herring) migrate for spawning, are protected through other existing state water quality standards.

To generate these boundaries, habitat distribution maps, drawn from the *Habitat Requirements for Chesapeake Bay Living Resources–Second Edition* (Funderburk et al. 1991), were used. The distribution maps used during delineation of the migratory spawning and nursery designated use included:

- Alewife spawning and nursery;
- Alewife nursery;

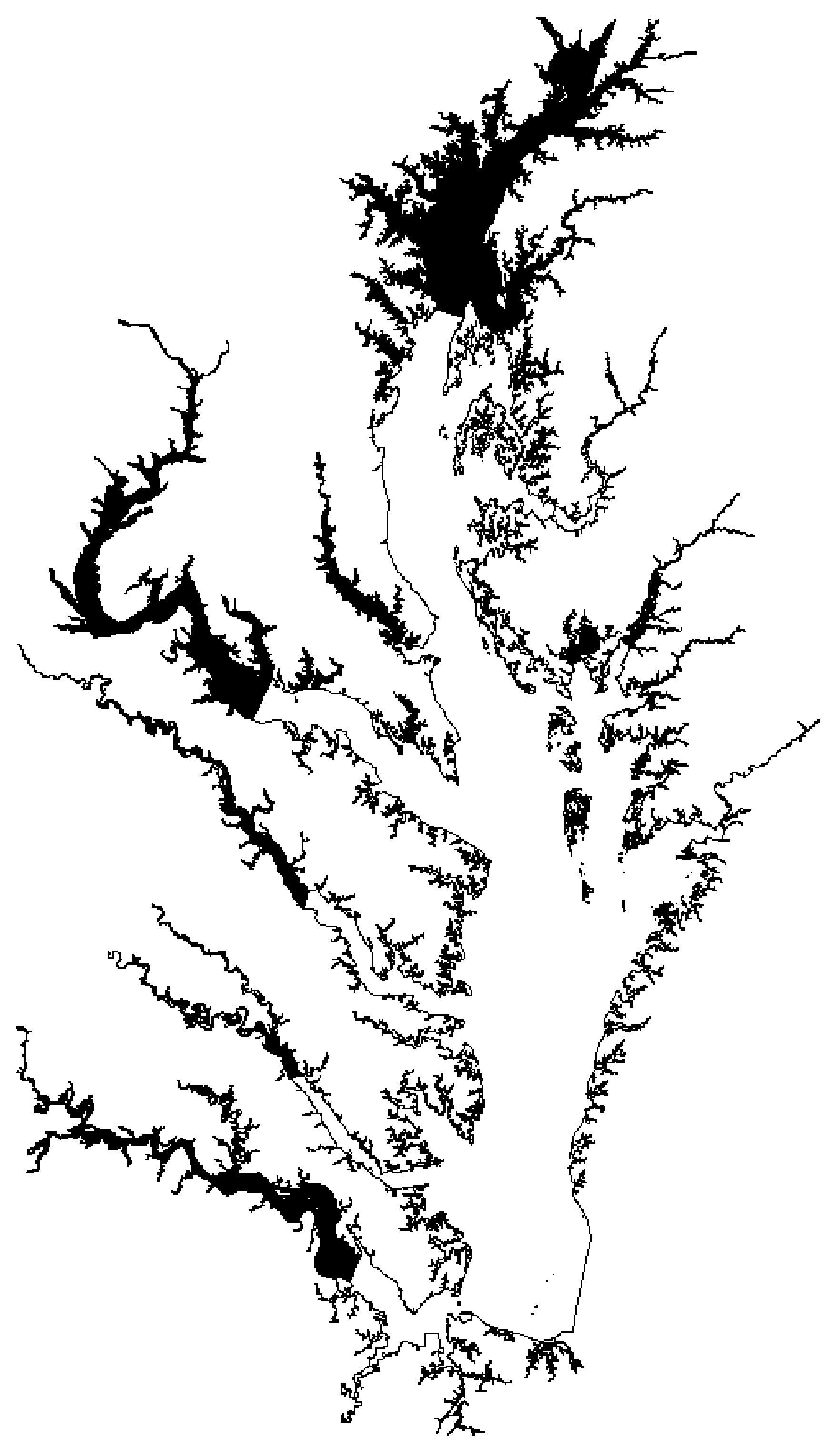

Figure IV-12. Map showing the migratory spawning and nursery designated use for the Chesapeake Bay and its tidal tributaries (black areas).

- American shad spawning and nursery;
- American shad nursery;
- Hickory shad spawning and nursery;
- Herring spawning and nursery;
- Herring nursery;
- Striped bass spawning reaches;
- Striped bass spawning rivers;
- White perch nursery;
- White perch spawning; and
- Yellow perch spawning and nursery.

For those species that had multiple habitat distribution maps for related life stages, the maps were merged into a single coverage. Then individual species maps were superimposed on a composite spawning and nursery habitat map.

The striped bass habitat distribution maps used in this process were originally titled "Striped Bass Chesapeake Bay Spawning Reaches and Spawning Rivers" by Funderburk et al. (1991). The sources of the spawning reach distributions were research and monitoring findings synthesized by Setzler-Hamilton and Hall (1991). However, the mapped extent of the nursery areas, referred to as spawning rivers in the original map, was based on Maryland and Virginia legislative definitions,[11] not on fisheries survey findings.

Those regulations, which define "spawning rivers and areas," did not attempt to define "early juvenile nursery habitat" but rather those rivers in which striped bass spawn. The spawning reach designation in the regulation was used to describe areas where striped bass eggs and larvae had been found. This justification was based on icthyoplankton collections done in the 1950s in Maryland (Mansueti and Hollis 1963). Tresselt (1952) defined spawning reaches in Virginia.

To further enhance understanding of nursery areas, discussions were held with fishery scientists Herb Austin and Deane Este of the College of William and Mary's Virginia Institute of Marine Science, and Eric Durell, Maryland Department of Natural Resources, who are responsible for their respective states' juvenile striped bass seine surveys. The primary nursery areas for young-of-the-year striped bass were delineated based on a comparison of long-term Maryland and Virginia seine survey data with the legislatively-defined extent of early juvenile nursery habitat. In any given year, juvenile striped bass can be found throughout a broader range of Chesapeake Bay tidal waters. The primary nursery areas where the highest concentrations of *early* juvenile life-stage striped bass are almost always found in the spring

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[11] Code of Maryland Regulations 08.02.05.02 and Virginia Marine Resources Commission Regulation 450-01-0034 as cited inChesapeake Bay Living Resources Task Force (1987).

were identified and incorporated into the composite map described above (e.g., Austin et al. 2000). The striped bass nursery areas were supplemented to ensure that shad and river herring spawning and nursery areas were fully represented within the migratory fish spawning and nursery designated use boundaries (Rulifson 1994; Olney 2002).

From February 1 through May 31, the migratory fish spawning and nursery designated use occurs in conjunction with, and, therefore, encompasses specific portions of the seasonal shallow-water bay grass and year-round open-water fish and shellfish designated use habitats (see shaded sections in Figure IV-5). The designated use extends horizontally from the shoreline across the body of water to the adjacent shoreline, and extends down through the water column to the bottom sediment-water interface.

The exact spatial and temporal extent of migratory fish spawning and nursery designated use would vary annually due to regional climatic patterns if actual observed salinity and temperature were used to define year-by-year boundaries. Because use of year-by-year delineation of the exact boundaries of the migratory fish spawning and nursery designated adds complexity, a fixed set of boundaries was established. The migratory fish spawning and nursery designated use habitat shown in Figure IV-12 reflects both long-term, decadal average salinity conditions and decades' worth of fisheries-independent beach seine and trawl monitoring data. States can adopt an approach (to be defined) for defining migratory spawning and nursery designated use boundaries on a year-to-year basis by directly factoring in the influence of interannual climatic patterns on the use boundaries.

OPEN-WATER, DEEP-WATER AND DEEP-CHANNEL DESIGNATED USE BOUNDARIES

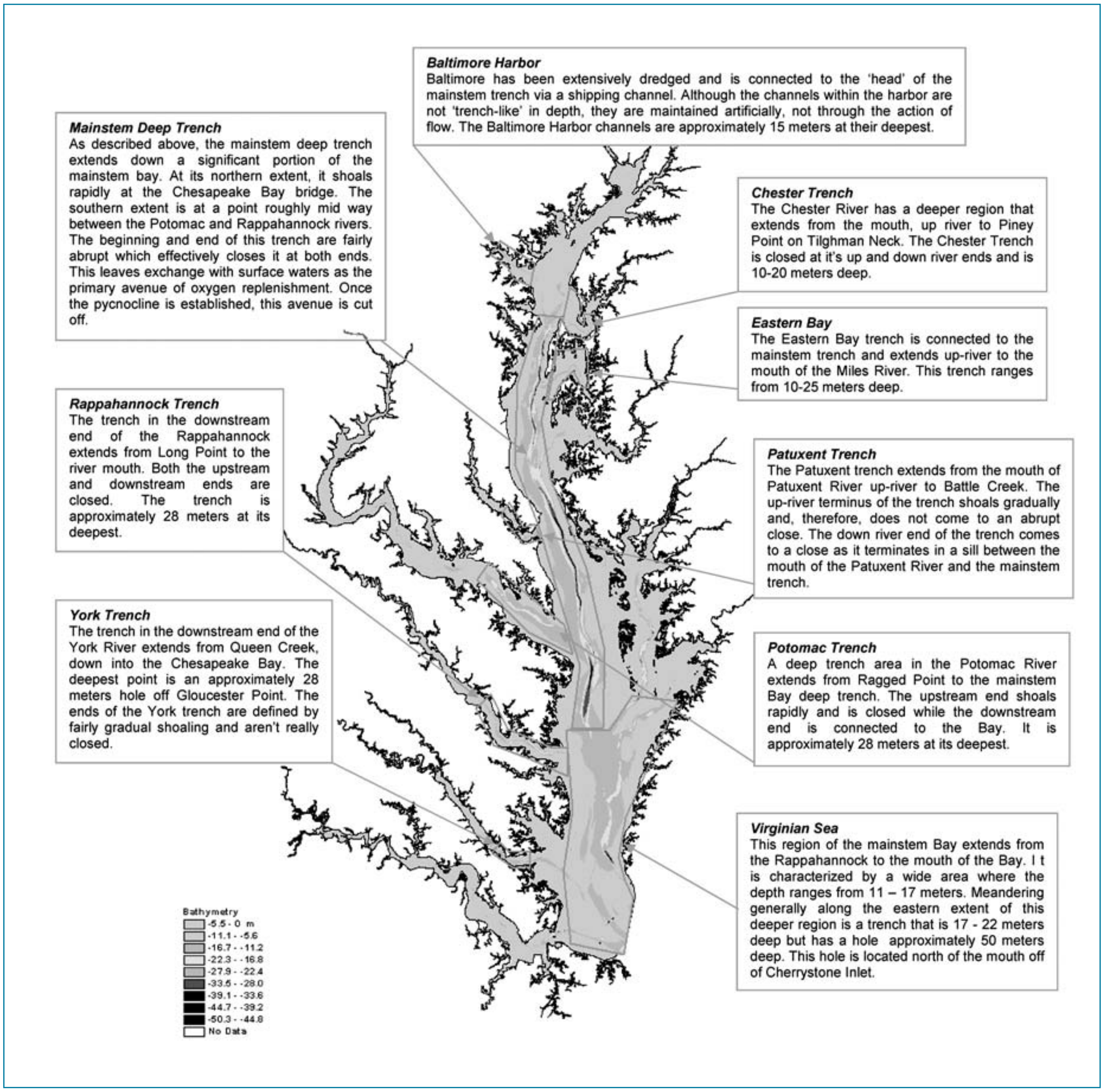
Background

The open-water, deep-water and deep-channel designated uses, the habitats they represent and the dissolved oxygen criteria for ensuring their protection are inextricably related to physical structure (water-column stratification, bottom bathymetry) and to physical, chemical, meteorological and fluvial forces and processes. Understanding these factors will enhance understanding of the designated use delineation process as well as the issues underlying application of the dissolved oxygen criteria. The following section provides background on these three principal factors: bathymetry, flow and circulation, and vertical density gradients and pycnoclines.

Bathymetry

Although the Chesapeake Bay is a relatively shallow estuary, bathymetric features play a large role both in defining the Bay's habitats as well as the eutrophication-related water quality problems observed throughout most of the tidal waters.

The most prominent bathymetric feature in the Bay is the deep trench that runs from the Chesapeake Bay Bridge between Annapolis and Kent Island, Maryland, to an area midway between the southern shore of the mouth of the Potomac River and the northern shore of the mouth of the Rappahannock River (figures IV-13 and IV-14). The trench ranges from 24 to 48 meters in depth and extends generally midchannel between the western and eastern shores of the mainstem Chesapeake Bay. It is thought to be a remnant of the ancient Susquehanna River. A shallower trench extends down along the Virginia Eastern Shore (Figure IV-15). Similar, smaller trenches and holes exist elsewhere in Bay tidal waters, generally in the larger tidal tributary rivers near their mouths. These are described later in the more detailed regional descriptions that follow.


Baltimore Harbor
Baltimore has been extensively dredged and is connected to the 'head' of the mainstem trench via a shipping channel. Although the channels within the harbor are not 'trench-like' in depth, they are maintained artificially, not through the action of flow. The Baltimore Harbor channels are approximately 15 meters at their deepest.

Mainstem Deep Trench
As described above, the mainstem deep trench extends down a significant portion of the mainstem bay. At its northern extent, it shoals rapidly at the Chesapeake Bay bridge. The southern extent is at a point roughly mid way between the Potomac and Rappahannock rivers. The beginning and end of this trench are fairly abrupt which effectively closes it at both ends. This leaves exchange with surface waters as the primary avenue of oxygen replenishment. Once the pycnocline is established, this avenue is cut off.

Chester Trench
The Chester River has a deeper region that extends from the mouth, up river to Piney Point on Tilghman Neck. The Chester Trench is closed at it's up and down river ends and is 10-20 meters deep.

Eastern Bay
The Eastern Bay trench is connected to the mainstem trench and extends up-river to the mouth of the Miles River. This trench ranges from 10-25 meters deep.

Rappahannock Trench
The trench in the downstream end of the Rappahannock extends from Long Point to the river mouth. Both the upstream and downstream ends are closed. The trench is approximately 28 meters at its deepest.

Patuxent Trench
The Patuxent trench extends from the mouth of Patuxent River up-river to Battle Creek. The up-river terminus of the trench shoals gradually and, therefore, does not come to an abrupt close. The down river end of the trench comes to a close as it terminates in a sill between the mouth of the Patuxent River and the mainstem trench.

York Trench
The trench in the downstream end of the York River extends from Queen Creek, down into the Chesapeake Bay. The deepest point is an approximately 28 meters hole off Gloucester Point. The ends of the York trench are defined by fairly gradual shoaling and aren't really closed.

Potomac Trench
A deep trench area in the Potomac River extends from Ragged Point to the mainstem Bay deep trench. The upstream end shoals rapidly and is closed while the downstream end is connected to the Bay. It is approximately 28 meters at its deepest.

Virginian Sea
This region of the mainstem Bay extends from the Rappahannock to the mouth of the Bay. It is characterized by a wide area where the depth ranges from 11 – 17 meters. Meandering generally along the eastern extent of this deeper region is a trench that is 17 - 22 meters deep but has a hole approximately 50 meters deep. This hole is located north of the mouth off of Cherrystone Inlet.

Figure IV-13. Major bathymetric trenches within the Chesapeake Bay and its tidal tributaries.

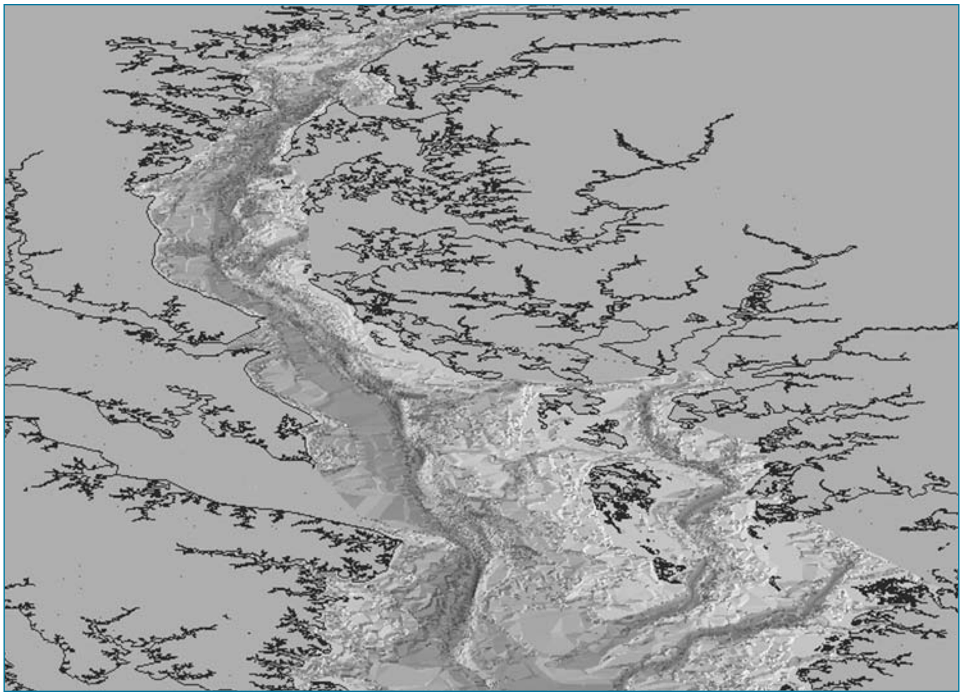


Figure IV-14. Three-dimensional view of the Chesapeake Bay mainstem trench as viewed from the south looking north. The depth versus width relationship has been enhanced to improve viewing.

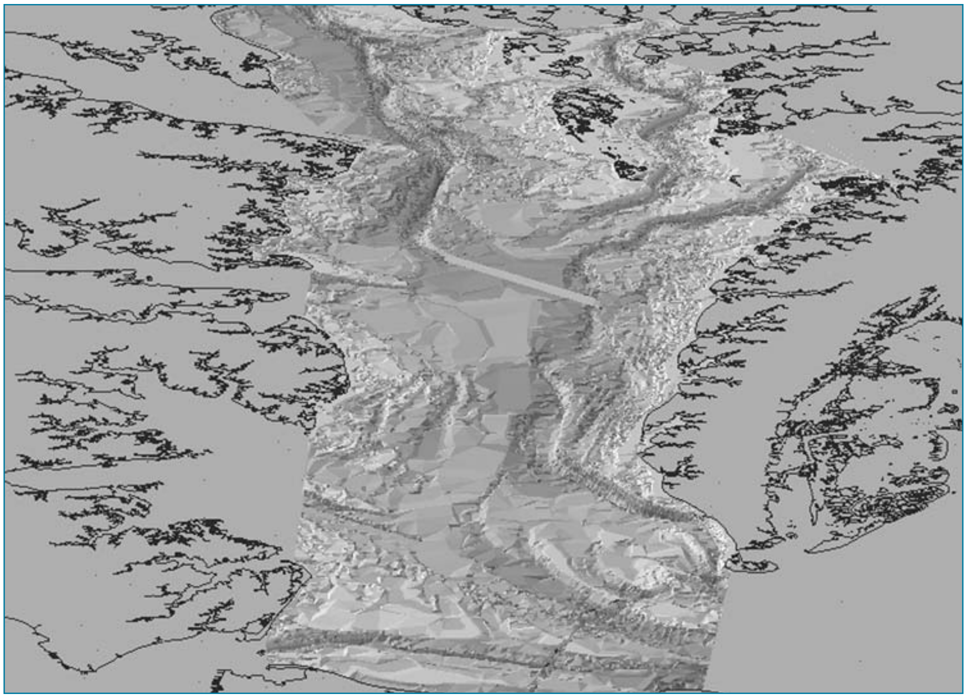


Figure IV-15. Three-dimensional view of the 'Virginian Sea' as viewed from the south looking north. The depth versus width relationship has been enhanced to improve viewing.

These deep regions contrast with the Chesapeake Bay as a whole, which has an average depth of only 6 meters. They also figure prominently in the Chesapeake Bay's dissolved oxygen problems. When it is overlain by a stratified water column, the bottom water in the trenches and holes is isolated from the oxygenated surface water and can become oxygen-depleted. This situation generally occurs in the late spring and summer when oxygen-consuming activity is high and discontinuity in water density through the water column can act as a barrier, i.e., act as a 'lid,' capping off the exchange of oxygenated water with the oxygen-depleted waters in the trenches and holes. However, some of the deep areas of the Chesapeake Bay, although capped as described, do not suffer from chronically low dissolved oxygen. These areas generally have their downstream or seaward end open so that deep-water exchange with the oxygenated deep water from the ocean can occur.

FLOW AND CIRCULATION

Processes within the Chesapeake Bay and its tidal tributaries are strongly influenced by flow and circulation patterns. These factors affect the mixing of the Bay's waters and the distribution of salinity, dissolved compounds and planktonic organisms. Like most estuaries, the Chesapeake Bay has a two-layer flow pattern. Net flow in the upper layer moves down the Bay or downriver, while net flow in the bottom layer moves up the Bay or upriver.

This two-layer flow is caused primarily by the difference in density between the less dense, low-salinity water that flows off the land and the more dense, high-salinity water that flows in from the ocean. The less dense, more buoyant, low salinity water floats on the surface of higher salinity water. The tendency of ocean water in summer to be cooler than freshwater also contributes to its higher density. Interannual and seasonal differences in freshwater inflow to the rivers and the Chesapeake Bay, due largely to meteorological factors, affect the interaction of the two layers.

Tidal forces move water into and out of the Chesapeake Bay and its rivers. Tidal currents interact with the bathymetric surfaces of the bottom, with the seaward flow of freshwater and with the air-water interface affecting internal turbulence and mixing. Tied to lunar cycles, the daily, monthly and seasonal tidal rhythms are relatively predictable components of flow and circulation.

The Coriolis force is another important physical circulation process in the Chesapeake Bay. The Coriolis force is related to the earth's rotation and causes moving objects such as fluids to veer to the right (clockwise) in the Northern Hemisphere and to the left (counter-clockwise) in the Southern Hemisphere. This force increases with proximity to the poles. Currents in the Northern Hemisphere tend to move clockwise over their course unless they encounter a barrier such as a land mass. Thus ocean water flowing into the Chesapeake Bay at the mouth is deflected north due to the Coriolis force. The current continues around to the right until it encounters the Eastern Shore, which directs the flow up the Bay. Water flowing down and out of the Chesapeake Bay on the surface, flows primarily down the Western Shore as the

Coriolis force tends to push it to the right. This same phenomenon of inflow on the bottom on the right and outflow on the surface on the left occurs in the Bay's tidal tributaries as well.

VERTICAL DENSITY GRADIENTS AND PYCNOCLINES

In many parts of the Chesapeake Bay, the water column becomes stratified because of differences in water density. These differences are caused primarily by differences in salinity and, to lesser degree, in temperature. The water column becomes vertically stratified when, at some depth, a difference in water density from one depth to the next is large enough to inhibit or prevent exchange between water above and below it. Fisher et al. (2003) found the density gradient for defining inhibition or prevention of water exchange in the Chesapeake Bay to be 0.1 kg/m^4. The depth nearest the surface where this first occurs is referred to as the pycnocline. The discontinuity may be gradual, as shown in Figure IV-16a, exhibiting a generally uniform gradient of increasing density from one depth to the next through the water column. In such cases, one refers to the *region* of the pycnocline.

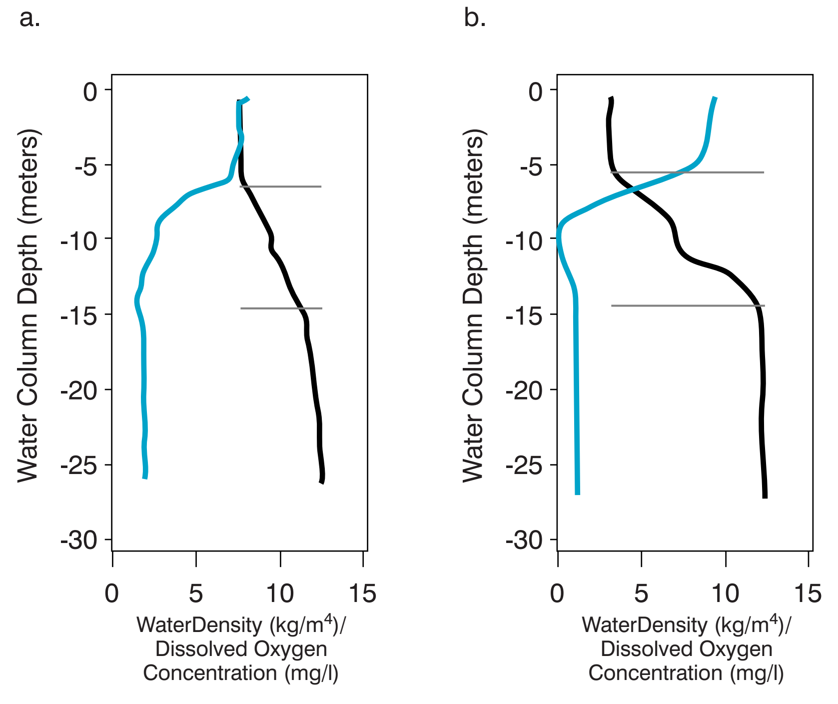


Figure IV-16. The figures illustrate a variety of water density and dissolved oxygen profiles found in the Chesapeake Bay and its tidal tributaries. The black line represents water density (kg/m ^{4}), the blue line represents dissolved oxygen concentration (mg/l). The vertical axis indicates depth (meters) below the surface. The horizontal line crossing the density line, when present, indicates upper and lower pycnocline depth using the Fisher et al. 2003 method. Figure 'a' is an example of a sharp, upper pycnocline with density gradually increasing with distance from the surface. Figure 'b' is an example of a more distinct three-layer structure.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

In areas where stratification is common, the pycnocline typically forms at about the same depth, but is subject to seasonal and annual variations in depth due to river flow, temperature and salinity patterns. The pycnocline is generally shallower at the mouths of tidal rivers and the Chesapeake Bay and deeper with distance upriver and up-Bay. In the central, deepest part of the mainstem Chesapeake Bay, the pycnocline tends to deepen and 'tilt' slightly on the east-west axis, depending on the strength and direction of prevailing winds as well as the relative balance of the several forces controlling Chesapeake Bay circulation. North of this area, where the Bay narrows and grows shallow, and north-moving bottom water shoals up from the deep trench, the pycnocline is generally found closer to the surface. In upriver areas of tidal tributaries, pycnoclines may occur occasionally depending on episodic intrusions of saline waters. In other areas, such as the mouth of Tangier Sound in the lower Chesapeake Bay, pycnoclines are occasional or intermittent because fresh and saline waters are typically well-mixed by tidal currents and bathymetric features.

In some areas, the many factors acting on circulation create a more complex stratification structure. Below the surface mixed layer, there is a layer where density continues to change with depth. Then a second, sharp density discontinuity is encountered, creating a discrete bottom mixed layer (Figure IV-16b). A density gradient of 0.2 kg/m^4 was found to inhibit upward vertical exchange and form a boundary for this lower mixed zone. (See Appendix D for a more thorough explanation of the methods for determining the pycnocline.)

For these reasons, the shape of a density profile can be highly variable within and between locations. The profile in Figure IV-16b is common in medium-to-deep areas of the mainstem Chesapeake Bay and lower tributaries during the summer months. There is an upper mixed layer several meters thick, followed by a distinct change in the density gradient. This change marks the upper depth of the pycnocline and the lower depth of the upper mixed layer. The thickness of the inter-pycnocline region in this example is 9 meters, about a third of the water column. The bottom mixed layer is fairly thick in this case, extending approximately 13 meters to the bottom. The figure illustrates the effect of the pycnocline and density gradient on oxygen concentration in this part of the Chesapeake Bay. Oxygen in the surface mixed layer is close to saturation. Below the upper pycnocline depth, oxygen levels fall with increasing distance from the oxygenated upper layer. The bottom mixed layer is consistent at about 1 mg/l through the entire thickness to the bottom.

Figure IV-17a shows a pycnocline type that is common to shallow to medium-depth areas of the mainstem Chesapeake Bay and mid-to-lower areas of the tidal tributaries. There is a well-defined surface mixed layer, marked by a sharp density discontinuity, but no lower mixed layer. The pycnocline extends through the water column to the bottom sediment-water interface, with dissolved oxygen concentrations decreasing with distance from the upper pycnocline boundary. Figure IV-17b shows a different density structure at the same location on a different date. There is no density discontinuity, the upper mixed layer extends through the entire water column and dissolved oxygen levels greater than 5 mg/l are sustained through to the bottom sediment-water interface. The vertical profiles in figures IV-17a and IV-17b

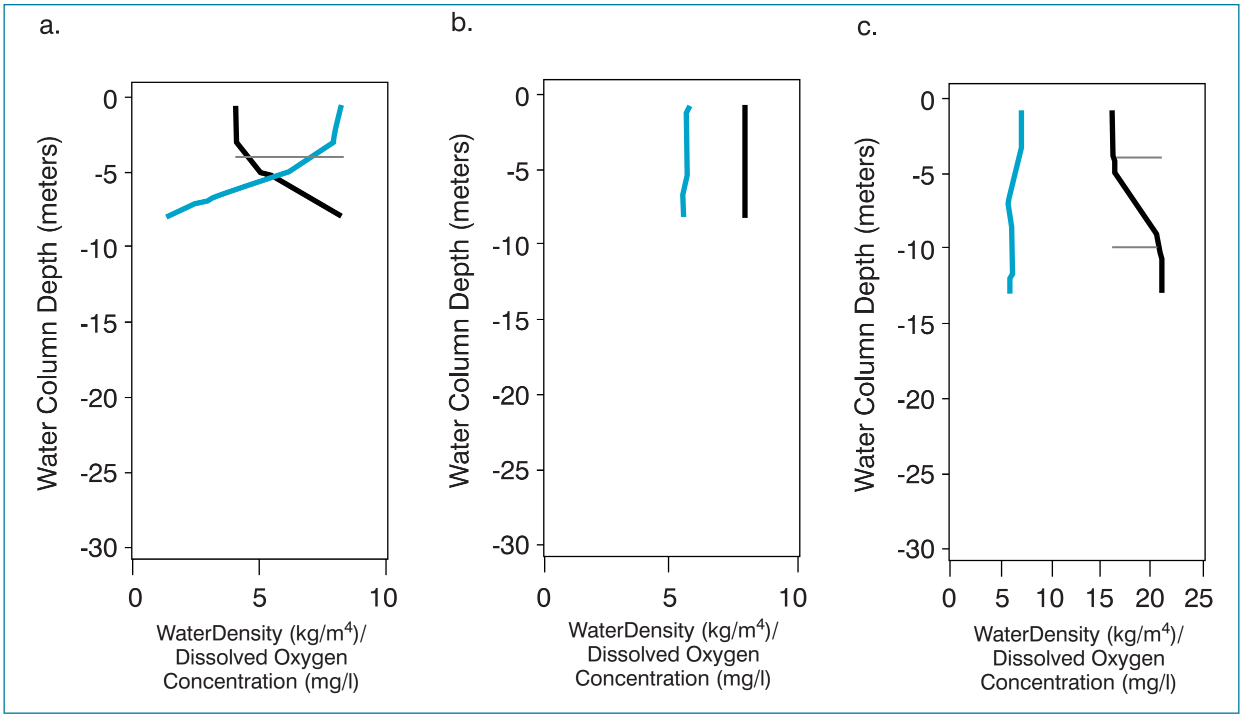


Figure IV-17. The figures illustrate a variety of water density and dissolved oxygen profiles found in the Chesapeake Bay and its tidal tributaries. The black represents water density (kg/m ^{4}), the blue line represents dissolved oxygen concentration (mg/l). The vertical axis is depth (meters) below the surface. The horizontal line crossing the density line, when present, indicates upper and lower pycnocline depth using the Fisher et al. 2003 method. Figure 'a' represents vertical profiles of density and dissolved oxygen concentration at a relatively shallow site. A layer of homogenous, oxygenated low salinity water lies over water with a gradually increasing salinity/density gradient. Figure 'b' represents vertical profiles of density and dissolved oxygen at the same relatively shallow site when the water column is fully mixed. Figure 'c' represents vertical profiles of density and dissolved oxygen at a site in the lower mainstem Chesapeake Bay where dissolved oxygen levels are sustained throughout the water column in the presence of a density gradient and pycnocline.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

are typical of tidal-fresh and shallow areas of the mainstem Chesapeake Bay and tidal tributaries and can frequently be observed in medium-depth regions of the mainstem Bay and mid- to lower sections of the tidal tributaries.

The relationship of dissolved oxygen to the presence or absence of a pycnocline and density gradient is different in the lower Chesapeake Bay mainstem (Figure IV-17c). A sharp pycnocline exists, but the gradient in dissolved oxygen concentrations is not as pronounced. Vertical mixing is still retarded by the pycnocline as in other areas of the Chesapeake Bay, but bottom waters are not as low in oxygen due to the replenishment of oxygenated waters from the ocean.

Figure IV-18 is a snapshot of water density and dissolved oxygen profiles at various sites in the Chesapeake Bay during the summer of 1997. The lines depicting water density demonstrate the layering and mingling of water masses of different sources and histories within the confines of the trenches and on the shoals. The plots also

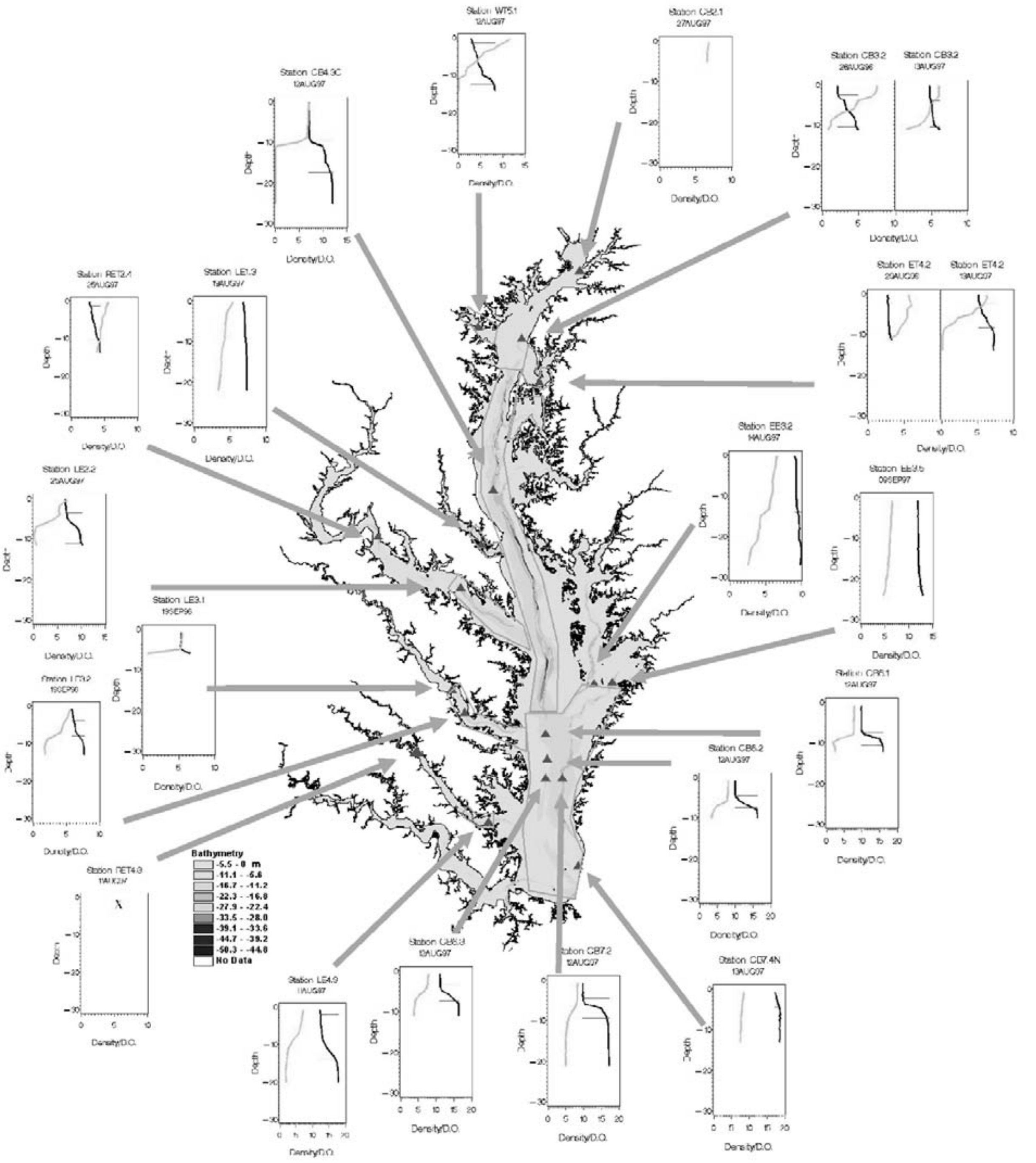


Figure IV-18. 'Snapshot' of water density and dissolved oxygen vertical depth profiles at various water quality monitoring program stations in the Chesapeake Bay and its tidal tributaries in the summer of 1997.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

illustrate the difference small and large variations in density can have on dissolved oxygen concentrations as described above. For example, at monitoring station EE3.2 in Tangier Sound, the decrease in dissolved oxygen concentration (about 2 mg/l) at 14 meters has a density difference just large enough to be considered a pycnocline. Downstream, at station CB7.2, the change in density is much larger but induces about the same magnitude of decrease in the dissolved oxygen concentration gradient.

DELINEATING THE DESIGNATED USE BOUNDARIES

Vertical stratification has direct implications for delineating the designated use boundaries. Much of the water in the Chesapeake Bay and its tidal tributaries is shallow and well-mixed or easily aerated. These areas plus the surface mixed layers overlying stratified water in channels and holes constitute the open-water fish and shellfish designated use. The upper layer mixes on time scales of minutes to hours (Alldredge et al. 2002), which means that all of the water in this layer comes in close contact with the atmosphere and should be able to attain the most protective surface water dissolved oxygen criterion. The open-water designated use boundary is, therefore, defined as the upper mixed layer, extending from the water surface to the bottom water-sediment interface, where no stratification occurs or to the measured depth of the upper pycnocline where, in combination with bottom bathymetry and water-column circulation, it presents a barrier to oxygen replenishment of deeper waters. From June through September, the open-water designated use accounts for approximately 70 percent of the total volume of the Chesapeake Bay and its tidal tributaries, and many Chesapeake Bay Program segments have only this one designated use (Table IV-9).

Water in the bottom mixed layer is essentially trapped. The bottom mixed layer is separated from the upper mixed layer by the pycnocline and receives very limited oxygen from either mixing or diffusion. Biological respiration and decomposition processes deplete the ambient dissolved oxygen, and bottom sediments exert additional oxygen demand. The shape of the bottom mixed layer or deep-channel designated use is essentially a thin layer along the bottom in most areas, with thicker sections in some deeper areas of the Chesapeake Bay. Water within the pycnocline between the upper and lower mixed layers is defined as the deep-water designated use.

However, as noted and illustrated above, a pycnocline and density gradient do not affect dissolved oxygen concentration conditions to the same degree in all areas of the Chesapeake Bay and its tidal tributaries. There are regional peculiarities in bathymetry and flow that strongly influence the effect of a pycnocline on dissolved oxygen concentrations, and these must be taken into account.

THE BOUNDARY DELINEATION PROCESS

The process of identifying and delineating the open-water, deep-water and deep-channel designated use boundaries employed observed and model-simulated characterizations of dissolved oxygen concentrations and the theoretical effects of the physical and chemical processes discussed above. The process first identified the

Table IV-9. The tidal-water volume of the designated uses by Chesapeake Bay Program segment. Calculations are based on the 1998-2000 summer (June through September) mean depths of the upper and lower pycnoclines.

Chesapeake Bay Program Segment	Volume (cubic kilometers)			
	Migratory	Open-Water	Deep-Water	Deep Channel
CB1TF	.35/4%	.35/1%		
CB2OH	1.22/14%	1.23/2%		
CB3MH	2.27/27%	1.05/2%	.87/6%	.47/5%
CB4MH		4.26/9%	2.73/9%	2.25/26%
CB5MH		7.57/15%	3.17/15%	4.62/52%
CB6PH		5.03/10%	5.03/10%	
CB7PH		10.29/21%	10.29/21%	
CB8PH		3.16/6%		
BSHOH	.05/<1%	.02/<1%		
GUNOH	.06/<1%	.06/<1%		
MIDOH	.03/<1%	.03/<1%		
BACOH	.02/<1%	.02/<1%		
PATMH	.37/4%	.06/<1%	.02/<1%	
MAGMH	.06/1%	.08/<1%		
SEVMH	.08/1%	.11/<1%		
SOUMH	.05/<1%	.07/<1%		
RHDMH	.01/<1%	.02/<1%		
WSTMH	.01/<1%	.02/<1%		
PAXTF	.01/<1%	.01/<1%		
PAXOH	.03/<1%	.03/<1%		
PAXMH	.39/5%	.38/1%	.38/1%	
POTTF	.48/6%	.48/1%		
PISTF	.003/<1%	.003/<1%		
MATTF	.01/<1%	.01/<1%		
POTOH	.84/10%	.84/2%		
POTMH	1.16/14%	3.17/6%	1.25/9%	1.20/14%
RPPTF	.10/1%	.10/<1%		
RPPOH	.05/<1%	.05/<1%		
RPPMH	.17/2%	1.00/2%	.33/2%	.13/1%
CRRMH	.07/1%	.07/<1%		
PIAMH	.20/2%	.20/<1%		
MPNTF	.01/<1%	.01/<1%		
MPNOH	.04/<1%	.04/<1%		
PMKTF	.03/<1%	.03/<1%		
PMKOH	.06/<1%	.06/<1%		
YRKMH	.08/1%	.28/1%		
YRKPH		.24/<1%	.15/<1%	
MOBPH		1.33/3%		

continued

Table IV-9. The tidal-water volume of the designated uses by Chesapeake Bay Program segment. Calculations are based on the 1998-2000 summer (June through September) mean depths of the upper and lower pycnoclines *(cont.)*.

	Volume (cubic kilometers)			
Chesapeake Bay Program Segment	**Migratory**	**Open-Water**	**Deep-Water**	**Deep Channel**
JMSTF	.26/3%	.27/<1%		
APPTF	.002/<1	.002/<1%		
JMSOH	.43/5%	.43/1%		
CHKOH	.05/<1%	.05/<1%		
JMSMH	.36/4%	.97/2%		
JMSPH		.43/1%		
WBEMH		.01/<1%		
SBEMH		.03/<1%		
EBEMH		.01/<1%		
LAFMH		.003/<1%		
ELIPH		.04/<1%	.02/<1%	.002/<1%
LYNPH		.02/<1%		
NORTF	.03<1%	.03<1%		
C&DOH	.02/<1%	.02/<1%		
BOHOH	.02/<1%	.02/<1%		
ELKOH	.10/1%	.10/<1%		
SASOH	.08/1	.08/<1%		
CHSTF	.003/<1%	.003/<1%		
CHSOH	.03/<1%	.03/<1%		
CHSMH	.41/5%	.41/1%	.01/<1%	<1%
EASMH		.78/2%	.09/1%	.12/1%
CHOTF	.02/<1%	.02/<1%		
CHOOH	.04/<1%	.04/<1%		
CHOMH2	.12/1%	.26/1%		
CHOMH1	.02/<1%	.95/2%		
LCHMH		.21/1%		
HNGMH		.19/<1%		
FSBMH	.14/2%	.14/<1%		
NANTF	.01/<1%	.01/<1%		
NANOH	.05/<1%	.05/<1%		
NANMH	.03/<1%	.10/<1%		
WICMH	.02/<1%	.06/<1%		
MANMH	.01/<1%	.09/<1%		
BIGMH	.002/<1%	.04/<1%		
POCTF	.004/<1%	.004/<1%		
POCOH	.02/<1%	.02/<1%		
POCMH	.01/<1%	.35/1%		
TANMH		3.98/8%		
Total	**8.54/100%**	**49.65/100%**	**13.41/100%**	**8.79/100%**

deep-channel designated use habitats: the areas of the Chesapeake Bay and its tidal tributaries that suffer chronic low dissolved oxygen concentrations due to the natural interplay of water-column stratification, bottom bathymetry and water circulation patterns. These areas are so strongly isolated by these factors that they become immune from remediation. The next step was to identify the deep-water designated use habitats—areas with chronically low dissolved oxygen concentrations driven largely by water-column stratification, bottom bathymetry and water circulation patterns, but with hypoxic conditions (extent and severity) that are responsive to change, including changes in anthropogenic inputs. The rest of the tidal Bay habitats were identified as open-water designated use habitats.

First it was necessary to identify potential areas for delineation as deep-channel and deep-water designated use habitats by examining empirical dissolved oxygen concentration and distribution data under the 'best' observed conditions. The 17-year dissolved oxygen record from the Chesapeake Bay Program's Water Quality Monitoring Program, 1984-2000, was reviewed to find the best summer dissolved oxygen conditions in this time period.[12] Using hypoxic volume-days as the metric, 1997 was chosen. The dissolved oxygen conditions of that year largely reflect the effect of low freshwater inflow and lower nutrient and sediment inputs from reduced rain and subsequent runoff.

Maps of bottom-water dissolved oxygen concentrations in the summer of 1997 revealed the areas with the most recalcitrant low dissolved oxygen concentrations. These maps also revealed areas with adequate dissolved oxygen concentrations, but with episodic low dissolved oxygen concentrations under other flow and runoff loading conditions. Maps of the spatial extent of waters with concentrations of 1 mg/l and 3 mg/l over the 17-year period helped identify areas where physical processes strongly influence dissolved oxygen concentrations and where low dissolved oxygen persists over a wide range of flows and associated nutrient loads. The regions identified as having chronic low dissolved oxygen concentrations attributable to the combined affects of pycnocline, bathymetry and flow were as follows:

- Upper, middle and lower central Chesapeake Bay segments (CB3MH, CB4MH and CB5MH);
- Northern reaches of the western and eastern lower Chesapeake Bay (CB6PH and CB7PH);

Dissolved Oxygen and Temperature

As the temperature of a liquid increases, the ability of gases to dissolve into it decreases. In other words, as water gets warmer, the concentration of gases, such as oxygen, within it decreases. This change has implications for the Chesapeake Bay in the summer time because, as the water's temperature increases, it can hold less and less oxygen.The inability to hold oxygen happens at a time when overall metabolism in the Bay is increasing with temperature. Higher metabolism is coupled with increased dissolved oxygen consumption.

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[12] Historical dissolved oxygen data were available from as early as the 1950s; however, the temporal and spatial coverage prior to 1984 was uneven and too coarse for this analysis.

- Patapsco River (PATMH);
- Mesohaline segments of the Chester, Eastern Bay, Patuxent, Potomac and Rappahannock rivers (CHSMH, EASMH, PXTMH, POTMH and RPPMH); and
- Polyhaline segment of the York River (YRKPH) (Figure IV-19).

How water-column stratification, bottom bathymetry and water circulation patterns affect dissolved oxygen conditions and, therefore, the designated use boundaries in each of these regions are discussed and illustrated below.

Upper Central Chesapeake Bay

The upper central Chesapeake Bay, or segment CB3MH, includes the ‘head’ of the mainstem Chesapeake Bay trench at its northern border near the Chesapeake Bay Bridge (Figure IV-19). In this segment the flow shifts from a single to a two-layer flow. The exact point where this occurs shifts south and north as the flow from the Susquehanna River increases and decreases with seasonal and interannual variation. Its location in the center of this estuarine transition zone puts segment CB3MH at the extreme end of oxygen dynamics in the Chesapeake Bay. As ocean water moves up the Bay beneath the pycnocline, metabolic processes are consuming its reserve of dissolved oxygen. By the time this water reaches segment CB3MH, it has traveled approximately 220 kilometers and, depending on the time of year, it can be partly or completely deprived of dissolved oxygen. Because of this, the very southern portion of segment CB3MH is the first part of the Chesapeake Bay mainstem to show oxygen depletion in the spring and the last to become reoxygenated in the fall. As the northward-flowing bottom water encounters the head of the mainstem trench, it spills into the shallower waters of the middle portion of segment CB3MH before meeting and mixing with the south-flowing waters of the Susquehanna River (Figure IV-20). Therefore, even though this middle portion of segment CB3MH is not ‘trench-like’ in depth, this area has deep-channel and deep-water designated uses.

Middle Central Chesapeake Bay

The middle central Chesapeake Bay, or segment CB4MH, encompasses the entire northern half of the Chesapeake Bay mainstem trench with the exception of the head, which lies in segment CB3MH (Figure IV-19). The trench runs 20 to 35 meters deep along the eastern side of the segment. Once a pycnocline develops in this segment, it acts as a lid over the trench and effectively isolates below-pycnocline waters from the overlying waters. The source of the below-pycnocline water in segment CB4MH is the already depleted below-pycnocline water of segment CB5MH (Figure IV-21). Therefore, the only source of dissolved oxygen for below-pycnocline segment CB4MH water is the occasional storm-induced downwelling event. Given the size of this segment, these events are relatively localized and short-lived. Because the pycnocline so effectively isolates the deeper waters in this segment, along with bottom bathymetry and water circulation patterns, these within-pycnocline waters are designated as deep-water and the below-pycnocline waters are designated as deep-channel designated use habitats.

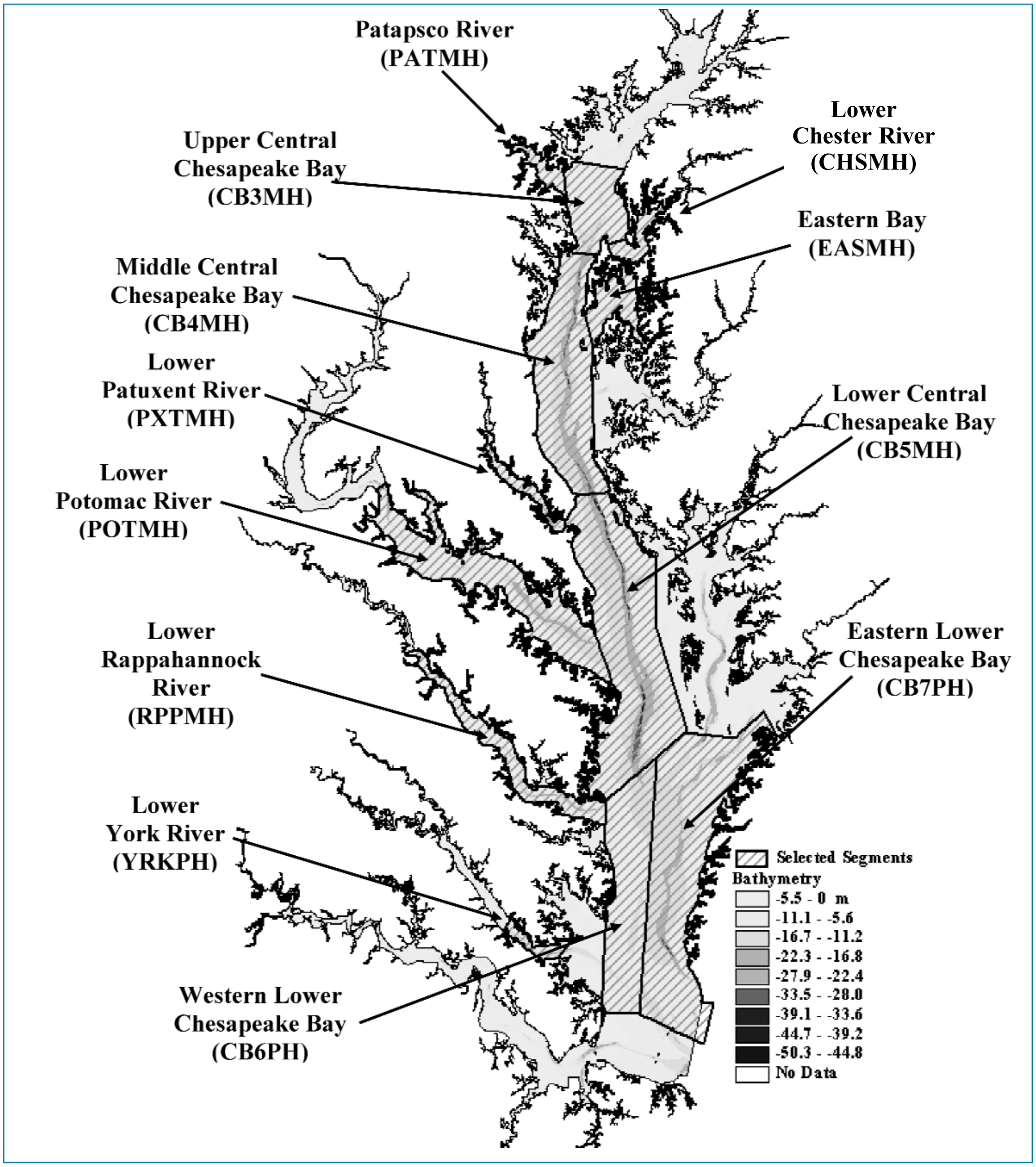


Figure IV-19. Chesapeake Bay Program segments identified as having chronic low dissolved oxygen attributable to the combined effects of pycnocline, bathymetry and flow.

Lower Central Chesapeake Bay

The lower central Chesapeake Bay, or segment CB5MH, encompasses the entire southern half of the Bay's mainstem trench (see Figure IV-19). As in segment CB4MH, the pycnocline in this segment can 'cap' waters in the trench so that the only significant source of exchange is water flowing into the southern end of the trench, beneath the pycnocline. During most of the year, as this source water enters

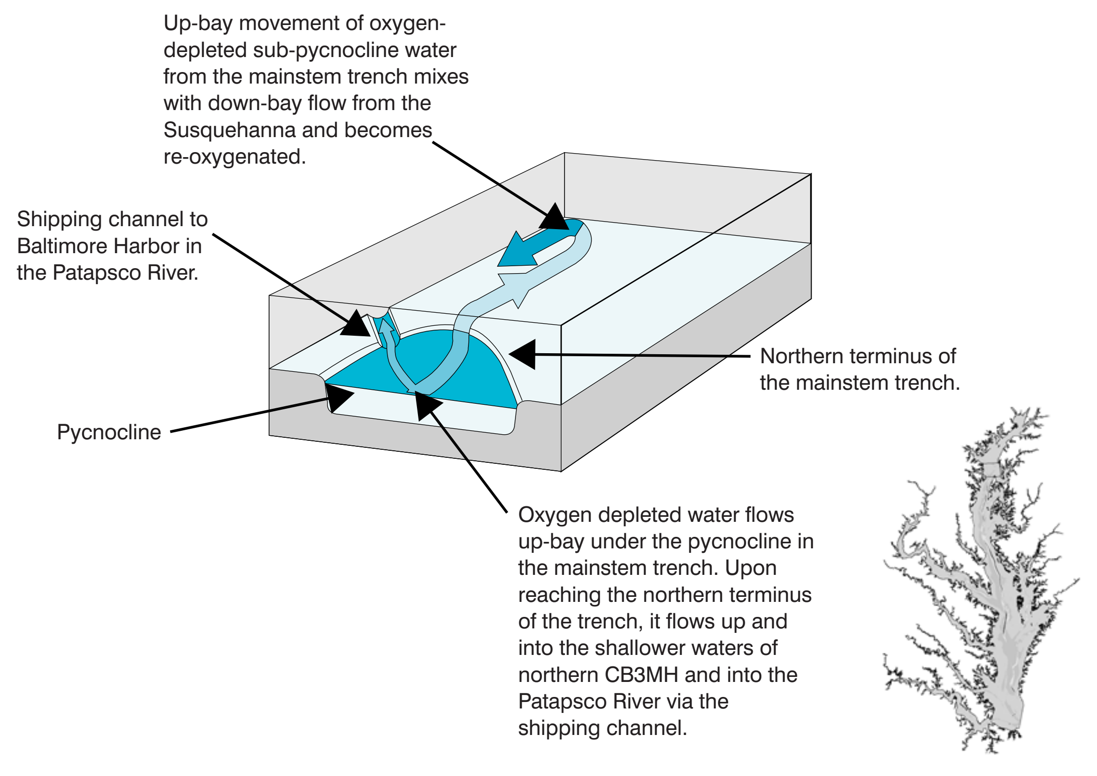


Figure IV-20. Three-dimensional schematic of the northern terminus of the mainstem Chesapeake Bay trench. Flow is depicted by thick arrows. Above and below pycnocline waters are shaded differently. Region depicted is boxed on inset map.

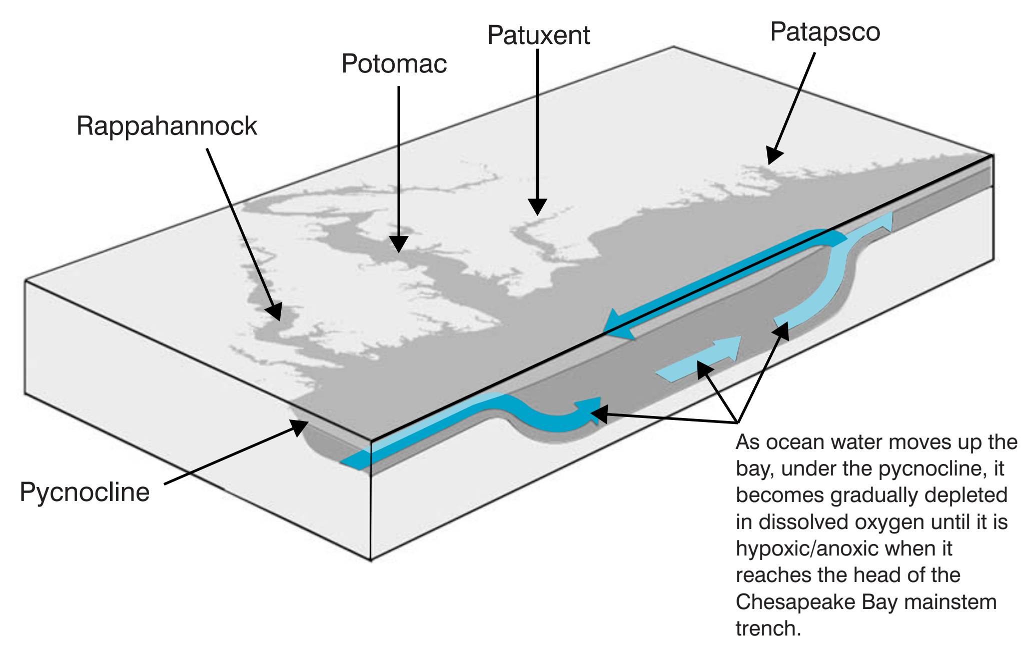


Figure IV-21. Three-dimensional schematic of the hydrodynamics of the Chesapeake Bay mainstem trench. View is from the southeast looking northwest.

the trench, its dissolved oxygen concentration is still relatively undepleted, because it is not far from its ocean source. However, during July and August, temperatures in the southern mainstem Chesapeake Bay can be warm enough and benthic metabolism high enough for this source water to have depleted oxygen supplies (see “Dissolved Oxygen and Temperature” sidebar, above). As this water moves up the trench during the late spring and summer months, metabolic processes under the pycnocline gradually consume the available dissolved oxygen until it is severely depleted by the time it reaches the northern part of segment CB5MH (Figure IV-21). The southern half of segment CB5MH is generally the last part of the Chesapeake Bay mainstem to become oxygen-depleted and the first to become replenished. Because the pycnocline so effectively isolates the bottom waters in this segment, along with bottom bathymetry and water circulation patterns, the within-pycnocline waters are designated as deep-water designated use habitat and the below-pycnocline waters are designated as deep-channel designated use habitat.

Western and Eastern Lower Chesapeake Bay

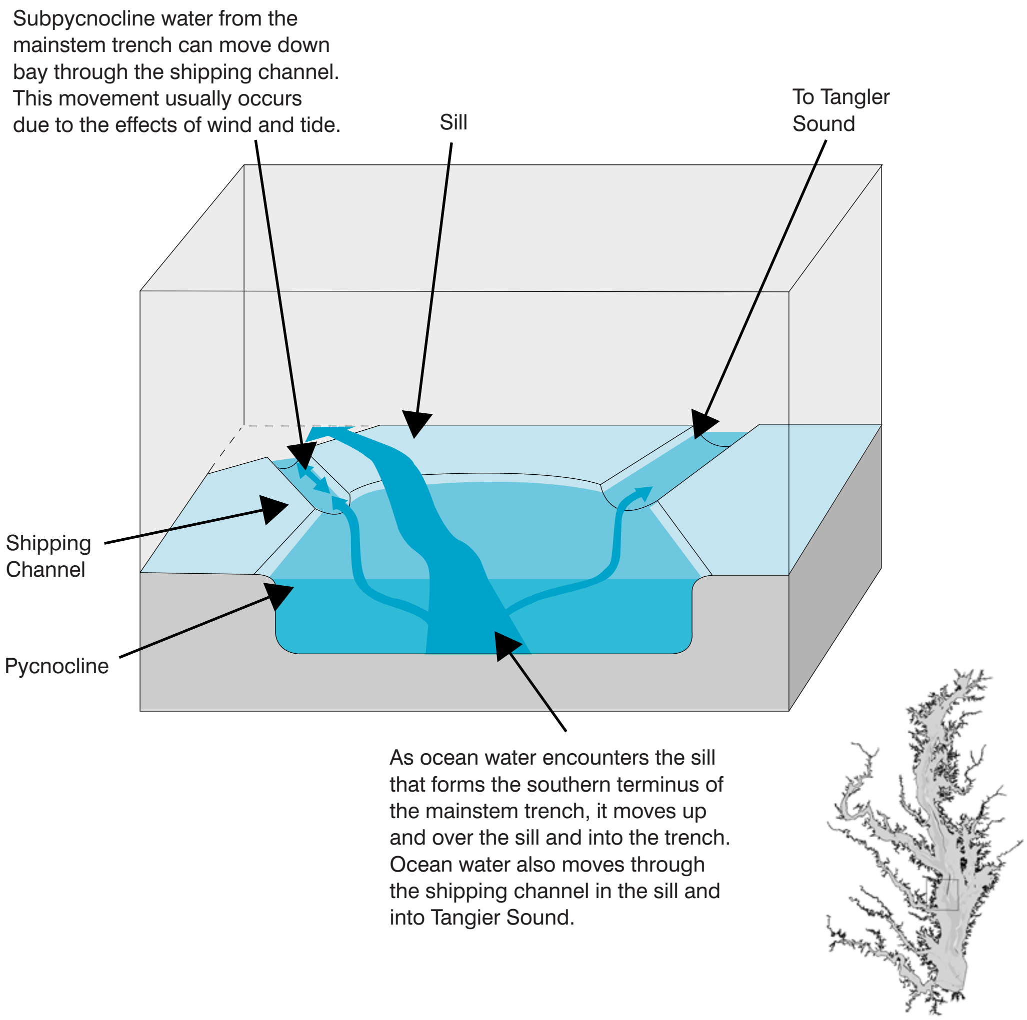
The western and eastern lower Chesapeake Bay, segments CB6PH and CB7PH, respectively, together make up the broadest region of the Chesapeake Bay mainstem. The entire region is heavily influenced by the ocean. A 17- to 22-meter trench runs along the axis of segment CB7PH, extending from the northern end of the segment almost to its southern boundary (see Figure IV-19). The trench is approximately 2.5 kilometers wide and deepens to an approximately 50-meter hole near its southern terminus. Although the trench becomes capped by a pycnocline, below-pycnocline dissolved oxygen concentrations within the trench are usually not affected. As ocean water flows into the Chesapeake Bay mouth along the bottom, the Coriolis force swings this flow northward along the lower eastern shore of the Chesapeake Bay. This waterflow pattern carries ocean water directly into the trench in segment CB7PH and provides a steady supply of oxygenated water to the below-pycnocline habitats. Ocean water similarly replenishes the below-pycnocline waters of segment CB6PH.

Only the very northern portions of segments CB6PH and CB7PH appear to have a chronic dissolved oxygen depletion problem related to the pycnocline and local bottom bathymetry. The northern boundary of these two segments forms a line, inclining northeastward from the mouth of the Rappahannock River to a point at the southern tip of the islands forming Tangier Sound (see Figure IV-19). The line approximates the location of a broad shoal or sill on the Chesapeake Bay bottom. The sill defines the southern terminus of the mainstem Chesapeake Bay deep trench and functions as a ‘hydrologic control point’ for waters passing over it.

A shipping channel cuts through the sill, connecting the trench in segment CB7PH to the trench in the middle Chesapeake Bay (Figure IV-22). The channel enables an exchange of oxygen-depleted bottom waters from the mainstem trench with water in the northern portions of segments CB6PH and CB7PH.

Although the overall direction of flow in the bottom layer is northward in this region, the smaller-scale actions of the outgoing tide can pulse bottom waters down-estuary (Figure IV-22). Oxygen-deficient water intrudes on the bottom and as lenses into mid-water depths. This effect can be intensified during a strong north-westerly wind event (see sidebar, “Tides Affected by Moon and Sun” on page 100).

The deep-water designated use, therefore, extends below the sill in these two segments. Its lower boundary runs along a line more or less parallel to, but south of, the northern segment line (Figure IV-23). The delineation of the boundary was determined by examining maps of contemporary dissolved oxygen concentration distributions and the anecdotal historical dissolved oxygen concentration data record.


Subpycnocline water from the mainstem trench can move down bay through the shipping channel. This movement usually occurs due to the effects of wind and tide.

As ocean water encounters the sill that forms the southern terminus of the mainstem trench, it moves up and over the sill and into the trench. Ocean water also moves through the shipping channel in the sill and into Tangier Sound.

Figure IV-22. Three-dimensional schematic of the hydrodynamics of the northern portion of segments CB6PH and CB7PH. View is from the south. Area portrayed is boxed on the inset map.

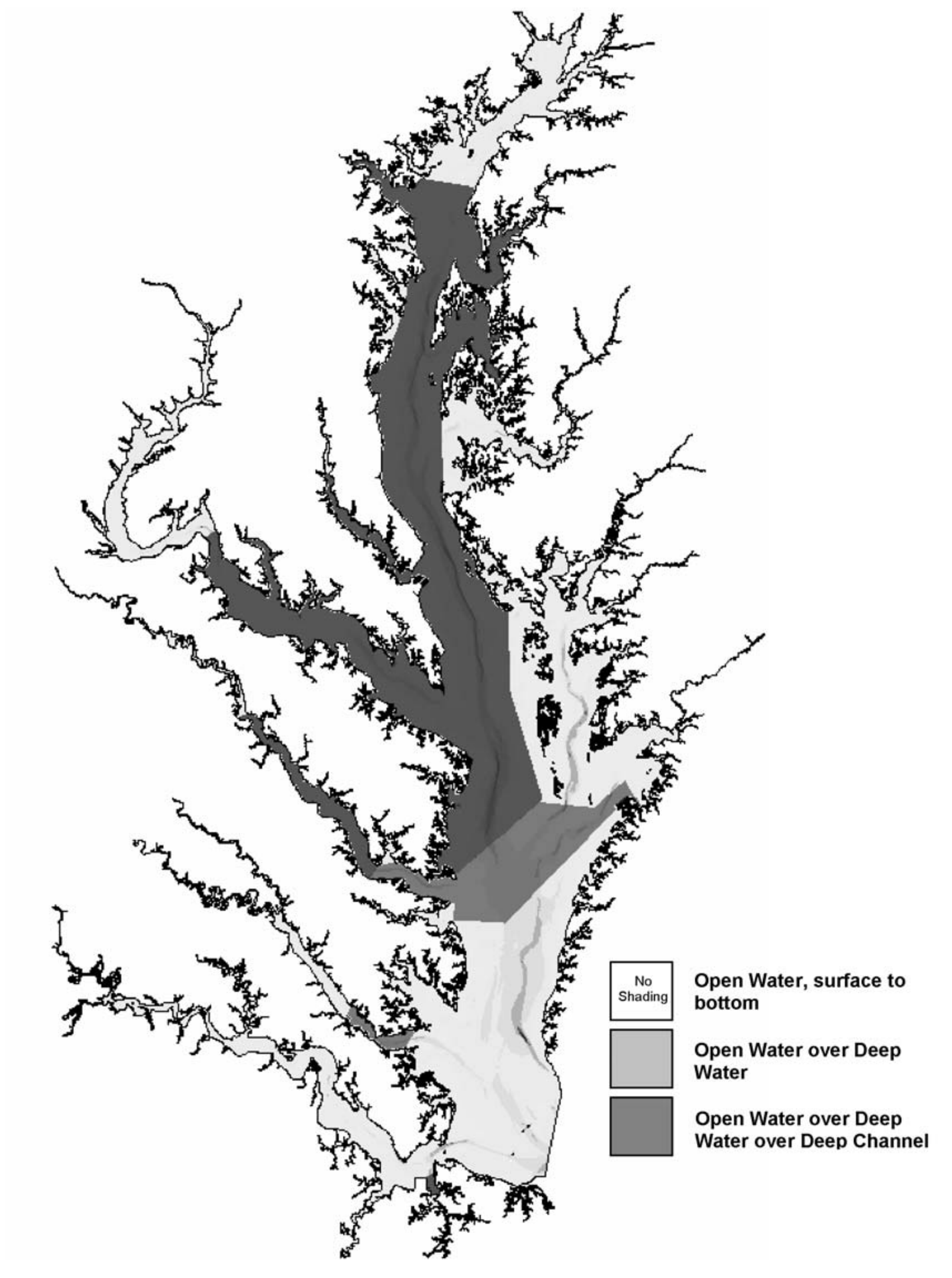


Figure IV-23. Map showing the dissolved oxygen designated uses of the Chesapeake Bay and its tidal tributaries.

Tides Affected By Moon and Sun

Tides are controlled by the gravitational pull of the sun as well as the moon. When the moon and the sun are aligned, such as during a full moon or a new moon, tides achieve their highest highs and lowest lows. This phenomenon is called a 'spring' tide. When the pull of the sun and moon are at right angles, they act to cancel each other out, and tidal amplitude is at its lowest. This is called a 'neap' tide.

The higher amplitude tide that occurs during 'spring' tide results in increased tidal flow. This can be beneficial as when this increased flow advects oxygen rich water into an estuary. Conversely, it can be detrimental if the advected water is coming from deeper waters with low dissolved oxygen.

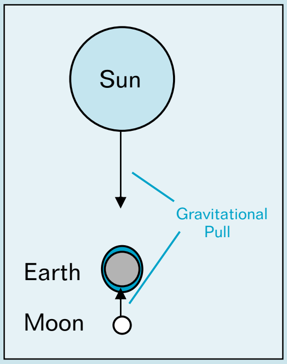


Diagram depicts 'spring' tide alignment of sun and moon.

Patapsco River

The Patapsco River, segment PATMH, is a highly urbanized tidal waterway, home to a large industrial center and one of the largest shipping ports on the eastern seaboard. It is heavily and routinely dredged, and a significant portion of its shoreline has been hardened. Its shipping channel is directly connected to the Chesapeake Bay mainstem trench, allowing for the advection of oxygen-depleted water to its below-pycnocline layer (figures IV-20 and IV-24). The river has a complex three-layer flow structure. The middle, pycnocline waters of the Patapsco River are designated as a deep-water use, and the below-pycnocline waters are designated as a deep-channel use.

Chester River

The downriver, mesohaline portion of the Chester River, segment CHSMH, contains a trench that ranges in depth from 20 to 25 meters (see Figure IV-19). The trench is separated from the mainstem Chesapeake Bay by a sill. This sill can potentially affect dissolved oxygen levels in the deep waters of the trench that are chronically low in the summer months. The pycnocline can form a 'lid' over the trench, cutting off the exchange with surface waters. Because of the sill at the mouth of the river, tidal flushing by bottom waters can be restricted, reducing the replenishment of the bottom waters of the trench as well as the

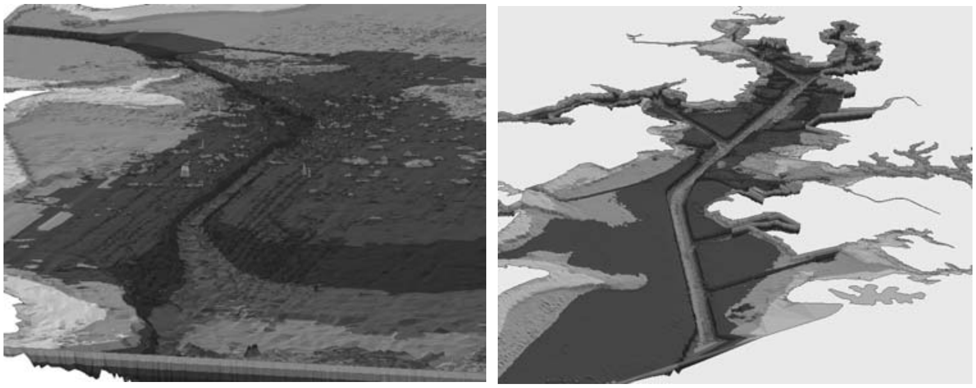


Figure IV-24. The image on the left shows the bathymetry of the shipping channel approach to Baltimore Harbor and how it is connected to the 'head' of the Chesapeake Bay mainstem trench at the bottom of the picture (middle to right side). The image on the right is of the bathymetry of Baltimore Harbor. To improve visualization, the depth versus width relationship has been enhanced.

potential mixing force that the inflow might have. It may also be the case that during extreme (spring) tidal events (see sidebar, "Tides Affected by Moon and Sun," on previous page) low dissolved oxygen bottom water from the mainstem trench is advected into the Chester River trench, where it is sequestered under the pycnocline (Figure IV-25).

When a measurable pycnocline is observed (often due to these 'spill-over events'), the within-pycnocline waters of the lower Chester River (river mouth up to the sill at Ringgold Point on Eastern Neck) have a deep-water designated use, and the below-pycnocline waters have a deep-channel designated use. In the absence of

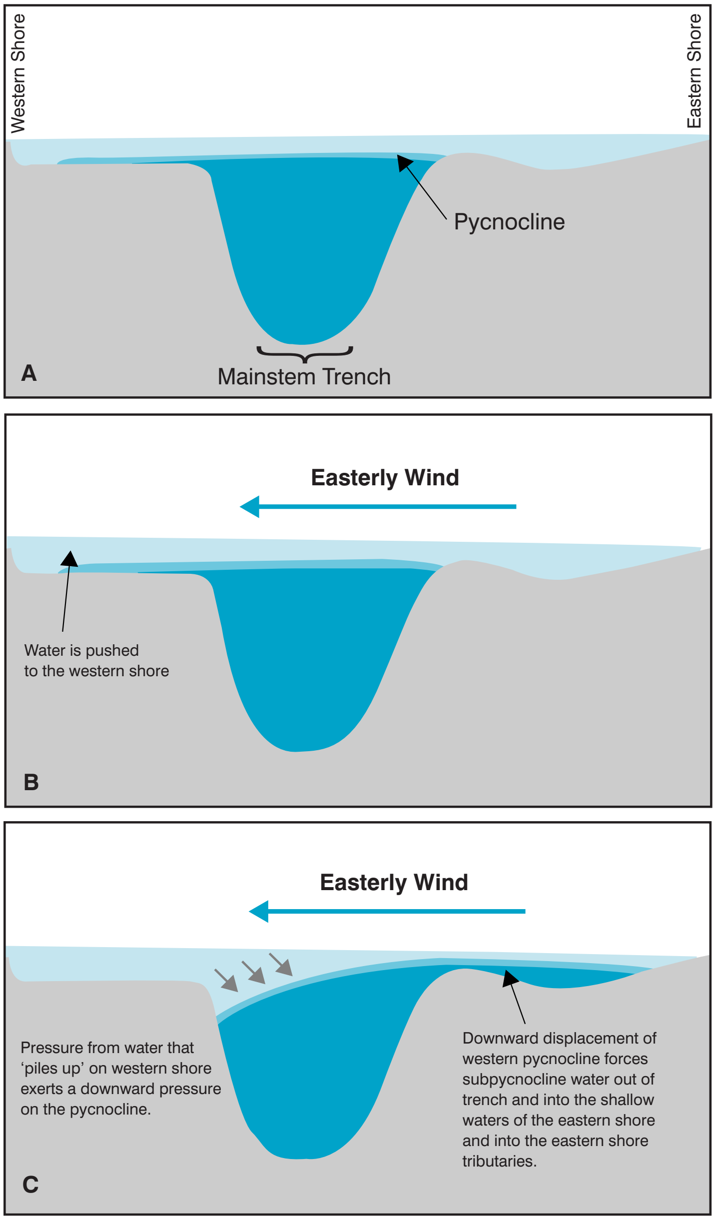


Figure IV-25. Panel A shows the 'normal' state of the pycnocline over the Chesapeake Bay mainstem trench. In Panel B, a strong easterly wind pushes water from the eastern shore to the western shore. As water 'piles up' on the western shore in Panel C, it exerts a downward pressure on the pycnocline there. As the pycnocline is pushed down on the western shore, a pressure differential is created between the west and east shores causing water to be displaced up and out of the Chesapeake Bay mainstem trench and into the shallow waters of the eastern shore and into the eastern shore tributaries. Strong westerly winds result in the opposite phenomena, where the pycnocline tilts in the opposite direction and subpycnocline water is advected to the western shore.

water-column stratification, the open-water designated use will apply throughout the water column to the bottom sediment-water interface in the lower Chester River.

Eastern Bay

In the Eastern Bay, segment EASMH, a trench extends from the river mouth, where it connects with the mainstem trench to a point halfway up the Bay (see Figure IV-19). This connection with the mainstem Chesapeake Bay trench has implications for dissolved oxygen in the bottom waters of lower Eastern Bay, since the below-pycnocline waters of this portion of Eastern Bay and the mainstem Chesapeake Bay trench exchange freely. This region of the mainstem trench has some of the worst dissolved oxygen conditions in the entire Chesapeake Bay. Because of this, below-pycnocline waters in lower Eastern Bay are chronically low in dissolved oxygen in summer. When a measurable pycnocline is observed, the within-pycnocline waters of Eastern Bay have a deep-water designated use and the below-pycnocline waters have a deep-channel designated use (see Figure IV-23). In the absence of water-column stratification, the open-water designated use will apply throughout the water column to the bottom sediment-water interface in Eastern Bay.

Patuxent River

The trench in the lower Patuxent River, segment PXTMH, contains one of the deepest points in the Chesapeake Bay just off of Point Patience. The Patuxent River trench terminates at a sill at the mouth of the river (Figure IV-26). Dissolved oxygen concentrations become depressed beneath the pycnocline in the summer, but not to the degree they do in the mainstem Chesapeake Bay trench. These depressed dissolved oxygen concentrations may be due to pycnocline-disrupting turbulence as the river flows through the constriction at Point Patience. Below-pycnocline dissolved oxygen does not become completely replenished, but these waters do naturally reoxygenate enough to maintain levels high enough for a deep-water designated use (see Figure IV-23). Given the depth of this trench, it is likely that hypoxia is a natural condition below the pycnocline in the summer.

Potomac River

The lower Potomac River trench, located in segment POTMH, extends from the mouth of the river up to Ragged Point and averages 15 to 25 meters deep (see Figure IV-19). A 10- to 15-meter shelf extends from the sides of the trench and connects with a similar region in the mainstem Chesapeake Bay (Figure IV-27). Although the Potomac trench is not connected to the mainstem Bay trench there is not a sill across the mouth of the Potomac. The pycnocline effectively isolates the water volume in the trench from the surface waters. In addition, given the size of the Potomac River watershed, a relatively large amount of organic matter could be delivered to the below-pycnocline waters of the Potomac trench. It is very likely that, due to the size and depth of this deep-water area coupled with strong water-column stratification, low dissolved oxygen conditions are a natural feature of the Potomac trench. The

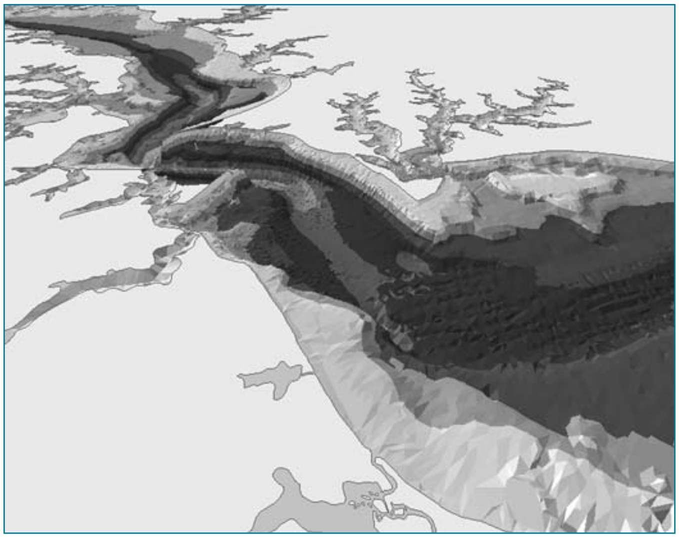


Figure IV-26. Bathymetry at the mouth of the Patuxent River. To improve visualization, the depth relative to the width has been enhanced.

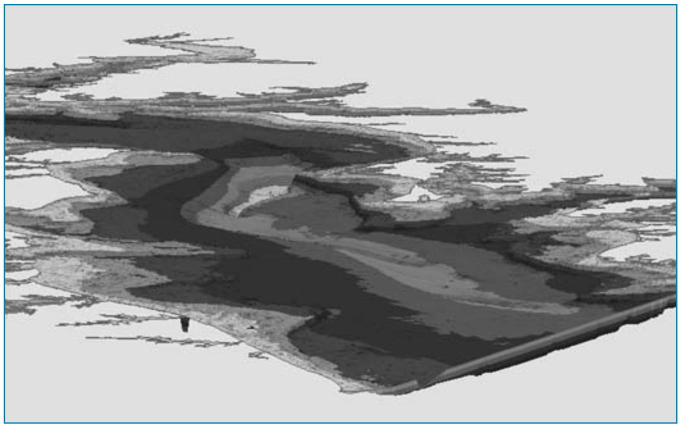


Figure IV-27. Bathymetry at the mouth of the Potomac River. To improve visualization, the depth relative to width has been enhanced.

pycnocline waters of the lower Potomac River (POTMH) have a deep-water designated use and the below-pycnocline waters have a deep-channel designated use (see Figure IV-23).

Rappahannock River

The Rappahannock trench, located in segment RPPMH, extends from the mouth of the Rappahannock River to Belle Isle (see Figure IV-19). The downriver end of the trench terminates in a sill that extends across the mouth of the river. Dissolved oxygen concentrations in the bottom waters of the trench are affected by the formation of the pycnocline. However, bottom water in the upriver half of the trench is more affected than the downriver half. This phenomenon may be related to strong currents flowing in the Rappahannock River along the bottom and over the sill. Chao and Paluskiewicz (1991) found that lower-layer density currents flowing over a sill cause downward mixing upriver of the sill (Figure IV-28). If this downward mixing is occurring in the downriver half of the Rappahannock trench, it would explain why

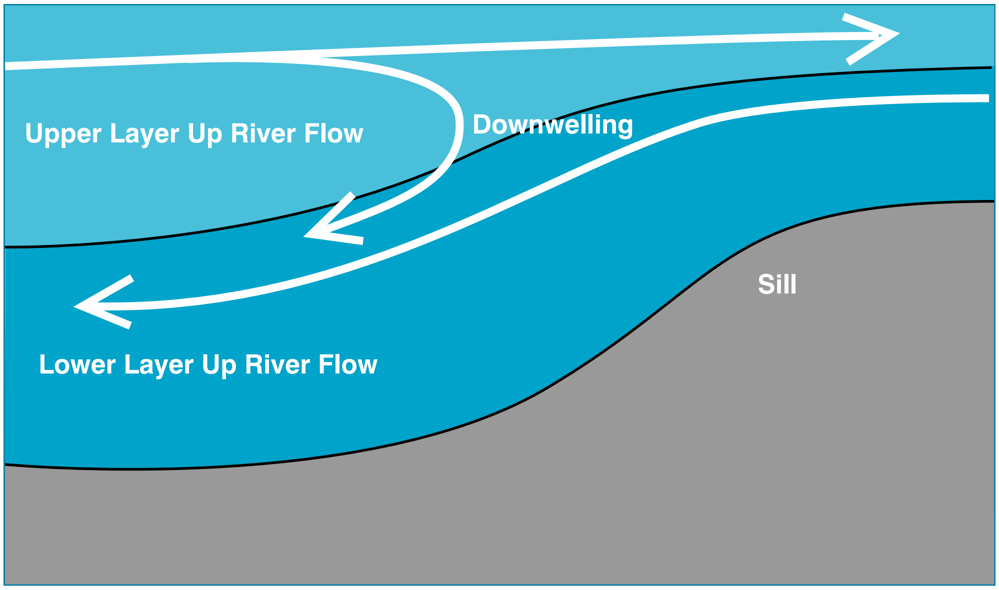


Figure IV-28. Diagram of the hydrodynamics of flow over a sill. As lower layer waters flow over the sill, downwelling surface waters occur.

Source: Chao and Paluszkiewicz 1991.

bottom water dissolved oxygen is less affected by the pycnocline in this region. In the Virginia rivers, bottom layer, upriver flow in the Rappahannock River is second only to that of the James River and is greater, on average, than in the Potomac River (Wang 2003, personal communication). Given this rapid upriver flow beneath the pycnocline, the below-pycnocline waters of the Rappahannock trench are not depleted of dissolved oxygen until they reach the head of the trench. Based on a decadal-scale analysis of dissolved oxygen within the trench, it appears that low dissolved oxygen in the upriver portion is a chronic condition.

Because of the unique hydrodynamics of the lower Rappahannock River, the deep-water and deep-channel designated uses are not uniform across this segment. From the upriver shore of the Corrotoman River to the mouth of the Rappahannock River, the deep-water designated use extends from the upper pycnocline to the bottom sediment-water interface. Upriver of this section to Belle Isle, the pycnocline volume has a deep-water designated use and the below-pycnocline volume a deep-channel designated use (see Figure IV-23).

York River

The York trench, located principally in segment YRKMH, extends from where the York River empties into Mobjack Bay up-river to Kings Creek. A 10-15 meter channel runs from the down-river terminus of the trench, through Mobjack Bay to a point in the mainstem Bay adjacent to the Chesapeake Bay mouth (see Figure IV-19). This channel effectively connects the lower York River to ocean water flowing into the Chesapeake Bay. This connection apparently is a benefit to bottom water dissolved oxygen as concentrations below the pycnocline in this region do not get as low as they do in other below-pycnocline trench areas of the Bay. For this reason, the waters below the upper pycnocline down to the bottom sediment-water interface from the York River mouth to Timberneck Creek have a deep-water designated use (see Figure IV-23).

SHALLOW-WATER BAY GRASS DESIGNATED USE BOUNDARIES

Restoration of underwater bay grasses to acreages supporting "the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats" is ultimately the best measure of attainment of shallow-water bay grass designated use. Therefore, delineation of the shallow-water designated use boundaries must reflect the desired acreage of underwater bay grass restoration. In shallow-water habitats out to the 2-meter depth contour, the exact shallow-water designated use boundaries can:

- Follow a Chesapeake Bay Program segment-specific depth contour;
- Reflect an established segment-specific acreage of underwater bay grasses to be restored; or
- Match an established segment-specific acreage of shallow-water habitat meeting the water clarity criteria necessary to support achievement of the underwater bay grasses restoration goal acreage.

The Chesapeake Bay Program segment-specific maximum depth of persistent, abundant underwater bay grasses growth sets the initial boundary for the habitat necessary for supporting the shallow-water designated use. That same segment-specific maximum depth was used in combination with the single best year of underwater bay grass distribution mapped across the available 1930-2000 data record to set the new restoration goals on a segment-by-segment basis. Finally, the ratio of the above shallow-water habitat out to the maximum depth of persistent, abundant plant growth and the corresponding segment-specific underwater bay grasses restoration acreage are used to calculate an acreage of shallow-water habitat meeting the water clarity criteria necessary to support achievement of the restoration goal acreage.

The following sections describe and quantify these three approaches to setting the shallow-water designated use boundaries, which are consistent with options the EPA put forth for measuring attainment of the Chesapeake Bay shallow-water underwater bay grass designated use (U.S. EPA 2003). EPA recommends the states adopt one (or more) of the three approaches to defining the shallow-water designated use boundaries in addition to adoption of numerical water clarity criteria into their water quality standards. States can adopt shallow-water designated use boundaries covering higher acreages or greater depths than those provided here during their upcoming water quality standards adoption processes once the expanded river-specific information has become available to be incorporated. During future state triennial reviews of their water quality standards, states also may expand their shallow-water designated use boundaries to reflect resulting levels of restoration of underwater bay grasses in prior years.

MAXIMUM DEPTH OF PERSISTENT OR ABUNDANT PLANT GROWTH-BASED BOUNDARIES

The 2-meter depth contour was selected as the maximum depth for the lower vertical boundary of the shallow-water designated use. This is the maximum depth to which underwater bay grasses could be restored in many of the tidal tributaries and mainstem Chesapeake Bay shallow-water habitats. Although historical underwater bay grass beds in the Chesapeake Bay probably grew to 3 meters or more, the 2-meter depth was chosen following an extensive evaluation of grass bed distribution over the past 70 years (1930s-2000) and of light levels anticipated to be required to restore viable shallow-water habitats out to the 2-meter depth (Batiuk et al. 1992; Dennison et al. 1993; Moore et al. 1999; Batiuk et al. 2000; Moore et al. 2001; Naylor 2002).

The intertidal zone was selected as the inner boundary for the shallow-water bay grass designated use because some species can grow in the upper end of the intertidal zone (Batiuk et al. 2000; Koch 2001). Numerous field studies of underwater bay grass distributions in the Chesapeake Bay and its tidal tributaries have indicated that what is controlling the minimum depth of their distribution is not wave action or other factors, but length of exposure to air at low tide (Moore, unpublished data; Naylor, unpublished data).

Shallow-water habitats also may be offshore flats such as those observed in Tangier Sound and Poquoson Flats in the lower mainstem Chesapeake Bay. These areas may have an inner boundary not in the intertidal zone but rather a relatively deep and wide channel between them and the shore. These areas are included in the delineation of shallow-water bay grass designated use habitats if they have or have had underwater bay grasses and met the decision rules described below.

BENEFITS OF DEEPER UNDERWATER BAY GRASS DISTRIBUTION

There are obvious benefits to restoring underwater bay grasses to greater depths than where they currently exist in the Chesapeake Bay and its tidal tributaries (Table IV-10). Increasing the depth and, therefore, the areal distribution of the grasses can greatly increase the habitat and food available to the Chesapeake Bay's fish, crabs and waterfowl.

It is important to note that underwater bay grass distribution is directly related to the tidal bathymetry of the basins in which the beds occur. In a shallow bay with a gradual slope to deeper waters, such as the Chesapeake Bay, even a moderate increase in water clarity can result in tremendous increases in the areal extent of bay grasses.

Table IV-10. Ecological and water quality benefits of deeper underwater bay grasses distribution in the Chesapeake Bay and its tidal tributaries.

- Ensures growth of underwater bay grasses where previously there may have been none because wave energy at shallower depths prevented plants from rooting in the bottom sediments (e.g., the beds that formerly grew on the western side of Kent Island, Maryland, at depths greater than where the critical wave energy threshold exists);
- Adds habitat below the grazing depth of non-native mute swans and non-migratory Canada geese (approximately 1 and 0.5 meters, respectively) to increase food availability for native waterfowl;
- Reduces the likelihood of ice damage to the beds;
- Reduces the negative effects of unusually low tides;
- Minimizes thermal stress (as deeper beds are inherently cooler);
- Stabilizes sediments at greater depths (through the reduction of water velocity within the underwater bay grass beds);
- Increases overall nutrient uptake and supports increased denitrification;
- Increases summertime oxygen production (which is particularly important in the headwaters of tidal creeks); and
- Increases habitat for fish, crabs and macroinvertebrates.

HISTORICAL UNDERWATER BAY GRASS DISTRIBUTION

The distribution and, therefore, the depth of historical underwater bay grass beds were mapped from photographs dating from the late 1930s through the mid-1960s by scientists at the Maryland Department of Natural Resources and the Virginia Institute of Marine Science. Historical underwater bay grass distribution data from Maryland and Virginia were aggregated into a single data set using ArcInfo GIS software. The two states' approaches reflect differences in the quality and quantity of historical aerial photographs available for interpretation. Full documentation of the methods employed and the detailed results are reported in Moore et al. (1999, 2001) and Naylor et al. (2002).

To determine historic underwater bay grass acreage, aerial photos of Maryland's portion of the Bay taken in 1938, 1952, 1957 and 1964 were evaluated to determine the year in which the most underwater bay grass was visible for each area (Naylor 2002). The photos for the year of greatest abundance in each area were then scanned, geo-referenced and photo-interpreted to determine the extent of underwater bay grass beds during these years.

In the Virginia portion of the Chesapeake Bay and its tidal tributaries, historical underwater bay grass acreage in the James River was mapped using photographs taken in 1937, 1947, 1948, 1953, 1954, 1958, 1959, 1963, 1968, 1969, 1970 and

1973, with the historical coverage defined by the composite of the individual years (Moore et al. 1999). Historical and recent ground survey results were superimposed on the maps of historical underwater bay grass distributions to help determine whether the patterns exhibited in the photographs were actually those of underwater bay grass beds (Moore et al. 1999).

For the Rappahannock and York rivers and the adjacent smaller western shore rivers, creeks and embayments, a series of photographs from 1952 to 1956 was chosen to delineate the maximum coverage of bay grasses in these areas (Moore et al. 2001). The 1936 and 1937 photographs of these rivers showed less underwater bay grass coverage compared to the 1950s photographs. The difference appeared to be related to poorer overall atmospheric and water clarity conditions (Moore et al. 2001).

The interpretation of these historic aerial photographs closely followed current methods to delineate underwater bay grass beds throughout the Chesapeake Bay and its tidal tributaries through annual aerial underwater bay grass surveys (e.g., Orth et al. 2000). In neither state did a single year of photography provide comprehensive coverage of each state's tidal shorelines.

These state-specific analyses provide a *conservative* estimate of past underwater bay grass distributions prior to the 1970s. The conservative nature of the estimate is due, in part, because the older photographs were not collected specifically to map underwater bay grasses, but were gathered to assist in analyzing land use or farming practices. While atmospheric criteria were usually met, the factors that are important for delineating and mapping underwater bay grasses (such as tidal stage, water transparency and plant growth stage) often were not met. Underwater bay grasses likely grew at greater depths between the 1930s and 1960s, according to published and anecdotal information, than was observed in a number of segments in the historical photographs. Grasses that grow beyond the 1-meter depth contour become increasingly difficult to map, given the conditions under which the historical photographs were collected. There were limited numbers of years—often only three to five—for which historical photographs of a particular shallow-water habitat region were available for interpretation and mapping between the 1930s and early 1970s. Evidence suggests that underwater bay grass distributions already had declined by the time photographs of suitable quality were available for interpretation (Moore et al. 1999). All of these factors led to conservative estimates of past underwater bay grasses distributions and depths of bed growth.

UNDERWATER BAY GRASS NO-GROW ZONES

A series of underwater bay grass 'no-grow zones' were originally delineated in 1992 in the *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis* (Batiuk et al. 1992). Habitats exposed to high wave energy or that have undergone physical modifications such that they could not support underwater bay grasses growth were excluded based on an extensive review of data available at the time. With the mapping of historical underwater bay grass distributions, a composite of available distribution data from the 1930s through 2001 was superimposed on the 1992 bay grass no-grow zones. A number of shoreline habitats previously considered no-grow zones showed clear evidence of historical underwater bay grass growth and, therefore, their no-grow zone designation was dropped. These revised underwater bay grass no-grow zones also include areas where the no-grow zone applies to a 1- to 2-meter depth contour as well as a 0- to 2-meter depth contour.

The revised underwater bay grass no-grow zones illustrated in Figure IV-29 show shoreline habitats of 2 meters or less where underwater bay grasses are never expected to grow due to:

- Extreme physical wave energy, which prevents the plants from rooting in the bottom sediments (e.g., Calvert Cliffs on Maryland's lower western shore and Willoughby Split to Cape Henry near the Chesapeake Bay mouth in Virginia);
- Permanent physical alterations to nearshore habitats, including dredging close to shore accompanied by hardening of the shoreline and installation of permanent structures (i.e., shipping terminals) as observed in the inner Baltimore Harbor and the Elizabeth River;
- Natural, extreme discoloration of the water from tidal-fresh wetlands (e.g., tidal-fresh 'blackwater' rivers on the Eastern Shore); or
- No functional shallow-water habitat due to natural river channeling (e.g., tidal headwaters of several lower Eastern Shore rivers).

These underwater bay grass no-grow zones reflect the full set of findings on underwater bay grasses distributions from the historical (select years from the 1930s–early 1970s) and 1978–2001 data records, as well as altered nearshore/shoreline habitats as described above. The no-grow zones illustrated in Figure IV-29 are based on the best available information and are subject to future revision based on new research and information.

If no physical reasons prevent underwater bay grasses from growing in a specific shallow-water habitat, it should be expected that grasses can grow there, given appropriate water quality conditions and local sources of propagules (i.e., reproductive vegetative materials such as seeds and rhizomes). For example, evidence exists of underwater bay grasses growing within estuarine turbidity maximum zones in the upper Chesapeake Bay mainstem and selected tidal tributaries (e.g., the Potomac River), but not in other tidal tributaries. The *Regional Criteria* provides specific guidance to the states on how to address estuarine turbidity maximum zones in applying the Chesapeake Bay water clarity criteria (see Chapter 7 in U.S. EPA 2003). The lack of historical data on the presence of underwater bay grasses in a particular habitat is not a valid reason to delineate that shallow-water area as an underwater bay grass no-grow zone.

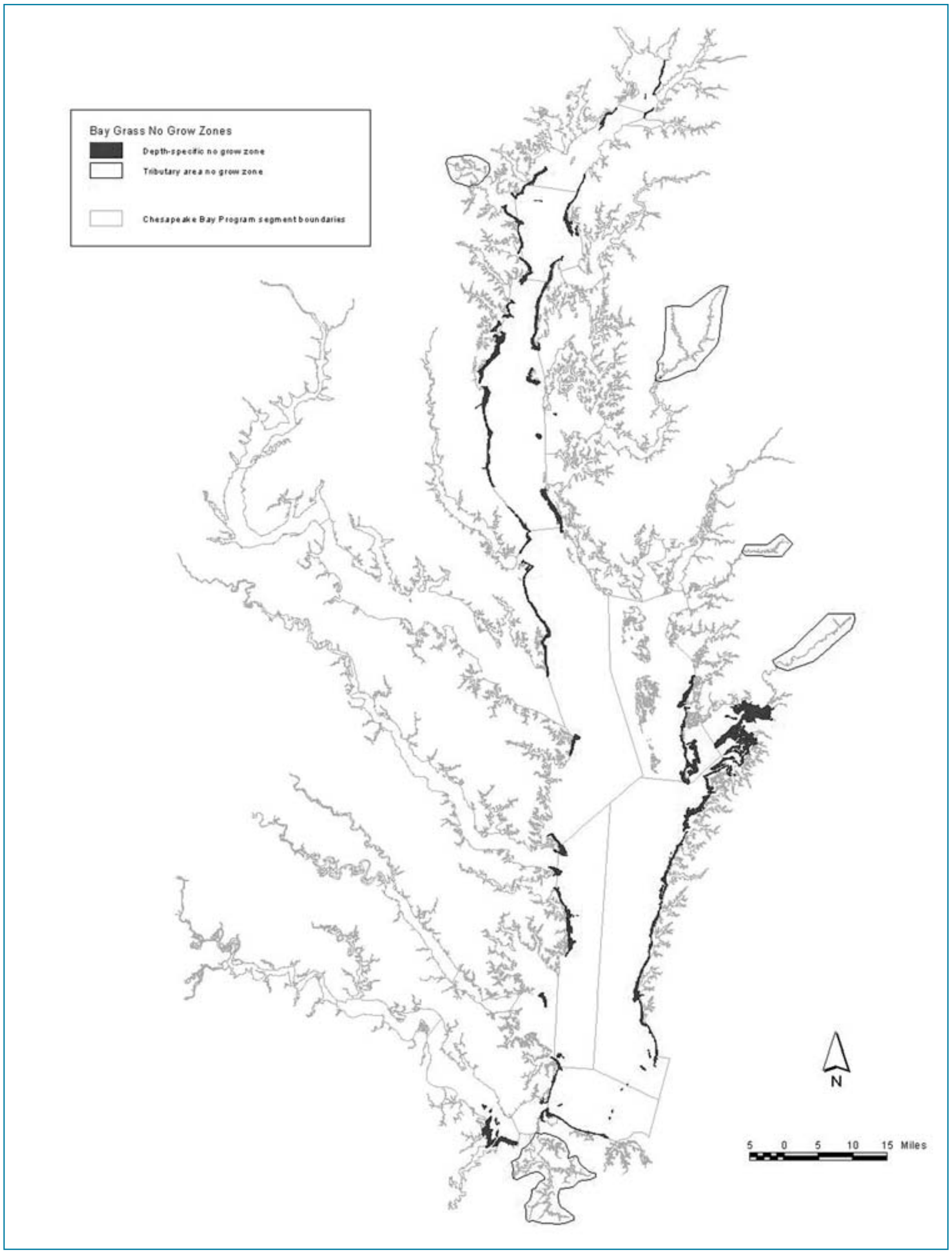


Figure IV-29. Map illustrating the revised underwater bay grass no-grow zones of the Chesapeake Bay and its tidal tributaries.

Six Chesapeake Bay Program segments were not assigned a shallow-water bay grass designated use depth boundary (see Table IV-13). The established bay grass no-grow zones covered the 2-meter and less habitats along the entire tidal shoreline in each of these segments–upper Choptank River, upper Pocomoke River, Western Branch Elizabeth River, Southern Branch Elizabeth River, Eastern Branch Elizabeth River and Lafayette River (see Appendix C).

DETERMINING THE MAXIMUM DEPTH OF PERSISTENT/ABUNDANT PLANT GROWTH

The first step in the process to define the maximum depth of persistent and abundant underwater bay grass beds by Chesapeake Bay Program segment (Table IV-11, Figure IV-30) was to establish decision rules. The rules developed take full advantage of the entire record of underwater bay grass distribution and abundance survey data and reflect the findings published in scientific literature (Table IV-12). Also, the decision rules help ensure full consistency between the establishment of the shallow-water bay grass designated use depths (the depth at which the Chesapeake Bay water clarity criteria will be applied) and the new quantitative underwater bay grasses acreage restoration goal for Chesapeake Bay and its tidal tributaries.

The available data record included interpreted aerial photography from the 1930s to the early 1970s as well as the annual baywide aerial survey data from 1978-2000. From these photos and surveys, the acreage of underwater bay grasses within three depth intervals was calculated for every Chesapeake Bay Program segment: 0-0.5 meters, > 0.5-1 meter and > 1-2 meters (Appendix B, Table B-1). Thus, each Chesapeake Bay Program segment has three 'segment-depth intervals' (e.g., CB4MH 1-2 meter is a segment-depth interval).

The total surface area within each segment-depth interval minus any delineated underwater bay grass no-grow zones is an estimate of the area of potential underwater bay grass habitat in that segment-depth interval. Thus, there is an acreage of potential underwater bay grass habitat for each of the three segment-depth intervals in every Chesapeake Bay Program segment except for those segments that are entirely no-grow zones (Appendix C, Table C-1).

The decision rules described in Table IV-12 are based on the observed single best year of underwater bay grass coverage for each Chesapeake Bay Program segment (i.e., not the single best year by segment-depth) (Appendix B, Table B-2). Using each segment's single best year, the percentage of available habitat at each segment-depth interval that was occupied by underwater bay grasses in that single best year was calculated (Appendix B, Table B-3). That percentage is a measure of the relative importance of each segment-depth interval as bay grass habitat. Upon application of the decision rules (Table IV-12), a set of Chesapeake Bay Program segment-specific shallow-water designated use depths was generated (Table IV-13).

Rationale for the 20 Percent and 10 Percent Rules

In setting application depths, it was important to select a percentage of cover high enough to assure that underwater plants definitely occupied that habitat, but low enough that the resulting depths realistically represented true light availability attained during the available historical data record. Underwater bay grass beds in tidal waters of the Chesapeake Bay display a spatial heterogeneity that is characteristic of underwater grass beds elsewhere in the world (Lehmann et al.1997; Kuenen and Debrot 1995; Carpenter and Titus 1984). This heterogeneity exists both in micro

Table IV-11. Chesapeake Bay Program segmentation scheme segments.

Northern Chesapeake Bay	CB1TF
Upper Chesapeake Bay	CB2OH
Upper Central Chesapeake Bay	CB3MH
Middle Central Chesapeake Bay	CB4MH
Lower Central Chesapeake Bay	CB5MH
Western Lower Chesapeake Bay	CB6PH
Eastern Lower Chesapeake Bay	CB7PH
Mouth of the Chesapeake Bay	CB8PH
Bush River	BSHOH
Gunpowder River	GUNOH
Middle River	MIDOH
Back River	BACOH
Patapsco River	PATMH
Magothy River	MAGMH
Severn River	SEVMH
South River	SOUMH
Rhode River	RHDMH
West River	WSTMH
Upper Patuxent River	PAXTF
Western Branch Patuxent River	WBRTF
Middle Patuxent River	PAXOH
Lower Patuxent River	PAXMH
Upper Potomac River	POTTF
Anacostia River	ANATF
Piscataway Creek	PISTF
Mattawoman Creek	MATTF
Middle Potomac River	POTOH
Lower Potomac River	POTMH
Upper Rappahannock River	RPPTF
Middle Rappahannock River	RPPOH
Lower Rappahannock River	RPPMH
Corrotoman River	CRRMH
Piankatank River	PIAMH
Upper Mattaponi River	MPNTF
Lower Mattaponi River	MPNOH
Upper Pamunkey River	PMKTF
Lower Pamunkey River	PMKOH
Middle York River	YRKMH
Lower York River	YRKPH
Mobjack Bay	MOBPH
Upper James River	JMSTF
Appomattox River	APPTF
Middle James River	JMSOH
Chickahominy River	CHKOH
Lower James River	JMSMH
Mouth of the James River	JMSPH
Western Branch Elizabeth River	WBEMH
Southern Branch Elizabeth River	SBEMH
Eastern Branch Elizabeth River	EBEMH
Lafayette River	LAFMH
Mouth to mid-Elizabeth River	ELIPH
Lynnhaven River	LYNPH
Northeast River	NORTF
C&D Canal	C&DOH
Bohemia River	BOHOH
Elk River	ELKOH
Sassafras River	SASOH
Upper Chester River	CHSTF
Middle Chester River	CHSOH
Lower Chester River	CHSMH
Eastern Bay	EASMH
Upper Choptank River	CHOTF
Middle Choptank River	CHOOH
Lower Choptank River	CHOMH1
Mouth of the Choptank River	CHOMH2
Little Choptank River	LCHMH
Honga River	HNGMH
Fishing Bay	FSBMH
Upper Nanticoke River	NANTF
Middle Nanticoke River	NANOH
Lower Nanticoke River	NANMH
Wicomico River	WICMH
Manokin River	MANMH
Big Annemessex River	BIGMH
Upper Pocomoke River	POCTF
Middle Pocomoke River	POCOH
Lower Pocomoke River	POCMH
Tangier Sound	TANMH

Source: Chesapeake Bay Program 1999.

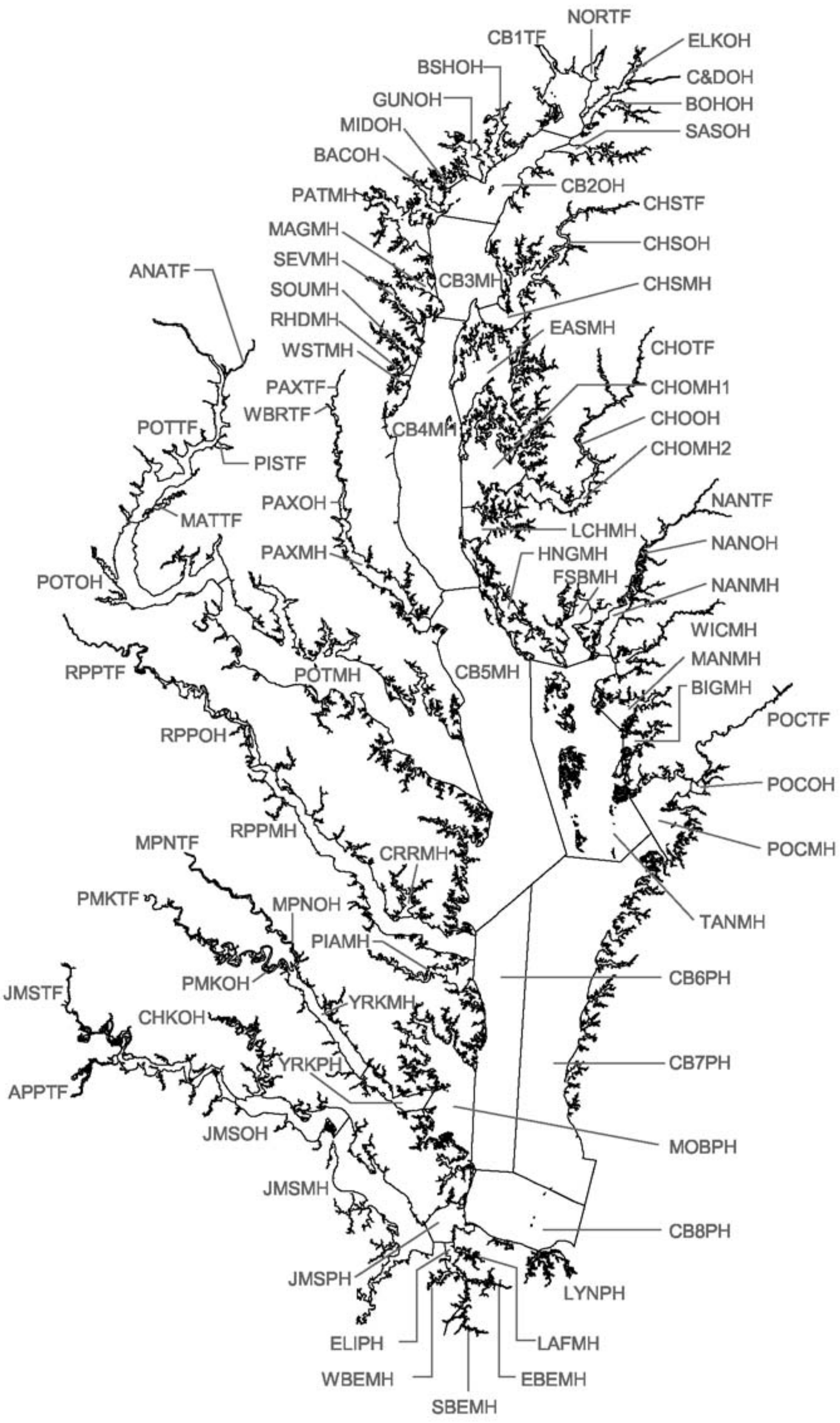


Figure IV-30. The geographical location of the 78 Chesapeake Bay Program segments.

Source: Chesapeake Bay Program 1999.

Table IV-12. Methodology used in determining the shallow-water bay grass designated use depths by Chesapeake Bay Program segment, which led to the establishment of the 185,000 Chesapeake Bay baywide underwater grasses restoration goal.

The baywide underwater bay grass goal acreage was established based on the single best year acreage out to a shallow-water bay grass designated use depth determined as follows:

1. Bathymetry data and aerial photographs were used to divide the mapped single best year underwater bay grasses acreage in each Chesapeake Bay Program segment into three depth zones: 0-0.5 meters, > 0.5-1 meters and >1-2 meters. The delineated underwater bay grass no-grow zones were then removed from consideration as shallow-water bay grass designated use habitat.
2. The aerial photographs were used to determine the depth to which the mapped underwater bay grass beds grew in each Chesapeake Bay Program segment with either a minimum abundance or minimum persistence. The underwater bay grass goal for a Chesapeake Bay Program segment is the portion of the single best year acreage mapped out to the higher depth in the determined depth range. The decision rules for this process were as follows:

    In all segments, the 0-0.5 meter depth interval was designated for shallow-water bay grass use. In addition, the shallow-water bay grass use was designated for deeper depths within a Chesapeake Bay Program segment if either:

    A) The single best year of underwater bay grasses distribution covered at least 20 percent of the potential habitat in a deeper depth interval; or,

    B) The single best year of underwater bay grass distribution covered at least 10 percent of the potential habitat in the segment-depth interval, and at least 3 of the 4 five-year periods of the more recent record (1978–2000) showed at least 10 percent underwater bay grasses coverage of potential habitat in the segment-depth interval.

3. The single best year underwater bay grasses distribution acreage of all Chesapeake Bay Program segments were clipped at the deeper depth of the segment-depth interval determined above. The resulting underwater bay grass acreage for each segment were added, resulting in the total baywide underwater bay grass acreage goal of 185,000 acres.

and macro scales, and as viewed by aerial photography results in a spatial distribution that is virtually never 100 percent coverage of available shallow-water habitat at any depth. This growth pattern was true historically as well. Manning (1957) estimated that lower Patuxent River underwater bay grass beds covered only about one-third of shoal waters. Photography from Maryland from 1938 and 1952 revealed an average percent cover of 35 percent (Naylor 2002) at depths of less than 1 meter. Virginia photographic analysis revealed up to 48 percent coverage in the York and Rappahannock rivers at the less than 1-meter depth (Moore et al. 2001). These findings were supported by similar findings from analysis of the more recent 1978–2000 Chesapeake Bay underwater bay grass aerial survey distribution data.

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Northern Chesapeake Bay	CB1TF	Historical			▲	2
Upper Chesapeake Bay	CB2OH	Historical	✪			0.5
Upper Central Chesapeake Bay	CB3MH	1978	▲			0.5
Middle Central Chesapeake Bay	CB4MH	Historical			▲	2
Lower Central Chesapeake Bay	CB5MH	Historical			▲	2
Western Lower Chesapeake Bay	CB6PH	Historical		▲		1
Eastern Lower Chesapeake Bay	CB7PH	Historical			▲	2
Mouth of the Chesapeake Bay	CB8PH	1996	✪			0.5
Bush River	BSHOH	Historical	✪			0.5
Gunpowder River	GUNOH	2000			▲	2
Middle River	MIDOH	Historical			▲	2
Back River	BACOH	*	✪			0.5
Patapsco River	PATMH	Historical		▲		1
Magothy River	MAGMH	Historical		▲		1
Severn River	SEVMH	1999		▲		1
South River	SOUMH	Historical		▲		1
Rhode River	RHDMH	Historical	✪			0.5
West River	WSTMH	Historical	▲			0.5
Upper Patuxent River	PAXTF	1996	▲			0.5
Western Branch (Patuxent River)	WBRTF	*	✪			0.5
Middle Patuxent River	PAXOH	2000	✪			0.5
Lower Patuxent River	PAXMH	Historical		▲		1
Upper Potomac River	POTTF	1991			✜	2
Anacostia River	ANATF	1991	✪			0.5
Piscataway Creek	PISTF	1987			▲	2
Mattawoman Creek	MATTF	2000		▲		1
Middle Potomac River	POTOH	1998			✜	2

continued

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Lower Potomac River	POTMH	Historical		▲		1
Upper Rappahannock River	RPPTF	2000	✪			0.5
Middle Rappahannock River	RPPOH	*	✪			0.5
Lower Rappahannock River	RPPMH	Historical		▲		1
Corrotoman River	CRRMH	Historical		▲		1
Piankatank River	PIAMH	Historical			▲	2
Upper Mattaponi River	MPNTF	1998	✪			0.5
Lower Mattaponi River	MPNOH	*	✪			0.5
Upper Pamunkey River	PMKTF	1998	✪			0.5
Lower Pamunkey River	PMKOH	*	✪			0.5
Middle York River	YRKMH	Historical	✪			0.5
Lower York River	YRKPH	Historical		▲		1
Mobjack Bay	MOBPH	Historical			▲	2
Upper James River	JMSTF	Historical	✪			0.5
Appomattox River	APPTF	Historical	▲			0.5
Middle James River	JMSOH	1998	✪			0.5
Chickahominy River	CHKOH	2000	✪			0.5
Lower James River	JMSMH	Historical	✪			0.5
Mouth of the James River	JMSPH	Historical		▲		1
Western Branch Elizabeth River	WBEMH	*	❖	❖	❖	*
Southern Branch Elizabeth River	SBEMH	*	❖	❖	❖	*
Eastern Branch Elizabeth River	EBEMH	*	❖	❖	❖	*
Lafayette River	LAFMH	*	❖	❖	❖	*
Mouth to mid-Elizabeth River	ELIPH	*	✪			0.5
Lynnhaven River	LYNPH	1986	✪			0.5
Northeast River	NORTF	Historical	✪			0.5
C&D Canal	C&DOH	1978	✪			0.5

continued

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Bohemia River	BOHOH	2000	✪			0.5
Elk River	ELKOH	2000			▲	2
Sassafras River	SASOH	2000		▲		1
Upper Chester River	CHSTF	*	✪			0.5
Middle Chester River	CHSOH	Historical	✪			0.5
Lower Chester River	CHSMH	Historical		▲		1
Eastern Bay	EASMH	Historical			▲	2
Upper Choptank River	CHOTF	*	❖	❖	❖	*
Middle Choptank River	CHOOH	Historical	✪			0.5
Lower Choptank River	CHOMH2	Historical		▲		1
Mouth of the Choptank River	CHOMH1	Historical			▲	2
Little Choptank River	LCHMH	Historical			▲	2
Honga River	HNGMH	Historical			▲	2
Fishing Bay	FSBMH	Historical	✪			0.5
Upper Nanticoke River	NANTF	*	✪			0.5
Middle Nanticoke River	NANOH	Historical	✪			0.5
Lower Nanticoke River	NANMH	Historical	✪			0.5
Wicomico River	WICMH	Historical	✪			0.5
Manokin River	MANMH	Historical			▲	2
Big Annemessex River	BIGMH	Historical			▲	2
Upper Pocomoke River	POCTF	*	❖	❖	❖	*
Middle Pocomoke River	POCOH	*	✪			0.5
Lower Pocomoke River	POCMH	Historical		▲		1
Tangier Sound	TANMH	Historical			▲	2

✪ Decision rules not met – default depth interval of 0-0.5 meters applies.
▲ Single best year percent of total potential habitat is 20 percent.
✜ Percent of total potential habitat is 10-19.9% and underwater bay grasses are persistent (1978–2000).
❖ Chesapeake Bay Program segment completely within the underwater bay grass no-grow zone.
*Denotes no data available or no underwater bay grasses mapped (1930s-2000).

Several possible reasons account for less-than-complete habitat occupation. These include small-scale sediment type differences, small-scale sediment movement patterns, sediment slope, fetch, uneven seed distribution and localized disturbance. In addition to these reasons for real variations in plant presence, only the most dense areas of underwater bay grasses are visible using high-altitude photography. Very sparse beds reveal no signature in the water and are never delineated through photo interpretation. Each year, Chesapeake Bay researchers and resource managers find dozens of underwater bay grass beds in places not identified in the annual aerial survey due to these limitations. Thus, reporting of percent coverage is generally lower than the total amount of habitat actually occupied by sparse plant beds, which further lowers the total percent coverage. Given the starting point of 1 percent, and the typical maximum of 35-48 percent from the historical photography, 20 percent was seen as a defensible midpoint figure reflective of sufficient coverage to define maximum depth of the underwater bay grasses growth (Moore 1999, 2001; Naylor 2002).

In order to provide an additional measure of the importance of a segment-depth interval as underwater bay grass habitat, the record of underwater bay grass aerial survey data from 1978–2000 (there is not a survey for every year between 1979-1983 and in 1988) was segmented into four five-year intervals (Appendix B, Table B-4). The persistence of underwater bay grasses in each segment-depth interval was then assessed by counting the number of five-year intervals in which at least 10 percent of potential habitat was occupied by underwater bay grasses (see Table IV-12).

UNDERWATER BAY GRASS RESTORATION GOAL-BASED BOUNDARIES

The *Chesapeake 2000* agreement committed to revising the existing underwater bay grass restoration goals and strategies:

> *. . . to reflect historic abundance, measured as acreage and density from the 1930s to present. The revised goals will include specific levels of water clarity which are to be met in 2010. Strategies to achieve these goals will address water clarity, water quality and bottom disturbance.*

The eligible segments and depths included in calculating the new underwater bay grass restoration goal were limited to segment-depth intervals designated for shallow-water bay grass use. The new restoration goal was derived from the total single best year acreage summed over all the segment depths that were designated for shallow-water bay grass use after considering a wide array of data and information (Figure IV-31).

Data Used to Establish the Restoration Goal

It was essential to use historical underwater bay grass data in determining the underwater bay grass acreage goal for the Chesapeake Bay. But using these data presented obvious limitations. They were originally collected for agricultural landuse mapping purposes and thus did not include all areas of tidal shallow-water habitats, which

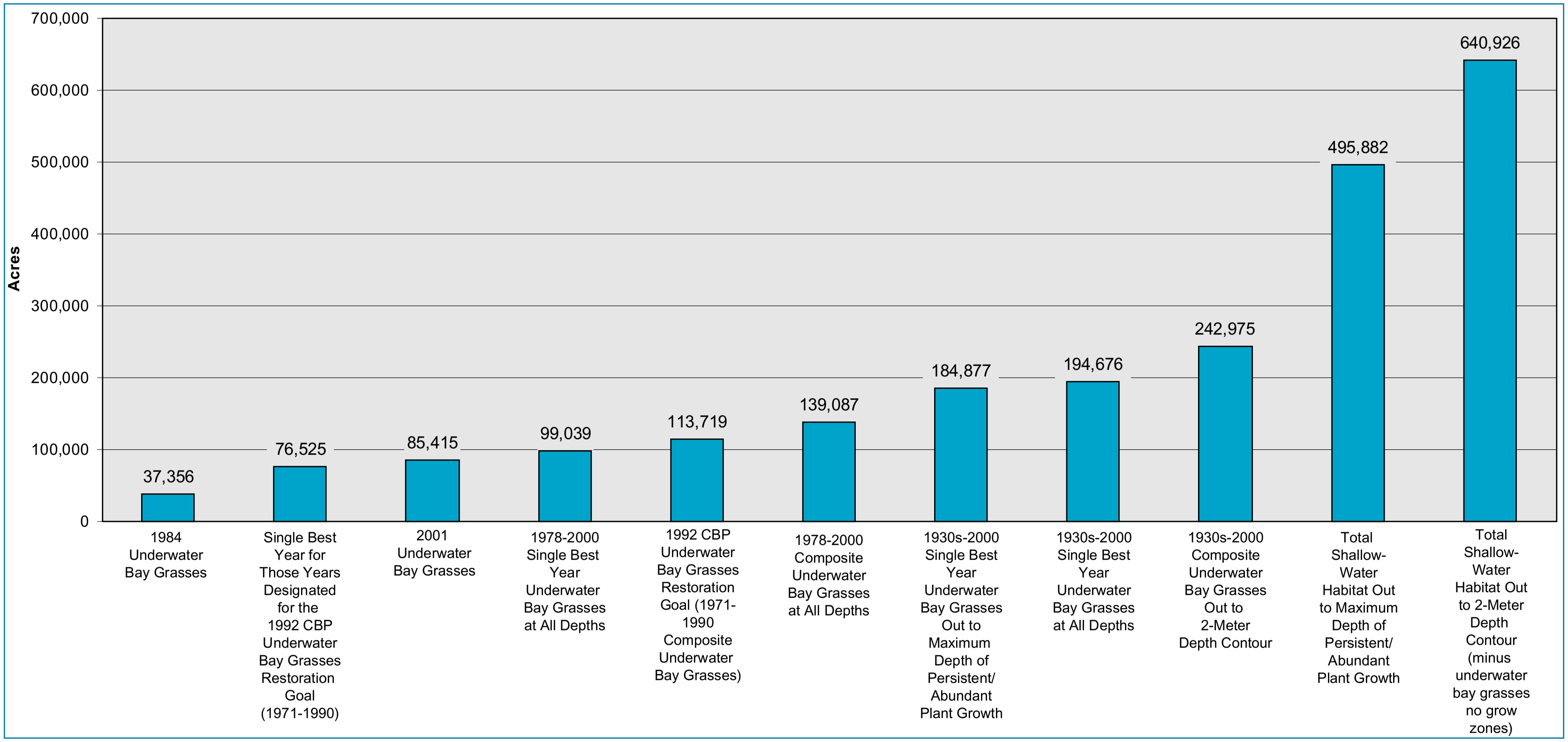


Figure IV-31. Array of different underwater bay grass and shallow-water habitat acreages considered during the process for setting the shallow-water designated use depth and establishing the new Chesapeake Bay underwater bay grass restoration goals.

Sources: Moore et al. 1999; Naylor 2002; Virginia Institute of Marine Science Chesapeake Bay SAV website http://www.vims.edu/bio/sav; Chesapeake Bay Program website http://www.chesapeakebay.net.

resulted in an underestimate of the mapped acreage. Historic data also were limited by the fact that pre-Hurricane Agnes (June 1972) underwater bay grass data exist only for a limited number of years in each Chesapeake Bay Program segment. Thus, using only historical data to determine a new goal would likely underestimate the potential for underwater bay grass recovery.

Rationale for Use of the Single Best Year

The single best year of underwater bay grass growth observed in each Chesapeake Bay Program segment from the entire available record of aerial photographs (1930s–2000) is the best available data on underwater bay grass occurrence over the long-term. Of the 62 Chesapeake Bay Program segments with mapped underwater bay grasses, 68 percent of the segment single best year acreages occurred in the 1930s to early 1970s time period; 3 percent occurred in 1978; 5 percent occurred between 1986 and 1991; and 24 percent occurred between 1996 and 2000 (see Table IV-13).

There were several obvious benefits in using the single best year approach to setting the new restoration goal. The single best year acreage is the most solid available data on underwater bay grass acreage over the multi-decade data record. Even in suitable water quality conditions, underwater bay grass beds often move around within a segment. By combining acreage over a number of years into a composite acreage it would be possible to overestimate the likely future abundance of underwater bay grasses in any single year.

Using the single best year as the basis for the new restoration goal ensures consistency with the method for determining the segment-specific shallow-water designated use depths and the resulting water clarity criteria application depths. The consistency between methods links the segment-specific water clarity application depths, shallow-water designated use boundaries and underwater bay grass restoration goals. This method is scientifically valid because when the acreage goals for segments in the same salinity range are totaled (see "Shallow-Water Habitat Area to Support Restoration," below), the percentage of available habitat covered by the restoration goal acreage is consistent with the average rate of habitat occupancy described in the scientific literature as reflecting healthy underwater bay grass growth.

The new underwater bay grass goal focuses the restoration effort on areas that demonstrated a minimal level of abundance or persistence in the past and which are likely to respond to water clarity improvements in the future. Focusing on the single best year versus a composite underwater bay grass coverage ensures that vegetated portions of potential underwater bay grass habitats are not over-accounted-for based on underwater bay grass beds that may have 'migrated' year-to-year over the past seven decades.

New Underwater Bay Grass Restoration Goal

Table IV-14 lists the Chesapeake Bay Program segment-specific single best year acreage within the shallow-water bay grasses designated use depths that, added together, make up the baywide 185,000 acre restoration goal.

Table IV-14. Chesapeake Bay underwater bay grass restoration goals by Chesapeake Bay Program segment.

Segment Name	Segment	Single Best Year	Acres
Northern Chesapeake Bay	CB1TF	Historical	12,908
Upper Chesapeake Bay	CB2OH	Historical	302
Upper Central Chesapeake Bay	CB3MH	1978	943
Middle Central Chesapeake Bay	CB4MH	Historical	2,511
Lower Central Chesapeake Bay	CB5MH	Historical	14,961
Western Lower Chesapeake Bay	CB6PH	Historical	980
Eastern Lower Chesapeake Bay	CB7PH	Historical	14,620
Mouth of the Chesapeake Bay	CB8PH	1996	6
Bush River	BSHOH	Historical	158
Gunpowder River	GUNOH	2000	2,254
Middle River	MIDOH	Historical	838
Back River	BACOH	*	0
Patapsco River	PATMH	Historical	298
Magothy River	MAGMH	Historical	545
Severn River	SEVMH	1999	329
South River	SOUMH	Historical	459
Rhode River	RHDMH	Historical	48
West River	WSTMH	Historical	214
Upper Patuxent River	PAXTF	1996	5
Western Branch (Patuxent River)	WBRTF	*	0
Middle Patuxent River	PAXOH	2000	68
Lower Patuxent River	PAXMH	Historical	1,325
Upper Potomac River	POTTF	1991	4,368
Anacostia River	ANATF	1991	6
Piscataway Creek	PISTF	1987	783
Mattawoman Creek	MATTF	2000	276
Middle Potomac River	POTOH	1998	3,721
Lower Potomac River	POTMH	Historical	10,173
Upper Rappahannock River	RPPTF	2000	20
Middle Rappahannock River	RPPOH	*	0
Lower Rappahannock River	RPPMH	Historical	5,380
Corrotoman River	CRRMH	Historical	516
Piankatank River	PIAMH	Historical	3,256
Upper Mattaponi River	MPNTF	1998	75
Lower Mattaponi River	MPNOH	*	0
Upper Pamunkey River	PMKTF	1998	155
Lower Pamunkey River	PMKOH	*	0
Middle York River	YRKMH	Historical	176
Lower York River	YRKPH	Historical	2,272
Mobjack Bay	MOBPH	Historical	15,096

continued

Table IV-14. Chesapeake Bay underwater bay grass restoration goals by Chesapeake Bay Program segment *(cont.)*.

Segment Name	**Segment**	**Single Best Year**	**Acres**
Upper James River	JMSTF	Historical	1,600
Appomattox River	APPTF	Historical	319
Middle James River	JMSOH	1998	7
Chickahominy River	CHKOH	2000	348
Lower James River	JMSMH	Historical	531
Mouth of the James River	JMSPH	Historical	604
Western Branch Elizabeth River	WBEMH	*	0
Southern Branch Elizabeth River	SBEMH	*	0
Eastern Branch Elizabeth River	EBEMH	*	0
Lafayette River	LAFMH	*	0
Mouth to mid-Elizabeth River	ELIPH	*	0
Lynnhaven River	LYNPH	1986	69
Northeast River	NORTF	Historical	88
C&D Canal	C&DOH	1978	0
Bohemia River	BOHOH	2000	97
Elk River	ELKOH	2000	1,648
Sassafras River	SASOH	2000	764
Upper Chester River	CHSTF	*	0
Middle Chester River	CHSOH	Historical	63
Lower Chester River	CHSMH	Historical	2,724
Eastern Bay	EASMH	Historical	6,108
Upper Choptank River	CHOTF	*	0
Middle Choptank River	CHOOH	Historical	63
Lower Choptank River	CHOMH2	Historical	1,499
Mouth of the Choptank River	CHOMH1	Historical	8,044
Little Choptank River	LCHMH	Historical	3,950
Honga River	HNGMH	Historical	7,686
Fishing Bay	FSBMH	Historical	193
Upper Nanticoke River	NANTF	*	0
Middle Nanticoke River	NANOH	Historical	3
Lower Nanticoke River	NANMH	Historical	3
Wicomico River	WICMH	Historical	3
Manokin River	MANMH	Historical	4,359
Big Annemessex River	BIGMH	Historical	2,014
Upper Pocomoke River	POCTF	*	0
Middle Pocomoke River	POCOH	*	0
Lower Pocomoke River	POCMH	Historical	4,092
Tangier Sound	TANMH	Historical	37,965
Total acres			**184,889**

*No underwater grasses recorded for any year within the available 1930s–2000 data record.

SHALLOW-WATER HABITAT AREA TO SUPPORT RESTORATION GOAL-BASED BOUNDARIES

As described previously, the restoration of underwater bay grasses within a segment requires that shallow-water habitat meet the Chesapeake Bay water clarity criteria over a greater acreage than the underwater bay grasses will actually cover. The ratio of underwater bay grass acreage to the required shallow-water habitat acreage varies based on the different species of underwater bay grasses that inhabit the Bay's four salinity regimes. Shallow-water habitat acreage ratios have been derived scientifically through evaluation of extensive underwater bay grasses distribution data within tidal fresh, low, medium and high salinity regimes (reflecting different levels of coverage by different underwater bay grass communities).

The Chesapeake Bay Program segment-specific restoration goal acreage and corresponding shallow-water designated use acreage (to the previously determined maximum depth of abundant and persistent underwater plant growth) listed in Table IV-15 were summed by major salinity regime–tidal fresh (0-0.5 ppt), oligohaline (> 0.5-5 ppt), mesohaline (> 5ppt-18 ppt) and polyhaline (>18 ppt).[13] The underwater bay grasses acreage to shallow-water habitat acreage ratios were then expressed as a percentage of the total shallow-water designated use habitat. Compared with a baywide value of 38 percent, the tidal-fresh (37 percent), mesohaline (39 percent) and polyhaline (41 percent) values were all very close to the baywide value as well as the other salinity regime-specific values (Table IV-16). These values are consistent with findings published in the scientific literature and the 35 to 48 percent range derived from evaluation of the 1930s through early 1970s historical data record by Naylor (2002) and Moore (1999, 2001). Influenced by the natural presence of the estuarine turbidity maximum, the value was 21 percent in oligohaline habitats.

CONFIRMING THAT THE REFINED DESIGNATED USES MEET EXISTING USES

The EPA Water Quality Standards regulations at 40 CFR 131.10(g) and (j) specify that states may remove a designated use that is not an existing use, or establish subcategories of a use, if they can demonstrate that attaining the designated use is not feasible. The current regulation at 40 CFR Part 131 identifies the factors that must be considered in making such a demonstration. As the regulation explains, existing uses, by definition, are attainable and must be protected by designated uses in water quality standards (40 CFR 131.10[g], 131.10[h][1] and 131.10[i]). Any

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[13] Note that all Chesapeake Bay Program segments have been assigned to one of the four salinity regimes based on an evaluation of almost two decades of salinity data. The segment-naming convention documents each individual segment's long-term averaged respective salinty regime: TF = tidal fresh, OH = oligohaline, MH = mesohaline, and PH = polyhaline.

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Northern Chesapeake Bay	CB1TF	7979	7773	12,908	20,907	61.7	2
Upper Chesapeake Bay	CB2OH	203	640	302	2405	12.5	0.5
Upper Central Chesapeake Bay	CB3MH	1	1,296	943	2,011	46.9	0.5
Middle Central Chesapeake Bay	CB4MH	112	176	2,511	10,630	23.6	2
Lower Central Chesapeake Bay	CB5MH	4,487	4,240	14,961	29,959	49.9	2
Western Lower Chesapeake Bay	CB6PH	715	1,208	980	3,939	24.9	1
Eastern Lower Chesapeake Bay	CB7PH	9,168	10,729	14,620	33,304	43.9	2
Mouth of the Chesapeake Bay	CB8PH	8	11	6	381	1.5	0.5
Bush River	BSHOH	3	187	158	1,136	13.9	0.5
Gunpowder River	GUNOH	*	2,281	2,254	7,358	30.6	2
Middle River	MIDOH	*	698	838	2,479	33.8	2
Back River	BACOH	*	0	0	850	0.0	0.5
Patapsco River	PATMH	*	114	298	1,802	16.6	1
Magothy River	MAGMH	*	427	545	1,378	39.6	1
Severn River	SEVMH	120	433	329	1347	24.4	1
South River	SOUMH	27	50	459	1,432	32.1	1
Rhode River	RHDMH	*	14	48	267	18.0	0.5
West River	WSTMH	*	106	214	542	39.5	0.5
Upper Patuxent River	PAXTF	205	44	5	24	22.2	0.5
Western Branch (Patuxent River)	WBRTF	*	0	0	0	0.0	0.5
Middle Patuxent River	PAXOH	104	80	68	1,072	6.3	0.5
Lower Patuxent River	PAXMH	22	108	1,325	5121	25.9	1
Upper Potomac River	POTTF	1,964	4,465	4,368	17,501	25.0	2
Anacostia River	ANATF	4	11	6	85	6.6	0.5

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Piscataway Creek	PISTF	*	783	783	914	85.7	2
Mattawoman Creek	MATTF	*	311	276	695	39.7	1
Middle Potomac River	POTOH	3,070	3,766	3,721	15,193	24.5	2
Lower Potomac River	POTMH	1739	2130	10173	26075	39.0	1
Upper Rappahannock River	RPPTF	66	30	20	2175	0.9	0.5
Middle Rappahannock River	RPPOH	*	0	0	1226	0	0.5
Lower Rappahannock River	RPPMH	478	841	5,380	19,793	27.2	1
Corrotoman River	CRRMH	389	419	516	1,819	28.4	1
Piankatank River	PIAMH	539	1,003	3,256	8,014	40.6	2
Upper Mattaponi River	MPNTF	*	84	75	800	9.4	0.5
Lower Mattaponi River	MPNOH	*	0	0	358	0.0	0.5
Upper Pamunkey River	PMKTF	140	184	155	1,860	8.4	0.5
Lower Pamunkey River	PMKOH	*	0	0	420	0.0	0.5
Middle York River	YRKMH	*	0	176	4,728	3.7	0.5
Lower York River	YRKPH	801	815	2272	4,949	45.9	1
Mobjack Bay	MOBPH	9,508	10,653	15096	33990	44.4	2
Upper James River	JMSTF	95	76	1,600	8,249	19.4	0.5
Appomattox River	APPTF	*	0	319	1,085	29.4	0.5
Middle James River	JMSOH	15	8	7	3179	0.2	0.5
Chickahominy River	CHKOH	268	422	348	3283	10.6	0.5
Lower James River	JMSMH	2	3	531	9,618	5.5	0.5
Mouth of the James River	JMSPH	232	231	604	1,616	37.4	1
Western Branch Elizabeth River	WBEMH	*	0	0	0	0.0	*
Southern Branch Elizabeth River	SBEMH	*	0	0	0	0.0	*

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Eastern Branch Elizabeth River	EBEMH	*	0	0	0	0.0	*
Lafayette River LAFMH	*	0	0	0	0.0	*	
Mouthof the Elizabeth River	ELIPH	*	0	0	0	0.0	*
Lynnhaven River	LYNPH	43	105	69	2476	2.8	0.5
Northeast River	NORTF	*	19	88	456	19.3	0.5
C&D Canal	C&DOH	7	5	0	99	0.2	0.5
Bohemia River	BOHOH	354	330	97	735	13.2	0.5
Elk River	ELKOH	2034	2006	1,648	5,024	32.8	2
Sassafras River	SASOH	1,169	1,116	764	2614	29.2	1
Upper Chester River	CHSTF	*	0	0	574	0	0.5
Middle Chester River	CHSOH	*	0	63	926	6.8	0.5
Lower Chester River	CHSMH	205	2,369	2,724	6,980	39	1
Eastern Bay	EASMH	2,886	4,610	6,108	20,805	29.4	2
Upper Choptank River	CHOTF	*	0	0	0	0.0	*
Middle Choptank River	CHOOH	*	0	63	591	10.7	0.5
Lower Choptank River	CHOMH2	148	193	1,499	3,770	39.8	1
Mouth of the Choptank River	CHOMH1	5,257	6,445	8,044	20,857	38.6	2
Little Choptank River	LCHMH	2,377	1,454	3,950	12,367	31.9	2
Honga River	HNGMH	4,945	4,656	7,686	16,456	46.7	2
Fishing Bay	FSBMH	6	59	193	2,467	7.8	0.5
Upper Nanticoke River	NANTF	*	0	0	0	0.0	*
Middle Nanticoke River	NANOH	*	0	3	1,141	0.3	0.5
Lower Nanticoke River	NANMH	*	0	3	1583	0.2	0.5
Wicomico River	WICMH	*	0	3	1,513	0.2	0.5

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Manokin River	MANMH	404	420	4,359	10,700	40.7	2
Big Annemessex River	BIGMH	721	546	2,014	5,065	39.8	2
Upper Pocomoke River	POCTF	*	0	0	0	0.0	*
Middle Pocomoke River	POCOH	*	0	0	289	0.0	0.5
Lower Pocomoke River	POCMH	1,528	1,831	4,092	9,936	41.2	1
Tangier Sound	TANMH	13,310	17,688	37,965	68,578	55.4	2
Totals		**77,854**	**100,701**	**184889**	**491,968**		

*No underwater bay grasses mapped or aerial photography collected due to 9/11/01 flight path restrictions.

Table IV-16. Percent of shallow-water designated use habitat covered by single best year underwater bay grass acreage by salinity regime.

	Tidal-Fresh	Oligohaline	Mesohaline	Polyhaline
Median	37.2	20.5	39.2	41.3
Minimum	0	0	0.2	1.5
Maximum	85.7	33.8	54.3	45.9
No. of Segments	14	20	29	7

change in designated uses must show that the existing uses are still being protected. As the EPA 1983 Water Quality Standards Handbook describes, an existing use can be defined as fishing, swimming or other uses that have actually occurred since November 28, 1975; or the water quality that is suitable to allow the use to be attained—unless there are physical factors, such as substrate or flow, that prevent the use from being attained (U.S. EPA 1983). Section 131.12(a)(1) in turn requires state anti-degradation policies to protect existing water quality. This paragraph applies a minimum level of protection to all waters. In setting the five subcategories of current tidal-water designated uses, explicit steps were taken in developing the refined uses and their boundaries to ensure that existing aquatic life uses would continue to be protected.

MIGRATORY SPAWNING AND NURSERY EXISTING USE

The migratory fish spawning and nursery designated use will be protected by a set of Chesapeake Bay-specific dissolved oxygen criteria that are more protective—6 mg/l 7-day mean and 5 mg/l instantaneous minimum–than current state water quality standards that apply to these same habitats from February 1 through May 31 (U.S. EPA 2003). Existing uses within the migratory fish spawning and nursery habitats will continue to be protected.

SHALLOW-WATER EXISTING USE

In delineating the shallow-water use, the single best year of underwater bay grass distribution mapped since the 1930s was used to define a shallow-water designated use depth, underwater bay grass restoration goal and a corresponding shallow-water habitat acreage to support achievement of the restoration goal for each respective Chesapeake Bay Program segment. Most of the segment-specific restoration goal acreage is higher than the established existing use underwater bay grass acreage derived from the single best year of the 1978-2001 data record out to the maximum depth of abundant/persistent underwater plant growth (see Table IV-15). In those cases where the existing use acreage is higher than the restoration goal, the existing use acreage will drive the shallow-water designated use boundary. As most of the single best years were based on historical underwater bay grass distributions (1930s through the early 1970s), the shallow-water bay grass uses existing since 1975 will continue to be protected.

OPEN-WATER EXISTING USE

The application of the open-water fish and shellfish designated use dissolved oxygen criteria will provide an equal level of protection to the same tidal waters as current state water quality standards. The combined set of 5 mg/l 30-day mean, 4 mg/l 7-day mean, and 3 mg/l instantaneous minimum have been documented to protect all life stages of open-water habitat species in the Chesapeake Bay and its tidal waters (U.S. EPA 2003). Existing uses within the open-water habitats will continue to be protected.

DEEP-WATER AND DEEP-CHANNEL EXISTING USES

The application of the deep-water seasonal fish and shellfish designated use and the deep-channel seasonal refuge designated use and their respective oxygen criteria will result in improvements to existing water quality conditions that currently do not attain the applicable criteria (see Chapter V). Given that trends in dissolved oxygen conditions have been generally degrading since the early 1970s (see Chapter III; Hagy 2002), improvements to these conditions will ensure that existing uses within the deep-water and deep-channel habitats will continue to be protected.

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chapter iv

Refined Designated Uses for the Chesapeake Bay and Tidal Tributaries

BACKGROUND

RENEWED COMMITMENT TO RESTORE CHESAPEAKE BAY WATER QUALITY

The *Chesapeake 2000* agreement and the subsequent six-state, District of Columbia and EPA memoranda of understanding challenged the Bay watershed jurisdictions to, “by 2010, correct the nutrient- and sediment-related problems in the Chesapeake Bay and its tidal tributaries sufficiently to remove the Bay and the tidal portions of its tributaries from the list of impaired waters under the Clean Water Act.” (Chesapeake Executive Council 2000; Chesapeake Bay Watershed Partners 2001.)

These agreements included commitments to “define the water quality conditions necessary to protect aquatic living resources” and to have the jurisdictions with tidal waters “use their best efforts to adopt new or revised water quality standards consistent with the defined water quality conditions.” Against this backdrop of a renewed commitment to restore Bay water quality (in part through the adoption of a consistent set of Chesapeake Bay water quality criteria as state standards), the Chesapeake Bay watershed partners recognized that the underlying tidal-water designated uses must be refined to better reflect desired Bay water quality conditions.

CURRENT STATE TIDAL-WATER DESIGNATED USES

Virginia, Maryland, Delaware and the District of Columbia have identified parts of the Chesapeake Bay and its tidal tributaries as ‘state waters.’ The current designated uses for these state waters are for the protection of aquatic life (Table IV-1; figures IV-1 through IV-4). The accompanying current criteria addressing nutrient and sediment enrichment impairments are limited to different dissolved oxygen concentrations, which apply separately to each jurisdiction’s tidal waters.

Table IV-1. Summary of current designated uses for states' Chesapeake Bay and tidal tributary waters.

State	Current Designated Use for Chesapeake Bay and Tidal Tributary Waters
Maryland	• Use II (shellfish harvesting waters)—Chesapeake Bay proper • Use I (water contact recreation, protection of aquatic life)—All surface waters
Virginia	• Class II (estuarine waters) for tidal water—Coastal zone to fall line—Primary and secondary contact recreation, fish and shellfish consumption, aquatic life and wildlife "All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish."
Delaware	• Broad Creek, Nanticoke River—Industrial water supply, primary contact recreation, secondary contact recreation, fish and aquatic life and wildlife, agriculture water supply with additional classification as "waters of exceptional recreational and ecological significance" (ERES waters).
District of Columbia	• Potomac River Class A (primary contact recreation), B (primary contact recreation and aesthetics), C (protection and propagation of fish, shellfish, and wildlife), D (consumption of fish and shellfish) and E (navigation).

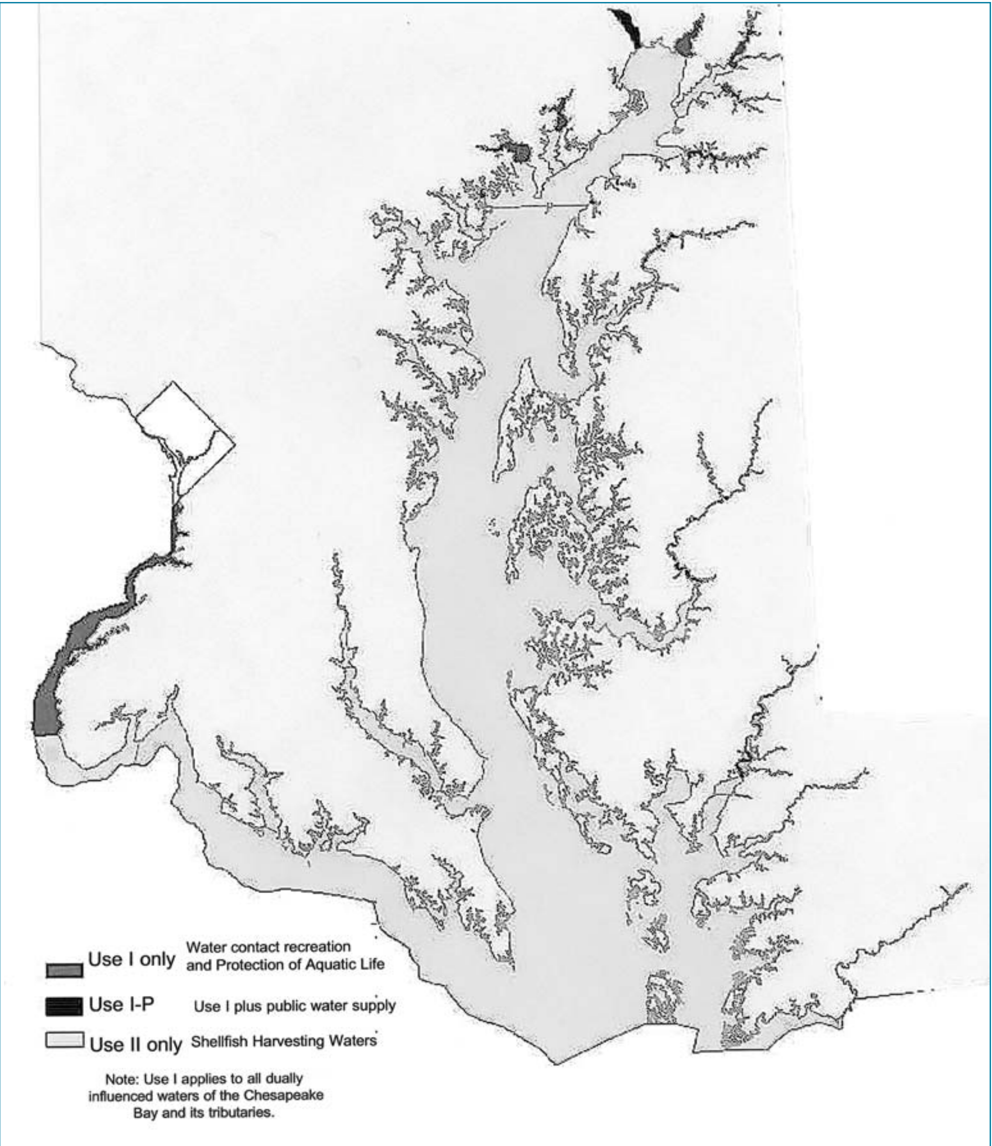
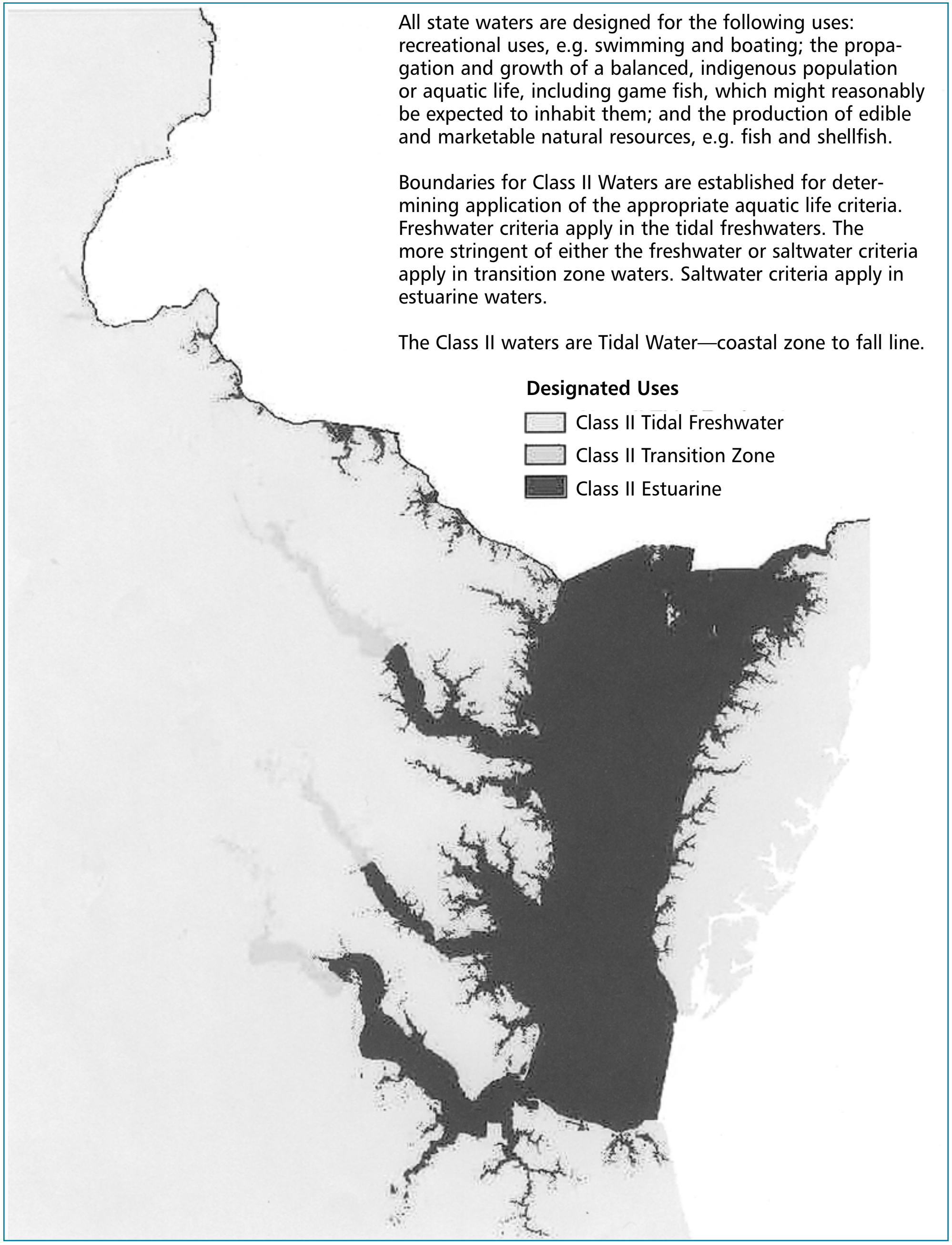


Figure IV-1. Current designated uses for Chesapeake Bay and tidal tributary waters located in Maryland.

Source: Code of Maryland Regulations 26.08.02 for water quality dated November 1, 1993.



All state waters are designed for the following uses: recreational uses, e.g. swimming and boating; the propagation and growth of a balanced, indigenous population or aquatic life, including game fish, which might reasonably be expected to inhabit them; and the production of edible and marketable natural resources, e.g. fish and shellfish.

Boundaries for Class II Waters are established for determining application of the appropriate aquatic life criteria. Freshwater criteria apply in the tidal freshwaters. The more stringent of either the freshwater or saltwater criteria apply in transition zone waters. Saltwater criteria apply in estuarine waters.

The Class II waters are Tidal Water—coastal zone to fall line.

Figure IV-2. Current designated uses for Chesapeake Bay and tidal tributary waters located in Virginia.

Source: Virginia State Water Control Board Regulation 9 VAC 25-260-5-et. seq. Water Quality Standards dated December 10, 1997.

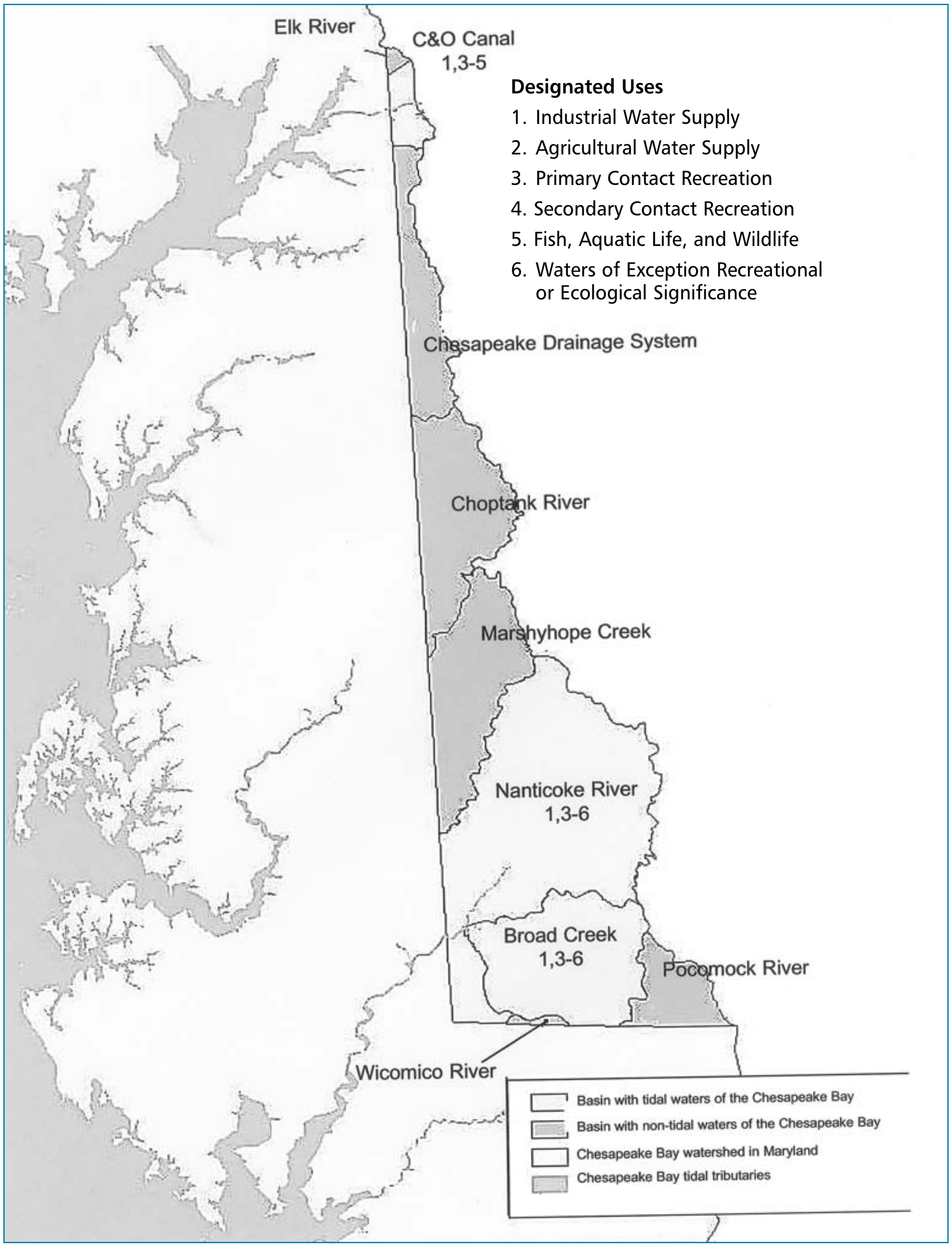


Figure IV-3. Current designated uses for Chesapeake Bay tidal tributary waters located in Delaware.

Source: State of Delaware Water Quality Regulations.

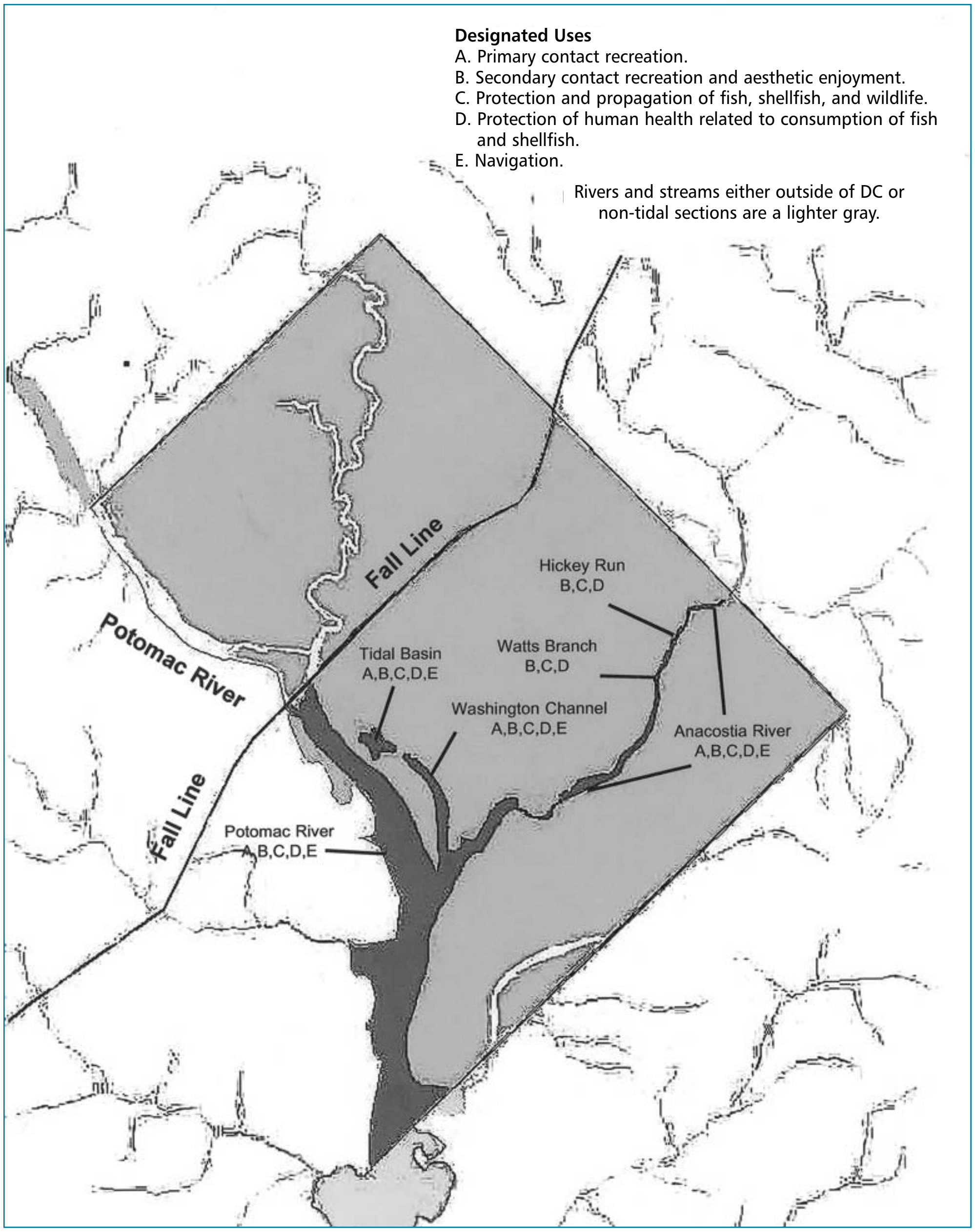


Figure IV-4. Current designated uses for Chesapeake Bay tidal tributary waters located in the District of Columbia.

Source: District of Columbia Department of Consumer and Regulatory Affairs Notice of Final Rulemaking.

REFINING TIDAL-WATER DESIGNATED USES

The Chesapeake Bay Program watershed partners determined that the underlying tidal-water designated uses must be refined to better reflect the desired and attainable Chesapeake Bay water quality conditions called for in the *Chesapeake 2000* agreement. In refining the current tidal-water designated uses, the six Chesapeake Bay watershed states and the District of Columbia took into account five principal considerations:

- Habitats used in common by sets of species and during particular life stages should be delineated as separate designated uses;
- Natural variations in water quality should be accounted for by the designated uses;
- Seasonal uses of different habitats should be factored into the designated uses;
- The Chesapeake Bay criteria for dissolved oxygen, water clarity and chlorophyll *a* should be tailored to support each designated use; and
- The refined designated uses applied to the Chesapeake Bay and its tidal tributary waters will support the federal Clean Water Act goals and state goals for uses existing in these water since 1975.

The Chesapeake Bay watershed partners are proposing five *refined subcategories* of the current broad aquatic life designated uses contained in the existing state water quality standards of the four jurisdictions bordering directly on Chesapeake Bay and its tidal tributaries. Figure IV-5 illustrates the conceptual framework of the refined tidal-water designated uses; Table IV-2 provides general descriptions of the five designated uses and the aquatic communities they were established to protect.[9] Four of the refined designated uses were derived largely to address seasonally distinct habitats and living resource communities with widely varying dissolved oxygen requirements:

- Migratory fish spawning and nursery;
- Open-water fish and shellfish;
- Deep-water seasonal fish and shellfish; and
- Deep-channel seasonal refuge.

The fifth refined designated use, the shallow-water bay grass designated use, occurs seasonally in conjunction with that part of the year-round open-water use which borders the land along the tidal portions of the Chesapeake Bay and its tributaries (Figure IV-5).

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[9] Note that for brevity, these refined designated uses may be referred to as migratory spawning and nursery, shallow-water, open-water, deep-water and deep-channel.

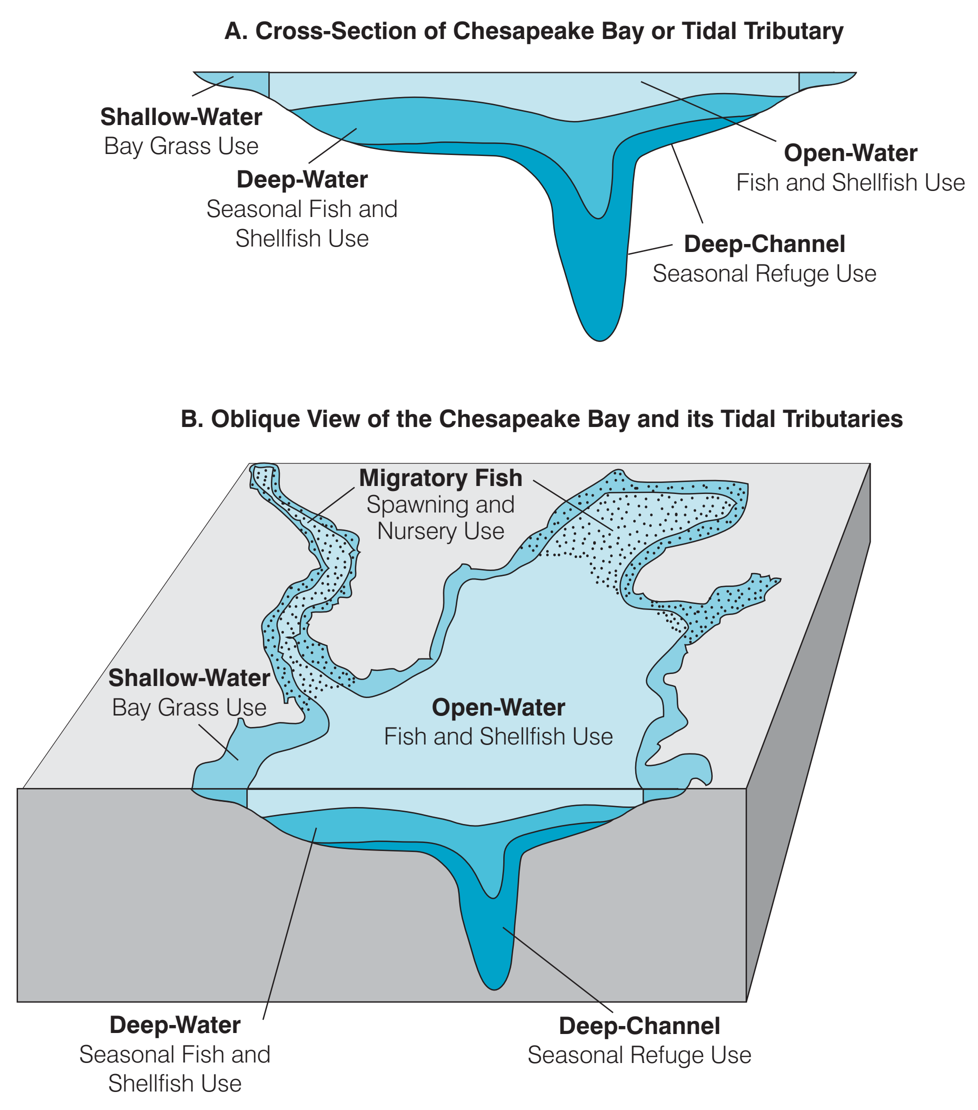

Figure IV-5. Conceptual illustration of the five Chesapeake Bay tidal-water designated use zones.

LIVING RESOURCE-BASED REFINED DESIGNATED USES AND PROTECTIVE CRITERIA

The five refined designated uses were derived to reflect the habitats of an array of recreationally, commercially and ecologically important species. The supporting prey communities were given full consideration along with the ‘target species’ in defining the designated uses.

Two extensive syntheses of habitat requirements for important target species and communities in the Chesapeake Bay and its tidal tributaries formed the basis from which these refined designated uses were conceived and developed (Chesapeake Bay

Table IV-2. General descriptions of the five proposed Chesapeake Bay tidal-water designated uses.

Migratory Fish Spawning and Nursery Designated Use: Aims to protect migratory finfish during the late winter/spring spawning and nursery season in tidal freshwater to low-salinity habitats. This habitat zone is primarily found in the upper reaches of many Bay tidal rivers and creeks and the upper mainstem Chesapeake Bay and will benefit several species, including striped bass, perch, shad, herring and sturgeon.

Shallow-Water Designated Use: Designed to protect underwater bay grasses and the many fish and crab species that depend on the shallow-water habitat provided by underwater bay grass beds.

Open-Water Fish and Shellfish Designated Use: Aims to improve water quality in the surface water habitats within tidal creeks, rivers, embayments and the mainstem Chesapeake Bay year-round. This use protects diverse populations of sport fish including striped bass, bluefish, mackerel and sea trout, bait fish such as menhaden and silversides, as well as the listed shortnose sturgeon.

Deep-Water Seasonal Fish and Shellfish Designated Use: Aims to protect living resources inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months. This use protects many bottom-feeding fish, crabs and oysters, as well as other important species, including the bay anchovy.

Deep-Channel Seasonal Refuge Designated Use: Designed to protect bottom sediment-dwelling worms and small clams that act as food for bottom-feeding fish and crabs in the very deep channel in summer. The deep-channel designated use recognizes that low dissolved oxygen conditions prevail in the deepest portions of this habitat zone and will naturally have very low to no oxygen during the summer.

Living Resource Task Force 1987; Funderburk et al. 1991). Only when coupled with analyses of the extensive Chesapeake Bay Monitoring Program's water quality, biological and living resource databases, now spanning 19 years, could the refined tidal-water designated uses described below be documented and delineated across all tidal-water habitats without constraints by jurisdictional borders.

The five tidal-water designated uses, in turn, provided the context for deriving dissolved oxygen, water clarity and chlorophyll *a* water quality criteria for the Chesapeake Bay and its tidal tributaries. These criteria, derived to protect each of the five refined designated uses, were based on effects data from a wide array of biological communities to capture the range of sensitivity of the thousands of aquatic species inhabiting the Chesapeake Bay and tidal tributary estuarine habitats (U.S. EPA 2003). Table IV-3 shows the proposed refined designated uses by Chesapeake Bay Program segment.

Table IV-3. Recommended tidal-water designated uses by Chesapeake Bay Program segment.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Migratory Spawning and Nursery (Feb. 1– May 31)	Open-Water (Year-Round)	Deep-Water (June 1– Sept. 30)	Deep-Channel (June 1– Sept. 30)	Shallow-Water (April 1– Oct. 30)
Northern Chesapeake Bay	CB1TF	x	x			x
Upper Chesapeake Bay	CB2OH	x	x			x
Upper Central Chesapeake Bay	CB3MH	x	x	x	x	x
Middle Central Chesapeake Bay	CB4MH	x	x	x	x	
Lower Central Chesapeake Bay	CB5MH		x	x	x	x
Western Lower Chesapeake Bay	CB6PH		x	x		x
Eastern Lower Chesapeake Bay	CB7PH		x	x		x
Mouth of the Chesapeake Bay	CB8PH		x			x
Bush River	BSHOH	x	x			x
Gunpowder River	GUNOH	x	x			x
Middle River	MIDOH	x	x			x
Back River	BACOH	x	x			x
Patapsco River	PATMH	x	x	x		x
Magothy River	MAGMH	x	x			x
Severn River	SEVMH	x	x			x
South River	SOUMH	x	x			x
Rhode River	RHDMH	x	x			x
West River	WSTMH	x	x			x
Upper Patuxent River	PAXTF	x	x			x
Western Branch (Patuxent River)	WBRTF	x	x			x
Middle Patuxent River	PAXOH	x	x			x
Lower Patuxent River	PAXMH	x	x	x		x
Upper Potomac River	POTTF	x	x			x
Anacostia River	ANATF	x	x			x
Piscataway Creek	PISTF	x	x			x
Mattawoman Creek	MATTF	x	x			x
Middle Potomac River	POTOH	x	x			x
Lower Potomac River	POTMH	x	x	x	x	x
Upper Rappahannock River	RPPTF	x	x			x
Middle Rappahannock River	RPPOH	x	x			x
Lower Rappahannock River	RPPMH	x	x	x	x	x
Corrotoman River	CRRMH	x	x			x
Piankatank River	PIAMH	x	x			x
Upper Mattaponi River	MPNTF	x	x			x
Lower Mattaponi River	MPNOH	x	x			x
Upper Pamunkey River	PMKTF	x	x			x
Lower Pamunkey River	PMKOH	x	x			x
Middle York River	YRKMH	x	x			x
Lower York River	YRKPH		x	x		x

continued

Table IV-3. Recommended tidal-water designated uses by Chesapeake Bay Program segment *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Migratory Spawning and Nursery (Feb. 1– May 31)	Open-Water (Year-Round)	Deep-Water (June 1– Sept. 30)	Deep-Channel (June 1– Sept. 30)	Shallow-Water (April 1– Oct. 30)
Mobjack Bay	MOBPH		x	x		x
Upper James River	JMSTF	x	x			x
Appomattox River	APPTF	x	x			x
Middle James River	JMSOH	x	x			x
Chickahominy River	CHKOH	x	x			x
Lower James River	JMSMH	x	x			x
Mouth of the James River	JMSPH		x			x
Western Branch Elizabeth River	WBEMH		x			
Southern Branch Elizabeth River	SBEMH		x			
Eastern Branch Elizabeth River	EBEMH		x			
Mouth to mid-Elizabeth River	ELIMH		x			
Lafayette River	LAFMH		x			
Mouth of the Elizabeth River	ELIPH		x	x	x	
Lynnhaven River	LYNPH		x			x
Northeast River	NORTF	x	x			x
C&D Canal	C&DOH	x	x			x
Bohemia River	BOHOH	x	x			x
Elk River	ELKOH	x	x			x
Sassafras River	SASOH	x	x			x
Upper Chester River	CHSTF	x	x			x
Middle Chester River	CHSOH	x	x			x
Lower Chester River	CHSMH	x	x	x	x	x
Eastern Bay	EASMH		x	x	x	x
Upper Choptank River	CHOTF	x	x			
Middle Choptank River	CHOOH	x	x			x
Lower Choptank River	CHOMH2	x	x			x
Mouth of the Choptank River	CHOMH1	x	x			x
Little Choptank River	LCHMH		x			x
Honga River	HNGMH		x			x
Fishing Bay	FSBMH	x	x			x
Upper Nanticoke River	NANTF	x	x			x
Middle Nanticoke River	NANOH	x	x			x
Lower Nanticoke River	NANMH	x	x			x
Wicomico River	WICMH	x	x			x
Manokin River	MANMH	x	x			x
Big Annemessex River	BIGMH	x	x			x
Upper Pocomoke River	POCTF	x	x			
Middle Pocomoke River	POCOH	x	x			x
Lower Pocomoke River	POCMH	x	x			x
Tangier Sound	TANMH		x			x

CHESAPEAKE BAY TIDAL-WATER DESIGNATED USES

The migratory fish spawning and nursery designated use is described first, given its unique seasonal role in protecting the spawning and nursery grounds of Chesapeake Bay and East Coast anadromous fish species. The shallow-water bay grass designated use is then described, as it protects the vegetated shallow-water habitats that are so critical to many individual estuarine species and living resource communities. Next, the open-water, deep-water and deep-channel designated uses are described as a series of year-round and seasonal subcategory designated uses formed around unique habitats defined largely by natural conditions (e.g., stratification of the water column, water circulation patterns) and physical barriers (Bay and tidal-water bottom bathymetry) in the tidal waters.

The watershed states with tidally influenced Chesapeake Bay waters (Maryland, Virginia and Delaware) and the District of Columbia ultimately are responsible for defining and adopting the designated uses into their state water quality standards. These uses will be adopted as subcategories of current state tidal-water designated uses, which are designed to protect aquatic life. The formal process for refining designated uses will meet the requirements of the Clean Water Act and any applicable jurisdiction-specific environmental laws or regulations.

The adopted designated uses will protect existing aquatic and human uses of the tidal waters that have been present since 1975. These designations go beyond minimum requirements (131.10[d] and [h][2]) and satisfy all requirements for meeting Clean Water Act goals (131.10 [a]), downstream waters maintenance and protection (131.10[b]) and for subcategorization as allowed by 131.10(g). The specific use definitions and the spatial application of the final designated uses will undergo public review through the four jurisdictions' respective regulatory adoption processes prior to EPA approval of the states' water quality standards.

MIGRATORY FISH SPAWNING AND NURSERY DESIGNATED USE

Waters with this designated use shall support the survival, growth and propagation of balanced indigenous populations of ecologically, recreationally and commercially important anadromous, semi-anadromous and tidal freshwater resident fish species inhabiting spawning and nursery grounds from February 1 through May 31 (Table IV-4).

Designated Use Rationale

Based on a commitment within the *1987 Chesapeake Bay Agreement* (Chesapeake Executive Council 1987), a list of target anadromous and semi-anadromous species was identified, including striped bass, American shad, hickory shad, alewife, blueback herring, white perch and yellow perch, based on their commercial, recreational and ecological value and "the threat to sustained production due to population

Table IV-4. Migratory fish spawning and nursery designated use summary.

Applicable Criteria:	*Dissolved Oxygen:* 6.0 mg/l 7-day mean (only tidal habitats with 0–0.5 ppt salinity) 5.0 mg/l instantaneous minimum
Application:	February 1 through May 31
Designated Use:	This designated use supports the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important anadromous, semi-anadromous and tidal freshwater resident fish species inhabiting spawning and nursery grounds.
Designated Use Boundary:	The boundaries of this use extend from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats. The use extends horizontally from the shoreline of the body of water to the adjacent shoreline, and extends down through the water column to the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

decline or serious habitat degradation" (Chesapeake Bay Living Resources Task Force 1987). These species form a representative subset of species comprising a "balanced, indigenous population." Other ecologically important anadromous and semi-anadromous fish species also will be protected under this designated use.

Chesapeake Bay tidal waters support spawning and nursery areas that are important not only to Bay fishery populations, but also to populations that inhabit the entire East Coast, such as striped bass. The eggs, larvae and early juveniles of anadromous and semi-anadromous species often have more sensitive habitat quality requirements than other species and life stages (Funderburk et al. 1991; Jordan et al. 1992). These same habitats are critical spawning and nursery grounds for tidal freshwater resident fish species from February 1 to May 31 (U.S. EPA 2003). Thus, the combined migratory and tidal freshwater resident fish spawning and nursery habitats were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries.

Designated Use Boundary Delineation

The boundaries of the migratory fish spawning and nursery designated use were delineated from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats (Figure IV-6).

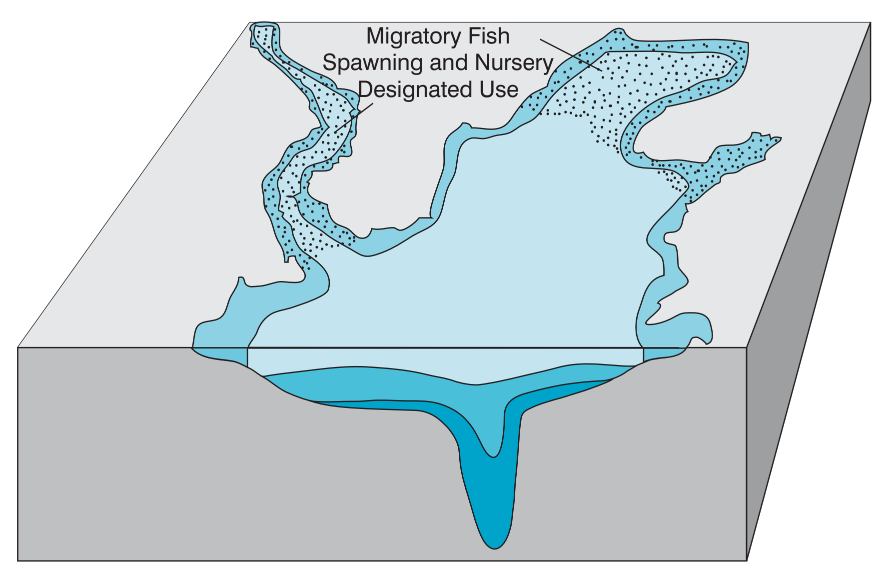

Figure IV-6. Illustration of the boundaries of the migratory fish spawning and nursery designated use.

Critical Support Communities—Food and Shelter

In this designated use, spawning adults and the resulting larvae and early juvenile fish depend on phytoplankton, zooplankton, bottom-dwelling worms and clams and forage fish as prey (Funderburk et al. 1991). The presence of underwater bay grasses in the shallows of the designated use habitat provides essential shelter for young juveniles as well as many prey species.

Seasonal Use Application

The migratory fish spawning and nursery designated use applies from February 1 through May 31. The defined season for applying this use is based on a composite of the full range of spawning and nursery periods of all the target anadromous and semi-anadromous species.

Striped bass and juveniles of other migratory spawners are passively dispersed as eggs and larvae and move farther downstream as they grow. Most juveniles do not leave the boundaries of their respective spawning and nursery areas. Adult yellow perch migrate from downstream to their spawning areas in the lower-salinity upper reaches of the tidal tributaries from mid-February through March (Richkus and Stroup 1987; Tsai and Gibson 1971). By early June, young-of-the-year juvenile striped bass begin to move shoreward, spending the summer and early fall in shoal waters less than six feet deep (Setzler-Hamilton et al. 1981). As juveniles grow, they move progressively downriver (Boreman and Klauda 1988; Dey 1981; Setzler-Hamilton et al. 1981). The February 1 beginning date reflects the initiation of the yellow perch spawning season; the May 31 end date reflects when the eggs and larvae have finished their transition to the juvenile life stage for all the target anadromous and semi-anadromous species.

Applicable Chesapeake Bay Water Quality Criteria[10]

The migratory fish spawning and nursery designated use is seasonally defined and occurs in conjunction with the year-round open-water designated uses and the seasonal shallow-water designated uses (see Figure IV-5). The migratory fish spawning and nursery designated use provides for the protection of the early life stages of anadromous, semi-anadromous and resident tidal-fresh species through the application of dissolved oxygen criteria derived for that purpose (U.S. EPA 2003). From February 1 through May 31, the migratory fish spawning and nursery dissolved oxygen criteria ensure protection of the egg, larval and early juvenile life stages (Table IV-4). Free-flowing streams and rivers, where several of the target species (e.g., shad, river herring) migrate for spawning, are protected through other existing state water quality standards.

The open-water fish and shellfish designated use dissolved oxygen criteria were derived to be protective of juvenile and adult life stages of anadromous and semi-anadromous species after May 31 (see Table IV-6; U.S. EPA 2003). The overlapping nature of these discrete designated uses will thus ensure that water quality conditions protective of different species' life stages are present in those designated use habitats. See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the individual dissolved oxygen criteria and criteria implementation procedures.

SHALLOW-WATER BAY GRASS DESIGNATED USE

Waters with this designated use support the survival, growth and propagation of rooted, underwater bay grasses necessary for the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats (Table IV-5).

Designated Use Rationale

The shallow-water bay grass designated use protects a wide variety of species, such as largemouth bass and pickerel, which inhabit vegetated tidal-fresh and low-salinity habitats; juvenile speckled sea trout in vegetated higher salinity areas; and blue crabs that inhabit vegetated shallow-water habitats covering the full range of salinities encountered in the Chesapeake Bay and its tidal tributaries. Underwater bay grasses,

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[10] Maryland, Virginia, Delaware and the District of Columbia currently have water quality standards in place that address pH conditions within the migratory fish spawning and nursery habitats.

Table IV-5. Shallow-water bay grass designated use summary.

Applicable Criteria:	*Water Clarity:* 13 percent ambient light through water (tidal habitats with 0–5 ppt salinity) 22 percent ambient light through water (tidal habitats with greater than 5 ppt salinity)
Application:	April 1 through October 31 for tidal-fresh, oligohaline and mesohaline habitats (0–18 ppt salinity); March 1 through May 31 and September 1 through November 30 for polyhaline habitats (>18 ppt salinity)
Designated Use:	Waters with this designated use support the survival, growth and propagation of rooted underwater bay grasses necessary for the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats.
Designated Use Boundary:	Tidally influenced waters from the intertidal zone out to a Chesapeake Bay Program segment-specific depth contour that varies from 0.5 to 2 meters.

Source for the Applicable Criteria: U.S. EPA 2003.

the critical community that the designated use protects, provide the shelter and food that make shallow-water habitats so unique and integral to the productivity of the Chesapeake Bay ecosystem. Many Chesapeake Bay species depend on vegetated shallow-water habitats at some point during their life cycle (Funderburk et al. 1991). Given the unique nature of this habitat and its critical importance to the Chesapeake Bay ecosystem, shallow waters were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries.

The shallow-water bay grass designated use is intended specifically to delineate the habitats where the water clarity criteria would apply. The open-water fish and shellfish designated use and the accompanying dissolved oxygen criteria will fully protect the biological communities inhabiting shallow-water habitats. The open-water designated use extends into the intertidal zone and protects shallow-water organisms beyond underwater bay grasses. The seasonal shallow-water bay grass designated use, similar to the migratory fish spawning and nursery use, actually occurs in conjunction with the year-round open-water designated use (see Figure IV-5) and provides specific protection for underwater bay grasses through the application of water clarity criteria.

Designated Use Boundary Delineation

The shallow-water bay grass designated use covers tidally influenced waters, from the intertidal zone out to a Chesapeake Bay Program segment-specific depth contour

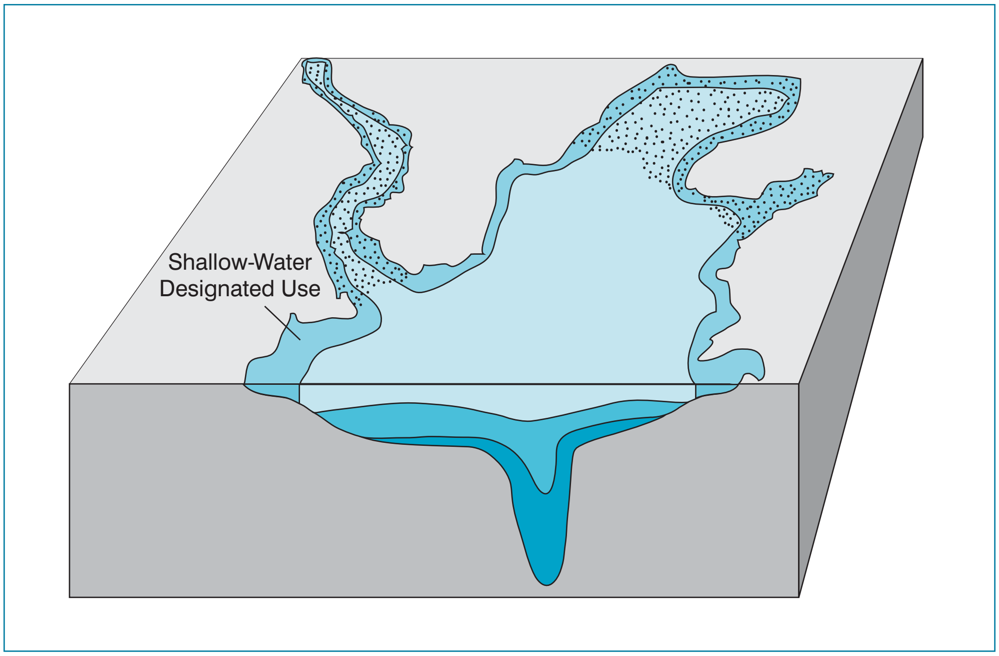

Figure IV-7. Illustration of the boundaries of the shallow-water bay grass designated use.

that varies from 0.5 to 2 meters (Figure IV-7). The segment-specific depths were based on rules described in detail in "Shallow-Water Bay Grass Designated Use Boundaries" (see page 105) along with two other approaches to defining shallow-water use boundaries.

Critical Support Communities—Food and Shelter

Phytoplankton, zooplankton, forage fish and bottom-dwelling worms and clams feed many fish, crab and mollusk species that inhabit shallow-water habitats for part or all of their life stages (Funderburk et al. 1991). Water quality criteria necessary to fully support the shallow-water designated use must provide for the survival, growth and successful propagation of prey communities in sufficient quantities.

Applicable Bay Water Quality Criteria

The shallow-water bay grass designated use is a seasonal use designation that occurs in conjunction with the year-round open-water use and the seasonal migratory spawning and nursery designated uses (see Figure IV-5). The shallow-water bay grass designated use boundary delineates where specific levels of water clarity must be restored to support restoration of underwater bay grasses. The applicable salinity regime-based water clarity criteria apply during the appropriate underwater bay grass growing season: April 1 through October 31 for tidal-fresh, oligohaline and mesohaline habitats and March 1 through May 31 and September 1 through November 30 for polyhaline habitats (see Table IV-5; U.S. EPA 2003).

Underlying the seasonal shallow-water bay grass designated use is the year-round open-water fish and shellfish designated use to support grass living resource communities inhabiting these shallow-water areas (see Table IV-6; U.S. EPA 2003). The open-water fish and shellfish dissolved oxygen criteria apply into the shallows to the intertidal zone. Therefore, nonvegetated shallow-water habitats and the living resource communities that depend on those habitats will receive protection under the open-water designated use. See chapters 3, 4 and 6, respectively, in U.S. EPA 2003 for more details on the individual dissolved oxygen criteria, water clarity criteria and criteria implementation guidelines.

OPEN-WATER FISH AND SHELLFISH DESIGNATED USE

Waters with this designated use support the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting open-water habitats (Table IV-6).

Designated Use Rationale

The natural temperature and salinity stratification of open waters influences dissolved oxygen concentrations and, thus, the distribution of Chesapeake Bay species. Surface mixed-layer waters with higher oxygen levels located above the pycnocline support a different community of species than deeper waters from late spring to early fall. Several well-known species that inhabit these open waters are menhaden, striped bass and bluefish. Their habitat requirements and prey needs differ from those of species and communities inhabiting deeper water habitats during the summer months. See the deep-water “Designated Use Rationale” on page 74 for more detailed documentation.

Clear evidence from the Chesapeake Bay as well as other estuarine and coastal systems, including Long Island Sound (Howell and Simpson 1994), Albemarle-Pamlico Sound (Eby 2001) and the Gulf of Mexico (Craig et al. 2001), indicates that the fish and other organisms inhabiting open-water habitats will use deeper within-pycnocline and below-pycnocline habitats, given suitable dissolved oxygen conditions. It is the lack of sufficient oxygen, not the presence of stratification, that limits the use of these deeper habitats. Therefore, the open-water designated use applies to transitional pycnocline and bottom mixed-layer below-pycnocline habitats where these below-pycnocline and pycnocline waters are sufficiently reoxygenated by oceanic or riverine waters.

During their first winter of life, members of five important Chesapeake Bay species—white perch, striped bass, Atlantic croaker, shortnose sturgeon and Atlantic sturgeon—are constrained to oligohaline and mesohaline regions (< 20 ppt) in the upper Chesapeake Bay mainstem, and seek out warmer temperatures that occur in deeper channel waters below the thermocline. From October through May, the deep-channel habitats in the upper Bay adjacent to shallower summer and fall habitats should be considered important nursery habitats for young-of-the-year juvenile white

Table IV-6. Open-water fish and shellfish designated use summary.

Applicable Criteria:	*Dissolved Oxygen* 5.5 mg/l 30-day mean (tidal habitats with 0–0.5 ppt salinity) 5.0 mg/l 30-day mean (tidal habitats with greater than 0.5 ppt salinity) 4.0 mg/l 7-day mean 3.2 mg/l instantaneous minimum
	Chlorophyll a*:* Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences–such as reduced water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions–or otherwise render tidal waters unsuitable for designated uses.
Application:	Year-round: open-water designated use and dissolved oxygen criteria. March 1 through May 31 and July 1 through September 30: chlorophyll *a* criteria.
Designated Use:	Waters with this designated use support the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting open-water habitats.
Designated Use Boundary:	From June 1 through September 30 the open-water designated use includes tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline. If a pycnocline is present and, in combination with bottom bathymetry and water-column circulation patterns, presents a barrier to oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column only as far as the measured upper boundary of the pycnocline. If a pycnocline is present but other physical circulation patterns (such as influx of oxygen rich oceanic bottom waters) provide for oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column to the bottom water-sediment interface. From October 1 through May 31, the open-water designated use includes all tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline, extending down through the water column to the bottom water-sediment interface.

Source for the Applicable Criteria: U.S. EPA 2003.

perch, striped bass, and Atlantic croaker (Pothoven et al. 1997) as well as Atlantic and shortnose sturgeon (Miller et al. 1997; Secor et al. 2000; Welsh et al. 2000).

During the coldest months, the interaction between temperatures and salinity tolerances may result in a 'habitat squeeze' or bottleneck, forcing juveniles into deep-channel habitats seeking preferred temperatures. Unpublished data from the Maryland Environmental Service indicate that a thermocline, separating the warmer deep waters from colder overlaying waters, typically occurs at a 10-to 20-meter depth in the deep channel from October through February. Therefore, from fall through late spring when the open-water designated use applies to these natural channel habitats, it also protects indigenous populations of important fish species that depend on deep-channel habitats for overwintering.

Based on these natural conditions and their influence on oxygen levels and the seasonal distributions of Chesapeake Bay species, open waters were delineated as a refined tidal-water designated use in the Chesapeake Bay.

Designated Use Boundary Delineation

From June 1 through September 30 the open-water designated use includes tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline (Figure IV-8). If a pycnocline is present and, in combination with bottom bathymetry and water-column circulation patterns, presents a barrier to oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column only as far as the measured upper boundary of the pycnocline

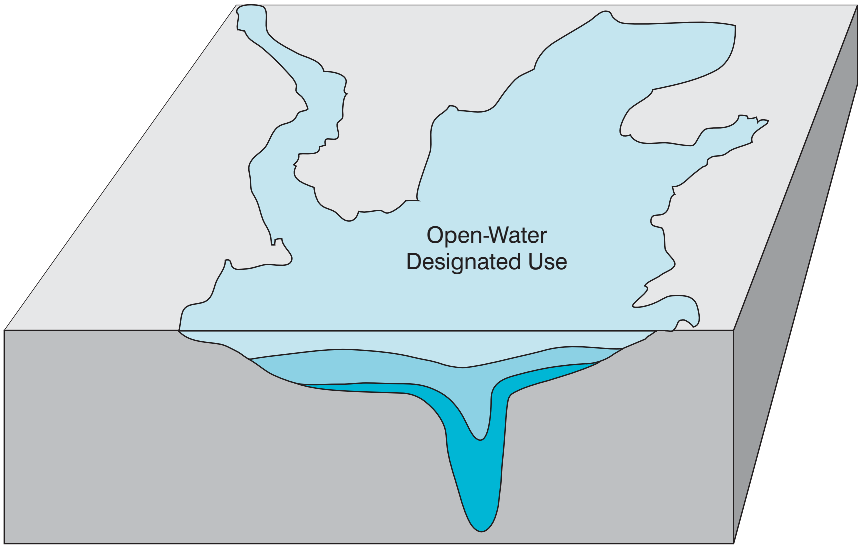

Figure IV-8. Illustration of the boundaries of the open-water fish and shellfish designated use.

(Figure IV-9). If a pycnocline is present but other physical circulation patterns (such as influx of oxygen rich oceanic bottom waters) provide for oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down through the water column to the bottom water-sediment interface.

From October 1 through May 31, the boundaries of the open-water designated use includes all tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline, extending down through the water column to the bottom water-sediment interface.

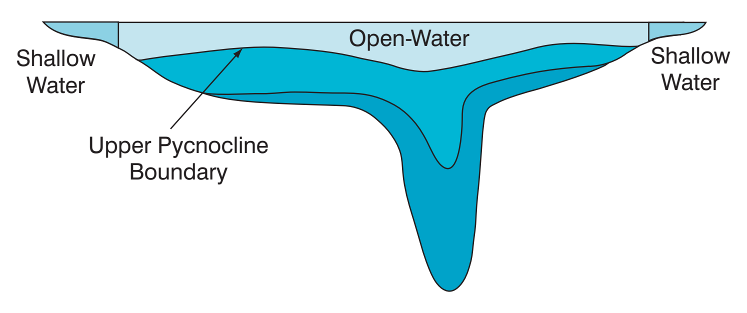

Figure IV-9. Illustration of the vertical boundaries for the refined open-water fish and shellfish designated use.

Critical Support Communities—Food and Shelter

Water column-dwelling phytoplankton, zooplankton and forage fish constitute the major prey for other species in the Chesapeake Bay's open waters (Funderburk et al. 1991). Water quality criteria to support the open-water designated use fully must provide for the survival, growth and successful propagation of quality prey communities in sufficient quantities.

Applicable Bay Water Quality Criteria

The open-water dissolved oxygen criteria apply year-round (see Table IV-6). The applicable salinity regime-based chlorophyll *a* criteria apply only in spring (March 1 through May 31) and summer (July 1 through September 30) to the open-water designated use habitats. See chapters 3 and 5, respectively, in U.S. EPA (2003) for more details on the individual dissolved oxygen and chlorophyll *a* criteria and chapter 6 for detailed criteria implementation procedures.

DEEP-WATER SEASONAL FISH AND SHELLFISH DESIGNATED USE

Waters with this designated use protect the survival, growth and propagation of balanced, indigenous populations of important fish and shellfish species inhabiting deep-water habitats (Table IV-7).

Table IV-7. Deep-water seasonal fish and shellfish designated use summary.

Applicable Criteria:	*Dissolved Oxygen:* 3 mg liter^{-1} 30-day mean 2.3 mg liter^{-1} 1-day mean 1.7 mg liter^{-1} instantaneous minimum
Application:	June 1 through September 30
Designated Use:	Waters with this designated use protect the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally, and commercially important fish and shellfish species inhabiting deep-water habitats.
Designated Use Boundary:	Tidally influenced waters located between the measured depths of the upper and lower boundaries of the pycnocline in areas where the measured pycnocline, in combination with bottom bathymetry and water circulation patterns, presents a barrier to oxygen replenishment of deeper waters. In some areas where a lower boundary of the pycnocline is not calculated, the deep-water designated use extends from the measured depth of the upper boundary of the pycnocline down through the water column to the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

Designated Use Rationale

In an eutrophic system such as the Chesapeake Bay, excess organic matter settles to the bottom, where it fuels microbial activity (e.g., Malone et al. 1986; Tuttle et al. 1987). With more fuel, more oxygen is consumed and, where replenishment with oxygen-saturated waters is restricted, the water becomes more severely oxygen-depleted. There is evidence that hypoxic and anoxic conditions existed in the deeper waters of the Chesapeake Bay prior to European settlement (Cooper and Brush 1991). These same data indicate that anthropogenic activity has increased the extent, frequency and severity of oxygen depletion in the Chesapeake Bay (Zimmerman and Canuel 2000; Hagy 2002).

Many parts of the Chesapeake Bay become, on a seasonal basis, vertically stratified because of depth-related density differences in the water column, caused primarily by variations in salinity and, to a lesser degree, temperature. Warmer, freshwater from the rivers floats on top of the cooler, denser saltwater at the bottom that enters the Bay from the ocean. The gravitational force of the downriver flow of freshwater causes a wedge of deeper, saltier water to move up the Bay and upriver. Vertically, at some point in the water column, a zone of maximum density difference is reached, which inhibits or prevents the exchange between water above and below it. This region is called the pycnocline. In the summer months, respiration by organisms living below the pycnocline can deplete concentrations of dissolved oxygen.

Because waters in and below the pycnocline are isolated from well-mixed surface waters, dissolved oxygen concentrations can decrease until they are stressful or lethal to higher organisms.

The formation of the pycnocline is a natural process. In areas where stratification is common, the pycnocline generally forms at about the same depth range, but is subject to seasonal and annual variations in depth due to river flow, temperature and salinity patterns. It is generally shallower at the mouths of rivers and the Chesapeake Bay and deeper at the heads of rivers. The effect of the pycnocline also is not the same everywhere in the Chesapeake Bay and is influenced by local characteristics such as bathymetry, vertical and horizontal water circulation patterns, and proximity to the ocean and major river fall-lines. In some parts of the Bay and its tidal rivers, these factors create a more complex stratification pattern: a second pycnocline is formed lower in the water column, dividing it into three layers. If a region is contained by the pycnocline above and by bottom bathymetry laterally, it is even more isolated from oxygen-replenishing waters.

Bay anchovy is a target species whose egg and larval life stages are spent in pycnocline waters (Keister et al. 2000; Rilling and Houde 1999; MacGregor and Houde 1996). Blue crabs, oysters, softshell clams, hard clams, spot, croaker, flounder and catfish inhabit the near-bottom waters in the deep-water habitats (Funderburk et al. 1991). The oxygen requirements of these species differ from those of species inhabiting shallow-water, open-water and deep-channel habitats. Their feeding patterns and distribution of eggs and larvae are greatly influenced by natural features of the water column such as the pycnocline.

Deep waters were delineated as a refined tidal-water designated use for the Chesapeake Bay and its tidal tributaries based on the unique nature of the pycnocline region as an important living resource habitat and the transitional nature of its water quality conditions.

Designated Use Boundary Delineation

The deep-water designated use includes the tidally influenced waters between the measured upper and lower boundaries of the pycnocline where, in combination with bottom bathymetry and water circulation patterns, the pycnocline limits oxygen replenishment of deeper waters (Figure IV-10). In some areas where a lower boundary of the pycnocline is not calculated, the deep-water designated use extends from the measured depth of the upper boundary of the pycnocline down through the water column to the bottom sediment-water interface.

Critical Support Communities—Food and Shelter

Bottom-dwelling worms and clams and reef-dwelling forage fish are important food sources for the fish and crabs in deep-water habitats (Funderburk et al. 1991). Water quality criteria to support the deep-water designated use must provide for the survival, growth and successful propagation of quality prey communities in sufficient quantities.

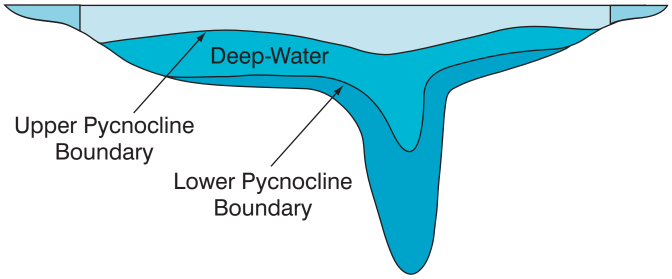

Figure IV-10. Illustration of the vertical boundaries for the refined deep-water designated use.

Seasonal Use Application

The deep-water seasonal fish and shellfish designated use applies from June 1 through September 30. By June, a combination of natural water-column stratification and increased biological oxygen consumption driven by higher water temperatures prevents the Chesapeake Bay's deep waters from retaining high concentrations of dissolved oxygen. These natural conditions generally persist into September. From October 1 through May 31 the open-water fish and shellfish designated use applies to these same waters.

Applicable Bay Water Quality Criteria

The deep-water dissolved oxygen criteria apply from June 1 through September 30 (see Table IV-7). See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the deep-water dissolved oxygen criteria and criteria implementation procedures.

DEEP-CHANNEL SEASONAL REFUGE DESIGNATED USE

Waters with this designated use must protect the survival of balanced, indigenous populations of ecologically important benthic infaunal and epifaunal worms and clams, which provide food for bottom-feeding fish and crabs (Table IV-8).

Designated Use Rationale

In the Chesapeake Bay, researchers have determined the oxygen minimum to be in the below-pycnocline waters throughout the deep trough in the mainstem Chesapeake Bay in the late spring to early fall (Smith et al. 1992). Isolated from aerated surface waters, low dissolved oxygen concentrations in this region are due to excess oxygen consumption from bacterial breakdown of organic material over oxygen additions from ocean waters flowing in from far down-Bay. North of this region, the

Table IV-8. Deep-channel seasonal refuge designated use summary.

Applicable Criteria:	*Dissolved Oxygen:* 1.0 mg/l instantaneous minimum
Application:	June 1 through September 30
Designated Use:	Waters with this designated use must protect the survival of balanced, indigenous populations of ecologically important benthic infaunal and epifaunal worms and clams, which provide food for bottom-feeding fish and crabs.
Designated Use Boundary:	Deep-channel designated use waters are defined as tidally influenced waters at depths greater than the measured lower boundary of the pycnocline in areas where, in combination with bottom bathymetry and water circulation patterns, the pycnocline presents a barrier to oxygen replenishment of deeper waters. The deep-channel designated use is defined laterally by bathymetry of the trough and vertically by the lower boundary of the pycnocline above, and below, at the bottom sediment-water interface.

Source for the Applicable Criteria: U.S. EPA 2003.

trough quickly becomes shallow and bottom waters are oxygenated as they mix with aerated waters in the shoals. Below-pycnocline waters to the south are reoxygenated through mixing with oxygenated oceanic waters entering the Chesapeake Bay mouth.

These deep channels are sinks for excess organic material which, in the process of decaying, increase oxygen consumption. They are isolated from surface and oceanic sources of oxygen replenishment. Vertical stratification and gravitational and horizontal circulation often cause severe, sudden oxygen depletion beginning just below the lower boundary of the pycnocline and extending to the bottom (Smith et al. 1992). Given the physical nature of the deep trough leading to naturally severe oxygen depletion during the summer, the deep-channel was delineated as a refined tidal-water designated use for Chesapeake Bay.

Designated Use Boundary Delineation

Deep-channel designated use waters are defined as tidally influenced waters at depths greater than the measured lower boundary of the pycnocline in areas where the pycnocline, in combination with bottom bathymetry and water circulation patterns, presents a barrier to oxygen replenishment of deeper waters (Figure IV-11). The deep-channel designated use is defined laterally by bathymetry of the trough and vertically by the lower boundary of the pycnocline above, and below, at the bottom sediment-water interface.

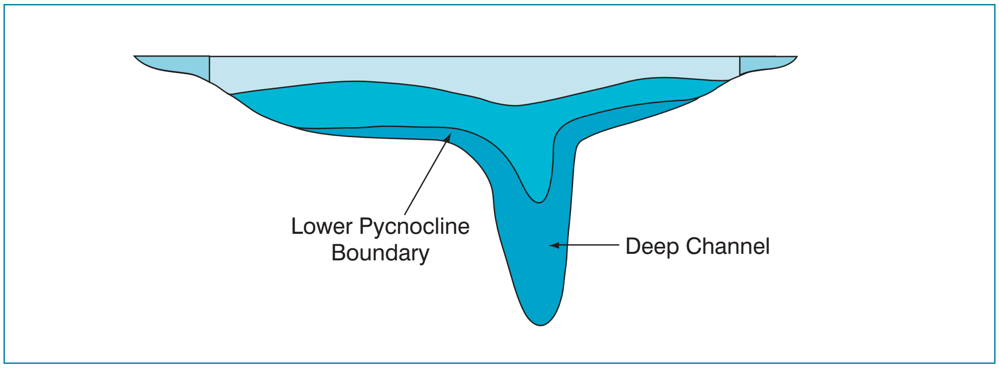

Figure IV-11. Illustration of the vertical boundaries of the refined deep-channel seasonal refuge designated use.

Critical Support Communities—Food and Shelter

Bottom-dwelling worms and clams are the principal food source of bottom-feeding fish and crabs in the deep-channel (Funderburk et al. 1991). Water quality criteria for the deep-channel designated use must provide for the survival of these prey communities.

Seasonal Use Application

The deep-channel designated use applies from June 1 through September 30. By June, a combination of natural water-column stratification and increased water temperature prevents the Chesapeake Bay's deep-channel waters from retaining high concentrations of dissolved oxygen. These natural conditions generally persist through September. From October 1 through May 31 the open-water designated use applies to these same habitats.

Applicable Bay Water Quality Criteria

The deep-channel dissolved oxygen criteria apply from June 1 through September 30 (see Table IV-8). See chapters 3 and 6, respectively, in U.S. EPA 2003 for more details on the deep-channel dissolved oxygen criteria and criteria implementation procedures.

CHESAPEAKE BAY TIDAL-WATER DESIGNATED USE BOUNDARIES

Correct application of the Chesapeake Bay water quality criteria depends on the accurate delineation of the five tidal-water designated uses. Each of the designated uses has different dissolved oxygen criteria derived to match the respective level of protection required by different living resource communities. In case of the shallow-water bay grass designated use, the location of the boundaries is critical to providing sufficient suitable habitat for the restoration of the desired number of acres of underwater bay grasses.

The vertical depth and horizontal breadth of the designated use boundaries are based on a combination of factors: natural water-column stratification, bottom bathymetric features and circulation patterns, among other considerations. It is important to note that these boundaries have been developed without consideration of attainability from the perspective of potentially widespread social and economic impacts. The states may find they need to adjust these boundaries according to such impacts (131.19[g][6]), which may prevent attainment of the designated use, and must justify these adjustments during their water quality standards adoption processes. The technology-based attainability of these refined tidal-water designated uses and their boundaries is documented in Chapter V.

Four of the six factors defined in 40 CFR 101.10(g) justify deriving the boundaries described in this chapter for the refined tidal-water designated uses:

- Natural, ephemeral, intermittent or low-flow conditions or water levels (e.g., application of a 10-year water quality data record (1985-1994) reflecting a wide range of watershed hydrologic and tidal bay hydrodynamic conditions);
- Dams, diversion or other types of hydrologic modifications (e.g., dredged shipping channels);
- Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles and the like (e.g., water-column stratification, bottom bathymetry); and
- Naturally occurring pollutant concentrations (see Chapter III).

MIGRATORY FISH SPAWNING AND NURSERY DESIGNATED USE BOUNDARIES

The boundaries of the migratory fish spawning and nursery designated use were delineated from the upriver extent of tidally influenced waters to the downriver and upper Chesapeake Bay end of spawning and nursery habitats that have been determined through a composite of all targeted anadromous and semi-anadromous fish species' spawning and nursery habitats (Figure IV-12). Free-flowing streams and rivers, where several of the target species (e.g., shad and river herring) migrate for spawning, are protected through other existing state water quality standards.

To generate these boundaries, habitat distribution maps, drawn from the *Habitat Requirements for Chesapeake Bay Living Resources–Second Edition* (Funderburk et al. 1991), were used. The distribution maps used during delineation of the migratory spawning and nursery designated use included:

- Alewife spawning and nursery;
- Alewife nursery;

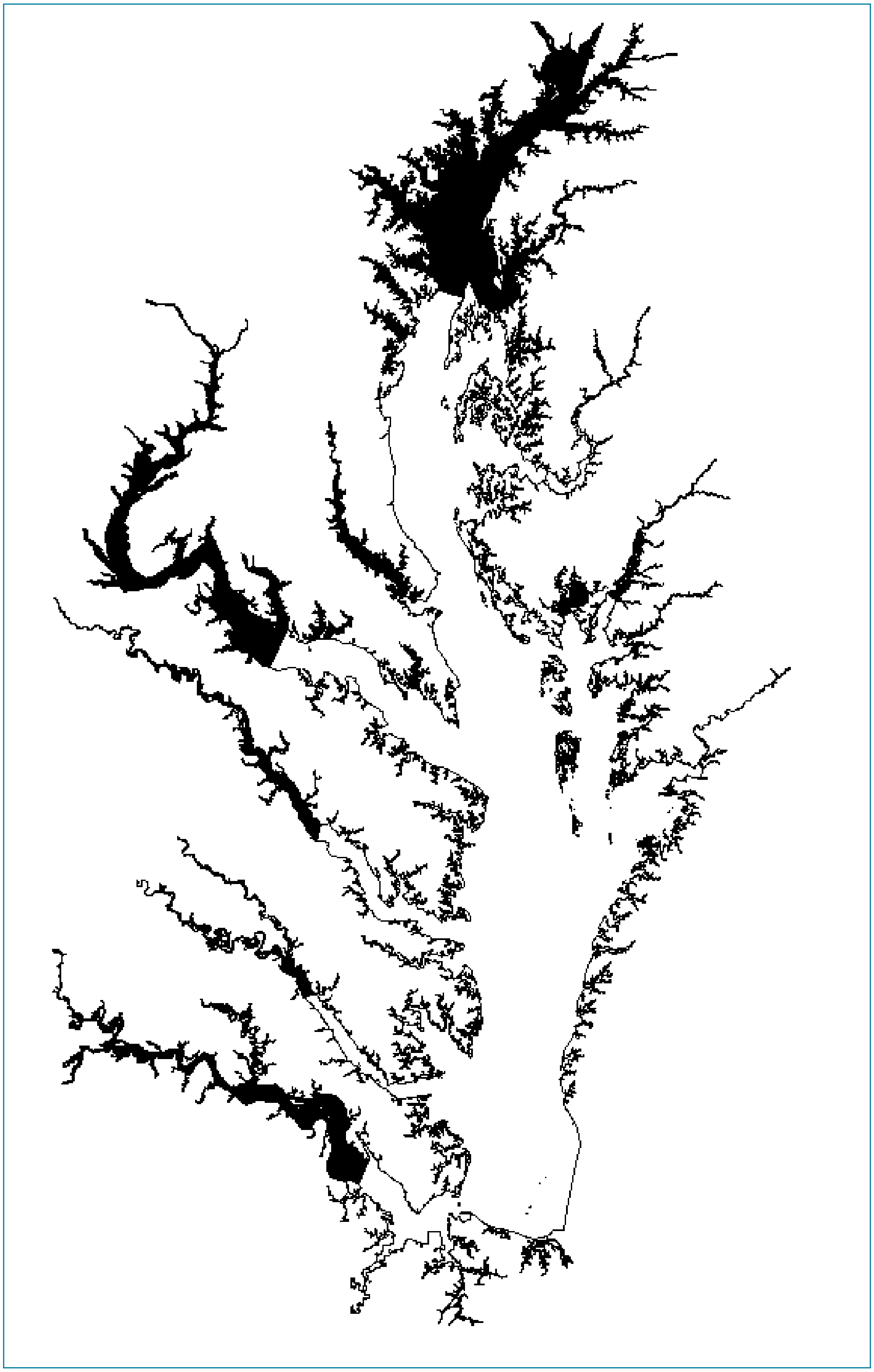

Figure IV-12. Map showing the migratory spawning and nursery designated use for the Chesapeake Bay and its tidal tributaries (black areas).

- American shad spawning and nursery;
- American shad nursery;
- Hickory shad spawning and nursery;
- Herring spawning and nursery;
- Herring nursery;
- Striped bass spawning reaches;
- Striped bass spawning rivers;
- White perch nursery;
- White perch spawning; and
- Yellow perch spawning and nursery.

For those species that had multiple habitat distribution maps for related life stages, the maps were merged into a single coverage. Then individual species maps were superimposed on a composite spawning and nursery habitat map.

The striped bass habitat distribution maps used in this process were originally titled "Striped Bass Chesapeake Bay Spawning Reaches and Spawning Rivers" by Funderburk et al. (1991). The sources of the spawning reach distributions were research and monitoring findings synthesized by Setzler-Hamilton and Hall (1991). However, the mapped extent of the nursery areas, referred to as spawning rivers in the original map, was based on Maryland and Virginia legislative definitions,[11] not on fisheries survey findings.

Those regulations, which define "spawning rivers and areas," did not attempt to define "early juvenile nursery habitat" but rather those rivers in which striped bass spawn. The spawning reach designation in the regulation was used to describe areas where striped bass eggs and larvae had been found. This justification was based on icthyoplankton collections done in the 1950s in Maryland (Mansueti and Hollis 1963). Tresselt (1952) defined spawning reaches in Virginia.

To further enhance understanding of nursery areas, discussions were held with fishery scientists Herb Austin and Deane Este of the College of William and Mary's Virginia Institute of Marine Science, and Eric Durell, Maryland Department of Natural Resources, who are responsible for their respective states' juvenile striped bass seine surveys. The primary nursery areas for young-of-the-year striped bass were delineated based on a comparison of long-term Maryland and Virginia seine survey data with the legislatively-defined extent of early juvenile nursery habitat. In any given year, juvenile striped bass can be found throughout a broader range of Chesapeake Bay tidal waters. The primary nursery areas where the highest concentrations of *early* juvenile life-stage striped bass are almost always found in the spring

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[11] Code of Maryland Regulations 08.02.05.02 and Virginia Marine Resources Commission Regulation 450-01-0034 as cited inChesapeake Bay Living Resources Task Force (1987).

were identified and incorporated into the composite map described above (e.g., Austin et al. 2000). The striped bass nursery areas were supplemented to ensure that shad and river herring spawning and nursery areas were fully represented within the migratory fish spawning and nursery designated use boundaries (Rulifson 1994; Olney 2002).

From February 1 through May 31, the migratory fish spawning and nursery designated use occurs in conjunction with, and, therefore, encompasses specific portions of the seasonal shallow-water bay grass and year-round open-water fish and shellfish designated use habitats (see shaded sections in Figure IV-5). The designated use extends horizontally from the shoreline across the body of water to the adjacent shoreline, and extends down through the water column to the bottom sediment-water interface.

The exact spatial and temporal extent of migratory fish spawning and nursery designated use would vary annually due to regional climatic patterns if actual observed salinity and temperature were used to define year-by-year boundaries. Because use of year-by-year delineation of the exact boundaries of the migratory fish spawning and nursery designated adds complexity, a fixed set of boundaries was established. The migratory fish spawning and nursery designated use habitat shown in Figure IV-12 reflects both long-term, decadal average salinity conditions and decades' worth of fisheries-independent beach seine and trawl monitoring data. States can adopt an approach (to be defined) for defining migratory spawning and nursery designated use boundaries on a year-to-year basis by directly factoring in the influence of interannual climatic patterns on the use boundaries.

OPEN-WATER, DEEP-WATER AND DEEP-CHANNEL DESIGNATED USE BOUNDARIES

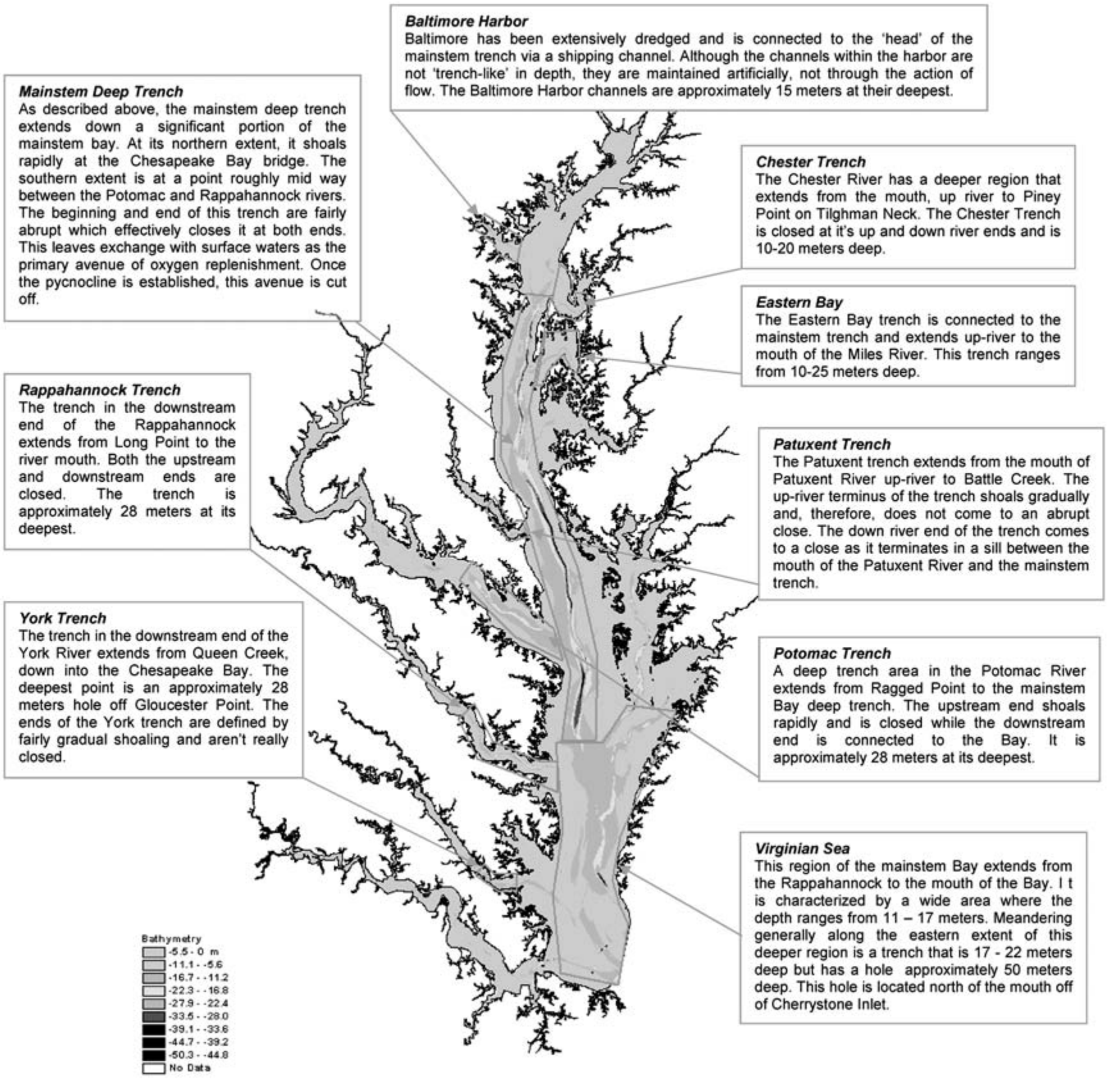
Background

The open-water, deep-water and deep-channel designated uses, the habitats they represent and the dissolved oxygen criteria for ensuring their protection are inextricably related to physical structure (water-column stratification, bottom bathymetry) and to physical, chemical, meteorological and fluvial forces and processes. Understanding these factors will enhance understanding of the designated use delineation process as well as the issues underlying application of the dissolved oxygen criteria. The following section provides background on these three principal factors: bathymetry, flow and circulation, and vertical density gradients and pycnoclines.

Bathymetry

Although the Chesapeake Bay is a relatively shallow estuary, bathymetric features play a large role both in defining the Bay's habitats as well as the eutrophication-related water quality problems observed throughout most of the tidal waters.

The most prominent bathymetric feature in the Bay is the deep trench that runs from the Chesapeake Bay Bridge between Annapolis and Kent Island, Maryland, to an area midway between the southern shore of the mouth of the Potomac River and the northern shore of the mouth of the Rappahannock River (figures IV-13 and IV-14). The trench ranges from 24 to 48 meters in depth and extends generally midchannel between the western and eastern shores of the mainstem Chesapeake Bay. It is thought to be a remnant of the ancient Susquehanna River. A shallower trench extends down along the Virginia Eastern Shore (Figure IV-15). Similar, smaller trenches and holes exist elsewhere in Bay tidal waters, generally in the larger tidal tributary rivers near their mouths. These are described later in the more detailed regional descriptions that follow.



Baltimore Harbor
Baltimore has been extensively dredged and is connected to the 'head' of the mainstem trench via a shipping channel. Although the channels within the harbor are not 'trench-like' in depth, they are maintained artificially, not through the action of flow. The Baltimore Harbor channels are approximately 15 meters at their deepest.

Mainstem Deep Trench
As described above, the mainstem deep trench extends down a significant portion of the mainstem bay. At its northern extent, it shoals rapidly at the Chesapeake Bay bridge. The southern extent is at a point roughly mid way between the Potomac and Rappahannock rivers. The beginning and end of this trench are fairly abrupt which effectively closes it at both ends. This leaves exchange with surface waters as the primary avenue of oxygen replenishment. Once the pycnocline is established, this avenue is cut off.

Chester Trench
The Chester River has a deeper region that extends from the mouth, up river to Piney Point on Tilghman Neck. The Chester Trench is closed at it's up and down river ends and is 10-20 meters deep.

Eastern Bay
The Eastern Bay trench is connected to the mainstem trench and extends up-river to the mouth of the Miles River. This trench ranges from 10-25 meters deep.

Rappahannock Trench
The trench in the downstream end of the Rappahannock extends from Long Point to the river mouth. Both the upstream and downstream ends are closed. The trench is approximately 28 meters at its deepest.

Patuxent Trench
The Patuxent trench extends from the mouth of Patuxent River up-river to Battle Creek. The up-river terminus of the trench shoals gradually and, therefore, does not come to an abrupt close. The down river end of the trench comes to a close as it terminates in a sill between the mouth of the Patuxent River and the mainstem trench.

York Trench
The trench in the downstream end of the York River extends from Queen Creek, down into the Chesapeake Bay. The deepest point is an approximately 28 meters hole off Gloucester Point. The ends of the York trench are defined by fairly gradual shoaling and aren't really closed.

Potomac Trench
A deep trench area in the Potomac River extends from Ragged Point to the mainstem Bay deep trench. The upstream end shoals rapidly and is closed while the downstream end is connected to the Bay. It is approximately 28 meters at its deepest.

Virginian Sea
This region of the mainstem Bay extends from the Rappahannock to the mouth of the Bay. I t is characterized by a wide area where the depth ranges from 11 – 17 meters. Meandering generally along the eastern extent of this deeper region is a trench that is 17 - 22 meters deep but has a hole approximately 50 meters deep. This hole is located north of the mouth off of Cherrystone Inlet.

Figure IV-13. Major bathymetric trenches within the Chesapeake Bay and its tidal tributaries.

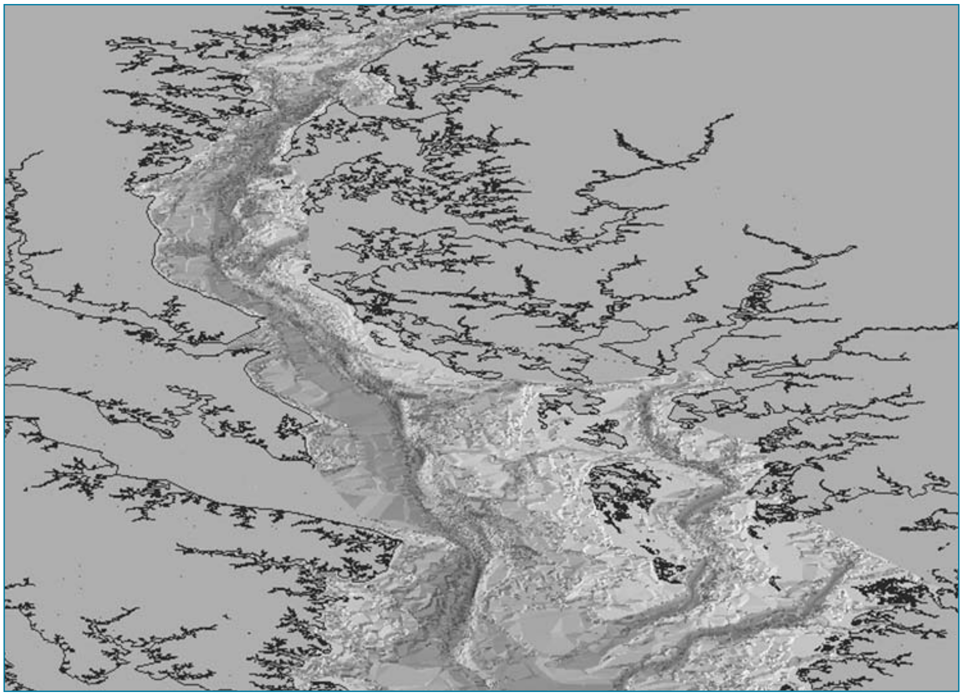


Figure IV-14. Three-dimensional view of the Chesapeake Bay mainstem trench as viewed from the south looking north. The depth versus width relationship has been enhanced to improve viewing.

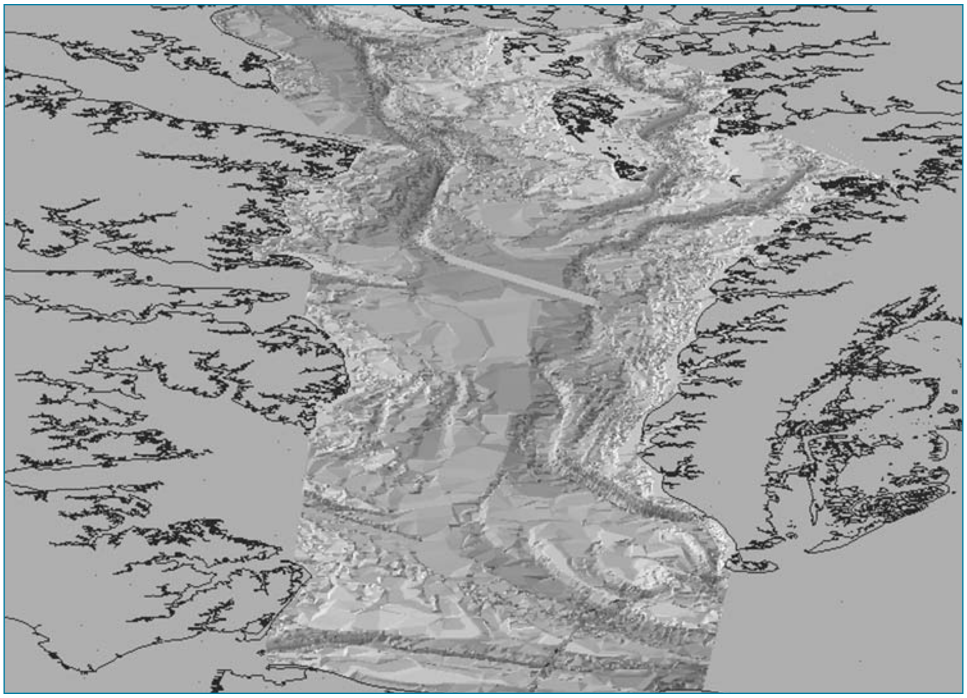


Figure IV-15. Three-dimensional view of the 'Virginian Sea' as viewed from the south looking north. The depth versus width relationship has been enhanced to improve viewing.

These deep regions contrast with the Chesapeake Bay as a whole, which has an average depth of only 6 meters. They also figure prominently in the Chesapeake Bay's dissolved oxygen problems. When it is overlain by a stratified water column, the bottom water in the trenches and holes is isolated from the oxygenated surface water and can become oxygen-depleted. This situation generally occurs in the late spring and summer when oxygen-consuming activity is high and discontinuity in water density through the water column can act as a barrier, i.e., act as a 'lid,' capping off the exchange of oxygenated water with the oxygen-depleted waters in the trenches and holes. However, some of the deep areas of the Chesapeake Bay, although capped as described, do not suffer from chronically low dissolved oxygen. These areas generally have their downstream or seaward end open so that deep-water exchange with the oxygenated deep water from the ocean can occur.

FLOW AND CIRCULATION

Processes within the Chesapeake Bay and its tidal tributaries are strongly influenced by flow and circulation patterns. These factors affect the mixing of the Bay's waters and the distribution of salinity, dissolved compounds and planktonic organisms. Like most estuaries, the Chesapeake Bay has a two-layer flow pattern. Net flow in the upper layer moves down the Bay or downriver, while net flow in the bottom layer moves up the Bay or upriver.

This two-layer flow is caused primarily by the difference in density between the less dense, low-salinity water that flows off the land and the more dense, high-salinity water that flows in from the ocean. The less dense, more buoyant, low salinity water floats on the surface of higher salinity water. The tendency of ocean water in summer to be cooler than freshwater also contributes to its higher density. Interannual and seasonal differences in freshwater inflow to the rivers and the Chesapeake Bay, due largely to meteorological factors, affect the interaction of the two layers.

Tidal forces move water into and out of the Chesapeake Bay and its rivers. Tidal currents interact with the bathymetric surfaces of the bottom, with the seaward flow of freshwater and with the air-water interface affecting internal turbulence and mixing. Tied to lunar cycles, the daily, monthly and seasonal tidal rhythms are relatively predictable components of flow and circulation.

The Coriolis force is another important physical circulation process in the Chesapeake Bay. The Coriolis force is related to the earth's rotation and causes moving objects such as fluids to veer to the right (clockwise) in the Northern Hemisphere and to the left (counter-clockwise) in the Southern Hemisphere. This force increases with proximity to the poles. Currents in the Northern Hemisphere tend to move clockwise over their course unless they encounter a barrier such as a land mass. Thus ocean water flowing into the Chesapeake Bay at the mouth is deflected north due to the Coriolis force. The current continues around to the right until it encounters the Eastern Shore, which directs the flow up the Bay. Water flowing down and out of the Chesapeake Bay on the surface, flows primarily down the Western Shore as the

Coriolis force tends to push it to the right. This same phenomenon of inflow on the bottom on the right and outflow on the surface on the left occurs in the Bay's tidal tributaries as well.

VERTICAL DENSITY GRADIENTS AND PYCNOCLINES

In many parts of the Chesapeake Bay, the water column becomes stratified because of differences in water density. These differences are caused primarily by differences in salinity and, to lesser degree, in temperature. The water column becomes vertically stratified when, at some depth, a difference in water density from one depth to the next is large enough to inhibit or prevent exchange between water above and below it. Fisher et al. (2003) found the density gradient for defining inhibition or prevention of water exchange in the Chesapeake Bay to be 0.1 kg/m^4. The depth nearest the surface where this first occurs is referred to as the pycnocline. The discontinuity may be gradual, as shown in Figure IV-16a, exhibiting a generally uniform gradient of increasing density from one depth to the next through the water column. In such cases, one refers to the *region* of the pycnocline.

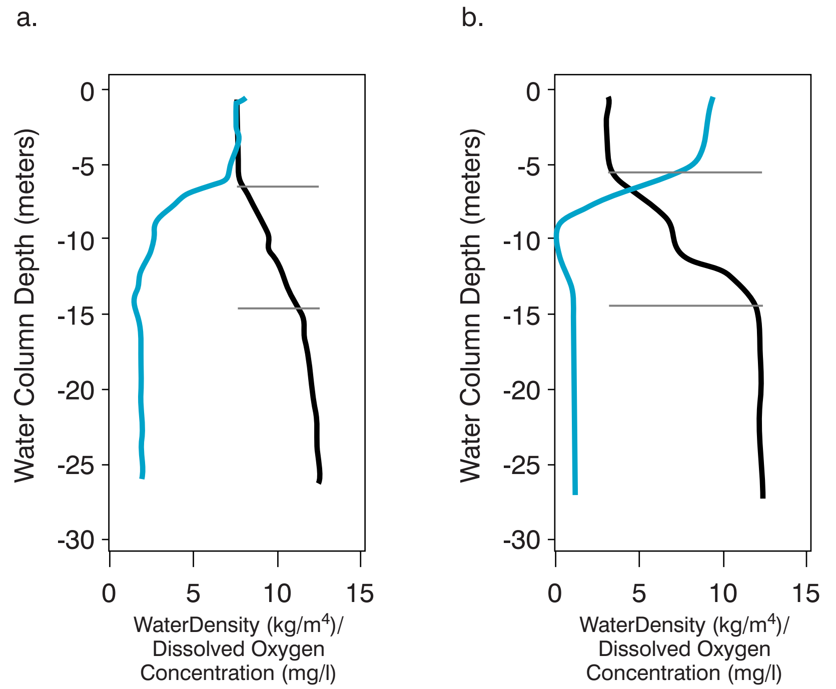


Figure IV-16. The figures illustrate a variety of water density and dissolved oxygen profiles found in the Chesapeake Bay and its tidal tributaries. The black line represents water density (kg/m ^{4}), the blue line represents dissolved oxygen concentration (mg/l). The vertical axis indicates depth (meters) below the surface. The horizontal line crossing the density line, when present, indicates upper and lower pycnocline depth using the Fisher et al. 2003 method. Figure 'a' is an example of a sharp, upper pycnocline with density gradually increasing with distance from the surface. Figure 'b' is an example of a more distinct three-layer structure.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

In areas where stratification is common, the pycnocline typically forms at about the same depth, but is subject to seasonal and annual variations in depth due to river flow, temperature and salinity patterns. The pycnocline is generally shallower at the mouths of tidal rivers and the Chesapeake Bay and deeper with distance upriver and up-Bay. In the central, deepest part of the mainstem Chesapeake Bay, the pycnocline tends to deepen and 'tilt' slightly on the east-west axis, depending on the strength and direction of prevailing winds as well as the relative balance of the several forces controlling Chesapeake Bay circulation. North of this area, where the Bay narrows and grows shallow, and north-moving bottom water shoals up from the deep trench, the pycnocline is generally found closer to the surface. In upriver areas of tidal tributaries, pycnoclines may occur occasionally depending on episodic intrusions of saline waters. In other areas, such as the mouth of Tangier Sound in the lower Chesapeake Bay, pycnoclines are occasional or intermittent because fresh and saline waters are typically well-mixed by tidal currents and bathymetric features.

In some areas, the many factors acting on circulation create a more complex stratification structure. Below the surface mixed layer, there is a layer where density continues to change with depth. Then a second, sharp density discontinuity is encountered, creating a discrete bottom mixed layer (Figure IV-16b). A density gradient of 0.2 kg/m^4 was found to inhibit upward vertical exchange and form a boundary for this lower mixed zone. (See Appendix D for a more thorough explanation of the methods for determining the pycnocline.)

For these reasons, the shape of a density profile can be highly variable within and between locations. The profile in Figure IV-16b is common in medium-to-deep areas of the mainstem Chesapeake Bay and lower tributaries during the summer months. There is an upper mixed layer several meters thick, followed by a distinct change in the density gradient. This change marks the upper depth of the pycnocline and the lower depth of the upper mixed layer. The thickness of the inter-pycnocline region in this example is 9 meters, about a third of the water column. The bottom mixed layer is fairly thick in this case, extending approximately 13 meters to the bottom. The figure illustrates the effect of the pycnocline and density gradient on oxygen concentration in this part of the Chesapeake Bay. Oxygen in the surface mixed layer is close to saturation. Below the upper pycnocline depth, oxygen levels fall with increasing distance from the oxygenated upper layer. The bottom mixed layer is consistent at about 1 mg/l through the entire thickness to the bottom.

Figure IV-17a shows a pycnocline type that is common to shallow to medium-depth areas of the mainstem Chesapeake Bay and mid-to-lower areas of the tidal tributaries. There is a well-defined surface mixed layer, marked by a sharp density discontinuity, but no lower mixed layer. The pycnocline extends through the water column to the bottom sediment-water interface, with dissolved oxygen concentrations decreasing with distance from the upper pycnocline boundary. Figure IV-17b shows a different density structure at the same location on a different date. There is no density discontinuity, the upper mixed layer extends through the entire water column and dissolved oxygen levels greater than 5 mg/l are sustained through to the bottom sediment-water interface. The vertical profiles in figures IV-17a and IV-17b

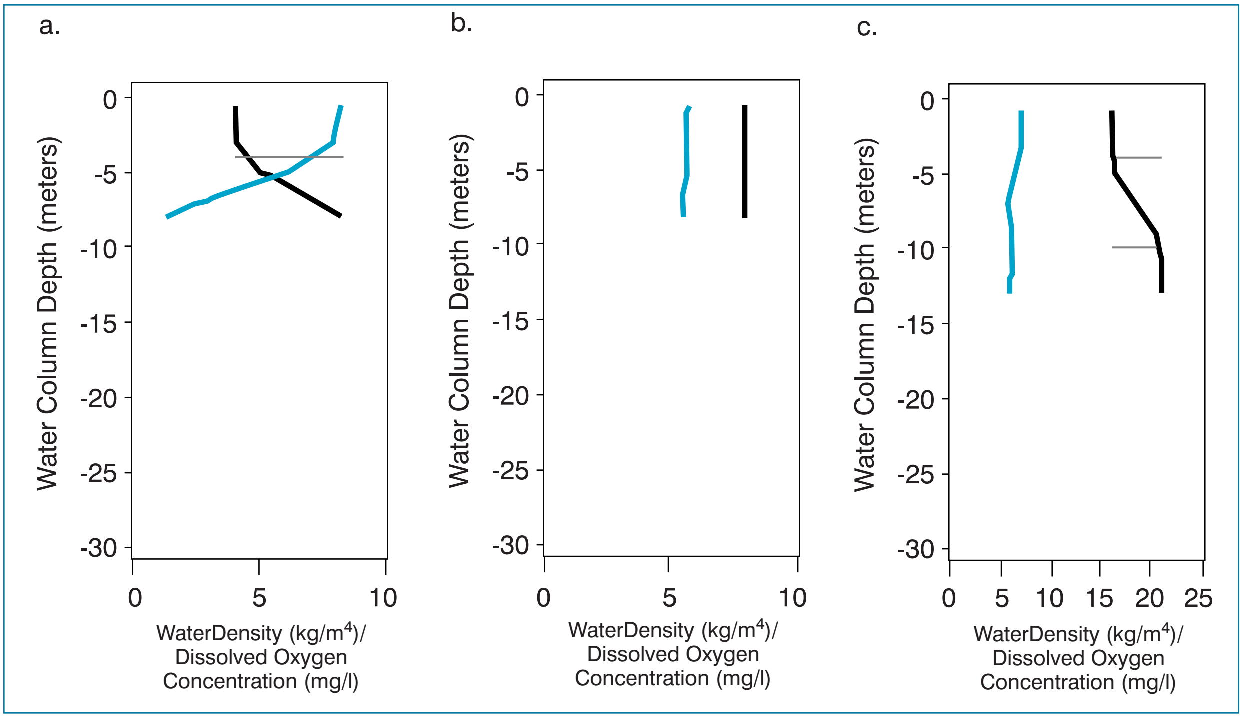


Figure IV-17. The figures illustrate a variety of water density and dissolved oxygen profiles found in the Chesapeake Bay and its tidal tributaries. The black represents water density (kg/m ^{4}), the blue line represents dissolved oxygen concentration (mg/l). The vertical axis is depth (meters) below the surface. The horizontal line crossing the density line, when present, indicates upper and lower pycnocline depth using the Fisher et al. 2003 method. Figure 'a' represents vertical profiles of density and dissolved oxygen concentration at a relatively shallow site. A layer of homogenous, oxygenated low salinity water lies over water with a gradually increasing salinity/density gradient. Figure 'b' represents vertical profiles of density and dissolved oxygen at the same relatively shallow site when the water column is fully mixed. Figure 'c' represents vertical profiles of density and dissolved oxygen at a site in the lower mainstem Chesapeake Bay where dissolved oxygen levels are sustained throughout the water column in the presence of a density gradient and pycnocline.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

are typical of tidal-fresh and shallow areas of the mainstem Chesapeake Bay and tidal tributaries and can frequently be observed in medium-depth regions of the mainstem Bay and mid- to lower sections of the tidal tributaries.

The relationship of dissolved oxygen to the presence or absence of a pycnocline and density gradient is different in the lower Chesapeake Bay mainstem (Figure IV-17c). A sharp pycnocline exists, but the gradient in dissolved oxygen concentrations is not as pronounced. Vertical mixing is still retarded by the pycnocline as in other areas of the Chesapeake Bay, but bottom waters are not as low in oxygen due to the replenishment of oxygenated waters from the ocean.

Figure IV-18 is a snapshot of water density and dissolved oxygen profiles at various sites in the Chesapeake Bay during the summer of 1997. The lines depicting water density demonstrate the layering and mingling of water masses of different sources and histories within the confines of the trenches and on the shoals. The plots also

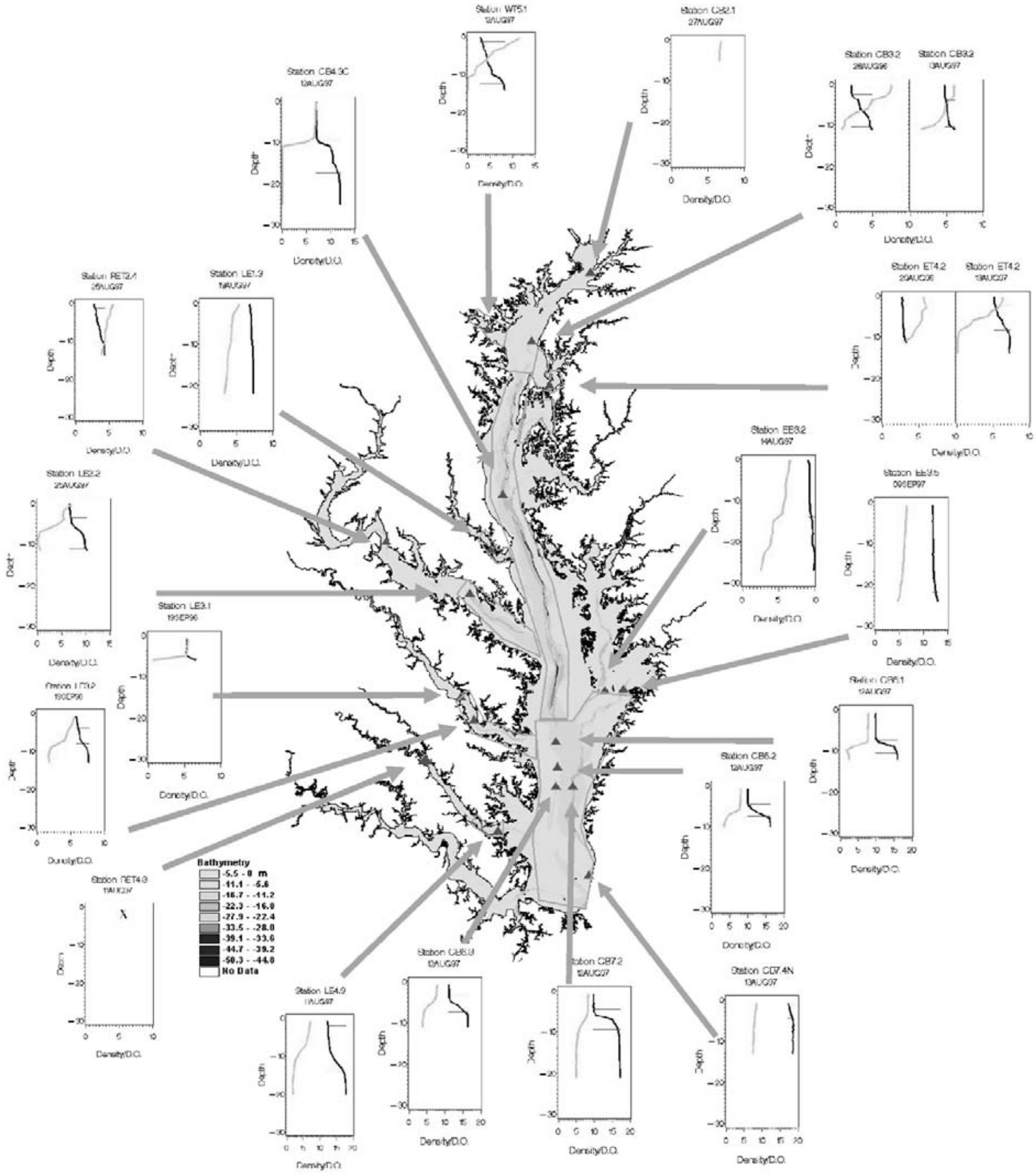


Figure IV-18. 'Snapshot' of water density and dissolved oxygen vertical depth profiles at various water quality monitoring program stations in the Chesapeake Bay and its tidal tributaries in the summer of 1997.

Source of data: Chesapeake Bay Program website http://www.chesapeakebay.net.

illustrate the difference small and large variations in density can have on dissolved oxygen concentrations as described above. For example, at monitoring station EE3.2 in Tangier Sound, the decrease in dissolved oxygen concentration (about 2 mg/l) at 14 meters has a density difference just large enough to be considered a pycnocline. Downstream, at station CB7.2, the change in density is much larger but induces about the same magnitude of decrease in the dissolved oxygen concentration gradient.

DELINEATING THE DESIGNATED USE BOUNDARIES

Vertical stratification has direct implications for delineating the designated use boundaries. Much of the water in the Chesapeake Bay and its tidal tributaries is shallow and well-mixed or easily aerated. These areas plus the surface mixed layers overlying stratified water in channels and holes constitute the open-water fish and shellfish designated use. The upper layer mixes on time scales of minutes to hours (Alldredge et al. 2002), which means that all of the water in this layer comes in close contact with the atmosphere and should be able to attain the most protective surface water dissolved oxygen criterion. The open-water designated use boundary is, therefore, defined as the upper mixed layer, extending from the water surface to the bottom water-sediment interface, where no stratification occurs or to the measured depth of the upper pycnocline where, in combination with bottom bathymetry and water-column circulation, it presents a barrier to oxygen replenishment of deeper waters. From June through September, the open-water designated use accounts for approximately 70 percent of the total volume of the Chesapeake Bay and its tidal tributaries, and many Chesapeake Bay Program segments have only this one designated use (Table IV-9).

Water in the bottom mixed layer is essentially trapped. The bottom mixed layer is separated from the upper mixed layer by the pycnocline and receives very limited oxygen from either mixing or diffusion. Biological respiration and decomposition processes deplete the ambient dissolved oxygen, and bottom sediments exert additional oxygen demand. The shape of the bottom mixed layer or deep-channel designated use is essentially a thin layer along the bottom in most areas, with thicker sections in some deeper areas of the Chesapeake Bay. Water within the pycnocline between the upper and lower mixed layers is defined as the deep-water designated use.

However, as noted and illustrated above, a pycnocline and density gradient do not affect dissolved oxygen concentration conditions to the same degree in all areas of the Chesapeake Bay and its tidal tributaries. There are regional peculiarities in bathymetry and flow that strongly influence the effect of a pycnocline on dissolved oxygen concentrations, and these must be taken into account.

THE BOUNDARY DELINEATION PROCESS

The process of identifying and delineating the open-water, deep-water and deep-channel designated use boundaries employed observed and model-simulated characterizations of dissolved oxygen concentrations and the theoretical effects of the physical and chemical processes discussed above. The process first identified the

Table IV-9. The tidal-water volume of the designated uses by Chesapeake Bay Program segment. Calculations are based on the 1998-2000 summer (June through September) mean depths of the upper and lower pycnoclines.

Chesapeake Bay Program Segment	Volume (cubic kilometers) Migratory	Open-Water	Deep-Water	Deep Channel
CB1TF	.35/4%	.35/1%		
CB2OH	1.22/14%	1.23/2%		
CB3MH	2.27/27%	1.05/2%	.87/6%	.47/5%
CB4MH		4.26/9%	2.73/9%	2.25/26%
CB5MH		7.57/15%	3.17/15%	4.62/52%
CB6PH		5.03/10%	5.03/10%	
CB7PH		10.29/21%	10.29/21%	
CB8PH		3.16/6%		
BSHOH	.05/<1%	.02/<1%		
GUNOH	.06/<1%	.06/<1%		
MIDOH	.03/<1%	.03/<1%		
BACOH	.02/<1%	.02/<1%		
PATMH	.37/4%	.06/<1%	.02/<1%	
MAGMH	.06/1%	.08/<1%		
SEVMH	.08/1%	.11/<1%		
SOUMH	.05/<1%	.07/<1%		
RHDMH	.01/<1%	.02/<1%		
WSTMH	.01/<1%	.02/<1%		
PAXTF	.01/<1%	.01/<1%		
PAXOH	.03/<1%	.03/<1%		
PAXMH	.39/5%	.38/1%	.38/1%	
POTTF	.48/6%	.48/1%		
PISTF	.003/<1%	.003/<1%		
MATTF	.01/<1%	.01/<1%		
POTOH	.84/10%	.84/2%		
POTMH	1.16/14%	3.17/6%	1.25/9%	1.20/14%
RPPTF	.10/1%	.10/<1%		
RPPOH	.05/<1%	.05/<1%		
RPPMH	.17/2%	1.00/2%	.33/2%	.13/1%
CRRMH	.07/1%	.07/<1%		
PIAMH	.20/2%	.20/<1%		
MPNTF	.01/<1%	.01/<1%		
MPNOH	.04/<1%	.04/<1%		
PMKTF	.03/<1%	.03/<1%		
PMKOH	.06/<1%	.06/<1%		
YRKMH	.08/1%	.28/1%		
YRKPH		.24/<1%	.15/<1%	
MOBPH		1.33/3%		

continued

Table IV-9. The tidal-water volume of the designated uses by Chesapeake Bay Program segment. Calculations are based on the 1998-2000 summer (June through September) mean depths of the upper and lower pycnoclines *(cont.)*.

	Volume (cubic kilometers)			
Chesapeake Bay Program Segment	**Migratory**	**Open-Water**	**Deep-Water**	**Deep Channel**
JMSTF	.26/3%	.27/<1%		
APPTF	.002/<1	.002/<1%		
JMSOH	.43/5%	.43/1%		
CHKOH	.05/<1%	.05/<1%		
JMSMH	.36/4%	.97/2%		
JMSPH		.43/1%		
WBEMH		.01/<1%		
SBEMH		.03/<1%		
EBEMH		.01/<1%		
LAFMH		.003/<1%		
ELIPH		.04/<1%	.02/<1%	.002/<1%
LYNPH		.02/<1%		
NORTF	.03<1%	.03<1%		
C&DOH	.02/<1%	.02/<1%		
BOHOH	.02/<1%	.02/<1%		
ELKOH	.10/1%	.10/<1%		
SASOH	.08/1	.08/<1%		
CHSTF	.003/<1%	.003/<1%		
CHSOH	.03/<1%	.03/<1%		
CHSMH	.41/5%	.41/1%	.01/<1%	<1%
EASMH		.78/2%	.09/1%	.12/1%
CHOTF	.02/<1%	.02/<1%		
CHOOH	.04/<1%	.04/<1%		
CHOMH2	.12/1%	.26/1%		
CHOMH1	.02/<1%	.95/2%		
LCHMH		.21/1%		
HNGMH		.19/<1%		
FSBMH	.14/2%	.14/<1%		
NANTF	.01/<1%	.01/<1%		
NANOH	.05/<1%	.05/<1%		
NANMH	.03/<1%	.10/<1%		
WICMH	.02/<1%	.06/<1%		
MANMH	.01/<1%	.09/<1%		
BIGMH	.002/<1%	.04/<1%		
POCTF	.004/<1%	.004/<1%		
POCOH	.02/<1%	.02/<1%		
POCMH	.01/<1%	.35/1%		
TANMH		3.98/8%		
Total	**8.54/100%**	**49.65/100%**	**13.41/100%**	**8.79/100%**

deep-channel designated use habitats: the areas of the Chesapeake Bay and its tidal tributaries that suffer chronic low dissolved oxygen concentrations due to the natural interplay of water-column stratification, bottom bathymetry and water circulation patterns. These areas are so strongly isolated by these factors that they become immune from remediation. The next step was to identify the deep-water designated use habitats—areas with chronically low dissolved oxygen concentrations driven largely by water-column stratification, bottom bathymetry and water circulation patterns, but with hypoxic conditions (extent and severity) that are responsive to change, including changes in anthropogenic inputs. The rest of the tidal Bay habitats were identified as open-water designated use habitats.

First it was necessary to identify potential areas for delineation as deep-channel and deep-water designated use habitats by examining empirical dissolved oxygen concentration and distribution data under the 'best' observed conditions. The 17-year dissolved oxygen record from the Chesapeake Bay Program's Water Quality Monitoring Program, 1984-2000, was reviewed to find the best summer dissolved oxygen conditions in this time period.[12] Using hypoxic volume-days as the metric, 1997 was chosen. The dissolved oxygen conditions of that year largely reflect the effect of low freshwater inflow and lower nutrient and sediment inputs from reduced rain and subsequent runoff.

Maps of bottom-water dissolved oxygen concentrations in the summer of 1997 revealed the areas with the most recalcitrant low dissolved oxygen concentrations. These maps also revealed areas with adequate dissolved oxygen concentrations, but with episodic low dissolved oxygen concentrations under other flow and runoff loading conditions. Maps of the spatial extent of waters with concentrations of 1 mg/l and 3 mg/l over the 17-year period helped identify areas where physical processes strongly influence dissolved oxygen concentrations and where low dissolved oxygen persists over a wide range of flows and associated nutrient loads. The regions identified as having chronic low dissolved oxygen concentrations attributable to the combined affects of pycnocline, bathymetry and flow were as follows:

- Upper, middle and lower central Chesapeake Bay segments (CB3MH, CB4MH and CB5MH);
- Northern reaches of the western and eastern lower Chesapeake Bay (CB6PH and CB7PH);

Dissolved Oxygen and Temperature

As the temperature of a liquid increases, the ability of gases to dissolve into it decreases. In other words, as water gets warmer, the concentration of gases, such as oxygen, within it decreases. This change has implications for the Chesapeake Bay in the summer time because, as the water's temperature increases, it can hold less and less oxygen.The inability to hold oxygen happens at a time when overall metabolism in the Bay is increasing with temperature. Higher metabolism is coupled with increased dissolved oxygen consumption.

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[12] Historical dissolved oxygen data were available from as early as the 1950s; however, the temporal and spatial coverage prior to 1984 was uneven and too coarse for this analysis.

- Patapsco River (PATMH);
- Mesohaline segments of the Chester, Eastern Bay, Patuxent, Potomac and Rappahannock rivers (CHSMH, EASMH, PXTMH, POTMH and RPPMH); and
- Polyhaline segment of the York River (YRKPH) (Figure IV-19).

How water-column stratification, bottom bathymetry and water circulation patterns affect dissolved oxygen conditions and, therefore, the designated use boundaries in each of these regions are discussed and illustrated below.

Upper Central Chesapeake Bay

The upper central Chesapeake Bay, or segment CB3MH, includes the 'head' of the mainstem Chesapeake Bay trench at its northern border near the Chesapeake Bay Bridge (Figure IV-19). In this segment the flow shifts from a single to a two-layer flow. The exact point where this occurs shifts south and north as the flow from the Susquehanna River increases and decreases with seasonal and interannual variation. Its location in the center of this estuarine transition zone puts segment CB3MH at the extreme end of oxygen dynamics in the Chesapeake Bay. As ocean water moves up the Bay beneath the pycnocline, metabolic processes are consuming its reserve of dissolved oxygen. By the time this water reaches segment CB3MH, it has traveled approximately 220 kilometers and, depending on the time of year, it can be partly or completely deprived of dissolved oxygen. Because of this, the very southern portion of segment CB3MH is the first part of the Chesapeake Bay mainstem to show oxygen depletion in the spring and the last to become reoxygenated in the fall. As the northward-flowing bottom water encounters the head of the mainstem trench, it spills into the shallower waters of the middle portion of segment CB3MH before meeting and mixing with the south-flowing waters of the Susquehanna River (Figure IV-20). Therefore, even though this middle portion of segment CB3MH is not 'trench-like' in depth, this area has deep-channel and deep-water designated uses.

Middle Central Chesapeake Bay

The middle central Chesapeake Bay, or segment CB4MH, encompasses the entire northern half of the Chesapeake Bay mainstem trench with the exception of the head, which lies in segment CB3MH (Figure IV-19). The trench runs 20 to 35 meters deep along the eastern side of the segment. Once a pycnocline develops in this segment, it acts as a lid over the trench and effectively isolates below-pycnocline waters from the overlying waters. The source of the below-pycnocline water in segment CB4MH is the already depleted below-pycnocline water of segment CB5MH (Figure IV-21). Therefore, the only source of dissolved oxygen for below-pycnocline segment CB4MH water is the occasional storm-induced downwelling event. Given the size of this segment, these events are relatively localized and short-lived. Because the pycnocline so effectively isolates the deeper waters in this segment, along with bottom bathymetry and water circulation patterns, these within-pycnocline waters are designated as deep-water and the below-pycnocline waters are designated as deep-channel designated use habitats.

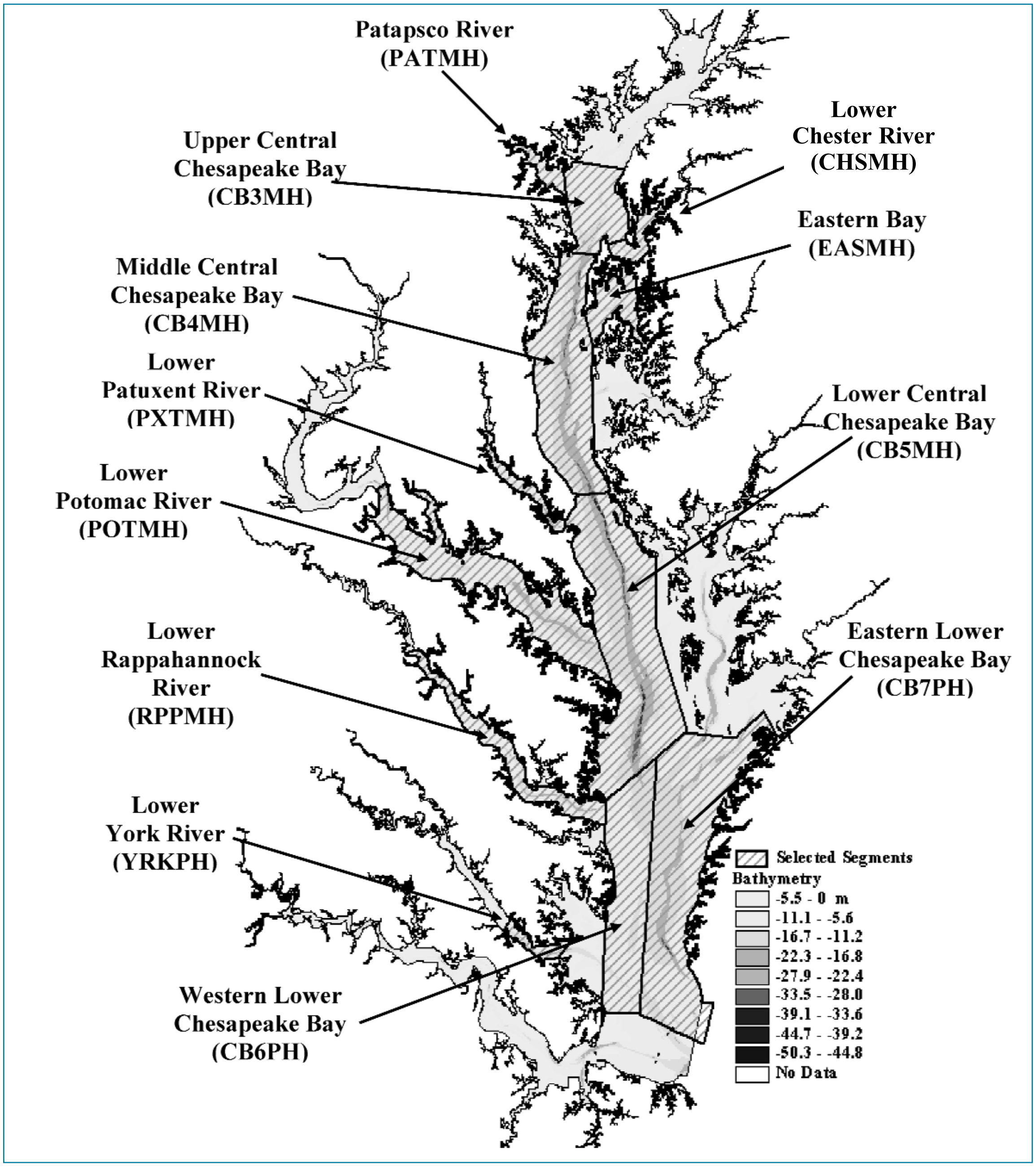

Figure IV-19. Chesapeake Bay Program segments identified as having chronic low dissolved oxygen attributable to the combined effects of pycnocline, bathymetry and flow.

Lower Central Chesapeake Bay

The lower central Chesapeake Bay, or segment CB5MH, encompasses the entire southern half of the Bay's mainstem trench (see Figure IV-19). As in segment CB4MH, the pycnocline in this segment can 'cap' waters in the trench so that the only significant source of exchange is water flowing into the southern end of the trench, beneath the pycnocline. During most of the year, as this source water enters

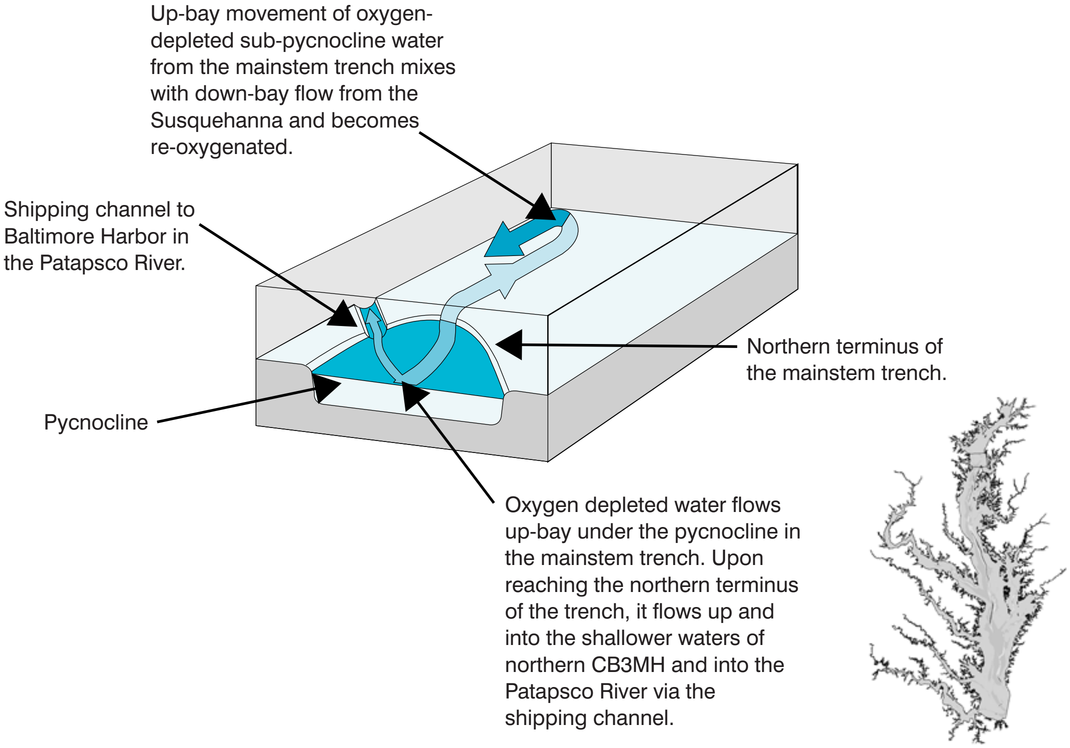

Figure IV-20. Three-dimensional schematic of the northern terminus of the mainstem Chesapeake Bay trench. Flow is depicted by thick arrows. Above and below pycnocline waters are shaded differently. Region depicted is boxed on inset map.

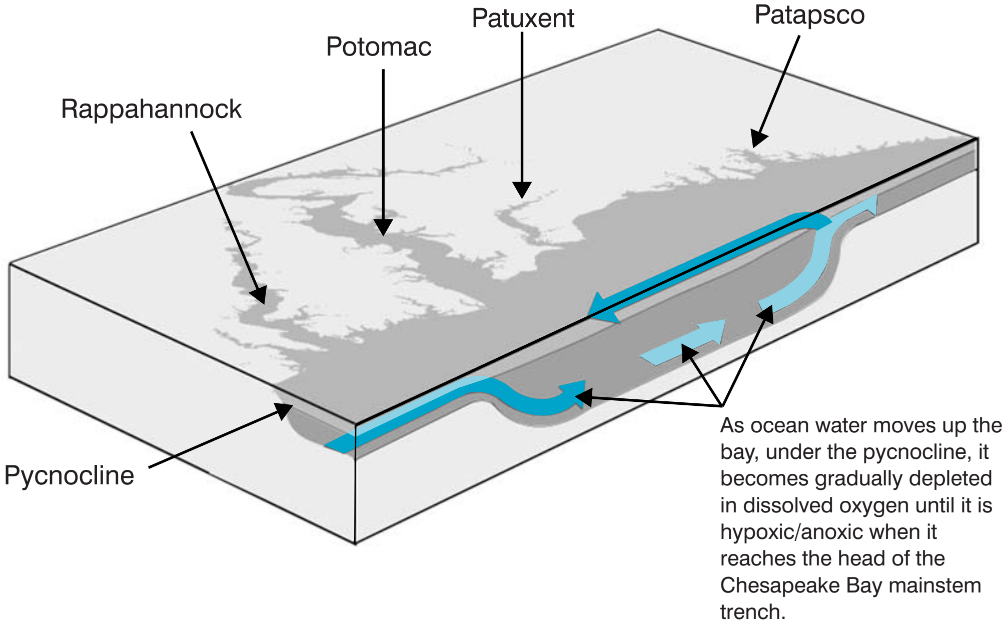

Figure IV-21. Three-dimensional schematic of the hydrodynamics of the Chesapeake Bay mainstem trench. View is from the southeast looking northwest.

the trench, its dissolved oxygen concentration is still relatively undepleted, because it is not far from its ocean source. However, during July and August, temperatures in the southern mainstem Chesapeake Bay can be warm enough and benthic metabolism high enough for this source water to have depleted oxygen supplies (see "Dissolved Oxygen and Temperature" sidebar, above). As this water moves up the trench during the late spring and summer months, metabolic processes under the pycnocline gradually consume the available dissolved oxygen until it is severely depleted by the time it reaches the northern part of segment CB5MH (Figure IV-21). The southern half of segment CB5MH is generally the last part of the Chesapeake Bay mainstem to become oxygen-depleted and the first to become replenished. Because the pycnocline so effectively isolates the bottom waters in this segment, along with bottom bathymetry and water circulation patterns, the within-pycnocline waters are designated as deep-water designated use habitat and the below-pycnocline waters are designated as deep-channel designated use habitat.

Western and Eastern Lower Chesapeake Bay

The western and eastern lower Chesapeake Bay, segments CB6PH and CB7PH, respectively, together make up the broadest region of the Chesapeake Bay mainstem. The entire region is heavily influenced by the ocean. A 17- to 22-meter trench runs along the axis of segment CB7PH, extending from the northern end of the segment almost to its southern boundary (see Figure IV-19). The trench is approximately 2.5 kilometers wide and deepens to an approximately 50-meter hole near its southern terminus. Although the trench becomes capped by a pycnocline, below-pycnocline dissolved oxygen concentrations within the trench are usually not affected. As ocean water flows into the Chesapeake Bay mouth along the bottom, the Coriolis force swings this flow northward along the lower eastern shore of the Chesapeake Bay. This waterflow pattern carries ocean water directly into the trench in segment CB7PH and provides a steady supply of oxygenated water to the below-pycnocline habitats. Ocean water similarly replenishes the below-pycnocline waters of segment CB6PH.

Only the very northern portions of segments CB6PH and CB7PH appear to have a chronic dissolved oxygen depletion problem related to the pycnocline and local bottom bathymetry. The northern boundary of these two segments forms a line, inclining northeastward from the mouth of the Rappahannock River to a point at the southern tip of the islands forming Tangier Sound (see Figure IV-19). The line approximates the location of a broad shoal or sill on the Chesapeake Bay bottom. The sill defines the southern terminus of the mainstem Chesapeake Bay deep trench and functions as a 'hydrologic control point' for waters passing over it.

A shipping channel cuts through the sill, connecting the trench in segment CB7PH to the trench in the middle Chesapeake Bay (Figure IV-22). The channel enables an exchange of oxygen-depleted bottom waters from the mainstem trench with water in the northern portions of segments CB6PH and CB7PH.

Although the overall direction of flow in the bottom layer is northward in this region, the smaller-scale actions of the outgoing tide can pulse bottom waters down-estuary (Figure IV-22). Oxygen-deficient water intrudes on the bottom and as lenses into mid-water depths. This effect can be intensified during a strong north-westerly wind event (see sidebar, “Tides Affected by Moon and Sun” on page 100).

The deep-water designated use, therefore, extends below the sill in these two segments. Its lower boundary runs along a line more or less parallel to, but south of, the northern segment line (Figure IV-23). The delineation of the boundary was determined by examining maps of contemporary dissolved oxygen concentration distributions and the anecdotal historical dissolved oxygen concentration data record.

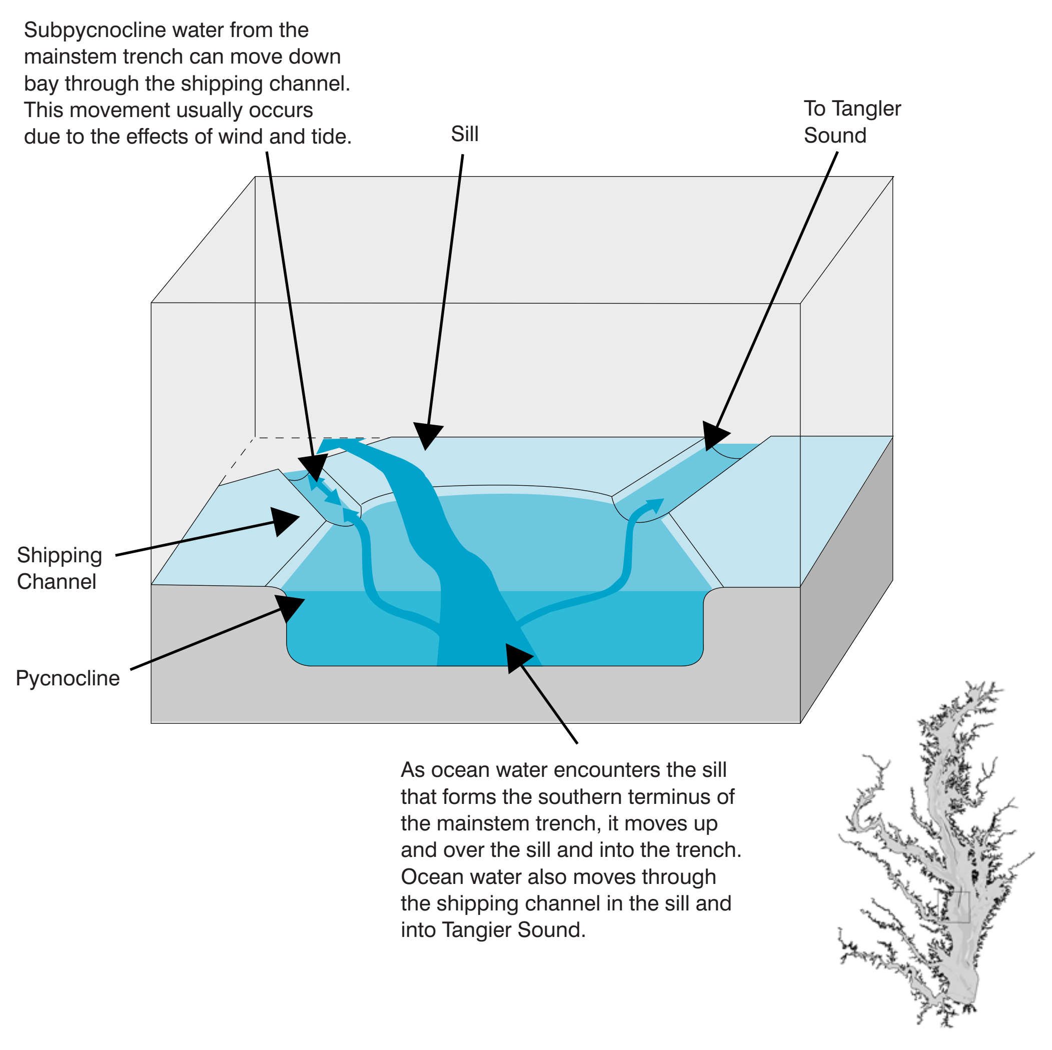

Figure IV-22. Three-dimensional schematic of the hydrodynamics of the northern portion of segments CB6PH and CB7PH. View is from the south. Area portrayed is boxed on the inset map.

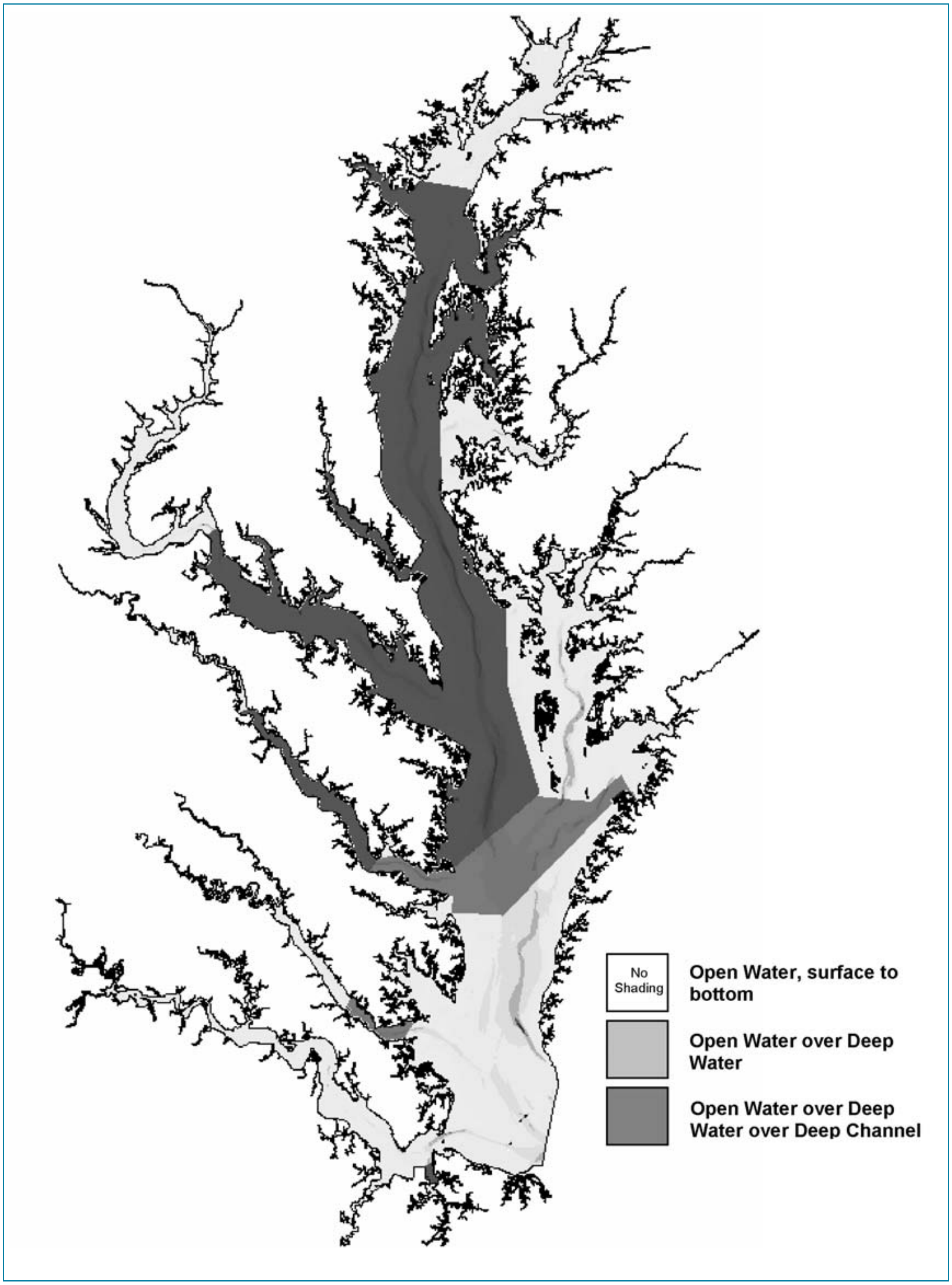

Figure IV-23. Map showing the dissolved oxygen designated uses of the Chesapeake Bay and its tidal tributaries.

Tides Affected By Moon and Sun

Tides are controlled by the gravitational pull of the sun as well as the moon. When the moon and the sun are aligned, such as during a full moon or a new moon, tides achieve their highest highs and lowest lows. This phenomenon is called a 'spring' tide. When the pull of the sun and moon are at right angles, they act to cancel each other out, and tidal amplitude is at its lowest. This is called a 'neap' tide.

The higher amplitude tide that occurs during 'spring' tide results in increased tidal flow. This can be beneficial as when this increased flow advects oxygen rich water into an estuary. Conversely, it can be detrimental if the advected water is coming from deeper waters with low dissolved oxygen.

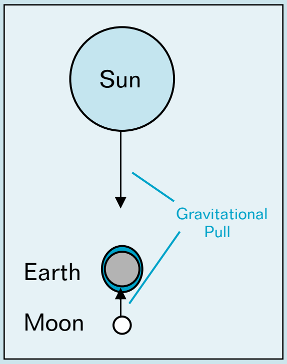

Diagram depicts 'spring' tide alignment of sun and moon.

Patapsco River

The Patapsco River, segment PATMH, is a highly urbanized tidal waterway, home to a large industrial center and one of the largest shipping ports on the eastern seaboard. It is heavily and routinely dredged, and a significant portion of its shoreline has been hardened. Its shipping channel is directly connected to the Chesapeake Bay mainstem trench, allowing for the advection of oxygen-depleted water to its below-pycnocline layer (figures IV-20 and IV-24). The river has a complex three-layer flow structure. The middle, pycnocline waters of the Patapsco River are designated as a deep-water use, and the below-pycnocline waters are designated as a deep-channel use.

Chester River

The downriver, mesohaline portion of the Chester River, segment CHSMH, contains a trench that ranges in depth from 20 to 25 meters (see Figure IV-19). The trench is separated from the mainstem Chesapeake Bay by a sill. This sill can potentially affect dissolved oxygen levels in the deep waters of the trench that are chronically low in the summer months. The pycnocline can form a 'lid' over the trench, cutting off the exchange with surface waters. Because of the sill at the mouth of the river, tidal flushing by bottom waters can be restricted, reducing the replenishment of the bottom waters of the trench as well as the

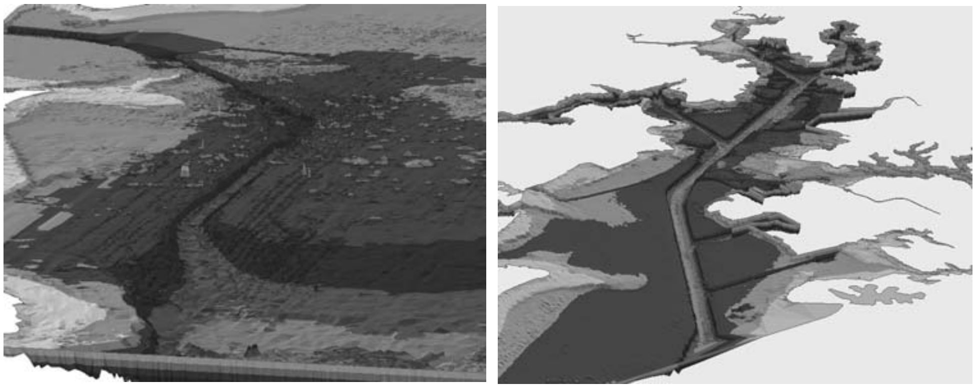

Figure IV-24. The image on the left shows the bathymetry of the shipping channel approach to Baltimore Harbor and how it is connected to the 'head' of the Chesapeake Bay mainstem trench at the bottom of the picture (middle to right side). The image on the right is of the bathymetry of Baltimore Harbor. To improve visualization, the depth versus width relationship has been enhanced.

potential mixing force that the inflow might have. It may also be the case that during extreme (spring) tidal events (see sidebar, "Tides Affected by Moon and Sun," on previous page) low dissolved oxygen bottom water from the mainstem trench is advected into the Chester River trench, where it is sequestered under the pycnocline (Figure IV-25).

When a measurable pycnocline is observed (often due to these 'spill-over events'), the within-pycnocline waters of the lower Chester River (river mouth up to the sill at Ringgold Point on Eastern Neck) have a deep-water designated use, and the below-pycnocline waters have a deep-channel designated use. In the absence of

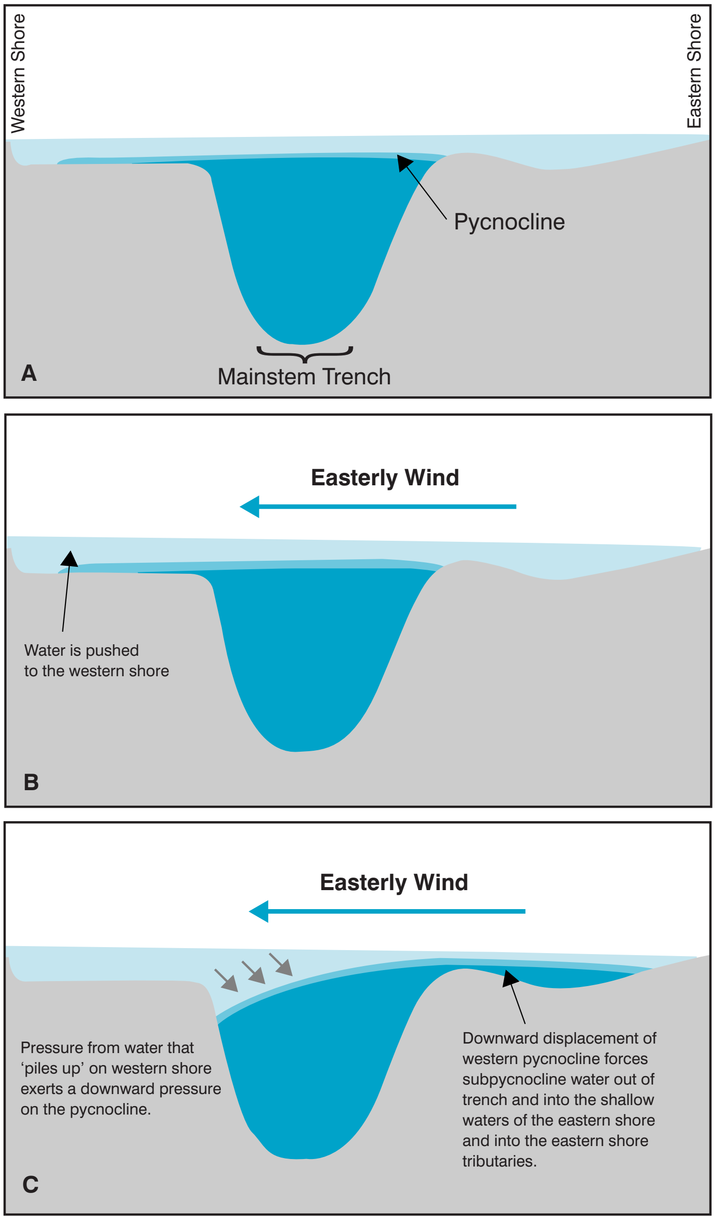

Figure IV-25. Panel A shows the 'normal' state of the pycnocline over the Chesapeake Bay mainstem trench. In Panel B, a strong easterly wind pushes water from the eastern shore to the western shore. As water 'piles up' on the western shore in Panel C, it exerts a downward pressure on the pycnocline there. As the pycnocline is pushed down on the western shore, a pressure differential is created between the west and east shores causing water to be displaced up and out of the Chesapeake Bay mainstem trench and into the shallow waters of the eastern shore and into the eastern shore tributaries. Strong westerly winds result in the opposite phenomena, where the pycnocline tilts in the opposite direction and subpycnocline water is advected to the western shore.

water-column stratification, the open-water designated use will apply throughout the water column to the bottom sediment-water interface in the lower Chester River.

Eastern Bay

In the Eastern Bay, segment EASMH, a trench extends from the river mouth, where it connects with the mainstem trench to a point halfway up the Bay (see Figure IV-19). This connection with the mainstem Chesapeake Bay trench has implications for dissolved oxygen in the bottom waters of lower Eastern Bay, since the below-pycnocline waters of this portion of Eastern Bay and the mainstem Chesapeake Bay trench exchange freely. This region of the mainstem trench has some of the worst dissolved oxygen conditions in the entire Chesapeake Bay. Because of this, below-pycnocline waters in lower Eastern Bay are chronically low in dissolved oxygen in summer. When a measurable pycnocline is observed, the within-pycnocline waters of Eastern Bay have a deep-water designated use and the below-pycnocline waters have a deep-channel designated use (see Figure IV-23). In the absence of water-column stratification, the open-water designated use will apply throughout the water column to the bottom sediment-water interface in Eastern Bay.

Patuxent River

The trench in the lower Patuxent River, segment PXTMH, contains one of the deepest points in the Chesapeake Bay just off of Point Patience. The Patuxent River trench terminates at a sill at the mouth of the river (Figure IV-26). Dissolved oxygen concentrations become depressed beneath the pycnocline in the summer, but not to the degree they do in the mainstem Chesapeake Bay trench. These depressed dissolved oxygen concentrations may be due to pycnocline-disrupting turbulence as the river flows through the constriction at Point Patience. Below-pycnocline dissolved oxygen does not become completely replenished, but these waters do naturally reoxygenate enough to maintain levels high enough for a deep-water designated use (see Figure IV-23). Given the depth of this trench, it is likely that hypoxia is a natural condition below the pycnocline in the summer.

Potomac River

The lower Potomac River trench, located in segment POTMH, extends from the mouth of the river up to Ragged Point and averages 15 to 25 meters deep (see Figure IV-19). A 10- to 15-meter shelf extends from the sides of the trench and connects with a similar region in the mainstem Chesapeake Bay (Figure IV-27). Although the Potomac trench is not connected to the mainstem Bay trench there is not a sill across the mouth of the Potomac. The pycnocline effectively isolates the water volume in the trench from the surface waters. In addition, given the size of the Potomac River watershed, a relatively large amount of organic matter could be delivered to the below-pycnocline waters of the Potomac trench. It is very likely that, due to the size and depth of this deep-water area coupled with strong water-column stratification, low dissolved oxygen conditions are a natural feature of the Potomac trench. The

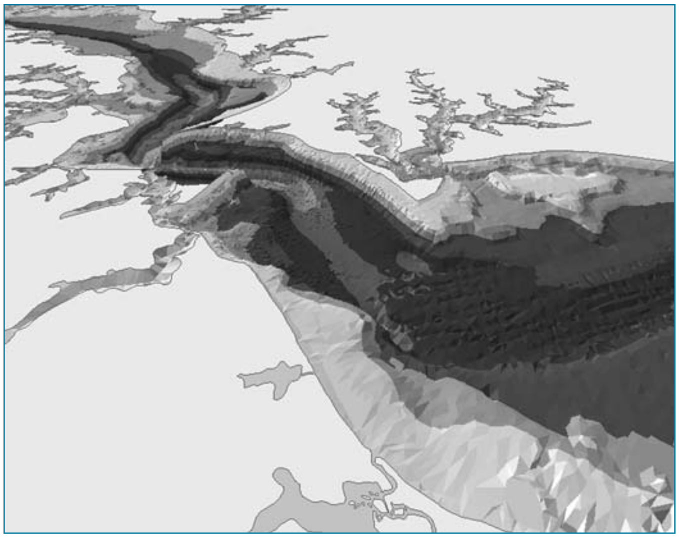

Figure IV-26. Bathymetry at the mouth of the Patuxent River. To improve visualization, the depth relative to the width has been enhanced.

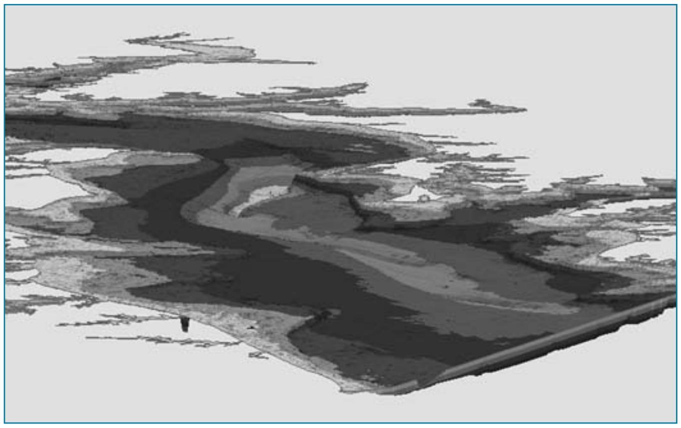

Figure IV-27. Bathymetry at the mouth of the Potomac River. To improve visualization, the depth relative to width has been enhanced.

pycnocline waters of the lower Potomac River (POTMH) have a deep-water designated use and the below-pycnocline waters have a deep-channel designated use (see Figure IV-23).

Rappahannock River

The Rappahannock trench, located in segment RPPMH, extends from the mouth of the Rappahannock River to Belle Isle (see Figure IV-19). The downriver end of the trench terminates in a sill that extends across the mouth of the river. Dissolved oxygen concentrations in the bottom waters of the trench are affected by the formation of the pycnocline. However, bottom water in the upriver half of the trench is more affected than the downriver half. This phenomenon may be related to strong currents flowing in the Rappahannock River along the bottom and over the sill. Chao and Paluskiewicz (1991) found that lower-layer density currents flowing over a sill cause downward mixing upriver of the sill (Figure IV-28). If this downward mixing is occurring in the downriver half of the Rappahannock trench, it would explain why

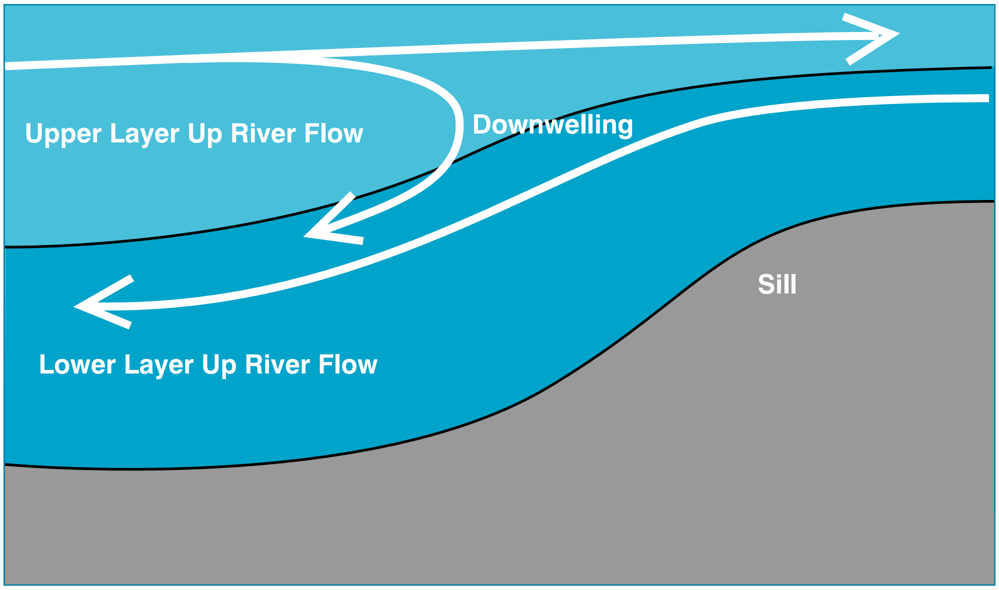

Figure IV-28. Diagram of the hydrodynamics of flow over a sill. As lower layer waters flow over the sill, downwelling surface waters occur.

Source: Chao and Paluszkiewicz 1991.

bottom water dissolved oxygen is less affected by the pycnocline in this region. In the Virginia rivers, bottom layer, upriver flow in the Rappahannock River is second only to that of the James River and is greater, on average, than in the Potomac River (Wang 2003, personal communication). Given this rapid upriver flow beneath the pycnocline, the below-pycnocline waters of the Rappahannock trench are not depleted of dissolved oxygen until they reach the head of the trench. Based on a decadal-scale analysis of dissolved oxygen within the trench, it appears that low dissolved oxygen in the upriver portion is a chronic condition.

Because of the unique hydrodynamics of the lower Rappahannock River, the deep-water and deep-channel designated uses are not uniform across this segment. From the upriver shore of the Corrotoman River to the mouth of the Rappahannock River, the deep-water designated use extends from the upper pycnocline to the bottom sediment-water interface. Upriver of this section to Belle Isle, the pycnocline volume has a deep-water designated use and the below-pycnocline volume a deep-channel designated use (see Figure IV-23).

York River

The York trench, located principally in segment YRKMH, extends from where the York River empties into Mobjack Bay up-river to Kings Creek. A 10-15 meter channel runs from the down-river terminus of the trench, through Mobjack Bay to a point in the mainstem Bay adjacent to the Chesapeake Bay mouth (see Figure IV-19). This channel effectively connects the lower York River to ocean water flowing into the Chesapeake Bay. This connection apparently is a benefit to bottom water dissolved oxygen as concentrations below the pycnocline in this region do not get as low as they do in other below-pycnocline trench areas of the Bay. For this reason, the waters below the upper pycnocline down to the bottom sediment-water interface from the York River mouth to Timberneck Creek have a deep-water designated use (see Figure IV-23).

SHALLOW-WATER BAY GRASS DESIGNATED USE BOUNDARIES

Restoration of underwater bay grasses to acreages supporting "the propagation and growth of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting vegetated shallow-water habitats" is ultimately the best measure of attainment of shallow-water bay grass designated use. Therefore, delineation of the shallow-water designated use boundaries must reflect the desired acreage of underwater bay grass restoration. In shallow-water habitats out to the 2-meter depth contour, the exact shallow-water designated use boundaries can:

- Follow a Chesapeake Bay Program segment-specific depth contour;
- Reflect an established segment-specific acreage of underwater bay grasses to be restored; or
- Match an established segment-specific acreage of shallow-water habitat meeting the water clarity criteria necessary to support achievement of the underwater bay grasses restoration goal acreage.

The Chesapeake Bay Program segment-specific maximum depth of persistent, abundant underwater bay grasses growth sets the initial boundary for the habitat necessary for supporting the shallow-water designated use. That same segment-specific maximum depth was used in combination with the single best year of underwater bay grass distribution mapped across the available 1930-2000 data record to set the new restoration goals on a segment-by-segment basis. Finally, the ratio of the above shallow-water habitat out to the maximum depth of persistent, abundant plant growth and the corresponding segment-specific underwater bay grasses restoration acreage are used to calculate an acreage of shallow-water habitat meeting the water clarity criteria necessary to support achievement of the restoration goal acreage.

The following sections describe and quantify these three approaches to setting the shallow-water designated use boundaries, which are consistent with options the EPA put forth for measuring attainment of the Chesapeake Bay shallow-water underwater bay grass designated use (U.S. EPA 2003). EPA recommends the states adopt one (or more) of the three approaches to defining the shallow-water designated use boundaries in addition to adoption of numerical water clarity criteria into their water quality standards. States can adopt shallow-water designated use boundaries covering higher acreages or greater depths than those provided here during their upcoming water quality standards adoption processes once the expanded river-specific information has become available to be incorporated. During future state triennial reviews of their water quality standards, states also may expand their shallow-water designated use boundaries to reflect resulting levels of restoration of underwater bay grasses in prior years.

MAXIMUM DEPTH OF PERSISTENT OR ABUNDANT PLANT GROWTH-BASED BOUNDARIES

The 2-meter depth contour was selected as the maximum depth for the lower vertical boundary of the shallow-water designated use. This is the maximum depth to which underwater bay grasses could be restored in many of the tidal tributaries and mainstem Chesapeake Bay shallow-water habitats. Although historical underwater bay grass beds in the Chesapeake Bay probably grew to 3 meters or more, the 2-meter depth was chosen following an extensive evaluation of grass bed distribution over the past 70 years (1930s-2000) and of light levels anticipated to be required to restore viable shallow-water habitats out to the 2-meter depth (Batiuk et al. 1992; Dennison et al. 1993; Moore et al. 1999; Batiuk et al. 2000; Moore et al. 2001; Naylor 2002).

The intertidal zone was selected as the inner boundary for the shallow-water bay grass designated use because some species can grow in the upper end of the intertidal zone (Batiuk et al. 2000; Koch 2001). Numerous field studies of underwater bay grass distributions in the Chesapeake Bay and its tidal tributaries have indicated that what is controlling the minimum depth of their distribution is not wave action or other factors, but length of exposure to air at low tide (Moore, unpublished data; Naylor, unpublished data).

Shallow-water habitats also may be offshore flats such as those observed in Tangier Sound and Poquoson Flats in the lower mainstem Chesapeake Bay. These areas may have an inner boundary not in the intertidal zone but rather a relatively deep and wide channel between them and the shore. These areas are included in the delineation of shallow-water bay grass designated use habitats if they have or have had underwater bay grasses and met the decision rules described below.

BENEFITS OF DEEPER UNDERWATER BAY GRASS DISTRIBUTION

There are obvious benefits to restoring underwater bay grasses to greater depths than where they currently exist in the Chesapeake Bay and its tidal tributaries (Table IV-10). Increasing the depth and, therefore, the areal distribution of the grasses can greatly increase the habitat and food available to the Chesapeake Bay's fish, crabs and waterfowl.

It is important to note that underwater bay grass distribution is directly related to the tidal bathymetry of the basins in which the beds occur. In a shallow bay with a gradual slope to deeper waters, such as the Chesapeake Bay, even a moderate increase in water clarity can result in tremendous increases in the areal extent of bay grasses.

Table IV-10. Ecological and water quality benefits of deeper underwater bay grasses distribution in the Chesapeake Bay and its tidal tributaries.

- Ensures growth of underwater bay grasses where previously there may have been none because wave energy at shallower depths prevented plants from rooting in the bottom sediments (e.g., the beds that formerly grew on the western side of Kent Island, Maryland, at depths greater than where the critical wave energy threshold exists);
- Adds habitat below the grazing depth of non-native mute swans and non-migratory Canada geese (approximately 1 and 0.5 meters, respectively) to increase food availability for native waterfowl;
- Reduces the likelihood of ice damage to the beds;
- Reduces the negative effects of unusually low tides;
- Minimizes thermal stress (as deeper beds are inherently cooler);
- Stabilizes sediments at greater depths (through the reduction of water velocity within the underwater bay grass beds);
- Increases overall nutrient uptake and supports increased denitrification;
- Increases summertime oxygen production (which is particularly important in the headwaters of tidal creeks); and
- Increases habitat for fish, crabs and macroinvertebrates.

HISTORICAL UNDERWATER BAY GRASS DISTRIBUTION

The distribution and, therefore, the depth of historical underwater bay grass beds were mapped from photographs dating from the late 1930s through the mid-1960s by scientists at the Maryland Department of Natural Resources and the Virginia Institute of Marine Science. Historical underwater bay grass distribution data from Maryland and Virginia were aggregated into a single data set using ArcInfo GIS software. The two states' approaches reflect differences in the quality and quantity of historical aerial photographs available for interpretation. Full documentation of the methods employed and the detailed results are reported in Moore et al. (1999, 2001) and Naylor et al. (2002).

To determine historic underwater bay grass acreage, aerial photos of Maryland's portion of the Bay taken in 1938, 1952, 1957 and 1964 were evaluated to determine the year in which the most underwater bay grass was visible for each area (Naylor 2002). The photos for the year of greatest abundance in each area were then scanned, geo-referenced and photo-interpreted to determine the extent of underwater bay grass beds during these years.

In the Virginia portion of the Chesapeake Bay and its tidal tributaries, historical underwater bay grass acreage in the James River was mapped using photographs taken in 1937, 1947, 1948, 1953, 1954, 1958, 1959, 1963, 1968, 1969, 1970 and

1973, with the historical coverage defined by the composite of the individual years (Moore et al. 1999). Historical and recent ground survey results were superimposed on the maps of historical underwater bay grass distributions to help determine whether the patterns exhibited in the photographs were actually those of underwater bay grass beds (Moore et al. 1999).

For the Rappahannock and York rivers and the adjacent smaller western shore rivers, creeks and embayments, a series of photographs from 1952 to 1956 was chosen to delineate the maximum coverage of bay grasses in these areas (Moore et al. 2001). The 1936 and 1937 photographs of these rivers showed less underwater bay grass coverage compared to the 1950s photographs. The difference appeared to be related to poorer overall atmospheric and water clarity conditions (Moore et al. 2001).

The interpretation of these historic aerial photographs closely followed current methods to delineate underwater bay grass beds throughout the Chesapeake Bay and its tidal tributaries through annual aerial underwater bay grass surveys (e.g., Orth et al. 2000). In neither state did a single year of photography provide comprehensive coverage of each state's tidal shorelines.

These state-specific analyses provide a *conservative* estimate of past underwater bay grass distributions prior to the 1970s. The conservative nature of the estimate is due, in part, because the older photographs were not collected specifically to map underwater bay grasses, but were gathered to assist in analyzing land use or farming practices. While atmospheric criteria were usually met, the factors that are important for delineating and mapping underwater bay grasses (such as tidal stage, water transparency and plant growth stage) often were not met. Underwater bay grasses likely grew at greater depths between the 1930s and 1960s, according to published and anecdotal information, than was observed in a number of segments in the historical photographs. Grasses that grow beyond the 1-meter depth contour become increasingly difficult to map, given the conditions under which the historical photographs were collected. There were limited numbers of years—often only three to five—for which historical photographs of a particular shallow-water habitat region were available for interpretation and mapping between the 1930s and early 1970s. Evidence suggests that underwater bay grass distributions already had declined by the time photographs of suitable quality were available for interpretation (Moore et al. 1999). All of these factors led to conservative estimates of past underwater bay grasses distributions and depths of bed growth.

UNDERWATER BAY GRASS NO-GROW ZONES

A series of underwater bay grass 'no-grow zones' were originally delineated in 1992 in the *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis* (Batiuk et al. 1992). Habitats exposed to high wave energy or that have undergone physical modifications such that they could not support underwater bay grasses growth were excluded based on an extensive review of data available at the time. With the mapping of historical underwater bay grass distributions, a composite of available distribution data from the 1930s through 2001 was superimposed on the 1992 bay grass no-grow zones. A number of shoreline habitats previously considered no-grow zones showed clear evidence of historical underwater bay grass growth and, therefore, their no-grow zone designation was dropped. These revised underwater bay grass no-grow zones also include areas where the no-grow zone applies to a 1- to 2-meter depth contour as well as a 0- to 2-meter depth contour.

The revised underwater bay grass no-grow zones illustrated in Figure IV-29 show shoreline habitats of 2 meters or less where underwater bay grasses are never expected to grow due to:

- Extreme physical wave energy, which prevents the plants from rooting in the bottom sediments (e.g., Calvert Cliffs on Maryland's lower western shore and Willoughby Split to Cape Henry near the Chesapeake Bay mouth in Virginia);
- Permanent physical alterations to nearshore habitats, including dredging close to shore accompanied by hardening of the shoreline and installation of permanent structures (i.e., shipping terminals) as observed in the inner Baltimore Harbor and the Elizabeth River;
- Natural, extreme discoloration of the water from tidal-fresh wetlands (e.g., tidal-fresh 'blackwater' rivers on the Eastern Shore); or
- No functional shallow-water habitat due to natural river channeling (e.g., tidal headwaters of several lower Eastern Shore rivers).

These underwater bay grass no-grow zones reflect the full set of findings on underwater bay grasses distributions from the historical (select years from the 1930s–early 1970s) and 1978–2001 data records, as well as altered nearshore/shoreline habitats as described above. The no-grow zones illustrated in Figure IV-29 are based on the best available information and are subject to future revision based on new research and information.

If no physical reasons prevent underwater bay grasses from growing in a specific shallow-water habitat, it should be expected that grasses can grow there, given appropriate water quality conditions and local sources of propagules (i.e., reproductive vegetative materials such as seeds and rhizomes). For example, evidence exists of underwater bay grasses growing within estuarine turbidity maximum zones in the upper Chesapeake Bay mainstem and selected tidal tributaries (e.g., the Potomac River), but not in other tidal tributaries. The *Regional Criteria* provides specific guidance to the states on how to address estuarine turbidity maximum zones in applying the Chesapeake Bay water clarity criteria (see Chapter 7 in U.S. EPA 2003). The lack of historical data on the presence of underwater bay grasses in a particular habitat is not a valid reason to delineate that shallow-water area as an underwater bay grass no-grow zone.

Figure IV-29. Map illustrating the revised underwater bay grass no-grow zones of the Chesapeake Bay and its tidal tributaries.

Six Chesapeake Bay Program segments were not assigned a shallow-water bay grass designated use depth boundary (see Table IV-13). The established bay grass no-grow zones covered the 2-meter and less habitats along the entire tidal shoreline in each of these segments–upper Choptank River, upper Pocomoke River, Western Branch Elizabeth River, Southern Branch Elizabeth River, Eastern Branch Elizabeth River and Lafayette River (see Appendix C).

DETERMINING THE MAXIMUM DEPTH OF PERSISTENT/ABUNDANT PLANT GROWTH

The first step in the process to define the maximum depth of persistent and abundant underwater bay grass beds by Chesapeake Bay Program segment (Table IV-11, Figure IV-30) was to establish decision rules. The rules developed take full advantage of the entire record of underwater bay grass distribution and abundance survey data and reflect the findings published in scientific literature (Table IV-12). Also, the decision rules help ensure full consistency between the establishment of the shallow-water bay grass designated use depths (the depth at which the Chesapeake Bay water clarity criteria will be applied) and the new quantitative underwater bay grasses acreage restoration goal for Chesapeake Bay and its tidal tributaries.

The available data record included interpreted aerial photography from the 1930s to the early 1970s as well as the annual baywide aerial survey data from 1978-2000. From these photos and surveys, the acreage of underwater bay grasses within three depth intervals was calculated for every Chesapeake Bay Program segment: 0-0.5 meters, > 0.5-1 meter and > 1-2 meters (Appendix B, Table B-1). Thus, each Chesapeake Bay Program segment has three 'segment-depth intervals' (e.g., CB4MH 1-2 meter is a segment-depth interval).

The total surface area within each segment-depth interval minus any delineated underwater bay grass no-grow zones is an estimate of the area of potential underwater bay grass habitat in that segment-depth interval. Thus, there is an acreage of potential underwater bay grass habitat for each of the three segment-depth intervals in every Chesapeake Bay Program segment except for those segments that are entirely no-grow zones (Appendix C, Table C-1).

The decision rules described in Table IV-12 are based on the observed single best year of underwater bay grass coverage for each Chesapeake Bay Program segment (i.e., not the single best year by segment-depth) (Appendix B, Table B-2). Using each segment's single best year, the percentage of available habitat at each segment-depth interval that was occupied by underwater bay grasses in that single best year was calculated (Appendix B, Table B-3). That percentage is a measure of the relative importance of each segment-depth interval as bay grass habitat. Upon application of the decision rules (Table IV-12), a set of Chesapeake Bay Program segment-specific shallow-water designated use depths was generated (Table IV-13).

Rationale for the 20 Percent and 10 Percent Rules

In setting application depths, it was important to select a percentage of cover high enough to assure that underwater plants definitely occupied that habitat, but low enough that the resulting depths realistically represented true light availability attained during the available historical data record. Underwater bay grass beds in tidal waters of the Chesapeake Bay display a spatial heterogeneity that is characteristic of underwater grass beds elsewhere in the world (Lehmann et al.1997; Kuenen and Debrot 1995; Carpenter and Titus 1984). This heterogeneity exists both in micro

Table IV-11. Chesapeake Bay Program segmentation scheme segments.

Northern Chesapeake Bay	CB1TF
Upper Chesapeake Bay	CB2OH
Upper Central Chesapeake Bay	CB3MH
Middle Central Chesapeake Bay	CB4MH
Lower Central Chesapeake Bay	CB5MH
Western Lower Chesapeake Bay	CB6PH
Eastern Lower Chesapeake Bay	CB7PH
Mouth of the Chesapeake Bay	CB8PH
Bush River	BSHOH
Gunpowder River	GUNOH
Middle River	MIDOH
Back River	BACOH
Patapsco River	PATMH
Magothy River	MAGMH
Severn River	SEVMH
South River	SOUMH
Rhode River	RHDMH
West River	WSTMH
Upper Patuxent River	PAXTF
Western Branch Patuxent River	WBRTF
Middle Patuxent River	PAXOH
Lower Patuxent River	PAXMH
Upper Potomac River	POTTF
Anacostia River	ANATF
Piscataway Creek	PISTF
Mattawoman Creek	MATTF
Middle Potomac River	POTOH
Lower Potomac River	POTMH
Upper Rappahannock River	RPPTF
Middle Rappahannock River	RPPOH
Lower Rappahannock River	RPPMH
Corrotoman River	CRRMH
Piankatank River	PIAMH
Upper Mattaponi River	MPNTF
Lower Mattaponi River	MPNOH
Upper Pamunkey River	PMKTF
Lower Pamunkey River	PMKOH
Middle York River	YRKMH
Lower York River	YRKPH
Mobjack Bay	MOBPH
Upper James River	JMSTF
Appomattox River	APPTF
Middle James River	JMSOH
Chickahominy River	CHKOH
Lower James River	JMSMH
Mouth of the James River	JMSPH
Western Branch Elizabeth River	WBEMH
Southern Branch Elizabeth River	SBEMH
Eastern Branch Elizabeth River	EBEMH
Lafayette River	LAFMH
Mouth to mid-Elizabeth River	ELIPH
Lynnhaven River	LYNPH
Northeast River	NORTF
C&D Canal	C&DOH
Bohemia River	BOHOH
Elk River	ELKOH
Sassafras River	SASOH
Upper Chester River	CHSTF
Middle Chester River	CHSOH
Lower Chester River	CHSMH
Eastern Bay	EASMH
Upper Choptank River	CHOTF
Middle Choptank River	CHOOH
Lower Choptank River	CHOMH1
Mouth of the Choptank River	CHOMH2
Little Choptank River	LCHMH
Honga River	HNGMH
Fishing Bay	FSBMH
Upper Nanticoke River	NANTF
Middle Nanticoke River	NANOH
Lower Nanticoke River	NANMH
Wicomico River	WICMH
Manokin River	MANMH
Big Annemessex River	BIGMH
Upper Pocomoke River	POCTF
Middle Pocomoke River	POCOH
Lower Pocomoke River	POCMH
Tangier Sound	TANMH

Source: Chesapeake Bay Program 1999.

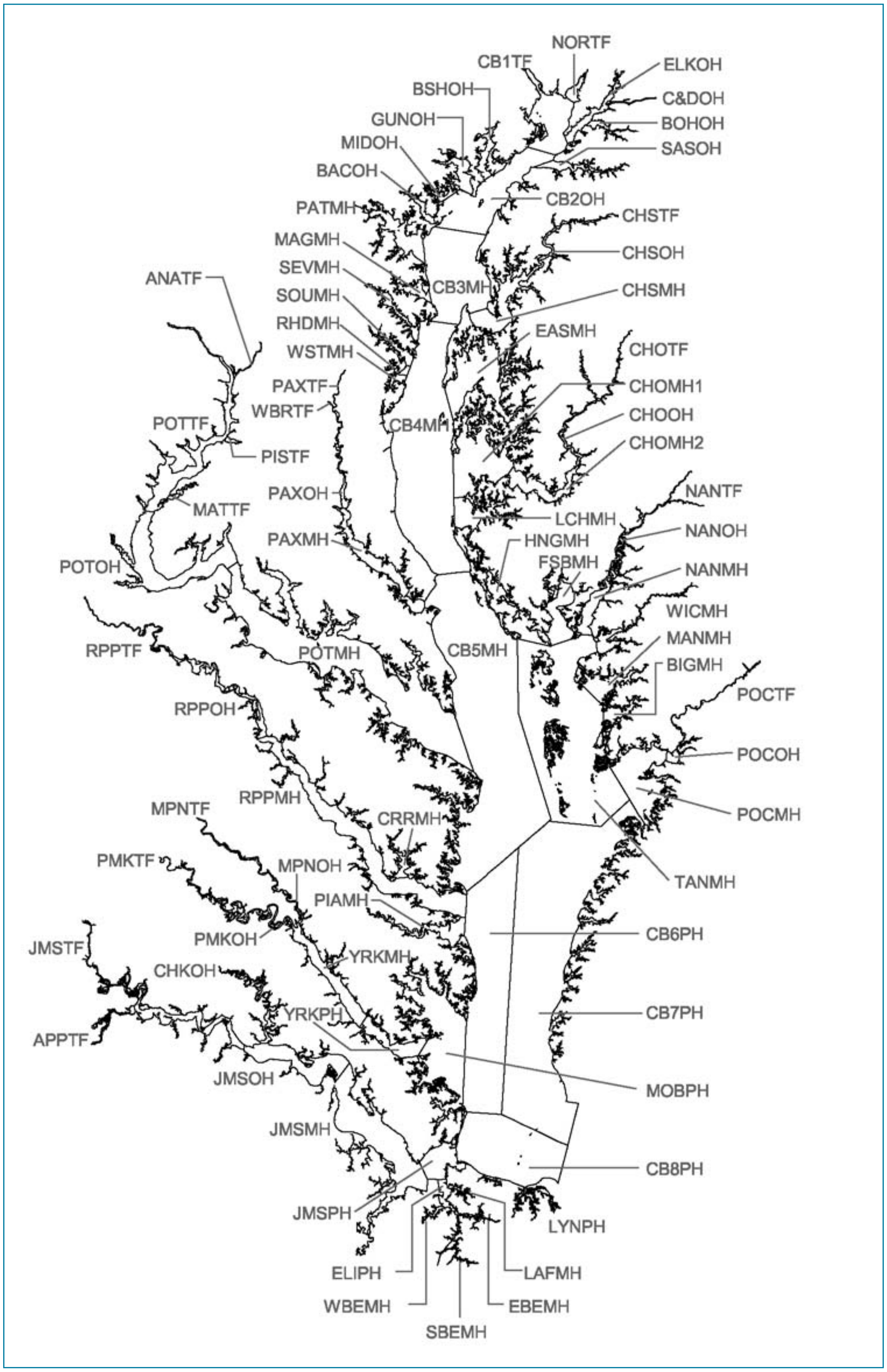

Figure IV-30. The geographical location of the 78 Chesapeake Bay Program segments.

Source: Chesapeake Bay Program 1999.

Table IV-12. Methodology used in determining the shallow-water bay grass designated use depths by Chesapeake Bay Program segment, which led to the establishment of the 185,000 Chesapeake Bay baywide underwater grasses restoration goal.

The baywide underwater bay grass goal acreage was established based on the single best year acreage out to a shallow-water bay grass designated use depth determined as follows:

1. Bathymetry data and aerial photographs were used to divide the mapped single best year underwater bay grasses acreage in each Chesapeake Bay Program segment into three depth zones: 0-0.5 meters, > 0.5-1 meters and >1-2 meters. The delineated underwater bay grass no-grow zones were then removed from consideration as shallow-water bay grass designated use habitat.
2. The aerial photographs were used to determine the depth to which the mapped underwater bay grass beds grew in each Chesapeake Bay Program segment with either a minimum abundance or minimum persistence. The underwater bay grass goal for a Chesapeake Bay Program segment is the portion of the single best year acreage mapped out to the higher depth in the determined depth range. The decision rules for this process were as follows:

   In all segments, the 0-0.5 meter depth interval was designated for shallow-water bay grass use. In addition, the shallow-water bay grass use was designated for deeper depths within a Chesapeake Bay Program segment if either:

   A) The single best year of underwater bay grasses distribution covered at least 20 percent of the potential habitat in a deeper depth interval; or,

   B) The single best year of underwater bay grass distribution covered at least 10 percent of the potential habitat in the segment-depth interval, and at least 3 of the 4 five-year periods of the more recent record (1978–2000) showed at least 10 percent underwater bay grasses coverage of potential habitat in the segment-depth interval.
3. The single best year underwater bay grasses distribution acreage of all Chesapeake Bay Program segments were clipped at the deeper depth of the segment-depth interval determined above. The resulting underwater bay grass acreage for each segment were added, resulting in the total baywide underwater bay grass acreage goal of 185,000 acres.

and macro scales, and as viewed by aerial photography results in a spatial distribution that is virtually never 100 percent coverage of available shallow-water habitat at any depth. This growth pattern was true historically as well. Manning (1957) estimated that lower Patuxent River underwater bay grass beds covered only about one-third of shoal waters. Photography from Maryland from 1938 and 1952 revealed an average percent cover of 35 percent (Naylor 2002) at depths of less than 1 meter. Virginia photographic analysis revealed up to 48 percent coverage in the York and Rappahannock rivers at the less than 1-meter depth (Moore et al. 2001). These findings were supported by similar findings from analysis of the more recent 1978–2000 Chesapeake Bay underwater bay grass aerial survey distribution data.

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Northern Chesapeake Bay	CB1TF	Historical			▲	2
Upper Chesapeake Bay	CB2OH	Historical	✪			0.5
Upper Central Chesapeake Bay	CB3MH	1978	▲			0.5
Middle Central Chesapeake Bay	CB4MH	Historical			▲	2
Lower Central Chesapeake Bay	CB5MH	Historical			▲	2
Western Lower Chesapeake Bay	CB6PH	Historical		▲		1
Eastern Lower Chesapeake Bay	CB7PH	Historical			▲	2
Mouth of the Chesapeake Bay	CB8PH	1996	✪			0.5
Bush River	BSHOH	Historical	✪			0.5
Gunpowder River	GUNOH	2000			▲	2
Middle River	MIDOH	Historical			▲	2
Back River	BACOH	*	✪			0.5
Patapsco River	PATMH	Historical		▲		1
Magothy River	MAGMH	Historical		▲		1
Severn River	SEVMH	1999		▲		1
South River	SOUMH	Historical		▲		1
Rhode River	RHDMH	Historical	✪			0.5
West River	WSTMH	Historical	▲			0.5
Upper Patuxent River	PAXTF	1996	▲			0.5
Western Branch (Patuxent River)	WBRTF	*	✪			0.5
Middle Patuxent River	PAXOH	2000	✪			0.5
Lower Patuxent River	PAXMH	Historical		▲		1
Upper Potomac River	POTTF	1991			✜	2
Anacostia River	ANATF	1991	✪			0.5
Piscataway Creek	PISTF	1987			▲	2
Mattawoman Creek	MATTF	2000		▲		1
Middle Potomac River	POTOH	1998			✜	2

continued

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Lower Potomac River	POTMH	Historical		▲		1
Upper Rappahannock River	RPPTF	2000	✪			0.5
Middle Rappahannock River	RPPOH	*	✪			0.5
Lower Rappahannock River	RPPMH	Historical		▲		1
Corrotoman River	CRRMH	Historical		▲		1
Piankatank River	PIAMH	Historical			▲	2
Upper Mattaponi River	MPNTF	1998	✪			0.5
Lower Mattaponi River	MPNOH	*	✪			0.5
Upper Pamunkey River	PMKTF	1998	✪			0.5
Lower Pamunkey River	PMKOH	*	✪			0.5
Middle York River	YRKMH	Historical	✪			0.5
Lower York River	YRKPH	Historical		▲		1
Mobjack Bay	MOBPH	Historical			▲	2
Upper James River	JMSTF	Historical	✪			0.5
Appomattox River	APPTF	Historical	▲			0.5
Middle James River	JMSOH	1998	✪			0.5
Chickahominy River	CHKOH	2000	✪			0.5
Lower James River	JMSMH	Historical	✪			0.5
Mouth of the James River	JMSPH	Historical		▲		1
Western Branch Elizabeth River	WBEMH	*	❖	❖	❖	*
Southern Branch Elizabeth River	SBEMH	*	❖	❖	❖	*
Eastern Branch Elizabeth River	EBEMH	*	❖	❖	❖	*
Lafayette River	LAFMH	*	❖	❖	❖	*
Mouth to mid-Elizabeth River	ELIPH	*	✪			0.5
Lynnhaven River	LYNPH	1986	✪			0.5
Northeast River	NORTF	Historical	✪			0.5
C&D Canal	C&DOH	1978	✪			0.5

continued

Table IV-13. The single best year and maximum depth interval for applying the water clarity criteria used in determining the Chesapeake Bay Program segment-specific shallow-water underwater bay grass designated use boundary depths *(cont.)*.

Chesapeake Bay Program (CBP) Segment Name	CBP Segment	Single Best Year	Maximum Depth Interval Application of the Water Clarity Criteria (meters)			Recommended Shallow-Water Designated Use Depth (meters)
			0–0.5	0.5–1	1–2	
Bohemia River	BOHOH	2000	✪			0.5
Elk River	ELKOH	2000			▲	2
Sassafras River	SASOH	2000		▲		1
Upper Chester River	CHSTF	*	✪			0.5
Middle Chester River	CHSOH	Historical	✪			0.5
Lower Chester River	CHSMH	Historical		▲		1
Eastern Bay	EASMH	Historical			▲	2
Upper Choptank River	CHOTF	*	❖	❖	❖	*
Middle Choptank River	CHOOH	Historical	✪			0.5
Lower Choptank River	CHOMH2	Historical		▲		1
Mouth of the Choptank River	CHOMH1	Historical			▲	2
Little Choptank River	LCHMH	Historical			▲	2
Honga River	HNGMH	Historical			▲	2
Fishing Bay	FSBMH	Historical	✪			0.5
Upper Nanticoke River	NANTF	*	✪			0.5
Middle Nanticoke River	NANOH	Historical	✪			0.5
Lower Nanticoke River	NANMH	Historical	✪			0.5
Wicomico River	WICMH	Historical	✪			0.5
Manokin River	MANMH	Historical			▲	2
Big Annemessex River	BIGMH	Historical			▲	2
Upper Pocomoke River	POCTF	*	❖	❖	❖	*
Middle Pocomoke River	POCOH	*	✪			0.5
Lower Pocomoke River	POCMH	Historical		▲		1
Tangier Sound	TANMH	Historical			▲	2

✪ Decision rules not met – default depth interval of 0-0.5 meters applies.
▲ Single best year percent of total potential habitat is 20 percent.
✜ Percent of total potential habitat is 10-19.9% and underwater bay grasses are persistent (1978–2000).
❖ Chesapeake Bay Program segment completely within the underwater bay grass no-grow zone.
*Denotes no data available or no underwater bay grasses mapped (1930s-2000).

Several possible reasons account for less-than-complete habitat occupation. These include small-scale sediment type differences, small-scale sediment movement patterns, sediment slope, fetch, uneven seed distribution and localized disturbance. In addition to these reasons for real variations in plant presence, only the most dense areas of underwater bay grasses are visible using high-altitude photography. Very sparse beds reveal no signature in the water and are never delineated through photo interpretation. Each year, Chesapeake Bay researchers and resource managers find dozens of underwater bay grass beds in places not identified in the annual aerial survey due to these limitations. Thus, reporting of percent coverage is generally lower than the total amount of habitat actually occupied by sparse plant beds, which further lowers the total percent coverage. Given the starting point of 1 percent, and the typical maximum of 35-48 percent from the historical photography, 20 percent was seen as a defensible midpoint figure reflective of sufficient coverage to define maximum depth of the underwater bay grasses growth (Moore 1999, 2001; Naylor 2002).

In order to provide an additional measure of the importance of a segment-depth interval as underwater bay grass habitat, the record of underwater bay grass aerial survey data from 1978–2000 (there is not a survey for every year between 1979-1983 and in 1988) was segmented into four five-year intervals (Appendix B, Table B-4). The persistence of underwater bay grasses in each segment-depth interval was then assessed by counting the number of five-year intervals in which at least 10 percent of potential habitat was occupied by underwater bay grasses (see Table IV-12).

UNDERWATER BAY GRASS RESTORATION GOAL-BASED BOUNDARIES

The *Chesapeake 2000* agreement committed to revising the existing underwater bay grass restoration goals and strategies:

> *. . . to reflect historic abundance, measured as acreage and density from the 1930s to present. The revised goals will include specific levels of water clarity which are to be met in 2010. Strategies to achieve these goals will address water clarity, water quality and bottom disturbance.*

The eligible segments and depths included in calculating the new underwater bay grass restoration goal were limited to segment-depth intervals designated for shallow-water bay grass use. The new restoration goal was derived from the total single best year acreage summed over all the segment depths that were designated for shallow-water bay grass use after considering a wide array of data and information (Figure IV-31).

Data Used to Establish the Restoration Goal

It was essential to use historical underwater bay grass data in determining the underwater bay grass acreage goal for the Chesapeake Bay. But using these data presented obvious limitations. They were originally collected for agricultural landuse mapping purposes and thus did not include all areas of tidal shallow-water habitats, which

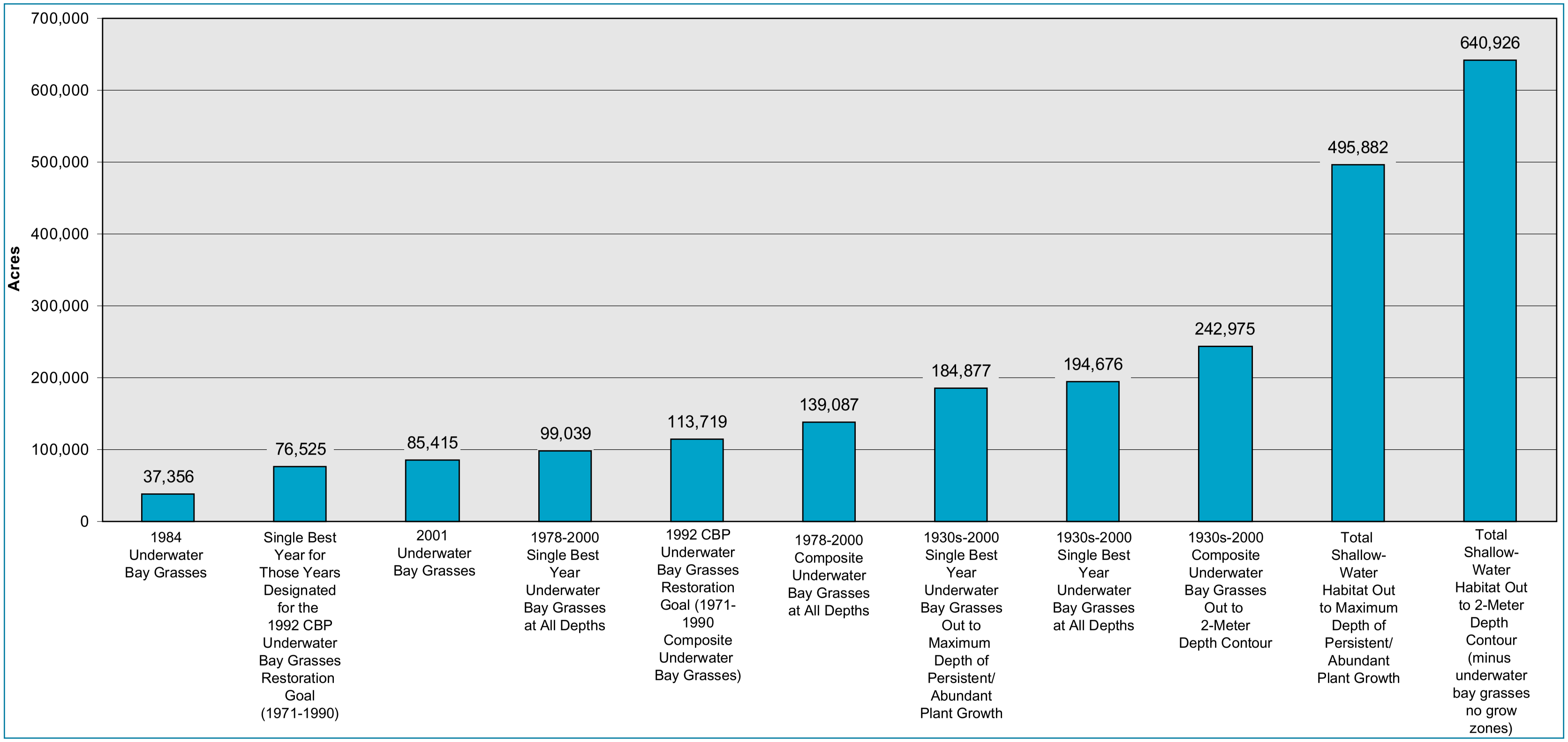

Figure IV-31. Array of different underwater bay grass and shallow-water habitat acreages considered during the process for setting the shallow-water designated use depth and establishing the new Chesapeake Bay underwater bay grass restoration goals.

Sources: Moore et al. 1999; Naylor 2002; Virginia Institute of Marine Science Chesapeake Bay SAV website http://www.vims.edu/bio/sav; Chesapeake Bay Program website http://www.chesapeakebay.net.

resulted in an underestimate of the mapped acreage. Historic data also were limited by the fact that pre-Hurricane Agnes (June 1972) underwater bay grass data exist only for a limited number of years in each Chesapeake Bay Program segment. Thus, using only historical data to determine a new goal would likely underestimate the potential for underwater bay grass recovery.

Rationale for Use of the Single Best Year

The single best year of underwater bay grass growth observed in each Chesapeake Bay Program segment from the entire available record of aerial photographs (1930s–2000) is the best available data on underwater bay grass occurrence over the long-term. Of the 62 Chesapeake Bay Program segments with mapped underwater bay grasses, 68 percent of the segment single best year acreages occurred in the 1930s to early 1970s time period; 3 percent occurred in 1978; 5 percent occurred between 1986 and 1991; and 24 percent occurred between 1996 and 2000 (see Table IV-13).

There were several obvious benefits in using the single best year approach to setting the new restoration goal. The single best year acreage is the most solid available data on underwater bay grass acreage over the multi-decade data record. Even in suitable water quality conditions, underwater bay grass beds often move around within a segment. By combining acreage over a number of years into a composite acreage it would be possible to overestimate the likely future abundance of underwater bay grasses in any single year.

Using the single best year as the basis for the new restoration goal ensures consistency with the method for determining the segment-specific shallow-water designated use depths and the resulting water clarity criteria application depths. The consistency between methods links the segment-specific water clarity application depths, shallow-water designated use boundaries and underwater bay grass restoration goals. This method is scientifically valid because when the acreage goals for segments in the same salinity range are totaled (see "Shallow-Water Habitat Area to Support Restoration," below), the percentage of available habitat covered by the restoration goal acreage is consistent with the average rate of habitat occupancy described in the scientific literature as reflecting healthy underwater bay grass growth.

The new underwater bay grass goal focuses the restoration effort on areas that demonstrated a minimal level of abundance or persistence in the past and which are likely to respond to water clarity improvements in the future. Focusing on the single best year versus a composite underwater bay grass coverage ensures that vegetated portions of potential underwater bay grass habitats are not over-accounted-for based on underwater bay grass beds that may have 'migrated' year-to-year over the past seven decades.

New Underwater Bay Grass Restoration Goal

Table IV-14 lists the Chesapeake Bay Program segment-specific single best year acreage within the shallow-water bay grasses designated use depths that, added together, make up the baywide 185,000 acre restoration goal.

Table IV-14. Chesapeake Bay underwater bay grass restoration goals by Chesapeake Bay Program segment.

Segment Name	Segment	Single Best Year	Acres
Northern Chesapeake Bay	CB1TF	Historical	12,908
Upper Chesapeake Bay	CB2OH	Historical	302
Upper Central Chesapeake Bay	CB3MH	1978	943
Middle Central Chesapeake Bay	CB4MH	Historical	2,511
Lower Central Chesapeake Bay	CB5MH	Historical	14,961
Western Lower Chesapeake Bay	CB6PH	Historical	980
Eastern Lower Chesapeake Bay	CB7PH	Historical	14,620
Mouth of the Chesapeake Bay	CB8PH	1996	6
Bush River	BSHOH	Historical	158
Gunpowder River	GUNOH	2000	2,254
Middle River	MIDOH	Historical	838
Back River	BACOH	*	0
Patapsco River	PATMH	Historical	298
Magothy River	MAGMH	Historical	545
Severn River	SEVMH	1999	329
South River	SOUMH	Historical	459
Rhode River	RHDMH	Historical	48
West River	WSTMH	Historical	214
Upper Patuxent River	PAXTF	1996	5
Western Branch (Patuxent River)	WBRTF	*	0
Middle Patuxent River	PAXOH	2000	68
Lower Patuxent River	PAXMH	Historical	1,325
Upper Potomac River	POTTF	1991	4,368
Anacostia River	ANATF	1991	6
Piscataway Creek	PISTF	1987	783
Mattawoman Creek	MATTF	2000	276
Middle Potomac River	POTOH	1998	3,721
Lower Potomac River	POTMH	Historical	10,173
Upper Rappahannock River	RPPTF	2000	20
Middle Rappahannock River	RPPOH	*	0
Lower Rappahannock River	RPPMH	Historical	5,380
Corrotoman River	CRRMH	Historical	516
Piankatank River	PIAMH	Historical	3,256
Upper Mattaponi River	MPNTF	1998	75
Lower Mattaponi River	MPNOH	*	0
Upper Pamunkey River	PMKTF	1998	155
Lower Pamunkey River	PMKOH	*	0
Middle York River	YRKMH	Historical	176
Lower York River	YRKPH	Historical	2,272
Mobjack Bay	MOBPH	Historical	15,096

continued

Table IV-14. Chesapeake Bay underwater bay grass restoration goals by Chesapeake Bay Program segment *(cont.)*.

Segment Name	**Segment**	**Single Best Year**	**Acres**
Upper James River	JMSTF	Historical	1,600
Appomattox River	APPTF	Historical	319
Middle James River	JMSOH	1998	7
Chickahominy River	CHKOH	2000	348
Lower James River	JMSMH	Historical	531
Mouth of the James River	JMSPH	Historical	604
Western Branch Elizabeth River	WBEMH	*	0
Southern Branch Elizabeth River	SBEMH	*	0
Eastern Branch Elizabeth River	EBEMH	*	0
Lafayette River	LAFMH	*	0
Mouth to mid-Elizabeth River	ELIPH	*	0
Lynnhaven River	LYNPH	1986	69
Northeast River	NORTF	Historical	88
C&D Canal	C&DOH	1978	0
Bohemia River	BOHOH	2000	97
Elk River	ELKOH	2000	1,648
Sassafras River	SASOH	2000	764
Upper Chester River	CHSTF	*	0
Middle Chester River	CHSOH	Historical	63
Lower Chester River	CHSMH	Historical	2,724
Eastern Bay	EASMH	Historical	6,108
Upper Choptank River	CHOTF	*	0
Middle Choptank River	CHOOH	Historical	63
Lower Choptank River	CHOMH2	Historical	1,499
Mouth of the Choptank River	CHOMH1	Historical	8,044
Little Choptank River	LCHMH	Historical	3,950
Honga River	HNGMH	Historical	7,686
Fishing Bay	FSBMH	Historical	193
Upper Nanticoke River	NANTF	*	0
Middle Nanticoke River	NANOH	Historical	3
Lower Nanticoke River	NANMH	Historical	3
Wicomico River	WICMH	Historical	3
Manokin River	MANMH	Historical	4,359
Big Annemessex River	BIGMH	Historical	2,014
Upper Pocomoke River	POCTF	*	0
Middle Pocomoke River	POCOH	*	0
Lower Pocomoke River	POCMH	Historical	4,092
Tangier Sound	TANMH	Historical	37,965
Total acres			**184,889**

*No underwater grasses recorded for any year within the available 1930s–2000 data record.

SHALLOW-WATER HABITAT AREA TO SUPPORT RESTORATION GOAL-BASED BOUNDARIES

As described previously, the restoration of underwater bay grasses within a segment requires that shallow-water habitat meet the Chesapeake Bay water clarity criteria over a greater acreage than the underwater bay grasses will actually cover. The ratio of underwater bay grass acreage to the required shallow-water habitat acreage varies based on the different species of underwater bay grasses that inhabit the Bay's four salinity regimes. Shallow-water habitat acreage ratios have been derived scientifically through evaluation of extensive underwater bay grasses distribution data within tidal fresh, low, medium and high salinity regimes (reflecting different levels of coverage by different underwater bay grass communities).

The Chesapeake Bay Program segment-specific restoration goal acreage and corresponding shallow-water designated use acreage (to the previously determined maximum depth of abundant and persistent underwater plant growth) listed in Table IV-15 were summed by major salinity regime–tidal fresh (0-0.5 ppt), oligohaline (> 0.5-5 ppt), mesohaline (> 5ppt-18 ppt) and polyhaline (>18 ppt).[13] The underwater bay grasses acreage to shallow-water habitat acreage ratios were then expressed as a percentage of the total shallow-water designated use habitat. Compared with a baywide value of 38 percent, the tidal-fresh (37 percent), mesohaline (39 percent) and polyhaline (41 percent) values were all very close to the baywide value as well as the other salinity regime-specific values (Table IV-16). These values are consistent with findings published in the scientific literature and the 35 to 48 percent range derived from evaluation of the 1930s through early 1970s historical data record by Naylor (2002) and Moore (1999, 2001). Influenced by the natural presence of the estuarine turbidity maximum, the value was 21 percent in oligohaline habitats.

CONFIRMING THAT THE REFINED DESIGNATED USES MEET EXISTING USES

The EPA Water Quality Standards regulations at 40 CFR 131.10(g) and (j) specify that states may remove a designated use that is not an existing use, or establish subcategories of a use, if they can demonstrate that attaining the designated use is not feasible. The current regulation at 40 CFR Part 131 identifies the factors that must be considered in making such a demonstration. As the regulation explains, existing uses, by definition, are attainable and must be protected by designated uses in water quality standards (40 CFR 131.10[g], 131.10[h][1] and 131.10[i]). Any

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[13] Note that all Chesapeake Bay Program segments have been assigned to one of the four salinity regimes based on an evaluation of almost two decades of salinity data. The segment-naming convention documents each individual segment's long-term averaged respective salinty regime: TF = tidal fresh, OH = oligohaline, MH = mesohaline, and PH = polyhaline.

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Northern Chesapeake Bay	CB1TF	7979	7773	12,908	20,907	61.7	2
Upper Chesapeake Bay	CB2OH	203	640	302	2405	12.5	0.5
Upper Central Chesapeake Bay	CB3MH	1	1,296	943	2,011	46.9	0.5
Middle Central Chesapeake Bay	CB4MH	112	176	2,511	10,630	23.6	2
Lower Central Chesapeake Bay	CB5MH	4,487	4,240	14,961	29,959	49.9	2
Western Lower Chesapeake Bay	CB6PH	715	1,208	980	3,939	24.9	1
Eastern Lower Chesapeake Bay	CB7PH	9,168	10,729	14,620	33,304	43.9	2
Mouth of the Chesapeake Bay	CB8PH	8	11	6	381	1.5	0.5
Bush River	BSHOH	3	187	158	1,136	13.9	0.5
Gunpowder River	GUNOH	*	2,281	2,254	7,358	30.6	2
Middle River	MIDOH	*	698	838	2,479	33.8	2
Back River	BACOH	*	0	0	850	0.0	0.5
Patapsco River	PATMH	*	114	298	1,802	16.6	1
Magothy River	MAGMH	*	427	545	1,378	39.6	1
Severn River	SEVMH	120	433	329	1347	24.4	1
South River	SOUMH	27	50	459	1,432	32.1	1
Rhode River	RHDMH	*	14	48	267	18.0	0.5
West River	WSTMH	*	106	214	542	39.5	0.5
Upper Patuxent River	PAXTF	205	44	5	24	22.2	0.5
Western Branch (Patuxent River)	WBRTF	*	0	0	0	0.0	0.5
Middle Patuxent River	PAXOH	104	80	68	1,072	6.3	0.5
Lower Patuxent River	PAXMH	22	108	1,325	5121	25.9	1
Upper Potomac River	POTTF	1,964	4,465	4,368	17,501	25.0	2
Anacostia River	ANATF	4	11	6	85	6.6	0.5

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Piscataway Creek	PISTF	*	783	783	914	85.7	2
Mattawoman Creek	MATTF	*	311	276	695	39.7	1
Middle Potomac River	POTOH	3,070	3,766	3,721	15,193	24.5	2
Lower Potomac River	POTMH	1739	2130	10173	26075	39.0	1
Upper Rappahannock River	RPPTF	66	30	20	2175	0.9	0.5
Middle Rappahannock River	RPPOH	*	0	0	1226	0	0.5
Lower Rappahannock River	RPPMH	478	841	5,380	19,793	27.2	1
Corrotoman River	CRRMH	389	419	516	1,819	28.4	1
Piankatank River	PIAMH	539	1,003	3,256	8,014	40.6	2
Upper Mattaponi River	MPNTF	*	84	75	800	9.4	0.5
Lower Mattaponi River	MPNOH	*	0	0	358	0.0	0.5
Upper Pamunkey River	PMKTF	140	184	155	1,860	8.4	0.5
Lower Pamunkey River	PMKOH	*	0	0	420	0.0	0.5
Middle York River	YRKMH	*	0	176	4,728	3.7	0.5
Lower York River	YRKPH	801	815	2272	4,949	45.9	1
Mobjack Bay	MOBPH	9,508	10,653	15096	33990	44.4	2
Upper James River	JMSTF	95	76	1,600	8,249	19.4	0.5
Appomattox River	APPTF	*	0	319	1,085	29.4	0.5
Middle James River	JMSOH	15	8	7	3179	0.2	0.5
Chickahominy River	CHKOH	268	422	348	3283	10.6	0.5
Lower James River	JMSMH	2	3	531	9,618	5.5	0.5
Mouth of the James River	JMSPH	232	231	604	1,616	37.4	1
Western Branch Elizabeth River	WBEMH	*	0	0	0	0.0	*
Southern Branch Elizabeth River	SBEMH	*	0	0	0	0.0	*

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Eastern Branch Elizabeth River	EBEMH	*	0	0	0	0.0	*
Lafayette River LAFMH	*	0	0	0	0.0	*	
Mouthof the Elizabeth River	ELIPH	*	0	0	0	0.0	*
Lynnhaven River	LYNPH	43	105	69	2476	2.8	0.5
Northeast River	NORTF	*	19	88	456	19.3	0.5
C&D Canal	C&DOH	7	5	0	99	0.2	0.5
Bohemia River	BOHOH	354	330	97	735	13.2	0.5
Elk River	ELKOH	2034	2006	1,648	5,024	32.8	2
Sassafras River	SASOH	1,169	1,116	764	2614	29.2	1
Upper Chester River	CHSTF	*	0	0	574	0	0.5
Middle Chester River	CHSOH	*	0	63	926	6.8	0.5
Lower Chester River	CHSMH	205	2,369	2,724	6,980	39	1
Eastern Bay	EASMH	2,886	4,610	6,108	20,805	29.4	2
Upper Choptank River	CHOTF	*	0	0	0	0.0	*
Middle Choptank River	CHOOH	*	0	63	591	10.7	0.5
Lower Choptank River	CHOMH2	148	193	1,499	3,770	39.8	1
Mouth of the Choptank River	CHOMH1	5,257	6,445	8,044	20,857	38.6	2
Little Choptank River	LCHMH	2,377	1,454	3,950	12,367	31.9	2
Honga River	HNGMH	4,945	4,656	7,686	16,456	46.7	2
Fishing Bay	FSBMH	6	59	193	2,467	7.8	0.5
Upper Nanticoke River	NANTF	*	0	0	0	0.0	*
Middle Nanticoke River	NANOH	*	0	3	1,141	0.3	0.5
Lower Nanticoke River	NANMH	*	0	3	1583	0.2	0.5
Wicomico River	WICMH	*	0	3	1,513	0.2	0.5

continued

Table IV-15. Summary of Chesapeake Bay underwater bay grass and shallow-water designated use acreage and goals *(cont.)*.

Chesapeake Bay Program Segment Name	CBP Segment	2001 Underwater Bay Grass Acreage	Existing Use Acreage (1978–2000 Single Best Year)	Restoration Goal Acreage	Shallow-Water Acreage to Maximum Depth of Persistent/Abundant Plant Growth	Percent Shallow-Water Designated Use Habitat Covered by Restoration Goal Acreage	Shallow-Water Designate Use Depth
Manokin River	MANMH	404	420	4,359	10,700	40.7	2
Big Annemessex River	BIGMH	721	546	2,014	5,065	39.8	2
Upper Pocomoke River	POCTF	*	0	0	0	0.0	*
Middle Pocomoke River	POCOH	*	0	0	289	0.0	0.5
Lower Pocomoke River	POCMH	1,528	1,831	4,092	9,936	41.2	1
Tangier Sound	TANMH	13,310	17,688	37,965	68,578	55.4	2
Totals		**77,854**	**100,701**	**184889**	**491,968**		

*No underwater bay grasses mapped or aerial photography collected due to 9/11/01 flight path restrictions.

Table IV-16. Percent of shallow-water designated use habitat covered by single best year underwater bay grass acreage by salinity regime.

	Tidal-Fresh	Oligohaline	Mesohaline	Polyhaline
Median	37.2	20.5	39.2	41.3
Minimum	0	0	0.2	1.5
Maximum	85.7	33.8	54.3	45.9
No. of Segments	14	20	29	7

change in designated uses must show that the existing uses are still being protected. As the EPA 1983 Water Quality Standards Handbook describes, an existing use can be defined as fishing, swimming or other uses that have actually occurred since November 28, 1975; or the water quality that is suitable to allow the use to be attained—unless there are physical factors, such as substrate or flow, that prevent the use from being attained (U.S. EPA 1983). Section 131.12(a)(1) in turn requires state anti-degradation policies to protect existing water quality. This paragraph applies a minimum level of protection to all waters. In setting the five subcategories of current tidal-water designated uses, explicit steps were taken in developing the refined uses and their boundaries to ensure that existing aquatic life uses would continue to be protected.

MIGRATORY SPAWNING AND NURSERY EXISTING USE

The migratory fish spawning and nursery designated use will be protected by a set of Chesapeake Bay-specific dissolved oxygen criteria that are more protective—6 mg/l 7-day mean and 5 mg/l instantaneous minimum–than current state water quality standards that apply to these same habitats from February 1 through May 31 (U.S. EPA 2003). Existing uses within the migratory fish spawning and nursery habitats will continue to be protected.

SHALLOW-WATER EXISTING USE

In delineating the shallow-water use, the single best year of underwater bay grass distribution mapped since the 1930s was used to define a shallow-water designated use depth, underwater bay grass restoration goal and a corresponding shallow-water habitat acreage to support achievement of the restoration goal for each respective Chesapeake Bay Program segment. Most of the segment-specific restoration goal acreage is higher than the established existing use underwater bay grass acreage derived from the single best year of the 1978-2001 data record out to the maximum depth of abundant/persistent underwater plant growth (see Table IV-15). In those cases where the existing use acreage is higher than the restoration goal, the existing use acreage will drive the shallow-water designated use boundary. As most of the single best years were based on historical underwater bay grass distributions (1930s through the early 1970s), the shallow-water bay grass uses existing since 1975 will continue to be protected.

OPEN-WATER EXISTING USE

The application of the open-water fish and shellfish designated use dissolved oxygen criteria will provide an equal level of protection to the same tidal waters as current state water quality standards. The combined set of 5 mg/l 30-day mean, 4 mg/l 7-day mean, and 3 mg/l instantaneous minimum have been documented to protect all life stages of open-water habitat species in the Chesapeake Bay and its tidal waters (U.S. EPA 2003). Existing uses within the open-water habitats will continue to be protected.

DEEP-WATER AND DEEP-CHANNEL EXISTING USES

The application of the deep-water seasonal fish and shellfish designated use and the deep-channel seasonal refuge designated use and their respective oxygen criteria will result in improvements to existing water quality conditions that currently do not attain the applicable criteria (see Chapter V). Given that trends in dissolved oxygen conditions have been generally degrading since the early 1970s (see Chapter III; Hagy 2002), improvements to these conditions will ensure that existing uses within the deep-water and deep-channel habitats will continue to be protected.

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chapter vi

Summary and Economic Analyses

In developing revised water quality criteria, designated uses and boundaries for those uses in the Chesapeake Bay and its tidal tributaries, the Chesapeake Bay Program used tiered scenarios of pollution controls to model water quality responses to varying levels of technology-based implementation. Although these scenarios do not represent actual management strategies that will be employed by states in achieving water quality standards (states are likely to find more cost-effective mixes of controls for achieving target reductions), the Chesapeake Bay Program partners sought to provide the public with information on the potential costs and effects associated with these different levels of effort.

This chapter summarizes three economic analyses that the Chesapeake Bay Program has performed—estimated costs, screening-level and economic impacts and benefits—which are documented in *Economic Analyses Associated with the Identification of Chesapeake Bay Designated Uses and Attainability* (U.S. EPA 2003). In particular, Part I of the *Economic Analyses* provides estimates of the total annual cost of achieving the three levels of controls (the Tier 1 through 3 scenarios presented in Chapter V) based on the costs of best management practices (BMPs) to remove nitrogen and phosphorus loads to the Chesapeake Bay. This cost information includes total capital cost requirements, and to the extent that information could be compiled, estimates of how these costs may be shared between the public and private sectors.

It is important to note, however, that the Chesapeake Bay Program partners did not use these economic analyses to show why the current designated uses to protect aquatic life in the Chesapeake Bay tidal waters are not attainable (Chapter III); to define the refined designated uses and boundaries presented in Chapter IV; or to assess attainability of the refined designated uses (Chapter V). Rather, the analyses are intended to provide information to assist the jurisdictions during their tributary strategy and water quality standards development processes.

ESTIMATED COSTS

The Chesapeake Bay Program estimated the costs of implementing three levels of controls captured in the Tier 1 through 3 scenarios. These are just three scenarios in what could be an infinite number of combinations of reduction actions. The Chesapeake Bay Program developed them by layering available reduction technologies and not by combining the most cost-effective mix of controls. Therefore, the costs may represent a near-worst case estimate of what will actually be incurred to meet the dissolved oxygen criteria. Not only are the types and combinations of nutrient reduction measures artificial, but when nutrient reduction costs will be incurred or how these reduction measures will be funded also is unknown. The Chesapeake Bay Program did not estimate costs for the E3 scenario because the reduction measures in this scenario are not physically plausible in all cases.

Implementation of sediment-related BMPs likely to be necessary to meet the water clarity criteria for underwater bay grass protection were not included in the tier scenarios, and thus their costs are not estimated, beyond what is inherently removed through nutrient reduction measures. Costs to meet the chlorophyll *a* criteria also are not included beyond those actions included in the tiers because these were published as narrative criteria, which provide no single value around which to determine reduction requirements or costs. In the process of setting the new nutrient and sediment cap load allocations, the Chesapeake Bay Program partners determined that, for the most part, reduction actions to meet the dissolved oxygen criteria defined by the tiers will be sufficient to meet anticipated region-specific numerical chlorophyll *a* criteria, except in certain local situations that will require individual state evaluations.

The tier scenarios include controls on publicly-owned treatment works, industrial facilities, forestry, agriculture, municipal storm water and onsite waste management systems sources of nitrogen and phosphorus to the Chesapeake Bay. Costs for publicly-owned treatment works and industrial sources (more than 330 combined sources) were based on facility-provided estimates and engineering calculations based on methods developed by the Chesapeake Bay Program's Nutrient Removal Technology Task Force and documented in *Nutrient Reduction Technology Cost Estimations for Point Sources in the Chesapeake Bay Watershed* (Chesapeake Bay Program 2003). The Nutrient Removal Technology Task Force generally accepted estimates provided by facilities 'as is' during the development of point source costs. Some documentation of the cost estimates, particularly for the largest facilities, is provided in the appendix to the report. Further review and refinement of these costs is left to states should they pursue additional economic analyses associated with revised adoption of water quality standards for the Chesapeake Bay tidal waters.

Costs for urban, agriculture, forestry and onsite system BMPs are based on the units (e.g., acres) of BMP implementation in each tier scenario and BMP-specific estimates of capital and operation and maintenance costs. The Chesapeake Bay Program performed an extensive literature search to estimate such costs. To estimate the costs for the onsite system denitrification BMP, the Chesapeake Bay Program collected data from manufacturers of such technology. The Chesapeake Bay Program gave preference to well-documented sources and studies in or near the Chesapeake Bay watershed and typically used a simple average of the estimated costs from appropriate sources.

Aside from controls specified in Tier 1 for the District of Columbia, the tier scenarios do not include controls on combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) because these sources are regulated separately, and costs are associated with the protection of human health parameters such as fecal coliform reduction. However, the Chesapeake Bay Program partners recognize that Bay watershed municipalities required to implement CSO and SSO measures will bear the burden of the additional cost, and such information will be relevant to the jurisdictions in assessing the total costs that certain cities may incur. Furthermore, it is recognized that there must be priority funding decisions to accommodate CSO/SSO and nutrient removal technology improvements at the federal, state and local levels of government. The appendices to the separately published *Economic Analyses* document (U.S. EPA 2003) include additional information on potential CSO and SSO costs.

Table VI-1 summarizes the total capital and annual operating and maintenance costs associated with the tier scenarios. The estimates for each tier are cumulative costs beyond what has already been expended up to the year 2000 (including already funded publically-owned treatment works upgrades). The estimates include costs to businesses and households as well as federal and state governments that provide funding for nutrient controls through cost-share programs, with existing cost-share programs alone possibly accounting for almost one-third of annual costs. Total capital costs represent total initial expenditures to achieve the level of control or degree of BMP implementation specified for each scenario. However, these costs will not be incurred in any single year but will be spread across many years though gradual implementation and financing. Similarly, total annual costs represent those

Table VI-1. Estimated cumulative costs and pollutant loading reductions.

Scenario	Total Nitrogen/Total Phosphorus Reduction from Levels in 2000 (millions of pounds per year)[1]	Total Capital Costs (in millions of 2001 dollars)[2]	Total Annual Costs (in millions of 2001 dollars)[3]
Tier 1	23.9	$1,442	$198
Tier 2	63.5	$3,644	$555
Tier 3	104.0	$7,975	$1,138

1. Loadings based on Phase 4.3 of the Chesapeake Bay Program's Watershed Model.
2. Costs include those paid by private-sector businesses and households in addition to those paid by public entities that provide cost-share funding for nutrient reduction controls and BMPs.
3. Total annual costs include amortized capital costs plus operating and maintenance costs.

at full implementation of the scenarios. Therefore, actual annual costs in the years prior to meeting the full implementation goals are expected to be lower.

A number of limitations and uncertainties are associated with the estimated costs. These considerations are described in detail in the separately published *Economic Analyses* document (U.S. EPA 2003). In addition, as noted above, the tier scenarios are not likely representative of any actual tributary strategy that states will adopt, nor do they represent the most cost-effective mix of controls possible.

SCREENING-LEVEL IMPACT ANALYSIS

One of the factors that states may consider in evaluating use attainability is whether controls more stringent than those required by sections 30l(b)(l)(A) and (B) and 306 of the Clean Water Act would result in substantial and widespread economic and social impacts. The EPA's *Interim Economic Guidelines for Water Quality Standards Workbook* (U.S. EPA 1995) provides detailed worksheets and guidance for evaluating whether meeting water quality standards would result in such impacts. Before embarking on the analysis of widespread impacts, the Chesapeake Bay Program did not implement this guidance for the tier scenarios because of the tremendous amount of data and resources required to do so. However, the Chesapeake Bay Program's UAA Workgroup performed a screening analysis to rule out areas that would not experience such negative effects. The screening analysis is based on the cost of each tier, although the tier scenarios likely do not represent the actual control strategies that will be employed by states, and the Chesapeake Bay Program's estimated costs of these scenarios are not precise values.

The Chesapeake Bay Program partners decided not to draw conclusions regarding affordability based on the screening analysis for several reasons. First, the analyses are screening-level, and do not represent the type required to support a claim of substantial and widespread economic and social impacts.[14] Second, the tier scenarios do not necessarily reflect a cost-effective mix of controls, which would be necessary to support a claim of substantial and widespread economic and social impacts. Finally, as discussed above, the estimated costs do not accurately reflect when costs will be incurred, or how such reduction measures will be funded. On a regional, state or large watershed scale, economic impacts can be mitigated by cost-share, loans and new federal or state funding programs. Therefore, the screening analyses may not indicate the actual potential for impacts. Analysis of the socioeconomic impacts associated with meeting water quality standards is best performed during the process of establishing tributary strategies, with more accurate information on actual reduction measures and costs within the respective jurisdictions.

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[14] The *Economic Analyses Associated with the Identification of Chesapeake Bay Designated Uses and Attainability* (U.S. EPA 2003) provides information for jurisdictions on the types of information and economic analyses they would need to conduct and submit as part of a UAA.

The screening analysis does provide some comparative information at the county level throughout the Chesapeake Bay watershed. This analysis consists of 12 county-level variables or ratios designed to indicate whether either substantial or widespread economic and social impacts would be likely (Table VI-2). For some sectors, the ratios indicate when the estimated control costs are small relative to household incomes and, therefore, substantial impacts are unlikely. For other sectors, the ratios indicate whether the sector is small relative to the local economy and, therefore, widespread impacts are unlikely. Because these screening variables cannot indicate when substantial and widespread impacts would occur, the report also directs states regarding the types of information and economic analyses that they would need to conduct and submit to support such a claim.

The screening analysis provides information, in addition to the modeling results described previously (see "Estimated Costs," above*)*, related to evaluating whether the tier scenarios would result in substantial and widespread impacts. Although the

Table VI-2. Screening-level impact analysis variables.

	Impact Condition	
Sector	**Substantial (Financial)**	**Widespread**
POTWs	Current household sewer rate plus average new household cost/median household income	None
Industrial	None	Percent of county earnings from industrial sectors containing affected facilities/total county earnings
Agriculture	• Average BMP costs/net cash return; • Crop plus portion of hay BMP costs/ crop plus hay sales; • Livestock plus portion of hay BMP costs/ livestock sales; and • Average BMP costs/median household income.	Percent of county earnings from agriculture, agriculture services, food and kindred products, and tobacco sectors/total county earnings
Forestry	None	Percent of county earning from forestry and logging/total county earnings
Urban Average	BMP costs/median household income	None
POTWs and urban	Total sewer costs (current plus new) plus average urban BMP cost/median household income	None
Onsite Treatment Systems	Average BMP costs/median household income	Percent of households affected in county

Chesapeake Bay Program partners did not use this information to delineate boundaries for the designated refined uses, this information may be useful for states as they conduct their own UAAs. The information may also be valuable for determining where additional funding, possibly in the form of government cost-shares or loans, would be most useful, or in determining the most appropriate level of funding assistance.

ECONOMIC IMPACTS AND BENEFITS

As stated previously, when evaluating use attainability, states may consider whether controls more stringent than those required by sections 30l(b)(l)(A) and (B) and 306 of the Clean Water Act would result in substantial and widespread economic and social impacts. The EPA's National Center for Environmental Economics (NCEE) offers economic models that can estimate changes in the value of regional output or goods produced, employment and wages and income, providing information on the widespread socio-economic effects of pollution controls. Estimating potential economic benefits also is integral to understanding the economic impacts of improving water quality in the Chesapeake Bay and its tidal tributaries.

Using economic models allows the evaluation of baseline conditions in the future as well as the direct and indirect effects of expenditures on pollution controls. Although the tier scenarios likely do not represent the actual control strategies that will be employed by states, and the Chesapeake Bay Program's estimated costs of these scenarios are not precise values, the Chesapeake Bay Program wanted to provide states with this type of information (such as baseline forecasts and direct and indirect impacts). To provide this information, the NCEE used a regional forecasting model developed by Regional Economic Modeling, Inc. (REMI), and an economic impact model (IMPLAN) from the Minnesota IMPLAN Group. The NCEE used IMPLAN to estimate the socio-economic changes resulting from the estimated expenditures; the REMI model provides a baseline forecast (for one state) over the next decades without tier scenario implementation.

The IMPLAN model indicates that the Tier 3 scenario would result in a net increase in output, employment, and value-added in the six Chesapeake Bay watershed states and the District of Columbia. In addition, the REMI model forecasts that gross regional product in the State of Maryland will grow by 37 percent by 2010, corresponding to 19 percent growth in employment and 17 percent growth in real disposable personal income. This estimated growth is not accounted for in the IMPLAN results (which are based on current economic conditions). The economic stimulus from Tier 3 results from increased spending in high-wage industries (e.g., wastewater treatment technologies) as well as an influx of funds for pollution controls (e.g., federal cost shares for agricultural BMPs); additional market benefits likely to result from improved water quality (e.g., commercial and recreational fishing industries) are not included. Therefore, the regional economy should expand as a result of the tier scenarios.

Some members of the Chesapeake Bay Program's UAA Workgroup raised the issue of other potential social impacts stemming from limits on wastewater treatment plants, as a result of water quality standards eventually imposed by the jurisdictions. Their concern is that nutrient allocation caps on wastewater treatment plants will promote urban sprawl. Most Chesapeake Bay Program partners contend that urban sprawl is occurring now regardless of the nutrient reduction measures that may ultimately be required, that it will not necessarily be affected by POTW caps and that not all jurisdictions will be imposing such caps. They further contend that current policies and growth trends, left unchecked (i.e., the baseline scenario), would result in greater environmental impacts than the tier scenarios. However, deliberations on this issue may be valuable on a watershed basis as sprawl is also an interstate issue. The Chesapeake Bay Program partners' concerns and deliberations to date also are provided in the separately published *Economic Analyses* document referenced above.

Numerous goods and services are associated with the Chesapeake Bay's ecological resources. Changes in water quality will lead to changes in ecological resources, and corresponding values of related goods and services. Time and resource constraints limited the ability of the Chesapeake Bay Program's UAA Workgroup to conduct original research and estimate comprehensive benefit values. However, the *Economic Analyses* document (U.S. EPA 2003) provides a brief summary of the benefits provided by estuaries such as the Chesapeake Bay and existing studies related to the value of these services.

The Chesapeake Bay Program expects that changes in water quality will affect many different aspects of the Bay's ecology (e.g., underwater bay grasses, fish and shellfish populations, water clarity and aesthetics), all of which affect how the Chesapeake Bay community, and society in general, will use and value the Chesapeake Bay. For example, ecological benefits will be derived from the increased size of fish, shellfish and aquatic plant populations and the increased stability (i.e., reduced variability) of these populations, and how humans value these improvements. Commercial fishery yields should improve, generating greater potential for economic returns, and secondary benefits accrue as support industries (e.g., sales and repair of harvest equipment, fuel) and value-added industry sectors (e.g., processing and retail facilities) expand in response to increased catch. Both market and nonmarket benefits should accrue from enhanced recreational opportunities, including hunting, fishing, boating, ecotourism and photography. For example, the increased value of recreational angling and support industries (e.g., gear, bait, charter boats) may be significant, and increased numbers of anglers will generate increased sales of fuel, lodging, and dining as the quality and number of fishing trips and opportunities increase.

Although no comprehensive estimate of the benefits from nutrient and sediment reduction actions in the Chesapeake Bay watershed is available, data suggest that the Chesapeake Bay affects industries that generate approximately $20 billion and 340,000 jobs (including commercial fishing, boat building and repair and tourism). Tourism, as a composite industry, represents the 14th largest source of output, and the 8th largest source of employment, in the Chesapeake Bay watershed. It is not clear the extent to which each of these sectors relies on Chesapeake Bay water quality; however, participation rates and expenditures on recreational fishing suggest that a significant percentage of tourism output is likely linked to the quality of water bodies such as the Chesapeake Bay. For example, the U.S. Fish and Wildlife Service's 2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation reports annual expenditures by fishermen of $1,261 million, and 1,859,000 fishing participants, in the states of Maryland, Virginia and Delaware.

Available studies of benefits include Bockstael et al. (1989), which estimate the total value of 20 percent improvement in nitrogen and phosphorous concentrations in the Chesapeake Bay to be $17 million to $76 million in 1996 dollars. Similarly, Krupnick (1988) estimated the total value of a 40 percent improvement in nitrogen and phosphorus concentrations at $43 million to $123 million (in 1996 dollars).

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Glossary

Airshed. A geographical region that, due to topography, meteorology and climate, shares the same air.

Anadromous. Fish that spend most of their lives in salt water but migrate into freshwater tributaries to spawn (such as shad and sturgeon).

Anoxia. A condition in which no oxygen is present. Much of the ‘anoxic zone’ is anaerobic and contains no oxygen. In this condition toxic hydrogen sulfide gas is emitted in the decomposition process.

Anthropogenic. Of human origin.

Bathymetry. The physical characteristics—including the depth, contour and shape—of the bottom of a body of water.

Benthos. A group of organisms, often invertebrates, that live in or on the bottom in aquatic habitats (such as clams that live in the sediments) and that are typically immotile or have limited mobility or range.

Biomass. The quantity of living matter, expressed as a concentration or weight per unit area.

Cap loads. The maximum pollutant load of nutrients and sediments that can be allowed and still meet water quality criteria.

Chlorophyll *a*. A pigment contained in plants that converts light energy into food. Chlorophyll *a* also gives plants their green color and is used to indicate the amount of microscopic algae growing in a water body.

Designated use. An element of a water quality standard, expressed as a narrative statement, describing an appropriate intended human or aquatic life objective for a body of water. Designated uses for a water body may refer to recreation, shellfishing, water supply and aquatic life habitat.

Dissolved oxygen. Microscopic bubbles of oxygen that are mixed in the water and occur between water molecules. Dissolved oxygen is necessary for healthy lakes, rivers, and estuaries. Most aquatic plants and animals need oxygen to survive. Fish will drown in water when the dissolved oxygen levels become too low. The absence of dissolved oxygen in water is a sign of possible pollution.

Epifaunal. Plants, animals and bacteria that are attached to the hard bottom or substrate (for example, to rocks or debris); are capable of movement; or that live on the sediment surface.

Epiphyte. Algae that grow on the surfaces of plants or other objects. The epiphyte does not "eat" the plant on which it grows, but merely uses it for structural support or as a means to enter the canopy environment. By encrusting leaf surfaces, they reduce the light available to the plant leaves and lead to loss of underwater bay grasses.

Estuarine species. A permanent resident of an estuary. Also called a resident species.

Estuary. A semi-enclosed body of water, such as the Chesapeake Bay, that has a free connection with the open sea and within which seawater from the ocean is diluted measurably with freshwater derived from land drainage. Brackish estuarine waters are decreasingly salty in the upstream direction, and vice versa. The ocean tides are projected upstream to the fall lines.

Eutrophic. A condition of an aquatic system containing high nutrient concentrations, which fuels algal growth. When the algae die off and decompose, the amount of dissolved oxygen in the water is reduced.

Filter feeders. Organisms that filter food from the environment using a straining mechanism, such as gills (e.g., barnacles, oysters and menhaden).

Hypoxia. A condition in which only very low levels of oxygen are present.

Light attenuation. The absorption, scattering or reflection of light by water, chlorophyll *a*, dissolved substances or particulate matter. Light attenuation reduces the amount of light available to underwater bay grasses.

Mean Low Water. The average of all the low water heights observed over the National Tidal Datum Epoch.

Mesohaline. Pertaining to moderately brackish water with low to middle range salinities (from 5 to 18 parts per thousand)

Mesotrophic. A condition of an aquatic system containing medium nutrient concentrations and, therefore, is between eutrophic (nutrient enriched) and oligotrophic (nutrient poor) conditions.

Mg liter^{-1}. Concentration unit milligrams per liter.

Mixed open. Herbaceous land that is not agricultural.

Nitrogen saturated. A state in which the forest vegetation and soils have reached their capacity to retain additional nitrogen. This state leads to greater leakage of nitrogen to sub-surface or ground waters.

Nutrients. Compounds of nitrogen and phosphorus dissolved in water that are essential to plants and animals. Too much nitrogen and phosphorus act as pollutants and can lead to unwanted consequences—primarily algae blooms that cloud the water and rob it of oxygen critical to most forms of aquatic life. Sewage treatment plants, industries, vehicle exhaust, acid rain and runoff from agricultural, residential and urban areas are sources of nutrients that enter the Bay.

Oligohaline. Pertaining to moderately brackish water with low range salinities (from 0.5 to 5 parts per thousand).

Percent-light-through-water. The amount of light reaching just above the canopy of underwater bay grasses, expressed as a fraction of the light at the water surface.

Phosphorus. A key nutrient in the Bay's ecosystem, phosphorus occurs in dissolved organic and inorganic forms, often attached to particles of sediment. This nutrient is a vital component in the process of converting sunlight into usable energy forms for the production of food and fiber. It is also essential to cellular growth and reproduction for organisms such as phytoplankton and bacteria. Phosphates, the inorganic form, are preferred, but organisms will use other forms of phosphorus when phosphates are unavailable.

Phytoplankton. Microscopic plants, such as algae, that are capable of making food via photosynthesis. They float and cannot move independent of water currents.

Polyhaline. Pertaining to waters with a higher range of salinities (18 to 30 parts per thousand).

Ppt. Parts per thousand (used as a measurement of salinity).

Pycnocline. The portion of the water column where density changes rapidly because of salinity and temperature. In an estuary the pycnocline is the zone separating deep, more saline waters from the less saline, well-mixed surface layer waters.

Salinity. A measure of the salt concentration of water. Higher salinity means more dissolved salts. Usually measured in parts per thousand (ppt).

Salinity regimes. A portion of an estuary distinguished by the amount of tidal influence and salinity of the water. The major salinity regimes are, from least saline to most saline:

- *Tidal fresh*—Describes waters with salinity between 0 and 0.5 parts per thousand (ppt). These areas are at the extreme reach of tidal influence.

- *Oligohaline*—Describes waters with salinity between 0.5 and 5 ppt. These areas are typically in the upper portion of an estuary.
- *Mesohaline*—Describes waters with salinity between 5 and 18 ppt. These areas are typically in the middle portion of an estuary.
- *Polyhaline*—Describes waters with salinity between 18 and 30 ppt. These areas are typically in the lower portion of an estuary, where the ocean and estuary meet.

Saturation. The state of a compound or solution that is fully saturated. For example, a condition in which water at a specific temperature contains all the dissolved oxygen it can hold. Dissolved oxygen percent saturation is an important measurement of water quality. Cold water can hold more dissolved oxygen than warm water. Also, high levels of bacteria from sewage pollution or large amounts of decomposing plants can cause the percent saturation to decrease. This can cause large fluctuations in dissolved oxygen levels throughout the day, which can affect the ability of plants and animals to thrive.

Secchi depth. A measure of cloudiness or turbidity of surface water determined by the depth at which the ‘Secchi disk,’ a flat black and white disk, cannot be seen any more. It is the greatest depth to which light can penetrate underwater.

Seiching. Formation of standing waves in a water body due to wave formation and subsequent reflections from the ends. These waves may be incited by earthquake motions (similar to the motions caused by shaking a glass of water), impulsive winds over the surface, or due to wave motions entering the basin. In the Chesapeake Bay, sustained winds force bottom water onto the shallows through this physical process.

Sill. A submerged ridge at relatively shallow depth separating the basins of two bodies of water.

Stratification. The formation, accumulation or deposition of materials in layers, such as layers of fresh water overlying higher salinity water (salt water) in estuaries.

Submerged Aquatic Vegetation (SAV). Rooted vegetation that grows under water in shallow zones where light penetrates. Also known as ‘underwater bay grasses.’

Subpycnocline. Bottom mixed layer waters located below the pycnocline layer (see definition for ‘pycnocline’).

Surficial. Of, relating to, or occurring on or near the surface of the sediment bottom.

Thermocline. A specific depth where the water temperature changes dramatically. Warmer surface water is separated from the cooler deep water. This temperature gradient results in the formation of a density barrier.

Total Suspended Solids (TSS). Solids in water that can be trapped by a filter (usually with a pore size greater than 0.45 micrometer). TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes and sewage. High concentrations of suspended solids can cause many problems for Chesapeake Bay health and aquatic life. For example, high TSS can block light from reaching underwater bay grasses, increase surface water temperature, because the suspended particles absorb heat from sunlight, and affect the ability of fish to see and catch food.

Trophic level. Layer in the food chain in which one group of organisms serves as the source of nutrition of another group of animals.

Turbidity. The decreased clarity in a body of water due to the suspension of silt or sedimentary material.

Underwater bay grass. Submerged vascular plants often referenced in the scientific literature as submerged aquatic vegetation or SAV, not to be confused with emergent wetland plants.

Water clarity. Measurement of how far you can see through the water. The greater the water clarity, the further you can see through the water.

Water column. The open-water environment, as distinct from the bed or shore, which may be inhabited by swimming marine, estuarine or freshwater organisms.

Water-column light requirement. The amount of light just above the leaf surface (estimated as the fraction of the light at the water surface) that is necessary for the survival and growth of underwater bay grasses.

Water quality criteria. Numeric or narrative description of a water quality parameter that represent a quality of water that supports a particular designated use. Adopted by states, along with designated uses, into water quality standards.

Water quality standards. A provision of State or Federal law consisting of a designated use or uses for a water body and a narrative or quantifiable criterion protective of the use(s) describing the desired conditions of the subject waters or water body to which they apply.

Watershed. A region bounded at the periphery by physical barriers that cause water to part and ultimately drain to a particular body of water.

Young-of-the-year. All of the fish of a species younger than one year of age. Usually scientists assign an arbitrary ‘birth date’ to all fish of a species hatched over a two or three month period in one year. The fish are then assigned to Age 1 status on that birth date. By convention, this is usually January 1.

Zooplankton. A community of floating, often microscopic animals that inhabit aquatic environments. Unlike phytoplankton, zooplankton cannot produce their own food, and so are consumers.

Acronyms

BMP	best management practice
CAA	Clean Air Act
CFD	cumulative frequency distribution
CSO	combined sewer overflow
CWA	Clean Water Act
E3	everything, everywhere by everybody
EPA	U.S. Environmental Protection Agency
ESD	environmental site design
km^2	kilometers squared
lbs	pounds
LID	low impact development
m	meter
MGD	million gallons per day

mg/l	milligrams per liter
mmBtu	million British thermal unit
No_x	nitrogen oxides
NRT	nutrient reduction technology
POTW	publically-owned treatment works
SAV	submerged aquatic vegetation
SED	sediment
SIP	state implementation plan
SO_2	sulfur dioxide
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solid
µg/l	micrograms per liter

appendix A

Development of the Level-of-Effort Scenarios

Listed in this appendix are the assumptions and methods employed in determining four best management BMP (including point source technologies) implementation levels for the three tiers and ‘everything, everywhere, by everybody’ (E3) scenarios. The scenarios were developed by the Chesapeake Bay Program’s Nutrient Subcommittee Workgroups to provide reference points for load reductions of nutrients and sediment that could be associated with increasing levels of BMP implementation for both point and nonpoint sources in the Chesapeake Bay watershed. The Use Attainability Analysis (UAA) workgroup was provided with examples of the types of BMPs and implementation levels to develop a defensible costing tool. These four scenarios range from Tier 1, which represents the current level of implementation throughout the watershed plus regulatory requirements implemented through the year 2010, up to a limit of technology scenario referred to as the E3 scenario. Tier 2 and Tier 3 represent intermediate levels of implementation between Tier 1 and the E3 scenario. Each tier has associated with it a given nitrogen, phosphorus and sediment load reduction effected by the different technologies assigned to the tier. The nutrient and sediment sources were divided into the following categories for tier development:

- point sources;
- nonpoint source agriculture;
- nonpoint source urban;
- nonpoint source forests;
- onsite treatment systems; and
- atmospheric deposition.

The Chesapeake Bay Program partners have acknowledged that the E3 scenario goes beyond what is physically possible in some cases, and that the feasibility of implementing certain reduction measures at Tier 3 are also questionable. These tiers are a broad brush estimate of technological reduction measures that could be implemented at the bay watershed level without regard to physical limitations. Certainly, there will be local circumstances and conditions that make implementation of these tiers as defined unreasonable. It will be up to the individual jurisdictions to tailor reduction programs that fit their specific capabilities and needs. The series of ranging scenarios were simulated using the Chesapeake Bay Program's Phase 4.3 Watershed Model, and the resultant loads for nitrogen, phosphorus, and sediment were used as inputs to the Chesapeake Bay Water Quality Model. Evaluation of dissolved oxygen, water clarity and chlorophyll *a* concentrations from the Water Quality Model, in turn, provided a sense of the response of key water quality parameters to the various loading levels. For the tiered and the E3 scenario scenarios, the BMP implementation levels, the resultant modeled loads, and the measured responses in tidal water quality are all informational. They are not intended to prescribe control measures the jurisdictions must implement to meet *Chesapeake 2000* nutrient and sediment cap load allocations.

All above and below fall line nitrogen, phosphorus, and sediment loads are included in the loadings for each tier. Shoreline erosion control sediment reductions at 2000 progress levels are assumed for all tiers.

The costs for specific management practices developed by the UAA Workgroup could be used by Chesapeake Bay basin jurisdictions for their individual UAAs. The Water Quality Steering Committee of the Chesapeake Bay Program believed it would be useful to provide data to the jurisdictions to promote coordination and consistency across all jurisdictions. It is a jurisdiction's prerogative to use the basin-wide cost analyses in developing its individual UAA.

Implementation levels in all of the tiers and the E3 scenario are not the most cost effective. More cost-effective combinations of BMPs will be evaluated by jurisdictions and their tributary strategy watershed teams as their strategies are developed. In addition, levels of BMP implementation for the E3 scenario are theoretical since, generally, the scenario does not account for physical limitations or participation levels in its design.

The tier and the E3 scenario BMP implementation levels were mostly deliberated and set by the 'source' workgroups of the Chesapeake Bay Program's Nutrient Subcommittee. These workgroups are made up of representatives of Chesapeake Bay watershed jurisdictions and Chesapeake Bay Program Office personnel. The specific workgroups that decided BMP implementation levels include the Agricultural Nutrient Reduction Workgroup, the Forestry Workgroup, the Point Source Workgroup, and the Urban Storm Water Workgroup. The Tributary Strategy Workgroup and Nutrient Subcommittee finalized the E3 scenario definitions after review and further deliberation.

To conform to *Chesapeake 2000* goals, all of the scenarios were based on 2010 projections of landuses, animals, point source flows, and septic systems as well as 2007/2010 or 2020 air emission controls. Landuses and animal populations in the

Chesapeake Bay Program Watershed Model are developed from an array of national, regional, and state databases as described in *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models* (Chesapeake Bay Program, 2000). The modeled landuses include the following categories:

- forest;
- conventional-tilled (high-till);
- conservation-tilled (low-till);
- hay;
- pasture;
- manure acres (model accounting of runoff from animal feeding operations);
- pervious urban;
- impervious urban; and
- mixed open.

The 2010 agricultural landuses were projected from 1982, 1987, 1992, and 1997 Agricultural Census information by county according to methods chosen by individual states. Projected animal populations, to estimate manure applications, were based on county Agricultural Census trends and information from state environmental and agricultural agencies.

Implementation of Low Impact Development (LID) or Environmental Site Design (ESD) in the tiered scenarios was used to reflect urban pollutant load reductions that go above and beyond conventional storm water management practices. The tiered scenarios reflect an ongoing shift from conventional storm water management to the more innovative LID/ESD practices that address both storm water quantity (replicating pre-development hydrology) and quality (reducing pollutant loads). The LID/ESD approach encourages practices that promote groundwater recharge, stream channel protection, flood protection, and improved water quality. The pollutant removal efficiencies for LID/ESD were developed by the Urban Storm Water Workgroup, based on national and watershed studies and expert professional judgement. The workgroup evaluated pollutant removal efficiencies for over 50 best management practices from sources such as the American Society of Civil Engineers Best Management Practices national database, the Center for Watershed Protection's National Pollutant Removal Performance Database for Stormwater Treatment Practices, the 2000 Maryland Stormwater Design Manual, the Virginia Stormwater Handbook, and Prince George's County's Low Impact Development Design Strategies manual. Maintenance costs of ESD/LID approaches were based on data primarily from Maryland (which promotes ESD) and Prince George's County (which promotes LID). There are several jurisdictions that are actively promoting ESD (Maryland state storm water regulations) and LID (Prince George's County, District of Columbia, various municipalities in Virginia).

The 2010 urban landuses were mostly projected from methods involving human population changes as determined by the U.S. Census Bureau for 1990 and 2000, and by individual state agencies for 2010. The population changes were related to 1990 high-resolution satellite imagery of the Chesapeake Bay watershed, which is the primary source of urban and forest acreages. In the case of Maryland, urban growth from 2000 to 2010 was determined by Maryland Department of Natural Resources and the Maryland Department of Planning.

For all jurisdictions except Maryland and Virginia, 2010 forest and mixed open landuses were determined by proportioning the net change between 2010 and 1990 agricultural and urban land to 1990 mixed open and 1990 forest. Maryland and Virginia forest acreage changes followed methodologies or data submitted by these states.

Each agricultural BMP in the tier scenarios is associated with research that identifies the expected level of nutrient reduction. In many cases this could be viewed as the best reduction one can expect from a BMP given optimal growing conditions and expected annual maintenance. However, the yield reserve BMP is slightly different. This BMP is not based solely on hydrologic conditions, but includes the known response of a particular crop to nutrient availability. There is an additional amount or cushion within universally recommended nutrient application rates to insure optimal yield under ideal growing conditions. Real world observations have shown that optimal growing conditions occur infrequently, and ‘average’ hydrologic conditions may result in substantially less than optimal yield. By combining this management practice with an insurance plan to protect against yield loss in suboptimal growth years, potential nitrogen leaching and phosphorus runoff are reduced while providing plant nutrient requirements seven or eight years out of every ten. The insurance program protects producers in those two to three years of yield loss. Since this is the reduction of a direct input based on plant response curves and not an estimate of nutrient reduction efficiency, the potential benefits from a yield reserve program can be fully modeled. Since yield is a function of rainfall and nutrient availability, the benefits of this type of program can be seen best in years with less than average rainfall when yields drop, yet spring application rates were high.

Estimates of the number of septic systems in the watershed in 2010 were derived from human population projections and people per septic system ratios from the 1990 U.S. Census Bureau survey.

Point sources were divided into categories which include 1) significant municipal wastewater treatment facilities—generally discharging flows greater than or equal to 0.5 million gallon per day, 2) significant industrial facilities—discharging nutrient loads of greater than or equivalent to municipal facilities with flows greater than or equal to 0.5 million gallon per day, and 3) non-significant municipal wastewater treatment facilities—discharging flows less than 0.5 million gallon per day, and limited to facilities in Maryland and Virginia due to availability of data.

Point source nitrogen and phosphorus loads from significant and non-significant municipal wastewater treatment facilities were determined using flows projected for the year 2010 for POTWs located in all jurisdictions of the Chesapeake Bay Watershed. These future flows were developed either from population projections or information obtained directly from the municipal facility operators. The tier and E3 scenario flows for industrial dischargers remained at 2000 levels because industrial flows are not necessarily subject to growth due to population.

Technologies in municipal facilities varied among the tiers depending on the nutrient concentrations to be achieved under each tier description. The technologies include extended aeration processes and denitrification zones, chemical additions, additional clarification tanks, deep bed denitrification filters, and micro-filtration. For industrial dischargers, site-specific information on reductions by facility was obtained via phone contacts or site visits.

Estimation of atmospheric deposition to the Chesapeake Bay watershed for all tier and E3 scenarios employed deposition data from the Regional Acid Deposition Model (RADM) which also provides deposition estimates representing current conditions used for 2000 Progress model runs. All of the air scenarios involve nitrogen oxide emissions reductions made by roughly 37 states (the deposition modeling domain). Air scenarios in Tiers 1 and 2 describe existing Clean Air Act regulations that have passed; the Tier 3 and E3 air scenarios describe additional voluntary control measures.

Table A-1 provides a brief overview of the reduction measures in the tiers organized by nutrient source. Table A-2 shows the implementation levels of the BMPs in the tier scenarios in terms of landuse acres, or their appropriate unit of measurement (Figures A-1 through A-3). The text that follows provides a more detailed overview of the reduction measures per source, organized by tier scenario.

In the listing of BMP levels in Table A-2, there are cases where implementation levels may be lower in a higher tier, or may be lower for the 2010 scenarios, when compared to 2000 Progress. It is important to note that landuses change from 2000 to 2010 and that these changes were based on trends specified by individual jurisdictions with concurrence from the Chesapeake Bay Program Nutrient Subcommittee's Tributary Strategy Workgroup. Also, landuses change through the 2010 tiers and the E3 scenario depending on degrees of BMP implementation (i.e., riparian buffers, wetland restoration, land retirement, carbon sequestration for agricultural land). In other words, as landuses change, less land may be available to apply BMPs in a higher level-of-effort scenario. Overall however, nutrient and sediment reductions will increase through the tiers to the E3 scenario as the combined impact of nonpoint source BMPs increases. Note that riparian buffer information is presented both in terms of acres and 1-side stream miles.

Table A-1. Description of the source reduction measures by tier scenario.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
CROPLAND CONVERSIONS TO FOREST HAYLAND				
Buffers—pasture to forest	Continue current level of implementation using average rate of 1997–2000. Note: Includes fencing	Increase level of implementation up to a total of 20% of the remaining stream reaches in pasture. Note: Includes fencing	Increase level of implementation up to a total of 30% of the remaining stream reaches in pasture. Note: Includes fencing	Both sides of all stream reaches within pasture receive 100 foot forest buffers and fencing.
Buffers—cropland to forest	Continue current level of implementation using average rate of 1997-2000.	Increase level of implementation up to a total of 20% of the remaining stream reaches in cropland.	Increase level of implementation up to a total of 30% of the remaining stream reaches in cropland.	Both sides of all stream reaches within cropland receive forest buffers.
Buffers—cropland to grass	Continue current level of implementation using average rate of 1997-2000.	25% of remaining stream reaches within cropland.	50% of remaining stream reaches within cropland.	
Buffers—hayland to forest	Continue current level of implementation using average rate of 1997-2000.	25% of remaining stream reaches within hayland over Tier 1.	50% of remaining stream reaches within hayland over Tier 1.	Both sides of all stream reaches within hayland receive forest buffers.
Wetland Reserve (cropland to forest)	Continue current level of implementation using average rate of 1997-2000.	Increase level of implementation up to a total of 33% of the remaining goal.	Increase level of implementation up to a total of 66% of the remaining goal.	Wetland Reserve equals 25,000 acres in signatory states (based on *Chesapeake 2000* goal).
CRP/CREP (cropland to mixed open)	Continue current level of implementation using average rate of 1997-2000.	CRP-CREP-Wetland Reserve-buffers (combined) comprise 10% of cropland within each county.	CRP-CREP-Wetland Reserve-buffers (combined) comprise 15% of cropland within each county.	CRP-CREP-Wetland Reserve buffers (combined) comprise 25% of cropland within each county.

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	**Tier 1**	**Tier 2**	**Tier 3**	**E3**
Carbon Sequestration & Bioenergy			Applied to 15% of remaining the E3 scenario cropland after land conversion programs applied.	Applied to 25% of remaining cropland after land conversion programs applied.
AGRICULTURE NPS				
Conservation Tillage	Continue current level of implementation using average rate of 1997-2000.	Applied to 30% of remaining cropland beyond Tier 1.	Applied to 60% of remaining cropland beyond Tier 1.	Conservation tillage on 100% of cropland.
Farm Plans	Continue current level of implementation using average rate of 1997-2000.	Applied to 30% of remaining agricultural land (crop, hay, pasture) beyond Tier 1.	Applied to 70% of remaining agricultural land (crop, hay, pasture) beyond Tier 1.	Applied to 100% of agricultural land (crop, hay, pasture).
Cover Crops	Continue current level of implementation using average rate of 1997-2000.	Applied to 40% of remaining cropland beyond Tier 1.	Applied to 75% of remaining cropland beyond Tier 1.	Applied to 100% of cropland
Nutrient Management Planning	MD & DE: 100% cropland and hayland under nutrient management. Other basin states: Continue current level of implementation using average rate of 1997-2000.	MD & DE: 100% cropland and hayland under nutrient management. Other basin states: Applied to 30% of remaining cropland and hayland beyond Tier 1.	MD & DE: 100% cropland and hayland under nutrient management. Other basin states: Applied to 30% of remaining cropland and hayland beyond Tier 2.	Applied to 100% of cropland and hayland.
Yield Reserve			Applied to 30% of the cropland and hayland under nutrient management. Replaces nutrient application component of nutrient management plan.	Applied to 100% of cropland and hayland. Replaces nutrient application component of nutrient management plan.

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
AGRICULTURE NPS *(cont.)*				
Excess Nutrients	Assume alternative use for excess manure.	Assume alternative use for excess manure.	Assume alternative use for excess manure.	Assume alternative use for excess manure.
Agriculture Waste Systems	Continue current level of implementation using average rate of 1997-2000.	Applied to 25% of remaining confined animal units beyond Tier 1 (combines storage system and barnyard runoff controls).	Applied to 60% of remaining confined animal units beyond Tier 1 (combines storage system and barnyard runoff controls).	Applied to 100% of confined animal units (combines storage system and barnyard runoff controls).
Stream Protection without fencing	Continue current level of implementation using average rate of 1997-2000.	Applied to 10% of remaining stream reaches within pasture land beyond Tier 1.	Applied to 25% of remaining stream reaches within pasture land beyond Tier 1.	N/A (see buffers-forest-pasture)
Stream Protection with fencing	Continue current level of implementation using average rate of 1997-2000.	Applied to 15% of remaining stream reaches within pasture land beyond Tier 1.	Applied to 75% of remaining stream reaches within pasture land beyond Tier 1.	N/A (see buffers-forest-pasture)
Grazing Land Protection	Continue current level of implementation using average rate of 1997-2000.	Applied to 25% of remaining pasture land beyond Tier 1.	Applied to 50% of remaining pasture land beyond Tier 1.	Applied to 100% of pasture land.
URBAN NPS				
Urban Land Conversion (PA, MD, VA and DC only)	Full 2000-2010 urban land conversion based on 2010 population.	2000-2010 urban conversion - reduced 10% (acres 'returned' as 65% forest, 20% mixed open, 15% agriculture).	2000-2010 urban conversion - reduced 20% (acres 'returned' as 65% forest, 20% mixed open, 15% agriculture).	2000-2010 urban conversion - reduced 30% (acres 'returned' as 100% forest).

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
Storm water management & LID—New Development (2001-2010)	66% of new development has storm water management. (TN=35, TP=45, TSS=80)	75% of new development has storm water management. 25% of new development employs environmental site design and low-impact development techniques. Efficiencies represent a 75%/25% weighted average reduction. (TN=40, TP=55, TSS=85)	50% of new development has storm water management. 50% of new development employs environmental site design and low-impact development techniques. Efficiencies represent a 50%/50% weighted average reduction. (TN=45, TP=57, TSS=87)	100% of new development employs environmental site design and low-impact development techniques (TN=50, TP=60, TSS=90).
Stormwater management—Recent Development (1986-2000)	60% of recent development has storm water management. (TN=27, TP=40,TSS=65)	60% of recent development has storm water management. (TN=27, TP=40,TSS=65)	60% of recent development has storm water management. (TN=27, TP=40,TSS=65)	
Retrofits—Recent (1986-2000) & Old (pre 1986) Development	0.8% of recent and old (pre-1986) development is retrofitted (TN=20, TP=30,TSS=65)	5% of recent and old (pre-1986) development is retrofitted (TN=20, TP=30,TSS=65)	20% of recent and old (pre-1986) development is retrofitted (TN=20, TP=30,TSS=65)	100% of recent and old (pre-1986) development is retrofitted (TN=40, TP=40, TSS=80).
Urban Nutrient Management	Continue to implement BMP at average annual rate through 2010, using average of 1997-2000. (TN=17%, TP=22%)	40% of urban pervious and mixed open lands are under nutrient management. (TN=17%, TP=22%)	75% of urban pervious and mixed open lands are under nutrient management. (TN=17%, TP=22%)	No fertilizer is applied to urban pervious or mixed open land.
Buffers—Grass (existing)	All urban stream reaches are assumed to have either grass or tree buffers. Where urban disturbance has altered a stream reach beyond repair/restoration, it is not included as a potential buffer area.	Reduce grass buffers by 10% below Tier 1 level. (conversion to forest buffers)	Reduce grass buffers by 30% below Tier 1 level. (conversion to forest buffers)	

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
URBAN NPS *(cont.)*				
Buffers—Grass to Forest		Increase forest buffer acreage by the same amount of 'reduced' grass buffer acreage.	Increase forest buffer acreage by the same amount of 'reduced' grass buffer acreage.	50-foot forest buffer on both sides of stream reaches in urban pervious areas. No credit given on upstream effects, land conservation only.
Buffers—Mixed Open to Forest	Continue current level of implementation using average rate of 1997-2000.	Increase forest buffer acreage by the same amount as forest buffers on urban pervious.	Increase forest buffer acreage by the same amount as forest buffers on urban pervious.	100-foot forest buffer on mixed open. No credit given on upstream effects, land conservation only.
ONSITE TREATMENT SYSTEMS				
New Systems (post-2000)	Maintain current concentration/load per system.	10% of new treatment systems will meet an edge of drainage field concentration for nitrogen of 10 mg/L TN per system. Remaining systems meet existing concentration/load levels.	100% of new treatment systems will meet an edge of drainage field concentration for nitrogen of 10 mg/L TN per system.	100% of new treatment systems will meet an edge of drainage field concentration of nitrogen of 10 mg/L TN per system.
Existing Systems (pre-2001)	Maintain current concentration/load per system.	Maintain current concentration/load per system.	1% of existing (per year) treatment systems will meet an edge of drainage field concentration for nitrogen of 10 mg/L TN per system. (1% represents failed systems and opportunities for upgrades.) Remaining systems maintain existing concentrations/loads.	100% of existing treatment systems will meet an edge of drainage field concentration of nitrogen of 10 mg/L TN per system.

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
POINT SOURCES				
Municipal Wastewater Treatment (Significant Facilities as of 2000)	Existing NRT and those planned to go to NRT by 2010: 2010 flow at 8.0 mg/l TN and 2000 concentrations for TP. For all remaining facilities without NRT existing or planned: 2000 TN & TP. For certain VA facilities in lower VA tributaries TP=1.5 mg/l	Reach and maintain 8.0 mg/l TN and 1.0 mg/l TP concentrations at 2010 flows at all facilities. (Phosphorus concentration is 1.0 mg/l or permit limit, whichever is lower).	Reach and maintain 5.0 mg/l TN and 0.5 mg/l TP concentrations at 2010 flows at all facilities. (Phosphorus concentration is 0.5 mg/l or permit limit, whichever is lower.)	Reach and maintain 3.0 mg/l TN and 0.10 mg/l TP concentrations at 2010 flows at all facilities. (Phosphorus concentration is 0.1 mg/l or permit limit, whichever is lower).
Industrial Wastewater Treatment (Significant Facilities as of 2000)	Maintain current levels.	Generally a 50% reduction from Tier 1 (2000 concentrations) or permit conditions if less.	Generally an 80% reduction from Tier 1 (2000 concentrations) or permit conditions if less.	TN = 3.0; TP = 0.1 or permit conditions if less.
Municipal Wastewater Treatment (Non-significant Facilities as of 2000)	Maintain current TN/TP concentrations with 2010 flows.	Maintain current TN/TP concentrations with 2010 flows.	Maintain current TN/TP concentrations with 2010 flows.	Maintain 8.0 mg/L nitrogen and 2.0 mg/L phosphorus concentrations or 2000 concentrations if less with 2010 flows.
CSO Control (DC)	43% reduction in CSOs.	43% reduction in CSOs.	43% reduction in CSOs.	Zero discharge from DC CSOs.

continued

Table A-1. Description of the source reduction measures by tier scenario *(cont.)*.

Nutrient Reduction Activity	Tier 1	Tier 2	Tier 3	E3
FOREST NPS				
Forest Harvest BMPs	Forestry BMPs are properly installed on 80% of all harvested lands.	Forestry BMPs are properly installed on 90% of all harvested lands.	Forestry BMPs are properly installed on 100% of all harvested lands with no measurable increase in nutrient and sediment discharge.	Forestry BMPs are properly installed on 100% of all harvested lands with no measurable increase in nutrient and sediment discharge.
AIR EMISSIONS				
Air Controls (NOx only)	2007/2010 Base with NOx SIP.	2020 CAA with Tier 2 and heavy duty diesel regulations.	2020 CAA with aggressive utility controls.	2020 CAA aggressive utility controls and industry-point and mobile controls.

Table A-2. 2000 Progress, 2010 tiers, and 2010 E3 scenario BMP implementation levels.

BMP	Unit of Measure	Applicable Landuse	2000 Progress	2010 Tier 1	2010 Tier 2	2010 Tier 3	2010 ES
AGRICULTURAL BMPs							
Conservation Tillage	Acres	Low Till	1,994,745	1,962,824	2,340,908	2,300,093	2,312,209
Riparian Forest Buffers	Acres	Row Crop, Hay	9,054	30,588	133,772	206,663	494,450
Riparian Forest Buffers	1 side stream miles, 100 foot width	Row Crop, Hay	747	2,524	11,036	17,050	40,792
Wetland Restoration	Acres	Row Crop, Hay	1,277	2,862	10,260	17,659	25,282
Land Retirement	Acres	Row Crop, Hay	87,488	128,510	500,452	742,695	1,090,540
Grass Buffers	Acres	Row Crop	4,294	15,036	71,985	113,800	0
Tree Planting	Acres	Row Crop, Pasture	8,568	4,142	0	0	0
Riparian Forest Buffers	Acres	Pasture	0	0	46,732	63,851	184,081
Riparian Forest Buffers	1 side stream miles, 100 foot width	Pasture	0	0	3,855	5,268	15,187
Carbon Sequestration/ Bio Energy	Acres	Row Crop	0	0	0	509,431	770,736
Standard Nutrient Management Plan Implementation	Acres	Row Crop, Hay	2,283,426	3,023,742	3,850,244	2,967,870	0
Yield Reserve Implementation	Acres	Row Crop, Hay	0	0	0	1,271,944	4,830,817
Total Nutrient Management Plan Implementation	Acres	Row Crop, Hay	2,283,426	3,023,742	3,850,244	4,239,814	4,830,817
Farm Plans	Acres	Agriculture	3,666,165	5,075,549	5,860,003	6,854,953	7,202,280
Cover Crops	Acres	Row Crop	220,134	152,766	1,544,635	2,203,196	2,312,209
Stream Protection With Fencing	Acres	Pasture	40,744	69,257	171,739	580,365	712,302
Stream Protection Without Fencing	Acres	Pasture	26,166	27,979	83,584	63,583	0
Grazing Land Protection	Acres	Pasture	134,327	304,868	853,863	1,394,909	2,371,463
Animal Waste Management	Acres	Manure Acres	4,886	6,425	6,953	7,692	8,537
Animal Waste Management	Animal Units	Manure Acres	708,498	931,677	1,008,208	1,115,351	1,237,801
Manure Excess	Wet Tons As Excreted	N/A	1,270,139	1,927,899	2,145,277	1,870,085	8,856,825

continued

Table A-2. 2000 Progress, 2010 tiers, and 2010 E3 scenario BMP implementation levels *(cont.)*.

BMP	Unit of Measure	Applicable Landuse	2000 Progress	2010 Tier 1	2010 Tier 2	2010 Tier 3	2010 ES
URBAN AND MIXED OPEN BMPs							
Abandoned Mine Reclamation	Acres	Urban/Exposed	6,062	0	0	0	0
Urban Growth Reduction	Acres	Urban	38,787	0	26,096	52,192	78,288
Riparian Forest Buffers	Acres	Pervious Urban	0	364	9,808	28,522	93,643
Riparian Forest Buffers	1 side stream miles, 50 foot width	Pervious Urban	0	60	1,618	4,706	15,451
Grass Buffers	Acres	Pervious Urban	0	95,022	84,997	65,702	0
Storm Water Management on New Development	Acres	Urban	0	153,157	207,705	183,440	159,560
SWM on Recent Development	Acres	Urban	165,040	374,357	373,817	373,236	0
SWM on Recent and Old Development	Acres	Urban	0	29,959	187,185	748,488	3,740,806
Total Storm Water Management	Acres	Urban	165,040	557,474	768,707	1,305,164	3,900,366
Erosion and Sediment Control	Acres	Urban	25,911	0	0	0	0
Urban Nutrient Management	Acres	Pervious Urban	6,608	28,630	1,055,077	1,964,784	2,601,733
Tree Planting	Acres	Mixed Open	22,596	44,280	0	0	0
Riparian Forest Buffers	Acres	Mixed Open	0	0	54,702	73,757	413,922
Riparian Forest Buffers	1 side stream miles, 100 ft. width	Mixed Open	0	0	4,513	6,085	34,149
Mixed Open Nutrient Management	Acres	Mixed Open	0	60,791	1,997,497	3,870,252	4,950,621

continued

Table A-2. 2000 Progress, 2010 tiers, and 2010 E3 scenario BMP implementation levels *(cont.)*.

BMP	Unit of Measure	Applicable Landuse	2000 Progress	2010 Tier 1	2010 Tier 2	2010 Tier 3	2010 ES
FORESTRY BMPs							
Forest Harvesting Practices	Acres	Forest	67,448	0	0	0	0
SEPTIC BMPs							
Septic BMPs							
Septic Connections	Systems	Septic	31,514	31,514	31,514	31,514	31,514
Septic Pumping	Systems	Septic	2,954	N/A	N/A	N/A	N/A
Septic Denitrification	Systems	Septic	312	312	N/A	N/A	N/A
Denitrification/Pumping on New & Existing Systems	Systems	Septic	N/A	N/A	8,305	93,014	1,357,026

2010 TIER 1 SCENARIO

2010 Tier 1 BMP implementation levels were generally determined by continuing current levels-of-effort and cost-share in the Chesapeake Bay watershed. In addition, expected regulatory measures, jurisdictional programs, and construction schedules between 2000 and 2010 were included.

2010 TIER 1 SCENARIO NONPOINT SOURCE BMPs

For most nonpoint source BMPs, implementation rates between 1997 and 2000 were continued to the year 2010 with limits that levels could not exceed the available or the E3 scenario land area to which BMPs levels could be applied. The scale of the calculations was a county segment, or the intersection of a county political boundary and a model hydrologic segment. This is the same scale on which most jurisdictions report BMP implementation levels to the Chesapeake Bay Program Office.

Every effort was made to include BMPs submitted by the jurisdictions for progress model runs into Tier 1. Since historic BMP data were not available from New York, Delaware, and West Virginia, 2010 Tier 1 projections were determined from watershed-wide implementation rates in the states which employ and track the practice.

2010 Tier 1 BMPs were extrapolated from recent implementation rates by the landuse types submitted by the states for each BMP. For example, if a jurisdiction submits data for nutrient management on crop, 2010 Tier 1 crop was projected and then split among high-till, low-till, and hay according to relative percentages. If a jurisdiction submits data as nutrient management on high-till, low-till, and hay individually, projections were done for each of these landuse categories.

The 2010 Tier 1 scenario does not include tree planting on tilled land, forest conservation, and forest harvesting practices as these BMPs are not part of the tier and E3 scenarios. For forest harvesting practices and erosion and sediment control, the model simulation does not account for additional loads from disturbed forest and construction areas, respectively. For forest conservation, planting above what is removed during development is accounted for in the 2010 urban and forest projections. Tree planting on agricultural land was included in Tier 1 for pasture as forest buffers since this BMP is also part of the tier and E3 scenarios and pasture tree planting and pasture buffers are treated the same in the model.

2010 TIER 1 SCENARIO AGRICULTURAL BMPs

- Tier 1 Conservation tillage
  - –Continue 1997–2000 implementation rates of conservation-tillage.
  - –Low-till acres cannot be below 2000 levels or greater than 75 percent of the available cropland by county-segment.
  - –Landuse conversion of high-till to low-till.

- Tier 1 Riparian forest buffers on agriculture
  - –Continue 1997–2000 implementation rates of riparian forest buffers on cropland and hay to the year 2010.
  - –Continue 1997–2000 implementation rates of tree planting on pasture to the year 2010.
  - –Tier 1 implementation levels cannot exceed the available or E3 scenario land area to which BMPs could be applied.
  - –The E3 scenario assumes 100-foot forest buffers on un-buffered stream miles (each side) associated with crop, hay, and pasture.
  - –Landuse conversion of crop, hay, and pasture to forest.
  - –For every acre of crop and hay converted, two upland acres of crop and hay receive a reduction of 57 percent (TN), 70 percent (TP), and 70 percent (SED).
  - –There is no upland benefit associated with forest buffers on pasture.
- Tier 1 Wetland restoration
  - –Continue 1997–2000 implementation rates of wetland restoration on cropland and hay to the year 2010.
  - –Landuse conversion of crop and hay to forest.
- Tier 1 Agricultural land retirement
  - –Continue 1997–2000 implementation rates of cropland and hay retirement to the year 2010.
  - –The sum of the acreage in Tier 1 riparian forest buffers, wetland restoration, and land retirement cannot exceed 25 percent of the total crop and hay in a county-segment.
  - –Landuse conversions of crop and hay to mixed open.
- Tier 1 Riparian grass buffers on cropland
  - –Continue 1997–2000 implementation rates of riparian grass buffers on cropland to the year 2010 with limits that levels cannot exceed the available or the E3 scenario land area to apply the BMPs to.
  - –The E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes 100-foot buffers on un-buffered stream miles (each side) associated with agricultural land.
  - –Landuse conversions of crop to mixed open.
  - –For every acre of cropland converted, two upland acres of crop receive a reduction of 43 percent (TN), 53 percent (TP), and 53 percent (SED).

- Tier 1 Nutrient Management Plan Implementation
  –Continue 1997–2000 rates of nutrient management plan implementation on crop and hay to the year 2010 in all jurisdictions except MD and DE where all crop and hay acres are fully implementing nutrient management plans.
  –Nutrient management plan implementation levels cannot exceed the available land area to apply the BMPs to.
  –Under nutrient management plans, crop and hay acres do not receive more than 130 percent of their TN and TP need.

- Tier 1 Manure excess
  –Excess nutrients resulting from the differences between manure generated and conforming to nutrient management rules and losses in agricultural land are reported.
  –It is assumed that all of the excess manure has alternative uses that do not affect loads to the Chesapeake Bay tidal waters.

- Tier 1 Animal waste management/runoff control
  –Continue 1997–2000 implementation rates of animal waste management on 'manure acres' to the year 2010 with limits that levels cannot exceed the available area to apply the BMPs to.
  –Manure acres are the model's accounting of runoff from animal feeding operations based on the number of animal units.
  –The BMP combines storage systems and barnyard runoff controls and reduction factors of 75 percent (TN and TP) are applied to protected manure acres.

- Tier 1 Farm Plans (non-nutrient management)
  –Continue 1997–2000 rates of Farm Plan implementation on agricultural land (crop, hay, and pasture) to the year 2010 with limits that levels cannot exceed the available land area to apply the BMPs to.
  –Nutrient and sediment reduction factors for Farm Plans on high-till are 10 percent (TN) and 40 percent (TP and SED). Low-till and hay reduction factors are 4 percent (TN) and 8 percent (TP and SED) while the reduction factors for Farm Plans on pasture are 20 percent (TN) and 14 percent (TP and SED).

- Tier 1 Cover crops
  –Since cover crop acreage varies annually or is not cumulative, cover crop implementation is determined as the average of 1997–2000 implementation acreage (or years in that period where data exists from the jurisdictions) with limits that levels cannot exceed the available land area to apply the BMPs to.
  –BMP reduction factors of 35 percent (TN) and 15 percent (TP and SED) are applied to cover crop acres.

- Tier 1 Streambank protection with fencing
  - –Continue 1997–2000 implementation rates of streambank protection with fencing on pasture to the year 2010 with limits that levels cannot exceed the available of the E3 scenario land area to apply the BMPs to.
  - –The E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes for every stream mile protected, 51 upland acres of pasture receive a reduction benefit.
  - –BMP reduction factors of 75 percent for TN, TP, and SED are applied to pasture acres protected.
- Tier 1 Streambank protection without fencing
  - –Continue 1997–2000 implementation rates of streambank protection without fencing on pasture to the year 2010 with limits that levels cannot exceed the available pasture land area to apply the BMPs to.
  - –BMP reduction factors of 40 percent for TN, TP, and SED are applied to pasture acres protected.
- Tier 1 Grazing land protection
  - –Continue 1997–2000 implementation rates of rotational grazing on pasture to the year 2010 with limits that levels cannot exceed the available land area to apply the BMPs to.
  - –BMP reduction factors of 50 percent (TN) and 25 percent (TP) are applied to protected pasture acres.

2010 TIER 1 URBAN AND MIXED OPEN BMPs

- Tier 1 Storm Water Management on new development
  - –Storm water management applied to 66 percent of new development between 2000 and 2010.
  - –Storm water management practices are designed to reduce TN by 35 percent, TP by 45 percent, and SED by 80 percent.
- Tier 1 Storm Water Management on recent development
  - –60 percent of recent development (1986–2000) is has storm water management that are designed to reduce nutrients and sediment in storm water runoff by 27 percent (TN), 40 percent (TP), and 65 percent (SED).
- Tier 1 Storm Water retrofits on old and recent development
  - –0.8 percent of pre-1986 urban land and 1986–2000 recent development is retrofitted with a suite of practices that reduce nutrients and sediment in runoff by 20 percent (TN), 30 percent (TP), and 65 percent (SED).

- Tier 1 Riparian forest and grass buffers on urban
  - –It is assumed that all urban stream reaches have either forest or grass riparian buffers except where urban disturbance has altered a stream reach beyond repair/restoration (i.e., impervious surface).
  - –50-foot buffers on all un-buffered stream miles (each side) associated with pervious urban.
  - –Landuse conversion of pervious urban to mixed open (grass buffers) or forest (forest buffers).
  - –There is no upland benefit associated with forest and grass buffers on urban.
- Tier 1 Riparian forest buffers on mixed open
  - –Continue 1997–2000 implementation rates of tree planting on mixed open to the year 2010 with limits that levels can not exceed the available or the E3 scenario land area to which BMPs could be applied.
  - –100-foot forest buffers on all un-buffered stream miles (each side) associated with mixed open.
  - –Landuse conversion of mixed open to forest.
  - –There is no upland benefit associated with forest buffers on mixed open.
- Tier 1 Nutrient management on urban and mixed open
  - –Continue 1997–2000 implementation rates of nutrient management on pervious urban and mixed open to the year 2010 with limits that levels cannot exceed the available land area to which BMPs could be applied.
  - –BMP reduction factors of 17 percent (TN) and 22 percent (TP) are applied to acres under nutrient management.

2010 TIER 1 FOREST HARVEST BMPs

- It is assumed that forestry BMPs designed to minimize the environmental impacts from timber harvesting, such as road building and cutting/thinning operations, are properly installed on all harvested lands with no measurable increase in nutrient and sediment discharge.
- The assumption is based on maintaining the state of forest loads as measured during the calibration of the Chesapeake Bay Watershed Model.

2010 TIER 1 SEPTIC BMPs

- Current edge-of-septic-field concentrations and flows per system are maintained.
- The number of systems varies according to population projections from 2000 to 2010.
- Septic BMPs incorporate submissions from the Chesapeake Bay-basin jurisdictions on the current number of systems employing denitrification technologies

(50 percent TN reduction) and those with regular maintenance through pumping (5 percent TN reduction).

2010 TIER 1 POINT SOURCE BMPs

- Tier 1 Significant municipal wastewater treatment facilities
  - –Nitrogen – POTWs with existing nutrient-removal technologies (NRT) and those planned to go to NRT by 2010 are at 2010 projected flows and 8 mg TN/L effluent concentrations (annual average). All remaining significant facilities are at 2010 projected flows and 2000 TN effluent concentrations.
  - –Phosphorus – 2010 projected flows and 2000 TP/L effluent concentrations except those targeted in VA which are at 1.5 mg TP/L (annual average).
- Tier 1 Significant industrial dischargers
  - –2000 flows and maintain current (2000) levels of effluent concentrations for TN and TP or the permit limit, whichever is less.
- Tier 1 Non-significant municipal wastewater treatment facilities
  - –2000 TN and TP effluent concentrations applied to 2010 projected flows.

2010 TIER 1 COMBINED SEWER OVERFLOW BMPs

- There is a 43 percent reduction in the current discharge from DC combined sewer overflows, the only CSO loads among all jurisdictions for which the Chesapeake Bay Program has nutrient load data specifically quantified in the model simulation.
- The reduction from 2000 loads is what is expected by the District to be achieved by 2010.

2010 TIER 1 ATMOSPHERIC DEPOSITION BMPs

Tier 1 atmospheric deposition assumes implementation of the 1990 Clean Air Act projected for the year 2010 with nitrogen oxide emissions regulations for ground-level ozone and acid rain that have passed. Estimated changes in deposition for the Tier 1 scenario includes the following controls on nitrogen oxide emissions:

- 2007 non-utility (industrial) point source and area source emissions.
- 2007 mobile source emissions with ‘Tier II’ tail pipe standards on light duty vehicles.
- 2010 utility emissions with Title IV (Acid Rain Program) fully implemented and 20-state NOx SIP call reductions at 0.15 lbs/MMbtu during the May to September ozone season only.

The impacts of Tier 1 emissions and deposition to the Chesapeake Bay watershed’s land area and non-tidal waters are part of the reported nutrient loads from the individual landuse source categories (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). The reported Watershed Model loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Water Quality Model, account for this source at levels prescribed by Tier 1.

2010 TIER 1 SHORELINE EROSION BMPs

- Tier 1 shoreline erosion controls include structural and non-structural practices at 2000 levels.

The impacts of Tier 1 shoreline erosion controls are not included in the reported Watershed Model loads although the water quality responses, as measured by the Model, account for this source at BMP levels prescribed by Tier 1.

2010 TIER 2 SCENARIO

2010 Tier 2 BMP implementation levels for nonpoint sources were generally determined by increasing levels above Tier 1 by a percentage of the difference between the Tier 1 and the E3 scenario levels for each BMP. These percentages were mostly recommended by individual source workgroups under the Chesapeake Bay Program Nutrient Subcommittee, and were applied watershed-wide by county segments, or the intersections of county political boundaries and the Watershed Model's hydrologic segmentation.

For Tier 2 point source municipal facilities, technologies to achieve 8 mg TN/L include extended aeration processes and denitrification zones, along with chemical addition to achieve a phosphorus discharge of 1.0 mg/l where facilities are not already achieving these levels.

In the design of the Tier 2 scenario, considerations of the costs of BMP implementation, participation levels, and physical limitations are very limited. Tier 2 BMP levels are considered technically possible, and are listed below for each of the major source categories.

2010 TIER 2 SCENARIO AGRICULTURAL BMPs

- Tier 2 Conservation tillage
  - –Applied to 'Tier 1' levels plus 30 percent of the available crop acres between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of high-till to low-till.

- Tier 2 Riparian forest buffers on agriculture
  - –Applied to 'Tier 1' levels plus 20 percent of the available stream reaches in cropland and pasture and 25 percent of the remaining stream reaches in hay between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes 100-foot forest buffers on un-buffered stream miles (each side) associated with crop, hay, and pasture.
  - –Tier 1 forest buffers on pasture are rooted in agricultural tree planting from jurisdictional BMP reporting.
  - –Landuse conversions of crop, hay, and pasture to forest.
  - –For every acre of crop and hay converted, two upland acres of crop and hay receive a reduction of 57 percent (TN), 70 percent (TP), and 70 percent (SED).
  - –There is no upland benefit associated with forest buffers on pasture.
- Tier 2 Wetland restoration
  - –Applied to 'Tier 1' levels plus 33 percent of the available crop and hay acres in PA, MD, and VA between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of crop and hay to forest.
- Tier 2 Agricultural land retirement
  - –The remainder of 10 percent of the total crop and hay acres and those acres converted through forest buffers and wetland restoration is retired to a grass condition.
  - –Landuse conversions of crop and hay to mixed open.
- Tier 2 Riparian grass buffers on cropland
  - –Applied to 'Tier 1' levels plus 25 percent of the available stream reaches in cropland between 'Tier 1' and the 'E3' scenario levels and after forest buffer planting.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes 100-foot buffers on un-buffered stream miles (each side) associated with agricultural land.
  - –Landuse conversions of crop to mixed open.
  - –For every acre of cropland converted, two upland acres of crop receive a reduction of 43 percent (TN), 53 percent (TP), and 53 percent (SED).
- Tier 2 Nutrient Management Plan Implementation
  - –Applied to 'Tier 1' levels plus 30 percent of the available crop and hay acres between 'Tier 1' and the 'E3' scenario levels in PA, VA, NY, and WV.

–All crop and hay acres in MD and DE are fully implementing nutrient management plans.

–Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.

–Under nutrient management plans, crop and hay acres do not receive more than 130 percent of their TN and TP need.

- Tier 2 Manure excess

–Excess nutrients resulting from the differences between manure generated and conforming to nutrient management rules and losses in agricultural land are reported.

–It is assumed that all of the excess manure has alternative uses that do not affect loads to the Chesapeake Bay tidal waters.

- Tier 2 Animal waste management/runoff control

–Applied to 'Tier 1' levels plus 25 percent of the available manure acres between 'Tier 1' and the 'E3' scenario levels.

–Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.

–BMP reduction factors of 75 percent (TN and TP) are applied to protected manure acres.

- Tier 2 Farm Plans (non-nutrient management)

–Applied to 'Tier 1' levels plus 30 percent of the available agricultural acres (crop, hay, and pasture) between 'Tier 1' and the 'E3' scenario levels.

–Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.

–Nutrient and sediment reduction factors for Farm Plans on high-till are 10 percent (TN) and 40 percent (TP and SED). Low-till and hay reduction factors are 4 percent (TN) and 8 percent (TP and SED) while the reduction factors for Farm Plans on pasture are 20 percent (TN) and 14 percent (TP and SED).

- Tier 2 Cover crops

–Applied to 'Tier 1' levels plus 40 percent of the available cropland between 'Tier 1' and the 'E3' scenario levels.

–Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.

–BMP reduction factors of 35 percent (TN) and 15 percent (TP and SED) are applied to cover crop acres.

- Tier 2 Streambank protection with fencing

–Applied to 'Tier 1' levels plus 15 percent of the available pasture land that can be protected between 'Tier 1' and the 'E3' scenario levels.

  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –BMP reduction factors of 75 percent for TN, TP, and SED are applied to pasture acres protected.
- Tier 2 Streambank protection without fencing
  - –Applied to ‘Tier 1’ levels plus 10 percent of the available pasture land area to apply the BMPs to accounting for the acres protected by fencing.
  - –Tier 1 levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes and streambank protection with fencing.
  - –BMP reduction factors of 40 percent for TN, TP, and SED are applied to pasture acres protected.
- Tier 2 Grazing land protection
  - –Applied to ‘Tier 1’ levels plus 25 percent of the available pasture land between ‘Tier 1’ and the ‘E3’ scenario’ levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –BMP reduction factors of 50 percent (TN) and 25 percent (TP) are applied to protected pasture acres.

2010 TIER 2 URBAN AND MIXED OPEN BMPs

- Tier 2 Reduction in 2000–2010 urban growth
  - –10 percent of the projected pervious and impervious urban growth in PA, MD, VA, and DC between 2000 and 2010 is not developed.
  - –It is assumed that 65 percent of the reduction in projected urban growth is retained in forest, 20 percent in mixed open, and 15 percent in agriculture.
  - –Landuse conversions of pervious and impervious urban to forest, mixed open, and agriculture (crop, hay, and pasture).
- Tier 2 Storm Water Management and environmental site design/low-impact development on new development
  - –Storm water management applied to 75% of new development between 2000 and 2010.
  - –Environmental site design/low-impact development practices applied to 25% of new development between 2000 and 2010.
  - –Efficiencies of storm water management and environmental site design and low-impact development practices represent a 75%/25% weighted average reduction of 40% for TN, 55% for TP, and 85% for TSS.

- Tier 2 Storm Water Management on recent development
  - –60 percent of recent development (1986–2000) has storm water management practices that are designed to reduce nutrients and sediment in storm water runoff by 27 percent (TN), 40 percent (TP), and 65 percent (SED).
- Tier 2 Storm Water retrofits on old and recent development
  - –5 percent of pre-1986 urban land and 1986–2000 recent development has storm water management practices that reduce nutrients and sediment in runoff by 20 percent (TN), 30 percent (TP), and 65 percent (SED).
- Tier 2 Riparian grass buffers on urban lands
  - –Urban grass buffer acreage is reduced 10 percent below 'Tier 1' levels and is converted to urban forest buffers.
  - –Tier 1 levels are revised following the same methodology but account for previously applied BMPs that involve landuse changes.
  - –The assumption is maintained that all urban stream reaches have 50-foot riparian buffers in either forest or grass except where urban disturbance has altered a stream reach beyond repair/restoration (i.e., impervious surface).
  - –There is no upland benefit associated with grass buffers on urban.
- Tier 2 Riparian forest buffers on urban lands
  - –Urban forest buffer acreage is increased by the same amount as the reduction in urban grass buffers.
  - –The assumption is maintained that all urban stream reaches have 50-foot riparian buffers in either forest or grass except where urban disturbance has altered a stream reach beyond repair/restoration (i.e., impervious surface).
  - –There is no upland benefit associated with forest buffers on urban.
- Tier 2 Riparian forest buffers on mixed open lands
  - –Mixed open forest buffer acreage is increased from 'Tier 1' levels by the same amount as the increase in urban forest buffers between 'Tier 1' and Tier 2.
  - –Tier 1 levels are revised following the same methodology but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of mixed open to forest.
  - –There is no upland benefit associated with forest buffers on mixed open.
- Tier 2 Nutrient management on urban and mixed open lands
  - –It is assumed that 40 percent of pervious urban and 40 percent of mixed open land are under nutrient management.
  - –BMP reduction factors of 17 percent (TN) and 22 percent (TP) are applied to acres under nutrient management.

2010 TIER 2 FOREST HARVEST BMPs

- It is assumed that forestry BMPs designed to minimize the environmental impacts from timber harvesting, such as road building and cutting/thinning operations, are properly installed on all harvested lands with no measurable increase in nutrient and sediment discharge.
- The assumption is based on maintaining the state of forest loads as measured during the calibration of the Chesapeake Bay Watershed Model.

2010 TIER 2 SEPTIC BMPs

- 10 percent of new treatment systems between 2000 and 2010 employ denitrification technologies and are maintained through regular pumping to meet an edge of septic field TN concentration of 10 mg/l or 2.3 lbs TN per person-year.
- Remaining new and existing systems are at current edge of septic field concentrations and flows per system.
- Septic BMPs incorporate submissions from the Chesapeake Bay basin jurisdictions of the current number of systems employing denitrification technologies (50 percent TN reduction) and those with regular maintenance through pumping (5 percent TN reduction).

2010 TIER 2 POINT SOURCE BMPs

- Tier 2 Significant municipal wastewater treatment facilities
  - –Nitrogen – All significant POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 8 mg TN/L (annual average) including those facilities that planned to go to NRT by 2010.
  - –Phosphorus – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 1.0 mg TP/L (annual average) or the permit limit, whichever is less.
- Tier 2 Significant industrial dischargers

  –2000 flows and generally maintain effluent concentrations that are 50 percent less that those in Tier 1 or the permit limit, whichever is less.
- Tier 2 Non-significant municipal wastewater treatment facilities

  –2000 TN and TP effluent concentrations applied to 2010 projected flows.

2010 TIER 2 COMBINED SEWER OVERFLOW BMPs

- There is a 43 percent reduction in the current discharge from District of Columbia combined sewer overflows, the only CSO loads among all jurisdictions for which the Chesapeake Bay Program has nutrient load data specifically quantified in the model simulation.

- The reduction from 2000 loads is what is expected by the District of Columbia to be achieved by 2010.

2010 TIER 2 ATMOSPHERIC DEPOSITION BMPs

Atmospheric deposition under Tier 2 reflects implementation of the 1990 Clean Air Act projected for the year 2020 with nitrogen oxide emissions regulations described in Tier 1 plus heavy-duty diesel regulations that have passed. Estimated changes in deposition for the Tier 2 scenario reflects the following controls on nitrogen oxide emissions:

- 2020 non-utility (industrial) point source and area source emissions with no additional controls beyond Tier 1.
- 2020 mobile source emissions with the effect of the Tier II tail pipe standards on light duty vehicles being felt, and the implementation of the heavy-duty diesel standards to further reduce NO_x emissions.
- 2020 utility emissions with Title IV (Acid Rain Program) fully implemented and 20-state NO_x SIP call reductions at 0.15 lbs/MMbtu during the May to September ozone season only—Same as Tier 1 controls.

The impacts of emissions and deposition to the Chesapeake Bay watershed's land area and non-tidal waters under Tier 2 are part of the reported nutrient loads from the individual landuse source categories (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). The reported Watershed Model loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Water Quality Model, account for this source at levels prescribed by Tier 2.

2010 TIER 2 SHORELINE EROSION BMPs

- Tier 2 shoreline erosion controls include structural and non-structural practices at 2000 levels.

The impacts of Tier 2 shoreline erosion controls are not included in the reported Watershed Model loads although the water quality responses, as measured by the Water Quality Model, account for this source at BMP levels prescribed by Tier 2.

2010 TIER 3 SCENARIO

The 2010 Tier 3 BMP implementation levels for nonpoint sources were generally determined by increasing levels above the Tier 1 scenario by a percentage of the difference between the Tier 1 and the E3 scenario levels, with the percentages being higher than those used in the Tier 2 scenario. As with the Tier 2 scenario, the levels of nonpoint source control were applied watershed-wide by county segments, or the intersections of county political boundaries and the Watershed Model's hydrologic segmentation.

For Tier 3 municipal point source facilities, technologies to achieve 5 mg TN/L include extended aeration processes beyond those in the Tier 2 scenario, a secondary anoxic zone plus methanol addition, additional clarification tanks, and additional chemicals to achieve a phosphorus discharge of 0.5 mg TP/L.

In the Tier 3 scenario, considerations of the costs of BMP implementation, participation levels, and physical limitations are very limited. Tier 3 BMP levels, considered technically possible, are listed below for each of the major source categories.

2010 TIER 3 AGRICULTURAL BMPs

- Tier 3 Conservation tillage
  - –Applied to 'Tier 1' levels plus 60 percent of the available crop acres between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of high-till to low-till.
- Tier 3 Riparian forest buffers on agriculture
  - –Applied to 'Tier 1' levels plus 30 percent of the available stream reaches in cropland and pasture and 50 percent of the remaining stream reaches in hay between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes 100-foot forest buffers on un-buffered stream miles (each side) associated with crop, hay, and pasture.
  - –Tier 1 forest buffers on pasture are rooted in agricultural tree planting from jurisdictional BMP reporting.
  - –Landuse conversions of crop, hay, and pasture to forest.
  - –For every acre of crop and hay converted, two upland acres of crop and hay receive a reduction of 57 percent (TN), 70 percent (TP), and 70 percent (SED).
  - –There is no upland benefit associated with forest buffers on pasture.
- Tier 3 Wetland restoration
  - –Applied to 'Tier 1' levels plus 66 percent of the available crop and hay acres in PA, MD, and VA between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of crop and hay to forest.

- Tier 3 Agricultural land retirement
  - –The remainder of 15 percent of the total crop and hay acres and those acres converted through forest buffers and wetland restoration is retired to a grass condition.
  - –Landuse conversions of crop and hay to mixed open.
- Tier 3 Carbon sequestration/bio-energy
  - –15 percent of crop acres (after BMP landuse conversions) are replaced with long-term grasses that serve as a carbon bank and could be converted to energy through combustion.
  - –Landuse conversion of low-till to hay.
- Tier 3 Riparian grass buffers on cropland
  - –Applied to 'Tier 1' levels plus 50 percent of the available stream reaches in cropland between 'Tier 1' and the 'E3' scenario levels and after forest buffer planting.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –The E3 scenario assumes 100-foot buffers on un-buffered stream miles (each side) associated with agricultural land.
  - –Landuse conversions of crop to mixed open.
  - –For every acre of cropland converted, two upland acres of crop receive a reduction of 43 percent (TN), 53 percent (TP), and 53 percent (SED).
- Tier 3 Nutrient Management Plan Implementation (standard and yield reserve program)
  - –Nutrient management is applied to 'Tier 2' levels plus 30 percent of the available crop and hay acres between 'Tier 2' and the 'E3' scenario levels in PA, VA, NY, and WV.
  - –Tier 2 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –All crop and hay acres in MD and DE are fully implementing nutrient management plans.
  - –Of the crop and hay acres available for nutrient management, 30 percent conforms to a yield reserve program where the land receives 25 percent less TN and TP than standard nutrient management applications - Do not receive more than 98 percent of TN and TP need.
  - –Yield reserve program assumes farmer insurance for yield losses.
  - –The remaining 70 percent of land available for nutrient management follows standard rules where crop and hay acres do not receive more than 130 percent of their TN and TP need.

- Tier 3 Manure excess
  - Excess nutrients resulting from the differences between manure generated and conforming to nutrient management rules and losses in agricultural land are reported.
  - It is assumed that all of the excess manure has alternative uses that do not affect loads to the Chesapeake Bay tidal waters.
- Tier 3 Animal waste management/runoff control
  - Applied to 'Tier 1' levels plus 60 percent of the available manure acres between 'Tier 1' and the 'E3' scenario levels.
  - Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - BMP reduction factors of 75 percent (TN and TP) are applied to protected manure acres.
- Tier 3 Farm Plans (non-nutrient management)
  - Applied to 'Tier 1' levels plus 70 percent of the available agricultural acres (crop, hay, and pasture) between 'Tier 1' and the 'E3' scenario levels.
  - Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - Nutrient and sediment reduction factors for Farm Plans on high-till are 10 percent (TN) and 40 percent (TP and SED). Low-till and hay reduction factors are 4 percent (TN) and 8 percent (TP and SED) while the reduction factors for Farm Plans on pasture are 20 percent (TN) and 14 percent (TP and SED).
- Tier 3 Cover crops
  - Applied to 'Tier 1' levels plus 75 percent of the available cropland between 'Tier 1' and the 'E3' scenario levels.
  - Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - BMP reduction factors of 35 percent (TN) and 15 percent (TP and SED) are applied to cover crop acres.
- Tier 3 Streambank protection with fencing
  - Applied to 'Tier 1' levels plus 75 percent of the available pasture land that can be protected between 'Tier 1' and the 'E3' scenario levels.
  - Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - BMP reduction factors of 75 percent for TN, TP, and SED are applied to pasture acres protected.

- Tier 3 Streambank protection without fencing
  - –Applied to 'Tier 1' levels plus 25 percent of the available pasture land area to apply the BMPs to accounting for the acres protected by fencing.
  - –Tier 1 levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes and streambank protection with fencing.
  - –BMP reduction factors of 40 percent for TN, TP, and SED are applied to pasture acres protected.
- Tier 3 Grazing land protection
  - –Applied to 'Tier 1' levels plus 50 percent of the available pasture land between 'Tier 1' and the 'E3' scenario levels.
  - –Tier 1 and the E3 scenario levels are revised following the same methodologies but account for previously applied BMPs that involve landuse changes.
  - –BMP reduction factors of 50 percent (TN) and 25 percent (TP) are applied to protected pasture acres.

2010 TIER 3 URBAN AND MIXED OPEN BMPs

- Tier 3 Reduction in 2000–2010 urban growth
  - –20 percent of the projected pervious and impervious urban growth in PA, MD, VA, and DC between 2000 and 2010 is not developed.
  - –It is assumed that 65 percent of the reduction in projected urban growth is retained in forest, 20 percent in mixed open, and 15 percent in agriculture.
  - –Landuse conversions of pervious and impervious urban to forest, mixed open, and agriculture (crop, hay, and pasture).
- Tier 3 Storm Water Management and environmental site design/low-impact development on new development
  - –Storm water management applied to 50 percent of new development between 2000 and 2010.
  - –Environmental site design/low-impact development practices applied to 50 percent of new development between 2000 and 2010.
  - –Efficiencies of storm water management and environmental site design and low-impact development practices represent a 50%/50% weighted average reduction of 45% for TN, 57% for TP, and 87% for TSS.
- Tier 3 Storm Water Management on recent development
  - –60 percent of recent development (1986–2000) has storm water management practices that are designed to reduce nutrients and sediment in stormwater runoff by 27 percent (TN), 40 percent (TP), and 65 percent (SED).
- Tier 3 Storm Water retrofits on old and recent development
  - –20 percent of pre-1986 urban land and 1986–2000 recent development has storm water management practices that reduce nutrients and sediment in runoff by 20 percent (TN), 30 percent (TP), and 65 percent (SED).

- Tier 3 Riparian grass buffers on urban lands
  - –Urban grass buffer acreage is reduced 30 percent below ‘Tier 1’ levels and is converted to urban forest buffers.
  - –Tier 1 levels are revised following the same methodology but account for previously applied BMPs that involve landuse changes.
  - –The assumption is maintained that all urban stream reaches have 50-foot riparian buffers in either forest or grass except where urban disturbance has altered a stream reach beyond repair/restoration (i.e., impervious surface).
  - –There is no upland benefit associated with grass buffers on urban.
- Tier 3 Riparian forest buffers on urban lands
  - –Urban forest buffer acreage is increased by the same amount as the reduction in urban grass buffers.
  - –The assumption is maintained that all urban stream reaches have 50-foot riparian buffers in either forest or grass except where urban disturbance has altered a stream reach beyond repair/restoration (i.e., impervious surface).
  - –There is no upland benefit associated with forest buffers on urban.
- Tier 3 Riparian forest buffers on mixed open lands
  - –Mixed open forest buffer acreage is increased from ‘Tier 1’ levels by the same amount as the increase in urban forest buffers between ‘Tier 1’ and Tier 3.
  - –Tier 1 levels are revised following the same methodology but account for previously applied BMPs that involve landuse changes.
  - –Landuse conversion of mixed open to forest.
  - –There is no upland benefit associated with forest buffers on mixed open.
- Tier 3 Nutrient management on urban and mixed open lands
  - –It is assumed that 75 percent of pervious urban and 75 percent of mixed open land are under nutrient management.
  - –BMP reduction factors of 17 percent (TN) and 22 percent (TP) are applied to acres under nutrient management.

2010 TIER 3 FOREST HARVEST BMPs

- It is assumed that forestry BMPs designed to minimize the environmental impacts from timber harvesting, such as road building and cutting/thinning operations, are properly installed on all harvested lands with no measurable increase in nutrient and sediment discharge.
- The assumption is based on maintaining the state of forest loads as measured during the calibration of the Chesapeake Bay Watershed Model.

2010 TIER 3 SEPTIC BMPs

- 100 percent of new treatment systems between 2000 and 2010 and 1 percent of existing systems employ denitrification technologies and are maintained through regular pumping to meet an edge-of-septic-field TN concentration of 10 mg/L or 2.3 lbs TN per person-year.
- The 1 percent of existing systems represents failed systems and opportunities for upgrades.
- The remaining existing systems are at current edge of septic field concentrations and flows per system.
- Septic BMPs incorporate submissions from the Chesapeake Bay basin jurisdictions of the current number of systems employing denitrification technologies (50 percent TN reduction) and those with regular maintenance through pumping (5 percent TN reduction).

2010 TIER 3 POINT SOURCE BMPs

- Tier 3 Significant municipal wastewater treatment facilities
  –Nitrogen – All significant POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 5 mg TN/L (annual average) including those facilities that planned to go to NRT by 2010.
  –Phosphorus – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 0.5 mg TP/L (annual average) or the permit limit, whichever is less.
- Tier 3 Significant industrial dischargers
  –2000 flows and generally maintain effluent concentrations that are 80 percent less that those in Tier 1 or the permit limit, whichever is less.
- Tier 3 Non-significant municipal wastewater treatment facilities
  –2000 TN and TP effluent concentrations applied to 2010 projected flows.

2010 TIER 3 COMBINED SEWER OVERFLOW BMPs

- There is a 43 percent reduction in the current discharge from District of Columbia combined sewer overflows, the only CSO loads among all jurisdictions for which the Chesapeake Bay Program has nutrient load data specifically quantified in the model simulation.
- The reduction from 2000 loads is what is expected by the District of Columbia to be achieved by 2010.

2010 TIER 3 ATMOSPHERIC DEPOSITION BMPs

Atmospheric deposition under the Tier 3 scenario reflects existing regulatory nitrogen oxide emissions controls under the 1990 Clean Air Act, as well as more aggressive but voluntary emissions controls on the utility sector, projected for the year 2020. Estimated changes in deposition for the Tier 3 scenario reflect the following controls on nitrogen oxide emissions:

- 2020 non-utility (industrial) point source and area source emissions with no additional controls than Tiers 1 and 2.
- 2020 mobile source emissions with the effect of the Tier II tail pipe standards on light duty vehicles being felt, and the implementation of the heavy duty diesel standards to further reduce NO_x emissions. Same as Tier 2 controls.
- 2020 utility emissions with major (90 percent) reductions in SO_2 and aggressive 20-state NO_x SIP call reductions through utilities going to 0.10 lbs/MMbtu for the entire year—no longer just seasonal.

The impacts of emissions and deposition to the Chesapeake Bay watershed's land area and non-tidal waters under the Tier 3 scenario are part of the reported nutrient loads from the individual landuse source categories (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). The reported loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Water Quality Model, account for this source at levels prescribed by the Tier 3 scenario.

2010 TIER 3 SHORELINE EROSION BMPs

- Tier 3 shoreline erosion controls include structural and non-structural practices at 2000 levels.

The impacts of Tier 3 shoreline erosion controls are not included in the reported Watershed Model loads although the water quality responses, as measured by the Water Quality Model, account for this source at BMP levels prescribed by the Tier 3 scenario.

2010 E3 SCENARIO

BMP implementation levels in the tier scenarios were bounded by the E3 scenario. The E3 scenario was specifically designed to take out most of the subjectivity surrounding what can or cannot be achieved in control measures. The E3 scenario BMP implementation levels were, in part, based on earlier work of the Chesapeake Bay Program partners when a 'limit-of-technology' condition was assessed by the Tributary Strategy Workgroup. However, the E3 scenario is less subjective than the limit-of-technology scenario in terms of maximum implementation levels. The BMP levels in the E3 scenario are theoretical: there are no cost and few physical limitations to implementing BMPs for point and nonpoint sources. In addition, the E3 scenario includes new BMP technologies and programs that are not currently part of jurisdictional pollutant control strategies.

For most nonpoint source BMPs, the workgroups assumed that the load from every available acre of the relevant land area was being controlled by a full suite of existing or innovative practices. In addition, management programs convert landuses from those with high-yielding nutrient and sediment loads to those with lower. For point sources in the E3 scenario, municipal wastewater treatment facilities reach and maintain effluent concentrations of 3 mg TN/L, and at least 0.1 mg TP/L, through technologies such as deep-bed denitrification filters and micro-filtration.

The E3 scenario implementation levels and their associated reductions in nutrients and sediment were developed without consideration of site specific physical constraints, costs, or even plausible BMP program participation levels. The Chesapeake Bay Program partners acknowledge that if these factors are considered, several aspects of the E3 scenario could not be achieved. On the other hand, there are some control measures in the E3 scenario that physically could be more aggressive. The E3 scenario conditions for these BMPs were established because a theoretical maximum implementation level would have been entirely subjective.

BMP implementation levels for the E3 scenario are described in detail below for the major source categories—agriculture, urban and mixed open, point sources, septic, and atmospheric deposition.

PHYSICAL LIMITATIONS TO THE E3 SCENARIO

In all appropriate circumstances, BMP implementation levels in the E3 scenario were applied to all relevant landuse areas or current limits-of-technology. In many cases and to remove the subjectivity in determining human-caused conditions that cannot be remedied, there were no physical limitations to employing the practices or programs.

For many BMPs, the E3 scenario implementation levels could not be physically achieved. For example, space may not be available for 50-foot riparian buffers in urban areas, or certain developed lands may not allow for retrofitting with practices that attain pollutant reduction efficiencies used in the E3 scenario. As other examples, certain crop types cannot be conservation-tilled, and it may be physically impossible to completely eliminate runoff from animal feeding operations.

It is also unlikely that every homeowner and farmer would efficiently apply fertilizers so that only the needs of the vegetation are met and that water-front property owners would plant 50-foot buffers even if it were physically possible. As a whole, ‘feasible’ participation levels are not built into the E3 scenario. All of the above-mentioned instances are examples of where the E3 scenario may overestimate reductions.

UNDERESTIMATIONS OF LOAD REDUCTIONS UNDER THE E3 SCENARIO

Contrarily, there are assumptions in the E3 scenario where BMP implementation levels could physically be even higher than those currently defined in the E3 scenario. For example, it is physically possible that more than 25,000 acres of cropland and hay in Chesapeake Bay watershed could be restored to wetlands. This limit on wetland acres restored in the E3 scenario in Pennsylvania, Maryland and Virginia was used to reflect the *Chesapeake 2000* goal since a theoretical maximum implementation level for wetlands restoration would be entirely subjective.

As an other example, 25 percent of cropland was replaced with long-term grasses that serve as a carbon bank and could be converted to energy through combustion. Benefits of a carbon sequestration program, in terms of lower pollutant loads, would increase as more agricultural land is converted. Conversion of more than 25 percent of cropland is physically possible. In addition, the 30 percent reduction in urban sprawl over a decade could be physically set at a higher level. This rate was employed in the E3 scenario to adhere to a *Chesapeake 2000* goal.

The E3 scenario only includes shoreline erosion controls at current levels for lack of a ‘maximum’ limit that would not be entirely subjective. It has been demonstrated through modeling efforts that additional controls of shoreline erosion can significantly improve tidal water quality. In general, much opportunity exists for reducing sediment and nutrient loads from eroding shorelines that would not be reflected in the E3 scenario water quality model results.

If greater BMP implementation levels than those designated in the E3 scenario could be physically achieved for any BMPs, pollutant loadings would decrease and the there would be corresponding improved responses in water quality. For the most part, however, the E3 scenario does not include real physical limitations to BMP implementation or participation levels.

2010 E3 AGRICULTURAL BMPs

- The E3 scenario conservation tillage
  - –All cropland (high-till and low-till) is conservation-tilled.
  - –Landuse conversion of high-till to low-till.
- The E3 scenario riparian forest buffers on agriculture
  - –100-foot forest buffers on all un-buffered stream miles (each side) associated with crop, hay, and pasture.
  - –Landuse conversion of low-till, hay, and pasture to forest.
  - –For every acre of low-till and hay converted, two upland acres of low-till and hay receive a reduction of 57 percent (TN), 70 percent (TP), and 70 percent (SED).
  - –There is no upland benefit associated with forest buffers on pasture.

- The E3 scenario wetland restoration
  - –In accordance with the *Chesapeake 2000* agreement, 25,000 acres of crop and hay in PA, MD, and VA are converted to and simulated as forest.
  - –The 25,000 acre restoration goal is allocated among these states as follows to conform to agreements subsequent to *Chesapeake 2000*: PA = 4,250 acres, MD = 15,000 acres, and VA = 5,750 acres.

- The E3 scenario agricultural land retirement
  - –The remainder of 25 percent of the total crop and hay acres and those acres converted through forest buffers and wetland restoration is retired to a grass condition.
  - –Landuse conversions of low-till and hay to mixed open.

- The E3 scenario carbon sequestration/bio-energy
  - –25 percent of crop acres (after BMP landuse conversions) are replaced with long-term grasses that serve as a carbon bank and could be converted to energy through combustion.
  - –Landuse conversion of low-till to hay.

- The E3 scenario yield reserve program
  - –All crop and hay acres (after BMP landuse conversions) receive 25 percent less TN and TP than normal nutrient management applications; do not receive more than 98 percent of TN and TP need.
  - –Yield reserve program assumes farmer insurance for yield losses.

- The E3 scenario manure excess
  - –Excess nutrients resulting from the differences between manure generated and conforming to yield reserve (nutrient management) rules and losses in agricultural land are reported.
  - –It is assumed that all of the excess manure has alternative uses that do not affect loads to the Chesapeake Bay tidal waters.

- The E3 scenario animal waste management/runoff control
  - –There is no runoff from manure in animal feeding operations.
  - –Modeled landuse acres that account for runoff from animal feeding operations are converted to pasture.
  - –Landuse conversion of manure acres to pasture.

- The E3 scenario Farm Plans (non-nutrient management)
  - –Farm Plans are fully implemented on all agricultural land (crop, hay, and pasture).
  - –Nutrient and sediment reduction factors for Farm Plans on low-till and hay are 4 percent (TN) and 8 percent (TP and SED). Pasture reduction factors are 20 percent (TN) and 14 percent (TP and SED).

- The E3 scenario cover crops
  - –All crop landuses have cover crops.
  - –BMP reduction factors of 35 percent (TN) and 15 percent (TP and SED) are applied to all low-till.
- The E3 scenario streambank protection with fencing
  - –Streambank protection with fencing on all unprotected stream miles (each side) associated with pasture.
  - –For every stream mile protected, 51 upland acres of pasture receive a reduction of 75 percent for TN, TP and SED.
- The E3 scenario grazing land protection
  - –All pasture land is protected through rotational grazing.
  - –BMP reduction factors of 50 percent (TN) and 25 percent (TP) are applied.

2010 E3 SCENARIO URBAN AND MIXED OPEN BMPs

- The E3 scenario reduction in 2000–2010 urban growth
  - –30 percent of the projected pervious and impervious urban growth in PA, MD, VA, and DC between 2000 and 2010 remains in forest to conform to the *Chesapeake 2000* agreement.
  - –It is assumed that the reduction in projected urban growth in PA, MD, VA, and DC over the decade is retained or planted in forest.
  - –Landuse conversions of pervious and impervious urban to forest.
- The E3 scenario environmental site design/low-impact development on new development
  - –Environmental site design/low-impact development practices applied to all urban growth between 2000 and 2010.
  - –Environmental site design and low-impact development practices are designed to reduce TN by 50 percent, TP by 60 percent, and SED by 90 percent.
- The E3 scenario storm water retrofits on existing urban
  - –All pre-2001 urban areas are retrofitted with a suite of practices to reduce nutrients and sediment in storm water runoff by 40 percent (TN), 40 percent (TP), and 80 percent (SED).
- The E3 scenario riparian forest buffers on urban
  - –50-foot forest buffers on all un-buffered stream miles (each side) associated with pervious urban.
  - –Landuse conversion of pervious urban to forest.
  - –There is no upland benefit associated with forest buffers on urban.

- The E3 scenario riparian forest buffers on mixed open
  - –100-foot forest buffers on all un-buffered stream miles (each side) associated with mixed open.
  - –Landuse conversion of mixed open to forest.
  - –There is no upland benefit associated with forest buffers on mixed open.
- The E3 scenario nutrient management on urban and mixed open
  - –All pervious urban and mixed open acres do not receive nutrient applications from chemical fertilizers.

2010 E3 SCENARIO FOREST HARVEST BMPs

- It is assumed that forestry BMPs designed to minimize the environmental impacts from timber harvesting, such as road building and cutting/thinning operations, are properly installed on all harvested lands with no measurable increase in nutrient and sediment discharge.
- The assumption is based on maintaining the state of forest loads as measured during the calibration of the Chesapeake Bay Program Watershed Model.

2010 E3 SCENARIO SEPTIC BMPs

- All septic systems employ denitrification technologies and are maintained through regular pumping to meet an edge-of-septic-field TN concentration of 10 mg/L or 2.3 lbs TN per person-year.

2010 E3 SCENARIO POINT SOURCE BMPs

- The E3 scenario significant municipal wastewater treatment facilities
  - –Nitrogen – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 3 mg TN/L (annual average).
  - –Phosphorus – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 0.1 mg TP/L (annual average).
- The E3 scenario significant industrial dischargers
  - –Nitrogen – 2000 flows and effluent concentrations of 3.0 mg TN/L (annual average) or the permit limit, whichever is less.
  - –Phosphorus – 2000 flows and effluent concentrations of 0.1 mg TP/L (annual average) or the permit limit, whichever is less.
- The E3 scenario non-significant municipal wastewater treatment facilities
  - –Nitrogen – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 8 mg TN/L (annual average).

–Phosphorus – POTWs are at 2010 projected flows and reach and maintain effluent concentrations of 2.0 mg TP/L (annual average) or 2000 concentrations, whichever is less.

2010 E3 SCENARIO COMBINED SEWER OVERFLOW BMPs

- There is no discharge from DC combined sewer overflows, the only CSO loads among all jurisdictions for which the Chesapeake Bay Program has nutrient load data specifically quantified in the model simulation.

2010 E3 SCENARIO ATMOSPHERIC DEPOSITION BMPs

Levels of atmospheric deposition in the E3 scenario reflect existing regulatory nitrogen oxide emissions controls under the 1990 Clean Air Act, as well as more aggressive but voluntary emissions controls on the utility, industrial, and mobile source sectors, projected for the year 2020. Estimated changes in deposition for the E3 scenario reflects the following controls on nitrogen oxide emissions:

- 2020 non-utility (industrial) point source emissions cut almost in half for both SO_2 and NO_x.
- 2020 area source emissions that are the same as the Tier 1-3 scenarios.
- 2020 mobile source emissions assuming super ultra-low emissions for light duty vehicles and heavy duty diesel standards to further reduce NO_x emission beyond Tier 2 and Tier 3.
- 2020 utility emissions with major (90 percent) reductions in SO_2 and aggressive 20-state NO_x SIP call reductions through utilities going to 0.10 lbs/MMbtu for the entire year—same as Tier 3 controls.

The impacts of emissions and deposition to the Chesapeake Bay watershed’s land area and non-tidal waters under the E3 scenario are part of the reported nutrient loads from the individual landuse source categories (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). The reported Watershed Model loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Water Quality Model, account for this source at levels prescribed by the E3 scenario.

2010 E3 SCENARIO SHORELINE EROSION BMPs

- The E3 scenario shoreline erosion controls include structural and non-structural practices at 2000 levels.

The impacts of the E3 scenario shoreline erosion controls are not included in the reported Watershed Model loads although the water quality responses, as measured by the Water Quality Model, account for this source at BMP levels prescribed by the E3 scenario.

BAY-WIDE LOADS FOR 2000, TIERS 1 TO 3, AND E3 SCENARIO

Figures A-1 through A-3 depict modeled Chesapeake Bay-wide nutrient and sediment loads delivered to the Chesapeake Bay and its tidal tributaries by major source category for each of the tier scenarios as well as the E3 scenario. As references, the estimated loads for the year 2000 are also portrayed.

The delivered loads are a yearly average of loads simulated over a 10-year period (1985–1994). This convention removes considerations of the effects of variable precipitation levels or flows on loads. Also, nutrient loads are reported in units of million pounds per year while sediment fluxes are in million tons per year.

Load reductions through the tiers to the E3 scenario show the impact of most point and nonpoint source BMPs in the scenarios as described previously in this Appendix. Atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal waters are part of the reported loads, but the loads do not include contributions from atmospheric deposition to tidal waters. In addition, the reported loads do not reflect

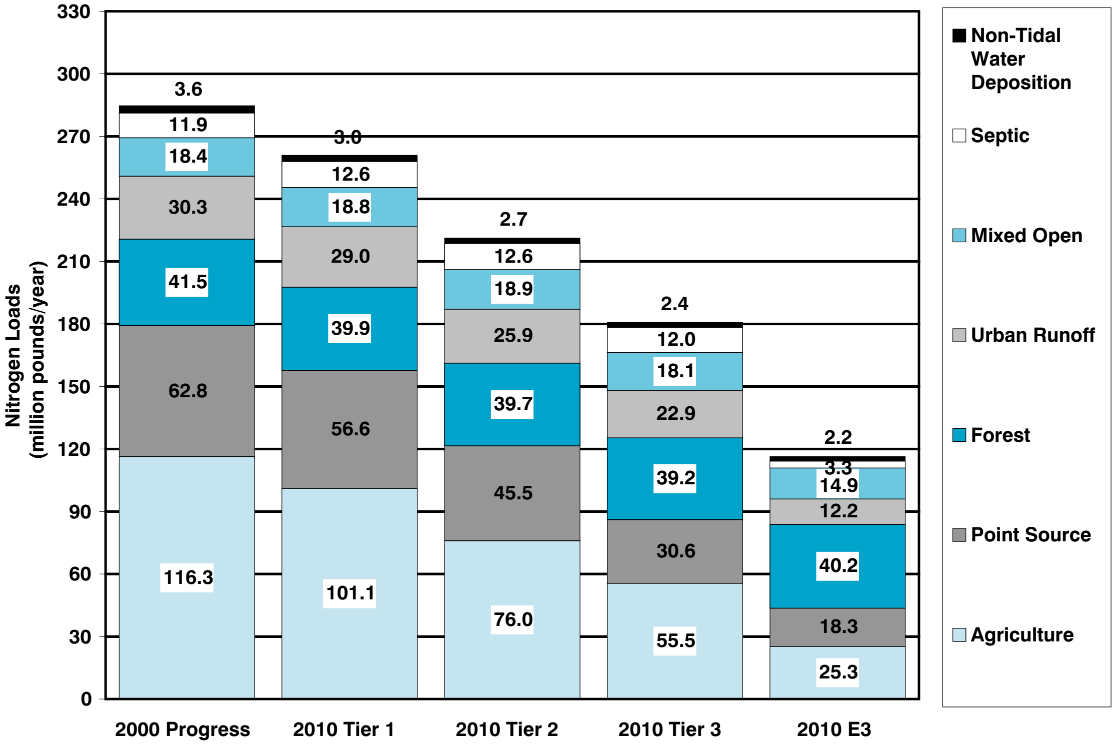

Figure A-1. Nitrogen loads delivered to the Chesapeake Bay and its tidal tributaries by source.

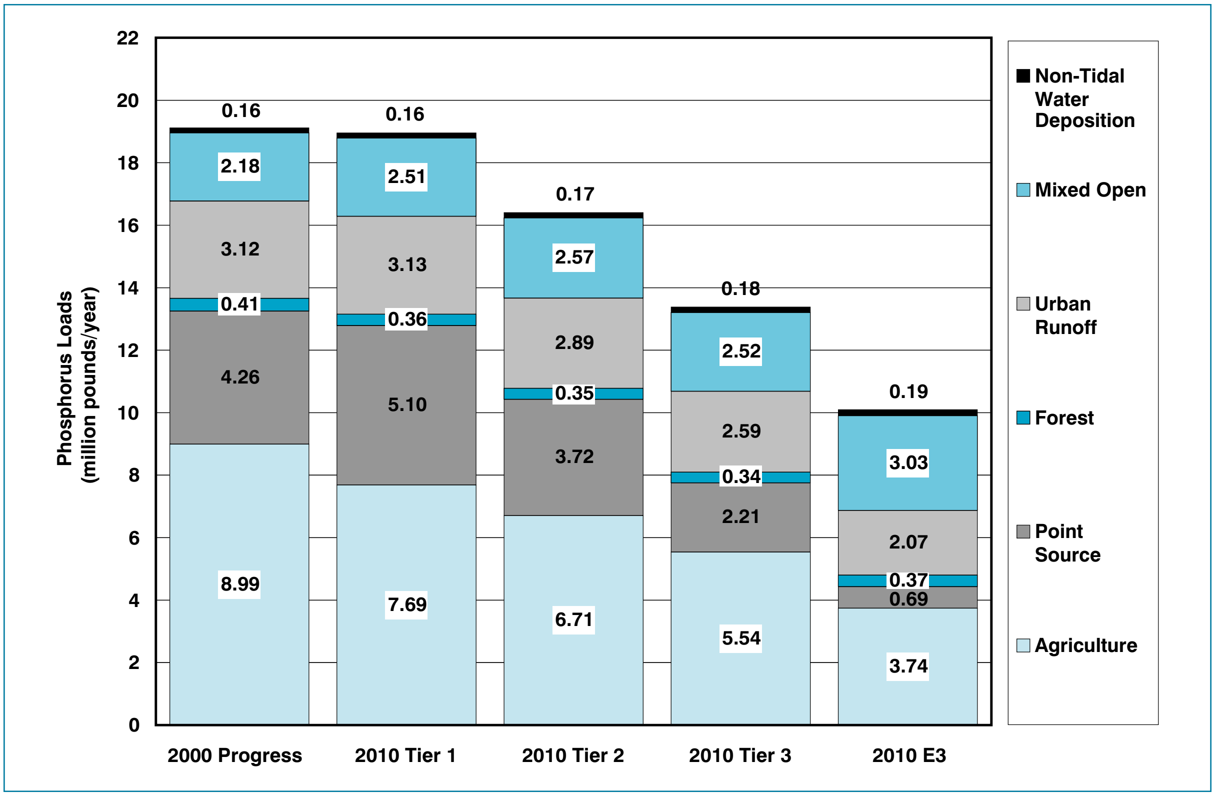

Figure A-2. Phosphorus loads delivered to the Chesapeake Bay and its tidal tributaries by source.

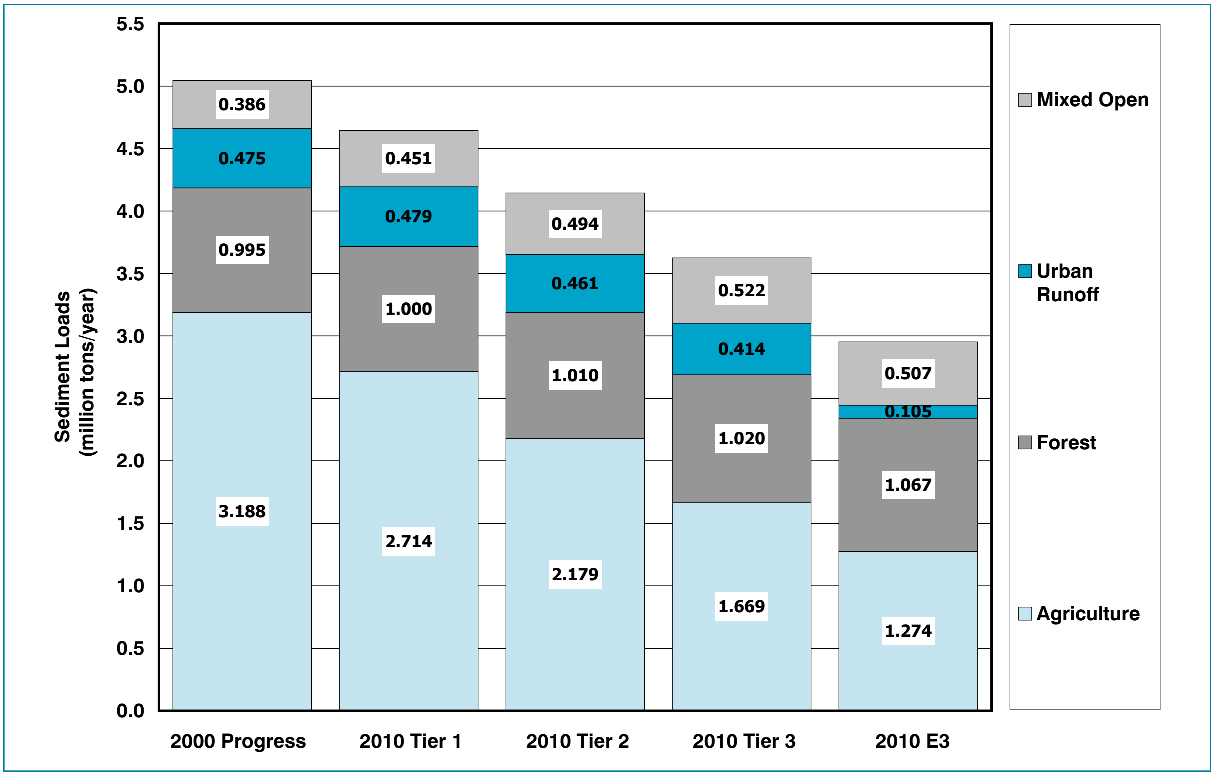

Figure A-3. Sediment loads delivered to the Chesapeake Bay and its tidal tributaries by source.

shoreline erosion controls employed in the scenarios. The water quality responses as measured by the Watershed Model, however, account for both atmospheric deposition to tidal waters and shoreline erosion at levels prescribed by the tier and E3 scenarios.

It is important to note that landuses and animal populations change considerably between 2000 Progress and the tier and E3 scenarios, which are based on projected 2010 landuses and populations. Therefore, nutrient applications to agricultural land change considerably over the decade. Also, the number of septic systems and the flows from municipal wastewater treatment facilities shift dramatically from 2000 to 2010 based on an increasing population. For example, point source phosphorous loads increase from 2000 to 2010 Tier 1 because of increases in POTW flows which, unlike nitrogen, are not offset by technologies to reduce this nutrient in effluents.

In addition to changes between 2000 and 2010 tier and E3 scenarios, it is imperative to consider landuse changes among the tier and E3 scenarios due to increasing non-point source BMP implementation levels. For example, sediment loads from forested land increase through the tier to E3 scenarios because the land area increases as, for example, more and more riparian buffers are planted on agricultural and urban land. In addition, increases in loads from mixed open land is attributable to greater acreage in this category as, for example, agricultural land is retired.

INFLUENCE OF EMISSION CONTROLS AND ATMOSPHERIC DEPOSITION ON LOADS

The impacts of emission controls and the resultant lower atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal waters are part of the reported nutrient loads from the individual landuse source categories in the tier and E3 scenarios (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). As mentioned previously, the reported loads however, usually do not include contributions from atmospheric deposition to tidal waters although the model simulated tidal Bay water quality responses account for this source.

To estimate the effects of only the tier and E3 scenarios air emission controls—without the influences of other point and non-point source BMPs—the following histogram (Figure A-4) show changes in atmospheric deposition of nitrogen to the watershed's land area and non-tidal waters, and the response in delivered loads. In these model simulations, all land uses, fertilizer applications, point sources, septic loads, and BMP implementation levels were held constant at 2000 conditions; only atmospheric deposition varied.

What these scenarios say is that "If projected emission and deposition reductions associated with the tiers and E3 scenarios were realized today (2000), loads to the Chesapeake Bay and its tidal tributaries are estimated to be the following." As references, Tier 1 and Tier 2 scenario loads delivered from the watershed are shown in the graphics.

As can be seen in Figure A-4, atmospheric deposition to the watershed progressively declines from 2000 through the tier to E3 scenarios as more emission controls are included in the model simulation. But note how the loads from the watershed's land area and non-tidal waters respond to these progressive emission and deposition reductions, but to a much smaller degree.

The most significant reason for the dampened response is that the Chesapeake Bay watershed is about 57 percent forested—or 57 percent of atmospheric nitrogen deposits on forests—and among landuses, forests have the greatest potential to uptake nitrogen. Generally, forests in the Chesapeake Bay basin are not nitrogen-saturated—whereby they leak nitrogen to sub-surface or ground water.

The largest single source of nitrogen loads to the Chesapeake Bay is agriculture where nitrogen-based commercial fertilizers and animal manure applied to agricultural land are currently eight times the input of nitrogen to agricultural land from atmospheric deposition.

It is the impacts of emission controls on loads that are important in evaluating water quality responses, the development of a cost estimating tool, and the establishment of tributary strategies—rather than the contribution to loads from atmospheric

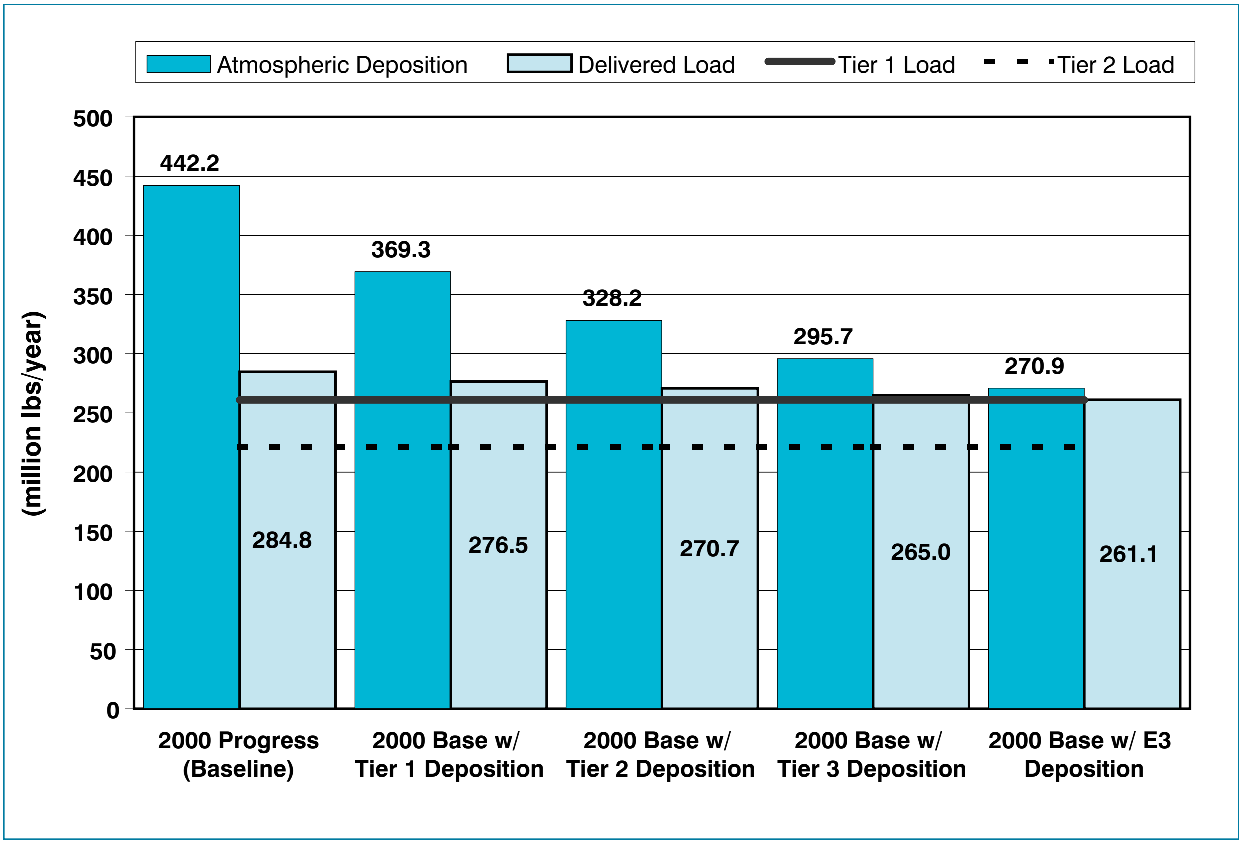

Figure A-4. Nitrogen deposits versus delivered loads.

deposition. Understanding the loading responses to changes in deposition better addresses to what degree the loads can be controlled. The proportion of the loads attributed to atmospheric deposition changes dramatically from 2000 through the tiers and E3 scenarios because of both variable emission controls and changes in landuses to which the atmospheric nitrogen is deposited.

In the most dramatic case, deposition of nitrogen to the watershed decreases 171 million pounds/year from the 2000 Progress to 2010 E3 scenarios. If this reduction in deposition were realized today, (i.e., deposition was to 2000 landuses with all other present conditions), nitrogen loads to the Chesapeake Bay would decrease 21 million pounds/year or would be at levels associated with the Tier 1 scenario.

It is important to note that the E3 scenario levels of emission controls are considered to be the current limits of technology with aggressive controls on all major sources—utilities, mobile, and industrial—and follow the format of defining the E3 scenario BMPs. It is not important that these emission controls would be voluntary, as opposed to regulatory, as the E3 scenario implementation levels for almost all other point and nonpoint source BMPs did not consider physical limitations, participation rates, and costs. In other words, the tier scenarios are not intended to establish what can and cannot be done through management actions—either regulatory or voluntary—as this is the responsibility of Chesapeake Bay watershed jurisdictions. However, the air scenarios involve actions taken by 37 states not just the Chesapeake Bay watershed states.

appendix B

Data Supporting Determination of the Shallow-Water Designated Use Depths and Underwater Bay Grasses Restoration Goals

Table B-1. Potential underwater bay grass habitat acreage by depth contour interval by Chesapeake Bay Program segment.

Chesapeake Bay Program Segment	0–0.5 Meter Depth	0.5–1 Meter Depth	1–2 Meter Depth
Northern Chesapeake Bay (CB1TF)	5,893	7,828	7,185
Northern Chesapeake Bay (CB1TF)	5,893	7,828	7,185
Upper Chesapeake Bay (CB2OH)	2,406	2,496	3,885
Upper Central Chesapeake Bay (CB3MH)	2,011	1,702	957
Middle Central Chesapeake Bay (CB4MH)	3,252	2,688	4,689
Lower Central Chesapeake Bay (CB5MH)	9,223	6,184	14,693
Western Lower Chesapeake Bay (CB6PH)	2,324.4	1,614	1,630
Eastern Lower Chesapeake Bay (CB7PH)	17,308	11,154	5,623
Mouth of the Chesapeake Bay (CB8PH)	381	314	355
Bush River (BSHOH)	1,136	932	2,536
Gunpowder River (GUNOH)	1,393	1,402	4,564
Middle River (MIDOH)	938	491	1,050
Back River (BACOH)	850	451	1,558
Patapsco River (PATMH)	1,042	766	1,610
Magothy River (MAGMH)	838	540	677
Severn River (SEVMH)	775	572	761
South River (SOUMH)	840	592	804
Rhode River (RHDMH)	267	162	281
West River (WSTMH)	542	491	435

continued

Table B-1. Potential underwater bay grass habitat acreage by depth contour interval by Chesapeake Bay Program segment *(cont.)*.

Chesapeake Bay Program Segment	0–0.5 Meter Depth	0.5–1 Meter Depth	1–2 Meter Depth
Upper Patuxent River (PAXTF)	24	10	20
Western Branch Patuxent River (WBRTF)	0	0	0
Middle Patuxent River (PAXOH)	1,072	362	638
Lower Patuxent River (PAXMH)	3,376	1,745	3,672
Upper Potomac River (POTTF)	4,751	2,944	9,807
Anacostia River (ANATF)	85	99	137
Piscataway Creek (PISTF)	241	347	326
Mattawoman Creek (MATTF)	397	298	693
Middle Potomac River (POTOH)	3,148	4,038	8,008
Lower Potomac River (POTMH)	15,964	10,111	19,729
Upper Rappahannock River (RPPTF)	2,175	1,012	1,324
Middle Rappahannock River (RPPOH)	1,226	427	857
Lower Rappanhannock River (RPPMH)	12,282	7,511	10,315
Corrotoman River (CRRMH)	1,279	540	792
Piankatank River (PIAMH)	3,237	2,429	2,348
Upper Mattaponi River (MPNTF)	835	203	371
Lower Mattaponi River (MPNOH)	323	80	151
Upper Pamunkey River (PMKTF)	1,860	327	465
Lower Pamunkey River (PMKOH)	420	129	258
Middle York River (YRKMH)	4,728	3,703	4,285
Lower York River (YRKPH)	3,332	1,617	2,049
Mobjack Bay (MOBPH)	14,207	8,761	11,022
Upper James River (JMSTF)	8,249	2,149	2,438
Appomattox River (APPTF)	1,084	221	298
Middle James River (JMSOH)	3,179	3,289	4,476
Chickahominy River (CHKOH)	3,283	222	996
Lower James River (JMSMH)	9,618	5,455	11,525
Mouth of the James River (JMSPH)	1,037	578	786
Western Branch Elizabeth River (WBEMH)	0	0	0
Southern Branch Elizabeth River (SBEMH)	0	0	0
Eastern Branch Elizabeth River (EBEMH)	0	0	0
Lafayette River (LAFMH)	0	0	0
Mouth to Mid-Elizabeth River (ELIPH)	0	0	0
Lynnhaven River (LYNPH)	2,476	807	658

continued

Table B-1. Potential underwater bay grass habitat acreage by depth contour interval by Chesapeake Bay Program segment *(cont.)*.

Chesapeake Bay Program Segment	0–0.5 Meter Depth	0.5–1 Meter Depth	1–2 Meter Depth
Northeast River (NORTF)	456	476	1,810
C & D Canal (C&DOH)	99	24	48
Bohemia River (BOHOH)	735	397	772
Elk River (ELKOH)	1,595	1,186	2,244
Sassafrass River (SASOH)	1,644	971	1,096
Upper Chester River (CHSTF)	574	192	104
Middle Chester River (CHSOH)	926	736	646
Lower Chester River (CHSMH)	4,183	2,798	4,520
Eastern Bay (EASMH)	7,423	5,659	7,723
Upper Choptank River (CHOTF)	0	0	0
Middle Choptank River (CHOOH)	592	260	432
Lower Choptank River (CHOMH2)	2,264	1,507	3,062
Mouth of the Choptank River (CHOMH1)	8,101	4,861	7,895
Little Choptank River (LCHMH)	5,012	3,011	4,344
Honga River (HNGMH)	6,117	4,513	5,826
Fishing Bay (FSBMH)	2,467	4,461	6,714
Upper Nanticoke River (NANTF)	0	0	0
Middle Nanticoke River (NANOH)	1,141	380	531
Lower Nanticoke River (NANMH)	1,583	1,605	4,524
Wicomico River (WICMH)	1,514	1,525	2,872
Manokin River (MANMH)	3,590	3,132	3,979
Big Annemessex River (BIGMH)	1,994	1,199	1,872
Upper Pocomoke River (POCTF)	0	0	0
Middle Pocomoke River (POCOH)	289	58	111
Lower Pocomoke River (POCMH)	3,915	6,090	4,412
Tangier Sound (TANMH)	20,101	18,720	31,052

Table B-2. Underwater bay grass acreage by Chesapeake Bay Program segment and year with the single best year of acreage highlighted.

Segment	Historical	1978	1979	1980	1981	1984	1985	1986	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CB1TF	**13,124**	2,057	527			5,338	5,033	5,774	5,461	4,798	4,378	4,161	4,348	4,360	6,614	5,087	5,185	6,008	5,529	6,209	7,619
CB2OH	**985**	116	42			21	277	31	199		16	9	86	19	8	19	47	242	272	1	640
CB3MH	834	**1,296**	905			887	808	420	532	205	74	40	412	767	767	799	827	832	665	6	7
CB4MH	**2,803**	176	8			21	62	12	9	1	11	5	17	12				46		23	
CB5MH	**16,121**	857	952	73	316	650	1,255	1,068	2,064	2,430	2,987	1,976	3,909	2,958	1,758	1,611	1,629	1,685	1,496	2,110	2,998
CB6PH	**1,232**	692		433	542	748	796	771	583	843	888	932	1,100	1,208	1,070	1,023	933	859	734	635	682
CB7PH	**14,753**	5,973		4,446	5,627	6,875	7,036	7,273	7,115	7,825	7,960	9,618	9,986	10,729	9,676	8,569	9,223	9,474	8,675	8,006	8,107
CB8PH																10	**11**	11	10	7	7
BSHOH	**227**	1				2	25		35				4				88	79	4		187
GUNOH	1,889	464	326				110		71	41	203	160	220	62	172	148	819	1,463	2,029	235	2,281
MIDOH	**870**	236	442				193		87	17	6	14	102	15	56	10	67	269	93	87	698
BACOH*																					
PATMH	**494**	114	5												1		6	5	13		
MAGMH	**682**	319	427			23	8	2	1					32	42	74	79	116	167	60	83
SEVMH	341	318	303					0							77	123	262	293	376	**433**	123
SOUMH	**532**	47													4	5	20	37	50	16	
RHDMH	**86**	14																			
WSTMH	**313**	106					5	1							11				8		
PAXTF*							10								34	23	**44**	31	38		16
WBRTF*																					
PAXOH	44	2													31	55	58	67	72		**80**
PAXMH	**1,630**	56				24	108	34	101	1				2	2			3		9	
POTTF	835					1,134	2,797	3,144	3,032	2,988	3,663	**4,466**	3,154	3,186	2,186	1,368	1,488	1,259	2,537	3,106	3,670
ANATF						9	8	5	9	10	10	11	11	13	13	**15**	13	8	5	8	10
PISTF						341	520	753	**783**	22	137	265	16	33	73	78	121	296	304	114	309

continued

Table B-2. Underwater bay grass acreage by Chesapeake Bay Program segment and year with the single best year of acreage highlighted *(cont.)*.

Segment	Historical	1978	1979	1980	1981	1984	1985	1986	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
MATTF	23							17	7	96	99	143	138	132	66	27	103	117	151	194	**311**
POTOH	902	569	361			429	952	857	1,080	2,683	2,800	2,974	3,184	2,750	2,683	2,084	2,262	2,478	**3,766**	2,752	3,393
POTMH	**12,765**	439				109	133	99	114	232	250	312	221	253	455	565	925	1,497	1,520	2,130	947
RPPTF*																			13	15	**20**
RPPOH*																					
RPPMH	**7,694**	65		1		33	20	19	244	841	261	119	160	301	69	48	54	27	16	78	173
CRRMH	**645**	4							147	412	419	354	329	214	123	18	51	35	38	164	243
PIAMH	**3,426**	107		5	10	25	26	25	97	323	556	615	738	1,003	569	333	326	403	305	273	390
MPNTF																			**84**		
MPNOH*																					
PMKTF																			**184**		167
PMKOH*																					
YRKMH	**228**																				
YRKPH	**2,740**	260		253	274	435	428	421	458	566	662	649	663	672	706	722	731	815	719	629	736
MOBPH	**15,602**	6,673		5,725	5,915	6,673	6,936	6,877	7,080	8,838	9,627	10,341	10,506	10,653	10,504	10,528	10,306	10,641	9,771	8,571	8,815
JMSTF	**1,724**																		72		52
APPTF	**353**																				
JMSOH																			**8**		3
CHKOH	0	113						29											388	79	**422**
JMSMH	**638**																2		2	3	2
JMSPH	**682**	22							7	9	7	7	9	10	15	38	46	184	129	77	93
WBEMH*																					
SBEMH*																					
EBEMH*																					
LAFMH*																					
ELIPH*																					

continued

Table B-2. Underwater bay grass acreage by Chesapeake Bay Program segment and year with the single best year of acreage highlighted *(cont.)*.

Segment	Historical	1978	1979	1980	1981	1984	1985	1986	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
LYNPH						94	90	**105**	93	89	68	54	46	50	97	29	69	37	38	91	46
NORTF	**163**	10						1	0						16	15	11	10	18	11	19
C&DOH		**2**																			
BOHOH	45						16	1		17	17	1	4	0	3	27	29	32	105	77	**172**
ELKOH	269	2				33	92	11	18	465	871	656	586	227	434	300	100	157	484	768	**1,670**
SASOH	4	14				17	56	34	18	214	69	60	15	175	178	423	221	247	143	216	**908**
CHSTF*																					
CHSOH	**103**																				
CHSMH	**3,558**	2,369	2,062			955	775	327	623	161	72	80	168	702	919	997	691	910	1,026	669	
EASMH	**6,296**	3,158	939			194	884	588	2,130	1,966	903	157	1,306	1,736	2,311	3,184	3,475	4,201	2,480	4,610	
CHOTF*																					
CHOOH	**79**																				
CHOMH2	**1,899**	193	161				80	20					14	6				3			
CHOMH1	**8,581**	4,328	1,942			130	3,171	646	674	1,988	275	197	2,232	4,110	3,425	3,513	5,512	6,444	5,228	3,646	1,622
LCHMH	**4,008**	301	8			56	797	341	164	65	160	70	315	368	121	41	809	1,220	1,375	1,454	1,046
HNGMH	**7,873**	319	367			32	743	623	1,546	2,344	2,769	3,122	3,520	4,245	3,192	2,081	1,434	2,096	725	1,816	2,674
FSBMH	**726**							0	5	19	13	1	32	36	59	27				5	6
NANTF*																					
NANOH	**4**																				
NANMH	**6**																				
WICMH	**8**																				
MANMH	**4,396**	187					168	328	327	200	239	263	326	357	145	214	18	130	32	226	420
BIGMH	**2,180**	435	0				334	388	212	299	291	396	379	400	344	388	194	311	207	409	546
POCTF*																					
POCOH*																					
POCMH	**4,851**	209	22	278	608	1,050	938	1,344	1,158	1,442	1,430	1,738	1,711	1,831	1,575	1,558	1,545	1,251	1,076	1,090	1,126
TANMH	**39,589**	7,126	1,704	4,512	6,226	11,019	11,675	13,944	12,245	15,336	15,886	16,966	17,688	16,463	12,086	11,205	10,829	9,268	6,479	10,386	12,272

Numbers in blue = Year of maximum underwater bay grass acreage.

* = No recorded underwater bay grass for any year.

Table B-3. Percent of potential shallow-water habitat covered by underwater bay grass from 1978–2000 at five-year intervals by Chesapeake Bay Program Segment.

CBP Segment Name	Bay Segment	1978–1984			1985–1990			1991–1995			1996–2000		
		0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m
Northern Chesapeake Bay	CB1TF	**51.0**	**26.3**	14.9	**61.1**	**29.8**	17.3	**66.0**	**30.0**	9.5	**80.1**	**36.8**	9.4
Upper Chesapeake Bay	CB2OH	4.6	1.2	0.2	7.9	8.5	1.8	2.3	1.9	0.2	13.2	8.1	6.2
Upper Central Chesapeake Bay	CB3MH	**52.7**	21.3	7.5	**41.3**	4.5	0.9	**39.4**	4.6	1.0	**41.9**	6.1	0.8
Middle Central Chesapeake Bay	CB4MH	5.5	0.6	0.0	2.5	0.0	0.0	0.7	0.0	0.0	2.1	0.0	0.0
Lower Central Chesapeake Bay	CB5MH	**15.8**	8.4	1.2	**23.1**	**15.9**	3.5	**24.4**	**21.3**	5.1	**18.8**	**18.6**	4.0
Western Lower Chesapeake Bay	CB6PH	**22.2**	**25.7**	4.8	**23.3**	**25.3**	3.6	**30.7**	**31.4**	4.9	**25.5**	**25.3**	4.0
Eastern Lower Chesapeake Bay	CB7PH	**33.1**	**26.1**	**10.8**	**38.2**	**27.6**	**11.0**	**43.7**	**31.0**	**13.6**	**42.1**	**29.0**	**13.9**
Mouth of the Chesapeake Bay	CB8PH	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.3	0.4	2.2	1.4	0.4
Bush River	BSHOH	0.2	0.0	0.0	2.8	1.4	0.0	0.4	0.0	0.0	11.4	9.4	1.2
Gunpowder River	GUNOH	**15.9**	8.9	4.2	8.6	6.9	3.4	**12.7**	7.4	3.4	**54.1**	40.1	30.0
Middle River	MIDOH	**43.4**	**18.1**	3.8	**11.9**	**11.3**	9.1	**10.3**	4.8	0.7	**41.0**	**41.1**	19.0
Back River	BACOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Patapsco River	PATMH	6.0	5.3	0.7	0.0	0.0	0.0	0.1	0.0	0.0	1.0	0.4	0.0
Magothy River	MAGMH	40.5	16.8	6.5	0.8	0.4	0.0	8.6	2.3	0.3	21.8	5.5	1.0
Severn River	SEVMH	25.4	19.5	7.8	0.0	0.0	0.0	7.9	8.9	1.7	27.7	24.7	11.7
South River	SOUMH	4.5	0.8	0.4	0.0	0.0	0.0	0.5	0.3	0.0	6.4	1.7	0.4
Rhode River	RHDMH	4.6	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West River	WSTMH	17.8	1.8	0.2	0.9	0.0	0.0	2.1	0.0	0.0	1.4	0.0	0.0
Upper Patuxent River	PAXTF	0.0	0.0	0.0	0.0	0.0	0.0	23.1	15.4	9.6	39.5	22.6	15.3
Western Branch (Patuxent River)	WBRTF	*	*	*	*	*	*	*	*	*	*	*	0
Middle Patuxent River	PAXOH	0.2	0.0	0.0	0.0	0.0	0.0	5.5	0.1	0.0	8.4	2.9	0.5
Lower Patuxent River	PAXMH	2.0	0.4	0.1	3.7	3.1	0.8	0.1	0.0	0.0	0.3	0.1	0.0
Upper Potomac River	POTTF	5.3	**17.4**	3.3	**32.7**	**65.6**	**24.4**	**39.5**	**60.2**	**16.4**	**36.1**	**51.5**	**11.2**

continued

Table B-3. Percent of potential shallow-water habitat covered by underwater bay grass from 1978–2000 at five-year intervals by Chesapeake Bay Program Segment (*cont.*).

CBP Segment Name	Bay Segment	1978–1984			1985–1990			1991–1995			1996–2000		
		0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m
Anacostia River	ANATF	5.8	1.8	1.2	7.0	2.9	3.1	8.5	4.3	4.4	9.6	4.1	3.2
Piscataway Creek	PISTF	**40.3**	**50.0**	**21.6**	**76.7**	**96.0**	**90.6**	**29.4**	**48.1**	**18.0**	**67.2**	**49.7**	**17.6**
Mattawoman Creek	MATTF	0.0	0.0	0.0	**14.6**	7.3	7.6	**18.5**	11.3	8.7	**55.8**	32.0	5.5
Middle Potomac River	POTOH	**20.2**	5.1	0.2	**46.0**	**23.7**	**11.8**	**51.3**	**31.6**	**13.1**	**66.3**	**45.5**	**15.0**
Lower Potomac River	POTMH	2.9	0.6	0.0	2.5	0.7	0.2	4.4	1.2	0.1	15.7	5.2	0.6
Upper Rappahannock River	RPPTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.4	0.1
Middle Rappahannock River	RPPOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Rappahannock River	RPPMH	0.5	0.2	0.1	6.5	2.3	0.2	2.2	0.8	0.2	1.2	0.3	0.2
Corrotoman River	CRRMH	0.2	0.2	0.1	**29.7**	16.0	2.9	**25.7**	13.1	3.2	**17.6**	6.6	1.8
Piankatank River	PIAMH	2.5	1.2	0.7	11.7	7.4	2.5	17.3	15.2	7.2	9.8	7.8	2.5
Upper Mattaponi River	MPNTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	2.5	1.0
Lower Mattaponi River	MPNOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Pamunkey River	PMKTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1	8.9	2.0
Lower Pamunkey River	PMKOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle York River	YRKMH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower York River	YRKPH	**12.1**	6.7	1.0	**13.9**	**13.7**	2.5	**15.8**	**15.3**	2.7	**18.3**	**16.2**	3.2
Mobjack Bay	MOBPH	**36.3**	**37.4**	5.8	**41.2**	**44.0**	8.9	**44.5**	**49.7**	8.3	**45.1**	**48.6**	8.2
Upper James River	JMSTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	0.5
Appomattox River	APPTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle James River	JMSOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Chickahominy River	CHKOH	2.9	3.7	0.8	0.6	1.9	0.3	0.0	0.0	0.0	14.8	27.6	3.5
Lower James River	JMSMH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mouth of the James River	JMSPH	1.6	1.0	0.0	1.1	0.0	0.0	3.4	0.7	0.0	17.2	10.1	0.8

continued

Table B-3. Percent of potential shallow-water habitat covered by underwater bay grass from 1978–2000 at five-year intervals by Chesapeake Bay Program Segment *(cont.)*.

CBP Segment Name	Bay Segment	1978–1984			1985–1990			1991–1995			1996–2000		
		0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m
Western Branch Elizabeth River	WBEMH	*	*	*	*	*	*	*	*	*	*	*	0
Southern Branch Elizabeth River	SBEMH	*	*	*	*	*	*	*	*	*	*	*	0
Eastern Branch Elizabeth River	EBEMH	*	*	*	*	*	*	*	*	*	*	*	0
Lafayette River	LAFMH	*	*	*	*	*	*	*	*	*	*	*	0
Mouth of the Elizabeth River	ELIPH	*	*	*	*	*	*	*	*	*	*	*	0
Lynnhaven River	LYNPH	2.3	3.0	1.7	4.1	4.9	2.7	3.6	2.6	1.6	3.5	3.3	1.1
Northeast River	NORTF	2.1	0.1	0.0	0.3	0.0	0.0	5.8	0.3	0.0	6.8	0.0	0.0
C&D Canal	C&DOH	0.2	0.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bohemia River	BOHOH	0.0	0.0	0.0	4.0	1.8	0.0	4.0	0.1	0.0	14.6	8.0	6.1
Elk River	ELKOH	1.8	0.5	0.0	**18.1**	**24.8**	**22.1**	**19.0**	**20.3**	**22.4**	**36.3**	**33.8**	**34.5**
Sassafras River	SASOH	1.4	0.7	0.0	6.8	6.5	7.9	18.0	15.9	0.9	28.0	40.5	12.7
Upper Chester River	CHSTF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle Chester River	CHSOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Chester River	CHSMH	**52.5**	25.2	5.0	**22.9**	5.5	1.0	**22.4**	7.7	1.4	**24.9**	10.0	2.1
Eastern Bay	EASMH	**33.1**	**13.8**	2.5	**37.5**	**11.7**	1.6	**38.4**	**11.9**	1.5	**54.8**	**28.3**	3.9
Upper Choptank River	CHOTF	*	*	*	*	*	*	*	*	*	*	*	0
Middle Choptank River	CHOOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Choptank River	CHOMH2	9.4	4.4	0.8	3.3	0.9	0.1	0.8	0.2	0.0	0.1	0.0	0.0
Mouth of the Choptank River	CHOMH1	**43.4**	**20.4**	6.2	**44.4**	**14.8**	2.1	**46.8**	**25.4**	5.2	**64.8**	**38.9**	8.4
Little Choptank River	LCHMH	6.4	0.7	0.1	19.3	4.4	0.6	9.0	2.5	0.5	37.5	16.9	2.7
Honga River	HNGMH	6.9	0.9	0.0	**47.8**	**13.6**	1.2	**61.2**	**18.8**	1.2	**46.2**	**14.3**	1.4
Fishing Bay	FSBMH	0.0	0.0	0.0	1.1	0.1	0.0	2.5	0.7	0.1	0.2	0.0	0.0
Upper Nanticoke River	NANTF	*	*	*	*	*	*	*	*	*	*	*	0
Middle Nanticoke River	NANOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Nanticoke River	NANMH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

continued

Table B-3. Percent of potential shallow-water habitat covered by underwater bay grass from 1978–2000 at five-year intervals by Chesapeake Bay Program Segment *(cont.)*.

CBP Segment Name	Bay Segment	1978–1984			1985–1990			1991–1995			1996–2000		
		0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m	0–0.5 m	0–1 m	1-2 m
Wicomico River	WICMH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Manokin River	MANMH	3.9	1.4	0.0	**11.8**	3.9	0.1	**10.6**	5.1	0.2	**11.1**	2.9	0.1
Big Annemessex River	BIGMH	**13.3**	**13.7**	0.3	**24.6**	**11.6**	0.7	**21.2**	8.6	0.2	**24.2**	**11.3**	0.3
Upper Pocomoke River	POCTF	*	*	*	*	*	*	*	*	*	*	*	0
Middle Pocomoke River	POCOH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Pocomoke River	POCMH	**11.7**	**12.4**	0.7	**17.7**	**17.5**	3.9	**19.7**	**17.8**	2.9	**17.7**	**16.8**	2.4
Tangier Sound	TANMH	**33.2**	**23.2**	5.3	**47.3**	**32.8**	8.7	**50.0**	**34.0**	8.9	**40.0**	**26.1**	6.6

Percentages in blue bold = Underwater bay grasses cover ≥ 10 percent of potential habitat for all 4 of the time periods.
Percentages in bold = Underwater bay grasses cover ≥ 10 percent of potential habitat for 3 of the time periods.
Note: While some periods span more than 5 years, each period represents only 5 years worth of data. There were some years when no underwater bay grass surveys occurred (i.e., 1982, 1983 and 1988).
*Denotes no data available or no underwater bay grasses mapped.

appendix C

Underwater Bay Grasses No-Grow Zones Acreage

Table C-1. Underwater bay grasses no-grow zones acreage by Chesapeake Bay Program segment.

Chesapeake Bay Program Segment	CBP Segment	Acres in No Grow Zones	Reason
Northern Chesapeake Bay	CB1TF	679	1
Upper Chesapeake Bay	CB2OH	1,564	1
Upper Central Chesapeake Bay	CB3MH	4,537	1
Middle Central Chesapeake Bay	CB4MH	14,590	1
Lower Central Chesapeake Bay	CB5MH	5,061	1
Western Lower Chesapeake Bay	CB6PH	3,684	1
Eastern Lower Chesapeake Bay	CB7PH	8,339	1
Mouth of the Chesapeake Bay	CB8PH	1,186	1
Patapsco River	PATMH	5,701	2
Magothy River	MAGMH	199	1
South River	SOUMH	102	1
Rhode River	RHDMH	375	1
West River	WSTMH	132	1
Lower Potomac River	POTMH	19	1
Lower Rappahannock River	RPPMH	395	1
Piankatank River	PIAMH	105	1
Mobjack Bay	MOBPH	635	1
Lower James River	JMSMH	4,312	1
Mouth of the James River	JMSPH	619	1
Western Branch Elizabeth River	WBELI	1,484	2
Southern Branch Elizabeth River	SBELI	2,073	2
Eastern Branch Elizabeth River	EBELI	1,426	2
Lafayette River	LAFMH	1,421	2
Mouth of the Elizabeth River	ELIPH	20,626	2

continued

Table C-1. Underwater bay grasses no-grow zones acreage by Chesapeake Bay Program segment *(cont.)*.

Chesapeake Bay Program Segment	CBP Segment	Acres in No Grow Zones	Reason
Northeast River	NORTF	<1	1
Sassafras River	SASOH	2	1
Eastern Bay	EASMH	134	1
Upper Choptank River	CHOTF	2,200	4
Middle Choptank River	CHOOH	984	4
Mouth of the Choptank River	CHOMH1	37	1
Little Choptank River	LCHMH	6	1
Upper Nanticoke River	NANTF	1,138	3
Wicomico River	WICMH	708	3
Big Annemessex River	BIGMH	4	1
Upper Pocomoke River	POCTF	988	3
Middle Pocomoke River	POCOH	2,466	1
Lower Pocomoke River	POCMH	13,293	1
Tangier Sound	TANMH	6,198	1

Reason Codes:

1 - Extreme physical wave energy.

2 - Permanent physical alteration to near-shore habitat.

3 - Natural, extreme coloration of the water.

4 - Natural river channelization.

appendix D

Vertical Stratification and the Pycnocline

The *pycnocline* has a functional role in defining designated use boundaries. The definitions of the designated use boundaries take into account the types and needs of the living resources that inhabit different parts of the Chesapeake Bay, as well as the bathymetry, hydrology, physical features, and natural stratification of the Chesapeake Bay waters as described in Chapter IV.

STRATIFICATION

Vertical stratification is foremost among the physical factors affecting dissolved oxygen concentrations in some parts of Chesapeake Bay and its tidal tributaries. Stratification arises from differences in water density within the water column due to vertical differences in the salinity and temperature of the source waters feeding into Chesapeake Bay tidal waters. The water coming into Chesapeake Bay and its tidal tributaries from the land via the tributaries is fresh while water from the ocean is saline. In the summer period, the water coming from the land is also warmer than ocean water. Colder water is more dense than warmer water, and saline water is more dense than fresh. The simple model is that the less dense freshwater moves seaward over the layer of more dense seawater moving from the mouth of Chesapeake Bay northward. An idealized example is shown in Figure D-1. To the extent that the two (or more) layers remain self-contained and poorly mixed, the waters are stratified. If the density discontinuity is great enough to prevent mixing of the layers and constitutes a vertical barrier to diffusion of dissolved oxygen, then a pycnocline is said to exist.

When physical features like channels, holes and sills inhibit lateral exchange of waters and a pycnocline inhibits vertical exchange, oxygen that is consumed in biological respiration or other oxygen-consuming processes in the imprisoned subpycnocline waters cannot be replenished. When there is no barrier to lateral exchange, the effect of the pycnocline on lower layer oxygen levels may be ameliorated. For this reason, the extent of isolation caused by a pycnocline, as well as the frequency of formation and the depth of the pycnocline when present are factors to be considered in defining designated use boundaries.

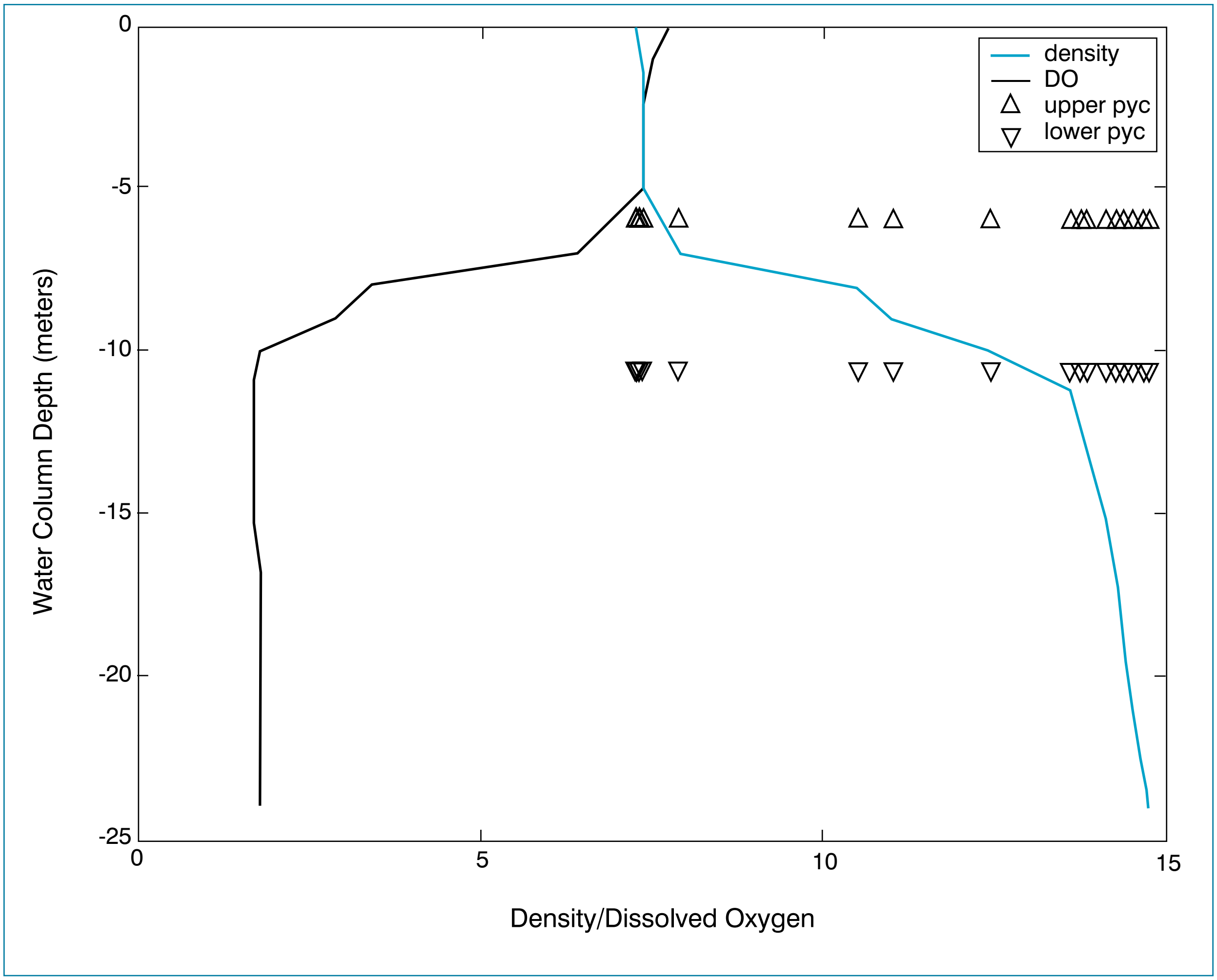

Figure D-1. Illustration of stratification of the water column in the mainstem of the Chesapeake Bay.

Source: Chesapeake Bay Program website http://chesapeakebay.net/data.htm.

CALCULATING PYCNOCLINE DEPTH

DENSITY GRADIENT THRESHOLD

The threshold for the density gradient that defines the upper pycnocline depth (0.1 kg/m^4) is taken from Fisher, et al. (2003). The density gradient sufficient to stop turbulent mixing for any water body is somewhat determined by the local physical processes in that body. Density gradient thresholds vary by water body. Fisher, et al determined the Chesapeake Bay upper pycnocline threshold by examining existing literature for other oceanic and estuarine systems and applying those methods to the Chesapeake Bay. Determination of this number involved examining thousands of vertical plots of density, dissolved oxygen concentration, and the vertical slopes of these two parameters to find a reasonable threshold value. The value of 0.1 kg/m^4 was judged to be the most reasonable value for the upper pycnocline depth in the Chesapeake Bay and is in line with values for other estuarine systems. The actual pycnocline depths were not overly sensitive to the threshold value chosen, since mixed layer gradients tend to be much less than 0.1 kg/m^4 and inter-pycnocline gradients tend to be much greater than 0.1 kg/m^4.

Using similar methods, the value of 0.2 kg/m^4 was chosen as the lower pycnocline depth gradient by the monitoring data analysis team at the Chesapeake Bay Program. Vertical density and dissolved oxygen concentration plots from around the Chesapeake Bay and its tidal tributaries were examined to determine the threshold value that was most representative of the density gradient defining the upper boundary of the lower mixed layer, when and where it existed. The upper layer density threshold of 0.1 kg/m^4 was judged to be too low as it sometimes placed the lower pycnocline depth at levels that did not have a large effect on the dissolved oxygen concentration.

PYCNOCLINE CALCULATION METHODOLOGIES

The Chesapeake Bay Program Water Quality Monitoring Program collects vertical profiles of temperature, salinity and conductivity measurements (among other parameters) at 1 to 2 meter intervals at each of its sampling stations. From these measurements, there are at least two approaches for determining a pycnocline.

Vertical Density Profile

The upper and lower pycnocline depths can be determined by constructing a vertical density (sigma_t) profile and applying an absolute density change threshold. This is the method used for all pycnocline calculations in this document and is recommended for application by the states in defining designated use boundaries. For a detailed explanation of the derivation of this method see Fisher et al. (2003).

1) Calculate density using the following equations:

```
temp c    =  water temperature in degrees Celsius

sigo      =  –0.069+((1.47808*((salinity-0.03)/1.805))
             (0.00157*(((salinityB0.03)/1.805)**2))
             +0.0000398*(((salinityB0.03)/1.805)**3)));

tsum      =  (–1*(((tempc-3.98)**2)/503.57))*
             ((tempc+283)/(tempc+67.26));

sa        =  (10**–3)*tempc)*(4.7867-
             (0.098185*tempc)+(0.0010843*(tempc**2)));

sb        =  ((10**–6)*tempc)*(18.030–
             (0.8164*tempc)+(0.01667*(tempc**2)));

Sigma_t   =  tsum+((sigo+0.1324)*(1–sa+sb*(sigo –0.1324)));
```

2) Apply the following rules to the density profile:
   - i) From the water surface, the first density slope observation that is greater than 0.1 kg/m^4 is designated as the upper pycnocline depth provided that:
     - a) That observation is not the first observation in the water column; and
     - b) The next density slope observation below is positive.
   - ii) From the bottom, the first density slope observation that is greater than 0.2 kg/m^4 is designated as the lower pycnocline depth provided that:
     - a) An upper pycnocline depth exists;
     - b) There is a bottom mixed layer, defined by the first or second density slope observation from the bottom being less than 0.2 kg/m^4; and
     - c) The next density slope observation above is positive.

Vertical Differences in Conductivity

A 'working' pycnocline depth can be calculated using vertical differences in conductivity. The following is the Chesapeake Bay Water Quality Monitoring Program field method applied during water quality monitoring sampling cruises for determining the presence of a pycnocline and, if one or more exist, the depth of the upper and lower boundary and, therefore, depths at which to collect water samples for chemical analysis in the laboratory.

1) Find the average rate of change from surface to bottom: i.e., subtract surface conductivity from bottom conductivity and divide by the depth.

2) Multiply the average rate of change by 2. This product is called the *threshold.*

3) If the threshold is less than 500, then it is determined that no pycnocline exists at the site.

4) It the threshold is 500 or greater, then each interval from surface to bottom is checked to determine if the difference from one meter to the next is greater than or equal to the threshold. The upper pycnocline is defined as the first encounter of a difference that exceeds the threshold and the upper pycnocline depth is set at one-half the depth interval distance. For example, if the threshold is first exceeded between 4 and 5 meters, then the pycnocline is set at 4.5 meters.

5) Then the process is reversed and each interval from bottom to surface is checked. If the threshold is exceeded at a depth more than 1.5 meters from the upper pycnocline, then a second pycnocline is said to exist and the lower pycnocline depth is set at one-half the depth interval distance, as before.

Table D-1 provides some statistics on the frequency of occurrence, depth of pycnoclines, and the distance between upper and lower pycnoclines in spring and summer at locations throughout the Chesapeake Bay and its tidal tributaries. The statistics are for each Chesapeake Bay Water Quality Monitoring Program station over the period analyzed for the allocations process 1985–1994. (See the Chesapeake Bay Program website at http://www.chesapeakebay.net for a map of these stations.)

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994.

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
CB1.1	6.1	-	-	-	0%	0%
CB2.1	6.0	2.3	-	-	17%	0%
CB2.2	12.1	4.0	2.8	6.9	68%	20%
CB3.1	12.8	2.9	5.0	7.9	99%	76%
CB3.2	11.7	2.9	4.2	7.1	93%	57%
CB3.3C	23.7	4.2	10.6	14.8	100%	88%
CB3.3E	8.2	2.6	1.6	4.2	80%	18%
CB3.3W	9.0	2.7	2.3	5.0	77%	13%
CB4.1C	31.8	5.6	11.7	17.3	100%	96%
CB4.1E	23.1	6.5	7.8	14.3	99%	84%
CB4.1W	9.1	3.4	2.6	5.9	56%	19%
CB4.2C	26.8	6.9	9.6	16.5	100%	98%
CB4.2E	9.3	4.1	2.1	6.2	65%	13%
CB4.2W	9.3	4.3	1.2	5.5	46%	11%
CB4.3C	25.9	6.5	8.6	15.2	100%	94%
CB4.3E	22.1	7.1	7.8	14.8	97%	86%
CB4.3W	9.7	4.4	1.2	5.6	51%	10%
CB4.4	29.4	6.6	10.3	16.9	100%	100%
CB5.1	33.3	6.4	8.6	15.0	100%	99%
CB5.1W	9.1	4.4	-	-	24%	0%
CB5.2	29.5	7.5	9.0	16.6	100%	100%
CB5.3	26.2	6.1	7.2	13.2	100%	96%
CB5.4	32.6	5.3	12.8	18.1	100%	97%
CB5.4W	5.3	2.5	1.0	3.5	29%	3%
CB5.5	19.5	4.7	8.4	13.1	99%	79%
CB6.1	13.1	4.5	4.3	8.7	100%	80%
CB6.2	11.2	4.3	3.3	7.6	96%	76%
CB6.3	12.8	3.7	4.5	8.1	97%	87%

continued

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994 *(cont.).*

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
CB6.4	10.3	3.3	3.3	6.6	90%	54%
CB7.1	25.2	4.8	9.7	14.5	85%	65%
CB7.1N	31.7	5.9	12.5	18.4	69%	35%
CB7.1S	16.1	3.8	5.5	9.3	96%	87%
CB7.2	22.1	3.4	9.0	12.4	97%	95%
CB7.2E	13.4	3.2	3.7	6.9	88%	72%
CB7.3	13.8	3.3	5.8	9.1	96%	81%
CB7.3E	17.8	4.1	6.1	10.2	93%	73%
CB7.4	13.9	3.2	5.3	8.5	95%	79%
CB7.4N	12.9	3.3	3.9	7.3	74%	44%
CB8.1	9.8	3.5	3.7	7.2	95%	38%
CB8.1E	17.9	4.3	6.2	10.5	96%	82%
EBE1	8.4	3.2	1.8	5.0	61%	9%
EBE2	9.0	2.5	-	-	100%	0%
EE1.1	12.3	6.6	2.6	9.2	74%	31%
EE2.1	7.8	3.3	1.4	4.7	53%	12%
EE2.2	13.1	5.0	3.6	8.6	72%	49%
EE3.0	7.1	2.8	-	-	12%	0%
EE3.1	13.2	4.1	2.5	6.6	60%	16%
EE3.2	26.8	6.9	10.7	17.6	42%	9%
EE3.3	3.9	1.5	-	-	19%	0%
EE3.4	4.7	2.0	0.5	2.5	26%	4%
EE3.5	27.3	7.0	8.7	15.7	41%	19%
ELI1	8.0	3.5	-	-	100%	0%
ELI2	13.5	5.9	4.9	10.8	87%	30%
ELI3	12.0	3.5	6.0	9.5	100%	100%
ET1.1	2.9	-	-	-	0%	0%
ET10.1	5.2	-	-	-	0%	0%

continued

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994 *(cont.)*.

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
ET2.1	13.2	4.0	-	-	3%	0%
ET2.2	2.9	-	-	-	0%	0%
ET2.3	12.3	4.5	-	-	8%	0%
ET3.1	5.3	-	-	-	0%	0%
ET4.1	5.4	1.8	-	-	5%	0%
ET4.2	13.9	5.4	4.4	9.8	70%	43%
ET5.1	5.7	2.0	-	-	8%	0%
ET5.2	11.8	3.7	3.4	7.1	76%	20%
ET6.1	5.0	1.5	-	-	3%	0%
ET6.2	3.8	1.5	-	-	49%	0%
ET7.1	7.7	2.3	0.6	2.9	71%	14%
ET8.1	5.1	1.7	2.8	4.5	31%	3%
ET9.1	4.8	1.5	1.0	2.5	11%	6%
LAF1	5.2	2.5	-	-	40%	0%
LE1.1	12.1	4.8	2.7	7.5	75%	25%
LE1.2	17.1	5.7	3.9	9.6	68%	16%
LE1.3	23.3	7.3	5.3	12.6	43%	9%
LE1.4	14.9	7.5	3.0	10.5	44%	4%
LE2.2	11.2	3.4	3.7	7.1	91%	64%
LE2.3	19.7	5.7	7.4	13.1	95%	77%
LE3.1	5.5	4.0	-	-	34%	0%
LE3.2	12.2	6.2	2.2	8.4	73%	43%
LE3.3	4.1	4.0	-	-	3%	0%
LE3.4	11.3	6.6	3.7	10.2	72%	23%
LE3.6	9.9	3.9	2.5	6.4	81%	30%
LE3.7	7.4	3.7	1.3	5.0	52%	8%
LE4.1	7.5	4.3	1.7	6.0	60%	6%
LE4.2	11.6	4.8	3.0	7.8	51%	17%

continued

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994 *(cont.).*

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
LE4.3	14.3	7.0	5.1	12.1	66%	39%
LE5.1	6.6	4.7	1.3	6.0	24%	1%
LE5.2	7.6	4.2	2.0	6.3	79%	10%
LE5.3	6.3	4.0	2.0	6.0	68%	3%
LE5.4	13.7	5.4	6.6	12.0	44%	13%
LE5.5	21.2	5.1	10.5	15.6	96%	73%
LE5.6	13.7	7.0	5.0	12.0	71%	16%
MAT0016	6.8	-	-	-	0%	0%
MAT0078	1.0	-	-	-	0%	0%
PIS0033	1.0	-	-	-	0%	0%
RET1.1	11.1	4.7	2.8	7.5	64%	9%
RET2.1	7.3	-	-	-	0%	0%
RET2.2	9.8	5.1	1.9	7.0	22%	2%
RET2.3	9.2	-	-	-	0%	0%
RET2.4	15.7	5.4	5.4	10.8	79%	33%
RET3.1	5.2	4.0	-	-	12%	0%
RET3.2	4.0	-	-	-	0%	0%
RET4.1	4.5	4.0	-	-	1%	0%
RET4.2	10.9	7.1	0.9	8.0	18%	1%
RET4.3	4.7	4.0	-	-	4%	0%
RET5.1	1.1	-	-	-	0%	0%
RET5.1A	2.8	-	-	-	0%	0%
RET5.2	7.5	4.9	-	-	15%	0%
SBE1	14.0	3.5	-	-	100%	0%
SBE2	12.5	4.4	4.9	9.3	83%	43%
SBE3	11.0	2.5	5.0	7.5	100%	100%
SBE4	12.0	2.5	-	-	100%	0%
SBE5	11.0	3.6	3.5	7.1	100%	70%

continued

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994 *(cont.)*.

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
TF1.2	1.0	-	-	-	0%	0%
TF1.3	1.0	-	-	-	0%	0%
TF1.4	1.2	-	-	-	0%	0%
TF1.5	10.5	-	-	-	0%	0%
TF1.6	6.0	-	-	-	0%	0%
TF1.7	2.9	1.8	-	-	5%	0%
TF2.1	19.0	-	-	-	0%	0%
TF2.2	8.3	-	-	-	0%	0%
TF2.3	12.8	-	-	-	0%	0%
TF2.4	8.9	-	-	-	0%	0%
TF3.1A	2.9	-	-	-	0%	0%
TF3.1B	2.9	-	-	-	0%	0%
TF3.1C	4.0	-	-	-	0%	0%
TF3.1D	2.7	-	-	-	0%	0%
TF3.1E	2.8	-	-	-	0%	0%
TF3.2	6.1	-	-	-	0%	0%
TF3.2A	4.0	-	-	-	0%	0%
TF3.3	5.7	4.2	-	-	14%	0%
TF4.1A	5.8	-	-	-	0%	0%
TF4.2	5.9	-	-	-	0%	0%
TF4.4	2.7	-	-	-	0%	0%
TF4.4A	6.3	-	-	-	0%	0%
TF5.2	1.0	-	-	-	0%	0%
TF5.2A	7.0	-	-	-	0%	0%
TF5.3	9.8	-	-	-	0%	0%
TF5.4	5.8	-	-	-	0%	0%
TF5.5	8.2	-	-	-	0%	0%
TF5.5A	7.4	-	-	-	0%	0%

continued

Table D-1. Chesapeake Bay Water Quality Monitoring Program stations median pycnocline depths and percent occurrence: 1985-1994 *(cont.).*

Station	Depth	Upper Depth	Interpyc Depth	Lower Depth	Upper Percent	Lower Percent
TF5.6	8.5	6.0	-	-	1%	0%
TF5.6A	7.8	-	-	-	0%	0%
WBE1	4.7	2.8	-	-	17%	0%
WE4.1	6.1	2.9	0.7	3.6	35%	9%
WE4.2	14.5	6.3	4.2	10.5	86%	35%
WE4.3	6.0	2.8	0.8	3.5	20%	1%
WE4.4	7.6	2.3	1.5	3.8	19%	4%
WT1.1	2.3	-	-	-	0%	0%
WT2.1	2.0	-	-	-	0%	0%
WT3.1	3.3	1.5	-	-	5%	0%
WT4.1	1.8	-	-	-	0%	0%
WT5.1	14.5	3.6	7.7	11.3	100%	69%
WT6.1	5.4	2.5	1.0	3.5	57%	5%
WT7.1	8.6	3.1	2.4	5.4	87%	31%
WT8.1	8.6	2.2	1.7	3.8	91%	58%
WT8.2	2.9	1.5	-	-	2%	0%
WT8.3	3.3	1.5	-	-	15%	0%
WXT0001	1.1	-	-	-	0%	0%
XFB1986	1.5	-	-	-	0%	0%
XGG8251	5.5	2.5	-	-	8%	0%

Literature Cited: Fisher, T.R., A.B. Gustafson, H.L. Berndt, L. Walstad, L.W. Haas, and S. MacIntyre, "The upper mixed layer of Chesapeake Bay, USA." Submitted to *Estuaries*, 2003.