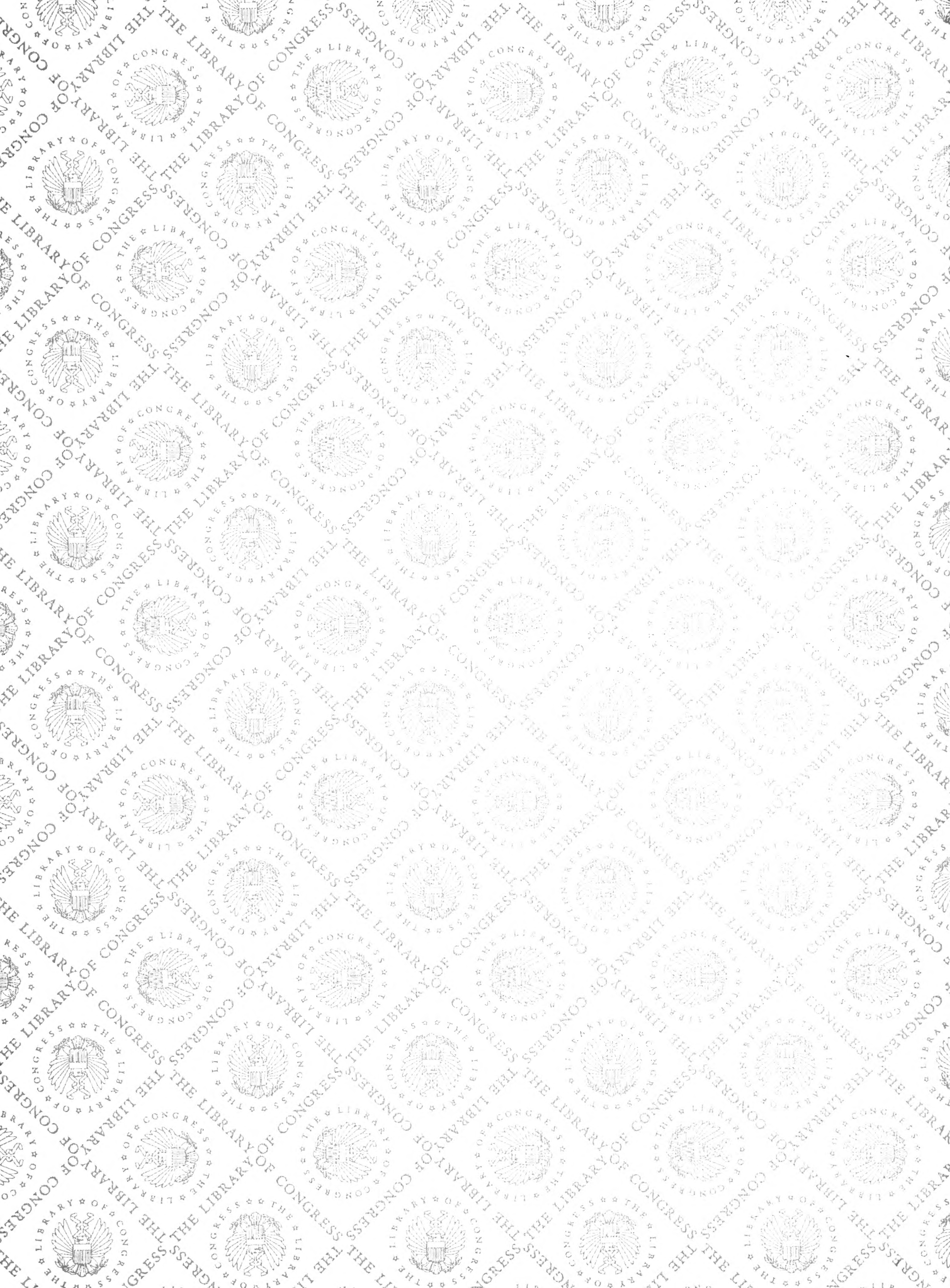
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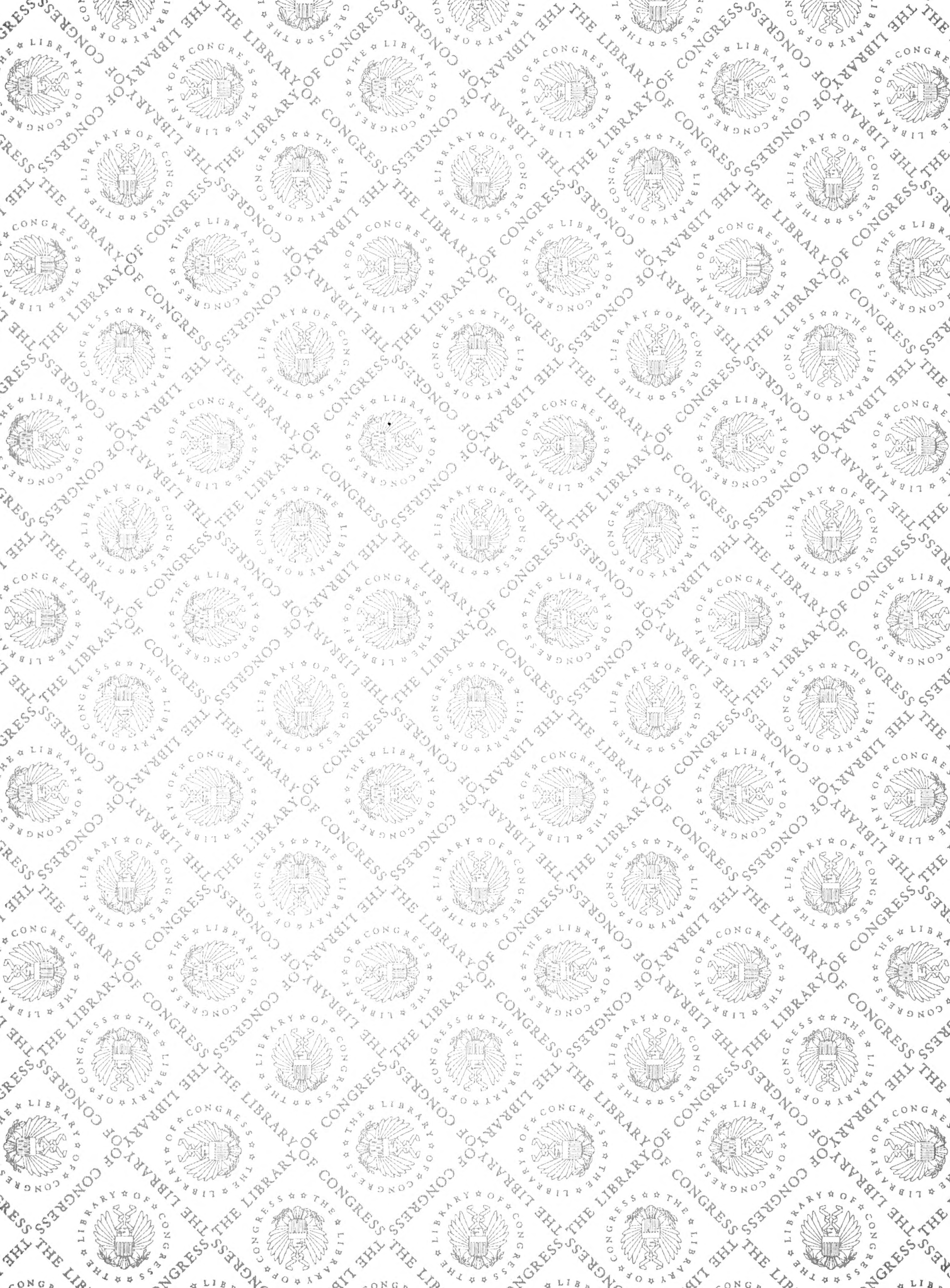


United States
Environmental Protection
Agency

Region III
Chesapeake Bay
Program Office

Region III
Water Protection
Division

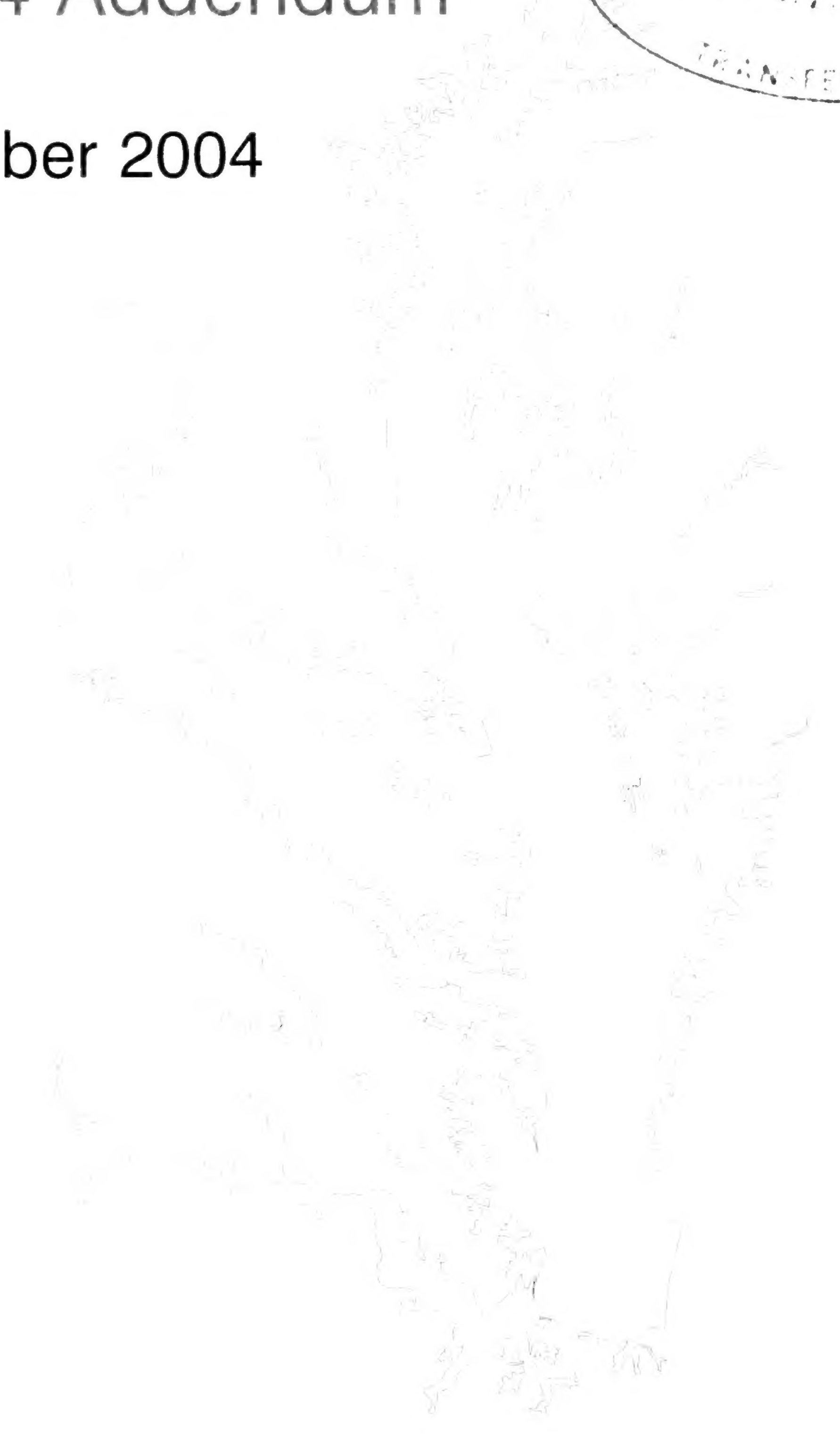
EPA 903-R-03-002
October 2004

In coordination with the Office of Water/Office of Science and Technology, Washington, DC

Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries

2004 Addendum

October 2004



Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries

2004 Addendum

October 2004

U.S. Environmental Protection Agency
Region III
Chesapeake Bay Program Office
Annapolis, Maryland

and

Region III
Water Protection Division
Philadelphia, Pennsylvania

in coordination with

Office of Water
Office of Science and Technology
Washington, D.C.

Contents

Acknowledgments

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chapter i

Introduction

In April 2003, the U.S. Environmental Protection Agency (EPA) published the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance)* in cooperation with and on behalf of the six watershed states—New York, Pennsylvania, Maryland, Delaware, Virginia and West Virginia—and the District of Columbia. The culmination of three years of work, the *Regional Criteria Guidance* document was the direct result of the collective contributions of hundreds of regional scientists, technical staff and agency managers and the independent review by recognized experts across the country.

At the time of publication of the *Regional Criteria Guidance* document, a number of technical issues still remained to be worked through, resolved and documented. The Chesapeake Bay Water Quality Standards Coordinators Team—water quality standards program managers and coordinators from the seven Chesapeake Bay watershed jurisdictions and EPA's Office of Water, Region 2 and Region 3—took on the responsibility on behalf of the Chesapeake Bay watershed partners to collectively work through these technical issues. The work on these issues was largely in support of the four jurisdictions with bay tidal waters who were formally adopting the published Chesapeake Bay water quality criteria, designated uses and criteria attainment procedures into their states' water quality standards regulations.

This first EPA published addendum to the 2003 *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* documents the resolution of and recommendations for addressing the following technical issues and criteria attainment procedures.

- Guidance to the jurisdictions on where and when to apply the temperature-based open-water 4.3 mg liter^{-1} instantaneous minimum dissolved oxygen criteria required to protect the endangered shortnose sturgeon (Chapter 2).
- Key findings published in the Endangered Species Act required EPA shortnose sturgeon biological evaluation of the potential impacts and benefits from publication of the *Regional Criteria Guidance* (Chapter 3).

- Summary of findings, incidental take and recommended reasonable and prudent measures published in the Endangered Species Act required NOAA shortnose sturgeon biological opinion on the potential impacts and benefits from state adoption of the *Regional Criteria Guidance* into water quality standards (Chapter 4).
- Guidance to the jurisdictions on when and where attainment of the instantaneous minimum, 1-day mean and 7-day mean dissolved oxygen criteria can be assessed using monthly mean water quality monitoring data (Chapter 5).
- Guidance to the jurisdictions for deriving site-specific dissolved oxygen criteria and assessing criteria attainment of those tidal systems where naturally low dissolved oxygen concentrations are due to extensive adjacent tidal wetlands (Chapter 6).
- Documentation of the methodology for delineating the upper and lower boundaries of the pycnocline used in defining the vertical boundaries between open-water, deep-water and deep-channel designated uses (Chapter 7).
- Updated guidance to the jurisdictions for potential combined application of the numerical water clarity criteria to shallow water habitats and submerged aquatic vegetation (SAV) restoration goal acreages for defining attainment of the shallow-water bay grass designated use (Chapter 8).
- Guidance to the jurisdictions for determining where numerical chlorophyll *a* criteria should apply to local Chesapeake Bay and tidal tributary waters (Chapter 9).

Through publication by EPA as a formal addendum to the 2003 Chesapeake Bay *Regional Criteria Guidance* document, this document should be viewed by readers as supplemental chapters and appendices to the original published *Regional Criteria Guidance* document. The publication of future addendums by EPA is likely as continued scientific research and management application reveal new insights and knowledge to be incorporated into revisions of state water quality standards regulations in upcoming triennial reviews.

chapter ii

Shortnose Surgeon Temperature Sensitivity Analyses

For water column temperatures greater than 29°C, documented as stressful to shortnose sturgeon, EPA established a Chesapeake Bay open-water dissolved oxygen criterion of 4.3 mg liter^{-1} instantaneous minimum to protect survival of this listed sturgeon species (U.S. EPA 2003). An investigation was conducted to determine if there were water column habitats within Chesapeake Bay and its tidal tributaries where water column temperatures routinely exceed 29°C. States would need to apply the 4.3 mg liter^{-1} instantaneous minimum dissolved oxygen criterion in such open-water habitats.

Bottom water temperature data were examined for the June through September period for the years 1996 through 2002 for all Chesapeake Bay tidal water quality monitoring stations throughout the mainstem Bay and tidal tributaries. Observations greater than 29°C at a station were expressed as a percentage of the total number of observations at the station for the 1996 through 2002 summer time period. These percentages were then interpolated and displayed on a map (Figure II-1). Due to the high density of stations within the District of Columbia's tidal waters, this region was examined in greater detail (Figure II-2).

Areas with a higher percentage of tidal water temperatures above 29°C were almost exclusively in the tidal fresh and oligohaline regions of the tidal tributaries. The tidal fresh James and Appomattox rivers had the highest percentages with 16–40 percent of the summer bottom water temperatures exceeding 29°C. In the Northeast, Elk, Bohemia, Sassafras, and tidal fresh segmemts of the Chester, Patuxent, Potomac, Rappahannock, Mattaponi and Pamunkey rivers, temperatures exceeded 29°C 5–15 percent of the time.

Examining the District of Columbia's water quality monitoring stations' bottom temperature data, it appeared that there were some stations with fairly high percentages of temperatures exceeding the 29°C temperature threshold (Figure II-2). But on closer examination, these stations were infrequently sampled and, therefore, the percentages were misleading. Based on a more strict evaluation of the total number of exceedences by station, it did not appear that elevated bottom water temperatures

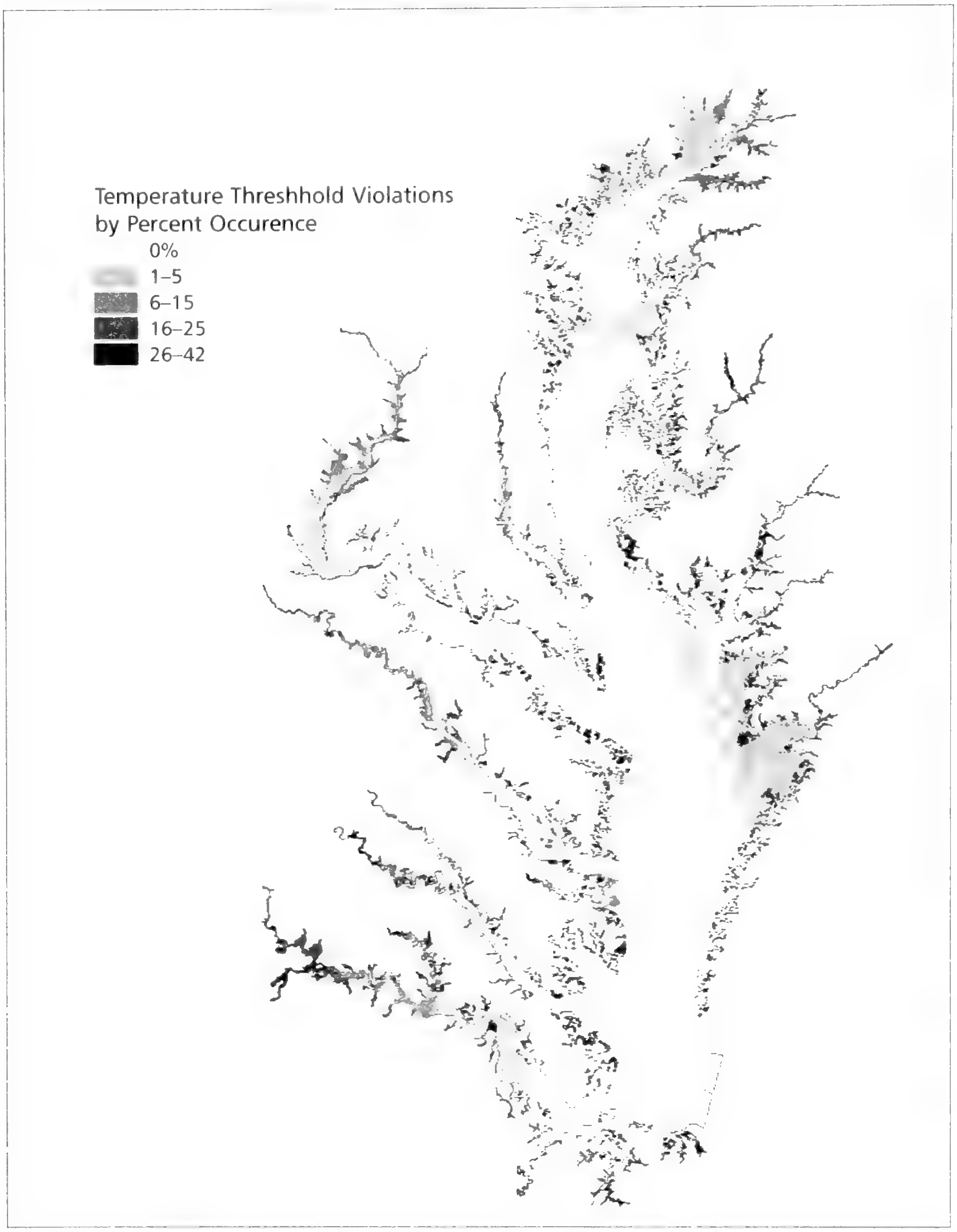

Figure II-1. Interpolated percent occurrence of bottom water temperatures greater than 29°C from June-September 1996-2002 at the Chesapeake Bay Water Quality Monitoring Program stations. Data were drawn from 48 monitoring cruises over the 7 year period.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

Figure II-2. Percent occurrence of bottom water temperatures greater than 29°C from June– September 1996–2002 at the Chesapeake Bay Water Quality Monitoring Program stations located in the District of Columbia's tidal waters.

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

were high enough to trigger routine application of the 4.3 mg liter^{-1} instantaneous minimum criterion in District of Columbia tidal waters (Figure II-3).

To further narrow down on those tidal water habitats where the temperature-based 4.3 mg liter^{-1} instantaneous minimum dissolved oxygen criterion would likely routinely apply, the baywide data set described previously was examined for the number of bottom water dissolved oxygen concentrations less than 4.3 mg liter^{-1} when the corresponding bottom water temperature exceeded 29°C. Over the summer periods of 1996 through 2002, there were a total of 20 incidences of these two conditions among 9 stations. Five of the stations were in the Southern Branch Elizabeth River and there was one station each in the tidal fresh segments of the Choptank, Patuxent, and Pamunkey rivers and in the oligohaline segment of the Rappahannock River (Figure II-4).

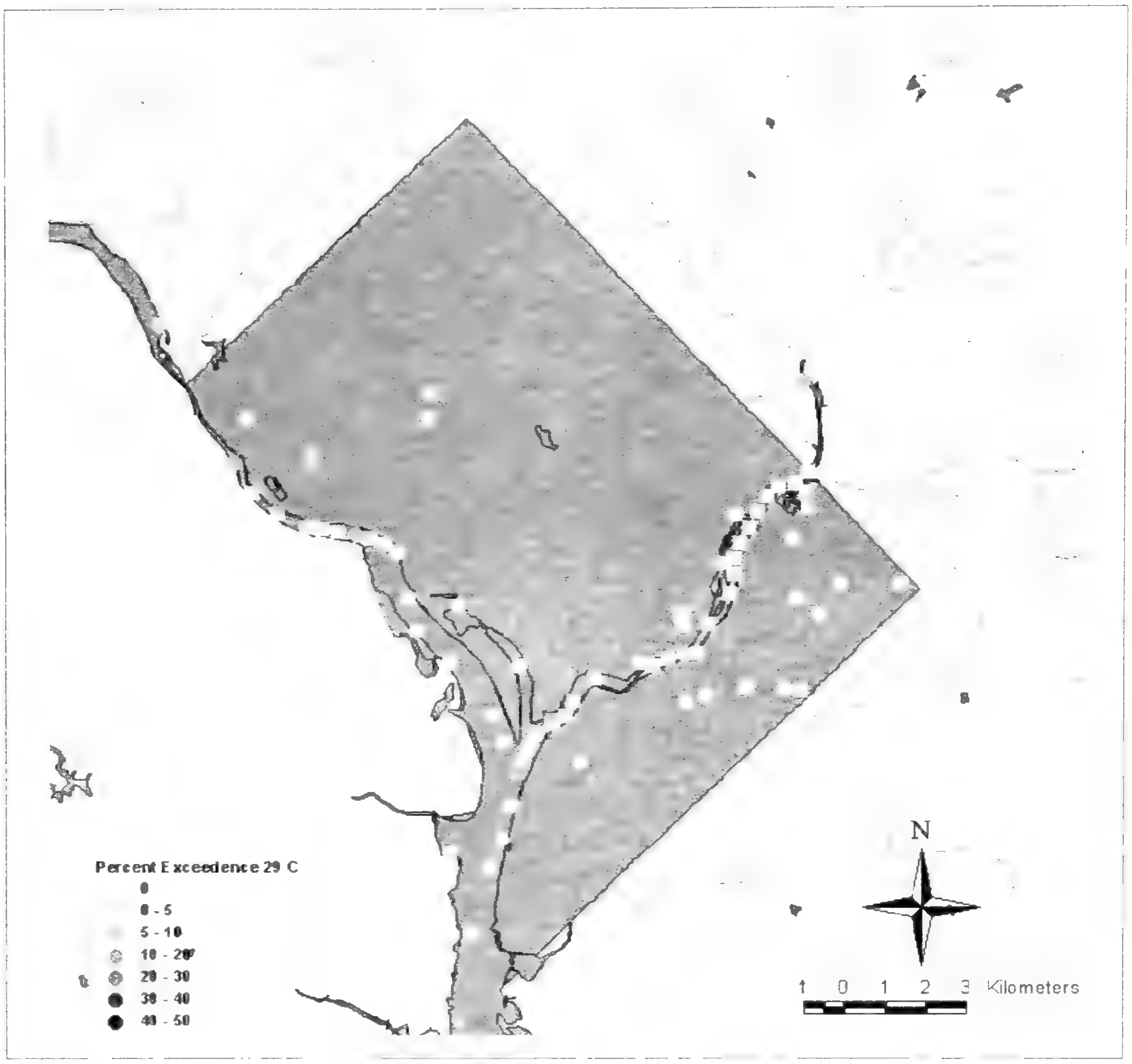

Figure II-3. The number of times the bottom water temperatures were greater than 29°C from June–September 1996–2002 at the Chesapeake Bay Water Quality Monitoring Program stations located in the District of Columbia's tidal waters.

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

Based on these evaluations, there appear to be no widespread tidal water habitats exceeding the 29°C threshold, thereby requiring routine application of the temperature-based 4.3 mg liter^{-1} instantaneous minimum dissolved oxygen criteria. Jurisdictions are advised to evaluate water column temperatures prior to assessing attainment of the open-water dissolved oxygen criteria to determine if, where and when this temperature-based dissolved oxygen criterion should be applied to protect the open-water designated use.

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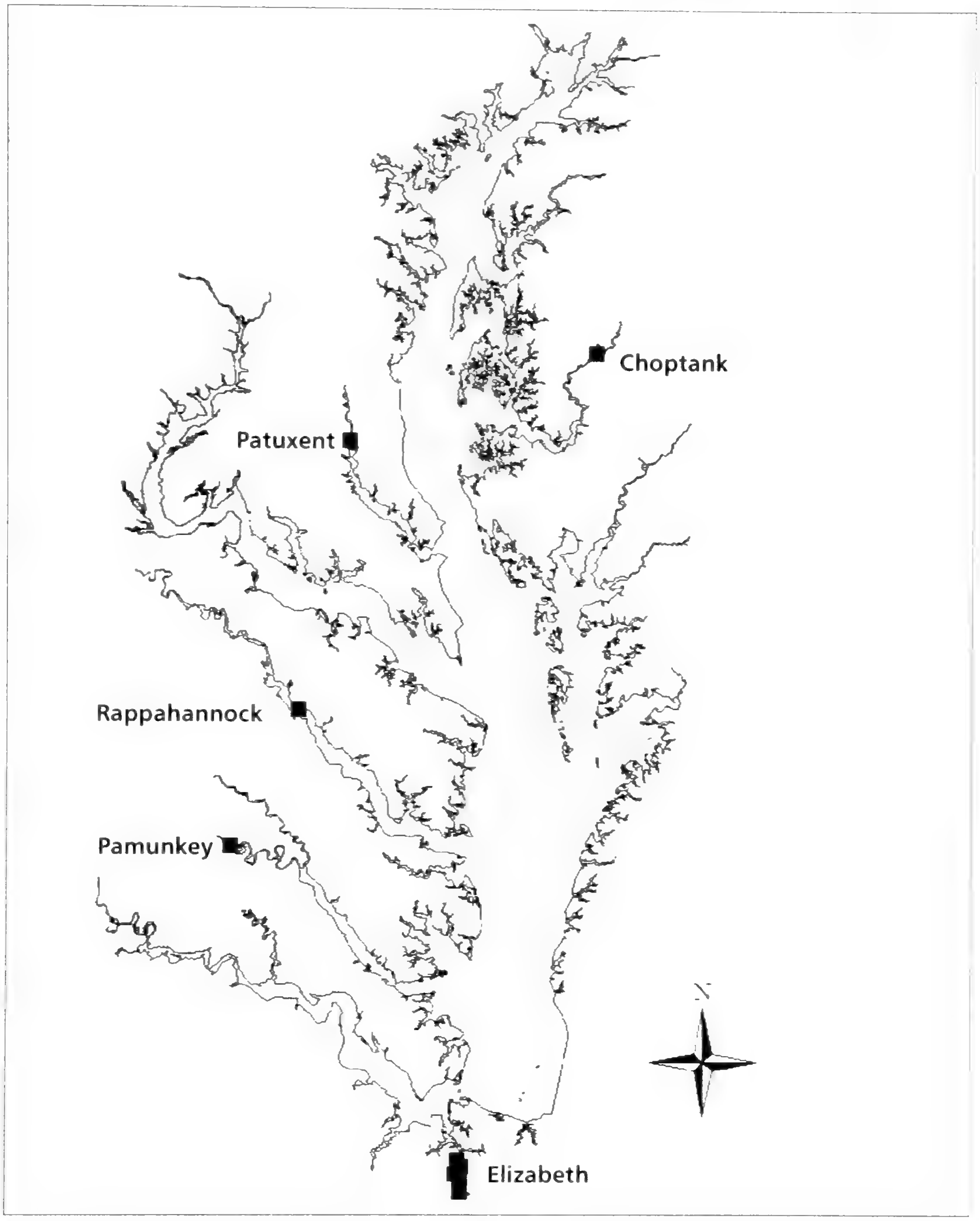

Figure II-4. Chesapeake Bay Water Quality Monitoring Program stations where both bottom water dissolved oxygen concentrations were less than 4.3 mg liter^{-1} and bottom water temperatures were greater than 29°C from June–September 1996–2002.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

chapter iii

Key Findings Published in the EPA ESA Shortnose Sturgeon Biological Evaluation

In November of 2000, EPA initiated a voluntary informal consultation with NOAA National Marine Fisheries Service (NOAA Fisheries) under Section 7(a)(2) of the Endangered Species Act (ESA) for the issuance of guidance for Chesapeake Bay specific water quality criteria for dissolved oxygen, water quality and chlorophyll *a*. Upon publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (*Regional Criteria Guidance*) (U.S. EPA 2003a), EPA initiated formal consultation with NOAA Fisheries. At the same time, EPA submitted its final *Biological Evaluation for the Issuance of Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries* (U.S. EPA 2003b) to NOAA Fisheries. This chapter provides a concise summary of key findings published in EPA's biological evaluation.[1]

CONSULTATION HISTORY

EPA sent a letter to NOAA Fisheries on November 24, 2000, requesting comments on the list of federally listed threatened or endangered species and/or designated critical habitat for listed species under the jurisdiction of NOAA Fisheries. NOAA Fisheries responded in a letter dated January 8, 2001. In this letter, NOAA Fisheries indicated that the endangered and threatened species under its jurisdiction in the vicinity of the Chesapeake Bay and its tidal tributaries were: federally threatened loggerhead (*Caretta caretta*), and endangered Kemp's ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and leatherback (*Dermochelys coriacea*) sea turtles; federally endangered North Atlantic right

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[1] The entire biological evaluation document can be viewed and downloaded at: http://www.chesapeakebay.net/pubs/subcommittee/wqsc/BE_final.pdf

(*Eubalaena glacialis*), humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*) and sperm (*Physter macrocephalus*) whales; and federally endangered shortnose sturgeon (*Acipenser brevirostrum*). In this letter, NOAA Fisheries indicated to EPA that the revised dissolved oxygen criteria should be evaluated for effects on shortnose sturgeon survival, foraging, reproduction and distribution due to the lowering of dissolved oxygen criteria in the Chesapeake Bay.

On December 20, 2002, EPA sent a letter to NOAA Fisheries requesting concurrence with EPA's conclusion that the proposed criteria and refined designated uses would not adversely affect the listed species under NOAA Fisheries' jurisdiction. Included with this letter were a Biological Evaluation regarding the shortnose sturgeon and a copy of the draft criteria document. In a January 7, 2003 letter, NOAA Fisheries replied to EPA and indicated that it concurred with EPA's conclusion as it applied to federally listed sea turtles and marine mammals but that NOAA Fisheries could not concur that the revised dissolved oxygen criteria would not adversely affect shortnose sturgeon. NOAA Fisheries provided several comments to EPA on the contents of the biological evaluation regarding the effects of the dissolved oxygen standards on shortnose sturgeon and indicated that EPA should revise the biological evaluation. Subsequent to receiving this letter, NOAA Fisheries and EPA staff communicated informally to revise the contents of the biological evaluation.

In February 2003, several meetings and conference calls took place between EPA and NOAA Fisheries staff. Included in these meetings was a discussion as to how the formal consultation would be conducted. The complicating factor was that while EPA was issuing the *Regional Criteria Guidance* document as guidance to the states, the states were not obligated to adopt the criteria exactly as outlined in the *Regional Criteria Guidance* document. It was determined between EPA and NOAA Fisheries staff that a programmatic approach would be taken in developing an appropriate biological opinion. In this scenario, EPA would consult with NOAA Fisheries on the effects of issuing the guidance document to the states and District of Columbia since EPA would evaluate the States and District of Columbia's revised water quality criteria in light of the Chesapeake Bay specific guidance. Then, when the states had developed their water quality standard regulations and submitted them to EPA, EPA would consult again with NOAA Fisheries on the effects of EPA approving the standards proposed by the states. This type of programmatic consultation was particularly appropriate as the pollutant loads from each State and the District of Columbia mix in the Chesapeake Bay and the water quality in the Bay and its tidal tributaries would be a result of the combined pollutant loads from the various states and the District of Columbia. The consultation that is the subject of EPA's final biological evaluation published April 25, 2003 and NOAA Fisheries final biological opinion dated April 16, 2004 serves as the first in a series of consultations that will take place between EPA and NOAA Fisheries on the effects of EPA's issuing water quality criteria and approving water quality standards for the Chesapeake Bay and its tidal tributaries.

In April 2003, EPA published the final *Regional Criteria Guidance* document. At that time, EPA indicated that it had not made any irreversible or irretrievable commitment of resources that would foreclose the formulation or implementation of any reasonable and prudent alternatives to avoiding jeopardizing endangered or threatened species.

On April 25, 2003, EPA submitted a final Biological Evaluation to NOAA Fisheries along with the published *Regional Criteria Guidance* and a letter requesting that NOAA Fisheries initiate formal consultation on the effects of the issuance of the dissolved oxygen criteria on shortnose sturgeon. The date April 25, 2003, serves as the initiation of formal consultation on the shortnose sturgeon for the issuance of the *Regional Criteria Guidance*.

During the formal consultation process, EPA and NOAA Fisheries staff continued to hold discussions regarding the evaluation of the effects of EPA's regional criteria on the shortnose sturgeon. On October 30, 2003, EPA management and staff traveled to NOAA Fisheries offices in Gloucester, Massachusetts, to provide technical information and background information on the Chesapeake Bay Program's ambient water quality criteria, designated uses, monitoring program and predictive modeling assessments of water quality conditions of the Bay. Subsequently, communication between the respective staffs continued, through which EPA provided NOAA Fisheries with requested data necessary to complete a determination analysis for the biological opinion. NOAA Fisheries communicated informally to the EPA that it concurred with EPA's determination that the issuance of the Chesapeake Bay specific criteria would not affect endangered and threatened whales and that the issuance of the criteria for water clarity and chlorophyll *a* likely would beneficially affect federally listed sea turtles and the endangered shortnose sturgeon. However, NOAA Fisheries indicated that the issuance of the dissolved oxygen criteria may affect shortnose sturgeon and sea turtles. The effect of EPA's issuance of the ambient water quality criteria on shortnose sturgeon and sea turtles was the subject of the consultation.

BIOLOGICAL EVALUATION FINDINGS

The EPA determined through consultation with the U.S. Fish and Wildlife Service and the NOAA National Marine Fisheries Service that the only endangered or threatened species under the NOAA Fisheries jurisdiction in the evaluation area that would potentially be affected was the endangered shortnose sturgeon (*Acipenser brevirostrum*). All the other federally-listed species within the Chesapeake Bay and its tidal tributaries would either not be affected or would be beneficially affected by the issuance of the *Regional Criteria Guidance*.

The EPA determined that the recommended water clarity criteria would not likely adversely effect the listed species evaluated. Furthermore, the EPA determined that the proposed water clarity criteria would beneficially affect preferred habitat, spawning areas and food sources that the listed shortnose sturgeon depends.

The EPA determined that the recommended chlorophyll *a* criteria would not likely adversely affect the listed species evaluated. Furthermore, the EPA determined that the recommended chlorophyll *a* criteria would beneficially affect preferred habitat, spawning habitat and food sources on which the listed species depends.

The EPA determined that the collective application of dissolved oxygen criteria for the migratory fish spawning and nursery and open-water fish and shellfish designated uses were fully protective of shortnose sturgeon survival and growth for all life stages based on the following:

- The migratory spawning and nursery 6 mg liter^{-1} 7-day mean and 5 mg instantaneous minimum criteria will fully protect spawning shortnose sturgeon. The February 1 through May 31 application period for the migratory spawning and nursery criteria fully encompasses the mid-March through mid-May spawning season documented previously from the scientific peer-reviewed literature.
- The individual components of the open-water criteria protect shortnose sturgeon growth (5 mg liter^{-1} 30-day mean), larval recruitment (4 mg liter^{-1} 7-day mean) and survival (3.2 mg liter^{-1} instantaneous minimum). A 4.3 mg liter^{-1} instantaneous minimum criterion applies to open waters with temperatures above 29°C considered stressful to shortnose sturgeon.
- The open-water criteria applied to tidal fresh waters include a 5.5 mg liter^{-1} 30-day mean criterion providing extra protection of shortnose sturgeon juveniles inhabiting tidal freshwater habitats.

The EPA determined that adoption of the proposed dissolved oxygen criteria into Maryland, Virginia, Delaware and the District of Columbia's state water quality standards and their eventual attainment would beneficially affect shortnose sturgeon spawning, nursery, juvenile and adult habitats and food sources by driving widespread nutrient loading reduction actions leading to increased existing ambient dissolved oxygen concentrations. EPA stated that this determination was consistent with and pursuant to Endangered Species Act provisions that the responsible federal agency—EPA in this case—use its authority to further the purpose of protecting threatened and endangered species (see 16 U.S.C. § 1536(a)). EPA also stated that its determination was also consistent with the NOAA National Marine Fisheries Recovery Plan for shortnose sturgeon which recommends working cooperatively with states to promote increased state activities to promote best management practices to reduce non-point sources (NOAA National Marine Fisheries Service 1998).

The EPA determined that adoption, implementation and eventual full attainment of the states' adopted dissolved oxygen water quality standards would result in significant improvements in dissolved oxygen concentrations throughout the tidal waters to levels last observed consistently more than four to five decades ago in Chesapeake Bay and its tidal tributaries.

The EPA recognized in the biological evaluation that dissolved oxygen criteria for June through September for the deep-water seasonal fish and shellfish and the deep-channel designated uses were at or below levels that protect shortnose sturgeon. The EPA believed there were strong lines of evidence that shortnose sturgeon historically have not used deep-water and deep-channel designated use habitats during the summer months due to naturally pervasive low dissolved oxygen conditions based on the following:

- Published findings in the scientific literature regarding salinity preferences (tidal fresh to 5 ppt) and salinity tolerances (<15 ppt) clearly indicated shortnose sturgeon habitats were unlikely to overlap with the higher salinity deep-water and deep-channel designated use habitats.
- The EPA concluded, based on extensive published scientific findings and in-depth analysis of the 1400 record U.S. Fish and Wildlife Service Reward Program database, that these same deep-water and deep-channel regions have not served as potential habitats for sturgeon during the June through September time period when there is a natural tendency for low dissolved oxygen conditions to occur.
- The EPA recognized the potential limitations of the U.S. Fish and Wildlife Service data set. However, the EPA believed the significant extent of the capture records—400 stations and 1400 individuals caught—provided substantial evidence for the lack of a potential conflict between shortnose habitat and seasonally applied deep-water and deep-channel designated uses.

The EPA determined that the recommended dissolved oxygen criteria for the refined designated uses would not likely adversely affect the listed species evaluated in this document. Furthermore, the EPA determined that the Chesapeake Bay dissolved oxygen criteria would beneficially affect critical habitat and food sources on which the listed species was dependent.

BIOLOGICAL EVALUATION CONCLUSIONS

Shortnose sturgeon are endangered throughout their entire range (NOAA National Marine Fisheries Service 2002). According to NOAA, in the *Final Biological Opinion for the National Pollutant Discharge Elimination System Permit for the Washington Aqueduct*, this species exists as 19 separate distinct population segments that should be managed as such. Specifically, the extinction of a single shortnose sturgeon population risks permanent loss of unique genetic information that is critical to the survival and recovery of the species (NOAA National Marine Fisheries Service 2002). The shortnose sturgeon residing in the Chesapeake Bay and its tributaries form one of the 19 distinct population segments.

Adult shortnose sturgeon are present in the Chesapeake Bay based on the 50 captures via the U.S. Fish and Wildlife Service Atlantic Sturgeon Reward Program. However, the presence and abundance of all life stages within the evaluation area itself are unknown. Preliminary published scientific evidence suggests that the shortnose sturgeon captured in the Chesapeake Bay may be part of the Delaware distinct population segment using the C & D Canal as a migratory passage. However, the NOAA National Marine Fisheries Service recommended that more studies utilizing nuclear DNA needed to be conducted before this can be proven conclusively.

Section 9 of the Endangered Species Act and Federal regulations pursuant to section 4(d) of the Endangered Species Act prohibit the take of endangered and threatened species, respectively, without special exemption. 'Take' is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. 'Harm' is further defined by NOAA National Marine Fisheries Service to include any act that kills or injures fish or wildlife. Such an act may include significant habitat modification or degradation that actually kills or injures fish or wildlife by significantly impairing essential behavioral patterns including breeding, spawning, rearing, migrating, feeding, or sheltering. 'Harass' is defined by U.S. Fish and Wildlife Service as intentional or negligent actions that create the likelihood of injury to listed species to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding or sheltering. 'Incidental take' is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity.

The shortnose sturgeon recovery plan further identifies habitat degradation or loss (resulting, for example, from dams, bridge construction, channel dredging, and pollutant discharges) and mortality (resulting, for example, from impingement on cooling water intake screens, dredging and incidental capture in other fisheries) as principal threats to the species' survival (NOAA National Marine Fisheries Service 1998). The recovery goal is identified as delisting shortnose sturgeon populations throughout their range, and the recovery objective is to ensure that a minimum population size is provided such that genetic diversity is maintained and extinction is avoided.

Considering the nature of the *Regional Criteria Guidance*, the effects of the recommended criteria, and future cumulative effects in the evaluation area, the issuance of *Regional Criteria Guidance* was not likely to adversely affect the reproduction, numbers, and distribution of the Chesapeake Bay distinct population segment in a way that appreciably reduces their likelihood of survival and recovery in the wild. This contention was based on the following: (1) the adoption of the recommended dissolved oxygen criteria into state water quality standards and subsequent attainment upon achievement of the Chesapeake Bay watershed's nutrient loading caps would provide for significant water quality improvements to the tributaries to the Chesapeake Bay (such as the Susquehanna, Gunpowder, and Rappahannock rivers) where the shortnose sturgeon would most likely spawn and spend their first year of life; (2) 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; and (3) there was strong evidence that shortnose sturgeon have historically not used deep-water and deep-channel designated use habitats during the summer months due to naturally pervasive low dissolved oxygen conditions.

Based on the evaluations conducted in the biological evaluation, EPA concluded that the issuance of the *Regional Criteria Guidance* would not adversely affect the continued existence of the Chesapeake Bay district population segment of shortnose sturgeon. No critical habitat has been designated for this species and, therefore, none will be affected. In fact, the EPA believed state adoption of the criteria into water quality standards would directly lead to increased levels of suitable habitat for shortnose sturgeon.

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chapter iv

Key Findings Published in the NOAA ESA Shortnose Sturgeon Biological Opinion

In response to EPA's submission of a biological evaluation and request for formal consultation under Section 7 (a)(2) of the Endangered Species Act as described in Chapter 2, the NOAA National Marine Fisheries Service published a biological opinion (NOAA National Marine Fisheries Service 2004). This chapter provides an extracted summary of key findings, the incidential take statement and recommended reasonable and prudent measures published in NOAA's biological opinion [2].

CHLOROPHYLL *A* CRITERIA

NOAA Fisheries determined that the chlorophyll *a* criteria will beneficially affect the food sources for several species of listed sea turtles and benefit the habitat of shortnose sturgeon and sea turtles (NOAA Fisheries 2004). This is based on the finding that the recommended Chesapeake Bay chlorophyll *a* criteria provide concentrations characteristic of desired ecological trophic conditions and protective against water quality and ecological impairments (U.S. EPA 2003a). When the chlorophyll *a* criteria are met, light levels and dissolved oxygen levels in the Chesapeake Bay system should improve (U.S. EPA 2003b). The proposed chlorophyll *a* concentrations should be protective against these water quality impairments. The criteria should significantly improve water quality conditions in the Bay, particularly for underwater Bay grasses.

WATER CLARITY CRITERIA

NOAA Fisheries determined that shortnose sturgeon and sea turtles are expected to benefit from the improved water quality resulting from the adoption of the proposed

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[2] The entire biological opinion document can be viewed and downloaded at: http://www.chesapeakebay.net/pubs/BONMFS.pdf

water clarity criteria (NOAA Fisheries 2004). The endangered green sea turtle feeds directly on sea grasses while other sea turtle species feed on shellfish which are dependent on the underwater grasses for habitat. The criteria for water clarity fully support the survival, growth and propagation of balanced, indigenous populations of ecologically important fish and shellfish inhabiting vegetated shallow-water habitats (U.S. EPA 2003b). As the water clarity criteria will lead to increased water quality and an increased forage base for sea turtles, NOAA Fisheries believed that these criteria will beneficially affect listed sea turtles. While shortnose sturgeon are not directly dependent on underwater grasses, these grasses are an important part of the food chain making the protection of bay grasses beneficial to shortnose sturgeon as well.

DISSOLVED OXYGEN CRITERIA

SEA TURTLES

After reviewing the best available information on the status of endangered and threatened species under NOAA Fisheries jurisdiction, the environmental baseline for the action area, the effects of the action, and the cumulative effects, it was NOAA Fisheries' opinion that the EPA's approval of the dissolved oxygen criteria for Chesapeake Bay and its tidal tributaries was not likely to adversely affect loggerhead, leatherback, Kemp's ridley, green, or hawksbill sea turtles. Because no critical habitat is designated in the action area, none will be affected by the project.

NOAA Fisheries believed that the dissolved oxygen criteria would beneficially affect endangered and threatened sea turtles that may be present in the Chesapeake Bay. Loggerhead, Kemps ridley, leatherback and green sea turtles are likely to be present in the action area. The occurrence of a hawksbill turtle in the area would be a rare occurrence. The effect of the dissolved oxygen levels on juvenile and adult turtles have been assessed. As turtles are air breathers, there are not likely to be any direct effects to sea turtles as a result of these dissolved oxygen criteria. As the dissolved oxygen conditions in the Bay were expected to continually improve over the next several years until the nutrient and sediment enrichment goals were met, NOAA Fisheries anticipated that as habitat conditions improve in the Bay and habitat was restored, there would be an increased forage base for sea turtles.

SHORTNOSE STURGEON

NOAA Fisheries determined that the water clarity and chlorophyll *a* criteria were expected to improve water quality conditions in the Bay and its tidal tributaries, beneficially affecting all native species of the Bay including shortnose sturgeon (NOAA Fisheries 2004). While the dissolved oxygen levels authorized by this set of criteria may result in some short-term adverse effects to shortnose sturgeon, no chronic or lethal effects were expected.

In addition, NOAA Fisheries determined that the adoption of the dissolved oxygen criteria would result in significantly improved water quality conditions in the Bay, elimination of anoxic zones and the improvement in the quality and quantity of habitat available to shortnose sturgeon as well as improving the chances for recovery of the Chesapeake Bay population of shortnose sturgeon and the long term sustainability of this population (NOAA National Marine Fisheries Service 2004).

This determination was based on the following conclusions:

- The effects of the ambient water quality criteria for the Chesapeake Bay and its tidal tributaries have been analyzed on the Chesapeake Bay population of shortnose sturgeon. While the dissolved oxygen levels authorized by this set of criteria may result in some short-term adverse effects to shortnose sturgeon through displacement or other behavioral or physiological adjustments, no chronic effects are expected. No lethal effects are expected as a result of the dissolved oxygen criteria and significant protections are being provided to essential habitats including deep water, spawning and nursery habitats.
- The adoption of the dissolved oxygen criteria will result in significantly improved water quality conditions in the Bay, elimination of anoxic zones and the improvement in the quality and quantity of habitat available to shortnose sturgeon as well as improving the chances for shortnose sturgeon recovery in the Bay and improving the likelihood of long-term sustainability of this population.
- NOAA Fisheries believes that the issuance of these criteria, as currently stated, would not reduce the reproduction, numbers and distribution of the Chesapeake Bay shortnose sturgeon population or the species as a whole in a way that appreciably reduces the likelihood of the species' survival and recovery in the wild. This conclusion was supported by the following: (1) no lethal takes of any life stage of shortnose sturgeon are anticipated to occur; (2) the demonstrated ability of shortnose sturgeon to avoid hypoxic areas and move to areas with suitable dissolved oxygen levels; (3) the availability of adequate habitat with not only suitable temperature, salinity and depth, but suitable dissolved oxygen levels; (4) the seasonal nature of the anticipated effects (i.e., no effects anticipated from October 1–May 31 of any year); (5) adequate protection of essential spawning and nursery areas protecting not only spawning adults but eggs and larvae from hypoxic conditions; (6) the elimination of anoxic areas within the Bay; (7) a large portion of the deep-water areas have low temperatures and adequate dissolved oxygen levels allowing shortnose sturgeon to be less dependent on the deepest areas of the Chesapeake Bay (deep-channels) for thermal refugia; and (8) the significant improvement in Bay water quality conditions and increased availability of suitable habitat for all life stages of shortnose sturgeon.

As such, it was NOAA Fisheries' biological opinion that the approval of these criteria by EPA may adversely affect the Chesapeake Bay population of endangered shortnose sturgeon through displacement to suboptimal habitat or other behavioral and metabolic responses to hypoxic conditions but was not likely to jeopardize the continued existence of the Chesapeake Bay population of shortnose sturgeon or the species as a whole (NOAA National Marine Fisheries Service 2004).

INCIDENTAL TAKE STATEMENT

Section 9 of the ESA and Federal regulations pursuant to section 4(d) of the ESA prohibit the take of endangered and threatened species, respectively. "Incidental take" is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity (50 CFR 402.02). Under the terms of section 7(b)(4) and section 7(o)(2) of the ESA, taking that is incidental to and not intended as part of the agency action is not considered to be prohibited under the ESA provided that such taking is in compliance with the terms and conditions of this Incidental Take Statement.

According to the EPA *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (*Regional Criteria Guidance*), the goal of this program is that states will adopt water quality standards consistent with the *Regional Criteria Guidance* and further implement those water quality standards so that nutrient and sediment load reductions will be achieved by 2010. At that time, EPA expects that the dissolved oxygen criteria will be met for all designated uses. This Incidental Take Statement accounts for take that will occur before the 2010 goals are met and after the goals are met. Unless NOAA Fisheries revokes, modifies or replaces this Incidental Take Statement, this Incidental Take Statement is valid for as long as the EPA's guidance document remains in effect (NOAA National Marine Fisheries Service 2004). When the States and the District of Columbia seek EPA approval of their dissolved oxygen criteria, NOAA Fisheries will verify at that time that EPA's approval of the state water quality criteria will also be subject to this programmatic take statement. At that time, NOAA Fisheries may revise this Incidental Take Statement based on a particular State's implementation plan, for example to include additional terms and conditions to minimize the likelihood of take.

AMOUNT AND EXTENT OF TAKE ANTICIPATED

The proposed action is reasonably certain to result in incidental take of shortnose sturgeon. NOAA Fisheries stated it is reasonably certain the incidental take described here will occur because (1) shortnose sturgeon are known to occur in the action area; and (2) shortnose sturgeon are known to be adversely affected by low dissolved oxygen levels as low dissolved oxygen levels cause them to avoid areas, increase surfacing behavior, and undergo metabolic changes. Based on the evaluation of the best available information on shortnose sturgeon and their use of the Chesapeake Bay, NOAA Fisheries has concluded that the issuance of the dissolved oxygen criteria for seasonal deep water, deep channel and open water aquatic life uses was likely to result in take of shortnose sturgeon in the form of harassment of shortnose sturgeon, where habitat conditions (i.e., dissolved oxygen levels below those protective of shortnose sturgeon) will temporarily impair normal behavior patterns of shortnose sturgeon (NOAA National Marine Fisheries 2004). This harassment will occur in the form of avoidance or displacement from preferred habitat and behavioral and/or metabolic compensations to deal with short-term hypoxic conditions. Neither lethal takes (see below) nor harm are anticipated in any Bay area due to the extent of available habitat in the Bay with dissolved oxygen levels protective of shortnose sturgeon and the demonstrated ability of shortnose sturgeon to avoid hypoxic areas and move to areas with suitable dissolved oxygen levels. Shortnose sturgeon displaced from hypoxic areas were expected to seek and find suitable alternative locations within the Bay. While shortnose sturgeon may experience temporary impairment of essential behavior patterns, no significant impairment resulting in injury (i.e., "harm") was likely due to: the temporary nature of any effects, the large amount of suitable habitat with adequate dissolved oxygen levels, and the ability of shortnose sturgeon to avoid hypoxic areas.

As outlined in the Biological Opinion, generally shortnose sturgeon are adversely affected upon exposure to dissolved oxygen levels of less than 5mg liter^{-1} and lethal effects are expected to occur upon even moderate exposure to dissolved oxygen levels of less than 3.2mg liter^{-1}. Because dissolved oxygen levels are known to be affected by various natural conditions (e.g., tides, hurricanes or other weather events including abnormally dry or wet years) beyond the control of EPA or the States and District of Columbia and can fluctuate greatly within any given period of time, a monthly average dissolved oxygen level has been determined to be the best measure of this habitat condition within the Bay. As indicated in the Biological Opinion, an area that achieves a 5mg liter^{-1} monthly average will also achieve at least a 3.2mg liter^{-1} instantaneous minimum dissolved oxygen level. As shortnose sturgeon are reasonably certain to be adversely affected by dissolved oxygen conditions below these levels, these levels can be used as a surrogate for take. As such, for purposes of this Incidental Take Statement areas failing to meet a 5mg liter^{-1} monthly average of dissolved oxygen will be a surrogate for take of shortnose sturgeon. As noted above, this take is likely to occur in the form of avoidance or displacement from preferred habitat and behavioral and/or metabolic compensations to deal with short-term hypoxic conditions (defined as harassment in this situation). The amount of habitat failing to meet an instantaneous minimum of 3.2mg liter^{-1} could be used as a surrogate for lethal take of shortnose sturgeon; however, due to limitations of the model developed by EPA (U.S. EPA 2003c), the amount of habitat failing to reach a 3.2mg liter^{-1} instantaneous minimum could not be modeled. However, an analysis of the likelihood of lethal take can be based on the amount of habitat failing to reach a 3mg liter $^{-1}$ monthly average (which would also likely be failing to meet a 3.2mg liter^{-1} instantaneous minimum). While a small portion of the Bay will fail to meet the 3 mg liter^{-1} monthly average, shortnose sturgeon are likely to be able to avoid these areas. Lethal effects are only expected to occur after at least 2-4 hours of exposure to dissolved oxygen levels of less than 3.2mg liter^{-1}, and this is not likely to occur given the mobility of shortnose sturgeon and the availability of suitable habitat. Therefore, no lethal take is expected to occur.

The probability of lack of attainment of dissolved oxygen levels protective of shortnose sturgeon when the 2010 sediment and nutrient reduction goals are met has been modeled by EPA (U.S. EPA 2003c) and was the basis for determining the extent of take anticipated. As such, take levels can be determined for each of the designated uses where take is anticipated (open water, deep-water and deep-channel). As indicated in the biological opinion, take is likely to occur only in the summer months (June 1–September 30). Based on the analysis documented in the accompanying biological opinion, the area of the Bay designated uses that fail to meet a 5mg $liter^{-1}$ monthly average dissolved oxygen level can be used as a surrogate for take of shortnose sturgeon by harassment. As shortnose sturgeon are benthic fish, the modeling runs done for the bottom layer of the Bay have been used to determine the extent of take. To further refine this analysis, the "tolerate" habitat threshold has been used; that is, the estimate of area that will have temperatures <28°C, salinity <29 ppt and depth <25 meters which can be reasonably expected to be the areas of the Bay where shortnose sturgeon may be present in the summer months (U.S. EPA 2003c).

Despite the use of the best available scientific and commercial data, NOAA Fisheries cannot quantify the precise number of fish that are likely to be taken. Because both the distribution of shortnose sturgeon throughout the Bay and the numbers of fish that are likely to be in an area at any one time are highly variable, and because incidental take is indirect and likely to occur from effects to habitat, the amount of take resulting from harassment is difficult, if not impossible, to estimate. In addition, because shortnose sturgeon are aquatic species who spend the majority of their time on the bottom and because shortnose sturgeon are highly mobile while foraging in the summer months, the likelihood of discovering take attributable to this proposed action is very limited. In such circumstances, NOAA Fisheries uses a surrogate to estimate the extent of take. The surrogate must be rationally connected to the taking and provide an obvious threshold of exempted take which, if exceeded, provides a basis for reinitiating consultation. For this proposed action, the spatial and temporal extent of the area failing to meet dissolved oxygen standards protective of shortnose sturgeon provides a surrogate for estimating the amount of incidental take.

EXTENT OF TAKE FROM 2004–2009

Using data provided by EPA, the extent of take occurring from the time of the adoption of the guidance[3] could be estimated. As habitat conditions in the Bay are expected to improve over time as interim measures are achieved before the 2010 goals are met, it is reasonable to assume that this surrogate level of take will decrease

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[3] Adoption of the guidance by the states and District of Columbia and approval by EPA is expected to occur in 2004 and 2005.

over time. Using the EPA model of dissolved oxygen conditions in 2000 in the bottom layer of habitat that was rated "tolerate" (see above) the following conditions were observed:

Designated Use	Percent of area failing to meet 5mg liter^{-1} monthly average 2004-2009 (see U.S. EPA 2003c)
Open Water	9.2
Deep Water	47.3
Deep Channel	78.3

Each year in the summer months, no more than the above percentages of the particular designated use areas were expected to fail to meet a 5 mg liter^{-1} monthly average dissolved oxygen level between 2004 and 2009. The extent of take would be limited to those percentages of each designated use area in the Bay. As such, for the period 2004 through 2009, NOAA Fisheries would consider take to have been exceeded when upon review of the annual monitoring data, NOAA Fisheries was able to determine that for the preceding summer, the dissolved oxygen data for any 30 days during the June 1–September 30 time frame indicate that any of the designated use area failed to meet the above goals.

EXTENT OF TAKE IN 2010 AND BEYOND

Using the EPA model, the extent of take anticipated in 2010 and beyond can be determined. Using the EPA model of dissolved oxygen conditions anticipated when the 2010 nutrient and sediment reduction goals were met and using the bottom layer of habitat that is rated "tolerate" (see above) the following conditions were anticipated:

Designated Use	Percent of area failing to meet 5mg liter^{-1} monthly average 2010 and beyond (see U.S. EPA 2003c)
Open Water	5.7
Deep Water	33.0
Deep Channel	65.9

As conditions were expected to be improving over time, no more than the above percentages of the particular habitats were expected to fail to meet a 5mg liter^{-1} monthly average dissolved oxygen level in 2010 and beyond. As such, for the period of 2010 and beyond, NOAA Fisheries will consider take to have been exceeded when upon review of the annual monitoring data, NOAA Fisheries was able to determine that for the preceding summer, the dissolved oxygen data for any 30 days during the June 1–September 30 time frame indicate that any of the designated use area failed to meet the above goals.

REASONABLE AND PRUDENT MEASURES

Reasonable and prudent measures are those measures necessary and appropriate to minimize incidental take of a listed species. For this particular action, however, it is not possible to design reasonable and prudent measures that are necessary and appropriate to minimize take, because the best available science has demonstrated that the EPA criteria are the limit of feasibility based on current technology. The purpose of the reasonable and prudent measure below is to monitor environmental conditions in the Bay and to monitor the level of take associated with this action. In order to monitor the level of incidental take, monitoring of dissolved oxygen and accompanying temperature conditions in the Bay must be completed each summer.

In order to be exempt from the prohibitions of section 9 of the ESA, the EPA must comply with the following terms and conditions, which implement the reasonable and prudent measure described above and outline the required reporting requirements. These terms and conditions are non-discretionary.

1. By April 1 of each year (beginning in 2005), EPA shall provide an annual report to NOAA Fisheries outlining the progress towards nutrient and sediment load reductions, including a discussion of any best management practices or other strategies put in place to achieve the target nutrient and sediment load reductions.
2. EPA shall continue using the results of the Chesapeake Bay Interpolator to extrapolate measured data to assess water quality conditions in the Bay. The Chesapeake Bay Interpolator extrapolates water quality concentrations throughout the Chesapeake Bay and/or tributary rivers from water quality measured at point locations. The purpose of the Interpolator is to assess water quality concentrations at all locations in the 3-dimensional water volume or as a 2-dimensional layer. The results from the Interpolator will be used by EPA to develop an annual report (see below).
3. By April 1 of each year (beginning in 2005), EPA shall provide an annual report to NOAA Fisheries on water quality conditions in the Bay, including temperature, dissolved oxygen, depth and salinity. The data provided will express actual monitoring data in volumetric figures (cubic kilometers) as well as bottom habitat area (squared kilometers) extrapolated from the Chesapeake Bay Interpolator. This report should include information on the percent of each designated use that failed to meet the 5mg liter^{-1} monthly average for June, July, August and September of the preceding year.

By April 30, 2010, EPA shall submit a report to NOAA Fisheries assessing the dissolved oxygen condition in the Bay which highlights the dissolved oxygen conditions in the Bay during the June 1–September 30 time frame for each of the years 2004 through 2009. In this report, EPA will determine the percent of each designated use that failed to attain a 5mg liter^{-1} monthly average. Included in this report will be an analysis of the likely causes of failures (i.e., weather events, point sources).

LITERATURE CITED

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chapter V

Guidance for Attainment Assessment of Instantaneous Minimum and 7-Day Mean Dissolved Oxygen Criteria

BACKGROUND

As published in the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (U.S. EPA 2003), it is accepted that concentration minima need to be defined, which if exceeded for some defined (short) duration result in lethal or other adverse effects. Instantaneous minimum criteria have been derived and published for protection of each of the five tidal water designated uses. A 1-day mean dissolved oxygen criterion was also determined to be necessary for the protection of the deep-water designated use. In addition, a 7-day mean criterion has been derived for protection of the open-water designated use (U.S. EPA 2003).

However, it is also acknowledged that assessing the attainment status of these criteria requires data collections at temporal and spatial scales that are simply not practicable nor sustainable across all Chesapeake Bay and tidal tributary waters. To address this issue, there are ongoing efforts to develop statistical methods to estimate attainment of these dissolved oxygen criteria using a synthesis of: 1) seasonal and inter-annual patterns found in the long term, low-frequency, spatially-limited monitoring data; 2) the short-term patterns of temporal variability found in high-frequency, spatially uneven 'buoy' data; and 3) the small-interval patterns of variability observed in data records generated through the 'data-flow' and 'scan-fish' sampling devices.

CURRENT STATUS

These methods are in the exploratory and trial application phases. However, we can still address the question of how best to assess attainment of these criteria given the almost two-decade record of dissolved oxygen concentrations for Chesapeake Bay tidal waters. First, there are some Chesapeake Bay Program segments, such as the deep-channel mid-Chesapeake Bay mainstem segments and the lower Potomac

River, whose hypoxic/anoxic conditions are of long standing and whose dynamics are well enough understood to be modeled mathematically and relatively precisely. There are other segments that have long term monthly and twice monthly dissolved oxygen concentration records whose station coverage is considered to represent the whole segment adequately or at least areas most likely to have dissolved oxygen concentrations below saturation levels. The Chesapeake Bay Program partners have previously demonstrated (see *Chesapeake Bay Dissolved Oxygen Goal for Restoration of Living Resource Habitats*; Jordan et al. 1992) that relatively good predictive models can be developed for segments that suffer hypoxia at some regular frequency and so far have demonstrated no long term trend in dissolved oxygen concentrations. These models produce estimates of the percent of time the segment depth is below some specified concentration. These monitoring data-based models reflect only daytime measurements, but can be enhanced (and validated) by the in-situ continuous records from the buoy deployments.

The remaining segments not characterized above are those segments where the long-term fixed monitoring stations, sampled on a monthly to twice-monthly basis, do not well represent dissolved oxygen conditions elsewhere in the segment. Typically these segments have a moderately deep channel with flanking nearshore areas of significant size. In these segments, tidal pulses from downstream, inflows from upstream, and local land-based influences vary in their dominance, and the current long-term water quality monitoring data do not capture ephemeral events or the nearshore conditions very well. The new shallow water monitoring component of the larger Chesapeake Bay Water Quality Monitoring Program is designed to generate the additional data necessary to assess criteria attainment in these segments. The Chesapeake Bay Program partners are now accumulating such data for a growing number of Chesapeake Bay Program segments.

ASSESSMENT OF INSTANTANEOUS MINIMUM CRITERIA ATTAINMENT FROM MONTHLY MEAN DATA

By overlaying information from the buoy data about diurnal variability and the frequency of common hypoxic events, such as those caused by phytoplankton bloom respiration and decay, pycnocline tilting, etc., on top of the long-term fixed-station monitoring data record, we can better understand the relationship between attainment/non-attainment of the 30-day mean and instantaneous minimum criteria. The reader should keep several things in mind. The temporal record of the long-term, fixed-station monitoring program is considered "low-frequency" relative to the high frequency record of the "continuous" data record from the buoy deployments. The available continuous records chronicle a few days to months of a single year. Each measurement is closely related to the previous and next measurement, providing a detailed record of the dissolved oxygen response to the specific conditions of that period. These buoy data records are measuring conditions at a single fixed point in the water column, usually about a meter off the bottom in these data sets. The sensors are fixed, but the water mass moves past, back and forth with the tide and the various complexities of the local riverine and estuarine circulation. The majority of the available buoy data were collected through buoy deployments that were sited using stratified random design considerations or to answer location-specific questions, but not directly to address the relationship between instantaneous minimum and monthly mean concentrations.

In contrast, the long term monitoring program includes a vast network of stations sited specifically to represent overall water quality conditions of the 78 Chesapeake Bay Program segments. The low-frequency monitoring record captures a snapshot of conditions only once or twice a month, but that series of snapshots now extends over an 19-year period and is ongoing. Each snapshot consists of synoptic measurements forming a relatively dense three-dimensional spatial data grid. The grid is formed horizontally by the network of mainstem and tidal tributary monitoring stations and vertically by the dissolved oxygen profiles measured at 1- to 2-meter intervals from water column surface to bottom water-sediment interface. A single summer 'snapshot cruise' typically includes over a thousand individual dissolved oxygen concentration measurements.

REFERENCE POINTS WITH RESPECT TO DEPTH

Dissolved oxygen levels are strongly related to depth, bathymetry, and flow and circulation patterns. Table V-1 provides information that helps to decide how representative the long-term fixed-station monitoring data and the continuous buoy data records are of their respective Chesapeake Bay Program segment. Table V-1 presents segment volume, the depth of the Chesapeake Bay Water Quality Program monitoring station(s) in the segment, and the segment-wide bottom depth distribution i.e., maximum depth, the depth encompassing 90 percent, 75 percent, 50 percent (the median) and 25 percent of the bottom depths, as well as the minimum depth.

DATA ASSEMBLAGE AND MANIPULATION

Table V-2 lists the 147 continuous buoy data sets available for analysis through the Chesapeake Information Management System (partner network of Chesapeake Bay data and information servers), latitude/longitude location information, the time interval between measurements, the total duration of deployment, water depth and depth of the sensor at the site and in what depth category the sensor depth falls, based on the depth distributions listed in Table V-1. The list of data sets has been categorized according to Chesapeake Bay Program segment so that it is obvious which segments have or do not have such high frequency information available for evaluating and establishing the 30-day mean and instantaneous minimum concentration relationship.

Table V-1. Depth (meters) and volume (x 10^9 cubic meters) distributions of Chesapeake Bay Program segments and Chesapeake Bay Water Quality Monitoring Program stations.

CBP Segment	Volume /1000	Maximum	90th Percentile	75th Percentile	Median	25th Percentile	Minimum	Depth of Individual Monitoring Stations Within Segment (in 1, 2, 3, etc., order)
CB1TF	360000	16	6	4	2	1	1	6.5, 6.3
CB2OH	1237000	15	6	5	3	2	1	13.3, 12.9
CB3MH	2391000	22	10	7	4	2	1	24.7, 12.5, 8.8, 8.6
CB4MH	9237000	33	16	11	7	3	1	32.3, 31.3, 27.2, 27.2, 23.6, 22.6, 9.9, 9.7, 9.4, 9.3
CB5MH	15416000	42	17	11	7	3	1	34.3, 32.2, 31.0, 27.1, 16.7, 9.2, 5.0
CB6PH	6503000	19	10	8	5	3	1	12.5, 11.3, 10.5, 9.9
CB7PH	13523000	34	12	9	6	3	1	25.7, 25.5, 22.6, 20.7, 18.7, 14.4, 13.1, 12.9, 12.0
CB8PH	3172000	27	10	7	5	3	1	15.3, 15.2, 9.7
BSHOH	49250	5	2	2	1	1	1	2.3
GUNOH	64250	4	2	2	1	1	1	1.9
MIDOH	25000	3	3	2	2	1	1	5.5
BACOH	22375	4	2	2	1	1	1	2.2
PATMH	451500	16	8	5	3	2	1	16.0
MAGMH	76500	7	4	3	2	1	1	5.6
SEVMH	113438	15	6	5	3	2	1	9.8
SOUMH	67000	8	5	4	2	1	1	9.1
RHDMH	20313	5	4	3	2	1	1	2.6
WSTMH	20375	5	4	3	2	1	1	3.5
PAXTF	11025	8	5	4	2	1	1	10.7, 3.4, 3.0
WBRTF	**	.	.	.	.	.	.	3.0, 1.1
PAXOH	27180	11	5	3	2	1	1	6.6, 3.1
PAXMH	561000	37	13	8	4	2	1	23.5, 17.2, 16.1, 12.1, 11.5
POTTF	484750	20	7	5	3	1	1	19.2, 12.7, 8.9, 8.2
PISTF	2850	2	1	1	1	1	1	1.5
MATTF	9500	4	2	2	1	1	1	6.9
POTOH	852250	33	7	5	3	2	1	10.9, 7.4
POTMH	5792000	26	11	8	5	2	1	20.2, 16.2, 13.0
RPPTF	107438	18	7	5	3	1	1	7.3, 6.6, 4.8, 4.5
RPPOH	53580	14	6	4	3	1	1	8.0
RPPMH	1482250	24	11	7	4	2	1	15.3, 14.7, 9.9, 7.4, 6.1, 5.7
CRRMH	65688	13	6	4	3	1	1	6.7
PIAMH	201438	13	6	5	3	2	1	7.1
MPNTF	15338	12	5	3	2	1	1	3.9
MPNOH	35390	15	7	5	3	2	1	14.8
PMKTF	28630	15	6	4	2	1	1	7.2
PMKOH	66680	18	7	5	3	2	1	6.5
YRKMH	275500	12	7	5	3	1	1	10.5, 6.3
YRKPH	400750	25	13	9	6	2	1	15.1, 14.3

MOBPH	1342500	22	8	5	3	2	1	12.4, 6.4, 5.5, 5.2
JMSTF	286188	25	9	6	4	2	1	10.7, 10.4, 10.1, 9.8, 9.0, 1.0
APPTF	1510	4	3	2	1	1	1	6.8
JMSOH	431500	19	6	4	3	1	1	12.6, 10.7
CHKOH	48563	12	6	4	2	1	1	5.0
JMSMH	977000	15	7	5	3	1	1	9.4, 7.0
JMSPH	434000	21	13	8	4	2	1	17.0, 7.1
WBEMH	6310	5	3	2	2	1	1	3.9
SBEMH	27730	11	10	7	4	2	1	12.2, 12.1, 11.8, 11.4, 5.7, 3.3
EBEMH	6460	8	6	4	2	1	1	8.4
ELIMH	53390	12	10	7	4	2	1	.
LAFMH	3390	2	2	2	1	1	1	.
ELIPH	61500	17	13	10	6	3	1	15.5, 12.3
LYNPH	16730	7	3	2	1	1	1	.
NORTF	26500	5	2	2	1	1	1	2.9
C&DOH	24130	11	10	8	5	2	1	13.5
BOHOH	17000	6	2	2	1	1	1	2.8
ELKOH	101250	10	6	4	2	1	1	12.5
SASOH	84188	13	5	4	2	1	1	7.7
CHSTF	3363	8	4	3	1	1	1	.
CHSOH	28875	9	5	3	2	1	1	5.5
CHSMH	455250	18	9	6	3	2	1	14.3, 5.7
EASMH	996750	24	9	6	4	2	1	13.1
CHOTF	15323	12	5	3	2	1	1	.
CHOOH	45125	17	7	5	3	2	1	8.6
CHOMH2	266750	25	8	5	3	2	1	12.0
CHOMH1	945000	17	7	5	3	2	1	7.7
LCHMH	208250	10	5	4	2	1	1	12.8
HNGMH	185680	16	6	4	2	1	1	.
FSBMH	143000	6	3	2	1	1	1	7.5
NANTF	6615	9	5	3	2	1	1	5.3
NANOH	45000	17	6	4	3	1	1	.
NANMH	97250	12	5	3	2	1	1	4.1
WICMH	56420	11	4	3	2	1	1	8.0
MANMH	89500	8	3	2	1	1	1	5.5
BIGMH	43625	6	4	2	2	1	1	5.1
POCTF	4470	8	4	3	2	1	1	6.3
POCOH	18000	11	4	2	1	1	1	.
POCMH	354500	9	3	2	2	1	1	5.0, 4.0
TANMH	4019000	33	14	7	4	2	1	27.6, 12.9

** = No bathymetry data available. Estimated volume is based on the count of Chesapeake Bay Interpolator cells of dimension 1 kilometer x 1 kilometer x 1 meter.

Table V-2. Listing of the available continuous dissolved oxygen buoy data sets for Chesapeake Bay and its tidal tributaries by Chesapeake Bay Program segment.

CBP Segment	Dataset Name	Station Name	Latitude	Longitude	Start Date	Duration (days)	Interval (minutes)	Total Depth (meters)	Sensor Depth (meters)	Data Source[1]
CB1TF	EMAP1057	VA91 353	39.5880	6.1090	July 30, 1991	9	15	9.8	8.8	EMAP
CB2OH	.	.	.	.	.	.	.	.	.	.
CB3MH	EMAP1232	VA91 058	39.1292	76.2813	July 17, 1991	1	15	3.1	2.1	EMAP
CB3MH	EMAP1058	VA91 343	39.2025	76.3357	July 28, 1991	3	15	5.8	4.8	EMAP
CB4MH	CBWDEEP3	CBW 9 ME	38.4517	76.4333	August 12, 1987	28	5	11.0	9.4	Sanford
CB4MH	CBWMID3	CBW 6 ME	38.4517	76.4333	August 12, 1987	28	5	11.0	6.0	Sanford
CB4MH	CE1DEEP3	CE1	38.5542	76.3967	August 12, 1987	28	15	23.0	19.0	Sanford
CB4MH	CBW5M	CmpCanoy	38.4166	76.4166	May 26, 1988	88	15	4.0	3.7	Breitburg
CB4MH	CBW2M	CmpCanoy	38.4166	76.4166	June 6, 1988	87	15	4.0	1.9	Breitburg
CB4MH	EPA88	KENT IS	38.9450	76.3800	August 8, 1988	78	20	7.0	6.1	EPA
CB4MH	CBL90	999	38.4450	76.4283	June 29, 1990	52	20	11.5	5.2	EPA
CB4MH	EMAP662039	VA90 065	38.5575	76.4013	July 27, 1990	5	30	9.6	8.6	EMAP
CB4MH	EMAP653039	VA90 065	38.5575	76.4013	August 6, 1990	10	30	9.6	8.6	EMAP
CB4MH	EMAP414039	VA90 065	38.5575	76.4013	August 16, 1990	12	30	10.5	9.5	EMAP
CB4MH	EMAP1077	VA91 325	38.6248	76.4643	August 15, 1991	3	15	12.0	11.0	EMAP
CB5MH	EMAP1230	VA91 060	37.7153	76.2768	July 8, 1991	2	15	7.3	6.3	EMAP
CB5MH	EMAP1040	VA91 284	37.7990	76.1313	August 10, 1991	2	15	10.3	9.3	EMAP
CB5MH	EMAP1045	VA91 290	37.8500	76.3607	August 11, 1991	2	15	5.3	4.3	EMAP
CB5MH	EMAP1049	VA91 291	37.9313	76.2560	August 11, 1991	2	15	8.5	7.5	EMAP
CB5MH	EMAP1012	VA91 295	38.0798	76.1723	August 21, 1991	3	15	7.0	6.0	EMAP
CB5MH	EMAP1026	VA91 303	38.2120	76.2973	August 27, 1991	1	15	12.7	11.7	EMAP
CB6PH	EMAPLTDO054	VA90 054	37.1535	76.1935	July 1, 1990	59	30	12.2	11.2	EMAP
CB6PH	EMAP627039	VA90 054	37.1535	76.1935	August 9, 1990	11	30	11.7	10.7	EMAP
CB6PH	EMAP635039	VA90 054	37.1535	76.1935	August 20, 1990	9	30	12.2	11.2	EMAP
CB6PH	EMAP1037	VA91 282	37.6505	76.2145	August 9, 1991	3	15	12.0	11.0	EMAP
CB6PH	EMAP1019	VA91 276	37.3697	76.1732	August 16, 1991	4	15	11.4	10.4	EMAP
CB6PH	EMAP1013	VA91 270	37.2210	76.2552	August 17, 1991	3	15	7.4	6.4	EMAP
CB7PH	EMAP1017	VA91 265	37.0888	76.1317	August 15, 1991	3	15	13.5	12.5	EMAP
CB7PH	EMAP1020	VA91 271	37.2373	76.0493	August 16, 1991	3	15	5.4	4.4	EMAP
CB7PH	EMAP1033	VA91 279	37.5182	76.0903	August 23, 1991	3	15	13.0	12.0	EMAP
CB7PH	EMAP1048	VA91 283	37.6665	76.0072	August 23, 1991	3	15	16.5	15.5	EMAP
CB8PH	EMAP1030	VA91 261	36.9402	76.2135	August 3, 1991	3	15	5.9	4.9	EMAP
CB8PH	EMAP1018	VA91 262	36.9563	76.0082	August 15, 1991	3	15	23.4	22.4	EMAP
BSHOH	.	.	.	.	.	.	.	.	.	.
GUNOH	.	.	.	.	.	.	.	.	.	.
MIDOH	EMAP1097	VA91 136	39.3050	76.4100	July 29, 1991	3	15	4.8	3.8	EMAP

BACOH	EMAP238039	VA90 090	39.2700	76.4433	July 26, 1990	10	30	3.1	2.1	EMAP
BACOH	EMAP667039	VA90 090	39.2700	76.4433	August 5, 1990	10	30	3.7	2.7	EMAP
BACOH	EMAP1091	VA91 090	39.2700	76.4433	July 29, 1991	2	15	2.6	1.6	EMAP
PATMH	RCCORDO	02	39.1500	76.4956	June 20, 1989	51	30	3.8	3.5	MDE
PATMH	EMAPLTDO134	VA90 134	39.2463	76.5570	August 15, 1990	8	30	8.8	7.8	EMAP
MAGMH	EMAP1059	VA91 339	39.0540	76.4210	July 28, 1991	2	15	6.3	5.3	EMAP
SEVMH	EPA95	SEVERN R	250.000	250.000	September 1, 1995	72	20	9.0	8.0	EPA
SOUMH	EMAP626039	VA90 088	38.8697	76.9975	July 28, 1990	10	60	6.5	5.5	EMAP
SOUMH	EMAP632039	VA90 088	38.8697	76.9975	August 7, 1990	10	60	7.3	6.3	EMAP
SOUMH	EMAP630039	VA90 088	38.8697	76.9975	August 17, 1990	9	60	7.1	6.1	EMAP
RHDMH	.	.	.	.	.	.	.	.	.	.
WSTMH	.	.	.	.	.	.	.	.	.	.
PAXTF	.	.	.	.	.	.	.	.	.	.
WBRTF	.	.	.	.	.	.	.	.	.	.
PAXOH	.	.	.	.	.	.	.	.	.	.
PAXMH	STCORDO	02	38.3950	76.4833	April 29, 1988	161	30	5.8	5.5	MDE
POTTF	EMAP1031	VA91 188	38.7367	77.0333	July 22, 1991	3	15	6.4	5.4	EMAP
POTTF	EMAP1032	VA91 333	38.8588	77.0342	July 22, 1991	3	15	4.4	3.4	EMAP
POTTF	EMAP1036	VA91 326	38.6250	77.1618	July 23, 1991	3	15	4.9	3.9	EMAP
PISTF	.	.	.	.	.	.	.	.	.	
MATTF	.	.	.	.	.	.	.	.	.	
POTOH	EMAPLTDO184	VA90 184	38.3982	77.0840	July 7, 1990	49	60	14.0	13.0	EMAP
POTOH	EMAP408039	VA90 184	38.3982	77.0840	July 27, 1990	10	60	10.4	9.4	EMAP
POTOH	EMAP637039	VA90 184	38.3982	77.0840	August 6, 1990	10	60	10.0	9.0	EMAP
POTOH	EMAP641039	VA90 184	38.3982	77.0840	August 16, 1990	9	60	8.0	7.0	EMAP
POTOH	EMAP1043	VA91 319	38.3363	77.2388	July 23, 1991	3	15	4.3	3.3	EMAP
POTMH	EMAP1024	VA91 315	38.2848	76.9277	July 24, 1991	3	15	4.2	3.2	EMAP
POTMH	EMAP1035	VA91 314	38.2813	76.7108	July 24, 1991	3	15	3.4	2.4	EMAP
POTMH	EMAP1054	VA91 302	38.2072	76.5990	July 28, 1991	3	15	6.5	5.5	EMAP
RPPTF	EMAP1042	VA91 300	38.1812	77.1930	July 29, 1991	3	15	5.3	4.3	EMAP
RPPTF	EMAP1044	VA91 309	38.2347	77.2297	July 29, 1991	3	15	7.6	6.6	EMAP
RPPTF	EMAP1052	VA91 298	38.1395	77.0540	July 30, 1991	3	15	4.6	3.6	EMAP
RPPOH	EMAP1053	VA91 294	38.0387	76.9167	July 30, 1991	3	15	4.6	3.6	EMAP
RPPMH	EMAP629039	VA90 192	37.9650	76.8672	August 15, 1990	8	60	1.2	0.2	EMAP
RPPMH	EMAP1029	VA91 288	37.8313	76.7470	August 10, 1991	3	15	3.9	2.9	EMAP
CRRMH	.		.	.	.	.	.	.	.	
PIAMH	EMAP1038	VA91 281	37.5397	76.4048	August 9, 1991	4	15	6.9	5.9	EMAP
MPNTF	.	.	.	.	.	.	.	.	.	.
MPNOH	.	.	.	.	.	.	.	.	.	.
PMKTF	.	.	.	.	.	.	.	.	.	.
PMKOH	.	.	.	.	.	.	.	.	.	.
YRKMH	.	.	.	.	.	.	.	.	.	.

continued

Table V-2 (continued). Listing of the available continuous dissolved oxygen buoy data sets for Chesapeake Bay and its tidal tributaries by Chesapeake Bay Program segment .

CBP Segment	Dataset Name	Station Name	Latitude	Longitude	Start Date	Duration (days)	Interval (minutes)	Total Depth (meters)	Sensor Depth (meters)	Data Source[1]
YRKPH	VIMS89	VIMS	38.2333	76.4666	June 21, 1989	116	20	19.0	18.0	VIMS
MOBPH	EMAPLTDO061	VA90 061	37.2858	76.3175	July 4, 1990	50	60	9.7	8.7	EMAP
MOBPH	VIMS91	999	37.2460	76.3945	June 13, 1991	102	30	19.0	10.0	VIMS
MOBPH	EMAP1022	VA91 266	37.0980	76.3333	August 17, 1991	3	15	2.8	1.8	EMAP
JMSTF	EMAP1046	VA91 273	37.2407	76.9550	August 4, 1991	3	15	7.4	6.4	EMAP
JMSTF	EMAP1051	VA91 278	37.3787	77.3163	August 5, 1991	3	60	10.2	9.2	EMAP
APPTF	.	.	.	.	.	.	.	.	.	.
JMSOH	.	.	.	.	.	.	.	.	.	.
CHKOH	.	.	.	.	.	.	.	.	.	.
JMSMH	EMAP1034	VA91 263	36.9767	76.4833	August 3, 1991	3	15	4.5	3.5	EMAP
JMSMH	EMAP1028	VA91 269	37.1633	76.6287	August 4, 1991	3	15	6.2	5.2	EMAP
JMSPH	.	.	.	.	.	.	.	.	.	.
WBEMH	.	.	.	.	.	.	.	.	.	.
SBEMH	EMAPLTDO086	VA90 086	36.8318	76.2938	July 2, 1990	59	30	8.2	7.2	EMAP
EBEMH	.	.	.	.	.	.	.	.	.	.
ELIMH	.	.	.	.	.	.	.	.	.	.
LAFMH	.	.	.	.	.	.	.	.	.	.
ELIPH	.	.	.	.	.	.	.	.	.	.
LYNPH	.	.	.	.	.	.	.	.	.	.
NORTF	.	.	.	.	.	.	.	.	.	.
C&DOH	.	.	.	.	.	.	.	.	.	.
BOHOH	.	.	.	.	.	.	.	.	.	.
ELKOH	.	.	.	.	.	.	.	.	.	.
SASOH	EMAP1078	VA91 346	39.3697	75.9250	August 27, 1991	2	15	5.0	4.0	EMAP
CHSTF	.	.	.	.	.	.	.	.	.	.
CHSOH	.	.	.	.	.	.	.	.	.	.
CHSMH	.	.	.	.	.	.	.	.	.	.
EASMH	EMAP1070	VA91 336	38.9060	76.1708	August 16, 1991	3	15	5.3	4.3	EMAP
EASMH	EMAP1075	VA91 330	38.7737	76.1852	August 17, 1991	2	15	6.2	5.2	EMAP
CHOTF	.	.	.	.	.	.	.	.	.	.
CHOOH	.	.	.	.	.	.	.	.	.	.
HOMH2	.	.	.	.	.	.	.	.	.	.
CHOMH1	CE2DEEP3	CE2	38.6458	76.3097	August 12, 1987	28	5	16.0	13.1	Sanford
CHOMH1	CS1DEEP3	CS1	38.6625	76.2567	August 12, 1987	26	12	8.0	6.0	Sanford
LCHMH	EMAP1064	VA91 322	38.5193	76.2685	August 15, 1991	3	15	5.7	4.7	EMAP

HNGMH	EMAP1016	VA91 316	38.3035	76.1837	August 27, 1991	2	15	3.2	2.2	EMAP
HNGMH	EMAP1025	VA91 307	38.2282	76.0883	August 27, 1991	2	15	4.6	3.6	EMAP
FSBMH	EMAP1014	VA91 317	38.3153	76.0198	August 29, 1991	1	15	5.8	4.8	EMAP
NANTF	.	.	.	.	.	.	.	.	.	.
NANOH	.	.	.	.	.	.	.	.	.	.
NANMH	.	.	.	.	.	.	.	.	.	.
WICMH	.	.	.	.	.	.	.	.	.	.
MANMH	.	.	.	.	.	.	.	.	.	.
BIGMH	.	.	.	.	.	.	.	.	.	.
POCTF	.	.	.	.	.	.	.	.	.	.
POCOH	.	.	.	.	.	.	.	.	.	.
POCMH	.	.	.	.	.	.	.	.	.	.
TANMH	EMAPLTDO041	VA90 041	38.0280	75.9017	June 30, 1990	60	30	6.6	5.6	EMAP
TANMH	EMAP1228	VA91 050	38.0122	76.1100	July 11, 1991	1	15	12.2	11.2	EMAP
TANMH	EMAP1233	VA91 045	38.1605	76.0260	July 12, 1991	3	15	3.1	2.1	EMAP
TANMH	EMAP1041	VA91 296	38.0957	75.9637	August 21, 1991	3	15	9.1	8.1	EMAP
TANMH	EMAP1027	VA91 285	37.8148	75.9237	August 22, 1991	3	15	5.4	4.4	EMAP

[1] Breitburg=Dr. Denise Breitburg, Smithsonian Environmental Research Center; EPA=U.S. Environmental Protection Agency; EMAP=U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program; MDE=Maryland Department of the Environment; Sanford=Dr. Larry Sanford, University of Maryland Center for Environmental Science; VIMS=Virginia Institute of Marine Science.

Source: Chesapeake Bay Water Quality Monitoring Program http://www.chesapeakebay.net/data

Table V-2 (continued). Listing of the available continuous dissolved oxygen buoy data sets for Chesapeake Bay and its tidal tributaries by Chesapeake Bay Program segment .

CBP Segment	Dataset Name	Station Name	Latitude	Longitude	Start Date	Duration (days)	Interval (minutes)	Total Depth (meters)	Sensor Depth (meters)	Data Source[1]
YRKPH	VIMS89	VIMS	38.2333	76.4666	June 21, 1989	116	20	19.0	18.0	VIMS
MOBPH	EMAPLTDO061	VA90 061	37.2858	76.3175	July 4, 1990	50	60	9.7	8.7	EMAP
MOBPH	VIMS91	999	37.2460	76.3945	June 13, 1991	102	30	19.0	10.0	VIMS
MOBPH	EMAP1022	VA91 266	37.0980	76.3333	August 17, 1991	3	15	2.8	1.8	EMAP
JMSTF	EMAP1046	VA91 273	37.2407	76.9550	August 4, 1991	3	15	7.4	6.4	EMAP
JMSTF	EMAP1051	VA91 278	37.3787	77.3163	August 5, 1991	3	60	10.2	9.2	EMAP
APPTF	.	.	.	.	.	.	.	.	.	.
JMSOH	.	.	.	.	.	.	.	.	.	.
CHKOH	.	.	.	.	.	.	.	.	.	.
JMSMH	EMAP1034	VA91 263	36.9767	76.4833	August 3, 1991	3	15	4.5	3.5	EMAP
JMSMH	EMAP1028	VA91 269	37.1633	76.6287	August 4, 1991	3	15	6.2	5.2	EMAP
JMSPH	.	.	.	.	.	.	.	.	.	.
WBEMH	.	.	.	.	.	.	.	.	.	.
SBEMH	EMAPLTDO086	VA90 086	36.8318	76.2938	July 2, 1990	59	30	8.2	7.2	EMAP
EBEMH	.	.	.	.	.	.	.	.	.	.
ELIMH	.	.	.	.	.	.	.	.	.	.
LAFMH	.	.	.	.	.	.	.	.	.	.
ELIPH	.	.	.	.	.	.	.	.	.	.
LYNPH	.	.	.	.	.	.	.	.	.	.
NORTF	.	.	.	.	.	.	.	.	.	.
C&DOH	.	.	.	.	.	.	.	.	.	.
BOHOH	.	.	.	.	.	.	.	.	.	.
ELKOH	.	.	.	.	.	.	.	.	.	.
SASOH	EMAP1078	VA91 346	39.3697	75.9250	August 27, 1991	2	15	5.0	4.0	EMAP
CHSTF	.	.	.	.	.	.	.	.	.	.
CHSOH	.	.	.	.	.	.	.	.	.	.
CHSMH	.	.	.	.	.	.	.	.	.	.
EASMH	EMAP1070	VA91 336	38.9060	76.1708	August 16, 1991	3	15	5.3	4.3	EMAP
EASMH	EMAP1075	VA91 330	38.7737	76.1852	August 17, 1991	2	15	6.2	5.2	EMAP
CHOTF	.	.	.	.	.	.	.	.	.	.
CHOOH	.	.	.	.	.	.	.	.	.	.
HOMH2	.	.	.	.	.	.	.	.	.	.
CHOMH1	CE2DEEP3	CE2	38.6458	76.3097	August 12, 1987	28	5	16.0	13.1	Sanford
CHOMH1	CS1DEEP3	CS1	38.6625	76.2567	August 12, 1987	26	12	8.0	6.0	Sanford
LCHMH	EMAP1064	VA91 322	38.5193	76.2685	August 15, 1991	3	15	5.7	4.7	EMAP

HNGMH	EMAP1016	VA91 316	38.3035	76.1837	August 27, 1991	2	15	3.2	2.2	EMAP
HNGMH	EMAP1025	VA91 307	38.2282	76.0883	August 27, 1991	2	15	4.6	3.6	EMAP
FSBMH	EMAP1014	VA91 317	38.3153	76.0198	August 29, 1991	1	15	5.8	4.8	EMAP
NANTF	.	.	.	.	.	.	.	.	.	.
NANOH	.	.	.	.	.	.	.	.	.	.
NANMH	.	.	.	.	.	.	.	.	.	.
WICMH	.	.	.	.	.	.	.	.	.	.
MANMH	.	.	.	.	.	.	.	.	.	.
BIGMH	.	.	.	.	.	.	.	.	.	.
POCTF	.	.	.	.	.	.	.	.	.	.
POCOH	.	.	.	.	.	.	.	.	.	.
POCMH	.	.	.	.	.	.	.	.	.	.
TANMH	EMAPLTDO041	VA90 041	38.0280	75.9017	June 30, 1990	60	30	6.6	5.6	EMAP
TANMH	EMAP1228	VA91 050	38.0122	76.1100	July 11, 1991	1	15	12.2	11.2	EMAP
TANMH	EMAP1233	VA91 045	38.1605	76.0260	July 12, 1991	3	15	3.1	2.1	EMAP
TANMH	EMAP1041	VA91 296	38.0957	75.9637	August 21, 1991	3	15	9.1	8.1	EMAP
TANMH	EMAP1027	VA91 285	37.8148	75.9237	August 22, 1991	3	15	5.4	4.4	EMAP

[1] Breitburg=Dr. Denise Breitburg, Smithsonian Environmental Research Center; EPA=U.S. Environmental Protection Agency; EMAP=U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program; MDE=Maryland Department of the Environment; Sanford=Dr. Larry Sanford, University of Maryland Center for Environmental Science; VIMS=Virginia Institute of Marine Science.

Source: Chesapeake Bay Water Quality Monitoring Program http://www.chesapeakebay.net/data

DESIGNATED USE ASSIGNMENTS

Both the low frequency long-term fixed station and the continuous buoy data records were assessed relative to the published Chesapeake Bay dissolved oxygen criteria. The criteria are specific to different designated uses and, therefore, seasons (U.S. EPA 2003). With very few exceptions, the buoy data currently available were summer deployments (June-September). One exception begins at the end of April; this one and a couple of other deployments extend through October, and one extends to November.

Each data record was assigned to a designated use within a Chesapeake Bay Program segment based on following method. Using the Chesapeake Bay Water Quality Monitoring Program data, the depth of the upper and lower pycnoclines, if any, were calculated for each station for each cruise date and the segment averages for the month/year were determined. These segment-averaged pycnocline depths were then merged by corresponding dates with the buoy sensor depths in those segments where deep-water and deep-channel designated uses apply. It is important to remember that pycnocline depths may be fairly stable in some areas, but changeable and ephemeral in others, even within the same segment. An average pycnocline depth for the month may have a lot of variability around it, and thus the designated use assignments for some buoy data records may not be correct. Where the buoy dissolved oxygen concentrations suggested an incorrect assignment, the monitoring data at stations and dates nearest in time and space to the buoy deployment were examined in detail and any appropriate changes to the designated use assignment were made accordingly.

FINDINGS

Day/Night Differences In Dissolved Oxygen Concentration

A commonly expressed concern about the Chesapeake Bay Water Quality Monitoring Program's dissolved oxygen data is that they reflect daytime dissolved oxygen levels, the time period when active photosynthesis by algae, and consequent generation and introduction of new oxygen into the water column, may mask lower nighttime concentrations. To address this concern, the buoy data were partitioned into day (defined as 9:00 AM to 5:00 PM) and night (defined as after 5:00 PM to before 9:00 AM) periods and summarized. Table V-3 provides the following statistics for the day and night periods: minimum concentration, the concentration of the lowest 1 percent of measurements, the lowest 10 percent, the median, mean, standard deviation, and coefficient of variation, separately for day and night periods each month, and the number of measurements taken in that month.

Table V-4 pools all the continuous buoy data for a station's designated use to show average day/night differences at each site. The difference between the daytime mean, minimum, 1 percent, etc. and the equivalent nighttime statistic was computed for each date of deployment and the means of the daily day-night differences are shown in the table (difference = daytime concentration minus nighttime concentration).

Table V-3. Day and night period statistics for the continuous dissolved oxygen buoy data records by Chesapeake Bay Program segment.

								Dissolved Oxygen Concentration (mg liter^{-1})						
CBP Segment	**Station**	**Depth (meters)**	**Designated Use**	**Month**	**Year**	**Period**	**Number of Observations**	**Minimum**	**1st Percentile**	**10th Percentile**	**Median**	**Mean**	**Standard Deviation**	**Coefficient of Variation**
CB1TF	VA91-353	8	Open-water	July	1991	Day	48	5.68	5.68	5.82	5.98	6.12	0.35	5.68
CB1TF	VA91-353	8	Open-water	July	1991	Night	90	4.74	4.74	4.98	5.40	5.59	0.62	11.03
CB1TF	VA91-353	8	Open-water	August	1991	Day	264	2.53	2.60	2.85	4.27	4.44	1.27	28.63
CB1TF	VA91-353	8	Open-water	August	1991	Night	504	2.34	2.53	2.96	4.01	4.07	0.90	22.13
CB3MH	VA91-058	2	Open-water	July	1991	Day	36	7.49	7.49	7.79	8.74	8.60	0.53	6.17
CB3MH	VA91-058	2	Open-water	July	1991	Night	63	7.03	7.03	7.48	8.47	8.40	0.61	7.21
CB3MH	VA91-343	4	Open-water	July	1991	Day	81	4.96	4.96	5.11	5.76	5.64	0.37	6.55
CB3MH	VA91-343	4	Open-water	July	1991	Night	184	4.52	4.54	5.03	5.64	5.71	0.56	9.77
CB4MH	CmpCanoy	2	Open-water	June	1988	Day	400	2.34	2.52	4.15	7.09	6.82	1.67	24.56
CB4MH	CmpCanoy	2	Open-water	June	1988	Night	720	1.49	1.67	3.23	6.57	6.33	1.85	29.23
CB4MH	CmpCanoy	2	Open-water	July	1988	Day	576	2.28	2.40	3.31	5.46	5.63	1.85	32.89
CB4MH	CmpCanoy	2	Open-water	July	1988	Night	1116	1.62	2.01	2.89	5.54	5.58	2.09	37.56
CB4MH	CmpCanoy	2	Open-water	August	1988	Day	637	1.23	2.01	2.76	4.27	4.58	1.70	37.15
CB4MH	CmpCanoy	2	Open-water	August	1988	Night	1200	0.68	0.93	2.44	3.91	4.25	1.79	42.21
CB4MH	CmpCanoy	2	Open-water	September	1988	Day	33	4.30	4.30	4.61	6.45	6.20	1.13	18.20
CB4MH	CmpCanoy	2	Open-water	September	1988	Night	43	4.25	4.25	4.60	5.05	5.76	1.89	32.87
CB4MH	CmpCanoy	4	Open-water	May	1988	Day	193	8.21	8.25	8.75	9.87	9.84	0.91	9.29
CB4MH	CmpCanoy	4	Open-water	May	1988	Night	342	8.06	8.31	8.80	9.51	9.57	0.63	6.59
CB4MH	CmpCanoy	4	Deep-water	June	1988	Day	985	1.32	1.78	3.60	7.48	7.09	2.18	30.82
CB4MH	CmpCanoy	4	Deep-water	June	1988	Night	1889	1.04	1.58	3.08	7.48	6.96	2.26	32.48
CB4MH	CmpCanoy	4	Deep-water	July	1988	Day	985	1.49	1.80	2.27	3.92	4.29	1.75	40.70
CB4MH	CmpCanoy	4	Deep-water	July	1988	Night	1889	0.83	1.29	2.31	4.16	4.50	1.91	42.38
CB4MH	CmpCanoy	4	Deep-water	August	1988	Day	693	1.08	1.24	1.84	3.26	3.47	1.33	38.18
CB4MH	CmpCanoy	4	Deep-water	August	1988	Night	1359	0.47	0.51	1.91	4.12	4.04	1.60	39.63
CB4MH	999	5	Open-water	June	1990	Day	37	5.92	5.92	6.13	7.66	7.75	1.10	14.21
CB4MH	999	5	Open-water	June	1990	Night	70	4.26	4.26	5.18	7.05	7.14	1.53	21.46
CB4MH	999	5	Deep-water	July	1990	Day	695	1.79	3.18	4.35	5.72	6.02	1.28	21.30
CB4MH	999	5	Deep-water	July	1990	Night	1397	1.73	2.69	4.31	5.99	6.22	1.50	24.13
CB4MH	999	5	Deep-channel	August	1990	Day	458	0.09	0.11	1.54	8.07	7.57	3.93	51.86
CB4MH	999	5	Deep-channel	August	1990	Night	959	0.04	0.31	2.69	6.84	7.45	3.61	48.42
CB4MH	CBW 6 ME	6	Open-water	August	1987	Day	1869	1.91	2.31	5.15	6.53	6.38	1.14	17.86
CB4MH	CBW 6 ME	6	Open-water	August	1987	Night	3732	2.99	4.05	5.38	6.65	6.67	1.01	15.22
CB4MH	CBW 6 ME	6	Open-water	September	1987	Day	772	5.17	5.29	5.82	6.82	6.92	0.91	13.17
CB4MH	CBW 6 ME	6	Open-water	September	1987	Night	1644	4.09	4.28	5.74	6.91	6.85	0.98	14.29
CB4MH	CBW 9 ME	9	Deep-water	September	1987	Day	772	1.78	1.90	2.57	5.54	5.49	1.60	29.05
CB4MH	CBW 9 ME	9	Deep-water	September	1987	Night	1644	1.65	1.77	2.13	5.14	4.89	1.90	38.86
CB4MH	CBW 9 ME	9	Deep-channel	August	1987	Day	1869	0.54	0.54	1.32	3.82	3.85	1.77	46.07
CB4MH	CBW 9 ME	9	Deep-channel	August	1987	Night	3732	-0.08	0.54	0.55	2.78	3.03	1.83	60.40

continued

Table V-3 (continued). Day and night period statistics for the continuous dissolved oxygen buoy data records by Chesapeake Bay Program segment.

								Dissolved Oxygen Concentration (mg liter^{-1})						
CBP Segment	Station	Depth (meters)	Designated Use	Month	Year	Period	Number of Observations	Minimum	1st Percentile	10th Percentile	Median	Mean	Standard Deviation	Coefficient of Variation
CB4MH	CE1	19	Deep-channel	August	1987	Day	635	0.05	0.05	0.05	0.05	0.29	0.38	129.37
CB4MH	CE1	19	Deep-channel	August	1987	Night	1224	0.05	0.05	0.05	0.05	0.28	0.42	151.53
CB4MH	CE1	19	Deep-channel	September	1987	Day	272	0.92	0.92	0.94	1.00	1.11	0.34	30.40
CB4MH	CE1	19	Deep-channel	September	1987	Night	540	0.93	0.93	0.95	1.01	1.23	0.71	58.02
CB4MH	VA90-065	9	Deep-channel	July	1990	Day	76	1.65	1.65	2.09	5.42	4.64	1.52	32.88
CB4MH	VA90-065	9	Deep-channel	July	1990	Night	137	0.31	0.34	1.39	4.17	3.68	1.69	45.98
CB4MH	VA90-065	9	Deep-channel	August	1990	Day	375	0.01	0.02	0.48	2.60	2.72	1.73	63.57
CB4MH	VA90-065	9	Deep-channel	August	1990	Night	698	0.00	0.00	0.05	1.82	2.07	1.81	87.73
CB4MH	VA91-325	11	Deep-channel	August	1991	Day	67	0.00	0.00	0.00	0.05	0.05	0.05	99.40
CB4MH	VA91-325	11	Deep-channel	August	1991	Night	186	0.00	0.00	0.00	0.05	0.09	0.12	137.31
CB4MH	KENT IS	6	Deep-water	August	1988	Day	706	0.10	1.20	2.70	4.60	4.40	1.19	26.96
CB4MH	KENT IS	6	Deep-water	August	1988	Night	1449	0.20	1.60	3.00	5.10	4.88	1.37	27.97
CB4MH	KENT IS	6	Deep-water	September	1988	Day	694	1.50	1.60	2.80	4.20	4.21	1.00	23.83
CB4MH	KENT IS	6	Deep-water	September	1988	Night	1395	1.20	1.40	3.10	4.50	4.39	1.00	22.88
CB4MH	KENT IS	6	Deep-water	October	1988	Day	407	0.80	1.30	3.80	4.80	4.62	0.98	21.20
CB4MH	KENT IS	6	Deep-water	October	1988	Night	887	1.80	3.10	3.90	4.90	4.83	0.70	14.46
CB5MH	VA91-060	6	Deep-water	July	1991	Day	62	2.85	2.85	4.89	6.57	6.28	1.10	17.43
CB5MH	VA91-060	6	Deep-water	July	1991	Night	126	3.98	4.27	4.89	6.61	6.51	1.12	17.16
CB5MH	VA91-284	9	Deep-water	August	1991	Day	78	3.47	3.47	3.58	4.77	4.57	0.71	15.48
CB5MH	VA91-284	9	Deep-water	August	1991	Night	126	2.67	2.74	2.94	3.74	3.84	0.75	19.42
CB5MH	VA91-290	4	Deep-water	August	1991	Day	53	2.25	2.25	2.57	3.91	3.80	0.72	19.04
CB5MH	VA91-290	4	Deep-water	August	1991	Night	126	2.39	2.40	2.65	3.12	3.27	0.62	18.88
CB5MH	VA91-291	7	Open-water	August	1991	Day	7	6.20	6.20	6.20	6.22	6.23	0.03	0.54
CB5MH	VA91-291	7	Open-water	August	1991	Night	32	6.02	6.02	6.16	6.41	6.37	0.16	2.48
CB5MH	VA91-291	7	Deep-water	August	1991	Day	27	5.62	5.62	6.01	6.26	6.24	0.20	3.26
CB5MH	VA91-291	7	Deep-water	August	1991	Night	89	4.84	4.84	5.71	6.68	6.57	0.59	8.91
CB5MH	VA91-295	6	Open-water	August	1991	Day	99	6.40	6.40	6.49	6.91	6.80	0.22	3.19
CB5MH	VA91-295	6	Open-water	August	1991	Night	192	6.47	6.49	6.63	7.00	6.96	0.23	3.31
CB5MH	VA91-303	11	Deep-water	August	1991	Day	50	3.16	3.16	3.52	4.55	4.86	0.96	19.65
CB5MH	VA91-303	11	Deep-water	August	1991	Night	63	3.18	3.18	3.54	5.05	4.99	0.84	16.92
CB6PH	VA90-054	11	Open-water	July	1990	Day	346	2.88	2.92	3.22	4.58	4.43	0.84	18.97
CB6PH	VA90-054	11	Open-water	July	1990	Night	633	2.79	3.14	3.50	4.60	4.51	0.78	17.22
CB6PH	VA90-054	11	Open-water	August	1990	Day	486	0.69	0.76	1.73	2.65	2.89	1.12	38.76
CB6PH	VA90-054	11	Open-water	August	1990	Night	886	0.44	0.83	1.68	2.90	3.04	1.06	34.94
CB6PH	VA91-270	6	Open-water	August	1991	Day	93	3.53	3.53	4.06	5.48	5.30	0.74	14.03
CB6PH	VA91-270	6	Open-water	August	1991	Night	189	2.79	2.80	4.02	5.94	5.53	0.96	17.29
CB6PH	VA91-276	10	Open-water	August	1991	Day	102	3.35	3.39	3.57	3.94	4.10	0.51	12.38
CB6PH	VA91-276	10	Open-water	August	1991	Night	251	3.12	3.16	3.34	3.93	4.17	0.73	17.53
CB6PH	VA91-282	11	Deep-water	August	1991	Day	78	1.65	1.65	1.69	2.67	3.09	1.42	45.90
CB6PH	VA91-282	11	Deep-water	August	1991	Night	189	1.58	1.59	1.75	3.00	3.29	1.38	42.10
CB7PH	VA91-265	12	Open-water	August	1991	Day	75	3.43	3.43	3.57	4.25	4.29	0.53	12.34
CB7PH	VA91-265	12	Open-water	August	1991	Night	189	3.65	3.68	3.95	4.40	4.47	0.44	9.73

CB7PH	VA91-271	4	Open-water	August	1991	Day	110	5.00	5.01	5.17	5.83	5.94	0.66	11.15
CB7PH	VA91-271	4	Open-water	August	1991	Night	189	5.02	5.21	5.60	6.25	6.27	0.58	9.27
CB7PH	VA91-279	12	Deep-water	August	1991	Day	95	4.34	4.34	4.40	5.08	5.04	0.45	8.89
CB7PH	VA91-279	12	Deep-water	August	1991	Night	155	4.03	4.04	4.45	4.76	4.74	0.30	6.25
CB7PH	VA91-283	15	Deep-water	August	1991	Day	67	3.86	3.86	3.99	4.86	4.71	0.55	11.71
CB7PH	VA91-283	15	Deep-water	August	1991	Night	183	3.90	3.92	4.15	4.64	4.74	0.51	10.77
CB8PH	VA91-261	4	Open-water	August	1991	Day	86	6.63	6.63	7.50	9.10	9.11	1.33	14.62
CB8PH	VA91-261	4	Open-water	August	1991	Night	188	5.26	5.42	6.32	7.89	8.15	1.35	16.61
CB8PH	VA91-262	22	Open-water	August	1991	Day	85	4.80	4.80	4.85	5.11	5.18	0.30	5.86
CB8PH	VA91-262	22	Open-water	August	1991	Night	188	4.64	4.65	4.91	5.18	5.32	0.41	7.69
MIDOH	VA91-136	3	Open-water	July	1991	Day	66	4.86	4.86	5.08	5.99	5.92	0.54	9.07
MIDOH	VA91-136	3	Open-water	July	1991	Night	151	3.32	4.53	4.96	6.19	6.10	0.90	14.75
MIDOH	VA91-136	3	Open-water	August	1991	Night	36	0.88	0.88	1.15	3.56	3.16	1.20	38.12
BACOH	VA90-090	2	Open-water	July	1990	Day	100	5.90	6.09	7.28	9.34	12.09	15.48	128.12
BACOH	VA90-090	2	Open-water	July	1990	Night	168	6.16	6.39	7.55	10.07	13.67	17.96	131.40
BACOH	VA90-090	2	Open-water	August	1990	Day	241	2.55	2.81	3.61	5.87	5.92	1.71	28.91
BACOH	VA90-090	2	Open-water	August	1990	Night	452	2.84	3.40	4.59	6.58	6.84	1.82	26.64
BACOH	VA91-090	2	Open-water	July	1991	Day	60	5.92	5.92	6.25	6.72	7.07	0.81	11.42
BACOH	VA91-090	2	Open-water	July	1991	Night	122	6.04	6.15	6.81	8.43	8.39	1.07	12.74
PATMH	RC 02	3	Open-water	June	1989	Day	102	1.94	2.70	3.65	5.47	5.53	1.49	26.91
PATMH	RC 02	3	Open-water	June	1989	Night	238	1.12	1.22	2.39	5.71	5.39	2.11	39.16
PATMH	RC 02	3	Open-water	July	1989	Day	50	1.12	1.12	2.14	4.64	4.77	2.06	43.20
PATMH	RC 02	3	Open-water	July	1989	Night	127	0.67	0.70	1.37	4.47	4.54	2.45	53.99
PATMH	RC 02	3	Open-water	August	1989	Day	46	0.39	0.39	2.75	3.71	3.91	1.28	32.70
PATMH	RC 02	3	Open-water	August	1989	Night	121	0.38	0.64	1.60	2.50	2.59	0.90	34.68
PATMH	RC 02	3	Deep-water	June	1989	Day	63	1.70	1.70	2.95	6.06	6.08	2.10	34.53
PATMH	RC 02	3	Deep-water	June	1989	Night	96	1.21	1.21	3.02	6.27	6.22	2.04	32.73
PATMH	RC 02	3	Deep-water	July	1989	Day	394	0.31	0.40	0.81	3.05	3.12	1.82	58.44
PATMH	RC 02	3	Deep-water	July	1989	Night	861	0.00	0.28	0.91	3.43	3.51	2.11	59.94
PATMH	RC 02	3	Deep-water	August	1989	Day	95	1.43	1.43	1.88	4.14	4.19	1.65	39.37
PATMH	RC 02	3	Deep-water	August	1989	Night	185	0.69	0.89	2.23	4.00	4.77	2.48	51.98
PATMH	VA90-134	7	Deep-water	August	1990	Day	140	0.00	0.07	0.93	2.44	2.59	1.51	58.17
PATMH	VA90-134	7	Deep-water	August	1990	Night	251	0.00	0.14	0.92	2.47	2.83	1.76	62.06
MAGMH	VA91-339	5	Open-water	July	1991	Day	52	4.22	4.22	5.02	5.84	5.61	0.50	8.89
MAGMH	VA91-339	5	Open-water	July	1991	Night	126	4.93	4.97	5.23	5.98	5.90	0.49	8.27
SEVMH	SEVERN R	8	Open-water	September	1995	Day	704	2.58	2.81	3.17	3.88	3.89	0.57	14.54
SEVMH	SEVERN R	8	Open-water	September	1995	Night	1416	2.62	2.91	3.30	4.01	4.11	0.67	16.33
SEVMH	SEVERN R	8	Open-water	October	1995	Day	746	2.34	2.69	3.04	3.45	3.58	0.51	14.28

continued

Table V-3 (continued). Day and night period statistics for the continuous dissolved oxygen buoy data records by Chesapeake Bay Program segment.

								Dissolved Oxygen Concentration (mg liter^{-1})						
CBP Segment	Station	Depth (meters)	Designated Use	Month	Year	Period	Number of Observations	Minimum	1st Percentile	10th Percentile	Median	Mean	Standard Deviation	Coefficient of Variation
SEVMH	SEVERN R	8	Open-water	October	1995	Night	1490	2.44	2.73	3.06	3.62	3.70	0.56	15.28
SEVMH	SEVERN R	8	Open-water	November	1995	Day	264	2.63	2.84	3.30	3.69	3.73	0.39	10.50
SEVMH	SEVERN R	8	Open-water	November	1995	Night	548	2.83	3.00	3.27	3.66	3.71	0.37	9.91
SOUMH	VA90-088	6	Open-water	July	1990	Day	32	2.27	2.27	2.46	3.51	3.82	1.43	37.48
SOUMH	VA90-088	6	Open-water	July	1990	Night	51	2.67	2.67	3.30	4.07	4.39	1.22	27.80
SOUMH	VA90-088	6	Open-water	August	1990	Day	224	0.34	0.50	0.97	2.55	2.93	1.74	59.50
SOUMH	VA90-088	6	Open-water	August	1990	Night	384	0.26	0.54	1.08	2.59	3.10	1.88	60.64
PAXMH	ST 02	7	Open-water	April	1988	Day	24	7.26	7.26	7.52	7.72	7.71	0.16	2.07
PAXMH	ST 02	7	Open-water	April	1988	Night	46	7.22	7.22	7.35	7.74	7.77	0.33	4.28
PAXMH	ST 02	7	Open-water	May	1988	Day	400	1.02	1.25	3.25	5.94	5.67	1.84	32.36
PAXMH	ST 02	7	Open-water	May	1988	Night	857	0.63	1.69	3.02	5.94	5.72	1.80	31.50
PAXMH	ST 02	7	Open-water	June	1988	Day	201	0.00	0.00	1.21	3.83	3.81	2.10	54.98
PAXMH	ST 02	7	Open-water	June	1988	Night	504	0.00	0.01	0.76	3.63	3.53	1.87	52.89
PAXMH	ST 02	7	Open-water	July	1988	Day	469	0.04	0.34	0.97	2.88	3.17	1.85	58.39
PAXMH	ST 02	7	Open-water	July	1988	Night	940	0.00	0.03	0.99	3.07	3.23	1.82	56.43
PAXMH	ST 02	7	Open-water	August	1988	Day	316	0.00	0.27	1.11	3.32	3.43	1.81	52.71
PAXMH	ST 02	7	Open-water	August	1988	Night	734	0.00	0.06	0.78	3.35	3.22	1.78	55.29
PAXMH	ST 02	7	Open-water	September	1988	Day	324	3.25	3.52	4.31	5.94	6.09	1.42	23.39
PAXMH	ST 02	7	Open-water	September	1988	Night	679	2.85	3.36	4.05	5.37	5.62	1.38	24.56
PAXMH	ST 02	7	Open-water	October	1988	Day	99	4.29	4.29	4.75	5.99	5.96	0.99	16.67
PAXMH	ST 02	7	Open-water	October	1988	Night	210	3.50	3.85	4.75	5.95	6.11	1.15	18.88
POTTF	VA91-326	3	Open-water	July	1991	Day	94	6.65	6.65	7.41	8.01	8.52	1.22	14.33
POTTF	VA91-326	3	Open-water	July	1991	Night	189	5.80	5.80	6.64	9.08	9.03	1.57	17.40
POTTF	VA91-188	5	Open-water	July	1991	Day	75	6.03	6.03	6.32	7.03	6.94	0.49	7.09
POTTF	VA91-188	5	Open-water	July	1991	Night	189	6.05	6.05	6.49	7.35	7.30	0.54	7.44
POTTF	VA91-333	3	Open-water	July	1991	Day	92	6.54	6.54	6.88	7.43	7.52	0.61	8.10
POTTF	VA91-333	3	Open-water	July	1991	Night	189	6.35	6.60	6.82	7.90	7.93	0.85	10.71
POTOH	VA91-319	3	Open-water	July	1991	Day	82	5.06	5.06	5.28	6.49	6.38	0.59	9.21
POTOH	VA91-319	3	Open-water	July	1991	Night	189	4.47	4.60	5.10	6.00	5.95	0.64	10.81
POTOH	VA90-184	13	Open-water	July	1990	Day	285	0.67	0.86	2.34	4.56	4.47	1.42	31.90
POTOH	VA90-184	13	Open-water	July	1990	Night	524	0.07	0.69	2.08	4.19	4.22	1.58	37.40
POTOH	VA90-184	13	Open-water	August	1990	Day	220	0.74	0.91	2.06	4.88	4.60	1.67	36.33
POTOH	VA90-184	13	Open-water	August	1990	Night	369	0.53	1.19	2.21	4.59	4.54	1.68	36.96
POTMH	VA91-302	5	Deep-water	July	1991	Day	66	1.54	1.54	1.82	2.44	2.72	0.87	31.87
POTMH	VA91-302	5	Deep-water	July	1991	Night	187	0.46	0.65	0.92	2.39	2.53	1.09	43.16
POTMH	VA91-314	2	Open-water	July	1991	Day	82	2.72	2.72	4.23	5.12	5.58	1.42	25.45
POTMH	VA91-314	2	Open-water	July	1991	Night	189	2.52	3.03	4.06	5.22	5.57	1.55	27.78
POTMH	VA91-315	3	Open-water	July	1991	Day	90	1.78	1.78	2.93	5.12	4.94	1.35	27.28
POTMH	VA91-315	3	Open-water	July	1991	Night	182	1.16	1.27	3.45	5.63	5.85	1.92	32.81
POTMH	VA91-315	3	Deep-water	July	1991	Night	4	2.49	2.49	2.49	2.60	2.74	0.36	13.04
RPPTF	VA91-298	3	Open-water	July	1991	Day	55	6.35	6.35	6.46	7.10	7.03	0.41	5.87

RPPTF	VA91-298	3	Open-water	July	1991	Night	92	6.28	6.28	6.44	6.99	7.02	0.51	7.28
RPPTF	VA91-298	3	Open-water	August	1991	Day	32	6.97	6.97	7.11	7.50	7.64	0.47	6.20
RPPTF	VA91-298	3	Open-water	August	1991	Night	98	6.67	6.67	7.11	7.60	7.72	0.52	6.71
RPPTF	VA91-300	4	Open-water	July	1991	Day	68	6.43	6.43	6.56	6.85	6.90	0.32	4.61
RPPTF	VA91-300	4	Open-water	July	1991	Night	153	6.17	6.30	6.51	7.23	7.31	0.72	9.80
RPPTF	VA91-300	4	Open-water	August	1991	Day	14	7.37	7.37	7.43	7.52	7.52	0.09	1.18
RPPTF	VA91-300	4	Open-water	August	1991	Night	36	7.21	7.21	7.35	7.70	7.71	0.33	4.33
RPPTF	VA91-309	6	Open-water	July	1991	Day	75	6.15	6.15	6.79	7.37	7.36	0.51	6.98
RPPTF	VA91-309	6	Open-water	July	1991	Night	153	6.81	6.83	7.07	7.56	7.60	0.43	5.66
RPPTF	VA91-309	6	Open-water	August	1991	Day	10	7.16	7.16	7.28	7.50	7.47	0.13	1.80
RPPTF	VA91-309	6	Open-water	August	1991	Night	36	7.06	7.06	7.53	7.97	7.92	0.34	4.25
RPPOH	VA91-294	3	Open-water	July	1991	Day	41	5.74	5.74	5.96	6.52	6.47	0.38	5.81
RPPOH	VA91-294	3	Open-water	July	1991	Night	92	5.65	5.65	6.01	6.22	6.25	0.23	3.72
RPPOH	VA91-294	3	Open-water	August	1991	Day	35	5.68	5.68	5.81	6.48	6.40	0.48	7.57
RPPOH	VA91-294	3	Open-water	August	1991	Night	100	4.93	5.20	5.84	6.34	6.32	0.40	6.31
RPPMH	VA91-288	2	Open-water	August	1991	Day	83	4.84	4.84	5.25	5.96	5.90	0.39	6.52
RPPMH	VA91-288	2	Open-water	August	1991	Night	180	5.00	5.08	5.43	6.25	6.22	0.59	9.55
RPPMH	VA90-192	3	Open-water	August	1990	Day	78	5.31	5.31	5.51	5.93	5.90	0.27	4.65
RPPMH	VA90-192	3	Open-water	August	1990	Night	120	4.79	4.85	5.44	6.18	6.11	0.47	7.64
PIAMH	VA91-281	6	Open-water	August	1991	Day	137	3.19	3.24	4.06	5.03	4.89	0.50	10.12
PIAMH	VA91-281	6	Open-water	August	1991	Night	252	3.62	3.68	4.15	5.07	5.03	0.62	12.33
YRKPH	VIMS	18	Open-water	September	1989	Day	582	1.00	1.20	1.80	4.60	4.33	1.67	38.47
YRKPH	VIMS	18	Open-water	September	1989	Night	1173	1.00	1.20	1.80	4.80	4.34	1.65	38.03
YRKPH	VIMS	18	Deep-water	June	1989	Day	212	1.70	1.90	2.40	3.70	3.73	0.93	24.94
YRKPH	VIMS	18	Deep-water	June	1989	Night	442	1.40	1.70	2.60	3.60	3.64	0.89	24.52
YRKPH	VIMS	18	Deep-water	July	1989	Day	749	1.10	1.30	1.40	2.90	2.94	1.08	36.83
YRKPH	VIMS	18	Deep-water	July	1989	Night	1452	1.10	1.30	1.60	3.00	3.10	1.13	36.54
YRKPH	VIMS	18	Deep-water	August	1989	Day	676	0.00	0.00	0.30	1.80	1.68	0.91	54.23
YRKPH	VIMS	18	Deep-water	August	1989	Night	1381	0.00	0.00	0.40	1.70	1.66	0.92	55.67
YRKPH	VIMS	18	Deep-water	October	1989	Day	360	4.80	4.90	5.40	6.30	6.22	0.58	9.27
YRKPH	VIMS	18	Deep-water	October	1989	Night	711	4.90	5.00	5.30	6.30	6.21	0.55	8.92
MOBPH	VA91-266	1	Open-water	August	1991	Day	82	5.58	5.58	5.70	6.17	6.22	0.51	8.16
MOBPH	VA91-266	1	Open-water	August	1991	Night	189	5.46	5.53	5.70	6.21	6.36	0.62	9.79
MOBPH	999	10	Open-water	June	1991	Day	189	3.19	3.28	4.17	5.12	5.09	0.75	14.76
MOBPH	999	10	Open-water	June	1991	Night	383	3.39	3.60	4.33	5.21	5.31	0.87	16.31
MOBPH	999	10	Open-water	July	1991	Day	143	1.09	1.13	2.27	4.21	3.95	1.15	29.10
MOBPH	999	10	Open-water	July	1991	Night	303	0.87	1.04	2.11	3.98	3.83	1.16	30.38
MOBPH	999	10	Open-water	August	1991	Day	408	1.30	1.69	2.64	5.54	5.43	2.01	36.97

Table V-3 (continued). Day and night period statistics for the continuous dissolved oxygen buoy data records by Chesapeake Bay Program segment.

								Dissolved Oxygen Concentration (mg liter^{-1})						
CBP Segment	Station	Depth (meters)	Designated Use	Month	Year	Period	Number of Observations	Minimum	1st Percentile	10th Percentile	Median	Mean	Standard Deviation	Coefficient of Variation
MOBPH	999	10	Open-water	August	1991	Night	838	1.00	1.77	2.72	5.14	5.29	1.89	35.81
MOBPH	999	10	Open-water	September	1991	Day	363	5.40	5.69	6.33	7.64	7.48	0.65	8.69
MOBPH	999	10	Open-water	September	1991	Night	675	4.97	5.41	6.29	7.63	7.43	0.75	10.11
MOBPH	VA90-061	7	Open-water	July	1990	Day	228	4.13	4.44	6.71	8.69	8.81	2.02	22.93
MOBPH	VA90-061	7	Open-water	July	1990	Night	406	4.75	5.12	6.41	8.25	8.74	2.26	25.87
MOBPH	VA90-061	7	Open-water	August	1990	Day	196	1.16	1.39	3.16	5.18	5.37	1.75	32.54
MOBPH	VA90-061	7	Open-water	August	1990	Night	339	1.21	1.58	3.01	4.93	5.31	1.89	35.60
JMSTF	VA91-273	6	Open-water	August	1991	Day	81	6.03	6.03	6.34	7.12	7.01	0.43	6.14
JMSTF	VA91-273	6	Open-water	August	1991	Night	189	6.00	6.01	6.29	7.23	7.64	1.20	15.74
JMSTF	VA91-278	9	Open-water	August	1991	Day	25	6.24	6.24	6.78	7.45	7.30	0.50	6.89
JMSTF	VA91-278	9	Open-water	August	1991	Night	44	5.85	5.85	6.45	7.38	7.37	0.76	10.34
JMSMH	VA91-263	3	Open-water	August	1991	Day	71	7.22	7.22	7.66	8.39	8.39	0.62	7.39
JMSMH	VA91-263	3	Open-water	August	1991	Night	189	6.60	6.62	7.12	7.74	7.86	0.65	8.31
JMSMH	VA91-269	5	Open-water	August	1991	Day	91	5.75	5.75	5.94	6.40	6.63	0.63	9.44
JMSMH	VA91-269	5	Open-water	August	1991	Night	189	5.56	5.62	5.98	6.42	6.59	0.57	8.63
SBEMH	VA90-086	6	Open-water	July	1990	Day	359	0.25	0.39	0.83	2.36	2.38	1.16	48.55
SBEMH	VA90-086	6	Open-water	July	1990	Night	664	0.19	0.43	0.99	2.32	2.39	1.07	44.86
SBEMH	VA90-086	6	Open-water	August	1990	Day	495	0.00	0.06	0.41	1.61	1.74	1.05	60.42
SBEMH	VA90-086	6	Open-water	August	1990	Night	917	0.00	0.05	0.38	1.48	1.74	1.19	68.23
SASOH	VA91-346	4	Open-water	August	1991	Day	45	5.57	5.57	6.60	6.97	6.94	0.31	4.49
SASOH	VA91-346	4	Open-water	August	1991	Night	126	5.43	5.68	6.58	7.51	7.53	0.91	12.04
EASMH	VA91-330	5	Open-water	August	1991	Day	49	3.98	3.98	4.14	4.39	4.44	0.27	6.02
EASMH	VA91-330	5	Open-water	August	1991	Night	123	3.11	3.15	3.52	4.37	4.51	0.80	17.75
EASMH	VA91-336	4	Open-water	August	1991	Day	83	4.07	4.07	4.35	5.12	5.14	0.58	11.19
EASMH	VA91-336	4	Open-water	August	1991	Night	189	3.80	3.85	4.52	5.61	5.63	0.77	13.71
CHOMH1	CE2	13	Open-water	August	1987	Day	1824	0.66	0.92	1.44	5.11	4.34	1.83	42.15
CHOMH1	CE2	13	Open-water	August	1987	Night	3713	0.43	1.03	1.58	5.31	4.59	1.81	39.56
CHOMH1	CE2	13	Open-water	September	1987	Day	796	1.98	2.18	2.61	5.38	4.94	1.27	25.65
CHOMH1	CE2	13	Open-water	September	1987	Night	1644	1.75	1.99	3.34	5.50	5.28	1.30	24.65
CHOMH1	CS1	6	Open-water	August	1987	Day	760	4.50	5.42	5.85	6.51	6.57	0.62	9.48
CHOMH1	CS1	6	Open-water	August	1987	Night	1547	3.38	5.01	5.58	6.62	6.70	0.90	13.41
CHOMH1	CS1	6	Open-water	September	1987	Day	280	0.54	4.38	4.80	5.80	5.75	0.71	12.43
CHOMH1	CS1	6	Open-water	September	1987	Night	545	3.68	4.56	5.04	5.98	6.07	0.75	12.43
LCHMH	VA91-322	4	Open-water	August	1991	Day	74	4.31	4.31	5.00	5.71	5.67	0.57	10.06
LCHMH	VA91-322	4	Open-water	August	1991	Night	189	3.66	3.75	4.84	5.81	5.71	0.65	11.47
HNGMH	VA91-307	3	Open-water	August	1991	Day	60	6.67	6.67	7.04	7.31	7.33	0.29	3.99
HNGMH	VA91-307	3	Open-water	August	1991	Night	126	6.64	6.81	7.03	7.59	7.57	0.41	5.38
HNGMH	VA91-316	2	Open-water	August	1991	Day	56	6.82	6.82	7.02	7.24	7.29	0.24	3.31
HNGMH	VA91-316	2	Open-water	August	1991	Night	124	6.61	6.64	6.74	7.13	7.19	0.36	4.94
FSBMH	VA91-317	4	Open-water	August	1991	Day	28	6.39	6.39	6.92	7.21	7.37	0.47	6.40
FSBMH	VA91-317	4	Open-water	August	1991	Night	63	6.05	6.05	6.38	7.09	6.99	0.43	6.12

TANMH	VA91-285	8	Open-water	August	1991	Day	67	5.32	5.32	5.88	6.63	6.59	0.55	8.37
TANMH	VA91-285	8	Open-water	August	1991	Night	186	4.88	4.89	5.18	6.37	6.31	0.84	13.26
TANMH	VA91-050	11	Open-water	July	1991	Day	29	3.27	3.27	3.30	4.03	3.99	0.38	9.61
TANMH	VA91-050	11	Open-water	July	1991	Night	60	2.13	2.13	2.21	2.76	3.14	0.97	30.90
TANMH	VA90-041	5	Open-water	June	1990	Day	4	5.49	5.49	5.49	5.67	5.81	0.42	7.24
TANMH	VA90-041	5	Open-water	June	1990	Night	13	5.91	5.91	6.00	6.47	6.42	0.25	3.91
TANMH	VA90-041	5	Open-water	July	1990	Day	369	3.16	3.76	4.69	5.96	5.98	0.98	16.38
TANMH	VA90-041	5	Open-water	July	1990	Night	682	3.46	3.73	4.83	5.99	6.00	0.91	15.13
TANMH	VA90-041	5	Open-water	August	1990	Day	484	1.61	2.22	3.93	5.12	5.05	0.97	19.31
TANMH	VA90-041	5	Open-water	August	1990	Night	886	1.32	2.19	3.99	5.42	5.29	1.02	19.31
TANMH	VA91-296	8	Open-water	August	1991	Day	86	4.81	4.81	5.09	5.65	5.62	0.43	7.59
TANMH	VA91-296	8	Open-water	August	1991	Night	189	4.76	5.02	5.10	5.61	5.75	0.55	9.62
TANMH	VA91-045	1	Open-water	July	1991	Day	117	7.24	7.26	7.47	8.53	8.46	0.73	8.69
TANMH	VA91-045	1	Open-water	July	1991	Night	189	7.07	7.10	7.21	8.00	8.01	0.67	8.38

Table V-4. Average day/night differences (day minus night) in dissolved oxygen concentrations in continuous dissolved oxygen buoy data records by Chesapeake Bay Program segment by designated use.

CBP Segment	Station	Designated Use	Number of Observations	Dissolved Oxygen (mg liter^{-1}) Difference				
				Minimum	1st Percentile	10th Percentile	Median	Mean
CB1TF	VA91-353	Open-water	10	0.65	0.65	0.51	0.47	0.40
CB3MH	VA91-058	Open-water	2	0.01	0.01	-0.08	0.13	0.07
CB3MH	VA91-343	Open-water	3	0.38	0.38	0.31	0.08	-0.01
CB4MH	CmpCanoy	Open-water	65	0.48	0.48	0.35	0.40	0.19
CB4MH	CmpCanoy	Deep-water	82	0.38	0.38	0.20	-0.06	-0.18
CB4MH	999	Open-water	2	2.01	2.01	1.65	0.43	0.78
CB4MH	999	Deep-water	30	0.49	0.49	0.18	-0.25	-0.24
CB4MH	999	Deep-channel	20	1.41	1.41	1.27	0.35	0.29
CB4MH	CBW 6 ME	Open-water	29	0.31	0.24	-0.05	-0.21	-0.20
CB4MH	CBW 9 ME	Deep-water	9	1.64	1.62	1.45	0.40	0.54
CB4MH	CBW 9 ME	Deep-channel	20	1.31	1.30	1.39	0.84	0.82
CB4MH	CE1	Deep-channel	29	0.01	0.01	0.03	0.03	-0.04
CB4MH	VA90-065	Deep-channel	28	1.07	1.07	1.22	0.70	0.72
CB4MH	VA91-325	Deep-channel	3	0.01	0.01	-0.01	-0.06	-0.07
CB4MH	KENT IS	Deep-water	61	0.23	0.23	0.01	-0.33	-0.29
CB5MH	VA91-060	Deep-water	3	0.12	0.12	-0.01	-0.37	-0.24
CB5MH	VA91-284	Deep-water	3	0.86	0.86	0.82	0.77	0.75
CB5MH	VA91-290	Deep-water	3	0.42	0.42	0.25	0.49	0.25
CB5MH	VA91-291	Open-water	1	0.18	0.18	0.04	-0.18	-0.13
CB5MH	VA91-291	Deep-water	2	0.94	0.94	0.72	-0.29	-0.26
CB5MH	VA91-295	Open-water	4	0.00	0.00	-0.10	-0.22	-0.23
CB5MH	VA91-303	Deep-water	2	0.38	0.38	0.37	-0.10	0.04
CB6PH	VA90-054	Open-water	51	0.23	0.23	0.09	-0.14	-0.11
CB6PH	VA91-270	Open-water	4	1.01	1.01	0.14	-0.31	-0.21
CB6PH	VA91-276	Open-water	4	0.73	0.73	0.67	0.32	0.34
CB6PH	VA91-282	Deep-water	4	0.20	0.20	0.18	0.04	-0.04
CB7PH	VA91-265	Open-water	4	-0.00	-0.00	-0.04	-0.10	-0.10
CB7PH	VA91-271	Open-water	4	-0.39	-0.39	-0.49	-0.35	-0.40
CB7PH	VA91-279	Deep-water	3	0.20	0.20	0.27	0.32	0.27
CB7PH	VA91-283	Deep-water	3	0.29	0.29	0.26	0.02	0.03
CB8PH	VA91-261	Open-water	3	0.77	0.77	0.89	0.60	0.88
CB8PH	VA91-262	Open-water	3	0.27	0.27	0.06	-0.09	0.04
MIDOH	VA91-136	Open-water	2	0.81	0.81	0.07	0.11	0.09
BACOH	VA91-090	Open-water	23	-0.29	-0.29	-0.59	-4.51	-2.24
PATMH	RC 02	Open-water	25	1.06	1.06	0.78	0.07	0.13
PATMH	RC 02	Deep-water	45	0.36	0.36	0.07	-0.44	-0.37
PATMH	VA90-134	Deep-water	9	0.19	0.19	-0.09	-0.04	-0.21
MAGMH	VA91-339	Open-water	3	-0.39	-0.39	-0.38	-0.49	-0.57
SEVMH	SEVERN R	Open-water	72	0.11	0.11	-0.01	-0.13	-0.14
SOUMH	VA90-088	Open-water	30	0.15	0.15	0.00	-0.27	-0.24

PAXMH	ST 02	Open-water	133	0.64	0.64	0.39	0.10	0.10
POTTF	VA91-326	Open-water	4	1.00	1.00	0.57	-1.22	-0.54
POTTF	VA91-188	Open-water	3	0.29	0.29	0.10	-0.30	-0.26
POTTF	VA91-333	Open-water	4	0.04	0.04	-0.14	-0.36	-0.49
POTOH	VA91-319	Open-water	4	0.51	0.51	0.47	0.26	0.22
POTOH	VA90-184	Open-water	49	0.42	0.42	0.20	0.22	0.14
POTMH	VA91-302	Deep-water	2	0.48	0.48	0.58	-0.04	-0.15
POTMH	VA91-314	Open-water	4	0.38	0.38	0.50	0.03	-0.06
POTMH	VA91-315	Open-water	3	-1.16	-1.16	-1.39	-2.05	-1.85
POTMH	VA91-315	Deep-water	0	.	.	.	.	.
RPPTF	VA91-298	Open-water	3	0.03	0.03	-0.07	0.16	-0.02
RPPTF	VA91-300	Open-water	4	0.17	0.17	0.03	-0.38	-0.43
RPPTF	VA91-309	Open-water	4	-0.18	-0.18	-0.17	-0.21	-0.25
RPPOH	VA91-294	Open-water	4	0.27	0.27	-0.09	0.14	0.04
RPPMH	VA91-288	Open-water	3	0.03	0.03	0.08	-0.20	-0.26
RPPMH	VA90-192	Open-water	9	-0.02	-0.02	-0.19	-0.24	-0.23
PIAMH	VA91-281	Open-water	5	-0.21	-0.21	-0.28	0.03	-0.14
YRKPH	VIMS	Open-water	25	0.25	0.25	0.18	-0.01	-0.00
YRKPH	VIMS	Deep-water	86	0.20	0.20	0.08	-0.01	-0.06
MOBPH	VA91-266	Open-water	4	0.24	0.24	0.11	-0.04	-0.07
MOBPH	999	Open-water	79	0.24	0.24	0.13	0.08	0.04
MOBPH	VA90-061	Open-water	41	0.54	0.54	0.28	0.05	0.10
JMSTF	VA91-273	Open-water	4	0.31	0.31	0.18	-0.75	-0.91
JMSTF	VA91-278	Open-water	4	-0.01	-0.01	-0.12	-0.38	-0.34
JMSMH	VA91-263	Open-water	4	1.07	1.07	0.70	0.49	0.46
JMSMH	VA91-269	Open-water	4	-0.02	-0.02	-0.07	-0.14	-0.11
SBEMH	VA90-086	Open-water	53	0.26	0.26	0.15	0.07	-0.00
SASOH	VA91-346	Open-water	3	0.22	0.22	0.08	-0.49	-0.53
EASMH	VA91-330	Open-water	2	0.63	0.63	0.66	0.38	0.35
EASMH	VA91-336	Open-water	4	0.14	0.14	0.04	-0.58	-0.49
CHOMH1	CE2	Open-water	28	0.47	0.39	0.15	-0.16	-0.24
CHOMH1	CS1	Open-water	26	0.33	0.33	0.18	-0.17	-0.16
LCHMH	VA91-322	Open-water	3	0.33	0.33	0.19	-0.15	-0.02
HNGMH	VA91-307	Open-water	3	-0.24	-0.24	-0.26	-0.38	-0.42
HNGMH	VA91-316	Open-water	2	0.26	0.26	0.28	0.14	0.19
FSBMH	VA91-317	Open-water	2	0.16	0.16	-0.04	-0.24	-0.14
TANMH	VA91-285	Open-water	3	0.41	0.41	0.53	0.01	-0.02
TANMH	VA91-050	Open-water	1	1.08	1.08	1.07	0.73	0.72
TANMH	VA90-041	Open-water	53	0.25	0.25	0.05	-0.15	-0.15
TANMH	VA91-296	Open-water	4	0.25	0.25	0.11	-0.15	-0.22
TANMH	VA91-045	Open-water	4	0.36	0.36	0.43	0.50	0.41

With some clear exceptions, the day-night concentration differences in these buoy data are small. Back River (segment BACOH), a tidal river known to be stressed by discharges from a large urban sewage treatment facility, exhibits the largest day-night difference in mean and median concentrations: -2.24 mg liter^{-1} and -4.51 mg liter^{-1}, respectively (Table V-4). Note that here the nighttime concentration is higher than during the daytime, which seems counterintuitive. But, in fact, the average day/night difference in the daily means and medians is almost always negative in this table. A buoy site in the lower Potomac River (POTMH) and one in upper Potomac River (POTTF) showed day-night differences greater than 1 mg liter^{-1} in the daily mean or median or both, but all other sites showed differences less than 1 mg liter^{-1}.

The average day-night differences in the daily minimum concentration and lowest 1 percent value were similarly generally small, but with more sites exhibiting day-night differences in excess of 1 mg liter^{-1}: mesohaline Patapsco River (PATMH), tidal fresh (POTTF) and mesohaline (POTMH) Potomac River, tidal fresh James River (JAMTF), middle central and lower western mainstem Chesapeake Bay segments CB4MH and CB6PH, respectively, and Tangier Sound (TANMH). In contrast to the findings for the daily mean and median, the concentration minima and lowest 1 percent were generally higher in the daytime than at night.

30-Day Mean and Instantaneous Minimum Criteria Attainment

Table V-5 shows how the continuous dissolved oxygen measurements stack up against the corresponding designated use dissolved oxygen criteria. The dissolved oxygen criteria are to be assessed for each segment/designated use separately. Thus, in this analysis, the day and night measurements are pooled and the mean, 1 percent concentration and other statistics are calculated within month, if the data record extends over multiple months. Asterisks flag the continuous buoy data records where the 30-day mean criterion is not achieved (i.e., monthly mean dissolved oxygen concentration is lower than the applicable criterion) or where the measured 1 percent dissolved oxygen concentration is lower than the instantaneous minimum criterion.

Looking down the columns in Table V-5 labeled "30-day Mean" and "Instantaneous Minimum" under the heading "Criterion Not Achieved", it can be seen frequently that if the 30-day mean criterion was achieved, the instantaneous minimum criterion was also achieved. Conversely, if the 30-day mean criterion was not achieved, the instantaneous minimum criterion also was not achieved. Further, if only one dissolved oxygen criterion was not achieved, then it was usually the instantaneous minimum criterion that was not achieved.

Table V-6 summarizes the criteria achieved/not achieved rate by segment and designated use and Table V-7 pools the Table V-6 findings by designated use. For the open-water designated use, in 80 out of 94 cases (~85 percent), if the 30-day mean criterion was achieved/not achieved, then the same was the case for the instantaneous minimum criterion. In deep-water designated use habitats, this condition was true in 15 out of 26 cases (~57 percent). The diversity of buoys deployed in deep-channel designated use habitats is too small for drawing very specific conclusions at this time.

Table V-5. Continuous dissolved oxygen buoy data 5 mg liter^{-1} 30 day mean and 3.2 mg liter^{-1} instantaneous minimum dissolved oxygen criteria achievement and statistics by Chesapeake Bay Program segment by designated use.

							Criterion Not Achieved		Dissolved Oxygen Concentration (mg liter^{-1})						
CBP Segment	Station	Depth (meters)	Designated Use	Month	Year	Number of Observations	30-Day Mean	Instantaneous Minimum	Minimum	1st Percentile	10th Percentile	Median	Mean	Standard Deviation	Coeficient Variation
CB1TF	VA91-353	8	Open-water	July	1991	138			4.74	4.90	5.02	5.83	5.78	0.59	10.263
CB1TF	VA91-353	8	Open-water	August	1991	768	*	*	2.34	2.56	2.93	4.07	4.20	1.06	25.182
CB3MH	VA91-058	2	Open-water	July	1991	99			7.03	7.03	7.53	8.53	8.47	0.58	6.896
CB3MH	VA91-343	4	Open-water	July	1991	265			4.52	4.57	5.07	5.65	5.69	0.51	8.931
CB4MH	CBW 6 ME	6	Open-water	August	1987	5601			1.91	3.24	5.33	6.60	6.57	1.07	16.231
CB4MH	CBW 6 ME	6	Open-water	September	1987	2416			4.09	4.37	5.76	6.87	6.87	0.96	13.942
CB4MH	CmpCanoy	4	Open-water	May	1988	535			8.06	8.31	8.78	9.60	9.67	0.76	7.817
CB4MH	CmpCanoy	2	Open-water	June	1988	1120		*	1.49	1.72	3.61	6.77	6.50	1.80	27.734
CB4MH	CmpCanoy	2	Open-water	July	1988	1692		*	1.62	2.09	3.04	5.49	5.59	2.01	36.011
CB4MH	CmpCanoy	2	Open-water	August	1988	1837	*	*	0.68	1.15	2.54	4.04	4.36	1.77	40.526
CB4MH	CmpCanoy	2	Open-water	September	1988	76			4.25	4.25	4.60	5.41	5.95	1.61	27.091
CB4MH	999	5	Open-water	June	1990	107			4.26	4.35	5.53	7.39	7.35	1.42	19.354
CB5MH	VA91-291	7	Open-water	August	1991	39			6.02	6.02	6.16	6.36	6.35	0.15	2.416
CB5MH	VA91-295	6	Open-water	August	1991	291			6.40	6.44	6.56	6.94	6.90	0.24	3.441
CB6PH	VA90-054	11	Open-water	July	1990	979	*	*	2.79	2.93	3.39	4.60	4.48	0.80	17.852
CB6PH	VA90-054	11	Open-water	August	1990	1372	*	*	0.44	0.80	1.69	2.81	2.99	1.09	36.327
CB6PH	VA91-270	6	Open-water	August	1991	282		*	2.79	2.82	4.04	5.70	5.46	0.90	16.444
CB6PH	VA91-276	10	Open-water	August	1991	353	*	*	3.12	3.16	3.40	3.93	4.15	0.67	16.248
CB7PH	VA91-265	12	Open-water	August	1991	264	*		3.43	3.47	3.82	4.36	4.42	0.47	10.634
CB7PH	VA91-271	4	Open-water	August	1991	299			5.00	5.02	5.31	6.09	6.15	0.63	10.277
CB8PH	VA91-261	4	Open-water	August	1991	274			5.26	5.52	6.88	8.11	8.45	1.42	16.764
CB8PH	VA91-262	22	Open-water	August	1991	273			4.64	4.68	4.88	5.15	5.28	0.38	7.293
MIDOH	VA91-136	3	Open-water	July	1991	217			3.32	4.75	4.98	6.09	6.04	0.81	13.392
MIDOH	VA91-136	3	Open-water	August	1991	36	*	*	0.88	0.88	1.15	3.56	3.16	1.20	38.122
BACOH	VA90-090	2	Open-water	July	1990	268			5.90	6.27	7.40	9.79	13.08	17.07	130.493
BACOH	VA90-090	2	Open-water	August	1990	693		*	2.55	2.95	4.11	6.36	6.52	1.84	28.170
BACOH	VA91-090	2	Open-water	July	1991	182			5.92	6.00	6.48	8.01	7.95	1.17	14.687
PATMH	RC 02	3	Open-water	June	1989	340		*	1.12	1.32	2.72	5.65	5.43	1.94	35.781
PATMH	RC 02	3	Open-water	July	1989	177	*	*	0.67	0.70	1.48	4.55	4.60	2.34	50.899
PATMH	RC 02	3	Open-water	August	1989	167	*	*	0.38	0.39	1.64	2.70	2.95	1.17	39.769
MAGMH	VA91-339	5	Open-water	July	1991	178			4.22	4.90	5.07	5.96	5.81	0.51	8.722
SEVMH	SEVERN R	8	Open-water	September	1995	2120	*	*	2.58	2.87	3.25	3.96	4.04	0.65	16.011
SEVMH	SEVERN R	8	Open-water	October	1995	2236	*	*	2.34	2.71	3.05	3.57	3.66	0.55	15.044
SEVMH	SEVERN R	8	Open-water	November	1995	812	*	*	2.63	2.98	3.28	3.66	3.71	0.38	10.103
SOUMH	VA90-088	6	Open-water	July	1990	83	*	*	2.27	2.27	2.74	4.02	4.17	1.33	31.819
SOUMH	VA90-088	6	Open-water	August	1990	608	*	*	0.26	0.54	1.04	2.59	3.04	1.83	60.285
PAXMH	ST 02	7	Open-water	April	1988	70			7.22	7.22	7.40	7.73	7.75	0.29	3.682
PAXMH	ST 02	7	Open-water	May	1988	1257		*	0.63	1.63	3.10	5.94	5.71	1.81	31.759
PAXMH	ST 02	7	Open-water	June	1988	705	*	*	0.00	0.00	0.83	3.68	3.61	1.94	53.664
PAXMH	ST 02	7	Open-water	July	1988	1409	*	*	0.00	0.16	0.98	3.03	3.21	1.83	57.059

continued

Table V-5 (continued). Continuous dissolved oxygen buoy data 5 mg liter^{-1} 30 day mean and 3.2 mg liter^{-1} instantaneous minimum dissolved oxygen criteria achievement and statistics by Chesapeake Bay Program segment by designated use.

CBP Segment	Station	Depth (meters)	Designated Use	Month	Year	Number of Observations	Criterion Not Achieved: 30-Day Mean	Criterion Not Achieved: Instantaneous Minimum	Dissolved Oxygen Concentration (mg liter^{-1}): Minimum	1st Percentile	10th Percentile	Median	Mean	Standard Deviation	Coeficient Variation
PAXMH	ST 02	7	Open-water	August	1988	1050	*	*	0.00	0.07	0.92	3.34	3.28	1.79	54.532
PAXMH	ST 02	7	Open-water	September	1988	1003			2.85	3.44	4.11	5.52	5.77	1.41	24.453
PAXMH	ST 02	7	Open-water	October	1988	309			3.50	4.09	4.75	5.98	6.06	1.11	18.243
POTTF	VA91-326	3	Open-water	July	1991	283			5.80	5.91	6.92	8.62	8.86	1.48	16.721
POTTF	VA91-188	5	Open-water	July	1991	264			6.03	6.05	6.40	7.22	7.19	0.55	7.680
POTTF	VA91-333	3	Open-water	July	1991	281			6.35	6.56	6.86	7.66	7.80	0.80	10.268
POTOH	VA90-184	13	Open-water	July	1990	809	*	*	0.07	0.76	2.14	4.31	4.31	1.53	35.516
POTOH	VA90-184	13	Open-water	August	1990	589	*	*	0.53	1.03	2.10	4.75	4.57	1.68	36.696
POTOH	VA91-319	3	Open-water	July	1991	271			4.47	4.72	5.14	6.11	6.08	0.66	10.779
POTMH	VA91-314	2	Open-water	July	1991	271		*	2.52	3.03	4.06	5.21	5.57	1.51	27.045
POTMH	VA91-315	3	Open-water	July	1991	272		*	1.16	1.66	3.09	5.46	5.55	1.80	32.447
RPPTF	VA91-298	3	Open-water	July	1991	147			6.28	6.35	6.44	7.02	7.02	0.47	6.764
RPPTF	VA91-300	4	Open-water	July	1991	221			6.17	6.34	6.53	6.94	7.18	0.65	9.045
RPPTF	VA91-309	6	Open-water	July	1991	228			6.15	6.49	6.85	7.53	7.52	0.47	6.281
RPPTF	VA91-298	3	Open-water	August	1991	130			6.67	6.88	7.11	7.58	7.70	0.51	6.586
RPPTF	VA91-300	4	Open-water	August	1991	50			7.21	7.21	7.36	7.62	7.66	0.30	3.901
RPPTF	VA91-309	6	Open-water	August	1991	46			7.06	7.06	7.44	7.70	7.82	0.36	4.566
RPPOH	VA91-294	3	Open-water	July	1991	133			5.65	5.67	5.96	6.30	6.32	0.30	4.769
RPPOH	VA91-294	3	Open-water	August	1991	135			4.93	5.47	5.82	6.34	6.34	0.42	6.653
RPPMH	VA90-192	3	Open-water	August	1990	198			4.79	4.85	5.46	6.05	6.03	0.41	6.877
RPPMH	VA91-288	2	Open-water	August	1991	263			4.84	5.00	5.42	6.10	6.12	0.56	9.075
PIAMH	VA91-281	6	Open-water	August	1991	389	*		3.19	3.62	4.13	5.05	4.98	0.58	11.686
YRKPH	VIMS	18	Open-water	September	1989	1755	*	*	1.00	1.20	1.80	4.70	4.34	1.66	38.170
MOBPH	VA90-061	7	Open-water	July	1990	634			4.13	4.89	6.49	8.40	8.77	2.18	24.825
MOBPH	VA90-061	7	Open-water	August	1990	535		*	1.16	1.52	3.10	5.02	5.33	1.84	34.472
MOBPH	999	10	Open-water	June	1991	572			3.19	3.53	4.28	5.19	5.24	0.84	15.949
MOBPH	999	10	Open-water	July	1991	446	*	*	0.87	1.09	2.11	4.06	3.86	1.16	29.962
MOBPH	VA91-266	1	Open-water	August	1991	271			5.46	5.54	5.70	6.20	6.32	0.59	9.386
MOBPH	999	10	Open-water	August	1991	1246		*	1.00	1.74	2.69	5.27	5.33	1.93	36.221
MOBPH	999	10	Open-water	September	1991	1038			4.97	5.43	6.32	7.63	7.45	0.72	9.634
JMSTF	VA91-273	6	Open-water	August	1991	270			6.00	6.03	6.31	7.13	7.45	1.07	14.380
JMSTF	VA91-278	9	Open-water	August	1991	69			5.85	5.85	6.45	7.42	7.35	0.68	9.216
JMSMH	VA91-263	3	Open-water	August	1991	260			6.60	6.74	7.18	7.93	8.01	0.69	8.559
JMSMH	VA91-269	5	Open-water	August	1991	280			5.56	5.63	5.97	6.41	6.60	0.59	8.887
SBEMH	VA90-086	6	Open-water	July	1990	1023	*	*	0.19	0.43	0.91	2.33	2.39	1.10	46.155
SBEMH	VA90-086	6	Open-water	August	1990	1412	*	*	0.00	0.05	0.40	1.54	1.74	1.14	65.580
SASOH	VA91-346	4	Open-water	August	1991	171			5.43	5.57	6.60	7.17	7.37	0.83	11.316
EASMH	VA91-330	5	Open-water	August	1991	172	*	*	3.11	3.15	3.67	4.38	4.49	0.69	15.404
EASMH	VA91-336	4	Open-water	August	1991	272			3.80	3.88	4.44	5.52	5.48	0.75	13.703
CHOMH1	CE2	13	Open-water	August	1987	5537	*	*	0.43	0.97	1.54	5.27	4.50	1.82	40.460

CHOMH1	CS1	6	Open-water	August	1987	2307			3.38	5.08	5.72	6.57	6.66	0.82	12.316
CHOMH1	CE2	13	Open-water	September	1987	2440		*	1.75	2.02	3.02	5.45	5.17	1.30	25.148
CHOMH1	CS1	6	Open-water	September	1987	825			0.54	4.49	5.02	5.93	5.96	0.76	12.675
LCHMH	VA91-322	4	Open-water	August	1991	263			3.66	3.77	4.87	5.77	5.70	0.63	11.083
HNGMH	VA91-307	3	Open-water	August	1991	186			6.64	6.67	7.03	7.47	7.49	0.39	5.212
HNGMH	VA91-316	2	Open-water	August	1991	180			6.61	6.64	6.76	7.17	7.22	0.33	4.525
FSBMH	VA91-317	4	Open-water	August	1991	91			6.05	6.05	6.41	7.15	7.11	0.47	6.644
TANMH	VA90-041	5	Open-water	June	1990	17			5.49	5.49	5.58	6.43	6.28	0.39	6.211
TANMH	VA90-041	5	Open-water	July	1990	1051			3.16	3.75	4.80	5.98	5.99	0.93	15.569
TANMH	VA90-041	5	Open-water	August	1990	1370		*	1.32	2.21	3.98	5.29	5.20	1.01	19.432
TANMH	VA91-050	11	Open-water	July	1991	89	*	*	2.13	2.13	2.23	3.42	3.42	0.92	26.775
TANMH	VA91-045	1	Open-water	July	1991	306			7.07	7.14	7.25	8.20	8.18	0.73	8.898
TANMH	VA91-285	8	Open-water	August	1991	253			4.88	4.90	5.23	6.48	6.39	0.78	12.222
TANMH	VA91-296	8	Open-water	August	1991	275			4.76	4.88	5.10	5.63	5.71	0.52	9.105
CB4MH	CBW 9 ME	9	Deep-water	September	1987	2416			1.65	1.81	2.26	5.25	5.08	1.83	36.008
CB4MH	CmpCanoy	4	Deep-water	June	1988	2874		*	1.04	1.64	3.29	7.48	7.01	2.24	31.916
CB4MH	CmpCanoy	4	Deep-water	July	1988	2874		*	0.83	1.34	2.30	4.09	4.43	1.86	41.916
CB4MH	CmpCanoy	4	Deep-water	August	1988	2052		*	0.47	0.53	1.86	3.88	3.85	1.54	39.944
CB4MH	KENT IS	6	Deep-water	August	1988	2155		*	0.10	1.30	2.90	5.00	4.73	1.33	28.116
CB4MH	KENT IS	6	Deep-water	September	1988	2089		*	1.20	1.60	3.00	4.40	4.33	1.01	23.265
CB4MH	KENT IS	6	Deep-water	October	1988	1294			0.80	1.80	3.90	4.80	4.77	0.80	16.853
CB4MH	999	5	Deep-water	July	1990	2092			1.73	2.88	4.32	5.91	6.15	1.43	23.314
CB5MH	VA91-060	6	Deep-water	July	1991	188			2.85	3.35	4.89	6.57	6.44	1.11	17.285
CB5MH	VA91-284	9	Deep-water	August	1991	204			2.67	2.76	3.16	3.87	4.12	0.81	19.713
CB5MH	VA91-290	4	Deep-water	August	1991	179			2.25	2.33	2.61	3.24	3.43	0.69	20.172
CB5MH	VA91-291	7	Deep-water	August	1991	116			4.84	4.97	5.82	6.49	6.49	0.54	8.298
CB5MH	VA91-303	11	Deep-water	August	1991	113			3.16	3.18	3.54	4.97	4.93	0.89	18.105
CB6PH	VA91-282	11	Deep-water	August	1991	267		*	1.58	1.60	1.71	3.00	3.23	1.40	43.171
CB7PH	VA91-279	12	Deep-water	August	1991	250			4.03	4.04	4.41	4.85	4.86	0.39	8.015
CB7PH	VA91-283	15	Deep-water	August	1991	250			3.86	3.88	4.07	4.65	4.73	0.52	11.009
PATMH	RC 02	3	Deep-water	June	1989	159		*	1.21	1.53	2.95	6.15	6.17	2.06	33.345
PATMH	RC 02	3	Deep-water	July	1989	1255		*	0.00	0.31	0.88	3.33	3.39	2.03	59.848
PATMH	RC 02	3	Deep-water	August	1989	280		*	0.69	1.05	2.12	4.07	4.58	2.25	49.124
PATMH	VA90-134	7	Deep-water	August	1990	391	*	*	0.00	0.07	0.92	2.46	2.75	1.67	60.967
POTMH	VA91-302	5	Deep-water	July	1991	253	*	*	0.46	0.69	1.02	2.39	2.58	1.04	40.301
POTMH	VA91-315	3	Deep-water	July	1991	4	*		2.49	2.49	2.49	2.60	2.74	0.36	13.037
YRKPH	VIMS	18	Deep-water	June	1989	654			1.40	1.70	2.60	3.70	3.67	0.91	24.671
YRKPH	VIMS	18	Deep-water	July	1989	2201		*	1.10	1.30	1.60	3.00	3.05	1.12	36.722
YRKPH	VIMS	18	Deep-water	August	1989	2057	*	*	0.00	0.00	0.40	1.70	1.66	0.92	55.183
YRKPH	VIMS	18	Deep-water	October	1989	1071			4.80	5.00	5.40	6.30	6.21	0.56	9.038
CB4MH	CBW 9 ME	9	Deep-channel	August	1987	5601		*	-0.08	0.54	0.56	3.21	3.30	1.85	56.074
CB4MH	CE1	19	Deep-channel	August	1987	1859	*	*	0.05	0.05	0.05	0.05	0.28	0.41	143.919
CB4MH	CE1	19	Deep-channel	September	1987	812		*	0.92	0.93	0.95	1.01	1.19	0.62	51.848
CB4MH	VA90-065	9	Deep-channel	July	1990	213		*	0.31	0.45	1.65	4.43	4.02	1.69	42.119
CB4MH	999	5	Deep-channel	August	1990	1417		*	0.04	0.14	2.19	7.32	7.49	3.71	49.571
CB4MH	VA90-065	9	Deep-channel	August	1990	1073		*	0.00	0.00	0.14	2.12	2.29	1.81	78.877
CB4MH	VA91-325	11	Deep-channel	August	1991	253	*	*	0.00	0.00	0.00	0.05	0.08	0.10	136.222

Table V-6. Summary of continuous dissolved oxygen buoy data achievement/non-achievement of the applicable 30-day mean and instantaneous minimum dissolved oxygen criteria by Chesapeake Bay Program segment by designated use.

CBP Segment	Designated Use	Number of Buoys	30-Day Mean Criterion		Instantaneous Minimum Criterion		Both Criteria		30-Day Mean Not Achieved/ Instantaneous Minimum Achieved	Instantaneous Minimum Not Achieved/ 30-Day Mean Achieved
			Not Achieved	Achieved	Not Achieved	Achieved	Not Achieved	Achieved		
CB1TF	Open-water	2	1	1	1	1	1	1	0	0
CB3MH	Open-water	2	0	2	0	2	0	2	0	0
CB4MH	Open-water	8	1	7	3	5	1	5	0	2
CB4MH	Deep-water	8	0	8	5	3	0	3	0	5
CB4MH	Deep-channel	7	2	5	7	0	2	0	0	5
CB5MH	Open-water	2	0	2	0	2	0	2	0	0
CB5MH	Deep-water	5	0	5	0	5	0	5	0	0
CB6PH	Open-water	4	3	1	4	0	3	0	0	1
CB6PH	Deep-water	1	0	1	1	0	0	0	0	1
CB7PH	Open-water	2	1	1	0	2	0	1	1	0
CB7PH	Deep-water	2	0	2	0	2	0	2	0	0
CB8PH	Open-water	2	0	2	0	2	0	2	0	0
MIDOH	Open-water	2	1	1	1	1	1	1	0	0
BACOH	Open-water	3	0	3	1	2	0	2	0	1
PATMH	Open-water	3	2	1	3	0	2	0	0	1
PATMH	Deep-water	4	1	3	4	0	1	0	0	3
MAGMH	Open-water	1	0	1	0	1	0	1	0	0
SEVMH	Open-water	3	3	0	3	0	3	0	0	0
SOUMH	Open-water	2	2	0	2	0	2	0	0	0
PAXMH	Open-water	7	3	4	4	3	3	3	0	1
POTTF	Open-water	3	0	3	0	3	0	3	0	0
POTOH	Open-water	3	2	1	2	1	2	1	0	0
POTMH	Open-water	2	0	2	2	0	0	0	0	2
POTMH	Deep-water	2	2	0	1	1	1	0	1	0
RPPTF	Open-water	6	0	6	0	6	0	6	0	0
RPPOH	Open-water	2	0	2	0	2	0	2	0	0
RPPMH	Open-water	2	0	2	0	2	0	2	0	0
PIAMH	Open-water	1	1	0	0	1	0	0	1	0
YRKPH	Open-water	1	1	0	1	0	1	0	0	0
YRKPH	Deep-water	4	1	3	2	2	1	2	0	1
MOBPH	Open-water	7	1	6	3	4	1	4	0	2
JMSTF	Open-water	2	0	2	0	2	0	2	0	0
JMSMH	Open-water	2	0	2	0	2	0	2	0	0
SBEMH	Open-water	2	2	0	2	0	2	0	0	0
SASOH	Open-water	1	0	1	0	1	0	1	0	0
EASMH	Open-water	2	1	1	1	1	1	1	0	0
CHOMH1	Open-water	4	1	3	2	2	1	2	0	1
LCHMH	Open-water	1	0	1	0	1	0	1	0	0
HNGMH	Open-water	2	0	2	0	2	0	2	0	0
FSBMH	Open-water	1	0	1	0	1	0	1	0	0
TANMH	Open-water	7	1	6	2	5	1	5	0	1

Table V-7. Summary of continuous dissolved oxygen buoy data achievement/non-achievement of the applicable 30-day mean and instantaneous minimum dissolved oxygen criteria summarized Bay-wide by designated use.

Designated Use	Number of Buoys	30-Day Mean Criterion		Minimum Criterion		Both Criteria		30-Day Mean Not Achieved/ Instantaneous Minimum Achieved	Instantaneous Minimum Not Achieved/ 30-Day Mean Achieved
		Not Achieved	Achieved	Not Achieved	Achieved	Not Achieved	Achieved		
Open-water	94	27	67	37	57	25	55	2	12
Deep-water	26	4	22	13	13	3	12	1	10
Deep-channel	7	2	5	7	0	2	0	0	5

Predicting the Lowest 1 Percent Concentration From The Mean

Down the left side of Figure V-1 are plots of the 1 percent measured dissolved oxygen concentration versus the measured monthly mean concentration for each designated use (all buoy records parsed by month and pooled within designated use). Down the right side of Figure V-1 are plots of the same sets of measurements only for an individual segment, CB4MH as an example, where multiple buoys or records including multiple months were available. Both solid circles and open triangles are displayed on the plots. The circles are the observed 1 percent concentration data; the triangles are concentrations predicted by a simple regression model including the observed monthly mean and the coefficient of variation. In these examples, the prediction model does pretty well because of the relative large number of observations and thus the very good estimate of the monthly mean and 1 percent concentrations, as well as the close relationship of each observation to the next. As the number of available continuous buoy data records increases for a wider array of segments and designated uses, the Chesapeake Bay Program partners should be in a position to develop a more generalized model for designated uses by segment that would enable the user to predict the 1 percent concentration from the monthly means obtained from the long-term fixed-station monitoring data.

One question still under investigation is how well those observed monthly means compare to the means obtained from the continuous buoy data records. Figure V-2, which shows the fixed station twice monthly monitoring data and semi-continuous buoy data plotted together, provides some current insights into answering this question. Down the left side of Figure V-2 are plots of the observed 1 percent concentrations versus observed monthly mean dissolved oxygen concentrations (June-September) obtained from fixed station monitoring data and plotted for open-water, deep-water and deep-channel designated uses in segment CB4MH. Down the right side of Figure V-2 are the plots from the continuous buoy data for CB4MH. The vertical and horizontal reference lines cutting each graph into 4 quadrants represent the 30-day mean and instantaneous minimum dissolved oxygen criteria concentrations. Again, a regression model using the mean and coefficient of variation of the monitoring data has been used to predict the 1 percent concentration. As illustrated in Figure V-1, solid circles represent the observed concentrations and open triangles represent the predicted concentrations. As expected from the fixed station monitoring data, the fit of predicted to observed is not as tight as with the buoy data. These regression models can be improved with the addition of more explanatory variables. The point is that in some, possibly many segments, the relationship of the monthly mean with the 1 percent concentration evidenced in monitoring data is similar to that found in the buoy data records. The regression models output illustrated in Figures V-1 and V-2 can be improved by including other explanatory variables to better predict the variability detected and quantified in the buoys.

Figure V-3 shows similar plots of the 1 percent concentration versus the monthly mean obtained from monitoring data in various other example segments. Note how tight the relationship is in segment BOHOH (Bohemia River) in contrast to the

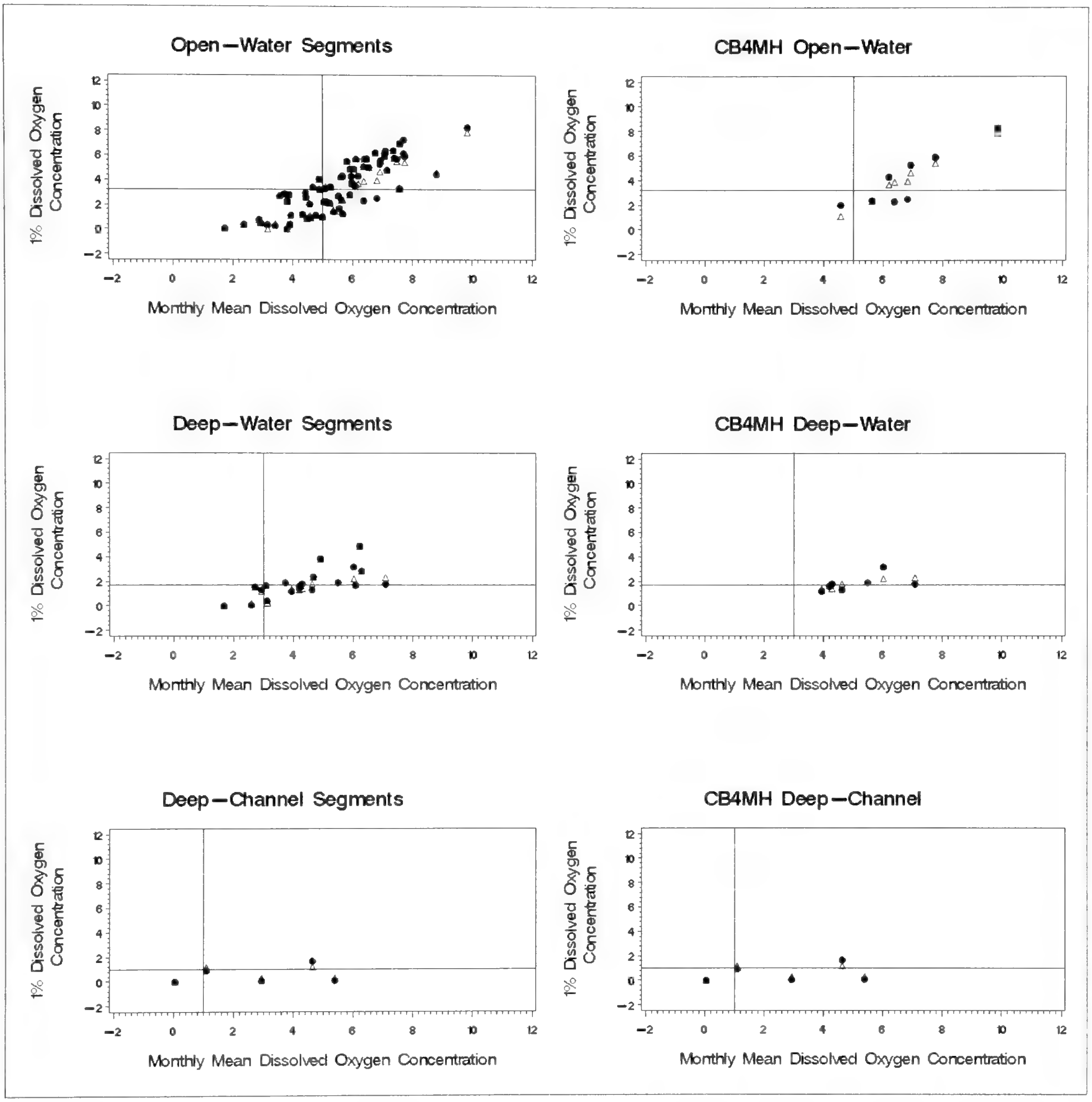


Figure V-1. Plots of monthly mean dissolved oxygen concentration (mg liter^{-1}) versus the 1 percentile dissolved oxygen concentration as measured by sensors on individual buoys. Plots on left side show patterns of dissolved oxygen concentration data pooled across Chesapeake Bay Program segments within open-water, deep-water and deep-channel uses. Plots on the right side show patterns of dissolved oxygen concentration data from middle central Chesapeake Bay, segment CB4MH. Circles are observed dissolved oxygen concentration data; open triangles are dissolved oxygen concentrations predicted by the regression model: 1 percent dissolved oxygen concentration as a function of monthly mean dissolved oxygen and the coefficient of variation.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

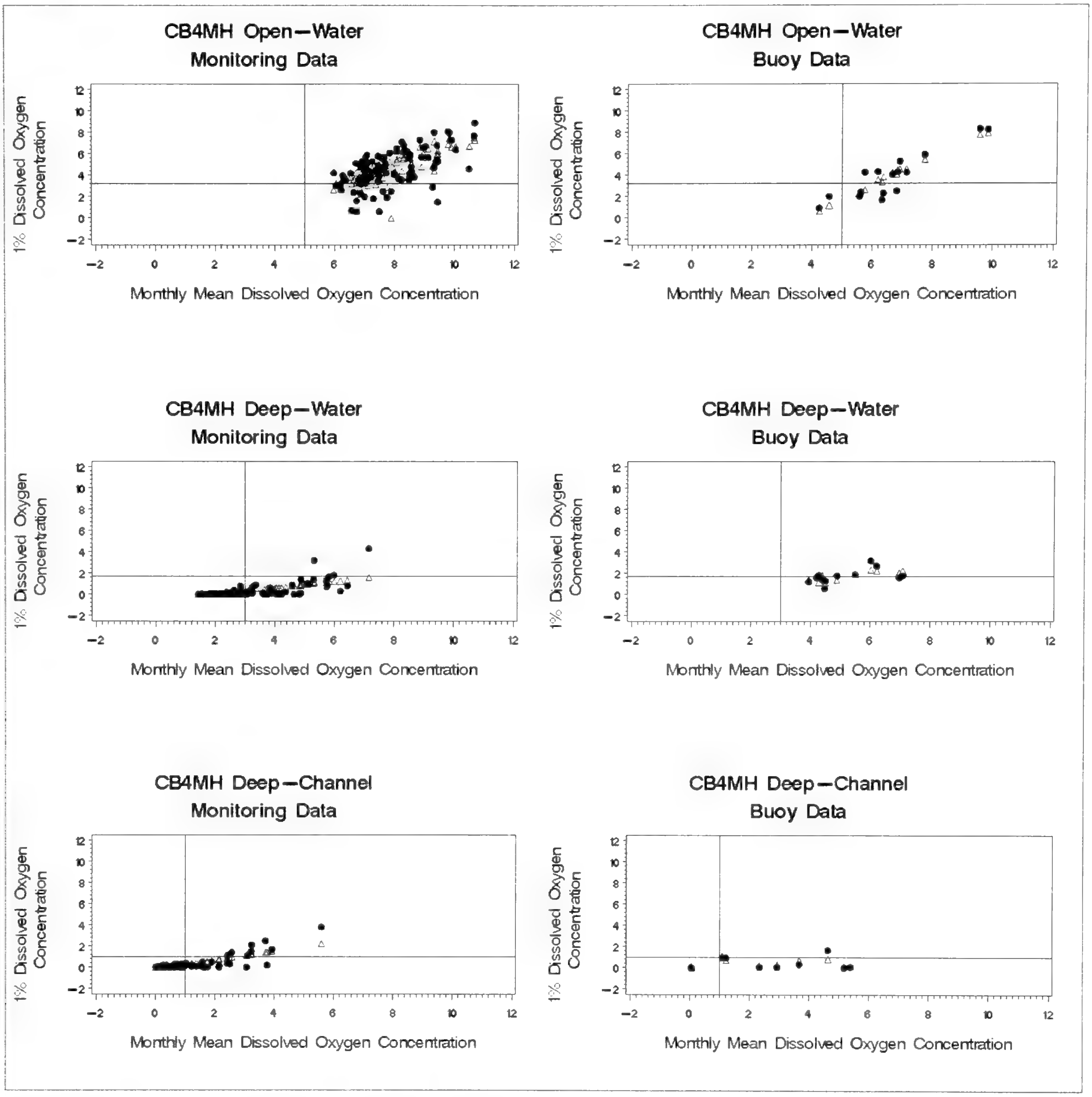


Figure V-2. Plots of monthly mean dissolved oxygen concentration (mg liter^{-1}) versus the 1 percentile dissolved oxygen concentration in middle central Chesapeake Bay, segment CB4MH. Plots on left side show the pattern of observed dissolved oxygen concentration data from the Chesapeake Bay Water Quality Monitoring Program (May–September 1985–2003). Plots on right side show observed dissolved oxygen data from segment CB4MH as measured during various buoy deployments. Circles are observed dissolved oxygen concentrations; open triangles are dissolved oxygen concentrations predicted by the regression model: 1 percent dissolved oxygen concentration as a function of monthly mean dissolved oxygen concentration and coefficient of variation.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

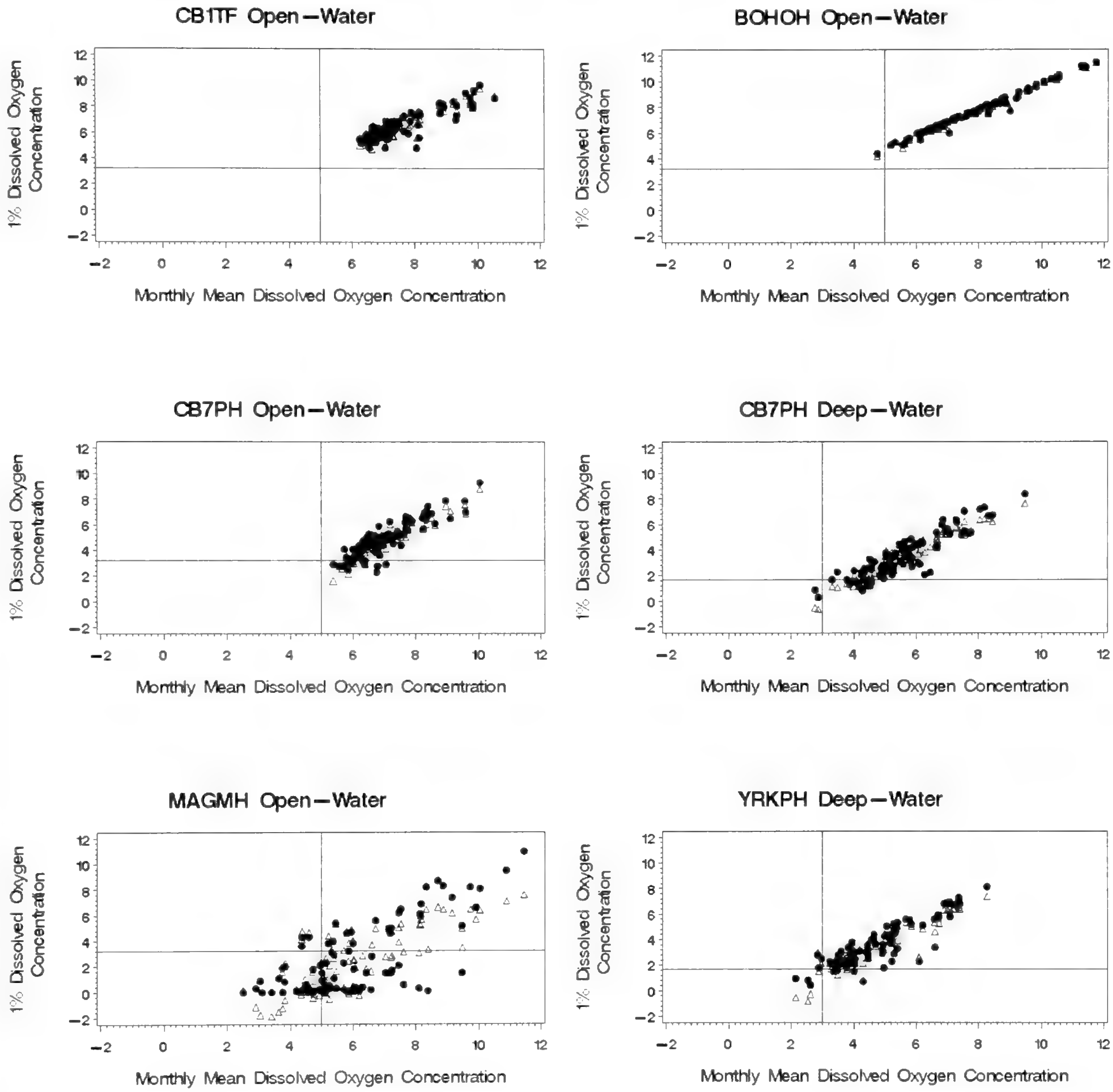


Figure V-3. Plots of monthly mean ambient dissolved oxygen concentration versus the one percentile dissolved oxygen concentrations in several example Chesapeake Bay Program segments: the northern Chesapeake Bay (CB1TF), Bohemia River (BOHOH), open-water and deep-water lower eastern Chesapeake Bay (CB7PH), Magothy River (MAGMH) and the lower York River (YRKPH). These graphics show patterns of dissolved oxygen data from the Chesapeake Bay Water Quality Monitoring Program from May-September 1985–2003. Circles are observed dissolved oxygen concentration data; open triangles are dissolved oxygen concentrations predicted by the regression model: 1 percent dissolved oxygen concentration as a function of monthly mean dissolved oxygen concentration and coefficient of variation.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

scatter of points in the plot for segment MAGMH (Magothy River), indicating large between-segment differences in variability and predictability.

The plots in Figure V-3 illustrate the differences among segments in their patterns of criteria non-achievement. The four quadrants bounded by the reference lines in the plots represent the four possible results from a two-criteria achievement assessment. Let the quadrants be numbered clockwise 1 through 4, beginning with the upper right hand quadrant. Any data points in quadrant 1 achieve both the 30-day mean and instantaneous minimum criteria. Data points in quadrant 2 achieve the 30-day mean criterion, but do not achieve the instantaneous minimum criterion. Data points in quadrant 3 do not achieve both the 30-day mean and instantaneous minimum criteria. Data points in quadrant 4 achieve the instantaneous minimum criterion, but do not achieve the 30-day mean criterion. In a fully restored Chesapeake Bay, one would expect that most data points would fall in quadrant 1. In impaired segments, where low dissolved oxygen conditions are frequent or chronic, one would expect most data points to fall in quadrant 3. In segments where low dissolved oxygen events are episodic, ranging from occasional to frequent, one would expect a dense population of data points in quadrant 2. And, where dissolved oxygen concentrations are chronically reduced, but really low dissolved oxygen concentrations are rare, then one would expect some data points in quadrant 4.

Providing plots such as those presented in Figure V-3 for each designated use for every segment is impractical for this document. Instead, Table V-8 shows the number of points in a representative data set that would be in each quadrant, if the data were plotted as in Figure V-3 using the summer only data from a recent 10-year period: June-September, 1993–2002.

There are 66 segments that have only open-water designated uses. A total of 28 of these segments achieve both the 30-day mean and instantaneous minimum criteria, i.e., which have all their data points in quadrant 1 and none or only one data point in the other quadrants. These segments are marked with a single asterisk in Table V-8. In these open-water only segments, assessment of attainment of the instantaneous minimum criterion can be directly based on assessment of attainment of the 30-day mean criterion (Table V-9).

A total of 18 segments with only open-water designated uses had the vast majority (greater than two-thirds) of their data points in either quadrant 1 or quadrant 3. These segments are marked with double asterisks in Table V-8. The assessment of attainment of the instantaneous minimum criterion can be directly based on assessment of attainment of the 30-day mean criterion in these segments (Table V-9).

In five segments with only open-water designated uses there were sufficient data points in quadrant 2 indicating a much higher occurrence where the 30-day mean criterion was achieved yet the instantaneous minimum criterion was not achieved. These segments are marked with a single dash in Table V-8. These five segments were: upper Chesapeake Bay (CB2OH), Magothy River (MAGMH), Severn River (SEVMH), Mobjack Bay (MOBPH) and Little Choptank River (LCHMH). Users

Table V-8. Characterization of the Chesapeake Bay Program segments based on occupied quadrants in a plot of the 1 percent dissolved oxygen concentration versus observed monthly mean dissolved oxygen concentration[1].

	Number of Data Points By Quadrant by Designated Use											
CBP	Open-Water				Deep-Water				Deep-Channel			
Segment	1	2	3	4	1	2	3	4	1	2	3	4
CB1TF*	39	0	0	0								
CB2OH-	12	19	8	0								
CB3MH	38	2	0	0	2	34	4	0	3	17	18	0
CB4MH	35	5	0	0	1	8	31	0	2	2	36	0
CB5MH	36	4	0	0	6	29	5	0	11	20	9	0
CB6PH	31	9	0	0	32	8	0	0				
CB7PH	36	4	0	0	33	5	2	0				
CB8PH*	39	1	0	0								
BSHOH*	37	0	0	1								
GUNOH**	38	0	1	1								
MIDOH*	40	0	0	0								
BACOH**	36	0	0	4								
PATMH	40	0	0	0	0	7	33	0	1	1	7	0
MAGMH-	8	16	16	0								
SEVMH-	7	9	19	4								
SOUMH**	3	2	31	3								
RHDMH**	37	0	1	1								
WSTMH**	28	3	5	3								
PAXTF*	40	0	0	0								
WBRTF*	40	0	0	0								
PAXOH**	31	0	2	7								
PAXMH	25	15	0	0	8	11	21	0				
POTTF*	39	1	0	0								
PISTF**	38	2	0	0								
MATTF*	39	1	0	0								
POTOH*	39	1	0	0								
POTMH	39	1	0	0	5	25	10	0	10	7	22	0
RPPTF*	39	0	0	0								
RPPOH*	39	0	0	0								
RPPMH	35	4	1	0	24	15	1	0	22	8	3	0
CRRMH**	20	2	11	7								
PIAMH**	38	2	0	0								
MPNTF	**29**	**0**	**0**	**8**								
MPNOH	**25**	**0**	**0**	**13**								
PMKTF	**26**	**0**	**3**	**10**								
PMKOH	**22**	**0**	**0**	**17**								
YRKMH**	30	0	2	8								
YRKPH**	35	0	0	5	32	2	3	1				
MOBPH-	25	14	1	0								
JMSTF*	40	0	0	0								
APPTF*	39	0	0	0								
JMSOH*	40	0	0	0								
CHKOH*	40	0	0	0								
JMSMH*	40	0	0	0								
JMSPH*	39	0	0	1								
WBEMH**	31	0	1	7								
SBEMH	22	0	4	13	29	0	3	2				
EBEMH	**25**	**0**	**2**	**12**								
LAFMH**	17	0	0	3								
ELIPH**	36	0	3	1								
NORTF*	40	0	0	0								
C&DOH*	40	0	0	0								

continued

Table V-8 (continued). Characterization of the Chesapeake Bay Program segments based on occupied quadrants in a plot of the 1 percent dissolved oxygen concentration versus observed monthly mean dissolved oxygen concentration[1] .

Number of Data Points By Quadrant by Designated Use

CBP Segment	Open-Water				Deep-Water				Deep-Channel			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
BOHOH*	39	0	0	1								
ELKOH*	39	0	0	0								
SASOH*	39	0	0	1								
CHSOH*	39	0	0	1								
CHSMH	37	2	1	0	12	8	14	1	2	0	3	0
EASMH	39	1	0	0	1	13	20	2	2	0	2	0
CHOOH**	34	0	0	6								
CHOMH2**	26	2	9	3								
CHOMH1**	33	6	1	0								
LCHMH-	4	11	24	0								
FSBMH*	36	0	0	1								
NANTF**	35	0	0	5								
NANMH*	38	0	0	0								
WICMH	**28**	**0**	**0**	**10**								
MANMH*	37	0	0	1								
BIGMH*	38	0	0	0								
POCTF	**18**	**0**	**3**	**19**								
POCMH*	40	0	0	0								
TANMH**	27	6	5	1								

[1] Quad 1: both 30-day mean and instantaneous minimum criteria achieved; quad 2: 30-day mean criterion achieved, instantaneous minimum criterion not achieved; quad 3: both 30-day mean and instantaneous minimum criteria not achieved; quad 4: 30-day mean criterion not achieved, instantaneous minimum criterion achieved. Based on data from the Chesapeake Bay Water Quality Monitoring Program twice monthly cruises between June and September, 1993 through 2002 (most recent 10 years).

Single asterisk (*): Open-water use only segment with all data points in quadrant 1 and none or only one data point in the other three quadrants.

Double asterisk (**): Open-water use only segment with a vast majority of data points (greater than two-thirds) in either quadrant 1 or quadrant 3.

Single dash(-): Open-water use only segment with sufficient data points in quadrant 2 indicating a much higher occurrence where the 30-day mean criterion was achieved yet the instantaneous minimum criterion was not achieved.

Boldface type: Open-water use only segment with a large number of data points in quadrant 1 and quadrant 4 and none or very few data points in the other two quadrants.

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

Table V-9. Chesapeake Bay Program segments and tidal water designated uses where attainment of the instantaneous minimum, 1-day mean and 7-day mean dissolved oxygen criteria can be assessed using 30-day mean data or dissolved oxygen criteria attainment assessment may require collection and evaluation of data of higher frequency than 30-day means.

Chesapeake Bay Program Segment		Instantaneous minimum/1-day mean/7-day mean criteria can be assessed using 30-day mean data			Instantaneous minimum/1-day day mean/7-day mean criteria assessment may require higher frequency data than 30-day mean		
Segment Name	**Segment Code**	**Open-Water**	**Deep-Water**	**Deep-Channel**	**Open-Water**	**Deep-Water**	**Deep-Channel**
Northern Chesapeake Bay	CB1TF	X					
Upper Chesapeake Bay	CB2OH				X		
Upper Central Chesapeake Bay	CB3MH	X				X	X
Middle Central Chesapeake Bay	CB4MH	X	X	X			
Lower Central Chesapeake Bay	CB5MH	X				X	X
Western Lower Chesapeake Bay	CB6PH	X	X				
Eastern Lower Chesapeake Bay	CB7PH	X	X				
Mouth of the Chesapeake Bay	CB8PH	X					
Bush River	BSHOH	X					
Gunpowder River	GUNOH	X					
Middle River	MIDOH	X					
Back River	BACOH	X					
Patapsco River	PATMH	X	X	X			
Magothy River	MAGMH				X		
Severn River	SEVMH				X		
South River	SOUMH	X					
Rhode River	RHDMH	X					
West River	WSTMH	X					
Upper Patuxent River	PAXTF	X					
Western Branch Patuxent River	WBRTF	X					
Middle Patuxent River	PAXOH	X					
Lower Patuxent	PAXMH				X	X	
Upper Potomac River	POTTF	X					

continued

Table V-9 (continued). Chesapeake Bay Program segments and tidal water designated uses where attainment of the instantaneous minimum, 1-day mean and 7-day mean dissolved oxygen criteria can be assessed using 30-day mean data or dissolved oxygen criteria attainment assessment may require collection and evaluation of data of higher frequency than 30-day means.

Chesapeake Bay Program Segment		**Instantaneous minimum/1-day mean/7-day mean criteria can be assessed using 30-day mean data**			**Instantaneous minimum/1-day day mean/7-day mean criteria assessment may require higher frequency data than 30-day mean**		
Segment Name	**Segment Code**	**Open-Water**	**Deep-Water**	**Deep-Channel**	**Open-Water**	**Deep-Water**	**Deep-Channel**
Anacostia River	ANATF	N/D					
Piscataway Creek	PISTF	X					
Mattawoman Creek	MATTF	X					
Middle Potomac River	POTOH	X					
Lower Potomac River	POTMH	X		X		X	
Upper Rappahannock River	RPPTF	X					
Middle Rappahannock River	RPPOH	X					
Lower Rappahannock River	RPPMH	X		X		X	
Corrotoman River	CRRMH	X					
Piankatank River	PIAMH	X					
Upper Mattaponi River	MPNTF				X		
Lower Mattaponi River	MPNOH				X		
Upper Pamunkey River	PMKTF				X		
Lower Pamunkey River	PMKOH				X		
Middle York River	YRKMH	X					
Lower York River	YRKPH	X	X				
Mobjack Bay	MOBPH				X		
Upper James River	JMSTF	X					
Appomattox River	APPTF	X					
Middle James River	JMSOH	X					
Chickahominy River	CHKOH	X					
Lower James River	JMSMH	X					
Mouth of the James River	JMSPH	X					

Chesapeake Bay Program Segment		Instantaneous minimum/1-day mean/7-day mean criteria can be assessed using 30-day mean data			Instantaneous minimum/1-day day mean/7-day mean criteria assessment may require higher frequency data than 30-day mean		
Segment Name	**Segment Code**	**Open-Water**	**Deep-Water**	**Deep-Channel**	**Open-Water**	**Deep-Water**	**Deep-Channel**
Western Branch Elizabeth River	WBEMH	X					
Southern Branch Elizabeth River	SBEMH		X		X		
Eastern Branch Elizabeth River	EBEMH				X		
Lafayette River	LAFMH	X					
Mouth to mid-Elizabeth River	ELIPH	X					
Lynnhaven River	LYNPH	N/D					
Northeast River	NORTF	X					
C&D Canal	C&DOH	X					
Bohemia River	BOHOH	X					
Elk River	ELKOH	X					
Sassafras River	SASOH	X					
Upper Chester River	CHSTF	N/D					
Middle Chester River	CHSOH	X					
Lower Chester River	CHSMH	X	X	X			
Eastern Bay	EASMH	X		X		X	
Upper Choptank River	CHOTF	N/D					
Middle Choptank River	CHOOH	X					
Lower Choptank River	CHOMH2	X					
Mouth of the Choptank River	CHOMH1	X					
Little Choptank River	LCHMH				X		
Honga River	HNGMH	N/D					
Fishing Bay	FSBMH	X					
Upper Nanticoke River	NANTF	X					

continued

Table V-9 (continued). Chesapeake Bay Program segments and tidal water designated uses where attainment of the instantaneous minimum, 1-day mean and 7-day mean dissolved oxygen criteria can be assessed using 30-day mean data or dissolved oxygen criteria attainment assessment may require collection and evaluation of data of higher frequency than 30-day means.

Chesapeake Bay Program Segment		**Instantaneous minimum/1-day mean/7-day mean criteria can be assessed using 30-day mean data**			**Instantaneous minimum/1-day day mean/7-day mean criteria assessment may require higher frequency data than 30-day mean**		
Segment Name	**Segment Code**	**Open-Water**	**Deep-Water**	**Deep-Channel**	**Open-Water**	**Deep-Water**	**Deep-Channel**
Middle Nanticoke River	NANOH	N/D					
Lower Nanticoke	NANMH	X					
Wicomico River	WICMH				X		
Manokin River	MANMH	X					
Big Annemessex River	BIGMH	X					
Upper Pocomoke River	POCTF				X		
Middle Pocomoke River	POCOH	N/D					
Lower Pocomoke Sound	POCMH	X					
Tangier Sound	TANMH	X					

N/D = insufficient fixed station and/or buoy dissolved oxygen data available.

assessing attainment of 30-day mean and instantaneous minimum dissolved oxygen criteria within these five segments are cautioned to not automatically assume attainment of the 30-day mean criterion reflects attainment of the instantaneous minimum criterion (Table V-9). Site-specific buoy deployments may be necessary to either better quantify a relationship or assess attainment using both low- and high-frequency data sources.

Seven segments with only open-water designated uses had a large number of data points in quadrant 1 (both criteria were achieved) and in quadrant 4 (instantaneous minimum criterion achieved, but the 30-day mean criterion not achieved) and none or very few data points in other quadrants were marked in bold typeface in Table V-8. These seven segments were: upper (MPNTF) and lower (MPNOH) Mattaponi, upper (PMKTF) and lower (PMKOH) Pamunkey River, Eastern Branch Elizabeth River (EBEMH), Wicomico River (WICMH), and upper Pocomoke River (POCTF.)

The segments in the Pamunkey and Mattaponi rivers (segments PMKTF, PMKOH and MPNTF, MPNOH, respectively) are known to be strongly influenced by relatively large expanses of fringing wetlands along the entire length of both tidal rivers. The Wicomico River (WICMH) and upper Pocomoke River (POCTF) also have large areas of tidal wetlands along particular reaches of these two rivers. The natural influences of extensive fringing tidal wetlands systems, described in more detail in Chapter 6, are the likely reason for why the 30-day mean/instantaneous minimum relationship does not fully apply to these seven segments. More site specific evaluation of the data and conditions within the Eastern Branch of the Elizabeth River (EBEMH) is required to understand what's happening in this tidal system.

Users assessing attainment of the 30-day mean and instantaneous minimum dissolved oxygen criteria within these seven segments are cautioned not to automatically assume that attainment of the 30-day mean criterion reflects attainment of the instantaneous minimum criterion (Table V-9). Site-specific buoy deployments may be necessary either to better quantify a relationship or assess attainment using both low- and high-frequency data sources.

For the remaining seven segments with only open-water designated uses, there were insufficient buoy data available to assess whether attainment of the 30-day mean criterion reflected attainment of the instantaneous minimum criterion. These segments are marked with a "N/D" in Table V-9.

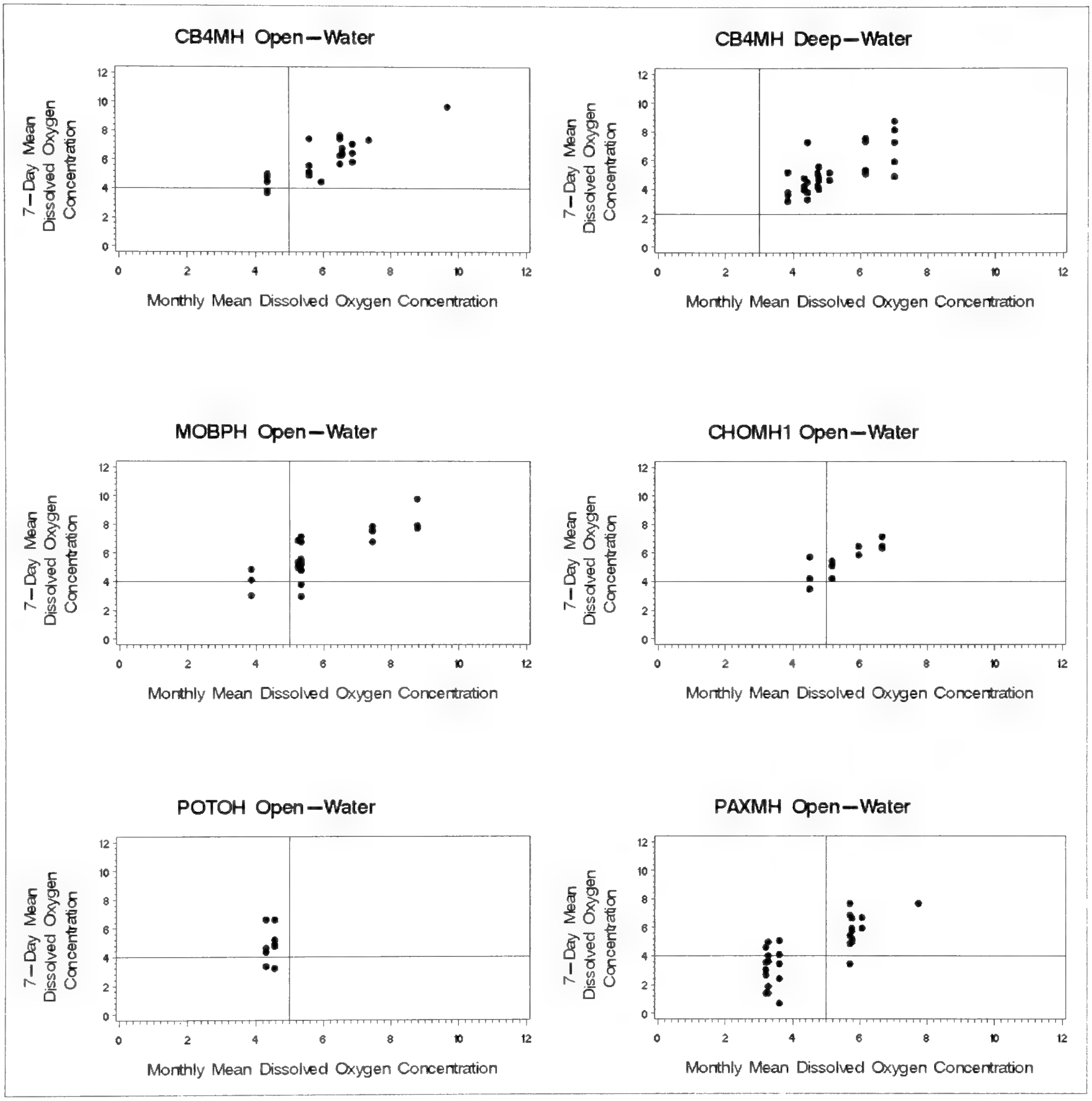
Of the thirteen segments with deep-water or deep-water and deep-channel designated uses, eleven of the segments had the vast majority (greater than two-thirds) of their open-water designated use data points in quadrant 1 (Table V-8), directly supporting the assessment of attainment of the instantaneous minimum criterion directly based on assessment of attainment of the 30-day mean criterion in these segments (Table V-9). Users assessing attainment of the 30-day mean and instantaneous minimum dissolved oxygen criteria within the lower Patuxent River (PAXMH) and Southern Branch Elizabeth River (SBEMH) are cautioned not to automatically assume that attainment of the 30-day mean criterion reflects attainment of the instantaneous minimum criterion.

Ten of these thirteen segments with deep-water or deep-water and deep-channel designated uses also showed evidence of a strong relationship between achieved/not achieved in the assessment of the instantaneous minimum using monthly mean data for the deep-water and/or deep channel designated uses (Table V-8). These segments were: middle central Chesapeake Bay (CB4MH), western lower Chesapeake Bay (CB6PH), eastern lower Chesapeake Bay (CB7PH), Patapsco River (PATMH), lower Potomac River (POTMH) [deep-channel use only], lower Rappahannock River (RPPMH) [deep-channel use only], lower York River (YRKPH), Southern Branch Elizabeth River (SBEMH), lower Chester River (CSHMH), and Eastern Bay (EASMH) [deep channel use only] (Table V-9).

In the cases of the upper central Chesapeake Bay (CB3MH), lower central Chesapeake Bay (CB5MH), lower Patuxent River (PAXMH), lower Potomac River (POTMH) [deep-water use only], lower Rappahannock River (RPPMH) [deep-water use only] and Eastern Bay (EASMH) [deep-water use only] there are sufficient data points in quadrant 2 indicating a higher occurrence where the 30-day mean criteria were achieved yet the instantaneous minimum criteria were not achieved in deep-water and/or deep-channel designated use habitats (Table V-8). Users assessing attainment of 30-day mean and instantaneous minimum dissolved oxygen criteria within these seven segments and their respective deep-water/deep channel designated uses are cautioned not to automatically assume that attainment of the 30-day mean criterion reflects attainment of the instantaneous minimum dissolved oxygen criterion (Table V-9). Site-specific buoy deployments may be necessary either to better quantify a relationship or assess attainment using both low- and high-frequency data sources.

ASSESSMENT OF 7-DAY MEAN CRITERIA ATTAINMENT FROM MONTHLY MEAN DATA

The open-water designated use habitats are also subject to a 7-day mean criterion. The continuous buoy data were examined to look for relationships between the 30-day mean and the 7-day mean values. Buoy data records with durations over 14 days (at least two 7-day periods) were examined. Figure V-4 shows plots of the sequential as opposed to a rolling series of 7-day means versus the 30-day mean for the more limited number of data records that were available. There is more scatter in these relationships than in the 30-day mean versus instantaneous minimum relationships. However, a significant majority of the data points are found in the first and third quadrants, where the data points both achieve (quadrant 1) or both do not achieve (quadrant 3) the 30-day mean and 7-day mean criteria. There is clearly a strong relationship between achieving/not achieving of the 30-day mean and 7-day mean criteria. The remaining data points tended to be in the second quadrant where the data points do not achieve the 30-day mean criterion but achieve the 7-day mean criterion. Only 3 data points were located in the fourth quadrant.



CB4MH Open—Water

CB4MH Deep—Water

MOBPH Open—Water

CHOMH1 Open—Water

POTOH Open—Water

PAXMH Open—Water

Figure V-4. Plots of monthly mean dissolved oxygen concentration (mg liter^{-1}) versus the 7-day mean dissolved oxygen concentration (mg liter^{-1}) in several example Chesapeake Bay Program segments: open-water and deep-water middle central Chesapeake Bay (CB4MH), Mobjack Bay (MOBPH), lower Choptank River (CHOMH1), middle Potomac River (POTOH) and lower Patuxent River (PAXMH).

Source: Chesapeake Bay Water Quality Monitoring Program database.
http://www.chesapeakebay.net/data

FINDINGS

For the majority of Chesapeake Bay Program segments and the designated use habitats within those segments identified in Table V-9, dissolved oxygen concentration data collected through monthly to twice monthly sampling at the Chesapeake Bay Water Quality Monitoring Program fixed-stations can be used to assess attainment of all higher frequency dissolved oxygen criteria components including the 7-day mean, 1-day mean and instantaneous minimum criteria. For the remaining segments and identified designated uses, further targeted buoys deployments are required to more fully characterize and quantify the relationships between the monthly mean, 7-day mean, 1-day mean and instantaneous minimum concentrations. Further work is underway to factor in additional variables to strengthen the predictive relationships between the 30-day mean, 7-day mean, 1-day mean and instantaneous minimum values and therefore, the assessment of attainment of the instantaneous minimum, 1-day mean and 7-day mean criteria using monthly mean observations.

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U.S. Environmental Protection Agency. 2003. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries.* EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, Maryland.

chapter vi

Guidance for Deriving Site Specific Dissolved Oxygen Criteria for Assessing Criteria Attainment of Naturally Low Dissolved Oxygen Concentrations in Tidal Wetland Influenced Estuarine Systems

Tidal wetlands are a valuable component of estuarine systems. In the Pamunkey River, they have been shown to be net sinks for sediments (Neubauer et al. 2001) and in most cases also serve to remove nutrients from overlying water (Anderson et al. 1997). High rates of organic production, accompanied by high rates of respiration (Neubauer et al. 2000), can significantly reduce dissolved oxygen and enhance dissolved inorganic carbon levels both in sediment pore water and overlying water in wetland systems. Another process that can deplete dissolved oxygen in wetland sediments is nitrification, which converts ammonium to nitrite and nitrate (Tobias et al. 2001).

Subsequent to publication of *Ambient Water Quality for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries* (U.S. EPA 2003a), Virginia, Maryland, Delaware and the District of Columbia initiated their respective processes for adopting new and/or revising existing state water quality standards. In so doing, Virginia requested support and guidance from EPA in determining the appropriate dissolved oxygen criteria/designated use/attainment procedures for the tidal Mattaponi and Pamunkey rivers for addressing the naturally lower ambient dissolved oxygen concentrations. Based on the scientific literature and personal communications with Chesapeake Bay wetland scientists, EPA recognized the need to explore accommodations for the special circumstances in these tidal wetland influenced estuarine systems with respect to criteria levels, designated uses and/or criteria attainment assessment.

NATURAL CONDITIONS/FEATURES INDICATING ROLE OF WETLANDS IN LOW DISSOLVED OXYGEN CONCENTRATIONS

A future objective is to define more fully the natural conditions and physical features in Chesapeake Bay tidal systems that would indicate that tidal wetlands are playing a significant role in naturally reducing ambient dissolved oxygen concentrations. Those natural conditions/features have not yet been firmly established but Tables VI-1 and VI-2 provide some key physical and water quality statistics for the tidal Mattaponi and Pamunkey rivers. Appendix A provides similar data for other tidal fresh and oligohaline regions in the Chesapeake Bay and its tidal tributaries for comparison. Four natural conditions/features have been evaluated here to document and help quantify the influence of tidal wetlands on the dissolved oxygen deficit observed in the tidal Mattaponi and Pamunkey rivers.

SURFACE TO VOLUME RATIOS/LARGE FRINGING WETLAND AREAS

The tidal fresh and oligohaline segments in the Mattaponi and Pamunkey rivers are among the smallest volume, with a small surface to volume ratio and large areas of fringing tidal marsh—1.5 times larger than the tidal surface water area—relative to other segments throughout the Bay's tidal waters (Table VI-1; Appendix A, Table A-1).

WATER QUALITY CONDITIONS

Table VI-2 gives some water quality statistics for recent years. These years happen to have had dry to record-dry summers and that low flow regime should be borne in mind. Severe low dissolved oxygen conditions (concentrations < 3 mg liter^{-1}) are not obvious, but average dissolved oxygen concentrations, in both surface and bottom waters, are about 2.5 to 3 mg liter^{-1} below calculated oxygen saturation levels (Table VI-2). Chlorophyll *a* concentrations are comparatively low, as are the total nitrogen concentrations (with the exception of the oligohaline Pamunkey River segment PMKOH). Phosphorus concentrations range from mid to high compared to other tidal systems.

The dissolved oxygen deficit in these two tidal systems is among the highest observed in the Chesapeake Bay's tidal tributaries. The dissolved oxygen deficits observed in the recent dry years (Table VI-2) are similar to those observed over the 1985-2002 Chesapeake Bay water quality monitoring program data record (Figure VI-1). These findings indicate that the processes driving the recorded dissolved oxygen deficits are due largely to natural processes internal to the tidal system and not as much to external nonpoint nutrient loadings (which are naturally reduced during the recent dry years due to decreased surface runoff).

Table VI-1. Some physical characteristics of the Mattaponi and Pamunkey tidal fresh (MPNTF and TMKTF, respectively) and oligohaline (MPNOH and PMKOH, respectively) segments: depth distribution based on depth of cells in the Chesapeake Bay Program volumetric interpolator, acres of fringing tidal wetlands, segment perimeter, segment water surface area, segment water column volume and segment water surface area:water column volume ratio.

CBP Segment	Maximum Depth (meters)	75th Percentile (meters)	Median Depth (meters)	25th Percentile (meters)	Minimum Depth (meters)	Wetland Acreage (acres)	Segment Perimeter (meters)	Segment Surface Area (meters^2)	Segment Volume (meters^3)	Surface Area to Volume Ratio
MPNTF	12	3	2	1	1	1,125	108,327	8,573,187	15,337,500	0.6
MPNOH	15	5	3	2	1	3,360	109,059	8,660,891	35,390,000	0.2
PMKTF	15	4	2	1	1	1,652	264,699	16,229,024	28,630,000	0.6
PMKOH	18	5	3	2	1	5,374	119,417	14,093,807	66,680,000	0.2

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

Table VI-2. Recent summer averaged water quality conditions in the Mattaponi and Pamunkey tidal fresh (MPNTF and PMKTF, respectively) and oligohaline (MPNOH and PMKOH, respectively) segments for 2000-2002, dry to record dry summers.

CBP Segment	Water Column Layer	Water Column Depth (meters)	Salinity (ppt)	Temperature (°C)	Dissolved Oxygen Concentration (mg liter^{-1})	Dissolved Oxygen Deficit (mg liter^{-1})	Chlorophyll *a* Concentration (ug liter^{-1})	Total Suspended Solids Concentration (mg liter^{-1})	Total Nitrogen Concentration (mg liter^{-1})	Total Phosphorus Concentration (mg liter^{-1})
MPNTF	S	0.7	0.0	27.3	5.6	2.4	5.9	10.3	0.61	0.079
MPNTF	B	3.0	0.0	27.2	5.6	2.4	.	12.3	0.61	0.080
MPNOH	S	0.7	7.4	26.8	5.6	2.1	10.6	35.4	0.76	0.115
MPNOH	B	14.3	8.4	26.5	5.0	2.7	.	100.6	0.94	0.174
PMKTF	S	0.7	0.3	26.9	5.3	2.5	6.2	18.3	0.61	0.084
PMKTF	B	6.1	0.3	26.8	5.5	2.6	.	31.0	0.68	0.107
PMKOH	S	0.7	6.6	26.2	5.0	2.9	12.6	46.0	0.73	0.105
PMKOH	B	5.2	7.0	26.2	4.9	3.0	.	139.9	1.11	0.220

S = surface
B = bottom

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net data

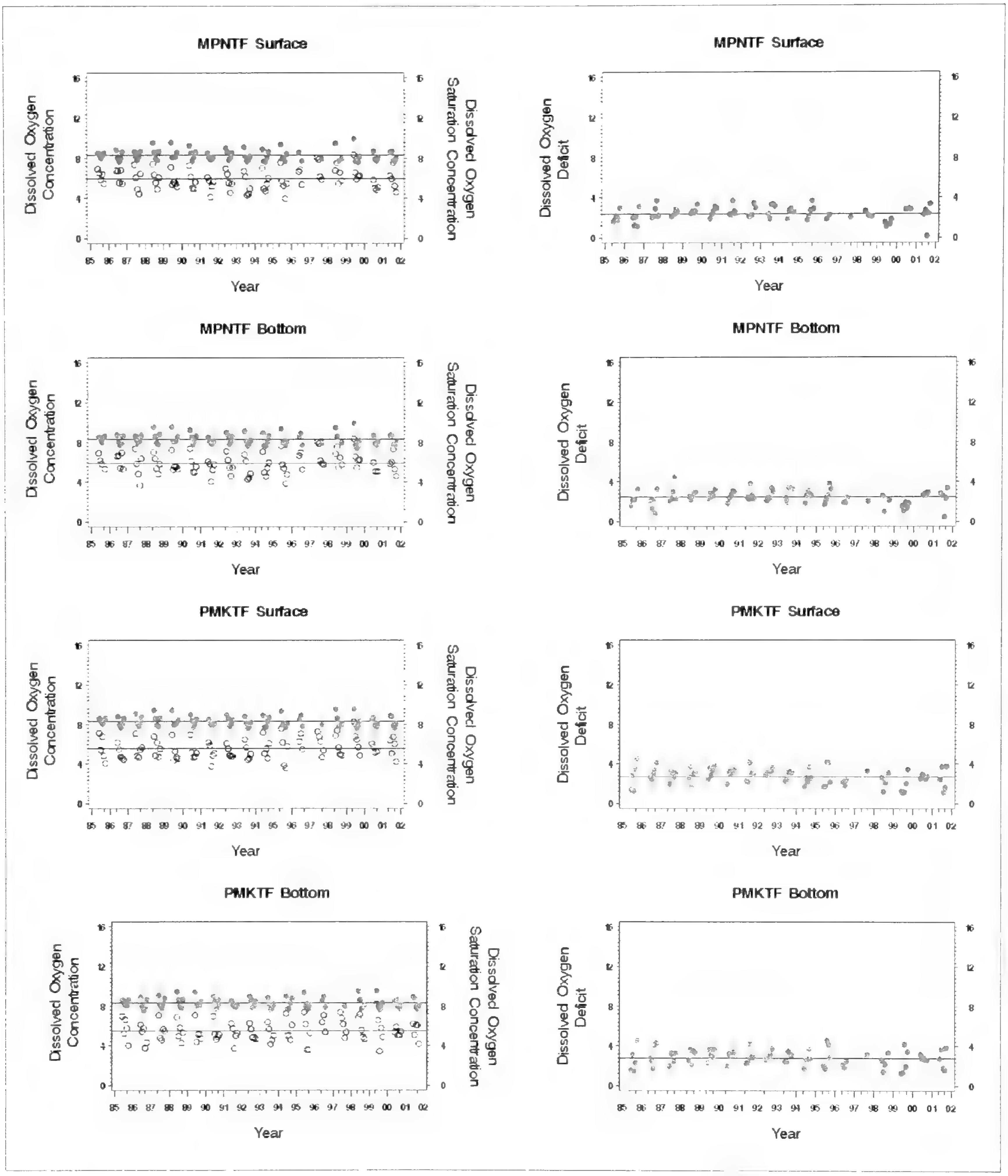

Figure VI-1. Time series plots of ambient dissolved oxygen concentrations (mg liter^{-1}) and calculated dissolved oxygen saturation concentrations (mg liter^{-1}) and resultant calculated dissolved oxygen deficit (saturation concentration minus ambient concentration) in surface and bottom waters of the tidal fresh segments of the Mattaponi (MPNTF) and Pamunkey (PMKTF) rivers.

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

DISSOLVED OXYGEN/TEMPERATURE RELATIONSHIPS

Another natural feature of tidal systems strongly influenced by extensive adjacent tidal wetlands would be a strong relationship between the ambient dissolved oxygen concentrations (and dissolved oxygen deficit) and water temperature, useful for separating out the wetlands' effect on dissolved oxygen versus an anthropogenic effect. Figure VI-2 shows dissolved oxygen concentration and dissolved oxygen deficit plotted versus water temperature for the tidal fresh and oligohaline segments of the Mattaponi and Pamunkey rivers and for the tidal fresh and oligohaline segments of the Rappahannock and Patuxent rivers for comparison. All the plots illustrated in Figure VI-2 show dissolved oxygen concentrations going down as water temperature rises due to decreasing saturation concentrations and likely increased biological/chemical demand.

In the Rappahannock and Patuxent segments, however, dissolved oxygen concentrations begin to trend back upward (and the dissolved oxygen deficit levels out) as temperatures continue to increase. Presumably the generation of oxygen from planktonic algal photosynthesis at these increasing temperatures provides the beneficial boost during the daytime when these measurements were collected.

This trend effect in which dissolved oxygen concentrations increase as temperatures continue to increase is not evident in the Mattaponi and Pamunkey segments. Based on a comparison of the values in Table VI-2 and Appendix A, the difference in chlorophyll *a* concentrations in Rappahannock and Patuxent (higher concentrations) versus Mattaponi and Pamunkey river segments (lower concentrations) supports this hypothesis. These findings lend further evidence of the lack of a strong influence of planktonic algal photosynthesis on dissolved oxygen concentrations with the Mattaponi and Pamunkey rivers.

LOW VARIABILITY IN DISSOLVED OXYGEN CONCENTRATIONS

One could also hypothesize that, within the temperature trend described above and illustrated in Figure VI-2, there should be less scatter in the data points in a system whose 'stressor' exerted its effect in a relatively constant manner, as the wetlands might. While this hypothesis may be true and is suggested in the plots provided in Figure VI-2, the differences among the segments in the number and diversity of stations contributing data points is confounding a clearer conclusion. Table VI-3, however, provides further quantitative information on dissolved oxygen concentration variability in the Mattaponi and Pamunkey segments which does support that hypothesis.

Through the long-term Chesapeake Bay Water Quality Monitoring Program, Virginia has been collecting monthly or twice monthly dissolved oxygen measurements (surface and bottom) at fixed stations in the Mattaponi and Pamunkey tidal fresh and oligohaline segments since 1985. The data are collected in the daytime and each measurement represents one point in time in the month or two-week interval.

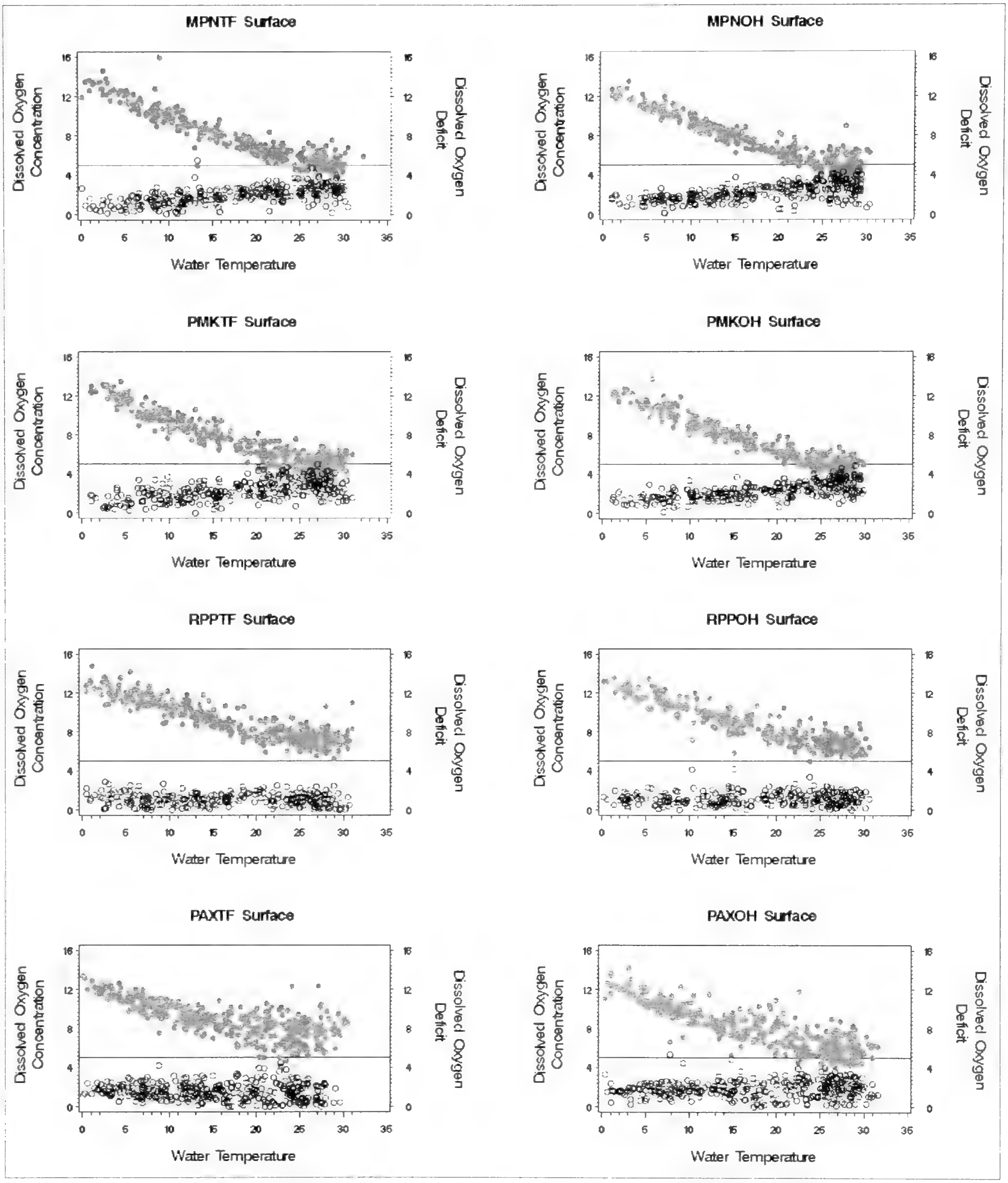

Figure VI-2. Plots of measured ambient dissolved oxygen concentrations (•, mg liter^{-1}) and calculated dissolved oxygen deficit (o, mg liter^{-1}) versus water temperature (°C) in tidal fresh and oligohaline segments of the Mattaponi (MPNTF and MPNOH, respectively) and Pamunkey (PMKTF and PMKOH, respectively) rivers and in the tidal fresh and oligohaline segments of Rappahannock (RPPTF and RPPOH, respectively) and Patuxent (PAXTF and PAXOH, respectively) rivers for comparison.

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

In 2003, in-situ, continuous monitoring devices were deployed by the Virginia Institute of Marine Science at a number of sites within both tidal rivers and all four salinity-based segments. These 'buoys' were deployed to collect data at time-scales more relevant to the Chesapeake Bay dissolved oxygen criteria, which have 7-day mean and instantaneous minimum as well as the 30-day mean averaging periods (U.S. EPA 2003a). These buoys collect dissolved oxygen concentration and other physical data continuously at 15-minute intervals.

For the comparisons in Table VI-3, the mean and other statistics of the long-term daytime Chesapeake Bay Water Quality Monitoring Program measurements were computed for each month over the 18-year record, separately for surface (water column depth = 1 meter) and bottom (where the water column depth was >1 meter) waters. The continuous buoy data were divided into day (6:00 AM-5:59 PM) and night (6:00 PM-5:59 AM) periods. All the buoys were deployed at the fixed depths listed in Table VI-3.

The low variability in dissolved oxygen concentrations measured in the Mattaponi and Pamunkey segments are documented by four separate measures: 1) the small within-month range of concentrations measured in the Chesapeake Bay Water Quality Monitoring Program over the 18-year data record; 2) the small dissolved oxygen concentration differences between surface and deeper waters (long-term water quality monitoring program data station); 3) the good agreement between dissolved oxygen concentrations measured at the long-term water quality monitoring program stations and the continuous buoy sites; and 4) the small differences between day and night concentrations recorded in the continuous buoy data. Similar comparisons are becoming possible in other Chesapeake Bay and tidal tributary segments with expanded implementation of shallow water and continuous buoy deployment monitoring programs. This expanding data record will be evaluated in the future to further confirm low-variability in dissolved oxygen concentrations are an important characteristic of segments where extensive tidal wetlands are directly influencing ambient dissolved oxygen concentrations.

APPROACHES FOR ADDRESSING NATURALLY LOW DISSOLVED OXYGEN CONDITIONS DUE TO TIDAL WETLANDS

Four approaches for addressing naturally low ambient dissolved oxygen concentrations due to adjacent extensive tidal wetlands within the context of state water quality standards were considered:

1. Define a completely new designated use with the appropriate dissolved oxygen criteria.
2. Develop a separate biological reference curve that would account for lower dissolved oxygen values in wetland-dominated tidal water segments.

Table VI-3. Dissolved oxygen concentration (mg liter^{-1}) data from the 1985-2002 Chesapeake Bay Water Quality Monitoring Program and the 2003 Virginia Institute of Marine Science continuous dissolved oxygen measurements collected in the Mattaponi and Pamunkey tidal fresh (MPNTF and PMKTF, respectively) and oligohaline (MPNOH and PMKOH, respectively) segments.

						Dissolved Oxygen Concentration (mg liter^{-1})				
CBP Segment	Station	Depth (meters)	Month	Year	Period	Mean	Standard Deviation	5th Percentile	Median	95th Percentile
MPNTF	Water Quality Monitoring Stations	1.0	May	.	Day	7.1	0.7	6.2	7.0	8.4
		3.0			Day	7.0	0.8	5.9	6.9	8.4
		1.0	June	.	Day	6.2	0.7	5.1	6.0	7.6
		2.9			Day	6.2	0.7	5.0	6.0	7.6
		1.0	July	.	Day	5.4	0.8	4.3	5.3	6.8
		3.4			Day	5.3	0.8	4.1	5.3	6.8
	Walkerton (Buoy station)	1.4	May	2003	Day	7.2	0.3	6.8	7.0	7.9
		1.6			Night	7.1	0.3	6.8	7.1	7.8
		1.4	June	2003	Day	6.2	0.6	5.2	6.3	6.9
		1.5			Night	6.1	0.5	5.3	6.3	6.9
		1.4	July	2003	Day	5.4	0.3	4.9	5.3	6.0
		1.4			Night	5.4	0.3	4.8	5.4	6.0
MPNOH	Water Quality Monitoring Stations	1.0	May	.	Day	6.4	0.7	5.4	6.4	7.7
		12.5			Day	6.3	0.7	5.4	6.2	7.6
		1.0	June	.	Day	5.5	0.8	4.3	5.4	6.7
		12.5			Day	5.4	0.8	4.1	5.4	6.6
		1.0	July	.	Day	5.0	1.2	3.4	4.9	6.6
		12.1			Day	4.7	0.8	3.3	4.8	6.0
	Muddy Point (Buoy station)	1.3	May	2003	Day	6.2	0.1	5.9	6.2	6.4
		1.4			Night	6.1	0.2	5.8	6.1	6.4
		1.3	June	2003	Day	5.1	0.8	4.2	4.9	6.5
		1.4			Night	5.1	0.8	4.1	4.9	6.4
		1.3	July	2003	Day	4.2	0.2	3.8	4.2	4.5
		1.3			Night	4.2	0.2	3.9	4.2	4.7
PMKTF	Water Quality Monitoring Stations	1.0	May	.	Day	6.8	0.9	5.7	6.8	8.4
		6.3			Day	6.8	0.9	5.4	6.7	8.4
		1.0	June	.	Day	5.6	0.8	4.7	5.4	7.1
		6.5			Day	5.6	0.8	4.6	5.5	7.1
		1.0	July	.	Day	5.3	1.0	3.6	5.5	6.7
		6.4			Day	5.0	1.3	3.6	5.1	6.4
	White House (Buoy station)	2.3	May	2003	Day	6.2	0.2	5.8	6.2	6.7
		2.3			Night	6.3	0.3	5.8	6.3	6.8
		2.0	June	2003	Day	6.3	0.7	5.2	6.4	7.4
		2.1			Night	6.3	0.6	5.3	6.4	7.1
		1.8	July	2003	Day	.	.	.	.	.

		1.9			Night	.	.	.	.	.
PMKOH	Water Quality Monitoring Stations	1.0	January	.	Day	11.5	0.9	10.5	11.4	13.7
		5.1			Day	11.7	0.8	10.7	11.7	13.6
		1.0	February	.	Day	11.2	1.1	8.8	11.2	12.8
		5.4			Day	11.4	1.1	8.9	11.2	12.9
		1.0	March	.	Day	10.0	0.8	9.0	9.9	11.3
		5.2			Day	10.1	0.9	9.0	10.1	11.4
		1.0	April	.	Day	8.2	0.7	6.9	8.2	9.3
		5.0			Day	8.2	0.8	6.9	8.2	9.7
		1.0	May	.	Day	6.7	0.8	5.5	6.6	8.2
		5.2			Day	6.7	0.9	5.6	6.6	8.2
		1.0	June	.	Day	5.3	0.8	4.0	5.1	6.5
		4.8			Day	5.3	0.9	4.0	5.2	7.0
		1.0	July	.	Day	4.8	0.9	3.5	4.9	6.0
		4.8			Day	4.7	0.9	3.5	4.9	5.6
	Sweethall Marsh (Buoy station)	0.3	January	2003	Day	12.0	0.7	10.7	12.1	13.0
		0.2			Night	12.0	0.7	10.8	12.1	13.0
		0.3	February	2003	Day	12.9	1.5	10.8	13.7	14.8
		0.3			Night	12.9	1.6	10.9	13.8	14.9
		0.4	March	2003	Day	10.3	1.1	8.5	10.5	11.9
		0.4			Night	10.3	1.2	8.3	10.5	11.9
		0.6	April	2003	Day	9.0	1.0	7.7	8.7	10.7
		0.6			Night	8.9	1.0	7.4	8.7	10.5
PMKOH	Sweethall Marsh (Buoy station)	0.6	May	2003	Day	6.8	0.5	6.1	6.8	7.5
		0.6			Night	6.6	0.6	5.7	6.7	7.4
		0.6	June	2003	Day	5.8	0.7	4.7	5.7	7.0
		0.7			Night	5.6	0.7	4.6	5.4	6.9
		0.5	July	2003	Day	5.1	0.4	4.5	5.1	5.6
		0.5			Night	4.8	0.3	4.3	4.8	5.4

Source: Chesapeake Bay Water Quality Monitoring Program
http://www.chesapeakebay.net/data

3. Determine a fixed or multivariate compensation factor to 'adjust' (upward) the observed dissolved oxygen concentration values. The adjusted values would be substituted for observed values in the criteria attainment assessment protocol used for all affected designated uses, i.e., comparing the cumulative frequency distribution curve of observed values to the biological reference curve.
4. Derive a set of site-specific dissolved oxygen criteria values that factor in the natural dissolved oxygen deficit.

The first approach—a completely new designated use—was rejected because the species and habitat requirements of those species that should be protected in these tidal wetland dominated segments are the same species that occupy other open-water designated use tidal water segments of similar salinity regimes. The assumption is that in these areas, the species' dissolved oxygen requirements are the same but that they may modify their behavior, utilize the area differently or otherwise make accommodation for the natural effect of the tidal wetlands on ambient dissolved oxygen concentrations with some level of adverse effects.

The second approach—developing a separate biological reference curve—was rejected because the biological reference levels are, by definition, based on ambient dissolved oxygen conditions exhibited by areas supporting high functioning living resources. Even if this definition were abandoned in favor of a curve or curves based on specific natural impairments, then the Mattaponi and Pamunkey segments would have to serve as their own reference sites since there are no other comparable segments within the Chesapeake Bay system. Taking this approach to deriving biological reference curves was difficult to rationalize.

The third approach—to find an appropriate adjustment factor for observed concentrations—was rejected because of concerns that the criteria, not the attainment procedures, should directly reflect the natural dissolved oxygen deficits caused by extensive tidal wetlands.

The fourth option—derive a set of set specific dissolved oxygen criteria values—was recommended as the best approach to factor in the natural wetlands-caused dissolved oxygen deficit directly for the reasons and technical basis documented below.

DERIVATION OF SITE-SPECIFIC DISSOLVED OXYGEN CRITERIA FACTORING IN NATURAL WETLAND-CAUSED DISSOLVED OXYGEN DEFICITS

Through evaluation of three independent sources of information—scientific findings published in the peer reviewed literature, Chesapeake Bay water quality model simulations, and the long-term Chesapeake Bay Water Quality Monitoring Program data record—efforts were made to quantify the deficit in dissolved oxygen concentrations below oxygen saturation levels due to natural tidal wetland processes. Once quantified, the wetland-caused oxygen deficits could then be subtracted from calculated oxygen saturation concentrations to determine the natural background oxygen levels that could be sustained within these wetland dominated tidal rivers *absent* any external anthropogenic nutrient pollutant loadings.

SCIENTIFIC RESEARCH-BASED ESTIMATES OF WETLAND RESPIRATION

As part of the analysis to examine dissolved oxygen criteria attainment in the various tidal wetland dominated segments, the Chesapeake Bay Water Quality Model was calibrated to account for wetland oxygen demand by applying a universal sediment oxygen demand of 2 grams O_2/meter^2-day to all Chesapeake Bay tidal wetland areas. This value is a best professional judgement based on values published in the scientific literature and communication with Chesapeake Bay wetland scientists (Neubauer 2003). The scientific literature indicates wetland sediment oxygen demand in Northeastern United States ranges from 1 to 5.3 grams O_2/meter^2-day (Neubauer et al. 2000; Cai et al. 1999).

The value for sediment oxygen demand used in the previous 1998 Chesapeake Bay water quality model calibration (2 grams O_2/meter^2-day) was re-examined and determined to be accurate for the Mattaponi and Pamunkey rivers. Scott Neubauer of the Smithsonian Environmental Research Center (personal communication June 19, 2003) estimates the marsh sediment oxygen consumption for Sweet Hall marsh, a freshwater marsh in the Pamunkey River, to range between 0.99-2.59 grams O_2/meter^2-day. Neubauer's estimated ranges further support the sediment oxygen demand of 2 grams O_2/meter^2-day that was used in the previous model calibration. Neubauer also concurred that the Mattaponi and Pamunkey systems are very similar (Neubauer 2003). Therefore, there was no need to recalibrate the sediment oxygen demand for either tidal tributary.

MODEL-BASED WETLAND-CAUSED OXYGEN DEFICITS

The impact of wetland oxygen demand on ambient dissolved oxygen concentrations was quantified for both the Mattaponi and Pamunkey segments through application of the Chesapeake Bay water quality model. A series of water quality model scenarios 'with wetlands' and 'without wetlands' were run to estimate the difference in model-adjusted interpolated monthly averaged dissolved oxygen concentration in the Mattaponi and Pamunkey segments. In the 'with wetlands' scenario, the water quality model simulated the full influence of the extensive adjacent tidal wetlands on ambient water quality conditions. In the 'without wetlands' scenario, the tidal wetland functions of the model were turned off in the Mattaponi and Pamunkey model cells in order to simulate ambient water quality conditions in the absence of any influence by tidal wetlands. The summer monthly averaged dissolved oxygen concentration difference simulated by the 'with wetlands' scenario minus the 'without wetlands' scenario was 3 mg liter^{-1}, i.e., the open-water dissolved oxygen concentrations in the Mattaponi and Pamunkey segments with the presence of the extensive tidal wetlands were simulated to be 3 mg liter^{-1} lower than model estimated dissolved oxygen saturated concentrations. The model estimated 3 mg liter^{-1} oxygen deficit is fully consistent with the average dissolved oxygen deficits observed in monitoring data collected in these segments (see text below, Tables VI-2 and VI-3, Figure VI-1).

MONITORING-BASED ESTIMATES OF WETLAND-CAUSED OXYGEN DEFICITS

The dissolved oxygen concentration and oxygen saturation levels were calculated from the 1985–2002 Chesapeake Bay Water Quality Monitoring Program data collected at stations in the Mattaponi and Pamunkey segments. Over the 18-year data record, these stations were sampled at least monthly—sometimes twice monthly—as part of the long-term water quality monitoring program. The almost two-decade data record covers years of varying climatic and hydrologic conditions in the watershed. Continuous, high frequency dissolved oxygen concentration data were also available for these segments, as described previously, but in most cases the duration of the data records is less than one year. Based on findings presented above, dissolved oxygen conditions characterized by the data collected at long-term (daytime) monitoring stations were very similar to those revealed by the continuous dissolved oxygen recording devices: short-term temporal and spatial variations in dissolved oxygen concentrations were relatively small; and deep nocturnal dips in dissolved oxygen concentrations were not observed in these segments.

For this analysis, the long-term water quality monitoring data were partitioned into surface and bottom depths and into 'cold' (sampling events when water column temperatures were less than or equal to 15° C) and 'warm' (greater than 15° C) temperature categories. Table VI-4 shows: the calculated mean dissolved oxygen saturation concentration over the 18 year data record; the difference between calculated oxygen saturation and actual observed dissolved oxygen concentrations, i.e., the dissolved oxygen deficit; the number and percent of dissolved oxygen measurements below the 5 mg liter^{-1} 30-day mean criterion and below a 4 mg liter^{-1} concentration value; and the average magnitude of those episodic excursions below the 5 and 4 mg liter^{-1} values. Dissolved oxygen concentrations are always well above the 5 mg liter^{-1} 30-day mean criterion in the cold months in the Mattaponi and Pamunkey river segments, so the cold month statistics are not discussed further.

As presented earlier and previewed in Table VI-2, the average dissolved oxygen deficit in the warm (>15° C) months was 2.6 +/- 0.8 mg liter^{-1} (Table VI-4). This long-term average monitoring data-based oxygen deficit value overlaps with the oxygen deficit of 3 mg liter^{-1} estimated through the Bay water quality model simulation of tidal dissolved oxygen concentrations with and without tidal wetlands.

The calculated dissolved oxygen saturation concentration in the Mattaponi and Pamunkey segments in the warm months was 8.5 +/- 0.7 mg liter^{-1}. That means that, in the absence of any anthropogenic pollutant influences on water quality conditions,

Table VI-4a. 1985–2002 monthly averaged Chesapeake Bay Water Quality Monitoring Program dissolved oxygen concentrations, saturation levels and deficits for the cold (≤15°C) and warm months (>15°C) of the year within the Mattaponi ande Pamunkey tidal fresh (MPNTF and PMKTF, respectively) and oligohaline (MPNOH and PMKOH, respectively) segments.

Temperature Group	Water Column Layer	CBP Segment	Rank*	Number of Observations	Mean Dissolved Oxygen Saturation (mg liter^{-1})	Standard Deviation Dissolved Oxygen Saturation (mg liter^{-1})	Mean Dissolved Oxygen Deficit (mg liter^{-1})	Standard Deviation Dissolved Oxygen Deficit (mg liter^{-1})
COLD	S	PMKTF	3	98	11.8	1.1	1.7	0.8
COLD	S	PMKOH	5	97	11.5	1.1	1.7	0.7
COLD	S	MPNOH	7	99	11.5	1.1	1.6	0.6
COLD	S	MPNTF	10	104	11.9	1.2	1.3	1.1
COLD	B	PMKTF	3	100	11.8	1.1	1.8	0.8
COLD	B	PMKOH	6	99	11.4	1.1	1.5	0.8
COLD	B	MPNOH	9	101	11.4	1.1	1.4	0.9
COLD	B	MPNTF	12	102	11.8	1.1	1.3	1.1
WARM	S	PMKOH	2	161	8.4	0.7	2.7	0.8
WARM	S	PMKTF	3	167	8.6	0.7	2.6	0.9
WARM	S	MPNOH	4	162	8.4	0.8	2.6	0.9
WARM	S	MPNTF	5	151	8.6	0.7	2.4	0.7
WARM	B	PMKTF	3	163	8.6	0.7	2.7	1.0
WARM	B	PMKOH	4	161	8.3	0.7	2.7	0.8
WARM	B	MPNOH	5	160	8.4	0.7	2.7	0.8
WARM	B	MPNTF	6	147	8.6	0.7	2.4	0.8

*Rank in a list of all Chesapeake Bay Program tidal fresh and oligohaline segments (~30 segments) ranked in order of their mean dissolved oxygen deficit, from highest to lowest within temperature group and layer.

S surface
B – bottom

Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

Table VI-4b. Differences of 1985–2002 monthly averaged Chesapeake Bay Water Quality Monitoring Program dissolved oxygen concentrations from target concentrations of 4- and 5 mg liter^{-1} for the cold (≤15°C) and warm months (>15°C) of the year within the Mattaponi and Pamunkey tidal fresh (MPNTF and PMKTF, respectively) and oligohaline (MPNOH and PMKOH, respectively) segments.

Temperature Group	Water Column Layer	CBP Segment	Number of Observations	Number of Observations < 4 mg liter^{-1}	Percent of Observations < 4 mg liter^{-1}	Mean Difference from 4 mg liter^{-1}	Standard Deviation from 4 mg liter^{-1}
COLD	S	PMKTF	98	0	0.0	.	.
COLD	S	PMKOH	97	0	0.0	.	.
COLD	S	MPNOH	99	0	0.0	.	.
COLD	S	MPNTF	104	0	0.0	.	.
COLD	B	PMKTF	100	0	0.0	.	.
COLD	B	PMKOH	99	0	0.0	.	.
COLD	B	MPNOH	101	0	0.0	.	.
COLD	B	MPNTF	102	0	0.0	.	.
WARM	S	PMKOH	161	11	6.8	-0.4	0.4
WARM	S	PMKTF	167	10	6.0	-0.3	0.3
WARM	S	MPNOH	162	7	4.3	-0.4	0.2
WARM	S	MPNTF	151	1	0.7	-0.7	.
WARM	B	PMKTF	163	9	5.5	-0.7	1.1
WARM	B	PMKOH	161	13	8.1	-0.4	0.4
WARM	B	MPNOH	160	7	4.4	-0.5	0.3
WARM	B	MPNTF	147	3	2.0	-0.4	0.3

Temperature Group	Water Column Layer	CBP Segment	Number of Observations	Number of Observations < 5 mg liter^{-1}	Percent of Observations < 5 mg liter^{-1}	Mean Difference from 5 mg liter^{-1}	Standard Deviation from 5 mg liter^{-1}
COLD	S	PMKTF	98	0	0.0	.	.
COLD	S	PMKOH	97	0	0.0	.	.
COLD	S	MPNOH	99	0	0.0	.	.
COLD	S	MPNTF	104	0	0.0	.	.
COLD	B	PMKTF	100	0	0.0	.	.
COLD	B	PMKOH	99	0	0.0	.	.
COLD	B	MPNOH	101	0	0.0	.	.
COLD	B	MPNTF	102	0	0.0	.	.
WARM	S	PMKOH	161	50	31.1	-0.7	0.5
WARM	S	PMKTF	167	42	25.1	-0.6	0.5
WARM	S	MPNOH	162	46	28.4	-0.6	0.4
WARM	S	MPNTF	151	20	13.2	-0.5	0.4
WARM	B	PMKTF	163	41	25.2	-0.7	0.8
WARM	B	PMKOH	161	48	29.8	-0.7	0.5
WARM	B	MPNOH	160	50	31.3	-0.6	0.4
WARM	B	MPNTF	147	21	14.3	-0.6	0.4

S = surface
B = bottom
Source: Chesapeake Bay Water Quality Monitoring Program database. http://www.chesapeakebay.net/data

much of the time the fully saturated ambient dissolved oxygen concentrations would still above the 5 mg liter^{-1} 30-day mean criterion level. However, from 13 to greater than 30 percent of the warm months' monitoring-based observations fell below a monthly mean of 5 mg liter^{-1} with the magnitudes of these exceedences up to 0.7 mg liter^{-1}. These observations indicate that the segments would likely fail a summertime application of the 5 mg liter^{-1} 30-day mean criteria. Tested against a monthly mean concentration of 4 mg liter^{-1}, however, the percentage of observations falling below this concentration is less than 7 percent in most cases, and the magnitude of the exceedance is ~0.5 mg liter^{-1} (Table VI-4).

The warm months calculated dissolved oxygen saturation concentration of 8.5 +/-0.7 mg liter^{-1} directly translates into a dissolved oxygen concentration range of 7.8 to 10.2 mg liter^{-1}. Similarly, the warm months average oxygen deficit of 2.6 +/-0.8 mg liter^{-1} converts into a oxygen deficit concentration range of 1.6 to 3.4 mg liter^{-1}. Assuming a maximum long-term average oxygen deficit of 3.4 mg liter^{-1}, we could anticipate an ambient dissolved oxygen range of 6.8 to 4.4 mg liter^{-1} upon factoring in the oxygen deficit to a saturated water column condition. These are the best dissolved oxygen conditions, assuming the maximum oxygen deficit, one could ever hope to measure in the absence of any anthropogenic nutrient pollutant loading influence on ambient dissolved oxygen conditions. Even without any human impacts, the 5 mg liter^{-1} 30-day mean dissolved oxygen criterion would be not attained all times in the warm months of the year, setting up the basis for a site-specific criterion based on natural conditions preventing attainment of the use (U.S. EPA 2003b).

SITE-SPECIFIC DISSOLVED OXYGEN CRITERIA DERIVATION

Factoring a natural tidal wetlands-based oxygen deficit into the oxygen saturation levels, based on the 18-year data record (see above), along with recognition that the antropogenic pollutant loads can be reduced but not eliminated (U.S. EPA 2003b), a site specific 4 mg liter^{-1} 30-day mean criterion is recommended in place of the published 5 mg liter^{-1} 30-day mean and 4 mg liter^{-1} 7-day mean open-water designated use criteria. The EPA-published 3.2 mg liter^{-1} instantaneous minimum dissolved oxygen criterion still applies to these waters year round (U.S. EPA 2003a). The 4 mg liter^{-1} 30-day mean site-specific criterion applies only to the tidal fresh and oligohaline segments of the Mattaponi and Pamunkey rivers during the time period of June 1 through September 30. Outside of this time period, the EPA-published set of open-water designated use dissolved oxygen criteria apply (U.S. EPA 2003a). The water column temperatures during the October through May time-frame are such that higher levels of oxygen saturation are maintained and the biological processes driving the natural tidal wetland oxygen deficits do not have nearly the same level of influence on ambient dissolved oxygen concentrations.

This approach assumes that the nature of the wetland effect on dissolved oxygen is relatively constant within season and that there are no other major stresses on dissolved oxygen in the system as documented previously. This results in relatively stable dissolved oxygen concentrations, which although sometimes below the 5 mg liter^{-1} 30-day mean criterion level due to natural oxygen deficits, remain substantially above the instantaneous minimum criterion. The magnitude of the wetland-caused oxygen deficit is not enough to cause the calculated oxygen saturated concentrations to fall below the 3.2 mg liter^{-1} instantaneous minimum. Therefore any future observed exceedences of this criterion value are likely due to anthropogenic nutrient pollutant loadings, not natural wetland-caused oxygen deficits.

At attainment levels sustained for long periods of time just above the 4 mg liter^{-1} criterion concentration (e.g., very few observed concentrations above 4 mg liter^{-1}), survival of open-water aquatic species in their larval, juvenile and adult lifestages will not be impaired but there is likely to be some unquantified level of growth-related impairments. However, the 18-year data record indicates a maximum of less than one-third of the segment-based dissolved oxygen concentrations would not attain a 5 mg liter^{-1} concentration (Table VI-4). Therefore, combined with implementation of further nutrient reduction actions in the upstream watersheds yielding higher measured ambient dissolved oxygen concentrations in the future, the number of exceedences of the 5 mg liter^{-1} concentration will be even less, further limiting growth effects.

With a 30-day mean criterion of 4 mg liter^{-1}, these segments are likely to pass or come close to passing a formal criteria assessment under current conditions. Given that some fraction of oxygen depletion in these segments is definitely caused by controllable nutrient inputs, tributary-based nutrient reduction strategies should be more than adequate to raise ambient oxygen levels above the 4 mg liter^{-1} concentration.

SITE-SPECIFIC CRITERIA BIOLOGICAL REFERENCE CURVE

The criteria assessment protocol for all segments and designated uses employs monitoring data to develop cumulative frequency distribution (CFD) curves of exceedance, which are compared to biological reference curves specific to designated uses, salinity regimes, and seasons. Monitoring data are interpolated over a fixed three-dimensional grid to obtain dissolved oxygen concentrations for each grid cell. These are compared to appropriate criteria values and yield a grid-cell by grid-cell estimate of the volume or area of criteria exceedance. The percentages of a segment's volume/area exceeding the criteria levels are accumulated over all observation dates in the assessment period. The CFD generated from these data reflect exceedance (and by difference, attainment) in both space and time. (See Chapter 6 of *Ambient Water Quality Criteria for Dissolved Oyxgen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries* (U.S. EPA 2003a) for more details on the criteria attainment assessment protocol.) The biological reference curve is the CFD of exceedances in segments or other areas that are determined to be 'healthy,' i.e., that demonstrably support growth and reproduction of the living resources targeted for protection by these criteria.

The biological reference levels are, by definition, based on ambient dissolved oxygen conditions exhibited by areas supporting high functioning living resources. Even if this definition were abandoned in favor of a curve or curves based on specific natural impairments, then the Mattaponi and Pamunkey segments would have to serve as their own reference sites, which is difficult to rationalize. In the absence of sufficient data necessary to generate a biological reference curve, EPA recommends application of a normal distribution curve representing approximately 10 percent allowable criteria exceedence (U.S. EPA 2003a).

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chapter vii

Upper and Lower Pycnocline Boundary Delineation Methodology

Vertical stratification is foremost among the physical factors affecting dissolved oxygen concentrations in some parts of Chesapeake Bay and its tidal tributaries. 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 (Figure VII-1). For the purposes of water quality criteria attainment assessment, the Chesapeake Bay and tidal tributary waters are separated into a surface mixed layer (e.g., open-water designated use), an inter-pycnocline layer (e.g., deep-water designated use) and a lower mixed layer (e.g., deep-channel designated use) (U.S. EPA 2003a, 2003b).

Accurate estimates of the pycnocline are important for assessing criteria attainment. The method documented here for assessing upper and lower mixed layer depths differs from the standard Chesapeake Bay Water Quality Monitoring Program field sampling cruise method (Chesapeake Bay Program 1996) in that this methodology uses a measured density gradient based on salinity and temperature rather than relying on the field surrogate, conductivity.

Defining the depth of the upper mixed layer based on the physical barrier of a density gradient is discussed in Brainerd and Gregg 1995. Culver and Perry (1999) and Larsson et al. (2001) propose particular density gradient thresholds for defining this layer. The critical density gradient is dependent on many factors, most importantly the strength of the turbulent mixing. Generally, for the Chesapeake Bay the upper pycnocline depth, defining the surface mixed layer, is the shallowest occurrence of a density gradient of 0.1 kg/m^4 or greater. The lower mixed layer depth is the deepest occurrence of a density gradient of 0.2 kg/m^4, if a lower mixed layer exists below it. These limits were based on an extensive review of thousands of density profiles throughout the Chesapeake Bay and its tidal tributaries throughout 19-year record of the Chesapeake Bay Water Quality Monitoring Program. These density gradient thresholds are consistent with the values published for other tidal water bodies and with similar studies in the Chesapeake Bay (Fisher 2003). Since pycnocline delineation is based on hydrodynamics and not bathymetry, the depth of the pycnocline and hence the boundaries of the designated uses changes on a monthly basis.

DETERMINATION OF THE VERTICAL DENSITY PROFILE

The vertical water column density profile (sigma-t) is calculated using the following equations:

Sigma_t = tsum+((sigo+0.1324)*(1–sa+sb*(sigo –0.1324)))

Where:

tempc = water temperature in degrees Celsius

salinity = salinity in grams per liter

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))),

and

sb = ((10**–6)*tempc)*(18.030–(0.8164*tempc)+(0.01667*(tempc**2))).

DETERMINATION OF THE PYCNOCLINE DEPTHS

To determine the depths of the pycnocline, the following rules are applied to the density profile:

1) From the water surface downward, the first density slope observation that is greater than 0.1 kgm^{-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.

2) From the bottom sediment-water interface upward, 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 sediment-water interface being less than 0.2 kg m^{-4}; and
    c) the next density slope observation above is positive.

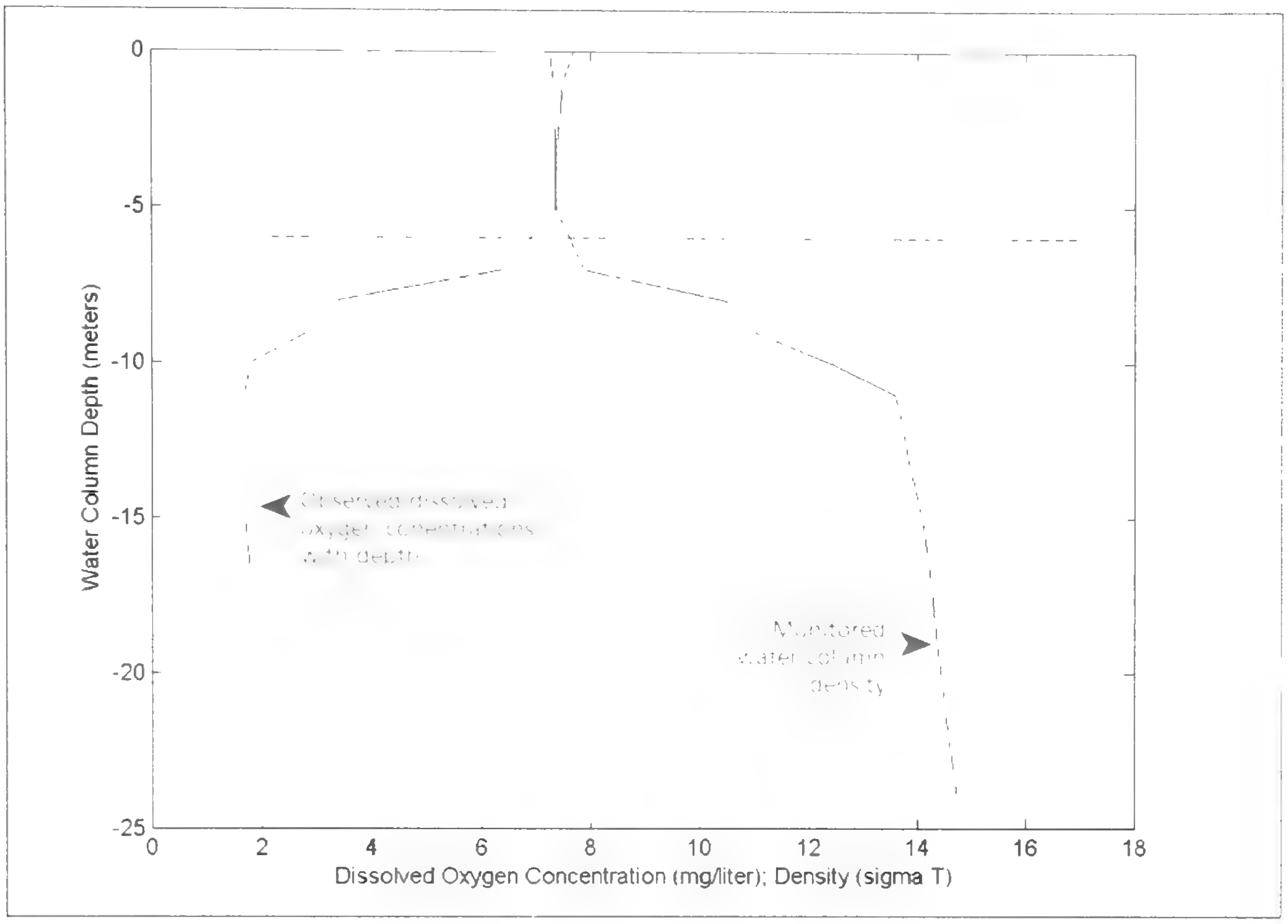

Figure VII-1. Example of a vertical density profile with calculated pycnocline boundaries and observed dissolved oxygen concentrations with depth. Monitored water column density and observed dissolved oxygen concentrations with depth are illustrated with the upper (dashed line) and lower (dotted line) pycnocline depths overlaid for station CB4.3 in the middle Chesapeake Bay mainstem on June 10, 1986.

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chapter viii

Updated Guidance for Application of Water Clarity Criteria and SAV Restoration Goal Acreages

With publication of the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance)* (U.S. EPA 2003a) and the *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability (Technical Support Document)* (U.S. EPA 2003b), the jurisdictions were provided with extensive guidance for how to determine attainment of the shallow-water bay grass designated use.

Specifically, the EPA *Regional Criteria Guidance* document provided the following guidance to the jurisdictions:

> To determine the return of water clarity conditions necessary to support restoration of underwater grasses and, therefore, attainment of the shallow-water designated use, states may: 1) evaluate the number of acres of underwater bay grasses present in each respective Chesapeake Bay Program segment, comparing that acreage with the segment's bay grass restoration goal acreage; and/or 2) determine the attainment of the water clarity criteria within the area designated for shallow-water bay grass use. The shallow-water bay grass use designated use area may be defined by either: 1) applying the appropriate water clarity criteria application depth (i.e., 0.5, 1 or 2 meters) along the entire length of the segment's shoreline (with exception of those shoreline areas determined to be bay grass no-zone grow zones; see U.S. EPA 2003 [*Technical Support Document*] for details); or 2) determining the necessary total acreage of shallow-water habitat within which the water clarity criteria must be met using a salinity regime specific ratio of underwater bay grass acres to be restored within a segment to acres of shallow-water habitat that must meet the water clarity criteria within the same segment (regardless of specifically where and at what exact depth those shallow water habitat acreages reside within the segment).

These approaches to assessing attainment of the shallow-water bay grass designated use were described in more detail in Chapter 6 of the *Regional Criteria Guidance* document (U.S. EPA 2003a). Since the 2003 publication of both the *Regional Criteria Guidance* and the *Technical Support Document*, new information has become available to the watershed jurisdictions and EPA in support of state adoption of SAV restoration goal, shallow water habitat and shallow-water existing use acreages into their water quality standards regulations. This new information will also help the four jurisdictions with Chesapeake Bay tidal waters adopt consistent, specific procedures for determining attainment of the shallow-water bay grass designated uses into their regulations. (Note the terms 'underwater bay grasses' and 'submerged aquatic vegetation' or 'SAV' are used interchangeably in this document.)

EPA continues to support and encourage the jurisdictions' adoption of the Chesapeake Bay Program segment-specific submerged aquatic vegetation (SAV) restoration goal acreages and the corresponding water clarity criteria attaining shallow-water acreage necessary to support restoration of those acreages of SAV into each jurisdictions' respective water quality standards regulations. Achievement of the SAV restoration goal and shallow-water acreages are two additional means, beyond numerical water clarity criteria applied to segment-specific application depths, for defining attainment of the shallow-water bay grass designated use.

WATER CLARITY CRITERIA APPLICATION PERIODS

The temporal application periods for the water clarity criteria were determined based on the growing seasons for the salinity-based SAV plant communities: April 1 through October 31 for tidal fresh, oligohaline and mesohaline salinity regimes and March 1 through May 31 and September 1 through November 30 for polyhaline regimes (U.S. EPA 2003a; Batiuk et al. 1992, 2000). The tidal fresh, oligohaline and mesohaline salinity regimes application period was based on the combined growing seasons for tidal fresh to middle salinity SAV species communities. The polyhaline temporal application periods were based on the bimodal *Zostera marina* or eelgrass growing seasons (Batiuk et al. 1992).

Given that *Ruppia maritima* or widgeon grass, principally a mesohaline species, has been found growing along with eelgrass in a majority of the polyhaline regions of the Chesapeake Bay and its tidal tributaries in Virginia waters (Moore et al. 2000), the water clarity criteria temporal application period for polyhaline waters should be an inclusive combination of the mesohaline and polyhaline temporal application periods or March 1 through November 30. This expanded temporal application period should apply to polyhaline Chesapeake Bay Program segments where there is evidence of past or present widgeon grass growth or the potential for future growth.

SHALLOW-WATER HABITAT ACREAGES

New information on shallow-water habitat acreages has been published in the *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability-2004 Addendum* (U.S. EPA 2004). These updated shallow-water habitat acreages factor in the full extent of the 0 to 2 meter depth contour area of shallow water habitat, minus the delineated SAV no-grow zones. Through comparison with the expanded restoration acreages, described below, new segment-specific expanded restoration acreages as a percentage of the shallow-water habitat acreages have also been published in the *Technical Support Document 2004 Addendum.*

SAV RESTORATION ACREAGE TO SHALLOW-WATER HABITAT ACREAGE RATIO

There is scientific documentation originally published in both the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries* (U.S. EPA 2003a) and the *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability* (U.S. EPA 2003b) supporting the findings that suitable shallow-water habitat must be at acreages greater than the corresponding SAV restoration goal to support restoration of SAV to those acreages.

Text on page 198 in the *Regional Criteria Guidance* states:

> Restoring underwater water grasses within a segment requires that the particular shallow-water habitat meet the Chesapeake Bay water clarity criteria across acreages much greater than those actually covered by bay grasses. The ratio of underwater bay grass acreage to the required shallow-water habitat acreage achieving the necessary level of water clarity to support return of those underwater bay grasses varies based upon the different species of bay grasses inhabiting the Chesapeake Bay's four salinity regimes. The baywide average ratio of underwater bay grass acreage to suitable shallow-water habitat acreage is approximately one acre of underwater bay grasses for every three acres of shallow-water habitat achieving the Chesapeake Bay water clarity criteria.
>
> The salinity regime and, therefore, bay grass community-specific underwater bay grass acreage to shallow-water habitat acreage ratios have been derived through an evaluation of extensive underwater bay grass distribution data within tidal-fresh, low (oligohaline), medium (mesohaline) and high (polyhaline) salinity regimes (reflecting different levels of coverage by different bay grass communities). The *Technical Support Document for the Identification of Chesapeake Bay Designated Uses and Attainability* documents the methodology followed and the resulting bay grasses acreage to shallow water habitat acreage ratios derived for each of the four salinity regimes (U.S. EPA 2003).

Text on page 123 in the *Technical Support Document* states:

> 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 regimeBtidal fresh (0-0.5 ppt), oligohaline (> 0.5-5 ppt), mesohaline (> 5ppt–18 ppt) and polyhaline (>18 ppt). 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.

The scientific literature along with analysis of the multi-decadal SAV aerial survey data record confirm that healthy SAV beds cover only a portion of the available suitable habitat due to a variety of natural reasons. Given that the information summarized above and further documented in the *Technical Support Document-2004 Addendum* indicates ratios from 1:2 to 1:3 in terms of the area covered by SAV beds compared to available shallow-water habitat area, a 1:2.5 ratio is recommended for determining the segment-specific acreage of shallow-water habitat that needs to achieve the applicable water clarity criteria required to support restoration of the segment specific SAV goal acreage.

SAV RESTORATION GOAL ACREAGES

The adopted Chesapeake Bay Program SAV restoration goal acreages were based on single best year coverages artificially clipped for shoreline and segment-specific water clarity criteria application depths, undercounting the actual mapped SAV acreages. In some segments, this resulted in the existing use acreages being higher than the restoration goal acreage. The chosen solution, described in more detail in the *Technical Support Document-2004 Addendum*, was to count all of the SAV acreage for a given segment that occurred within the single best year regardless of any shoreline, bathymetry data limitations or water clarity application depth restrictions.

The *Technical Support Document-2004 Addendum* documents the 'expanded restoration acreage', updated existing use acreage and the available shallow-water habitat area for each Chesapeake Bay Program segment (U.S. EPA 2004). As described in the addendum:

> The 'expanded restoration acreage' is the greatest acreage from among the updated existing use acreage (1978–2002; no shoreline clipping), the Chesapeake Bay Program adopted SAV restoration goal acreage (strictly adhering to adopted single best year methodology with clipping) and the goal acreage displayed without shoreline or application depth clipping and including SAV from areas still lacking bathymetry data. This 'expanded restoration acreage' is being documented here and provided to the partners as the best acreage values that can be directly compared with SAV acreages reported through the baywide SAV aerial survey. These acreages are not the officially adopted goals of the watershed partners; they are for consideration by the jurisdictions when adopting refined and new water quality standards regulations.

The Chesapeake Bay Program SAV restoration goal of 185,000 acres and the segment-specific goal acreages stand as the watershed partners' cooperative restoration goal for this critical living resource community (Chesapeake Executive Council 2003). EPA recommends that the jurisdictions with Chesapeake Bay tidal waters consider adopting the expanded restoration acreages (which factor in the updated existing use acreages) and shallow-water habitat acreages determined using the 1:2.5 ratio into their refined and new water quality standards regulations.

DETERMINING ATTAINMENT OF THE SHALLOW-WATER BAY GRASS USE

In addition to the methods previously described in the *Technical Support Document* (U.S. EPA 2003b) for determining attainment of the shallow-water bay grass designated use, there is an additional methodology which integrates both progress towards to the SAV restoration goal acreage and measurement of suitable shallow water habitat acreage necessary to support restoration of the remaining SAV beds needed to reach the goal acreage. This methodology calls for assessing attainment of the shallow-water designated use in a segment through a combination of mapped SAV acreage *and* meeting the applicable water clarity criteria in an additional, unvegetated shallow water surface area equal to 2.5 times the remaining SAV acreage necessary to meet the segment's restoration goal (SAV restoration goal acreage minus the mapped SAV acreage). In other words, a segment's shallow-water bay grass designated use would be considered in attainment if there are sufficient acres of shallow-water habitat meeting the applicable water clarity criteria to support restoration of the remaining acres of SAV, beyond the SAV beds already mapped, necessary to reach that segment's SAV restoration goal acreage. These measurements of SAV acreages and water clarity levels would be drawn from three years of data as previously described in the *Regional Criteria Guidance* (U.S. EPA 2003a).

Here's a hypothetical example of determining attainment of the shallow-water bay grass use using both mapped SAV acreage and shallow-water habitat acreage meeting the water clarity criteria. Segment X has an SAV restoration goal acreage of 1,400 acres. Over the past three years, SAV beds totaling 1,100 acres have been mapped within the segment for at least one of the three years. Therefore, the remaining SAV acreage necessary to meet the segment's restoration goal is 1,400 acres (SAV restoration goal) minus 1,100 acres (SAV currently mapped) or 300 acres. Beyond the currently vegetated shallow-water habitat, an additional 750 acres of shallow-water habitat (2.5 times 300 acres) would need to attain the water clarity criteria in order to determine that this segment is attaining the shallow-water bay grass use in combination with the 1,100 acres of mapped SAV.

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chapter ix

Determining Where Numerical Chlorophyll *a* Criteria Should Apply to Local Chesapeake Bay and Tidal Tributary Waters

As published in *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for Chesapeake Bay and Its Tidal Tributaries* (U.S. EPA 2003):

> The EPA expects states to adopt narrative chlorophyll *a* criteria into their water quality standards for all Chesapeake Bay and tidal tributary waters. The EPA strongly encourages states to develop and adopt site-specific numerical chlorophyll *a* criteria for tidal waters where algal-related impairments are expected to persist even after the Chesapeake Bay dissolved oxygen and water clarity criteria have been attained.

The Chesapeake Bay Program partners developed a general methodology for possible use by the jurisdictions with tidal waters to determine consistently which local tidal waters will likely attain the published Chesapeake Bay dissolved oxygen and water clarity criteria yet algal-related water quality impairments will persist. The methodology is for application by Maryland, Virginia, Delaware and the District of Columbia to assist in their future determinations of where they need to derive and apply numerical chlorophyll *a* criteria for localized tidal waters.

RECOMMENDED METHODOLOGY

The jurisdictions should evaluate the available Chesapeake Bay Water Quality Monitoring Program's time series of spring and summer chlorophyll *a* concentrations on a station by station, segment by segment basis and compare these concentrations to a range of season and salinity regime-based target chlorophyll *a* concentrations. Target concentrations, examples given in Table IX-1, should be derived from published chlorophyll *a* concentrations associated with an array of water quality and biological community effects and impairments. The jurisdictions should then identify those stations/segments that are persistently higher than the applicable target chlorophyll *a* concentrations with the individual jurisdictions developing their own

Table IX-1. Example numerical chlorophyll *a* thresholds (µg liter^{-1}) drawn from *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for Chesapeake Bay and its Tidal Tributaries*[1] reflective of an array of historical concentrations, ecosystem trophic status, potential harmful algal blooms, water quality impairments, user perceptions and state water quality standards.

	Chlorophyll *a* Concentration Thresholds (µg liter^{-1})						
Salinity Regime	**Historical Chesapeake Bay Levels** [2,3]	**Ecosystem Trophic Status**	**Phytoplankton Reference Communities**[6]	**Potentially Harmful Algal Blooms**[7]	**Water Quality Impairments**[8]	**User Perceptions**	**State Water Quality Standards**[11]
Tidal Fresh	Spring: 4 Summer: 7 Mainstem (annual): 3	2-15[4]	Spring: 4.3 Summer: 8.6	*Microcystis aeruginosa*: 15	Water Clarity: 9-16 Dissolved Oxygen: 4-5	Vermont Lakes: < 15[9] Minnesota Lakes: < 15[10]	AL: 16-27 (res.) CN: 2-15 (meso.) GA: 5-20 (lakes) NC: 15(lakes, res.)
Oligohaline	Spring: 6 Summer: 8 Mainstem (annual): 3		Spring: 9.6 Summer: 6.0	*Microcystis aeruginosa*: 15	Water Clarity 9-16 Dissolved Oxygen: 7-12		NC: 40 (tidal)
Mesohaline	Spring: 6 Summer: 8 Mainstem (annual): 4		Spring: 5.6 Summer: 7.1	*Prorocentrum minimum*: 5	Water Clarity: <8 Dissolved Oxygen: 5-6		NC: 40 (tidal)
Polyhaline	Spring: 4 Summer: 4 Mainstem (annual): 1	2-7[5]	Spring: 2.9 Summer: 4.4	*Prorocentrum minimum*: 5	Water Clarity: <8 Dissolved Oxygen: 4-5		NC: 40 (tidal) HW: 2; 5 <10%; 10 <2%

Sources: 1. U.S. EPA 2003; 2. Olson 2002; 3. Harding and Perry 1997; 4. Wetzel 2001, Ryding and Rast 1989, Smith et al. 1998, Novotny and Olem 1994; 5. Smith. 1998, Molvaer 1997; 6. U.S. EPA 2003; 7. U.S. EPA 2003; 8. U.S. EPA 2003; 9. Smeltzer and Heiskary 1990; 10.Heiskary and Walker 1988; 11. U.S. EPA 2003.

decision rules for defining "persistently higher". The jurisdictions should finally evaluate the degree of non-attainment of the dissolved oxygen and/or water clarity criteria within surrounding or "downstream" tidal waters. If these waters are in attainment of the dissolved oxygen and water clarity criteria, yet are persistently higher than the applicable target chlorophyll *a* concentrations, then these waters should be targeted for adoption of numerical chlorophyll *a* criteria.

The jurisdictions should also evaluate results from Chesapeake Bay water quality model-simulated water quality conditions with achievement of the assigned nitrogen, phosphorus and sediment cap load allocations. The jurisdictions would then identify those Chesapeake Bay Program segments where the model simulated surface chlorophyll *a* concentrations are above a range of season and salinity regime-based target concentrations. The jurisdictions are encouraged to factor in findings from state-generated local TMDL modeling in the smaller tidal tributaries and embayments (e.g., Nanticoke River in Delaware, Anacostia River in the District of Columbia and several tidal tributaries in Maryland) as an additional source of information on anticipated chlorophyll *a* concentrations upon attainment of the dissolved oxygen and/or water clarity criteria. Given that these model-simulated results reflect tidal water quality conditions estimated to attain the dissolved oxygen criteria[4], these segments should be targeted for adoption of numerical chlorophyll *a*. The jurisdictions should note that management-applicable Chesapeake Bay water quality model results are not available for all 78 Chesapeake Bay Program segments (Linker et al. 2002).

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[4] The applicable water clarity may not be attained within the model simulated output given suspended sediment contributions to reduced water clarity conditions independent of the algal contribution to reduced water clarity conditions.

appendix A

Wetland Area, Segment Perimeter/Area/Volume and Water Quality Parameter Statistics for Chesapeake Bay Tidal Fresh and Oligohaline Segments

Table A-1. Wetland area, perimeter, surface area and volume statistics for Chesapeake Bay tidal fresh and oligohaline segments.

Chesapeake Bay Program Segment	**Wetland Acreage (acres)**	**Segment Perimeter (meters)**	**Segment Surface Area (meters^2)**	**Segment Volume (meters^3)**	**Surface Area to Volume Ratio**
Western Branch Patuxent River-tidal fresh region	WBRTF	5181	131511	.	.
Appomattox River-tidal fresh region	APPTF	168938	8011611	1510000	5.3
Piscataway Creek-tidal fresh region	PISTF	15219	3708997	2850000	1.3
Chester River-tidal fresh region	CHSTF	60350	4084016	3362500	1.2
Pocomoke River-tidal fresh region	POCTF	77456	3998871	4470000	0.9
Nanticoke River-tidal fresh region	NANTF	69276	4608463	6615000	0.7
Mattawoman Creek-tidal fresh region	MATTF	37045	7280895	9500000	0.8
*Patuxent River-tidal fresh region	PAXTF	55373	4408622	11025000	0.4
*Choptank River-tidal fresh region	CHOTF	153218	9466475	15322500	0.6
Bohemia River-oligohaline region	BOHOH	79964	11927636	17000000	0.7
Pocomoke River-oligohaline region	POCOH	116755	13821501	18000000	0.8
Back River-oligohaline region	BACOH	64832	16175354	22375000	0.7
C&D Canal-oligohaline region	C&DOH	35654	3565828	24130000	0.1
Middle River-oligohaline region	MIDOH	93914	16214070	25000000	0.6
Northeast River-tidal fresh region	NORTF	40617	15817689	26500000	0.6
*Patuxent River-oligohaline region	PAXOH	76397	14243456	27180000	0.5
Chester River-oligohaline region	CHSOH	124641	14790537	28875000	0.5
Nanticoke River-oligohaline region	NANOH	238038	16455330	45000000	0.4
*Choptank River-oligohaline region	CHOOH	142681	14477365	45125000	0.3
Chickahominy River-oligohaline region	CHKOH	355816	27969270	48562500	0.6
Bush River-oligohaline region	BSHOH	107046	30542696	49250000	0.6
*Rappahannock River-oligohaline region	RPPOH	112097	19536530	53580000	0.4
Gunpowder River-oligohaline region	GUNOH	163323	41998392	64250000	0.7
Sassafras River-oligohaline region	SASOH	161366	33085712	84187500	0.4
Elk River-oligohaline region	ELKOH	138710	37270004	101250000	0.4
*Rappahannock River-tidal fresh region	RPPTF	252716	36503308	107437500	0.3
James River-tidal fresh region	JMSTF	562776	95301848	286187500	0.3
Chesapeake Bay-tidal fresh region	CB1TF	216814	151620944	360000000	0.4
James River-oligohaline region	JMSOH	271459	127749032	431500000	0.3
*Potomac River-tidal fresh region	POTTF	365926	153841616	484750000	0.3
*Potomac River-oligohaline region	POTOH	312495	214963696	852250000	0.3
Chesapeake Bay-oligohaline region	CB2OH	246410	275239520	1237000000	0.2

*Segments with similar characteristics or geographically close to the Mattaponi and Pamunkey segments.

Source: Chesapeake Bay Program http://chesapeakebay.net/data

Table A-2. Summer average conditions in other tidal fresh and oligohaline Chesapeake Bay Program segments, 2000–2002.

CBP Segment	Water Column Layer	Water Column Depth (meters)	Salinity (ppt)^1	Temperature (°C)	Dissolved Oxygen Concentration (mg liter^{-1})	Dissolved Oxygen Deficit (mg liter^{-1})	Chlorophyll *a* Concentration (µg liter^{-1})	Total Suspended Solids Concentration (mg liter^{-1})	Total Nitrogen Concentration (mg liter^{-1})	Total Phosphorus Concentration (mg liter^{-1})
APPTF	S	0.7	0.09	27.90	8.45	-0.50	44.5	35.5	1.0771	0.1169
APPTF	B	5.7	0.09	27.44	7.68	0.31	.	67.7	1.1839	0.1656
CB1TF	S	0.5	0.68	25.92	7.32	0.79	8.4	8.0	1.1310	0.0389
CB1TF	B	4.8	0.86	25.58	6.79	1.36	6.7	10.1	1.1603	0.0387
JMSTF	S	0.7	0.30	27.56	7.82	0.13	22.4	15.9	0.9022	0.0989
JMSTF	B	8.8	0.37	27.24	6.94	1.04	.	75.1	1.1113	0.1388
MATTF	S	0.3	0.19	24.46	6.98	1.38	18.1	8.1	0.9551	0.0608
NANTF	S	0.5	0.63	25.86	5.68	2.45	15.6	23.1	2.3553	0.0667
NANTF	B	4.1	0.67	25.77	5.44	2.69	14.6	50.4	2.3513	0.0891
NORTF	S	0.5	0.24	25.93	8.70	-0.57	44.3	22.0	1.1431	0.0847
NORTF	B	1.8	0.24	25.66	7.91	0.26	42.2	25.7	1.1207	0.0876
PAXTF	S	0.2	0.22	24.27	7.37	1.02	36.2	34.4	1.3724	0.1547
PAXTF	B	9.4	0.68	25.18	7.28	0.96	66.3	99.9	1.3846	0.2731
PISTF	S	0.2	0.00	24.22	6.97	1.45	14.2	10.3	1.3197	0.0962
POCTF	S	0.5	0.61	26.13	4.63	3.46	7.6	12.4	1.6927	0.1206
POCTF	B	4.9	0.72	26.00	4.64	3.46	7.8	25.8	1.6005	0.1408
POTTF	S	0.5	0.16	26.54	7.60	0.45	20.4	13.0	1.5054	0.0769
POTTF	B	10.9	0.24	25.97	6.36	1.76	18.7	35.1	1.6021	0.1047
RPPTF	S	0.7	0.71	26.89	7.20	0.84	31.0	23.4	0.9105	0.0776
RPPTF	B	5.1	0.75	26.68	6.84	1.10	.	37.1	0.9543	0.0883
WBRTF	S	0.0	0.01	21.97	6.82	1.94	12.8	37.1	1.1804	0.1868
BACOH	S	0.5	2.82	25.18	7.92	0.24	81.9	24.9	2.4796	0.2564
BACOH	B	0.8	2.92	25.17	7.26	0.89	66.9	23.9	2.1900	0.2347
BOHOH	S	0.5	1.27	26.68	7.73	0.26	24.7	21.6	0.8554	0.0653
BOHOH	B	1.8	1.30	26.43	7.27	0.75	21.2	22.6	0.9143	0.0666
BSHOH	S	0.5	1.16	25.82	8.19	-0.05	28.7	24.0	0.9170	0.0699
BSHOH	B	1.2	1.17	25.61	7.64	0.53	28.7	25.8	0.9117	0.0696
C&DOH	S	0.5	2.03	25.74	6.68	1.41	10.5	17.8	1.2866	0.0715
C&DOH	B	12.3	2.08	25.53	6.54	1.57	3.4	30.7	1.2121	0.0808
CB2OH	S	0.5	5.11	24.72	6.68	1.41	6.5	9.9	0.9548	0.0526
CB2OH	B	11.7	8.14	24.21	4.47	3.57	5.5	24.6	0.8730	0.0675
CHKOH	S	0.7	2.05	26.41	6.33	1.68	19.1	24.7	0.6205	0.0873
CHKOH	B	3.9	2.10	26.21	6.24	1.78	.	62.5	0.7355	0.1338
CHOOH	S	0.5	1.09	26.28	5.66	2.40	18.3	28.2	1.6772	0.1042
CHOOH	B	7.5	1.19	25.93	5.36	2.74	17.1	47.5	1.8115	0.1311
CHSOH	S	0.5	0.69	26.47	8.13	-0.09	61.2	53.2	2.2028	0.1619
CHSOH	B	4.0	0.71	26.18	7.86	0.23	59.6	65.9	2.1452	0.1747
ELKOH	S	0.5	1.68	25.89	6.80	1.27	4.1	11.7	1.1244	0.0584
ELKOH	B	11.4	1.77	25.62	6.59	1.52	3.5	25.7	1.1267	0.0736
GUNOH	S	0.5	2.23	25.12	7.13	1.06	10.3	16.3	0.6558	0.0476
GUNOH	B	0.9	2.24	25.08	6.55	1.64	10.5	18.8	0.6600	0.0489
JMSOH	S	0.7	6.20	26.71	6.77	1.03	8.9	22.8	0.5089	0.0828
JMSOH	B	10.1	7.00	26.69	6.49	1.28	.	73.5	0.6217	0.1202
MIDOH	S	0.5	3.67	25.42	7.63	0.45	19.3	10.1	0.6698	0.0493
MIDOH	B	2.7	4.14	25.07	5.90	2.20	15.7	13.7	0.6727	0.0478
PAXOH	S	0.5	3.33	26.36	5.87	2.10	17.3	28.6	0.8689	0.1378
PAXOH	B	3.6	3.61	26.08	5.38	2.61	18.0	56.1	0.9835	0.1912
POTOH	S	0.5	3.00	25.80	6.59	1.44	8.2	12.1	1.1141	0.0896
POTOH	B	7.8	3.77	25.66	5.92	2.09	3.8	50.9	1.1603	0.1258
RPPOH	S	0.7	3.12	26.84	7.40	0.55	19.5	21.9	0.6160	0.0753
RPPOH	B	7.2	3.63	26.51	6.40	1.57	.	73.3	0.8002	0.1198
SASOH	S	0.5	0.46	26.98	8.30	-0.32	71.6	23.2	1.6423	0.1170
SASOH	B	5.2	0.53	26.49	6.62	1.43	66.3	31.9	1.5082	0.1254

Source: Chesapeake Bay Program http://chesapeakebay.net/data

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