- Draft -

Influence of Climate Change Risk on the Chesapeake Bay Open-Water Dissolved Oxygen Water Quality Standard

April 24, 2020

Introduction

The Chesapeake Bay open-water dissolved oxygen (DO) water quality standard is based on protection of living resource habitat. The Chesapeake Bay TMDL is based on attainment of the summer open water monthly mean criteria of 5 mg/l (5.5 mg/l in tidal fresh waters), which was established to protect the growth of larval, juvenile, and adult fish and shellfish. In the summer, the criteria is generally applied to waters in the tidal Bay above the pycnocline where stratification is considered a naturally occurring phenomenon, or to the entire water column in well-mixed areas. In winter periods, when waters throughout the Bay are well mixed and cooler, the criteria applies to the entire water column. In the mainstem segments CB6PH and CB7PH the 5 mg/l criteria applies to the entire water column in summer for the southern portion of the two segments (Figures 1 and 6).

Under climate change conditions the average annual temperature is estimated to increase by 1° C over the 30-year period between the hydrology used for the Chesapeake TMDL (1991-2000) and the year 2025. By 2055 the average temperature is estimated to increase by 2° C for the 60 years between 2055 and 1995 (CBPO, 2020). Climate change temperature increases in Chesapeake tidal waters are inevitable over the next half-century, are global in origin, and are beyond CBP management and control.

Dissolved oxygen solubility in water is sensitive to temperature (Figure 2). In the summer, surface DO in the mainstem Bay is typically about 8 mg/l. But in the coolest winter months the surface DO is about 12 mg/l, one third more than that of the summer concentration. Temperature increases also increase the consumption of oxygen by increased respiration and strengthen stratification. Under estimated 2025 WIPIII loads and conditions, solely from a 1° C temperature increase, the increase in Chesapeake hypoxic water volume (< 1 mg/l) is estimated to be in part due to decreased solubility of oxygen (48 percent), in part from increased respiration (43 percent), and also from increased stratification (9 percent) (Figure 3). Temperature impacts on DO in the tidal Bay are further compounded by climate induced salinity increases in the Bay, which also decrease DO solubility and increase stratification.

Challenges in maintaining an open-water DO water quality criteria of 5 mg/l in all designated uses at all times will inevitably increase throughout the next half-century. This is particularly true in the shallow water portions of the open-water DO designated uses of the Bay, which are generally defined as those areas less than 2 meters in depth. In addition, the southern portion of the main Bay segments of CB6PH and CB7PH, which have an open-water designated use applied at all depths from the surface to bottom throughout the year, will also see increasing open-water DO violations under future climate temperatures and conditions.

Open-Water DO Assessment in Shallow Water TMDL Segments Under Current and Future Climate Temperatures

Shallow regions of the Bay average about 1 meter in depth, are no more than 2 meters in depth, and all have an open-water DO water quality standard. Shallow open-water areas in some CB segments currently have open-water DO violations (Figures 4a and 4b), and the segments in open-water DO violation are estimated to increase in number and degree under projected future climate temperatures.

Observed data used to assess water quality standards (temperature, DO, and salinity) are provided by the CBP Partnership's long-term monitoring stations (Figure 5a), and are augmented with the CBP's Shallow Water Monitoring Program (SWMP) observations of temperature, DO, and salinity, and other observations (Figure 5b). The SWMP typically provides summertime continuous monitoring at 15-minute intervals for DO, temperature, and salinity. Both data sets have examples of DO concentrations below 5 mg/L, and work is under way to discern the trend of criteria exceedance from the observed data.

The minimum depth represented in the 2017 Water Quality and Sediment Transport Model (WQSTM), used for the current assessment of climate change risk to tidal water quality standards, is 2 meters. Consequently, the depth of nearshore areas is inaccurately represented. Until now, the WQSTM was sufficient for open-water DO assessment, but in a changing climate with increasing temperatures the WQSTM simulation is unsuitable for shallow waters. Therefore, the Modeling Workgroup recommends that the application of the WQSTM to open-water DO water quality standard assessment be avoided in shallow waters under climate change conditions.

Nevertheless, assessment of open-water DO climate risk is needed in shallow water. Going forward, a new model system is required which can simulate shallow water at a finer scale, allow for an unstructured model grid to fit complicated shorelines, simulate wetting and drying of the intertidal region, project tidal wetland migration with sea level rise, and in general provide a state-of-the-art assessment of the important interface between land and water in the Chesapeake estuary. The estuarine model approach for shallow water described in the STAC Report on CBP Modeling in 2025 and Beyond (2019) outlines the direction needed for a sufficient simulation of open-water DO in shallow Chesapeake waters under climate change conditions.

Open-Water DO Assessment in CB TMDL Main-Stem Bay Segments of CB6PH and CB7PH Under Current and Future Climate Temperatures

The mainstem segments of CB6PH and CB7PH (Figure 1) are unique among mainstem segments with equivalent depths in that they contain subdivisions within which different designated uses apply. The summer deep water designated use, with its 30-day mean criteria of 3 mg/l, is applied only to the northernmost portions of these segments, while the open water criteria applies to the entire water column for the majority of the segments' volumes (Figure 6). As a result, large portions of these segments are assessed against the open-water DO criteria of 5 mg/l year round for the entire water column, including deep areas where pycnoclines have been detected.

According to the Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability (2003), the delineation of the open-water designated use for the entire water columns of the lower portions of CB6PH and CB7PH was based on bottom-water DO concentrations in the summer of 1997, a year characterized by low inflow from the watershed. “The regions identified as having chronic low dissolved oxygen concentrations attributable to the combined effects of pycnocline, bathymetry, and flow were as follows: Upper, middle, and lower central Chesapeake Bay segments (CB3MH, CB4MH, and CB5MH); and the northern reaches of the western and eastern lower Chesapeake Bay (CB6PH and CB7PH)” (U.S. EPA, 2003). The designated use boundary accounted for “the combined effects of pycnocline, bathymetry, and flow” but failed to account for future temperature increases throughout the water column which decrease DO solubility, increase consumption of DO through respiration, and increase stratification. The open water designated uses of CB6PH and CB7PH have failed the 30-day mean water quality standard in the past (Figure 7), and non-attainment will increase under projected future climate change. In 2004, the boundary of the open-water-only area in CB6PH was moved southward to a location that reduced non-attainment of the open-water DO criteria to less than 1 percent, based on model scenarios of estimated nutrient load allocations of 2003 (U.S. EPA, 2004).

However, when a pycnocline is used to delineate waters above the pycnocline as open-water and below as deep-water with an associated deep-water DO criterion of 3 mg/l, WQSTM simulations indicate that the open-water and deep-water DO criteria are readily achieved. Observations confirm that DO concentrations less than the 5 mg/l criteria are below the pycnocline in CB6PH and CB7PH. The CBP’s Criteria Assessment Protocol Workgroup (CAPW) plans to look into climate change risks to current water quality standard criteria and designated uses this summer. The CAPW should consider open-water DO in general, and the open-water designated use for CB6PH and CB7PH in particular, as areas of needed attention by the CBP.

An Expanded Assessment of Observed Open-Water DO

Over the spring and summer of 2020 an expanded assessment of observed open-water DO will use the data of long-term CBP and Shallow Water Monitoring Program observations of temperature, DO, and salinity. The existing degree of criteria exceedance (DO less than 5 mg/l) in both observed data sets will be quantified, and temperature, DO, and salinity trends from monitoring stations in both data sets will be estimated.

Extrapolation of trends to estimated future temperatures for 2025 (1° C increase relative to 1991-2000 temperatures) and 2055 (2° C increase relative to 1991-2000 temperatures) will be used to assess the estimated attainment of open-water DO in shallow water under future climate temperatures.

In addition, the standard analysis that usually spans June through September and covers open-water, deep-water, and deep channel DO will be broadened to examine the potential for an earlier shift of higher water temperatures and lower DO earlier in the summer season, which means including both the months of April and May in the analysis.

Finally, the “freeboard”, or how far away from nonattainment the 5 mg/l criteria is in open-water over the period of observations (1985 to present for the longest records), will be examined.

Conclusions

The Chesapeake Bay Program Partnership is appropriately protective of open-water habitat for living resources. At the same time there is widespread recognition that open-water habitat in the Chesapeake region is shifting toward estuarine and coastal species and ecosystems found in lower latitudes. Through the CBP’s Criteria Assessment Protocol Workgroup the Partnership will begin to address these issues in 2020.

Another approach is the use of variances in a TMDL for conditions beyond management and control. The implementing regulations of the Clean Water Act provide tools for states to address specific circumstances where specified designated uses are unattainable now, or in the future. One such tool is a restoration variance, which can be defined as the allowable exceedance of a specific water quality criteria based on the best available scientific understanding consistent with Clean Water Act requirements. Restoration variances are temporary and are reviewed at a minimum of every three years, as required by the Clean Water Act and EPA regulations, and may be modified based on new scientific findings.

An example of an open-water DO variance in the Chesapeake TMDL is for open-water designated uses in CB segments adjacent to extensive tidal wetlands. In these cases, the summer observed DO is frequently lower than the 5 mg/l criteria because of the high productivity of tidal wetlands, respiration within the tidal wetlands, and export of organic material to adjacent tidal waters. In these cases, an open-water variance with a criteria less than 5 mg/l DO, but usually at or above 4 mg/l, is established and maintained. Decreased living resource abundance in surface waters has yet to be reported in any of the Chesapeake’s open-water variance segments.

References

Chesapeake Bay Program Office, 2020. Chesapeake Bay Program Climate Change Analysis Documentation of Methods and Decisions for 2019-2021 Process. Annapolis, MD. 150 pages.

Hood, R.R., G. Shenk, R. Dixon, W. Ball, J. Bash, C. Cerco, P. Claggett, L. Harris, T.F. Ihde, L. Linker, C. Sherwood, and L. Wainger. 2019. Chesapeake Bay Program Modeling in 2025 and Beyond: A Proactive Visioning Workshop. STAC Publication Number 19-002, Edgewater, MD. 62 pages. http://www.chesapeake.org/pubs/401_Hood2019.pdf Accessed April 21, 2020.

U.S. EPA. 2003. Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. Chesapeake Bay Program Office, Annapolis, MD. 319 pages. https://www.chesapeakebay.net/content/publications/cbp_13218.pdf Accessed April 21, 2020.

U.S. EPA. 2004. Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability 2004 Addendum. Chesapeake Bay Program Office, Annapolis, MD. 75 pages. https://www.chesapeakebay.net/content/publications/cbp_13270.pdf Accessed April 21, 2020.

Figure 1. CB segments of the Chesapeake showing relative bathymetry.

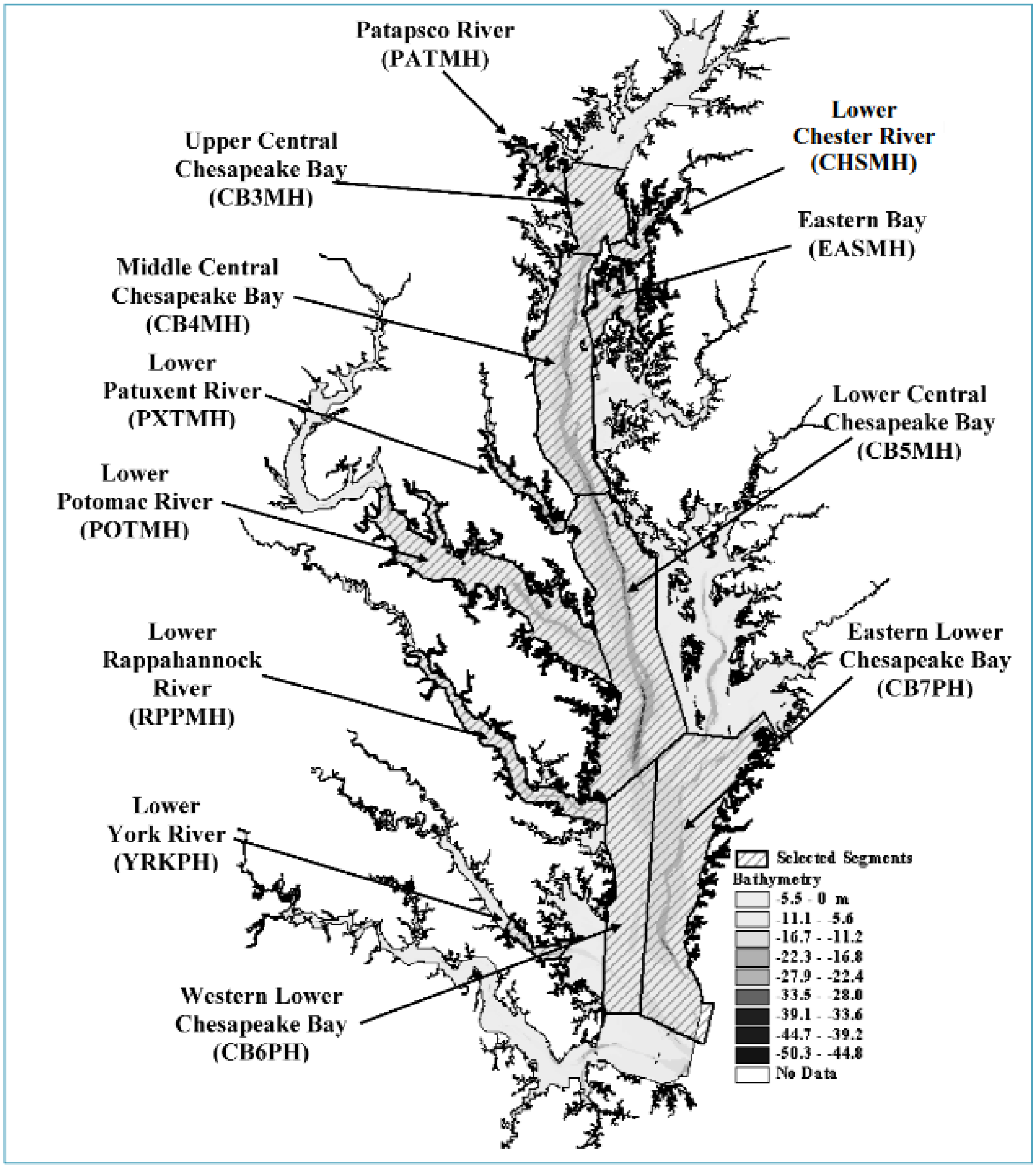


Figure 2. Plot of temperature and solubility of oxygen in water.

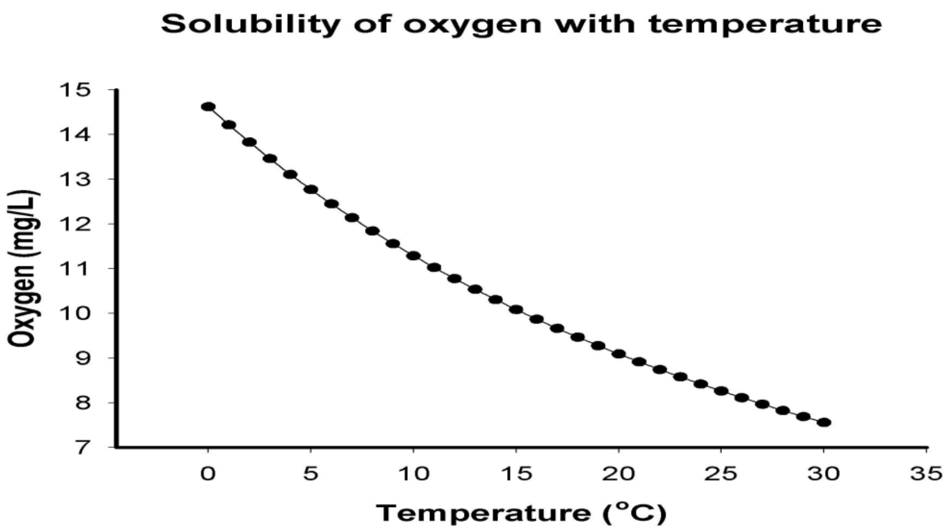
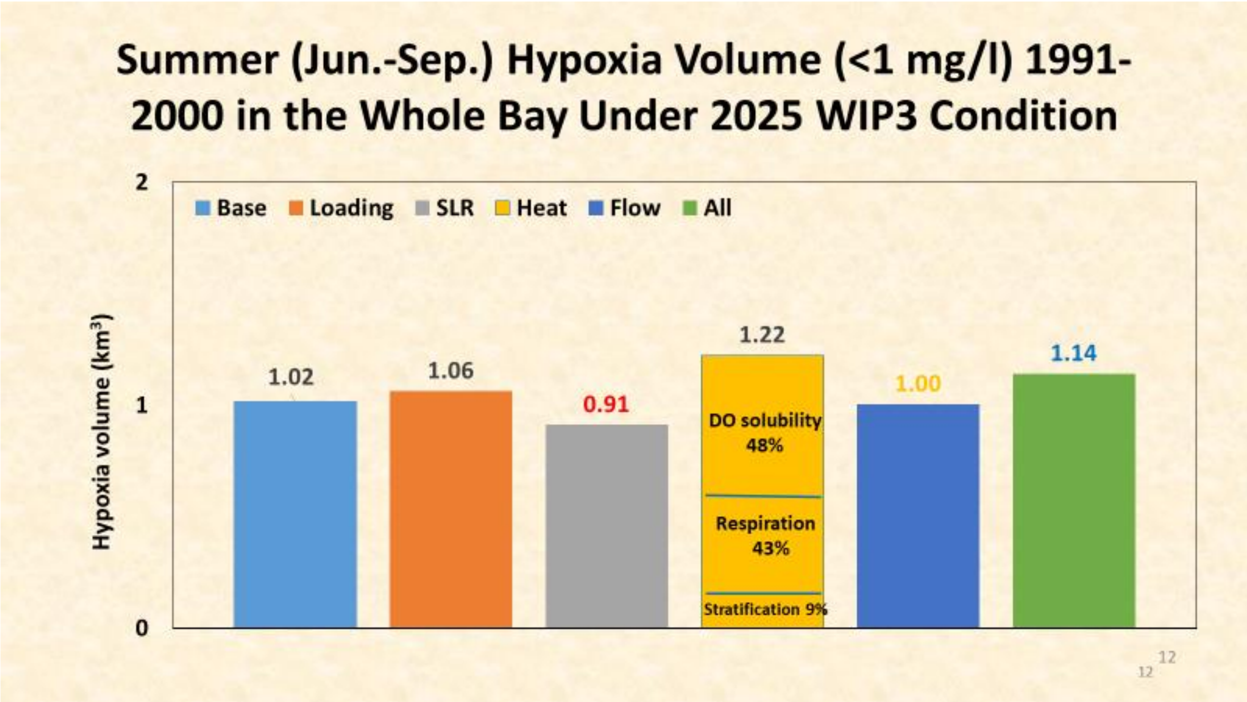
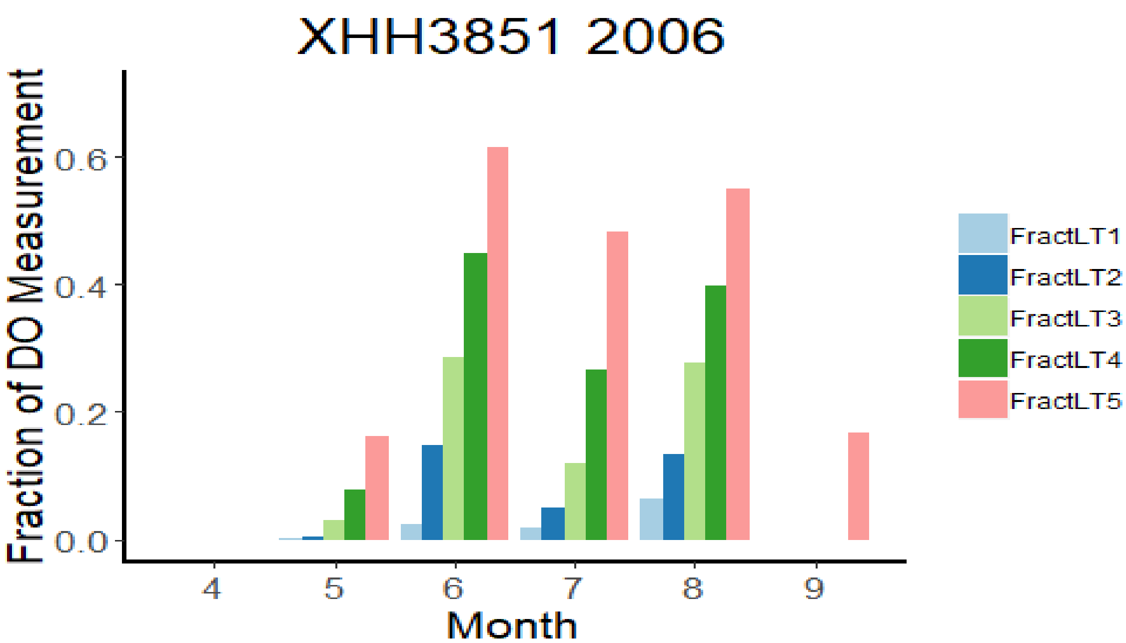


Figure 3: Summer hypoxic (< 1 mg/l DO) estimates soley under conditions of a 1.03° C temperature increase (1.22 km^3, Heat - amber bar) compared to the 2025 WIPIII scenario conditions without climate change (1.02 km^3, Base – blue bar). Other bars are solely 2025 climate change nutrient loads (Loading, orange bar) solely 2025 sea level rise condition (SLR, grey bar, solely watershed 2025 increased flows (Flow, dark blue bar), and all 2025 climate change conditions combined (All, green bar).



Source: Climate Resiliency Workgroup, April 20, 2020 meeting, slide 12: https://www.chesapeakebay.net/channel_files/40432/cc_model_findings_for_crwg_4-20-20.pdf

Figures 4a and 4b. High frequency (~15 minute) shallow water monitoring observations at a Jug Bay Patuxent River tidal fresh station for normal flow years of 2006 (Figure 4a) and 2016 (Figure 4b). The pink bars indicate the monthly fraction of DO observations less than 5 mg/l, dark green for the monthly fraction of DO observations less than 4 mg/l, light green for the monthly fraction of DO observations less than 3 mg/l, and the dark and light blue for the monthly fraction of DO observations less than 2 mg/l and 1 mg/l, respectively.



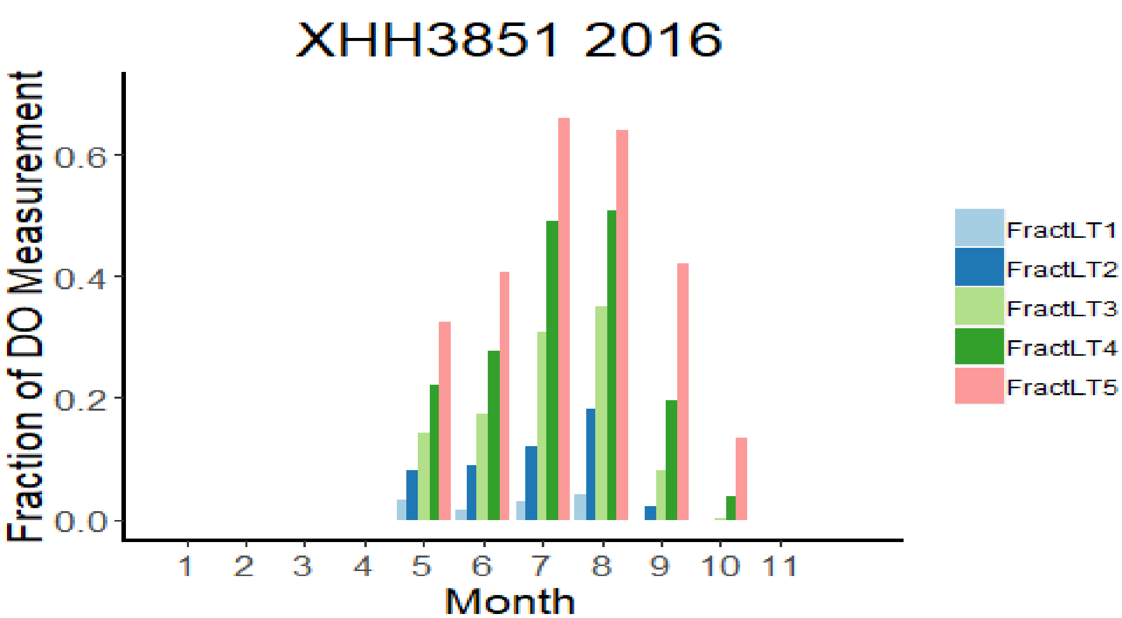


Figure 5a. Map of Chesapeake Bay monitoring stations.

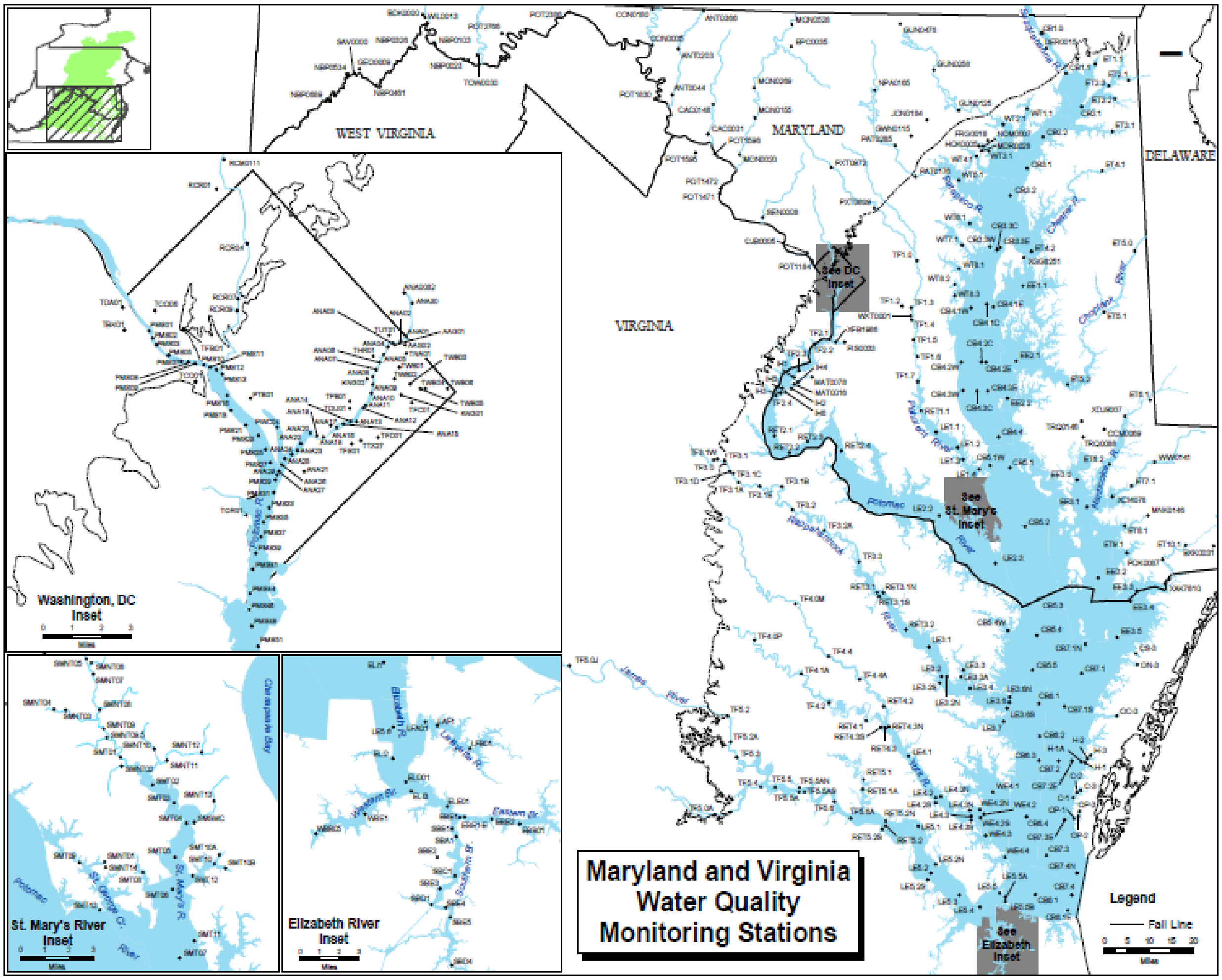


Figure 5b. Map of Maryland Shallow Water Monitoring Program stations. Continuous monitoring stations shown as yellow-orange or green symbols for real time, near time, off-line, and vertical profiler.

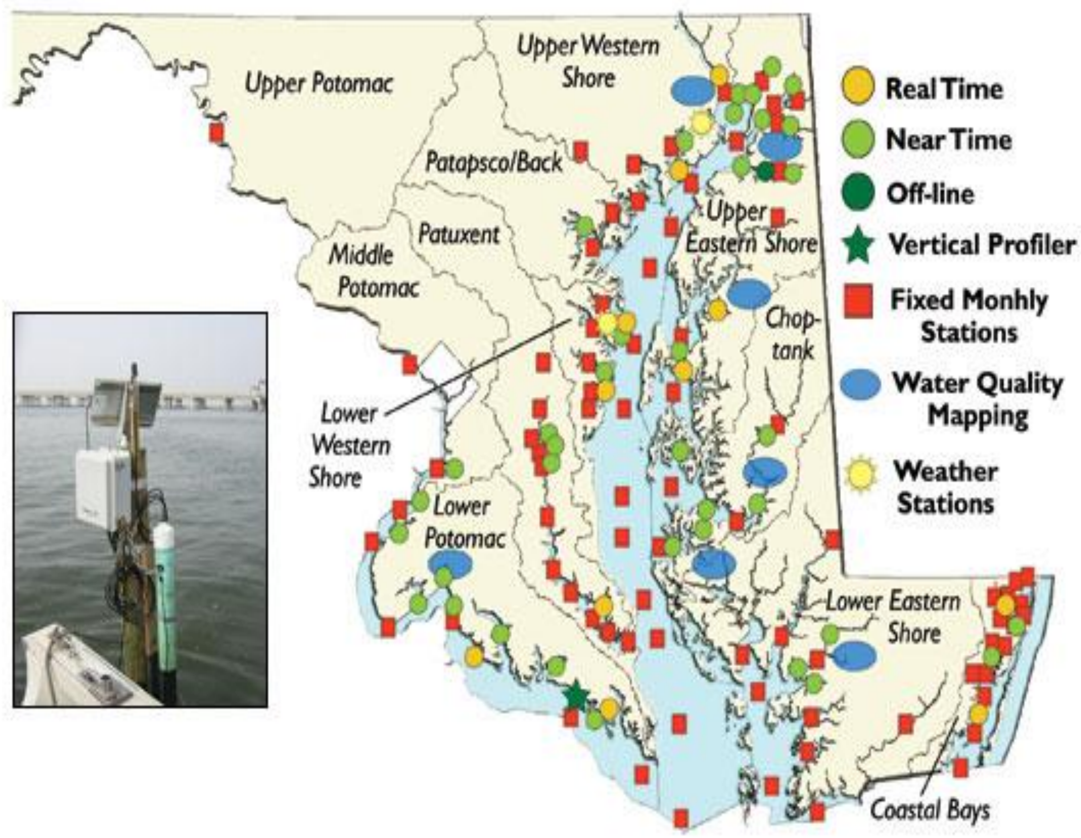


Figure 6. Dissolved oxygen designated uses of the CB segments showing the split nature of the open-water designated us in CB6PH and CB7PH where the open-water DO criteria of 5 mg/l DO extends throughout the water column in the southern reaches of the two CB segments.

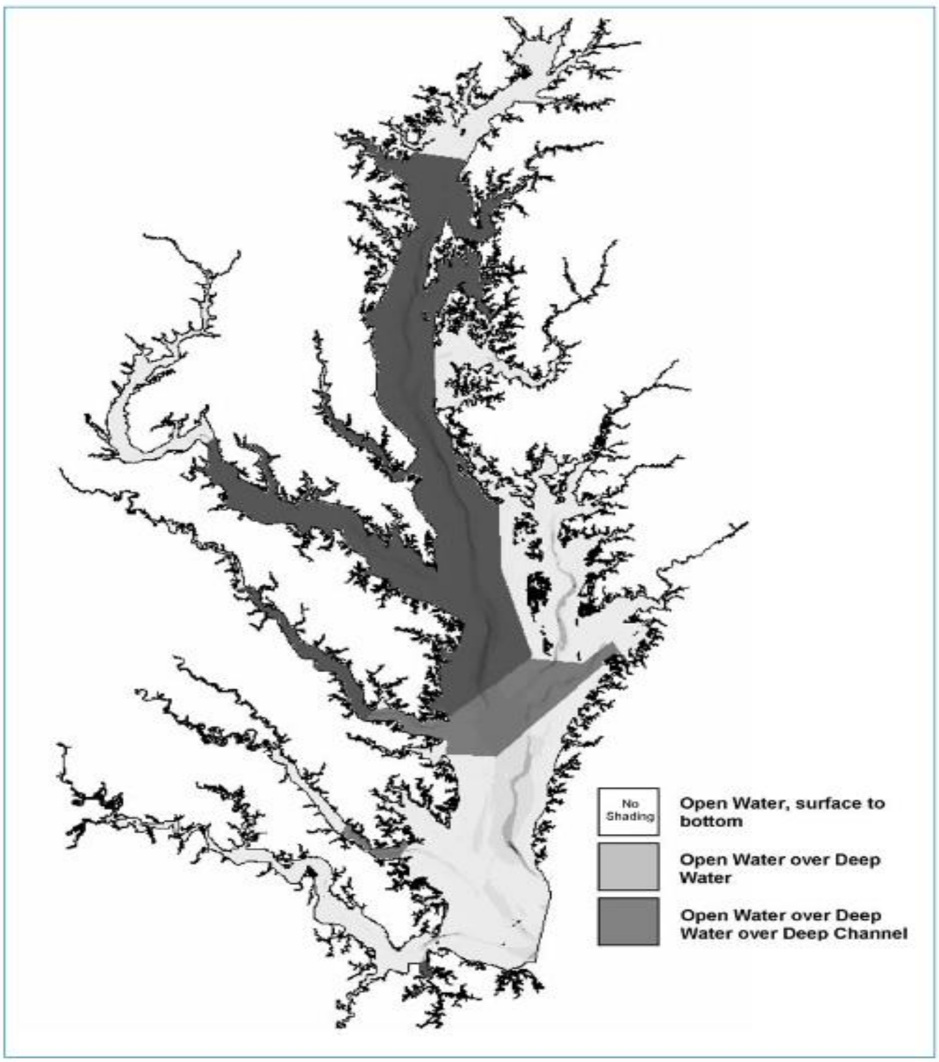
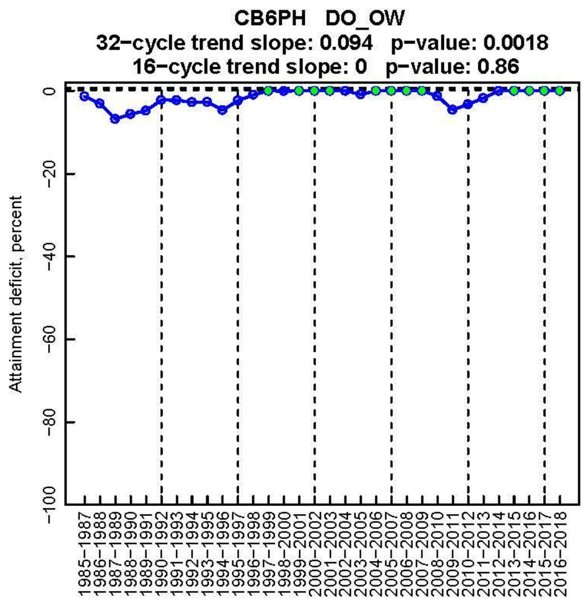


Figure 7a and 7b. Attainment of the 5 mg/l DO criteria in open-water designated use which includes the entire water column for the southern portion of CB6PH (Figure 7a, left) and the 3 mg/l DO criteria for deep-water DO (Figure 7a right) from 1985 to 2016. Blue values less than zero are nonattainment. Segment CB7PH shown in Figure 7b.

Figure 7a



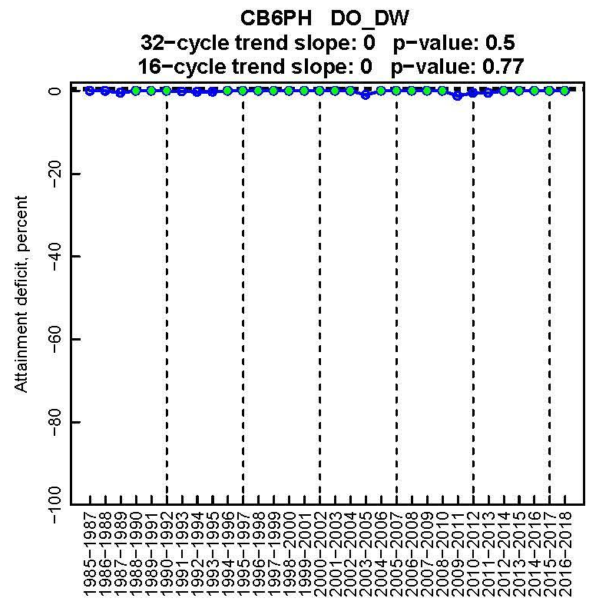


Figure 7b.