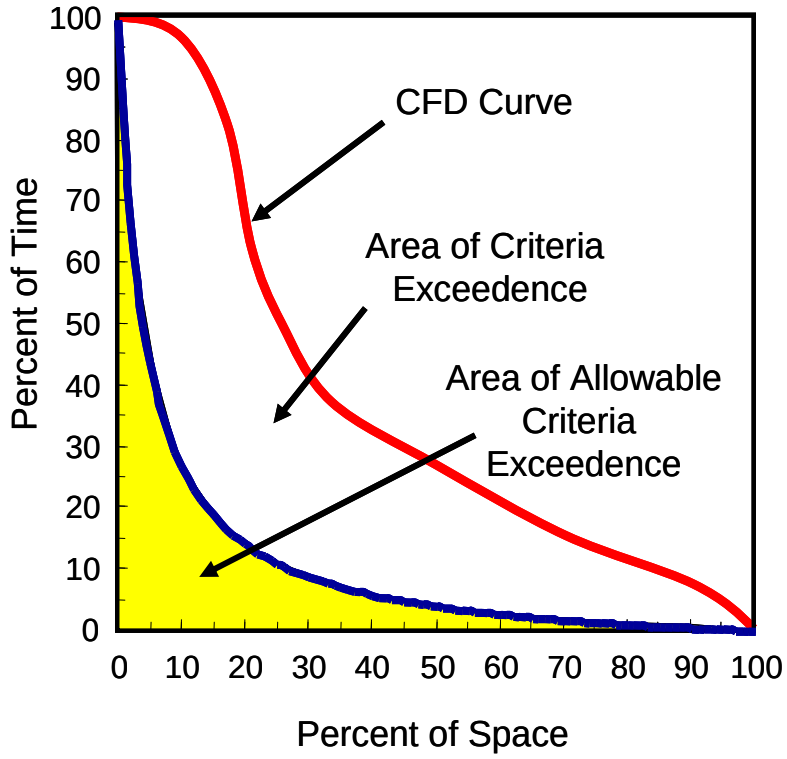
APPENDIX I.
Documentation of the Reduced Sensitivity to Load Reductions at Low Non-attainment Percentages

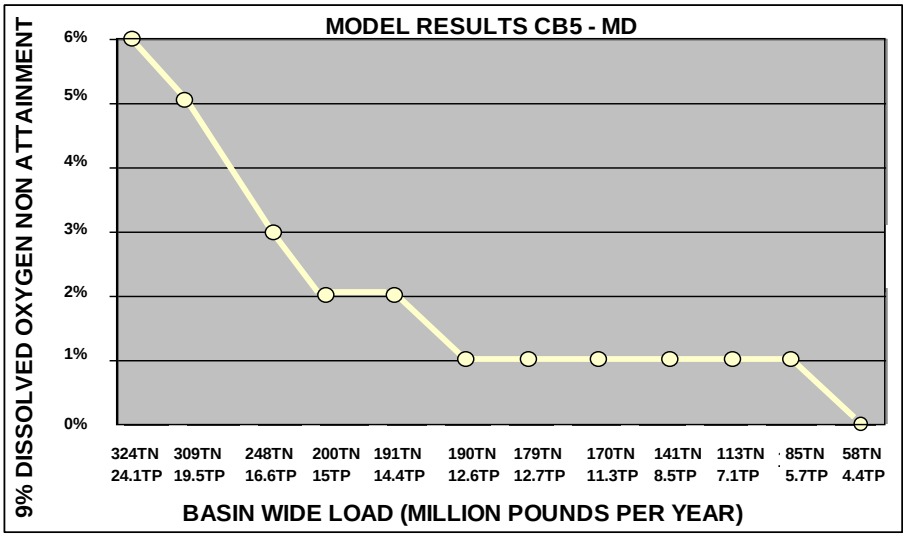
The Chesapeake Bay water quality criteria adopted by the four Bay jurisdictions into their respective water quality standards (WQS) regulations provide for allowable exceedances of each set of DO, water clarity and chlorophyll *a* criteria defined through application of a biological or default reference curve (U.S. EPA 2003). Figure I-1 depicts this concept in yellow as allowable exceedance of the criterion concentration. In order to compare the Chesapeake Bay Water Quality Model results with the Bay jurisdictions WQS, the model results for each scenario and for each modeled segment are analyzed to determine the percent of time and space that the modeled DO results exceed the allowable concentration. For any modeled result where the exceedance in space and time (shown in Figure I-1 as the red line) exceeds the allowable exceedance (shown in Figure I-1 as the yellow area), that segment is considered in non-attainment. This amount of non-attainment is shown in the figure as the area in white between the red line and the yellow area and is typically displayed in model results as percent of non-attainment for that segment. The amount of non-attainment is reported to the whole number percent. The yellow area below the blue reference curve reflects the amount of 'allowable' criteria exceedance. The area between the blue reference curve and the red CFD curve is the amount of 'unallowable' criteria exceedance, defined here as the 'red area'



Source: USEPA 2003.

Figure I-1. Illustration of the application of a reference curve to the cumulative frequency distribution to assess Chesapeake Bay water quality criteria attainment.

Figure I-2 below displays Chesapeake Bay Water Quality Model results showing percent non-attainment of the 30-day mean open-water dissolved oxygen criterion for various basin-wide loading levels of the Maryland portion of the lower central Chesapeake Bay segment CB5MH_MD.



Source: Appendix O.

Figure I-2. Example of dissolved oxygen criteria non-attainment results from a wide range of nutrient load reduction model scenarios.

As can be seen in Figure I-2, there is a notable improvement in the percent non-attainment as the loads are reduced until approximately 1 percent non-attainment. At a loading level of 190 million pounds per year total nitrogen and 12.7 million pounds per year total phosphorus, the 1 percent non-attainment is persistent through consecutive reductions in loading levels and remains consistent until a loading level of 58 million pounds per year total nitrogen and 4.4 million pounds per year of total phosphorus is reached. While this is one of the more extreme examples of persistent levels of 1 percent non-attainment, this general observation of persistent non-attainment at 1 percent is fairly common to the Bay Water Quality Model results as described and documented below.

This empirical observation is likely based on the geometry of the time and space-based assessment of the Bay WQS. An initial reduction made in the nutrient loads would be associated with an increase in attainment of the WQS as shown in the green line in Figure I-3. As reductions move toward attainment, they move toward the area of allowable criteria exceedance as shown by the light green line in Figure I-3. Note that even though the reduced nutrient loads under the scenario represented by the light green line continue to reduce the time and space of WQS nonattainment, different rates of improvement exist at different portions of the curve. In this hypothetical example, the scenario represented by the light green line has reduced the time of exceedance well below the area of allowable exceedance, but the space component still showed a very low level of non-attainment.

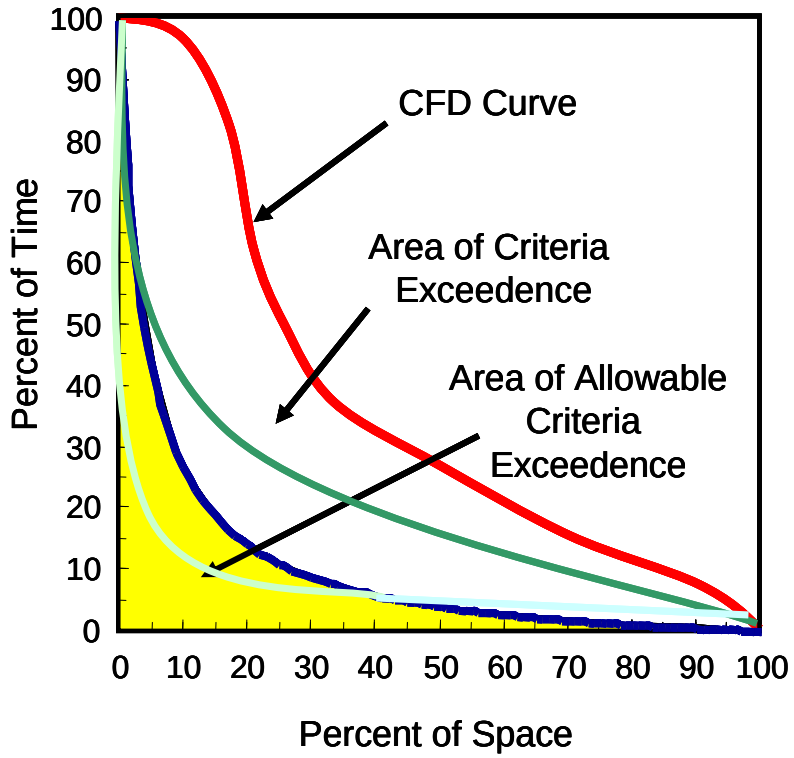


Figure I-3. A graphical representation of how the persistent 1% nonattainment may arise in the criteria assessment of the Chesapeake water quality standards.

The observation of a small, yet persistent percentage of model projected dissolved oxygen criteria non-attainment across a wide range of segments and designated uses, all of which are responding to nutrient load reductions, is an outcome of the criteria assessment methodology. Given that this has been observed in a wide variety of different segments across all three designated uses—open-water, deep-water and deep-channel—non-attainment percentages projected by the Bay Water Quality Model rounded to 1 percent were considered to be in attainment for a segment's designated use for purposes of developing the Chesapeake Bay TMDL. Clear evidence of small, yet persistent percentage of model projected DO criteria non-attainment across a wide range of segments and designated uses is documented within this appendix.

A separate validation of the findings described above was undertaken to confirm that 1 percent was the correct percentage below which the designated use-segment could be considered in attainment and is provided within this appendix.

Reporting of Criteria Non-Attainment Percentages

Chesapeake Bay modeling results for dissolved oxygen, chlorophyll *a* and water clarity criteria non-attainment percentages are rounded to whole numbers. This is a common scientific practice and principle for conveying data to the public and is fully consistent with how many others report modeling output.

Documenting Attainment for 1% Non-Attainment Dissolved Oxygen Criteria Values

The Chesapeake Bay water quality criteria adopted by the states and the District of Columbia into their respective water quality standards regulations already provides for 'allowable' exceedances of each set of dissolved oxygen, water clarity and chlorophyll *a* criteria defined through application of a biological or default reference curve (U.S. EPA 2003). What is being addressed here is how to address 1% non-attainment dissolved oxygen, water clarity and chlorophyll *a* criteria values assessed using the CFD-based criteria assessment procedures in the face of clear evidence: 1) for persistence over large simulated load reductions across numerous segments and designated uses; and 2) reduced sensitivity to load reductions at and below the 1% non-attainment level.

Evaluation of Residual 1.499 Percent or Less Non-attainment Values

There is clear evidence for a 'residual' of 1% non-attainment across a large span of model-simulated load reductions across a number of tidal Bay segments and designated uses (Table I-1). Within the Bay TMDL document and supporting appendices, the reported criteria attainment values already account for the allowable exceedances documented in each Bay jurisdiction's respective Chesapeake Bay water quality standards regulations. These reported criteria attainment values also account for any restoration variances adopted by the Bay jurisdictions into their water quality standards regulations. All the values that are colored green denote full attainment of the respective criteria, dissolved oxygen in this case.

For illustration purposes only, as observed in the dissolved oxygen 'stoplight plot' spreadsheet dated May 24, 2010 shared with members of the Chesapeake Bay Program's Water Quality Goal Implementation Team, there were 21 designated use-segments where the recorded model scenario-transformed monitoring data non-attainment values between 0.0% and 1.5% across a range of model scenarios. (Please note all the values reported in Table I-1 would round to 0% or 1%.) These model scenarios had loading levels which spanned 9 to 151 million pounds of nitrogen and comparable ranges of phosphorus loading levels (Table I-1).

Table I-1. The range of dissolved oxygen criteria non-attainment percentages across different model simulated nitrogen load ranges for 21 Chesapeake Bay segments-designated uses

Chesapeake Bay Segment	Designated Use	Criteria Non-attainment Range[1] (%)	Model Simulated Nitrogen Load Range (million pounds/yr)
CB7	Open-water	0.5-0.0	200-141
CHOMH1	Open-water	0.1-0.0	254-179
CSHMH	Open-water	0.8-0.1	342-309
DCATF	Open-water	1.2-0.1	191-179
PAXTF	Open-water	1.0-0.6	190-179
DCPTF	Open-water	0.6-0.2	309-254
MAGMH	Open-water	1.3-0.3	342-191
MOBPH	Open-water	1.0-0.0	342-200
PIAMH	Open-water	0.1-0.1	191-179
TANMH	Open-water	1.5-0.1	342-309
YRKMH	Open-water	1.0-0.4	191-170
CB3MH	Deep-water	0.6-0.0	254-179
CB5MH	Deep-water	1.5-0.0	254-141

Chesapeake Bay Segment	Designated Use	Criteria Non-attainment Range[1] (%)	Model Simulated Nitrogen Load Range (million pounds/yr)
CHSMH	Deep-water	0.5-0.4	170-141
EASMH	Deep-water	0.8-0.2	200-170
MD5MH	Deep-water	1.5-0.1	191-141
MAGMH	Deep-water	0.5-0.5	170-141
PATMH	Deep-water	1.1-0.1	200-190
VA5MH	Deep-water	0.7-0.0	254-179
CB3MH	Deep-channel	0.2-0.1	200-190
EASMH	Deep-channel	1.3-0.0	190-170

1. Each 0.0% value in this column is colored in red in the original May 24, 2010 'stoplight plot' spreadsheet, denoting a very low percentage of non-attainment was recorded below 0.1%.

Source: The dissolved oxygen criteria attainment detailed stoplight spreadsheet dated May 24, 2010 presented to the Chesapeake Bay Program's Water Quality Goal Implementation Team during the Team's May 24, 2010 conference call.

The observation of a small, yet persistent percentage of dissolved oxygen criteria non-attainment across a wide range of segments and designated uses, all of which are responding to nutrient load reductions, is an artifact of the criteria assessment methodology as described above and illustrated in Figure I-1. The entire analysis system can all result in such small non-attainment percentages over a range of scenario loading levels. The analysis system includes the following steps:

- calculate the model output differences between the scenario and the base calibration
- use differences to develop the regression
- apply regression to transform monitoring data to reflect scenario differences in water quality
- interpolate transformed monitoring data
- develop cumulative frequency distribution using interpolated data
- compare with the biological or default reference
- produce a non-attainment percentage—can all result in such small non-attainment percentages over a range of scenario loading levels.

There is not comparable evidence of persistent percentages of dissolved oxygen criteria non-attainment above 1% across a wide range of segments and designated uses for segments responding to nutrient load reductions. There were several open-water segments where the same percentage non-attainment persists across a wide set of nutrient loading reductions—e.g., Gunpowder River (GUNOH) at 5% from 342 TN to 85 TN, Wicomico River (WICMH) at 5% from 191 TN to 85 TN, several segments in Pocomoke River at 5% from 179 TN to 85 TN (see Appendix O). However, all these segments have been identified as having poor local responses to load reductions in the Bay Water Quality Model scenarios based on poor regressions. Other lines of evidence, separate from the model generated outputs were used to determine attainment and develop the respective Bay segment TMDL (see Appendix N). The cause for these persistent percentages is different from small, yet persistent percentages being addressed in this appendix.

Analysis of D.O. Criteria Attainment Sensitivity to Simulated Load Reductions

A separate validation of the findings described above was undertaken to confirm that 1% was the correct percentage below which the designated use-segment could be considered in attainment. This analysis involves plotting the change in unallowable dissolved oxygen criterion exceedance or "red area" under the reference curve (see Figure I-1) per loading unit against the starting "red area". The change in red area between two scenarios is divided by the change in load. For this analysis, the changes in nitrogen (N) and phosphorus (P) loads are combined into a single measure, load units, enabling the calculation of change in red area per change in load:

$$\text{load units} = (N + 10*P)/2 \qquad \text{Equation L-1}$$

This single measure, when plotted against starting red area, allows a direct comparison of sensitivity of the analysis system[1] to load changes across different levels of non-attainment. To get a true sensitivity, calculations involving scenarios that attained the applicable dissolved oxygen criteria were not included. Twelve scenarios were used with eight 3-year periods for a total of 88 possible sensitivity assessments per designated-use segment, decreased by the number of assessments that attained the applicable dissolved oxygen criterion.

This analysis was not amenable to tidal tributary segments as the loadings are bay-wide and not specific to an individual tidal tributary. Further, some of the existing scenarios used for this analysis have varying levels of reduction between different tributaries.

The CB7PH open-water segment provides a clear example of a decrease in sensitivity to load reductions as non-attainment approaches zero. The highest sensitivity to load reductions is with the highest red area, but there is still considerable sensitivity to load reductions through approximately 0.2% (Figure I-4). Another example is CB2OH open-water, where there is a sharp drop off in sensitivity to load reductions near 1% (Figure I-5).

[1] The analysis system referred to here is the combination of the Chesapeake Bay Water Quality/Sediment Transport Model, the procedures for using differences in Bay model scenarios outputs to transform Bay water quality monitoring data, and the EPA published Bay criteria assessment procedures.

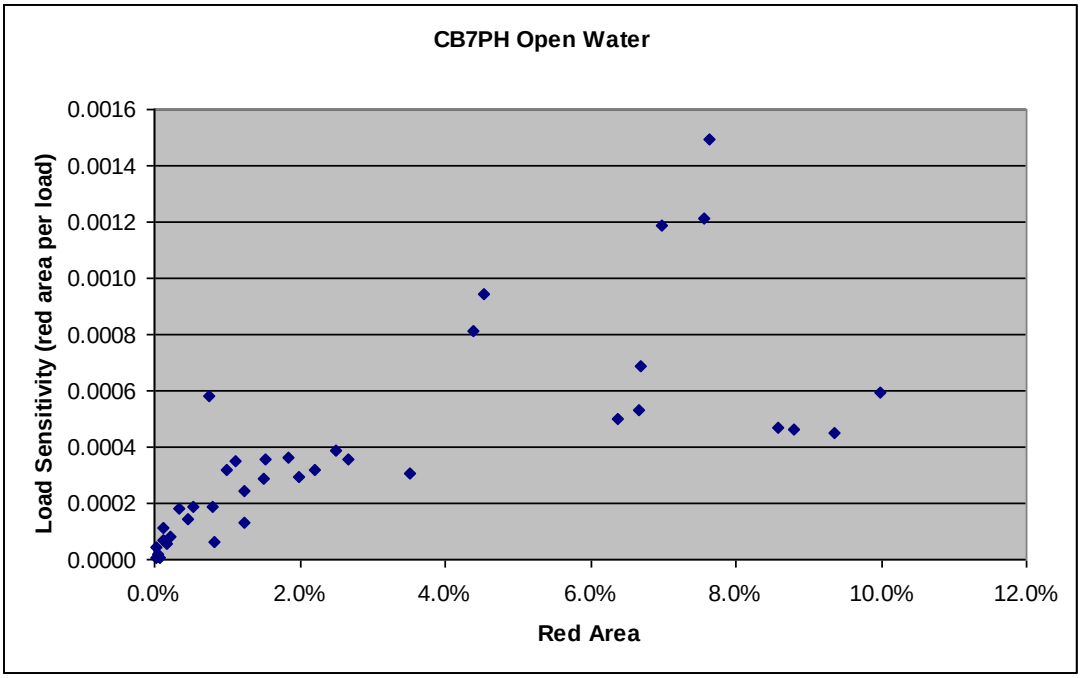


Figure I-4. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB7PH open-water.

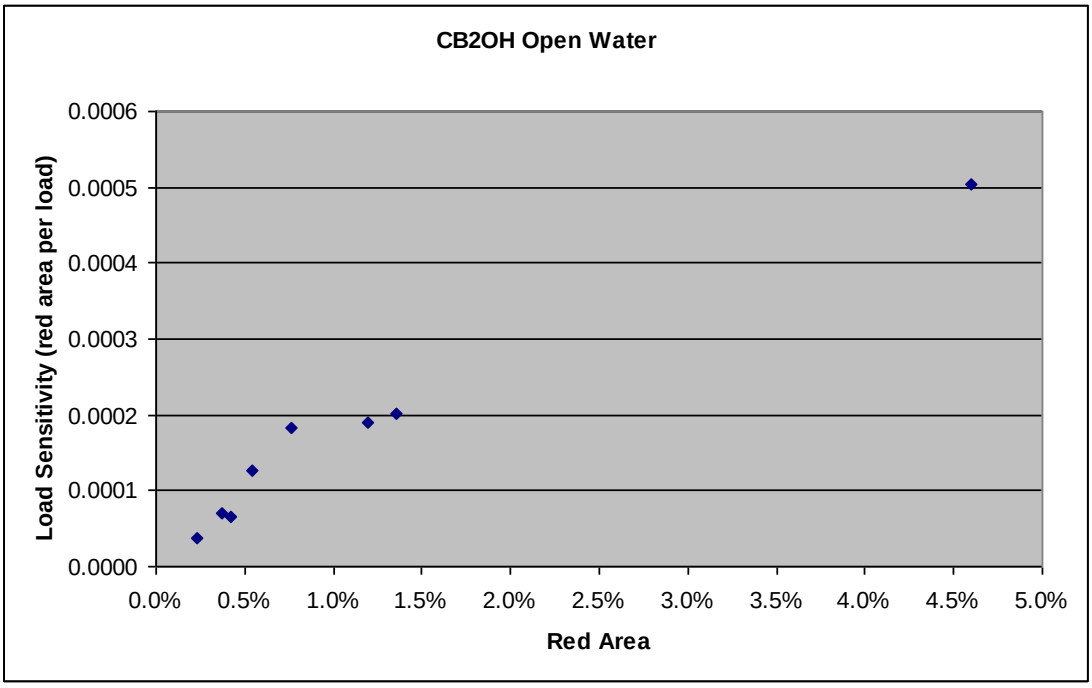


Figure I-5. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB2OH open-water.

A counter-example is CB5MH open-water, where the sensitivity to load reductions is relatively constant throughout the model simulated range of load reductions (Figure I-6).

There are a large number of segments that could be analyzed (see Table I-1), but it is most appropriate to focus on those designated-use segments most important to the Bay TMDL—those requiring significant basinwide nutrient reductions in order to come in attainment with the respective dissolved oxygen criterion. These designated use-segments are CB3MH, CB4MH, CB5MH for deep-water and deep-channel and POTMH for deep-channel.

The CB3MH deep-water segment has consistently reducing sensitivity to load reductions and no high sensitivity examples above 1% red area (Figure I-7). The CB4MH deep-water designated use-segment shows relatively consistent sensitivity across a wide range of red area (Figure I-8). The CB5MH deep-water designated use-segment (Figure I-9) and the POTMH deep-water designated use-segment (Figure I-10) are relatively constant across wide ranges but have a clear reduction in sensitivity to load reductions around 1%.

The deep-channel designated use-segment plots are similar to the deep-water designated use-segment plots. The CB3MH deep-channel designated use-segment also shows a consistent range of sensitivity throughout multiple ranges of red area, but has low sensitivity to further load reductions at 1-1.5% red area (Figure I-11). The CB4MH deep-channel designated use-segment shows a clear drop-off in sensitivity to load reductions at 1% (Figures I-12 and I-13). The CB5MH deep-channel designated use-segment has no basis to make the judgment as there are no red area values less than 15% (Figure I-14).

Although there is some discretion involved in the judgment of exactly when sensitivity to further load reductions becomes low, there is a general decrease in sensitivity when the red area is low. One percent is a relatively consistent level at which sensitivity decreases significantly across many of the principal designated use-segments used for decision-making in the Chesapeake Bay TMDL (Table I-2). At the non-attainment values of 1 percent (or less), there is a significant drop off in the sensitivity—further reduction in dissolved oxygen criteria non-attainment—of these designated use-segments to further load reductions. The analysis system is not sensitive to the effects of further load reductions at the 1% or less non-attainment level. This finding is fully consistent with findings from the parallel analysis summarized in Table I-1 for a wider array of designated use-segments.

Application in Development of the Bay TMDL

Given these findings have been observed in a wide variety of different segments across all three designated uses—open-water, deep-water and deep-channel—and confirmed through an independent analysis, non-attainment percentages rounded to 1% are considered in attainment for that Bay segment's designated use for purposes of developing the Bay TMDL.

For those designated use-segments for which a jurisdiction has adopted a restoration variance that sets attainment at a percentage of the non-allowable criteria exceedances, the 1% non-attainment described above does not apply to assessment of the restoration variance percentage. For example, Maryland's designated use-segment CB4MH deep water has a restoration variance

of 7%. Chesapeake Bay Water Quality Model-based criteria attainment assessment results showing 8% non-attainment would be considered in non-attainment.

The results of numerous dissolved oxygen criteria assessments are used here to illustrate and diagnosis the reasons behind the persistent low levels of non-attainment. However, the documentation of attainment for 1% non-attainment applies to dissolved oxygen, water clarity, and chlorophyll a criteria given each are assessed using the same set of CFD-based criteria attainment assessment procedures, the source of the persistent low levels of non-attainment (USEPA 2003).

Literature Cited

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.

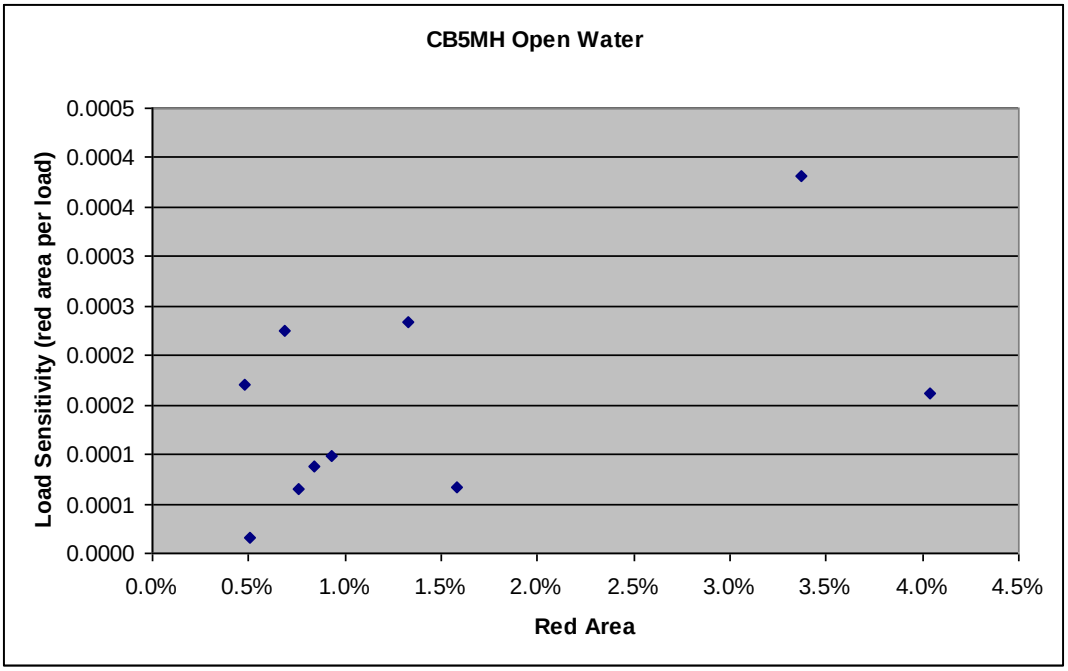


Figure I-6. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB5MH open-water.

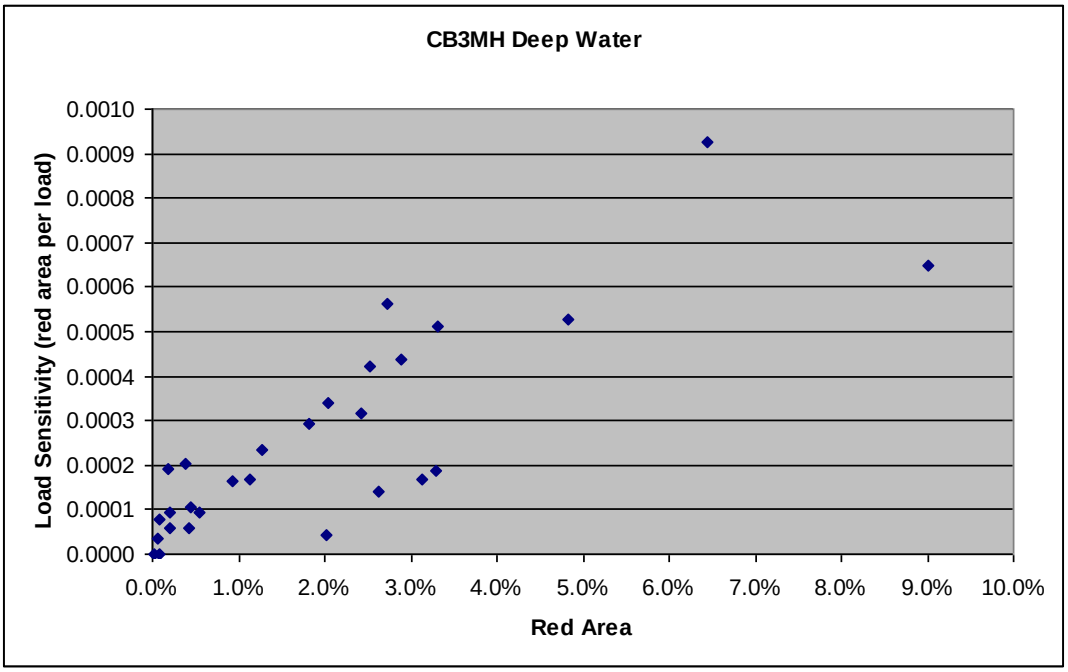


Figure I-7. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB3MH deep-water.

Table I-2. Summary of findings from the analysis of red area with low sensitivity to load reductions for the Chesapeake Bay designated use

Chesapeake Bay Segment	Designated Use	Red Area with Low Sensitivity to Load Reductions (%)
CB3MH	Deep-water	0.2
CB4MH	Deep-water	0
CB5MH	Deep-water	1
POTMH	Deep-water	1
CB3MH	Deep-channel	1-1.5
CB4MH	Deep-channel	1
CB5MH	Deep-channel	N/A

Sources: Figures I-7 through I-14 in this appendix.

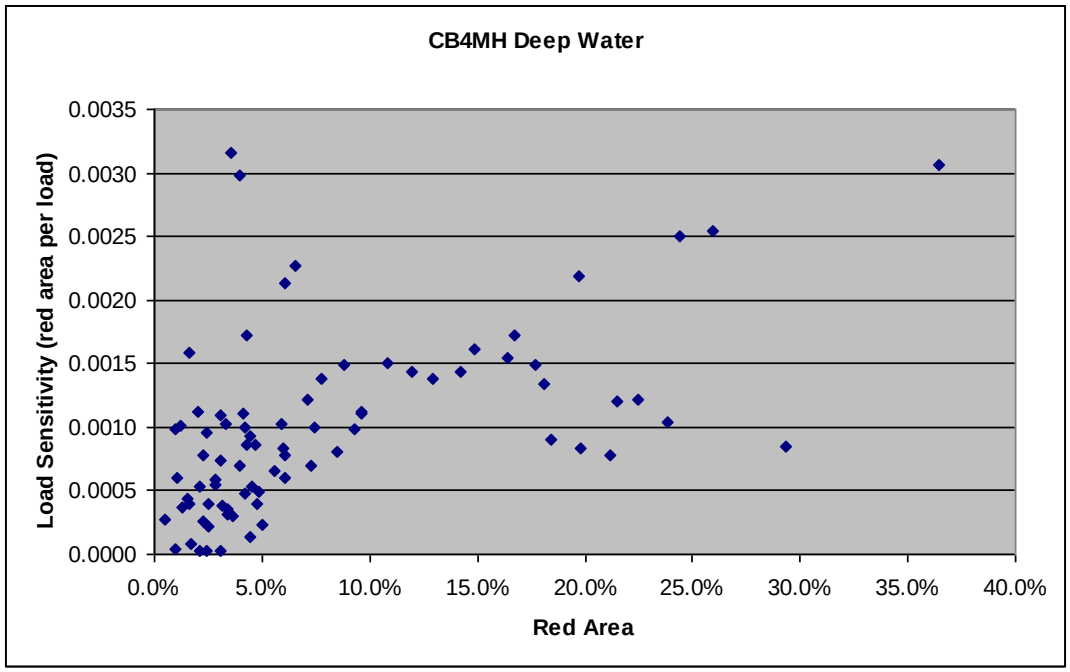


Figure I-8. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB4MH deep-water.

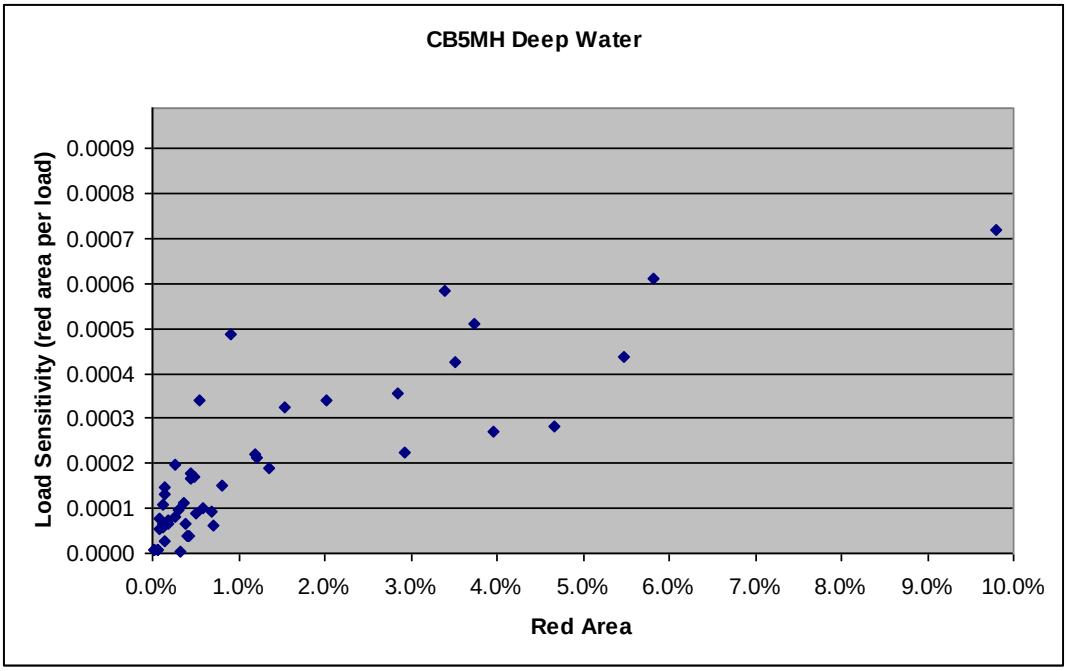


Figure I-9. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB5MH deep-water.

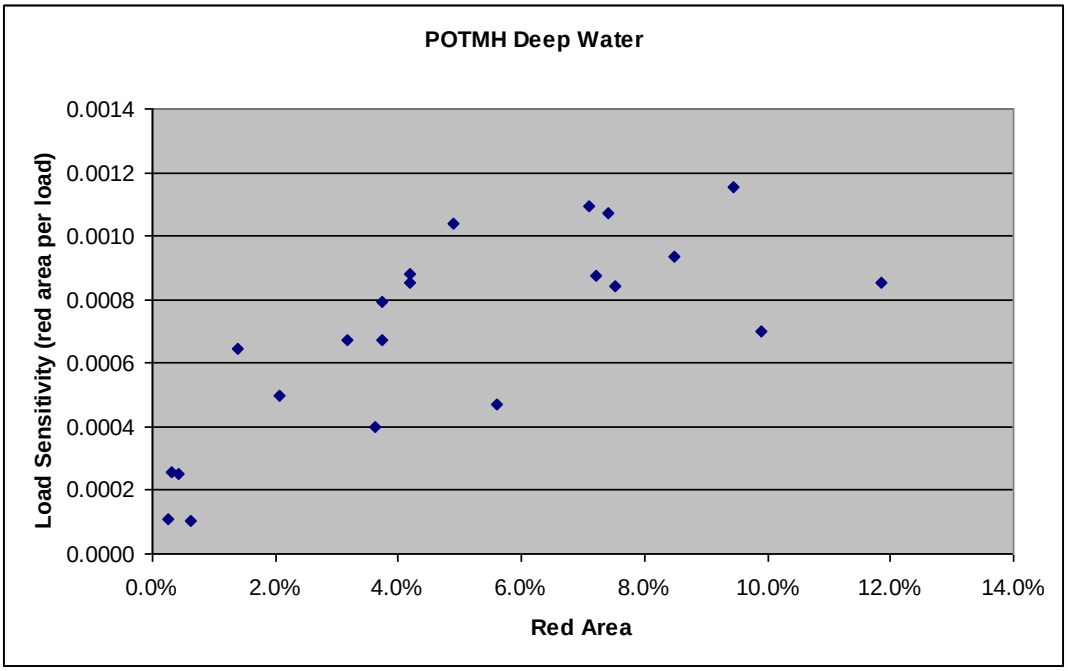


Figure I-10. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment POTMH deep-water.

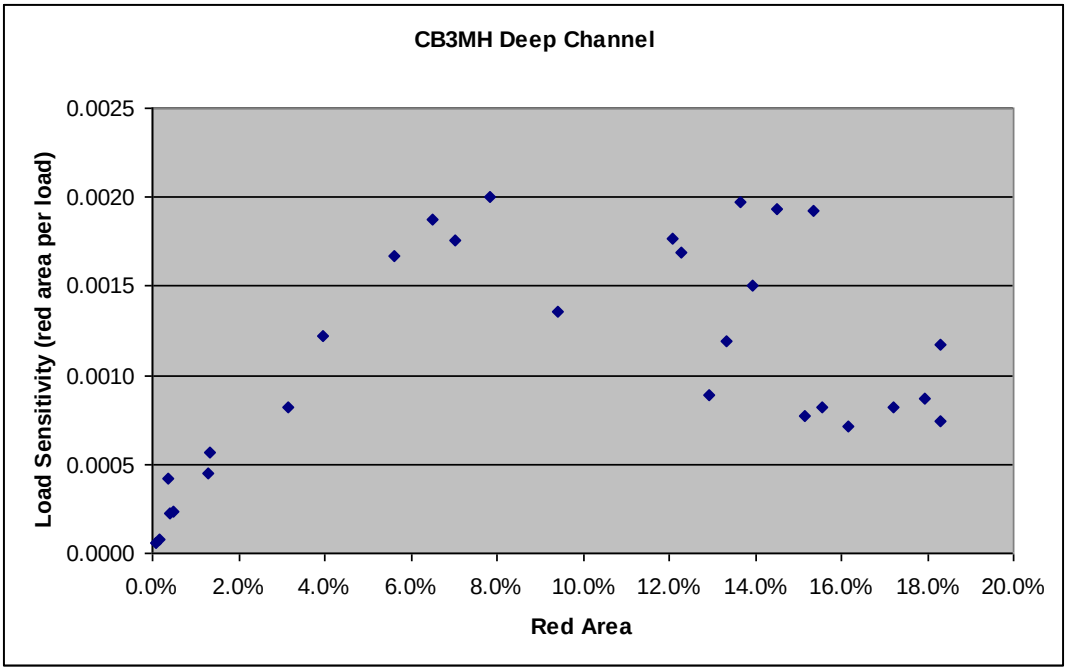


Figure I-11. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB3MH deep-channel.

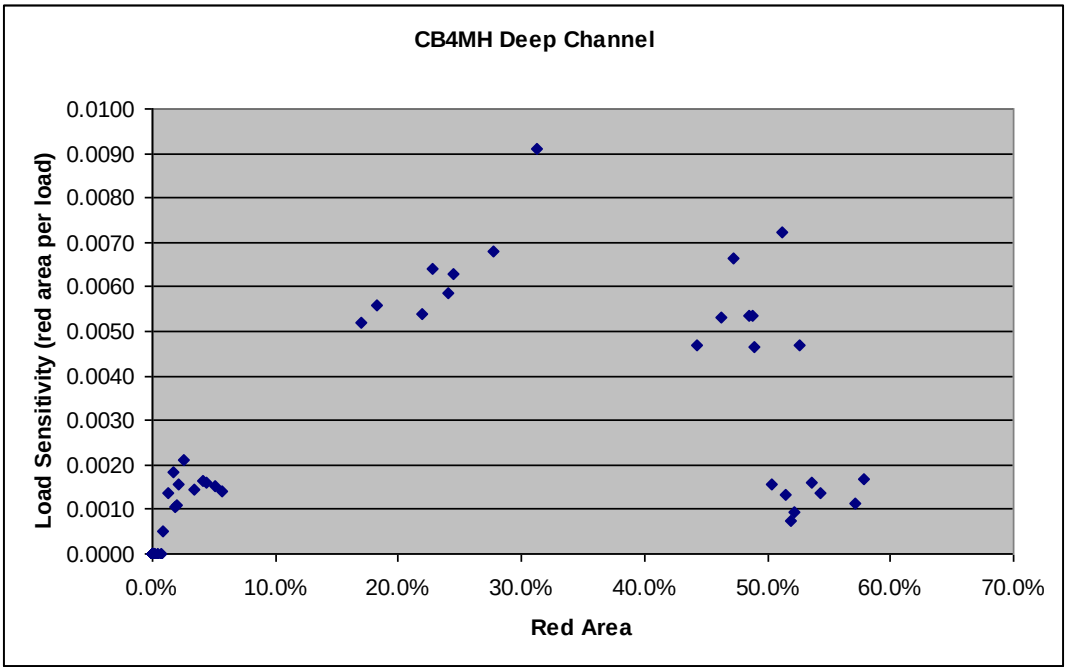


Figure I-12. Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB4MH deep-channel.

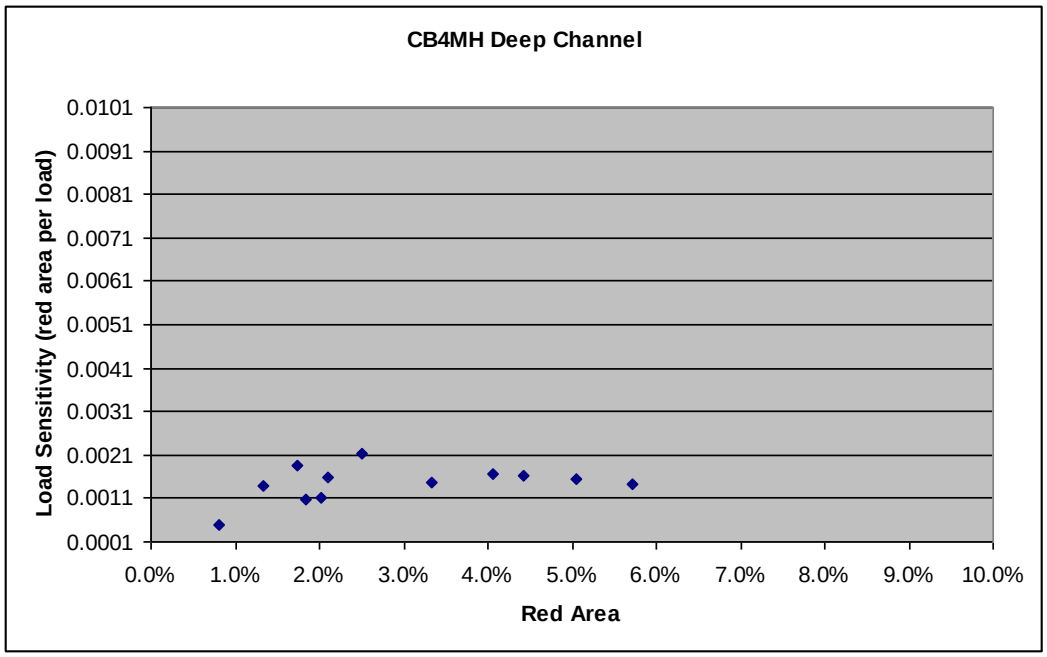


Figure I-13. Expanded view of the Figure 10 focusing down on the 0-10% red area for segment CB4MH deep-channel to illustrate the drop off in sensitivity at the 1-1.5% of red area.

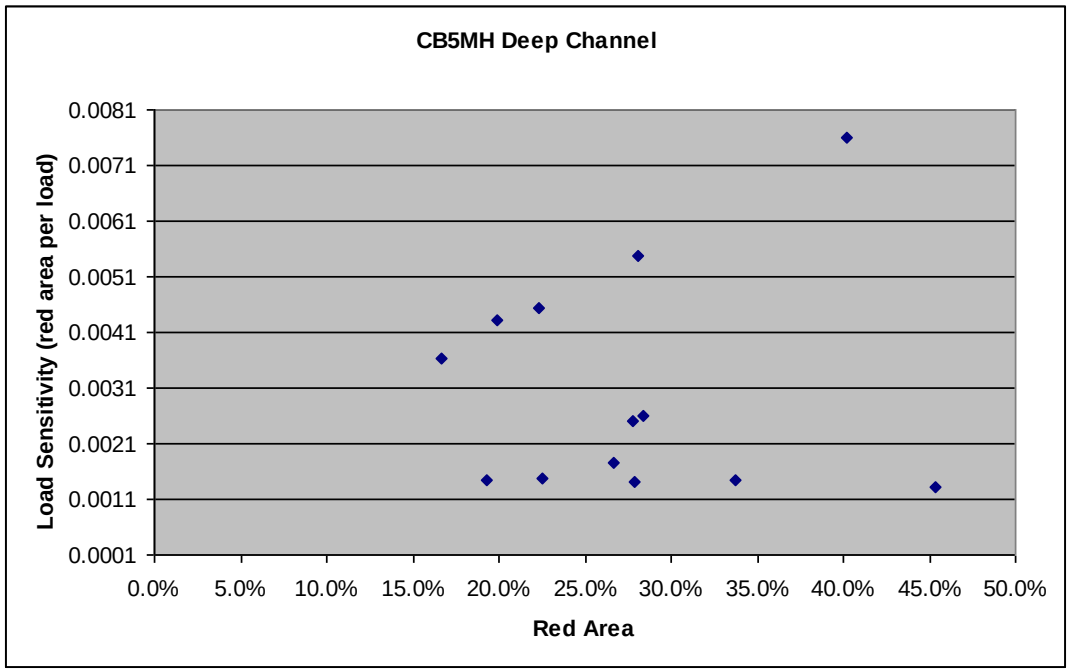


Figure I-14 Load sensitivity (unallowable dissolved oxygen criteria exceedances per load unit) vs. red area (unallowable dissolved oxygen criteria exceedances) for designated use-segment CB5MH deep-channel.