Appendix N-1.

Resolution of Segments Failing to Attain the Dissolved Oxygen Criteria

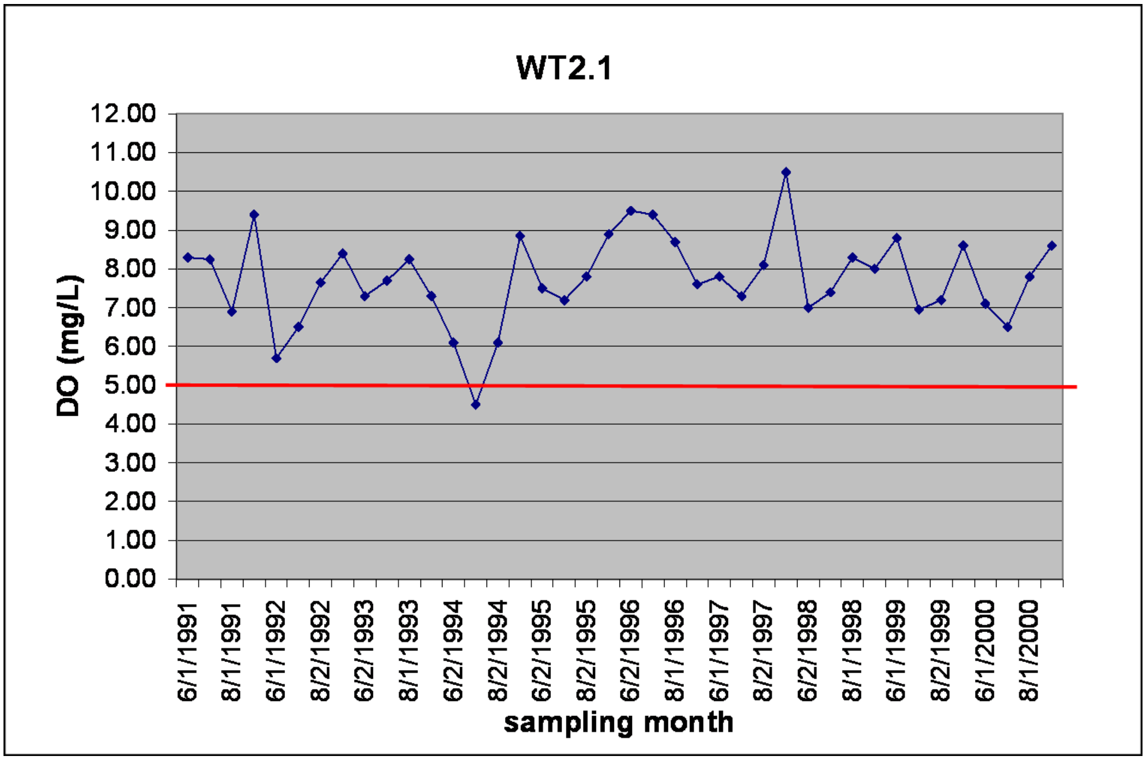
In the process of determining the target nutrient load allocations, it was observed that in a limited number of Chesapeake Bay segments, poor dissolved oxygen conditions appeared to persist even under scenarios of dramatically reduced nutrient loads. A series of systematic diagnostic analyses were conducted to determine the drivers of these persistent violations. The findings of these analyses, summarized in Section 6.4.1, are described in more detail here.

For the affected Bay segments, additional lines of evidence were explored to determine whether the apparent non-attainment represented an area of real concern, or whether these segments could reasonably be expected to show sufficient improvement to attain WQS given the proposed nutrient load reductions. Each Bay segment was evaluated to determine:

1. Whether violations of the dissolved oxygen (DO) criteria were isolated or widespread;
2. Whether the Chesapeake Bay Water Quality Model effectively simulated historical conditions and improvement in those conditions with reduced loads; and
3. Whether nearby Bay segments also exhibited persistent and/or widespread hypoxia (low to minimal dissolved oxygen levels).

Gunpowder River

The dissolved oxygen criteria non-attainment in the tidal Gunpowder River (GUNOH) was driven by two converging factors. First, the historical water quality dissolved oxygen monitoring data for this location show that the water in Gunpowder River is generally well-oxygenated in the summertime, with only a single instance of hypoxia observed (July 1994) over the course of 10 consecutive summers from 1991-2000 violated the open-water criterion of 5.0 mg/L (red line in Figure N1-1).



Source: http://www.chesapeakebay.net

Figure N1-1. measurements taken in summer months (June-September) at water quality monitoring station WT2.1 in the Gunpowder River from 1991-2000.

Second, the Bay Water Quality Model's simulations for this location, which ranged from about 8-10 mg/L, were only moderately higher than the average historical summertime conditions. However the Bay Water Quality Model did not simulate conditions below 8 mg/L in this region. Because no simulated hypoxia existed, there was no example of simulated improvement in DO concentrations with reduced nutrient inputs for this region. With summertime dissolved oxygen concentrations at or above 8 mg/L, the Bay Water Quality Model generally simulated a minimal increase in DO concentrations in response to reduced nutrient loads. This is in clear contrast to Bay Water Quality Model's performance when hypoxic conditions are simulated under calibration (i.e. historical) conditions—see Figure N1-2 for an example from the middle of the Chesapeake Bay. Figure N1-2 is example of a regression plot showing WQM performance consistent with historical observations. The pink symbols and line represent DO concentrations from the calibration scenario; the blue symbols and line represent DO concentrations under reduced nutrient loads of the E3 Scenario. The range of DO concentrations in the calibration scenario spans the range of historical observations. Greater increase in DO concentrations is observed with reduced loads when the initial (calibration) concentrations are low. In these cases the Bay Water Quality Model's predictions are consistent with empirical findings, namely, that hypoxic conditions will improve with reduced loads to a greater degree than will initially high DO concentrations.

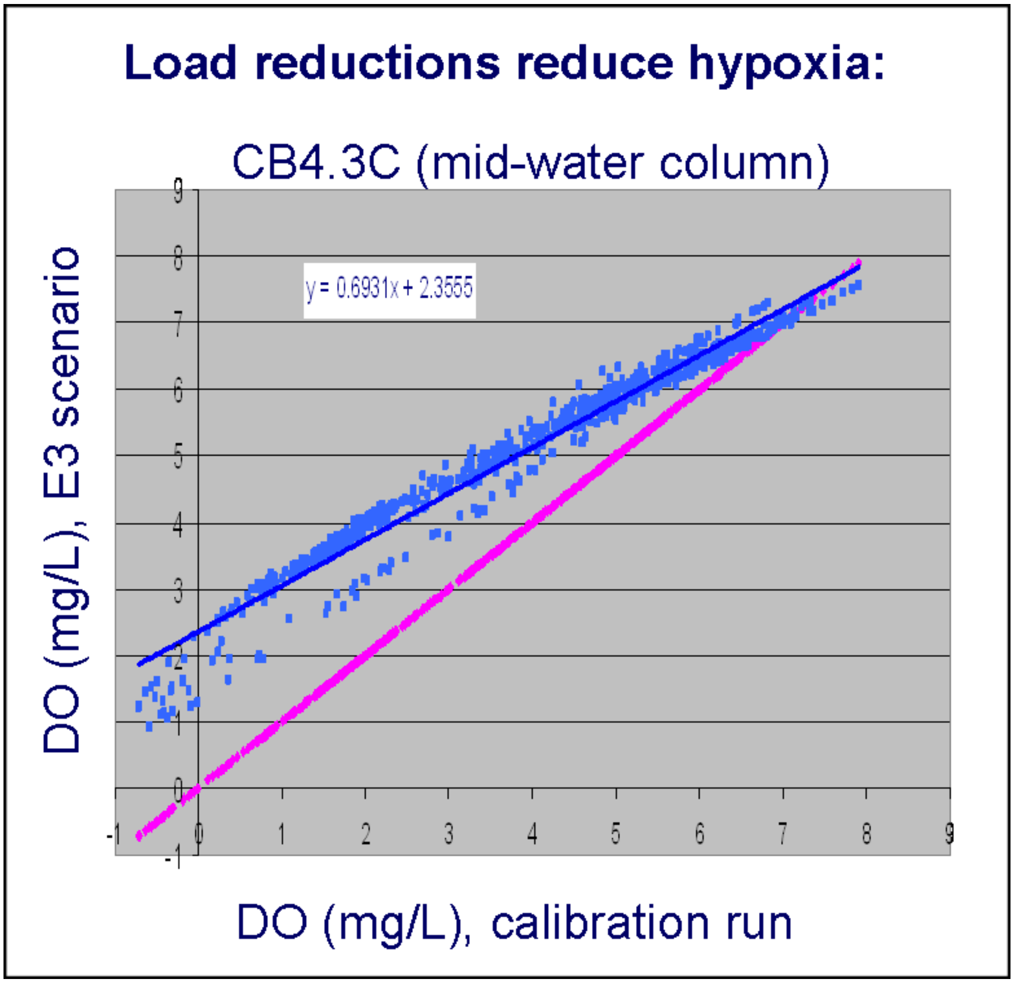


Figure N1-2. Example of a regression plot showing Bay Water Quality Model performance consistent with historical water quality monitoring dissolved oxygen observations in the lower central Chesapeake Bay segment CB4MH at station CB4.3C.

The regression equation that is used to scenario-modify dissolved oxygen concentrations (see Section 6.2.1 for a description of the scenario-modification procedure) is generated from a comparison of DO concentrations simulated in the calibration scenario with those simulated in a management scenario such as E3. When little change is observed in DO concentrations between the two scenarios, the resulting regression equation reflects this (Figure N1-3). When simulated DO concentrations are consistently at or above 8 mg/L in the calibration scenario, the Bay Water Quality Model generally does not show dramatic improvements in concentrations with reduced pollutant loads. Furthermore, when the resulting regression equation is applied to a DO concentration well outside the range of the simulated data, it can cause a “DO response” that does not accurately reflect the information provided by the Bay Water Quality Model.

In the case of Gunpowder River monitoring station WT2.1 for July 1994, the Bay Water Quality Model-simulated DO concentrations fell between about 8 and 10 mg/L for the calibration scenario as well as the numerous reduced loading “management” scenarios. In Figure N1-3, the pink symbols and line represent the calibration scenario DO concentrations; the light blue symbols and black line show the change in DO concentrations from the calibration to the E3 scenario. The red arrows show the predicted change in an initial DO concentration of 4.5 mg/L. In this case, a historical observation of 4.5 mg/L was scenario-modified to a concentration of 4.4 mg/L for the E3 scenario.

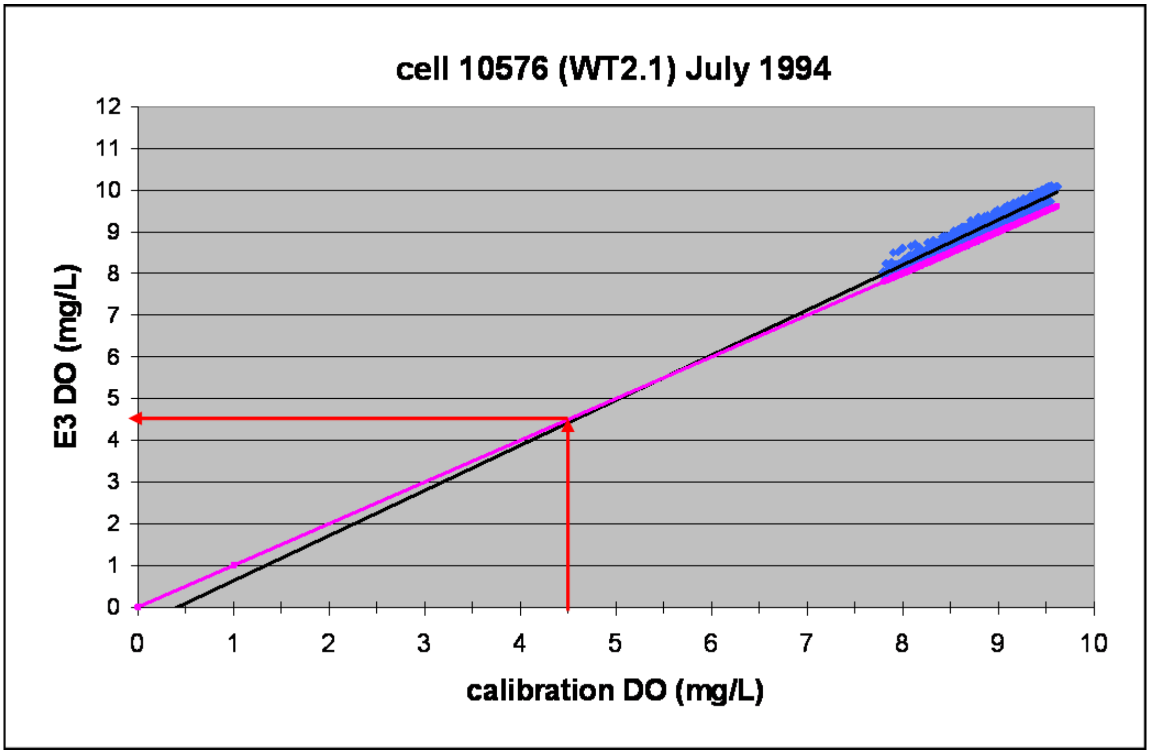


Figure N1-3. Bay Water Quality Model scenario DO concentrations and regression for station WT2.1 in the Gunpowder River.

As is shown here, even at the "E3" scenario (see Appendix J for a description of management scenarios) only a slight increase in DO concentrations is observed across the range of simulated concentrations. Typically, a greater response – in the form of higher DO concentrations – is observed when the initial (i.e. calibration) DO concentrations are low (i.e. less than 5 mg/L). In this case, when the linear regression representing the relationship between the calibration and E3 DO concentrations is extrapolated far below the range of simulated conditions, the result suggests that under "E3" conditions, hypoxia could actually get worse rather than better. This prediction is not an accurate representation of model simulations; rather it is the effect of extrapolating the regression equation well outside the range of the simulations from which it was generated. Such was the case for July 1994, when a historical observation of 4.5 mg/L was scenario-modified to a concentration of 4.4 mg/L under the dramatically reduced load conditions of the E3 scenario.

Examination of nearby segments – the Bush River (BSHOH), the upper Chesapeake Bay (CB2OH), and the Middle River (MIDOH) – showed attainment of DO WQS under historical loading conditions, as well as under all load reduction scenarios (Figure N1-4).

Cbseg	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
BSHOH	0%	0%	0%	0%	0%	0%	0%	0%	0%
CB2OH	0%	0%	0%	0%	0%	0%	0%	0%	0%
MIDOH	0%	0%	0%	0%	0%	0%	0%	0%	0%
GUNOH	5%	5%	5%	5%	5%	5%	5%	5%	5%

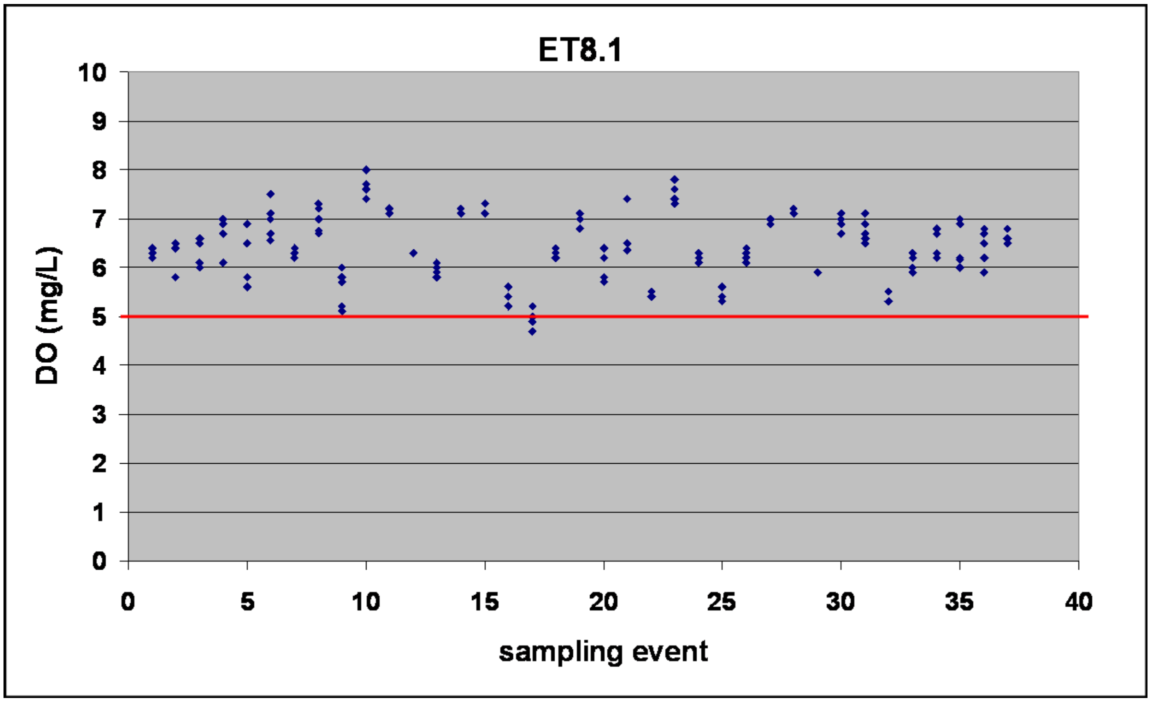
Figure N1-4. Open-water dissolved oxygen criteria attainment "stoplight plot" of the Gunpowder River segment GUNOH and nearby segments.

Source: Appendix N.

In summary, the incidence of hypoxia in the tidal Gunpowder River was isolated. In this single isolated case, the Bay Water Quality Model was unable to provide information on the magnitude of expected improvement in dissolved oxygen conditions with reduced nutrient loads in this region. Examination of nearby segments showed consistent attainment of DO WQS under historical ("Base") as well as reduced loading scenarios. Therefore, it is reasonable to expect that the open-water designated use of GUNOH will attain DO WQS under the basinwide target allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

Manokin River

In the Manokin River (MANMH), violations of the segment's open-water dissolved oxygen WQS for the years 1991-2000 were limited to three measurements, ranging from 4.7-4.9 mg/L, taken during one sampling event in the month of July 1995 (Figure N1-5).



Source: http://www.chesapeakebay.net

Figure N1-5. Summertime DO observations (dark blue symbols) at water quality monitoring station ET8.1 in the Manokin River from 1991-2000.

These isolated, marginal violations of the DO WQS under historical conditions were scenario-modified to greater non-attainment under simulated load reductions. At the same time, adjacent and nearby segments Tangier Sound (TANMH), Big Annemessex River (BIGMH), and the lower Pocomoke River (POCMH) all attained their respective DO WQS under historical conditions as well as reduced loading scenarios (Figure N-6).

Cbseg	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
MANMH	1%	5%	5%	5%	5%	5%	5%	5%	5%
TANMH	0%	0%	0%	0%	0%	0%	0%	0%	0%
BIGMH	0%	0%	0%	0%	0%	0%	0%	0%	0%
POCMH	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: Appendix N.

Figure N1-4. Open-water dissolved oxygen criteria attainment "stoplight plot" of the Manokin River segment MANMH and nearby segments.

Further examination of the performance of the Bay Water Quality Model in the vicinity of water quality monitoring station ET8.1 (MANMH's single tidal monitoring station) showed lower – rather than higher – DO concentrations under reduced loading scenarios (Figure N1-7).

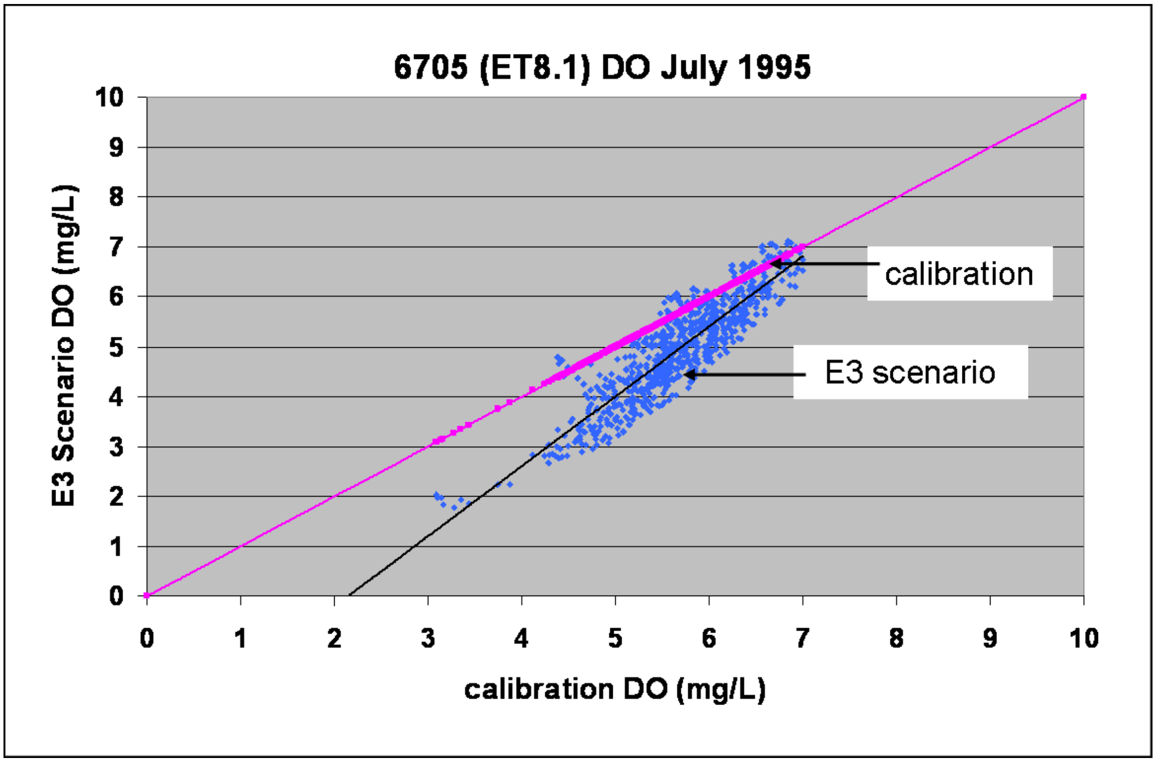


Figure N1-7. Regression plot for the Bay Water Quality Model cell (6705) corresponding to the MANMH water quality monitoring station (ET8.1).

The grid location that represents the Manokin River's single monitoring station is shallow, is directly adjacent to the land. The highlighted cell (cell 6705) in Figure N1-8 coincides with the location of long-term fixed station ET8.1. In such cases, the Bay Water Quality Model often struggles to integrate the multiple, interacting drivers of a parameter such as dissolved oxygen. Further investigation showed that chlorophyll *a* concentrations in cell 6705 decreased to zero (or less) at the E3 scenario (data not shown). If chlorophyll *a* concentrations had *increased* in concert with lower DO concentrations, then a temporal anomaly in pollutant loads to cell 6705 or its vicinity would have been suspected. However, the combination of non-existent chlorophyll *a* concentrations and low DO concentrations observed here indicates that the Water Quality Model struggled to integrate the effect of reduced loads on the feedbacks among multiple drivers of dissolved oxygen concentrations.

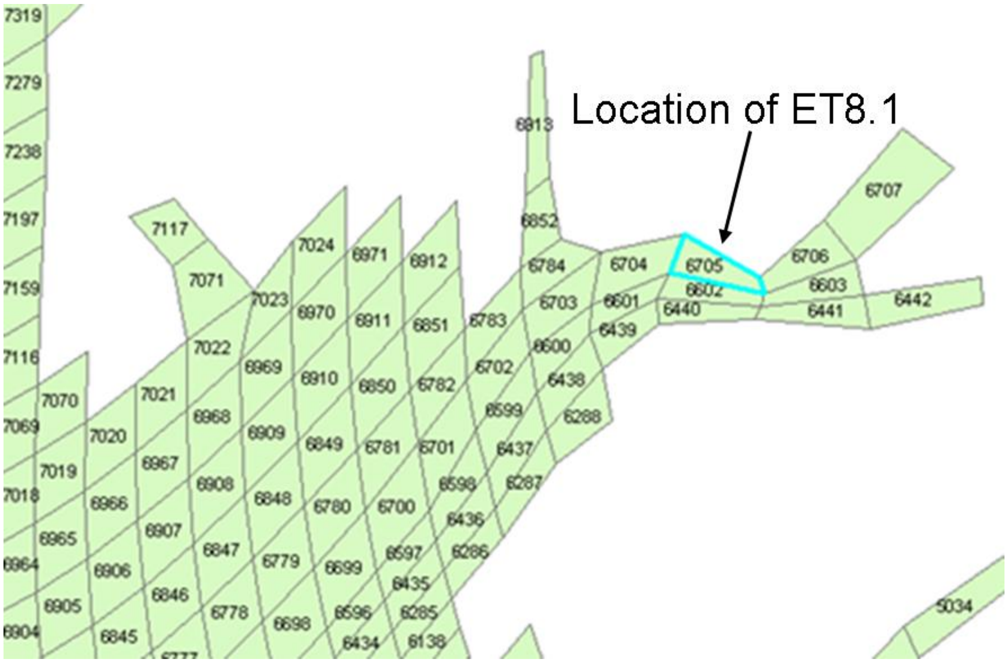
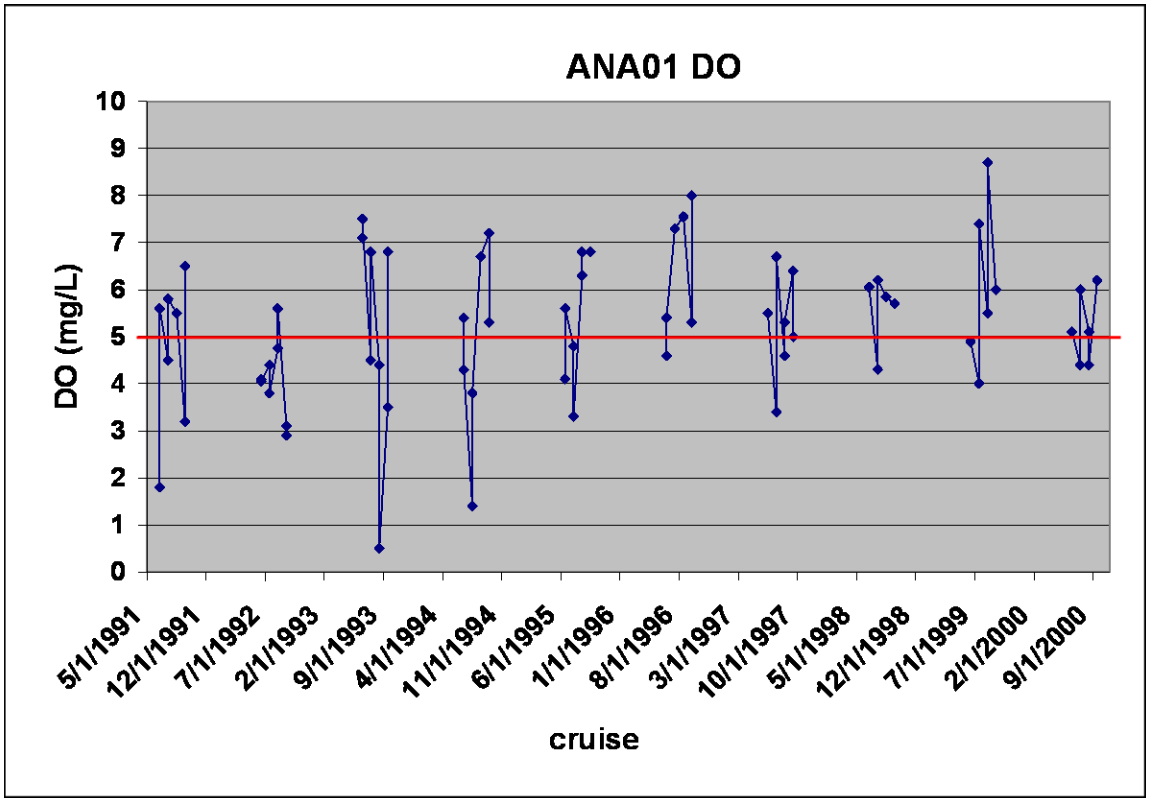


Figure N1-8. Chesapeake Bay Water Quality Model grid for the Manokin River and a portion of Tangier Bay.

Given the isolated nature of DO criteria violations in MANMH under historical conditions, the poor performance of the Water Quality Model, and the unimpaired nature of adjacent water bodies under historical conditions as well as simulated reduced loadings, the EPA concludes that it is reasonable to expect full attainment of the DO WQS in MANMH at the basin-wide target allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

Maryland Portion of the Anacostia River

In the Maryland portion of the tidal Anacostia River (ANATF_MD), substantial violations of the segment's open-water dissolved oxygen WQS were observed historically, with particularly serious violations occurring at station ANA01 in August 1993 and July 1994 (Figure N1-9).



Source: http://www.chesapeakebay.net

Figure N1-9. Summertime water quality dissolved oxygen monitoring observations at Maryland's tidal Anacostia River water quality monitoring station ANA01 from 1991-2000.

The majority of these historical violations were estimated to improve substantially or even reach full attainment with further load reductions. However, for the two months during the critical period with the most serious violations—August 1993 and July 1994, no improvement in DO WQS nonattainment percentage was predicted (Table N1-1).

Table N1-1. Monthly open-water dissolved oxygen criteria nonattainment percentages for ANATF_MD in the 1993-1995 critical period.

		violation rate	
year	month	calibration	179 TN, 12TP
1993	6	0.0%	0.0%
1993	7	20.3%	10.1%
1993	8	100.0%	100.0%
1993	9	53.6%	11.6%
1994	6	79.7%	0.0%
1994	7	100.0%	100.0%
1994	8	20.3%	0.0%
1994	9	20.3%	0.0%
1995	6	100.0%	0.0%
1995	7	100.0%	0.0%
1995	8	0.0%	0.0%
1995	9	0.0%	0.0%

For these months, EPA Chesapeake Bay Program Office (CBPO) analysts compared Bay Water Quality Model simulated dissolved oxygen concentration with historical water quality monitoring observations. For July 1994, model simulated DO concentrations at Bay Water Quality Model grid cell 6443 – the location coincident with monitoring station ANA01 – ranged from 7.2-13.0 mg/L. In contrast, monitoring observations for the same month ranged from 1.0-3.8 mg/L. Similar results were found for the month of August 1993, when Bay Water Quality Model-simulated DO concentrations for cell 6443 ranged from 7.5-15.5 mg/L while historical observations at the same location (ANA01) ranged from 0.5-4.4 mg/L. Because the Bay Water Quality Model did not simulate severe hypoxia in this region for these summer months, it was not able to provide a sufficient estimate of the magnitude of DO response to be expected with nutrient load reductions.

CBPO analysts also considered the attainment status of the two downstream segments closest to ANATF_MD: the District of Columbia's portion of the Anacostia River (ANATF_DC) and the District's portion of the tidal Potomac River (POTTF_DC) (Figure N1-10). Unlike segment ANATF_MD, ANATF_DC and POTTF_DC both attained their respective DO WQS at the target basinwide allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

Cbseg	1985 Scenario 342TN, 24.1TP, 9790TSS '93-'95 DO Open Water Summer Monthly	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly
DCATF	38%	28%	10%	14%	1%	2%	1%
DCPTF	10%	1%	0%	0%	0%	0%	0%
MDATF	34%	39%	19%	18%	12%	12%	12%

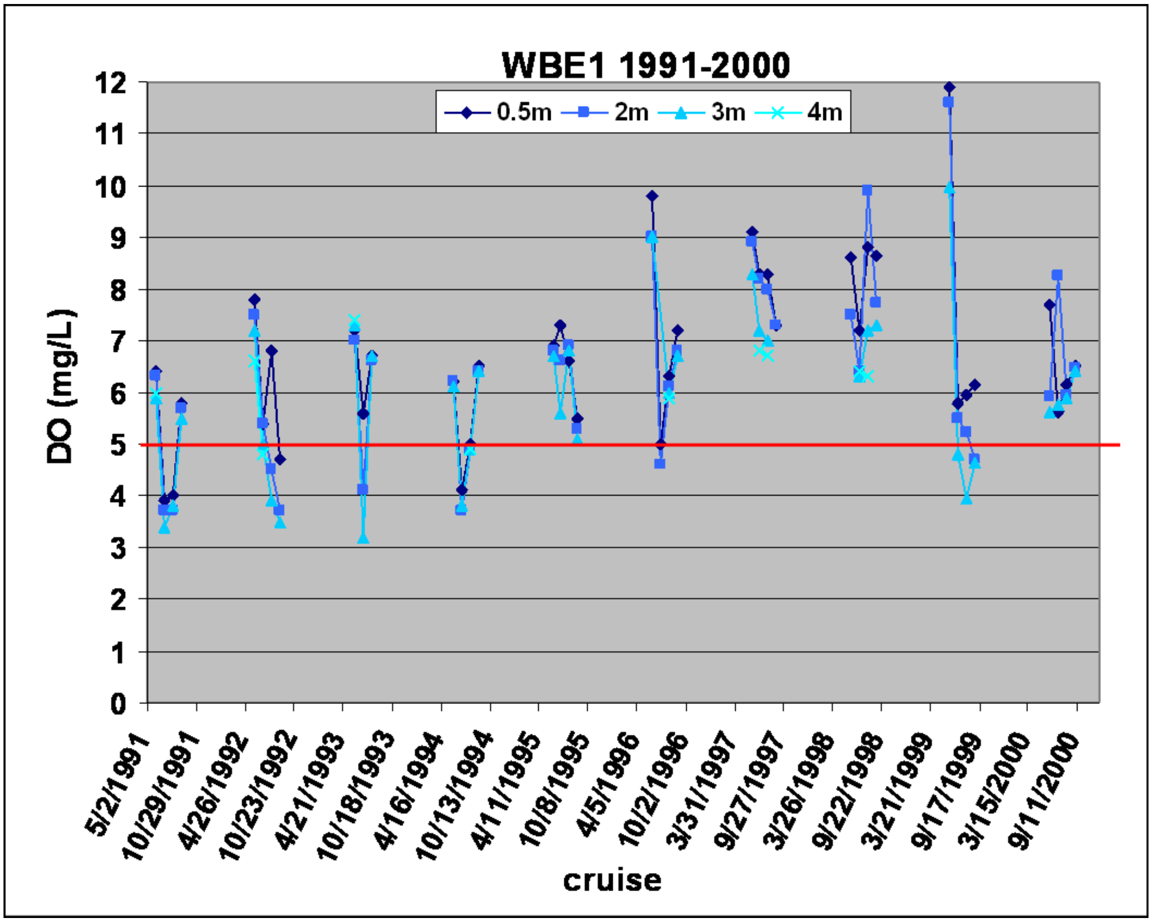
Source: Appendix N.

Figure N1-10. Open-water dissolved oxygen criteria nonattainment in ANANTF_MD MDATF and nearby Bay segments.

Given the lack of Bay Water Quality Model fit in this segment and the Bay Water Quality Model projected DO WQS attainment of the two segments immediately downstream, EPA concludes that it is reasonable to expect attainment of the DO WQS in Maryland's tidal Anacostia River at the basin-wide target allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

West Branch Elizabeth River

Violations of the DO WQS were not uncommon in the Western Branch of the Elizabeth River (WBEMH), particularly in the early half of the 1991-2000 decade. Violations of the 5.0 mg/L open-water DO criterion (red line in Figure N1-11) were common during summer months, particularly at depths below 0.5 meters.



Source: Appendix N.

Figure O1-11. Summertime DO concentrations observed at water quality monitoring station WBE1 in segment WBEMH from 1991-2000.

Some of these violations improved with model simulated load reductions such as those represented in Table N1-2, however for two months in particular – July 1993 and July 1994 – no improvement in monthly violation rate was observed under scenario-modified conditions.

Table N1-2. Monthly open-water dissolved oxygen criteria nonattainment percentages for water quality monitoring station WBE1 in the 1993-1995 critical period.

year	month	violation rate	
		calibration	179TN, 12TP
1993	6	0.0%	0.0%
1993	7	45.9%	45.9%
1993	8	0.0%	0.0%
1994	6	0.0%	0.0%
1994	7	100.0%	100.0%
1994	8	49.2%	0.0%
1994	9	0.0%	0.0%
1995	6	0.0%	0.0%
1995	7	0.0%	0.0%
1995	8	0.0%	0.0%
1995	9	0.0%	0.0%

Further investigation of model performance in WBEMH showed that the Bay Water Quality Model failed to simulate the range of DO concentrations observed at WBE1 for either of these months. While the Bay Water Quality Model consistently simulated concentrations greater than 7 mg/L for the Bay Water Quality Model cell located at station WBE1, monitoring observations for the same month and year were below 5.0 mg/L. In Figure O1-12, the pink symbols represent DO concentrations for the calibration scenario; blue symbols and line represent DO concentrations and linear regression for the 179 TN, 12TP load reduction scenario. Dark blue symbols represent DO observations for July 1994 at depths ranging from 0.5-3 meters.

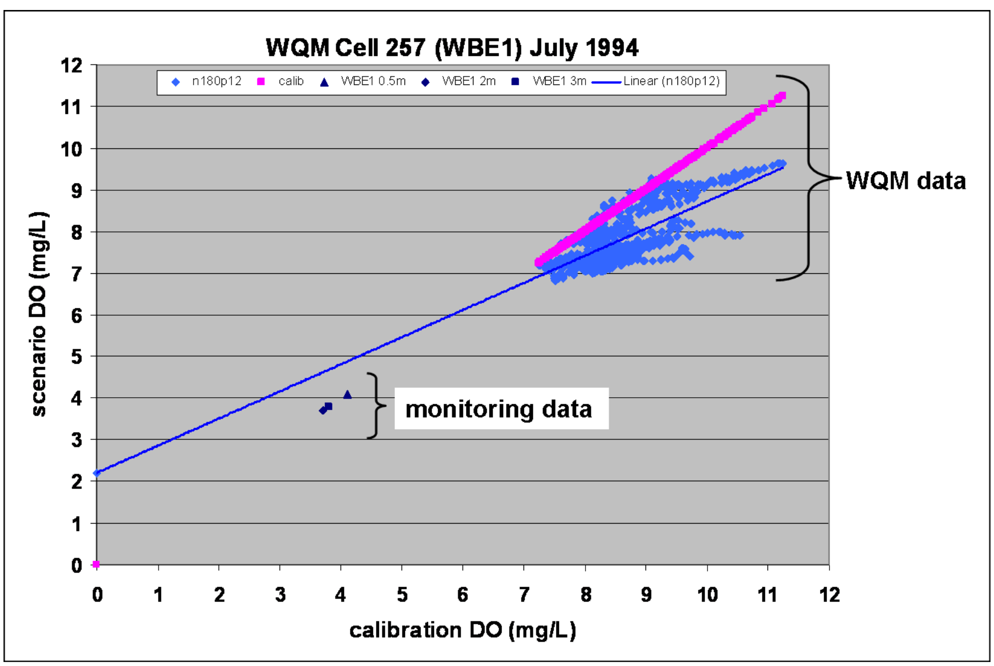


Figure O1-12: Chesapeake Bay Water Quality Model simulations at WQM cell 257 and observations at water quality monitoring station WBE1 for July 1994.

As described for previous segments, when the range of Bay Water Quality Model simulations falls in this range, the Bay Water Quality Model fails to provide an estimate of improvement in hypoxic conditions with load reductions.

When Bay Water Quality Model simulations do not span the range of hypoxic conditions observed, additional lines of evidence such as the attainment of nearby segments are considered in determining the necessity for further load reductions. In the case of WBEMH, adjacent and nearby segments attained their respective open-water DO WQS at or before the basinwide target nutrient allocations (Figure O1-13).

Cbseg	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
ELIPH	4%	0%	0%	0%	0%	0%	0%	0%	0%
JMSPH	0%	0%	0%	0%	0%	0%	0%	0%	0%
EBEMH	23%	18%	5%	0%	0%	0%	0%	0%	0%
JMSMH	0%	0%	0%	0%	0%	0%	0%	0%	0%
SBEMH	35%	16%	8%	0%	0%	0%	0%	0%	0%
WBEMH	11%	15%	8%	8%	8%	8%	8%	8%	0%

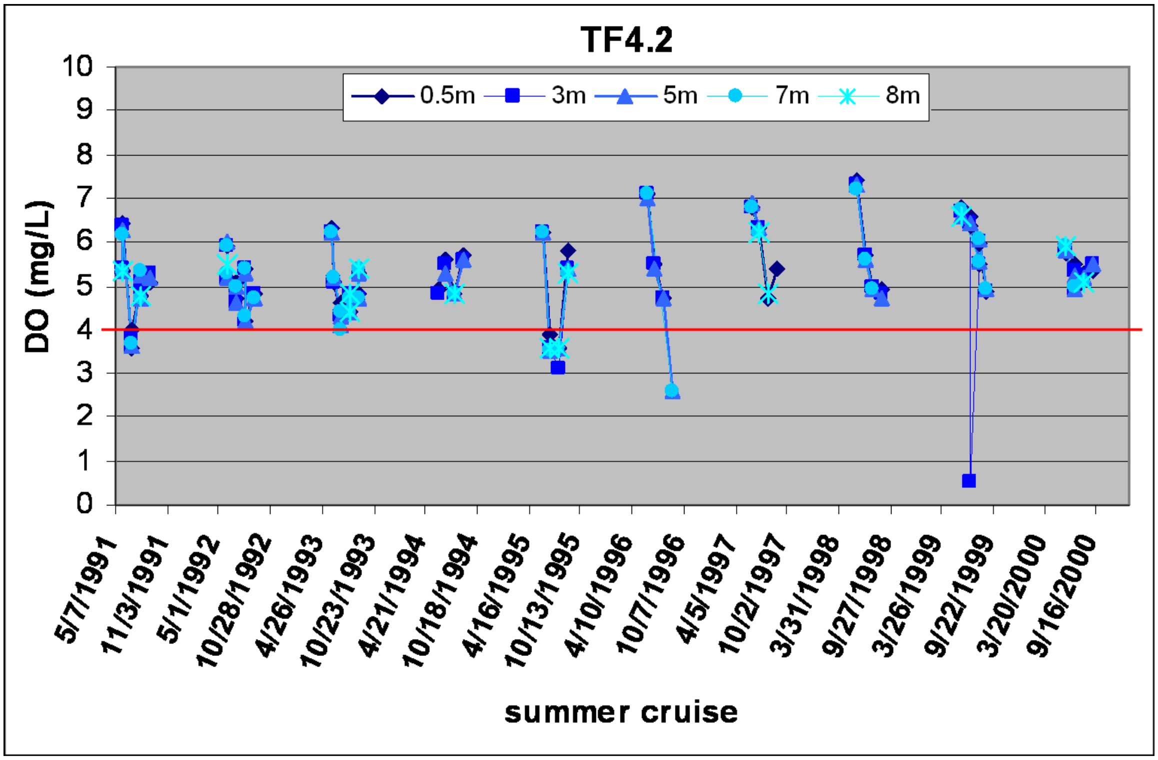
Source: Appendix N.

Figure O1-13. Attainment of the open-water DO WQS for WBEMH and nearby Bay segments under progressively stringent load reduction scenarios.

While the periodic occurrence of hypoxia in the Western Branch of the Elizabeth River remains a matter of concern, in this case the WQM provided no information on the magnitude of response in DO concentrations to be expected with load reductions. Considering the attainment of DO WQS observed in adjacent segments well before the target basinwide allocation, EPA concludes that it is reasonable to expect attainment of the DO WQS in Western Branch of the Elizabeth River at the basin-wide target allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

Upper Pamunkey River

Dissolved oxygen concentrations at station TF4.2 in the upper Pamunkey River (PMKTF) occasionally violated this segment's open-water DO criterion of 4.0 mg/L (Figure O1-14). Violations during the 1993-1995 critical period were moderate and limited to the summer of 1995.



Source: http://www.chesapeakebay.net

Figure O1-14. Summertime monitored dissolved oxygen concentrations (mg/L) at station TF4.2 in segment PMKTF.

A closer look at DO violations occurring in July and August of 1995 (Table N1-3) showed that while DO concentrations in August improved sufficiently to attain WQS with simulated load reductions, no improvement was observed in the July 1995 violation rate.

Table N1-3. Monthly open-water dissolved oxygen criteria nonattainment percentages for water quality monitoring station TF4.2 in segment PMKTF in the summer months of 1993-1995 critical period.

year	month	violation rate	
		calibration	190 TN, 12.7 TP
1993	6	0.0%	0.0%
1993	7	0.0%	0.0%
1993	8	0.0%	0.0%
1993	9	0.0%	0.0%
1994	6	0.0%	0.0%
1994	7	0.0%	0.0%
1994	8	0.0%	0.0%
1994	9	0.0%	0.0%
1995	6	0.0%	0.0%
1995	7	100.0%	100.0%
1995	8	100.0%	0.0%
1995	9	0.0%	0.0%

Investigation of the Bay Water Quality Model-derived regression for July 1995 revealed that as with other small tidal tributaries discussed in this section, simulated DO concentrations for the calibration scenario did not match historical observations for the same month and location in the upper Pamunkey River. In Figure O1-15, DO concentrations for the 190 TN, 12.7 TP load reduction scenario (blue symbols and linear regression line) showed little or no improvement compared with those of the calibration scenario (pink symbols). DO concentrations for both scenarios were greater than those observed at station TF4.2

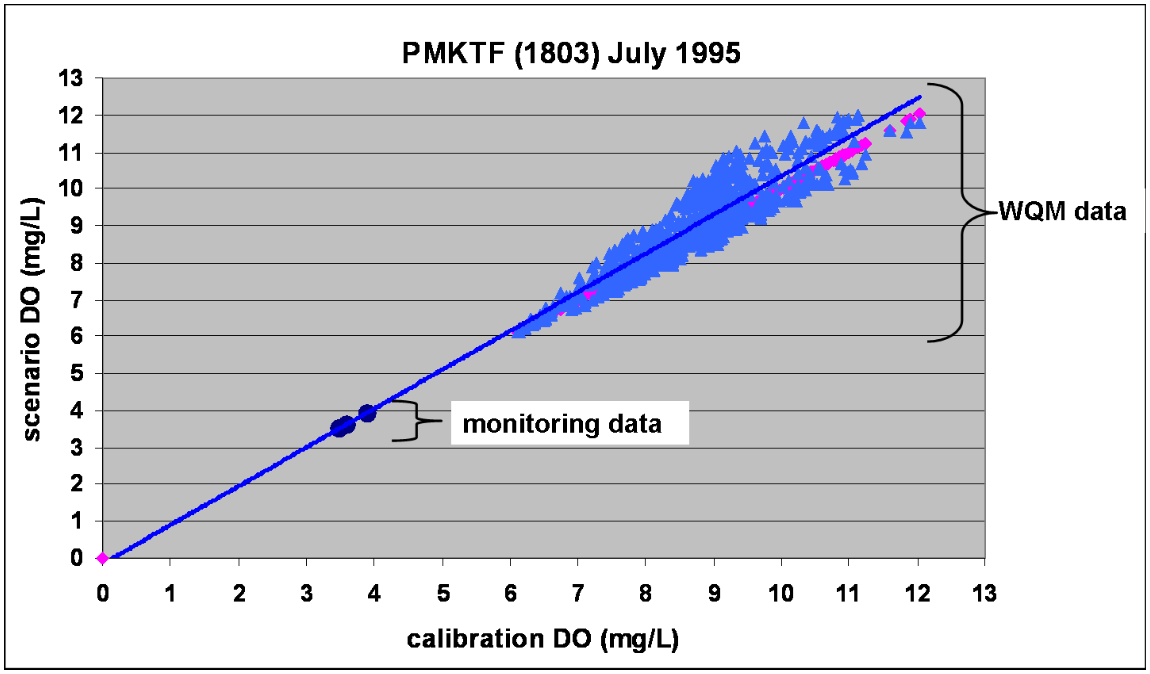


Figure O1-15. Simulated DO concentrations for cell 1803, the Bay Water Quality Model grid cell coincident with monitoring station TF4.2 in segment PMKTF.

It is also worth noting that the observed violations were only marginally lower than the 4.0 mg/L criterion. Furthermore, the two segments immediately downstream from PMKTF – the lower Pamunkey River (PMKOH) and the mesohaline York River (YRKMH) – attained their respective open-water DO WQS at or before the target load allocation (Figure O1-16).

Cbseg	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
PMKOH	1%	0%	0%	0%	0%	0%	0%	0%	0%
PMKTF	11%	5%	5%	5%	5%	5%	5%	2%	1%
YRKMH	24%	3%	3%	1%	1%	1%	1%	0%	0%

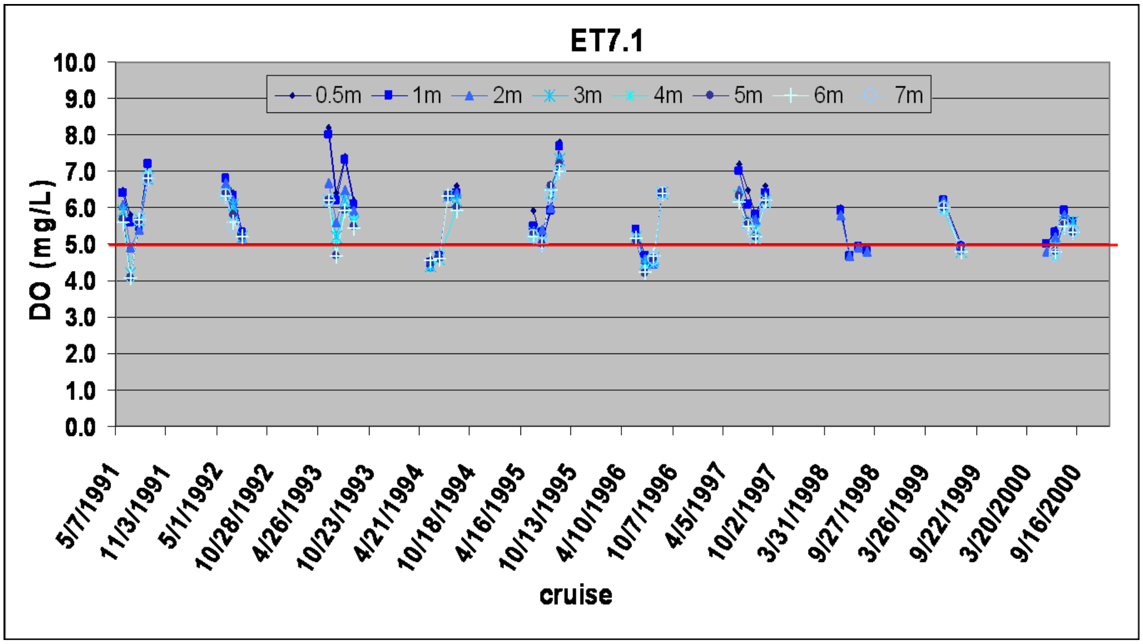
Source: Appendix N.

Figure O1-16. Attainment of the open-water DO WQS for PMKTF and nearby Bay segments under progressively stringent load reduction scenarios.

Given the mismatch between historical water quality monitoring observations and the Bay Water Quality Model simulations in this segment, the complete lack of response in DO concentrations with simulated load reductions, the moderate nature of violations observed in PMKTF for the critical period, and the attainment of the two nearest downstream segments at or before the target basinwide allocation, EPA concludes that it is reasonable to expect attainment of the DO WQS in upper Pamunkey River at the basin-wide target allocation of 190 million pounds per year TN and 12.7 million pounds per year TP.

Wicomico River

Moderate excursions below the Open Water criterion for Wicomico (WICMH) of 5.0 mg/L were not uncommon in summer months (Figure O1-17) between 1991-2000, however, few were extensive enough to cause high percentages of WQS non-attainment. For the 1993-1995 critical period, two months – June and July 1994—had extensive violations of the DO criterion.



Source: http://www.chesapeakebay.net

Figure O1-17: Dissolved oxygen concentrations observed at station ET7.1 (WICMH) in the summers months from 1991-2000.

While the historical violations present in July 1994 were resolved under scenario-modified conditions of the target basinwide allocation (190 TN, 12.7 TP Loading Scenario), DO concentrations in June 1994 showed no improvement in violation rate, even under the extensive load reductions of the E3 Scenario (Table N1-4).

Table N1-4. Monthly open-water dissolved oxygen criteria nonattainment percentages for water quality monitoring station ET7.1 in segment WICMH in the summer months of 1993-1995 critical period.

WICMH		violation rate		
year	month	calibration	190TN, 12.7TP	E3
1993	6	0.0%	0.0%	0.0%
1993	7	5.5%	0.0%	1.9%
1993	8	0.0%	0.0%	0.0%
1993	9	0.0%	0.0%	0.0%
1994	6	100.0%	100.0%	100.0%
1994	7	100.0%	0.0%	0.0%
1994	8	0.0%	0.0%	0.0%
1994	9	0.0%	0.0%	0.0%
1995	6	0.0%	0.0%	0.0%
1995	7	0.0%	0.0%	0.0%
1995	8	0.0%	0.0%	0.0%
1995	9	0.0%	0.0%	0.0%

Further investigation of the conditions causing this persistent violation revealed that DO concentrations simulated by the Bay Water Quality Model's Calibration Scenario for grid cell 7658 are higher than those observed at station ET7.1 for June 1994. Figure O1-18, the DO concentrations observed at station ET7.1 (dark blue symbols) are shown for June 1994. The E3 linear regression falls below these monitoring observations, illustrating the predicted decrease in scenario-modified DO concentrations. Furthermore, DO concentrations in this location were generally similar to (or sometimes even lower than) calibration conditions. In other words, no improvement in DO concentrations was observed at this location when even dramatically reduced loads were simulated. As a result, the mildly hypoxic conditions observed in June 1994 were scenario-modified to lower, rather than higher, values with reduced nutrient loads.

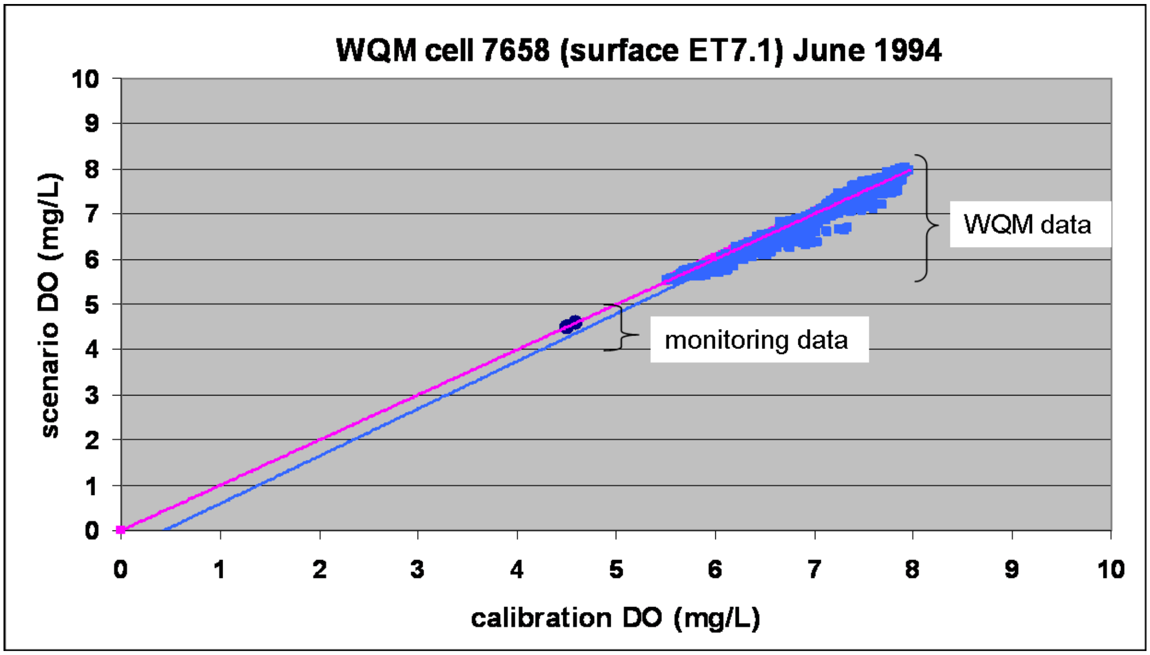


Figure O1-18: Simulated DO concentrations for the Calibration Scenario (pink symbols with 1:1 linear regression line) compared to those for the E3 Scenario (blue symbols and blue linear regression line).

In contrast with predictions for WICMH, adjacent Tangier Sound (TANMH) and other nearby segments attained DO WQS at or before the target basinwide load allocation (Figure O1-19).

Cbseg	1985 Scenario 342TN, 24.1TP, 9790TSS '93-'95 DO Open Water Summer Monthly	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
FSBMH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NANMH	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%
TANMH	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
WICMH	11%	11%	11%	15%	5%	5%	5%	5%	5%	5%

Source: Appendix N.

Figure O1-19. Attainment of the open-water DO WQS for WICMH and nearby Bay segments under progressively stringent load reduction scenarios.

As with other segments described herein, the Bay Water Quality Model effectively simulated neither the observed historical conditions nor the expected improvement in those conditions with reduced nutrient loads in this small, shallow region of the Wicomico River. Given the moderate nature of the observed violations the unimpaired condition of adjacent and nearby segments, and the considerable level of effort already required of this river basin with the current target load allocation, the EPA considers that it is reasonable to expect WICMH to attain WQS at the proposed target load allocations.

Upper and Middle Portions of the Pocomoke River

The Upper (POCTF) and Middle (POCOH) portions of the Pocomoke River are represented by the same, single monitoring station (ET10.1) for the time period of 1991-2000, therefore DO criteria violations are the same for both segments. Descriptions and data described here apply to all segments in this portion of the tributary. This portion of the Pocomoke River also constitutes a relatively narrow tributary; the Bay Water Quality Model grid is only one cell wide in both POCTF and POCOH (Figure O1-20). As mentioned previously, the Bay Water Quality Model often struggles to integrate multiple drivers of DO concentrations in narrow, shallow waters – especially in model cells that directly abut land.

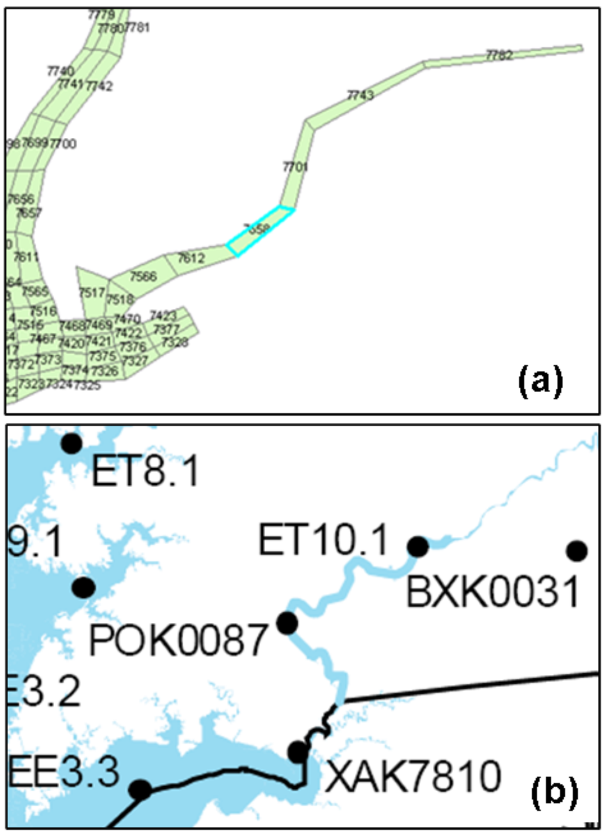
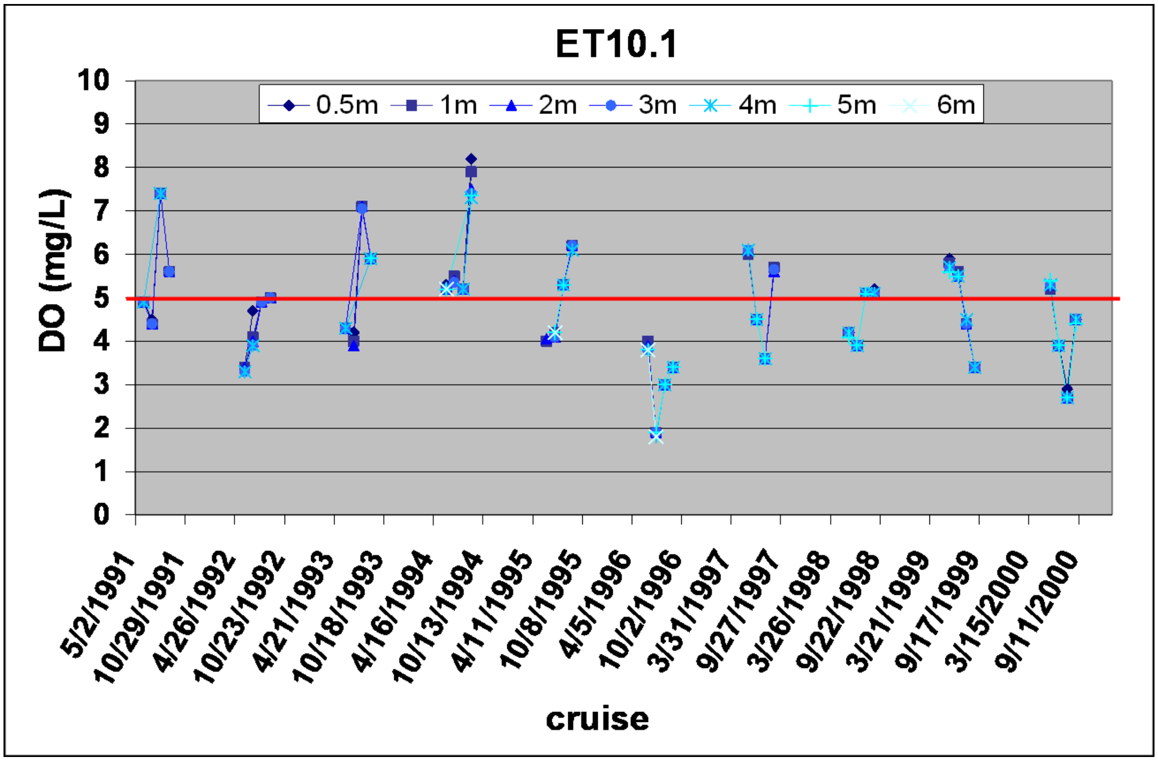


Figure O1-20: Chesapeake Bay Water Quality Model grid cell (a) coincident with long-term fixed station ET10.1 (b) in the Pocomoke River.

Violations of the open-water DO criterion of 5.0 mg/L occurred rather frequently in the summer months from 1991-2000 at station ET10.1 (Figure O-21); in fact DO concentrations often decreased to levels below 4.0 mg/L.



Source: http://www.chesapeakebay.net

Figure O1-21. Summer dissolved oxygen concentrations observed at water quality monitoring station ET10.1 for the 1991-2000 time period.

In spite of this, considerable improvement was observed for most cases of hypoxia in the 1993-1995 critical period under scenario-modified conditions. However, there was no decrease in violation rates of the DO criterion for June 1993 even when nutrient loads were reduced to “E3” levels (Table N1-5).

Table N1-2. Monthly open-water dissolved oxygen criteria nonattainment percentages for water quality monitoring station ET10.1 in segments POCTF and POCOH in the summer months of 1993-1995 critical period.

POCTF/POCOH		violation rate	
year	month	calibration	E3
1993	6	100.0%	100.0%
1993	7	100.0%	0.0%
1993	8	0.0%	0.0%
1993	9	0.0%	0.0%
1994	6	100.0%	0.0%
1994	7	29.2%	0.0%
1994	8	100.0%	0.0%
1994	9	0.0%	0.0%
1995	6	100.0%	0.0%
1995	7	100.0%	0.0%
1995	8	0.0%	0.0%
1995	9	0.0%	0.0%

Further investigation of the DO concentrations underlying this persistent violation revealed that conditions in June 1993 were only moderately hypoxic (~ 4.3 mg/L), but that DO concentrations simulated by the Bay Water Quality Model were much higher than those observed – ranging from about 8 to greater than 10 mg/L The historically observed DO concentration at monitoring station ET10.1 (dark blue symbol) fell well below the range of Bay Water Quality Model simulated dissolved oxygen concentrations. (Figure O1-22).

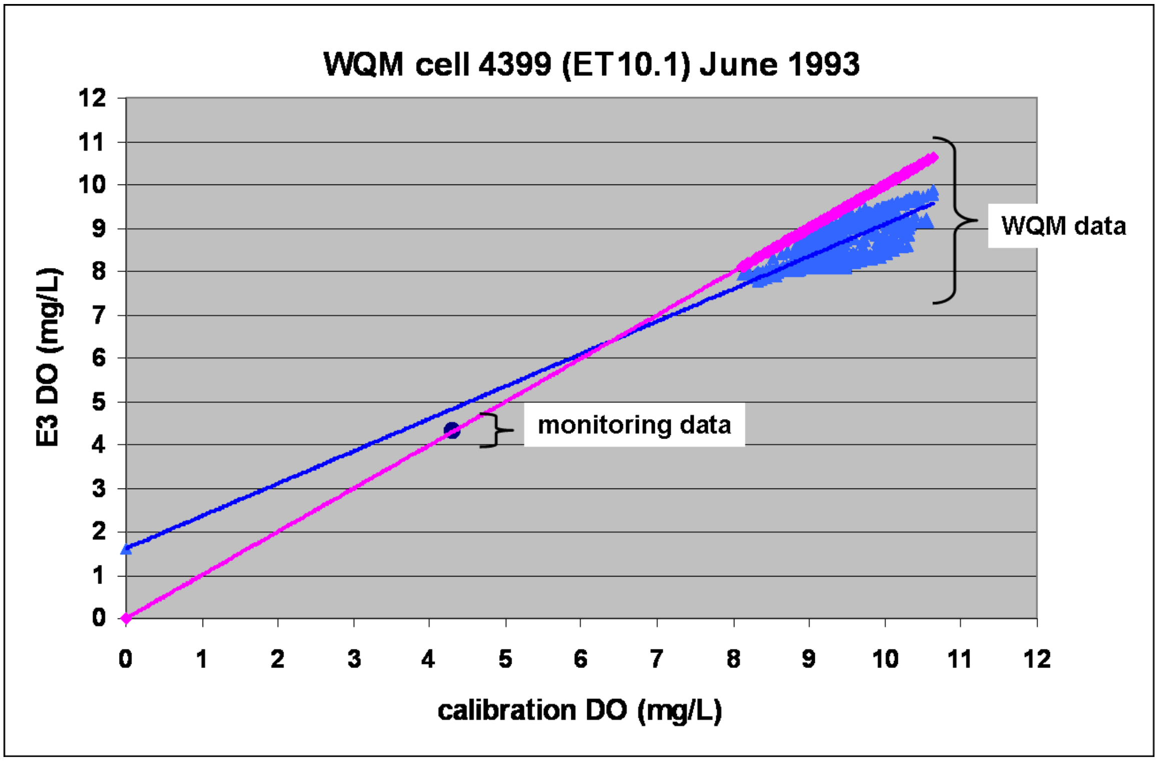


Figure O1-22: Simulated dissolved oxygen concentrations in Bay Water Quality Model cell 4399 for the calibration (pink symbols and regression line) and E3 (light blue symbols and regression line) scenarios.

Because the Bay Water Quality Model failed to simulate the hypoxia observed in the location of station ET10.1, it was unable to provide a true estimate of the magnitude of improvement to be expected in DO concentrations with reduced loads. In the absence of sufficient information, the attainment status of the deeper, wider region of the lower Pocomoke River was considered as an alternative line of evidence for predicting attainment of POCTF and POCOH (Figure O1-23). While POCTF and POCOH showed persistent non-attainment even under the considerable load reductions represented by the E3 Scenario, the adjacent lower Pocomoke River (POCMH) attained WQS even under historical conditions.

Cbseg	1985 Scenario 342TN, 24.1TP, 9790TSS '93-'95 DO Open Water Summer Monthly	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Open Water Summer Monthly	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Open Water Summer Monthly	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Open Water Summer Monthly	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Open Water Summer Monthly	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Open Water Summer Monthly	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Open Water Summer Monthly	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Open Water Summer Monthly	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Open Water Summer Monthly	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Open Water Summer Monthly
POCTF	33%	43%	32%	25%	25%	18%	18%	5%	5%	5%
POCOH	33%	42%	29%	25%	25%	18%	18%	5%	5%	5%
POCMH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: Appendix N.

Figure O1-23: Attainment of open-water DO WQS in the three tidal Pocomoke River segments under numerous scenarios representing progressively more stringent load reductions.

Causes of persistent non-attainment for the upper and middle Pocomoke River appear sufficiently similar to those described for other segments described here, thus the same rationale may apply. However, an additional characteristic of the tidal Pocomoke River likely plays a role in the extensive violations observed historically, affecting the ability of DO concentrations to rebound as nutrient loads to this river basin are reduced. The headwaters of the Pocomoke River originate in the Great Cypress Swamp, which serves as a source of considerable dissolved organic matter to the tributary. The combined effect of the Great Cypress Swamp and other extensive tidal and non-tidal wetlands occurring along the length of the river is clear; the Upper Pocomoke River has recorded some of the highest dissolved organic carbon concentrations seen in any tidal fresh tributary in the state of Maryland (Maryland Department of Natural Resources 2010).

Because these naturally occurring high concentrations of dissolved organic matter often generate high rates of respiration that can in turn lead to significant, natural reductions in dissolved oxygen, Maryland has proposed that a site-specific open-water dissolved oxygen criterion of 4.0 mg/L be applied to the upper and middle Pocomoke River (POCTF and POCOH). The proposed site-specific dissolved oxygen criterion is fully consistent with EPA's amended Chesapeake Bay water quality criteria guidance published in 2004 (USEPA 2004).

Magothy River

The Magothy River (MAGMH) is a small, shallow tidal tributary adjacent to the upper central Chesapeake Bay segment CB3MH. The Magothy River is represented by one long-term fixed monitoring station, WT6.1. The narrow, embayment-like nature of the Magothy River is evident in the portion of the Bay Water Quality Model grid that represents it; the entire tributary is represented by only five WQM cells. The grid cell representing station WT6.1 highlighted in Figure O1-24.

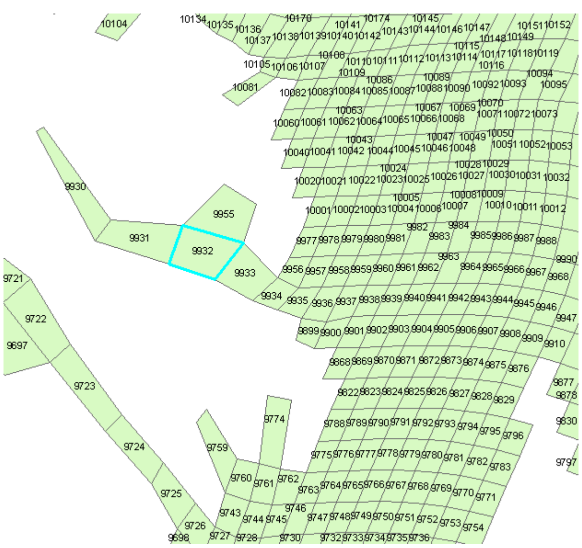
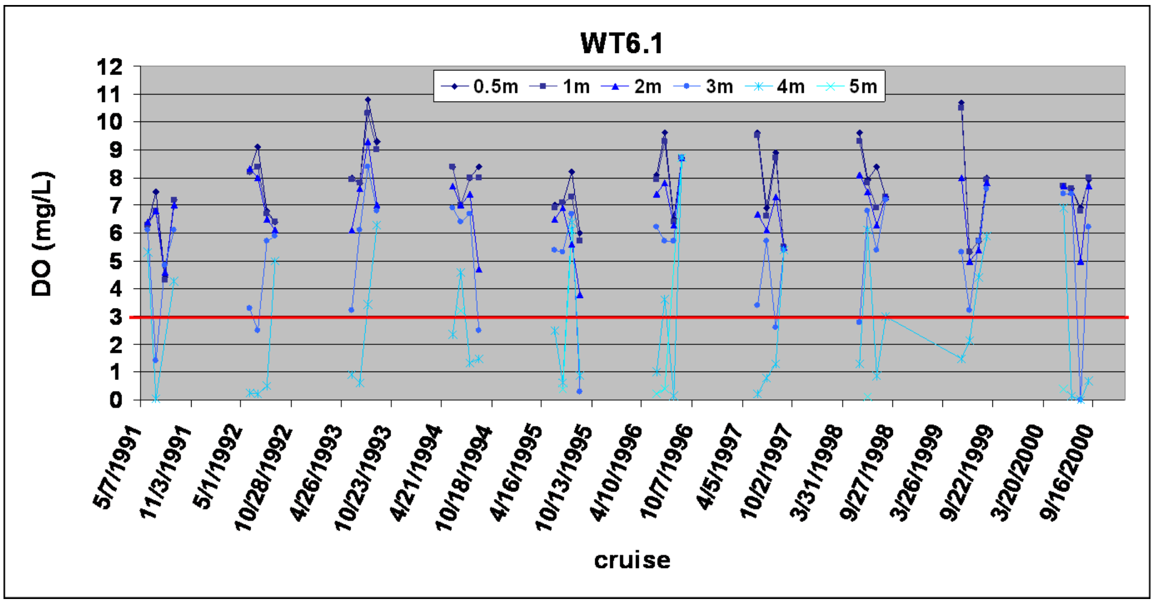


Figure O1-24: Chesapeake Bay Water Quality Model grid for the Magothy River and the adjoining portion of the mainstem Chesapeake Bay.

Severely hypoxic conditions are common during the summer months in the Magothy River (Figure O1-25). Low dissolved oxygen concentrations are often exacerbated by water column stratification, which prevents the vertical mixing that would otherwise re-oxygenate bottom waters. Concentrations often fell below the Deep Water criterion of 3.0 mg/L (red line), particular at depths greater than 2-3 meters (Figure N1-25). The documented presence of an upper pycnocline boundary in the Magothy River recently led the EPA and the State of Maryland recommend adding a Summer Deep Water designated use to the Magothy River (USEPA 2010). However, even when the deep-water criterion of 3.0 mg/L is applied to stratified bottom waters, non-attainment of the DO WQS persists with simulated load reductions at the level of the target basin-wide allocation (see Figure O1-27).



Source: http://www.chesapeakebay.net

Figure O1-25: Dissolved oxygen concentrations observed at station WT6.1 in segment MAGMH during summer months from 1991-2000.

Further investigation of the persistent non-attainment of DO WQS observed in MAGMH showed that while violations occurring in some summer months improved with load reductions, hypoxic conditions in other months improved to a much lesser degree or not at all (Table N1-6). In particular, violations of the DO criterion that occurred in September 1994 showed no improvement, even when loads were reduced to the 179 TN, 12 TP level.

Table N-6: Summer monthly violation rates for MAGMH during the 1993-1995 critical assessment period.

MAGMH		violation rate	
year	month	observed	179 TN 12 TP
1993	6	44.9%	0.0%
1994	9	44.9%	44.9%
1995	7	100.0%	0.0%
1995	8	0.0%	0.0%
1995	9	100.0%	44.9%

The performance of the Bay Water Quality Model in the location of the MAGMH monitoring station was examined. As illustrated in Figure O1-26, simulated DO concentrations in the WQM cell representing the bottom depths at station WT6.1 were consistently higher than 5.0 mg/L for September 1994. However, historical measurements for the lower depths at station WT6.1 showed concentrations less than 3.0 mg/L. In Figure O1-26, the Calibration Scenario (pink symbols and regression line) is compared with the 179 TN, 12.0 TP Loading Scenario (light blue symbols and linear regression). Historical observations (dark blue circles) fall well outside the range of simulations. As described previously, the failure of the Bay Water Quality Model to simulate hypoxic conditions affects its ability to predict the magnitude of improvement that will occur in DO concentrations when nutrient loads are reduced.

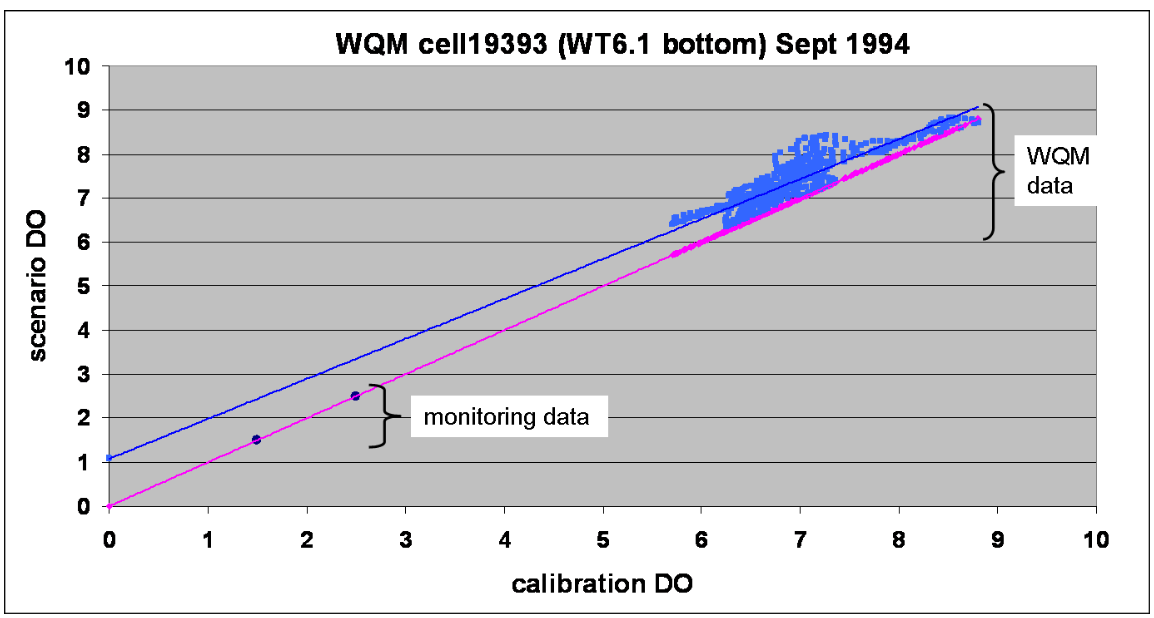


Figure O1-26. Simulated dissolved oxygen concentrations in grid cell 19393 of the Bay Water Quality Model for September 1994.

The inability of the Bay Water Quality Model to simulate the hypoxic conditions observed during summer months in the Magothy River reduces its ability to predict the magnitude of improvement in DO concentrations that can be expected as nutrient loads are reduced. However, the Bay Water Quality Model much more effectively simulates historical conditions and, therefore, predicted improvements, in nearby deeper, wider regions of the Chesapeake Bay. Thus the predicted attainment of WQS in the deep-water designated use of CB3MH, well before the target basin-wide load allocation (see Figure O1-27), can help to inform expectations of attainment for the Magothy River.

Cbseg	1985 Scenario 342TN, 24.1TP, 9790TSS '93-'95 DO Deep Water	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Deep Water	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Deep Water	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Deep Water	Tributary Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Deep Water	190/13 Loading Scenario 190TN, 13TP, 6123TSS '93-'95 DO Deep Water	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Deep Water	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Deep Water	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Deep Water	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Deep Water
CB3MH	3%	2%	0%	0%	0%	0%	0%	0%	0%	0%
MAGMH	35%	35%	35%	16%	16%	16%	3%	3%	1%	1%

Source: Appendix N.

Figure N1-27. Predicted attainment of DO WQS for the summer deep-water designated use in CB3MH and MAGMH.

While the severely hypoxic conditions commonly observed in the Magothy River during the summer months remain a matter of concern, at this time EPA lacks data to effectively predict the recovery of the Magothy River in those months when the Bay Water Quality fails to simulate historical conditions. However, given attainment of adjacent deep-waters of CB3MH, and the extensive load reductions already required of the Magothy River basin for the target basin-wide allocation of 190 million pounds per year TN and 12.7 million pounds per year TP, the EPA anticipates that the MAGMH Deep Water designated use will attain WQS when the target load allocation is achieved.

Lower Chester River

Historical monitoring data show a consistent pattern of summer severe hypoxic to anoxic (<0.2 mg/L dissolved oxygen concentrations) conditions in the deep-channel region of the lower Chester River (CHSMH), in the vicinity of water quality monitoring station ET4.2 (Figure N1-28).

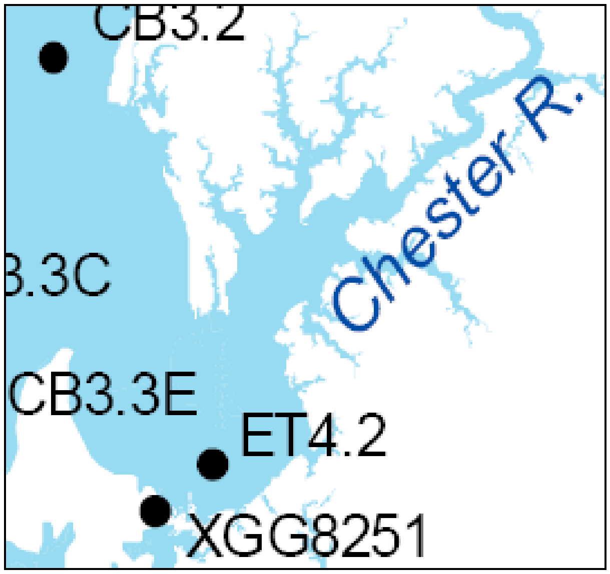
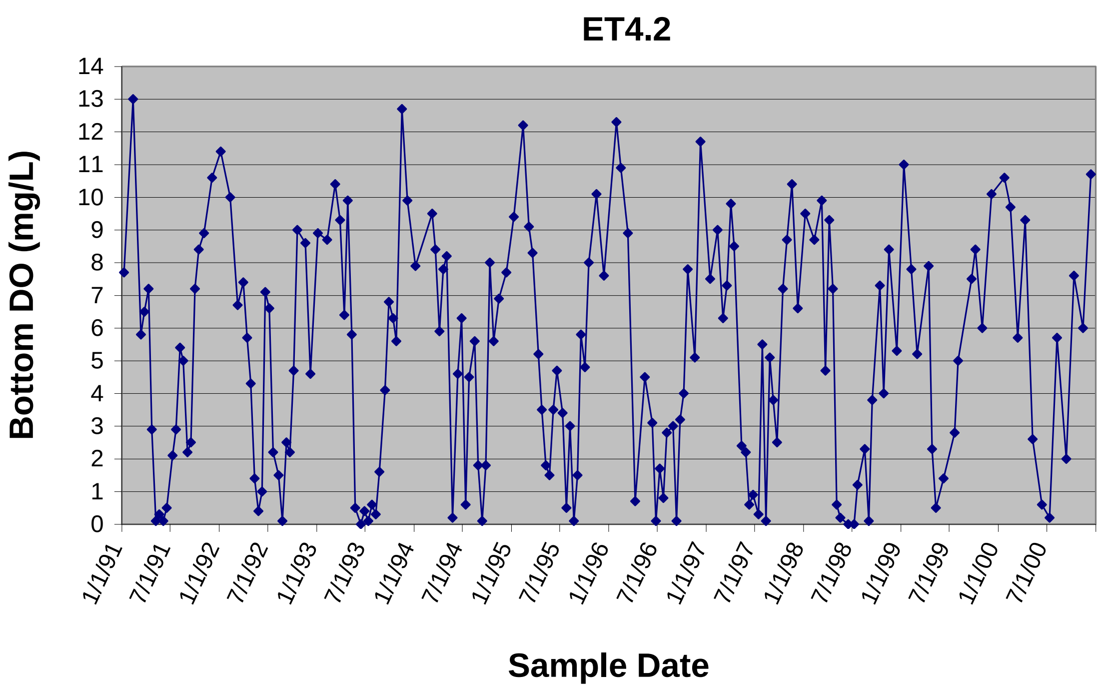


Figure N1-28. The lower Chester River is characterized by Maryland's Chesapeake Bay water quality monitoring program station ET4.2.

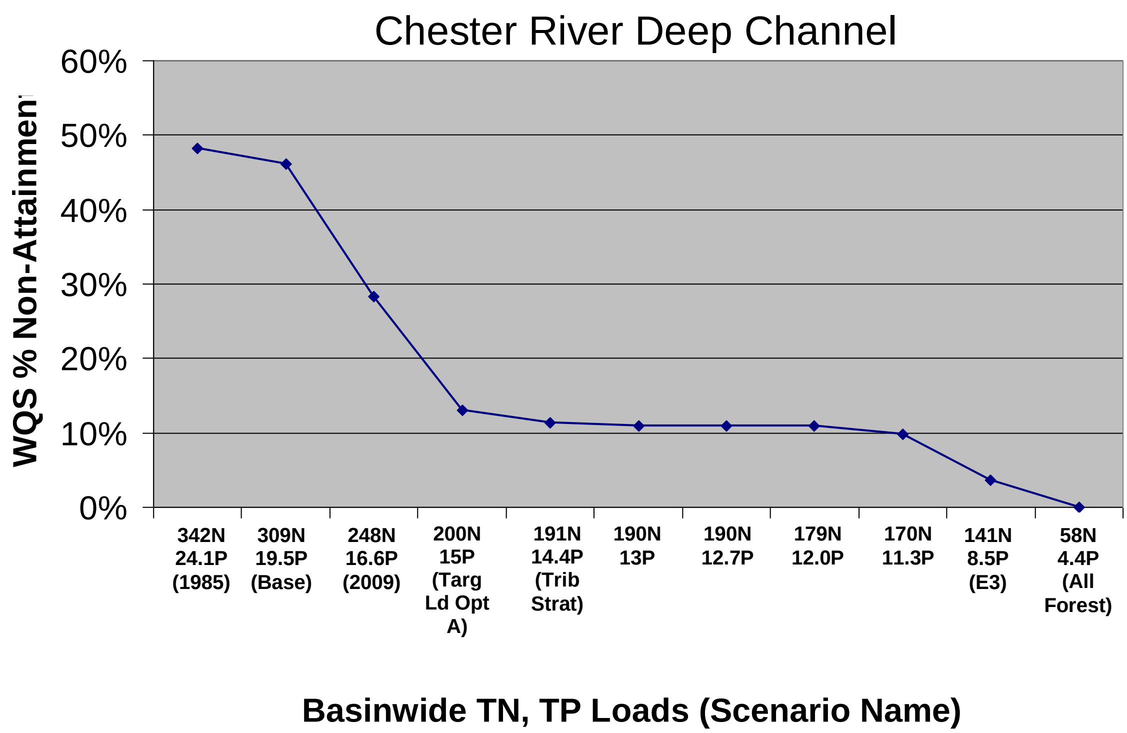
In summer months, observed DO concentrations at monitoring station ET4.2 consistently fell below 1.0 mg/L, the instantaneous minimum criterion for the deep-channel designated use (Figure N1-29).



Source: http://www.chesapeakebay.net

Figure N1-29. Bottom depth dissolved oxygen concentrations measured at water quality monitoring station ET4.2 in the lower Chester River from January 1991 – December 2000.

At model-simulated nutrient load reductions that led to attainment of deep-channel dissolved oxygen criteria in all other deep-channel regions of the Chesapeake Bay and tidal tributaries (e.g. segments in the Chesapeake Bay mainstem, lower Potomac River, lower Rappahannock River, and Patapsco River) (see Appendix M), model simulated improvements in dissolved oxygen concentration in the lower Chester River's deep-channel did not yield full attainment of the dissolved oxygen criteria. Whereas other deep-channel regions showed attainment of the deep channel dissolved oxygen criterion at or before the 190 TN, 12.7 TP loading scenario, the lower Chester River's deep-channel non-attainment remained at a plateau of approximately 10-14% under loading scenarios ranging from 191 TN, 14.4 TP down to approximately 170 TN, 11.3 TP. Full attainment of the applicable dissolved oxygen criterion was not achieved for this deep-channel region until the highly theoretical and unattainable "All Forest" scenario, for which it is assumed that all land in the Chesapeake Bay watershed reverts to a forested condition (Figure N1-30).



Source: Appendix N.

Figure N1-30. Percent non-attainment of lower Chester River deep-channel dissolved oxygen criterion with decreasing total nitrogen (TN) and total phosphorus (TP) loads.

In-depth examination of the Bay water quality model scenario outputs showed stepwise increases in DO concentrations with incremental nutrient load reductions in the lower Chester River (CHSMH) segment at surface and mid-depths, and consistent simulation of bottom water anoxia. However, the response of DO concentrations at lower-depths in the water column—and particularly at the bottom of the water column—appeared to be constrained to a degree that prevented full attainment of the 1.0 mg/L deep-channel dissolved oxygen criterion under model simulated nutrient load reductions that yield full attainment in all other deep-channel regions of the Chesapeake Bay and its tidal tributaries (Figure N1-31).

Cbseg	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS '93-'95 DO Deep Channel	2009 Scenario 248TN, 16.6TP, 8110TSS '93-'95 DO Deep Channel	Target Load Option A 200TN, 15TP, 6390TSS '93-'95 DO Deep Channel	Trib Stategy 191TN 14.4TP, 6462 TSS '93-'95 DO Deep Channel	190 Loading Scenario 190TN 12.6TP, 6030TSS '93-'95 DO Deep Channel	179 Loading Scenario 179TN 12.0TP, 5510TSS '93-'95 DO Deep Channel	170 Loading Scenario 170TN 11.3TP, 5650TSS '93-'95 DO Deep Channel	E3 2010 Scenario 141TN 8.5TP, 5060TSS '93-'95 DO Deep Channel	All Forest Scenario '93-'95 DO Deep Channel
CB3MH	14%	6%	0%	0%	0%	0%	0%	0%	0%
CB4MH	46%	22%	4%	2%	2%	0%	0%	0%	0%
CB5MH	22%	2%	0%	0%	0%	0%	0%	0%	0%
CHSMH	38%	27%	14%	14%	14%	14%	9%	4%	0%
EASMH	26%	13%	4%	2%	1%	0%	0%	0%	0%
MD5MH	24%	4%	0%	0%	0%	0%	0%	0%	0%
PATMH	27%	21%	0%	0%	0%	0%	0%	0%	0%
POMMH	20%	0%	0%	0%	0%	0%	0%	0%	0%
POTMH	20%	0%	0%	0%	0%	0%	0%	0%	0%
POVMH	0%	0%	0%	0%	0%	0%	0%	0%	0%
RPPMH	31%	0%	0%	0%	0%	0%	0%	0%	0%
VA5MH	11%	0%	0%	0%	0%	0%	0%	0%	0%

Source: Appendix N.

Figure N1-31. Dissolved oxygen percent non-attainment for all the deep-channel designated use segments in the Chesapeake Bay and its tidal tributaries.

EPA postulates that the bathymetry of the lower Chester River provides a physical barrier to complete re-oxygenation of the deepest region of the lower Chester River even under extremely high nutrient reductions. A narrow deep channel transects the center of the lower Chester River, and exchange of oxygenated deep waters between the mainstem Chesapeake Bay and this deep hole may be restricted by the wider, shallower shoal region at the mouth of the river (Figures N1-32 and O1-33).

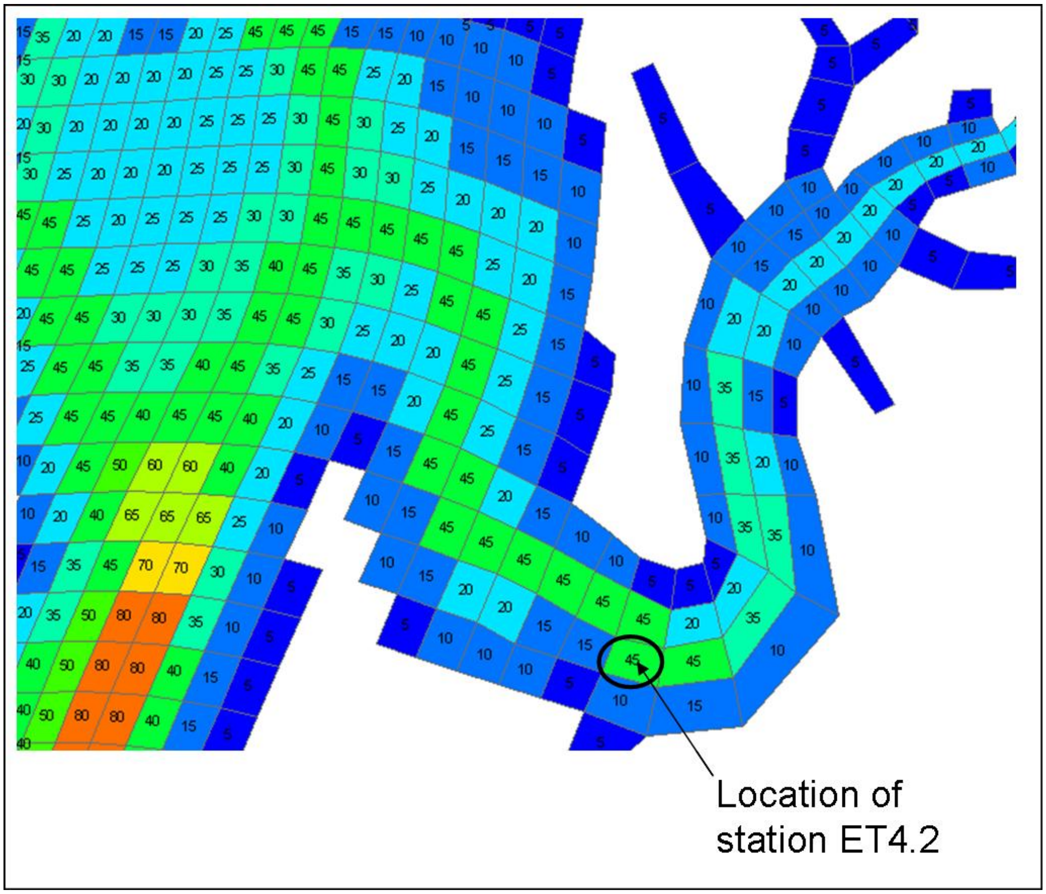
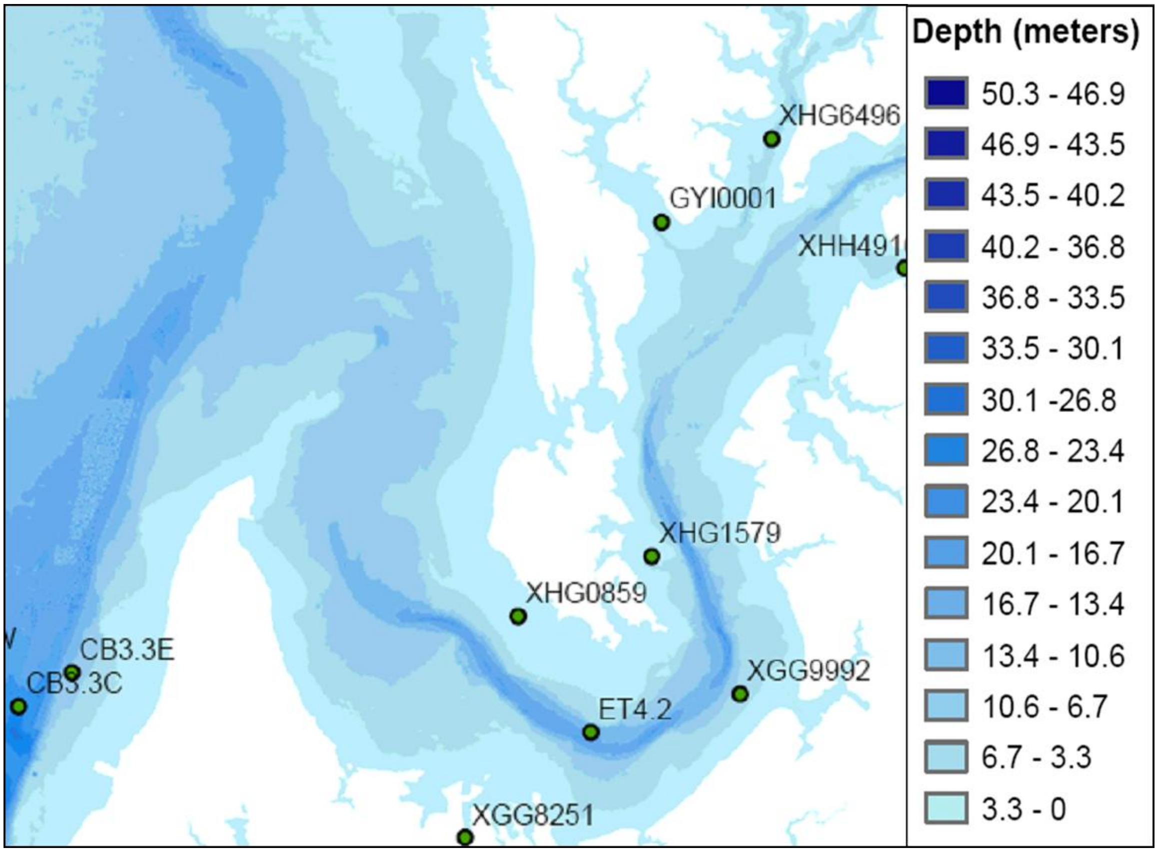


Figure N1-32: Chesapeake Bay Water Quality Model grid for the lower Chester River, with total depth for each cell labeled (in feet).



Source: EPA Chesapeake Bay Program Office

Figure N1-33. Bathymetry of the lower Chester River.

The limited response of DO concentrations to reduced nutrient loads (e.g., 30-140 million pounds basinwide) in the lower Chester River deep-channel, combined with the physical characteristics of the narrow, deep channel in this region, suggest a natural constraint on the re-oxygenation of the lower mixed layer by either deep riverine flows or deep estuarine flows from the adjacent mainstem Bay. Therefore, given the currently available information, EPA recommends a restoration variance of 14% to account for persistent WQS non-attainment in the CHSMH deep-channel designated use at the basinwide loads of 190 TN, 12.7 TP. The selection of a 14% variance is based on the observation that dropping the basinwide loads by up to 20 million pounds per year yields relatively little change in the non-attainment percentage, which ranges only from 10-14% over this reduction level.

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