Appendix K.
Allocation Methodology to Relate Relative Impact to Needed Controls

Introduction

The nutrient allocation procedures agreed to by five of the seven Bay watershed partners and followed by EPA are described in Section 6.4 of the main document. The reader should be familiar with Section 6.4 before reading this appendix. The goal of this appendix is to expand the options that were considered before selecting the final procedures and to provide rationale for the final decisions. Unless otherwise noted, the information presented in this appendix is based on the Phase 5.3 Chesapeake Bay Watershed Model and is the same information that was used to inform the decisions in the spring and summer of 2009 using the Phase 5.2 Chesapeake Bay Watershed Model, which had known limitations. Many of the values given in this appendix will be different from the final version as these decisions were not revisited with Phase 5.3 Bay Watershed Model.

Relative Effectiveness Options

Section 6.3.1 of the main document is a discussion of the relative effectiveness of major basins in improving dissolved oxygen in the critical areas of the tidal waters of the Chesapeake.

Relative effectiveness is a combination of riverine effectiveness, also known as a delivery factor, which is expressed as

- pounds of reduction reaching tidal waters/pounds of reduction to the local river and estuarine effectiveness, which is expressed as
- improvement in dissolved oxygen/pounds of reduction reaching tidal waters Multiplying the two together gives
- improvement in dissolved oxygen/pounds of reduction to the local river

Riverine Effectiveness Options

No options were considered in calculating riverine delivery factors. The principles of calculating delivery factors in the Chesapeake Bay Program watershed models are long-standing and have been approved several times by Chesapeake Bay Program workgroups and subcommittees. These principles were also reviewed in the Chesapeake Bay Program’s Scientific and Technical Advisory Committee sponsored independent scientific peer reviews of the Phase 5 Chesapeake Bay Watershed Model in 2007 and 2009. Nitrogen delivery factors are calculated for each river segment. Nitrogen levels are lowered naturally in river systems through denitrification, providing a long-run removal of nitrogen. Phosphorus and sediment do not undergo a similar process to denitrification and do not have long-run removal mechanisms other than delivery through the river system and burial. Burial is offset by scour, both of which are episodic in nature. That does not hold true in reservoir systems, where burial is much more significant and is not offset by scour to a great degree. Because of the lack of spatially and temporally detailed phosphorus and sediment data that would be needed to precisely calibrate scour and burial on the segment scale, the calculation of delivery factors for phosphorus and sediment is closed around reservoirs rather than segment by segment. That is, all segments upstream of a reservoir or an entrance to the tidal system and downstream of other reservoirs receive the same riverine delivery factor.

Geographic Grouping of Estuarine Effectiveness

The estuarine effectiveness is calculated by comparing the dissolved oxygen simulated in the Bay of the calibration run to the dissolved oxygen simulated in the Bay when a given watershed area has reduced loads relative to the calibration loads. The effectiveness for that given area is then calculated by dividing the improvement in dissolved oxygen by the reduction delivered loads. A choice has to be made regarding the geographic areas to test.

Each area along the estuary would theoretically have a different estuarine effectiveness, but there are limitations to what can be effectively calculated. If the area tested has a low total load and, therefore, a small change in going to a reduced load, the estuarine model might not be able to resolve the change in dissolved oxygen. Tested areas must be aggregated up to a reasonably large load to be able to record the change. Also, the estuarine model takes a few days to complete a run, and it would be time-prohibitive to make 100 or so more runs.

There is no difference in estuarine effectiveness between loads in the same nontidal watershed. Loads from areas just west of Washington, DC, would have the same estuarine effectiveness as loads from West Virginia because they enter the tidal waters at the same point, although they would have different overall effectiveness scores because of the differences in their riverine effectiveness. Therefore, the head of tide of large river systems is a natural place to define a discrete watershed. The estuarine portion of major river systems like the Potomac and Rappahannock would have significantly different effects on the critical area for dissolved oxygen and also have large enough loads to resolve these differences, so those areas are another reasonable place to lump geographically. The Eastern Shore is not amenable to simple rules like this because there are no large nontidal river systems connected to large estuarine river systems. There are, however significant differences in estuarine effectiveness between the northernmost and southernmost portions of the Eastern Shore. The Eastern Shore was therefore divided in to four sections.

The final geographic breakout, as a balance between the desire to calculate a different effectiveness where a distinction exists and the limiting factors of computer run time and the ability of the estuarine model to resolve the oxygen effect of small differences in loading are

Susquehanna
West Shore
Patuxent Above Fall Line
Patuxent Below Fall Line
Potomac Above Fall Line
Potomac Below Fall Line
Rapp Above Fall Line
Rapp Below Fall Line
York Above Fall Line
York Below Fall Line
James Above Fall Line
James Below Fall Line
Upper East Shore
Middle East Shore
Lower East Shore
East Shore VA

To be clear, the allocation calculations are split between those geographic areas within jurisdictions, resulting in 30 different spatial units. The allocations, however, are expressed on the jurisdiction and major river basin scale. That is, there is a calculation of Maryland Potomac above and below the fall line, but the allocation is expressed only as Maryland Potomac.

Choice of the Critical Designated Uses and Segments for Calculating Relative Effectiveness

To estimate the estuarine effectiveness, the change in dissolved oxygen must be calculated for a relevant area of the Chesapeake Bay. The most persistent areas of dissolved oxygen violations are in the mainstem of the Chesapeake Bay from roughly the Bay Bridge between Annapolis and Kent Island, Maryland, south to the mouth of the Potomac River and also the lower tidal Potomac River. The deep-water and deep-channel designated uses are impaired at a higher rate than the open-water designates use and also better integrators of baywide rather than local loads.

The deep-water and deep-channel designated uses of CB3MH, CB4MH, and CB5MH and the deep-water designated use of POTMH_MD were selected as the most appropriate grouping to use in calculating estuarine relative effectiveness for the following reasons:

1. These segments and designated uses had high levels of impairment
2. They are centrally located
3. They represent a large group of segments and a large volume of the Bay
4. Deep-water and deep-channel designated uses are good geographic integrators

Further tests of other combinations showed that the estuarine effectiveness was not particularly sensitive to the addition or subtraction of any given designated use.

Metric for Relative Effectiveness

To estimate the change in dissolved oxygen an appropriate metric of dissolved oxygen must be calculated that is sensitive to load changes across a wide array of segments, designated uses, and impairment levels and is relevant to the assessment of dissolved oxygen criteria. Three metrics were investigated:

1. Percent nonattainment.
2. Average dissolved oxygen during the summer assessment period
3. 25^{th} percentile (quartile) of dissolved oxygen during the summer assessment period

Three criteria were applied in determining which of these make the best metric

1. Relevance to attainment of dissolved oxygen standards
2. Broad applicability to designated uses and water quality segments
3. Linearity of response—does the first pound have the same effect as the last?

Percent nonattainment is clearly the most relevant metric to standards attainment, although other measures of dissolved oxygen are certainly also relevant. The quartile is more relevant than the average in that EPA is estimating increases in the lower values of oxygen.

Percent nonattainment is applicable only to areas that are not in attainment in the calibration and do not come into attainment when simulating a reduction in any single basin, which is a considerable limitation. Average dissolved oxygen is not an appropriate measure for many open-water segments. An impaired open-water segment might have average dissolved oxygen near saturation but experience large swings between super saturation and low oxygen. A load reduction might not change the average but improve the water quality by reducing the variability of oxygen levels and the frequency of low values. The quartile is applicable to all segments and all designated uses.

Linearity of response is a crucial component. If a metric responded much more to the first pound of reduction than to the last, smaller basins would be estimated to have a greater pound-for-pound influence than larger basins. To determine the linearity of the response to the three candidate metrics, a run was made with the Susquehanna at half the level of reduction normally used to calculate estuarine effectiveness. In general, across multiple segments and designated uses, the response for all three metrics was mostly linear. There was not a significant difference between the metrics on this count.

The average was judged to be not suitable because of its limited applicability. The percent nonattainment was judged to be slightly more relevant than the quartile, but the quartile was selected as the appropriate metric because of its universal applicability.

Level of Effort Options

Section 6.3 of the main document describes the expression of level of effort as between the two extreme scenarios of No Action scenario and E3. Selection of those two scenarios is an expression of the third principle under Section 6.3 that all previous reductions are credited toward achieving the allocations.

Atmospheric Deposition

The atmospheric deposition options and rationale for choosing the air allocation is documented in Section 6.4.1. The method of incorporation is to hold atmospheric deposition constant through the bookend scenarios of No Action and E3, and through all the prospective management scenarios unless specific actions are called for in state plans that go beyond the federal levels. One example of states going beyond the federal level is that the E3 has atmospheric deposition set to a level that incorporates reduced agricultural emissions and other possible state actions. That allows the jurisdictions to be responsible strictly for the reductions that they can control and not for federal actions on atmospheric deposition.

Scenario Options

The E3 scenario was selected as the appropriate lower end of loading rather than other candidate scenarios such as the Current Programs, Maximum Feasible, or All Forest. Current Programs could be used as the lower end and an assessment made of how far efforts had to increase beyond current programs, but doing so would violate the expression of equity described above because jurisdictions that had already achieved significant reductions would have to do proportionately more than jurisdictions that have not. Maximum Feasible would be a similar expression as E3 and would meet the equity provision, but it was judged to be much more subjective and, therefore, inferior to E3 as a metric. The All Forest scenario would be an expression of anthropogenic, rather than controllable loads. The All Forest was used in the 2003 goal setting. Basing the allocation method on E3 recognizes that various sources have different possible levels of reduction. An allocation based on anthropogenic load could require levels of reduction beyond E3. For example, if an allocation required all loads to go 60 percent of the way toward All

Forest, certain theoretical land uses that can achieve only a 50 percent reduction at E3 would not be able to achieve the allocations, while wastewater treatment plants would be able to achieve a much larger than 60 percent reduction from No Action. Those distortions would increase at smaller scales as sources become more dominant locally.

The No Action scenario was chosen as the upper end to follow the principle of accounting for previous reductions. Using a starting point that incorporated management practices or higher levels of treatment would give a disadvantage to jurisdictions that had implemented the actions.

Allocation Method Options

Section 6.3.1 describes the method used to relate relative effectiveness to reduction effort. With that basic outline there is an infinite number of ways to define the allocation and still meet water quality standards. The major decisions to be made are the number of lines that represent different source categories and the shapes of those lines. The options were discussed in the Chesapeake Bay Program's Water Quality Goal Implementation Team (WQGIT) and the Principals' Staff Committee, and agreement was reached between EPA and five of the seven jurisdictional partners.

Number of Allocation Lines

During the allocation process, the WQGIT recognized that different source categories had different abilities to make progress toward an E3 level of implementation. Figure K-1 is a plot of implementation progress through 2009 plotted on the same vertical axis as the allocation charts, percent of E3 from No Action.

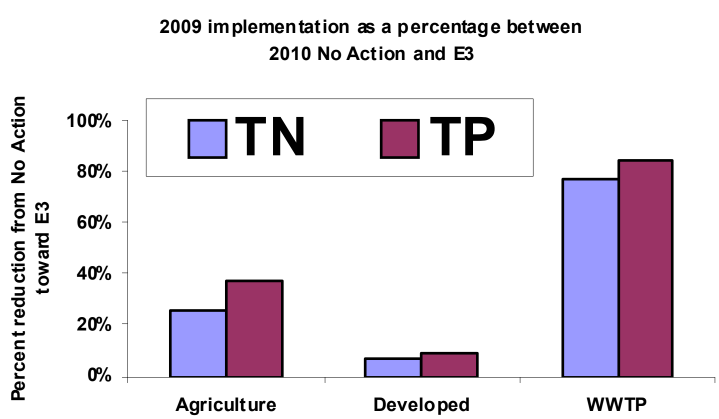

Figure K-1. 2009 implementation by sector.

The 2009 implementation represents the choices that the jurisdictions have made to date, presumably taking into account the same types of criteria that will be used to make decisions on restoration spending in the future.

There is a clear separation between the sources in that jurisdictions have chosen to set wastewater treatment plants at a level closer to E3, relative to No Action, than either agriculture or developed land. There is also a separation between agriculture and developed land, but it is not as large as the separation between wastewater treatment plants and all other sources. With that information, the decision was made to use two lines, one for wastewater treatment plants and one or all other sources.

Shape of the Allocation Lines

Several allocation line shapes were discussed with the three main shapes being

1. Straight: This is the most straightforward expression of the allocation principle stated under section 6.3 that areas with a greater pound for pound effect on water quality should do more.
2. Hockey Stick: It was recognized that a natural maximum existed for some sources, particularly with waste water treatment where a given technology could reach a concentration that could be expressed as a percentage from No Action to E3. A hockey stick line has a maximum for watershed areas in the range of relative effectiveness and slopes down for lower levels of relative effectiveness.
3. Z-curve: Similar to the hockey stick but also recognizing that a natural minimum also might exist. Again, related to wastewater treatment plants, a given technology producing a known concentration can be seen as a minimum technology that should be implemented.

As reported in more detail in Section 6.3.3 the wastewater line was set first in a hockey stick shape such that the upper 50 percent of the relative effectiveness values were at a maximum attainment percentage, according to a given concentration and the rest sloped off to a minimum value also based on a concentration. The straight line for all other sources was set such that a zero relative effectiveness would have a 20 percent lower value on the percent controllable axis than the area with the maximum relative effectiveness value. The intercept for all other sources was set such that the water quality standards were attained. Figure K-2, which is also Figure 6-7 in the main document, is the implementation of this method for nitrogen.

To make the above decision, the partnership was presented with several options for constructing the lines. Basin-jurisdiction loads were calculated for each option.

Table K-1 is a sample of options that were explored using the Phase 5.2 Chesapeake Bay Watershed Model. Several more options were generated before the final decision was made.

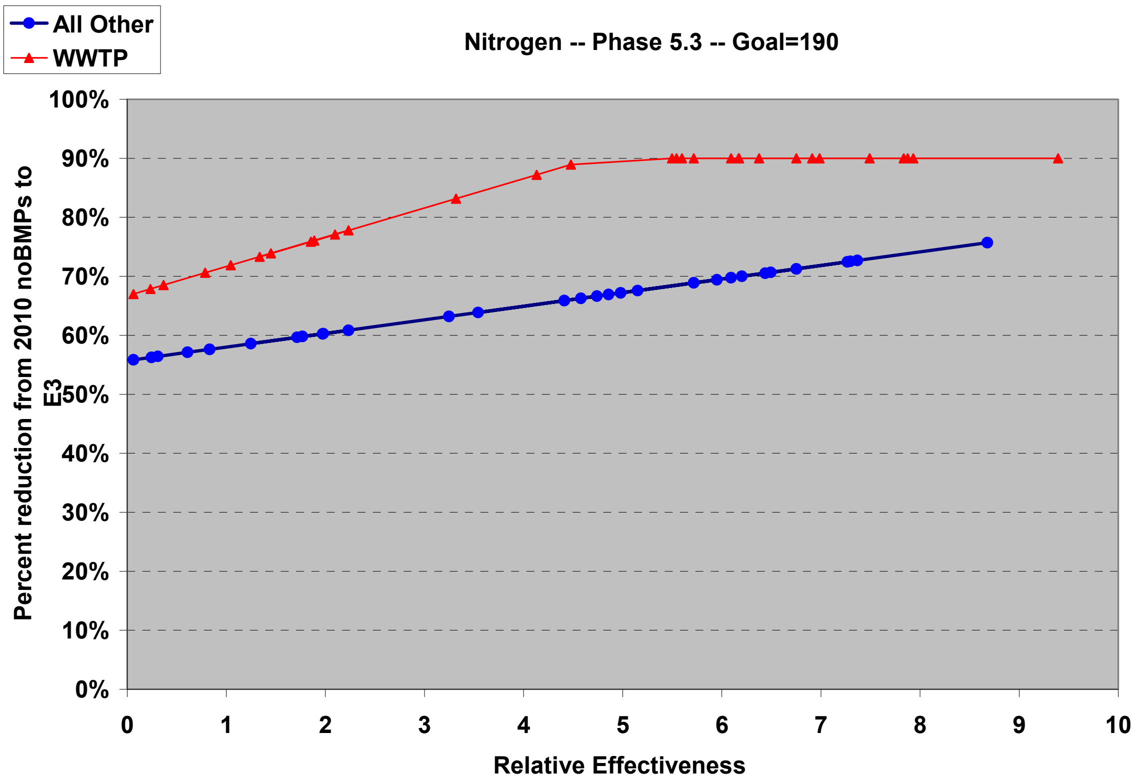

Figure K-2. Allocation methodology example showing the hockey stick and straight line reductions approaches, respectively, to wastewater (red line) and all other sources (blue line).

Table K-1: Initial options presented to the Chesapeake Bay Program's Water Quality Goal Implementation Team on September 30, 2009

Lines	2	2	2	2	2				
WWTP rule	3-8 mg/l	3-8 mg/l	3-8 mg/l HS	3-8 mg/l HS	3-8 mg/l Z				
Other Load Rule	20%	10%	20%	10%	20%	**Largest**			
DO goal	200	200	200	200	200	**Difference**	2010 Noact	E3 load	TS load
DC Potm	2.82	2.82	2.37	2.37	2.37	16%	9.68	1.53	2.12
DE Esh	5.12	5.21	5.25	5.34	5.21	4%	9.28	3.45	6.43
MD Esh	12.54	12.76	12.81	13.03	12.70	4%	23.94	8.25	13.84
MD Patux	3.26	3.25	3.15	3.13	3.27	4%	6.57	2.15	3.17
MD Potm	14.73	14.52	14.10	13.89	14.29	6%	30.31	9.65	14.66
MD Susq	0.81	0.83	0.83	0.85	0.82	4%	1.35	0.61	0.97
MD Wsh	10.18	10.15	10.15	10.11	10.12	1%	36.50	6.15	9.49
NY Susq	10.54	10.41	10.54	10.41	10.55	1%	16.36	7.78	8.68
PA Potm	4.76	4.58	4.83	4.65	4.83	5%	7.08	3.12	4.31
PA Susq	67.96	68.59	68.81	69.44	68.37	2%	121.19	49.23	68.86
VA Esh	1.60	1.59	1.61	1.61	1.60	1%	3.25	0.88	1.67
VA James	28.84	28.14	28.49	27.78	29.58	6%	52.63	15.80	28.85
VA Potm	16.85	16.47	16.09	15.72	16.50	7%	33.05	10.72	15.81
VA Rap	6.54	6.37	6.49	6.32	6.60	4%	10.61	4.33	6.49
VA York	6.55	6.32	6.53	6.30	6.72	6%	10.54	4.05	6.48
WV Potm	5.65	5.44	5.71	5.50	5.73	5%	8.32	3.76	5.69
Total	**198.77**	**197.46**	**197.76**	**196.45**	**199.27**	1%	**380.66**	**131.45**	**197.53**

Calculation of Equivalent Allocation Options

For any given level of water quality, an infinite number of lines can be drawn on the allocation plots like Figure K-2. To calculate an equivalent line to an existing line, it is necessary to meet the condition of

$$\sum(DeliveredLoad) \times (EstuarineDelivery) = C$$

or the sum of all delivered loads for each state/basin/fall-line combination times its estuarine delivery factor must equal a constant for the family of lines that meets the same water quality.

Expanding the delivered load term to create an equation between relative effectiveness and delivered load gives

$$\sum\left(E3_i + (NoBMP_i - E3_i)(1 - mX_i - b)\right)EstuarineDelivery_i = C$$

where

X_i	is the relative effectiveness
$E3_i$ and $NoBMP_i$	are the loads for that state/basin/fall-line/sector for the two scenarios
m and b	are the slope and intercept of the line and the only unknowns

Given a slope or an intercept, the above equation can be solved numerically for the other parameter of the line. This equation was implemented in MS Excel for multiple lines with enforced maximum and minimum to accommodate the decisions above.