A SCREENING APPROACH FOR NUTRIENT CRITERIA IN VIRGINIA: COMMENTS AND RESPONSES

Report of the Academic Advisory Committee
for
Virginia Department of Environmental Quality

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Introduction and Purpose

The Academic Advisory Committee (AAC) to Virginia Department of Environmental Quality (VADEQ) has recommended to VADEQ an approach to development of nutrient criteria for wadeable freshwater streams in Virginia's Mountain and Piedmont regions. The approach is described in the AAC's FY2012 report to VADEQ (AAC 2012a). The approach was presented to EPA Region 3 personnel in a webinar on December 3, 2012. EPA personnel viewing the webinar compiled comments on the webinar and FY2012 report. EPA Region 3 forwarded those comments to VADEQ on January 3, 2013. Those comments follow, along with AAC responses. The AAC is providing the responses to VADEQ for their consideration in formulating a response to EPA.

AAC Response Overview

We much appreciate the time and effort of EPA commenters. It is clear that, in addition to participating in the webinar, many commenters also reviewed the AAC's FY2012 report to VADEQ.

We have prepared responses to individual comments below. However, we find that, when viewed collectively, the comments do not address an essential question: Does EPA view the Screening Approach concept as a viable and potentially acceptable framework for nutrient criteria development? If the answer to that question is yes, then it is reasonable for the AAC and VADEQ to consider additional time, effort, and fiscal resource expenditures to refine details. If EPA prefers that Virginia pursue a traditional single-numeric approach, then additional efforts by the AAC and VADEQ to develop the Screening Approach concept may not be wise or appropriate. The rationale for the Screening Approach, as a general framework, has been described in more detail by the AAC's FY2013 report to VADEQ (AAC 2012b).

We have addressed individual comments below. Comment numbers have been added by AAC to aid preparation of the response.

General Comments and Comments on the Executive Summary and Introduction Sections

1. The AAC Report states "Nutrients are common water contaminants that challenge conventional methods for establishing water quality criteria for an essential designated use, and that nutrients in surface waters are well known as stressors that impair aquatic life and impact other uses." VADEQ will need to be more specific and speak to how other designated uses such as recreation and drinking water are protected or specify that the criteria be designed to protect only the aquatic life use.

AAC Response: We agree that nutrient criteria should be set at levels that protect all designated uses. Virginia assesses the following designated uses for its freshwater resources: wildlife, aquatic life, swimming, fish consumption, and for some waters, public water supply.

We focused our efforts on protecting the stream's capability to support aquatic life because we believe the aquatic-life use (ALU) is most sensitive to excessive nutrients. Furthermore, maintaining a healthy aquatic community is essential to the support of other uses, e.g., wildlife, recreational fishing.

The drinking-water provision is an essential designated use for surface waters, including certain of Virginia's larger wadeable streams. We expect that nutrient criteria to protect aquatic life would be applied in association with criteria to protect other designated uses, as deemed appropriate by Virginia DEQ.

2. Data set filtering for reference-like conditions (especially with only probabilistic data) might not be the best approach, as it misses the reality of co-stressor occurrence across the landscape. In a statistical sense probabilistic monitoring data also misses many of the more serious nutrient pollution problems across the state, truncating the nutrient gradient; supplemental-targeted data could benefit this process.

AAC Response: The VADEQ probabilistic monitoring data has larger ranges of measured values for most water quality parameters than other VADEQ datasets, lending itself to specialized studies such as verification of the Virginia Stream Condition Index (VASCI, VADEQ 2006) and development of nutrient criteria. In contrast, targeted monitoring data collected by VADEQ contain far fewer water-quality and site-attribute parameters than the probabilistic monitoring data.

We used data filtering and probabilistic monitoring data only for the no-observed-effect concentrations (NOECs). Because the NOECs are used to identify streams where nutrient impairment is considered unlikely, samples that represent the "more serious nutrient pollution problems" are not needed to determine the NOECs.

The streams with more serious problems related to nutrient pollution are of direct relevance to the observed-effect concentrations (OECs), and as suggested, we used targeted monitoring data for OEC identification.

3. While it is beneficial to look at nutrient effects in the absence of all other stressors, too little is known about the synergistic effects of other stressors (temperature, oxygen, pH, siltation, loss of canopy) and even natural factors (headwaters versus larger rivers). It might be unrealistic to model responses in their absence (as filtered criteria). Granted, stressors are often auto correlated and caution should be exercised when analyzing large datasets. Excluding co-located stressors could result in derivations of much higher nutrient thresholds than what might actually drive impairment. For example, while sedimentation and nutrients often go hand in hand, the magnitude of each stressor and their combined effects should not be overlooked. In low sedimentation situations, a given TP or TN endpoint might be protective, but with some increase in sedimentation does that same nutrient concentration protect aquatic life? Are there synergistic effects unaddressed?

AAC Response: There are several possible ways to approach the task at hand. We have chosen to estimate an NOEC by using actual, measured data and a reference-filtering approach using methods applied previously by VADEQ with approval by EPA for SCI validation (VADEQ 2006). The consideration of synergistic effects by other stressors would require an approach other than the reference-filtering approach applied here.

4. VADEQ should also evaluate the role canopy cover plays in the manifestation or amelioration of other biotic effects of nutrients and evaluated the role other independent chemicals (or co-dependent) that effect diatom community structure like silica, which strongly relates to alga-nutrient responses.

AAC Response: It would be possible to examine canopy-cover effects statistically, given that canopy cover is a habitat variable and is included in the probabilistic monitoring dataset.

5. Some method of early detection or built-in safety factor concentrations would be needed to prevent nutrient-related impairments. For example, because of the known negative benthic habitat interference by Cladophora algae, nutrient concentrations that initiate and maintain blooms (from the literature) could be evaluated for use as a means of early-warning prevention.

AAC Response: VADEQ conducts water quality trend analysis as part of its periodic water quality assessment. Temporal trend analysis, when applied to nutrients either within or without a screening-approach context, can serve as an early warning system.

6. Overall, it appears that the family-level index (SCI) might not be an appropriate endpoint for modeling nutrients with poor dose responses observed. First, the nutrient-criteria dataset used for deriving the NOECs are probably too range restricted. Need to anchor both ends of the gradient (lowest and highest) for the regression analyses. Also, the "cancelling" effect (like with most IBIs) by some responsive versus non-responsive component SCI metrics might miss significant community shifts that SCI cannot detect. Moreover, SCI of <60 as a modeling endpoint fails to protect high quality streams.

AAC Response: Family-level SCI is an EPA-approved surrogate for attainment of the ALU and is currently used by VADEQ for that purpose within an EPA-approved Clean Water Act implementation framework. We (AAC) are not in a position to suggest or develop an alternative ALU surrogate for use in developing nutrient criteria. Use of an alternate measure for establishing nutrient criteria would be equivalent to establishing an alternate *de facto* aquatic-life standard.

Virginia has an anti-degradation policy that applies to streams designated as "exceptional state waters." It is quite possible that such streams could be treated separately and differently if Virginia were to adopt the Screening Approach as an integral component of nutrient criteria. Virginia's nutrient criteria for lakes and reservoirs, for example, treat natural lakes separately from constructed impoundments; historic nutrient concentrations within Virginia's natural lakes were used as a basis for development of nutrient criteria for those lakes. It would be possible to

use a similar method for assessing exceptional waters within a nutrient criteria framework that also employs a screening approach for assessing waters not classified as exceptional waters.

7. AAC's modeled endpoints should be compared and contrasted with other modeled concentrations in: a) Mid-Atlantic highlands (Stevenson et al. 2008) diatom community change ~NOEC. Although performed with different biological endpoints recommended TP was 0.01 to 0.03 mg/L, and TN of 0.4 to 1.0 mg/L. b) Tennessee (TDEC) in multiple ecoregions (look at differences in a very phosphorus-rich Ordovician limestone ecoregion 71 (TP=0.18), versus ecoregion 69 (TP=0.02) based on 90th %ile of reference conditions). Noting, Tennessee also uses biology to determine if stream is actually impaired. This analysis points to huge differences at reference sites across ecoregions. In Virginia, we would expect nutrient concentrations to naturally differ in some Ridge and Valley subecoregions and some Piedmont streams draining limestone areas, compared to the southern coalfields. Even between broader Virginia Mountain and Piedmont regions, modeled OECs were strikingly different for TN.

AAC Response: We agree that it is reasonable to compare AAC's NOECs to other endpoints being used throughout the region, but we would not agree that endpoints developed in other states using other methods should be used to pass judgment on the validity of Virginia NOECs. We agree that it would be appropriate to apply differing screening values to the Mountains and Piedmont ecoregions if such an approach is supported by the data. Available monitoring data may not be adequate to establish screening values for sub-ecoregions.

We have reviewed alternative endpoints developed by other studies, including that mentioned by the commenter. Those reviews are attached as an addendum to these responses (Appendix A).

8. Other potential statistical approaches could be explored: Propensity score analysis (e.g., Lester Yuan, ORD)—can use entire data set without filtering, but statistics can derive endpoints when multiple stressors are present (e.g., models give nutrient threshold amongst different levels of non-nutrient stress). Multiplicative-type interactions of TNxTP might exist (e.g., Miltner and Rankin, Ohio EPA), or other combinations; OEPA explained that combining TP and TN was more realistic in biological dose responses. It would be interesting to see if SCI responds better when these 2 nutrients are considered together, rather than independently. Other threshold seeking techniques such as TITAN, breakpoint analysis, CART, LOESS or concentration "binning" might be more informative than fitting straight-line regression models. Finally, TP is measured in 0.01 mg/L increments; if measured in micrograms/, it might have allowed for detecting finer scale changes in SCI.

AAC Response: The precision of TP measurement by VADEQ is a water monitoring issue. Our analysis uses the data obtained by VADEQ to its maximum precision.

We looked at combined TN/TP applications, but found that – within the context of current data analysis techniques – combined TN/TP applications provided no advantage to estimation of NOEC and OEC over applying individual parameters separately.

Other sections of this comment concern other potential techniques that may provide advantages over straight-line regression models. Although we attempted application of straight-line regression models, we rejected that approach.

Certainly, it would be possible to apply other data analysis techniques, and it is possible that such techniques "might be more informative." If the commenter wishes to suggest one or a few specific technique(s) as possibly or likely more informative than the technique we have applied, we would welcome that suggestion.

9. The AAC Report states, "A common theme among these results is the tradeoff between accuracy/certainty of screening approach outcomes and potential new resource expenditures that would be required by application." Relative to what? Setting the NOEC at a relatively high concentration may not be protective. VADEQ will need to demonstrate that these values are protective of applicable designated uses and are based on sound science.

AAC Response: Comments in our report concerning resource expenditures were intended for the sponsor of our activities, VADEQ. Fiscal-resource expenditures were not considered in the analyses that derived potential NOECs.

We have analyzed potential fiscal-resource requirements because we expect that nutrient criteria expressed through the Screening Approach would require greater fiscal-resource expenditures on monitoring by VADEQ than would nutrient criteria applied as traditional single-numeric thresholds. Nonetheless, we believe the Screening Approach to be advantageous (AAC 2012b). We have provided information concerning potential fiscal-resource requirements of the Screening Approach as a means of informing VADEQ.

10. Although the AAC recognize that loading effects to downstream areas is critical, the reliance on SCI and visual assessments at the 100 m reach level may not be appropriate for screening potential impairments and ultimate effect levels that could impair downstream waters, including larger rivers, lakes, wetlands, and estuaries. For instance, if a stream that is equivalent to a nutrient-reference stream (i.e., no non-nutrient stressors) is allowed to discharge concentrations that are just barely less than the OEC value, nutrients could exacerbate impacts to receiving streams already compromised by other stressors at much lower receiving nutrient levels.

AAC Response: The AAC considered downstream-loading issues and discussed them at length in earlier reports to VADEQ (e.g., AAC 2006, pp. 18-28; AAC 2007, pp. 29-51; AAC 2010, pp. 1-3 of last appendix; AAC 2012b, p. 14). The Screening Approach is for application as localized criteria only. Downstream-loading issues would be dealt with separately.

Screening Approach Sections

11. The AAC Report states "[t]o monitor and assess the attainment of the designated aquatic-life use, Virginia has developed a biological monitoring procedure that employs a measure of biological community integrity using benthic macroinvertebrate to calculate a Stream Condition Index (SCI) that was developed for the freshwater streams and small rivers in the Piedmont and Mountain regions (Tetra Tech 2003; DEQ 2006)." For Level III ecoregions IX and XI, EPA developed separate criteria guidance for these two Ecoregions. IX: TP-36.56 ug/L, TN-0.69 mg/L. XI: TP-10 ug/L, TN-0.52 mg/L. VADEQ should explain why it combined these two Ecoregions for rivers and streams while for lakes; criteria were developed separately for each ecoregion. If not enough VADEQ data was available; maybe VADEQ should investigate using data from adjoining States and Federal agencies for the same ecoregions?

AAC Response: We agree that it would be appropriate to develop separate OECs and NOECs for the two major ecoregions if such an approach is supported by the data. If adjoining states have data that are compatible with the VADEQ data being used to develop OECs and NOECs for Virginia, use of such data for criteria development would be welcome and appropriate. However, we hesitate to approach adjoining states for the purpose of requesting such data in the absence of a clearly stated EPA opinion regarding the appropriateness of the Screening Approach as a general concept for nutrient criteria development.

12. The AAC recommends the screening approach as an alternative to traditional single-numeric fixed criteria because nutrient effects on aquatic systems differ in a fundamental manner from effects of traditional pollutants. This is problematic in the sense that the intended outcome is unclear. Nutrient criteria as part of WQS are an integrated part of a State Water program. A criterion derived from NOEC with an acceptable margin of error is preferred.

AAC Response: The intended outcome is to maximize the accuracy and precision of water quality assessments for nutrient impairment. Comment is not clear in defining why single-numeric, fixed criterion should be preferred over the flexibility embodied by the Screening Approach, given the manner in which nutrients affect streams and, hence, the wide range of tolerance to nutrient inputs among individual streams. EPA has approved nutrient criteria in other states that do not rely on a single numeric criterion. We are confident that the Screening Approach would be integrated into water quality standards if it were found to be a satisfactory and reliable means for identifying nutrient impairments.

Incorrect water quality assessments produce real costs. The Screening Approach is intended to reduce both false-positive errors and false-negative errors of assessment, relative to errors that would likely occur through use of traditional single-numeric nutrient criteria. Listing waters that are in fact unimpaired directs agency time and funding toward waters where the designated use is being met, and in so doing reduces the resources available to address true water quality problems and challenges including those caused by actual nutrient-induced impairments. Failing to list waters that are, in fact, impaired also imposes costs to the public in the form of failure to achieve

designated use and through reduced ecosystem services. The Screening Approach is intended to minimize incorrect assessments.

NOEC Section

13. Over filtering might be an issue (by simply limiting the data range). VADEQ should consider relaxing filter criteria to remedy this. Other filtering criteria seem too restrictive as well, for example: Page 8 "significant non-nutrient stressors, such as sedimentation, intermittent flows, proximity to a dam, or the like" —please elaborate on the filtering process for these. "[N]o evidence of nutrient-induced impairment" —this would exclude sites undergoing subtle shifts in periphyton communities undetected by the naked eye, yet could significantly contribute to altered benthic communities. Filtering these factors out restricts range of data for use in modeling. Further, essential to modeling nutrient thresholds with biological data, is the need to classify stream assemblages in the context of natural (stream size, ecoregion, season) and land use pressures. Nutrient concentrations and biological response among agricultural or urban, versus headwater or river, versus cold water or warm water stream types should be evaluated as they might be critical in biological response and subsequently derived thresholds.

AAC Response: The filtering procedure was essential to development of the nutrient-criteria reference dataset and was modeled after the procedure used by VADEQ with EPA approval to validate the VASCI as a water quality assessment tool (VADEQ 2006).

Because our goal is to determine nutrient concentrations that cause impairments, filtering to remove sites and observations where non-nutrient factors appear to be causing impairment is logical. If a non-nutrient factor is the primary factor causing an observed impairment, the nutrient concentration at that place and time is not relevant to the impairment. Hence, its inclusion in models intended for developing nutrient criteria would not contribute to the accuracy and precision of outputs by such models.

If we had a much larger dataset available for use in nutrient criteria development, it would be possible to produce models that reflect influence by stream size, ecoregion, season, land use, non-nutrient stressors, and stream canopy, as suggested by this and other EPA comments.

14. Looking at Figure II-5, seeing the whole data set data plotted with the filtered data set would be helpful. For instance, this would show if the whole data set and filtered data set have a similar slope to the regression line.

AAC Response: The slope of the regression line was not used in developing the potential NOEC value. Therefore, even though this graph could be easily created, we fail to see how such effort would contribute to the process.

15. For a NOEC, EPA expects to see demonstration of no effects or low likelihood of effects. The AAC Report explains that the "nutrient-criteria reference" sites were intended to produce a dataset without non-nutrient stressor effects, but include sites that are impacted

by nutrient enrichment, not true reference sites. Therefore, a lower bound of a confidence interval as discussed on page 10 would better represent a low chance of observed effects than the regression line predictions where SCI=60. In the December 3, 2012 AAC presentation the alternative of ignoring the regressions and using the 90th percentiles of the "nutrient-criteria reference" data was shown. Since this data set includes streams impacted by excess nutrients, a lower percentile may be more representative of "no effects." Perhaps an even better representation for no effects would be from a true reference dataset.

AAC Response: The regression line referenced by the comments was not used to define an NOEC. We used the 90th percentile because the 90th percentile is commonly used in the development and enforcement of water quality standards. Also, sites with TN and/or TP concentrations exceeding the 90th percentile (NOEC) may or may not be impaired, as demonstrated by our data in Section III of the report.

Decisions concerning the appropriateness for use of any given percentile, in this context, are (in essence) decisions concerning tradeoffs of risk concerning false-positive versus false-negative outcomes. Hence, we consider such to be policy decisions. If EPA is willing to make a definitive statement concerning how such risks should be considered in nutrient criteria development and to provide guidance concerning what would be an appropriate percentile, we would re-evaluate our decision to use the 90th percentile.

16. What is the difference in the data used in Figure II-2 (reference screened data) SCI vs. nutrients and Figure II-5 (reference dataset) SCI vs. nutrients? Is it only the biologist screening shown in Table II-3? In addition to Figure II-5 a figure showing SCI vs. nutrients for all data would be helpful.

AAC Response: Figure II-2 shows data for ProbMon sites satisfying the reference filters of Table II-1. Figure II-5 shows data for ProbMon sites satisfying the reference filters of Table II-1 and an additional filter: The best professional judgment of a VADEQ biologist who was familiar with the site and able to state that the site is *not* stressed due to factors that were visually evident (the "nutrient-criteria reference dataset"). Hence, Figure II-5 shows a dataset derived using methods described by a prior EPA-approved study (VADEQ 2006). If a clearly stated EPA opinion were to lead the AAC and VADEQ to conclude that it is prudent to continue investing time and effort in the direction established by VADEQ (2012a), we can show SCI vs. nutrients for all data – that is not a problem.

17. Are there NOEC considered to be a reference condition? If so couldn't a set of overlapping distribution curves be developed comparing upper 25% of impaired with lower 25% (reference or some other %) to see where the overlaps occur to note what nutrient concentration (range?) criteria can be developed.

AAC Response: Streams with nutrient concentrations lower than the NOECs are not considered to be "reference condition." The purpose of the NOEC is to set a nutrient-concentration threshold below which impairment of the aquatic-life use due to nutrients is deemed unlikely; however, streams with nutrient concentrations below the NOEC threshold could still be impaired for other

reasons. Additionally, simply because a stream has nutrient values higher than the NOEC does not mean it is impaired because of nutrients.

18. Once the NOEC is determined, VADEQ has a targeted nutrient criteria value by which a determination of impairment can be made. Everything else should lead up to this these criteria value development. If SCI and visual observations are to be used, somehow, they should be incorporated into WQS.

AAC Response: If actual nutrient criteria are developed using the Screening Approach or any other method, we fully expect they will be incorporated into WQS.

19. This analysis was conducted using VADEQ's probabilistic monitoring dataset, 2001-2009, Mountain and Piedmont ecoregions only. At the EPA national level, they were considered different enough to warrant separate TP/TN/Chl criteria guidance. If the issue is location of sufficient reference sites within in Virginia for each, has attempts been made to solicit data outside Virginia either in surrounding states, federal agencies, other studies or via the national assessment initiative for wadeable streams?

AAC Response: We agree that it would be appropriate to develop separate OECs and NOECs for the two major ecoregions if such an approach is supported by the data. If adjoining states have data that are compatible with the VADEQ data being used to develop OECs and NOECs for Virginia, use of such data for criteria development would be welcome and appropriate. However, we hesitate to approach adjoining states for the purpose of requesting such data in the absence of a clearly stated EPA opinion regarding the appropriateness of the Screening Approach as a general concept for nutrient criteria development.

20. Ideally, this application would produce a dataset that eliminates most non-nutrient stressor effects and thus would isolate TN and TP as aquatic-life stressors – a nutrient-criiteria reference dataset. For Maryland, Buchanan (2010) used statistical method for weeding out confounding factors in nutrient threshold development. Has that approached been evaluated for use in this approach?

AAC Response: The mentioned approach has not been evaluated. We have searched the peer-reviewed literature for the Buchanan (2010) reference, but the search was not successful. If the commenter is able to provide a more complete citation or a copy of the Buchanan (2010) study, we would be able to evaluate the suggested approach.

21. The AAC Report states that "Because the 2001-2009 probabilistic monitoring data contains >600 monitoring locations, it was not feasible to ask regional biologists to apply BPJ as a means of identifying significant non-nutrient stressors at all monitoring sites." Was non-stressor information available in database to do a Buchanan-type of statistical analysis to eliminate confounding factors?

AAC Response: The probabilistic monitoring dataset is data rich, but the ambient monitoring dataset is not. Hence, a statistical analysis to identify confounding factors is not possible for the ambient monitoring data.

Note that we attempted to use non-nutrient data in the probabilistic monitoring dataset as a means of defining reference conditions, but application of reference filters in the absence of best professional judgment by regional biologists failed to define a nutrient-criteria reference dataset (as evidenced by Figure II-1).

The nutrient-criteria reference selection method used in Section II of the report, which relied on both the reference filters of Table II-1 and the best professional judgment applied by VADEQ biologists, was identical to the procedure applied in VADEQ (2006) and approved by EPA.

22. The AAC Report states that "[i]t is possible that the limited extent of benthic algae data contributed to this finding, as benthic algae data are available only for a portion of the ProbMon data. Benthic algae data are available only for fall collections, and no benthic algae observations were collected prior to 2004." Can VADEQ define benthic algae - Diatoms, filamentous and/or macrophytes?

AAC Response: The term "benthic algae," as we use it here, described algal biomass collected through application of the ProbMon protocol. It includes algal biomass collected through scraping of rocks sampled from the streambed, but it does not include macrophytes.

23. The AAC Report states "[t]he lower bounds of the regression lines' 95% confidence intervals cross SCI=60 at about 0.7 mg/L for TN, and at about 0.05 mg/L for TP." This particular TP value has shown up in many diatom studies as cut off point between tolerant and non-tolerant diatom communities. These TN/TP values are above values determined in EPA guidance recommendations for these two Level III Ecoregions.

AAC Response: The regression was not used to establish potential NOECs for reasons explained in the text (AAC 2012a, p. 10).

Are the EPA-guidance recommendations referenced by the comment those that were released in the year 2000 and determined as 25th percentiles of available data? If so, it is reasonable that our results would differ from those recommendations. We are applying an effects-based approach that is very different from the method applied by EPA (2000) in developing guidance recommendations. The AAC prefers the effects-based approach as explained in the AAC 2012b report (pp. 3-7).

OEC Section

24. For the NOECs a filtered data set to focus on the nutrient-SCI relationship was used. Why are the data sets changed for the OECs? Did the AAC try SCI-nutrient regressions for the whole data set and then apply the filters to improve the regression?

AAC Response: Datasets are changed because they have different characteristics. The ambient monitoring dataset has more observations for TN and TP; however, it does not include the wide range of water-quality and site-description data that are included within the ProbMon dataset. The ambient monitoring dataset does not include watershed land-use information; hence, the

"<5% Urban" filter (see Table II-1) cannot be applied. Similarly, the ambient monitoring observations do not include information concerning the supplementary reference filters (see Table II-2). Hence, the ProbMon data were used for the NOEC estimation.

As noted by an EPA commenter (see comment 2): "In a statistical sense probabilistic monitoring data also misses many of the more serious nutrient pollution problems across the state, truncating the nutrient gradient …" The ambient monitoring data (described as "targeted" monitoring in comment 2) does characterize the more extreme nutrient conditions. Hence, these data were more appropriate than the ProbMon for the OEC derivation. *(See also response to comment 2).*

The method suggested by the commenter ("SCI-nutrient regressions for the whole dataset and then apply the filters to improve the regression") was not attempted due to (1) the wide range of conditions, including non-nutrient stressors, that occur at monitoring locations; and (2) the paucity of measured data that describe co-occurring stressors for the ambient monitoring dataset.

25. The "probability of impairment at equal-or-greater concentrations" analysis is a conditional probability analysis, and is shown in figures III-1, III-2, and III-3. These figures show the probability of SCI being less than 60 given that the indicated TN or TP stressor level is exceeded. The error associated with the higher nutrient concentrations is large due to the diminishing sample size moving from left to right on the plots. Because of this large error EPA recommends that conditional probability analysis not be used to derive the OECs. EPA's stressor response guidance explains that conditional probability analysis can be used in exploratory data analysis to screen variables for use in stressor-response relationships. However, we don't recommend using it to directly derive criteria. (US EPA, November 2010, Using Stressor-response Relationships to Derive Numeric Nutrient Criteria, EPA-820-S-10-001)

AAC Response: The conditional-probability approach has not been used to derive criteria – it has been used to estimate potential OECs. We agree that this approach has deficiencies, including that mentioned by the commenter, and have stated such in the report. If the commenter is able to suggest an alternative approach for use in deriving OECs, we are open to it.

26. Regarding the logistic inverse prediction approach described in Appendix A we have the following comments. (1) We recommend log transforming TP and TN before using them in the regression. The distributions of both TN and TP are so skewed that the logistic regressions are hugely uncertain; (2) AAC applied these models to the full data set, and to get to a more accurate relationship between impairment and TP and TN. EPA recommends that VADEQ factor in covariates (e.g., physical habitat quality, other water quality variables) into their models. The AAC Report only speaks to season and ecoregion as additional variables. When computing the OEC, how did the AAC factor in season, since it was a significant explanatory variable?

AAC Response: The logistic-regression approach is illustrated in the report because it was conducted as an AAC activity supported by VADEQ funds. However, it was not used to define the potential OEC due to divergence of the estimated logistic regression line from the observed

data at the 90% probability level that was the focus for the analysis. Season was not considered as a potential explanatory variable.

27. The concentrations modeled for TN and TP OEC were very high, high enough to probably pass over and search for another method. Use of OECs this high to help screen for probable effects is not practical; the authors admit that this would represent (i.e., flag as impaired) very few sites overall. Perhaps conditional probability of impairment is too high (90%). VADEQ will need to clearly establish how these thresholds as protective of aquatic life in rivers and stream throughout Virginia. AAC suggests alternative probabilities could be used; why not something lower given the use of the more conservative family-level index (SCI)?

AAC Response: We agree with the comment and would appreciate some guidance from EPA Region 3 as to what might be an appropriate probability level for definition of OECs. We would not be comfortable with selecting and applying an alternative probability arbitrarily, in the absence of supporting rationale, but we would welcome the suggestion of a rationale that would support an alternative probability level. We see the selection of an appropriate probability for use in OEC derivation as, essentially, a policy decision; and we do not see ourselves as being in a position where it is appropriate that we should define such probability levels in the absence of agency guidance.

28. When viewing conditional probability plots of Mountain versus Piedmont, there were clear differences in the SCI response for TP and TN, VADEQ should consider region-specific criteria for Piedmont and Mountain.

AAC Response: We agree that it would be appropriate to apply different screening values to the Mountains and Piedmont ecoregions if such an approach is supported by the data, and thus we developed and interpreted conditional probability plots, and derived OECs, separately for the Mountain and Piedmont ecoregions. We have addressed related issues concerning NOECs in response to comment 19 above.

29. The AAC Report says that the SCIs derived from the benthic macroinvertebrate assessments were sorted by the associated nutrient concentration. Can VADEQ explain how this family level SCI sensitive enough to be used as triggering mechanism?

AAC Response: Family-level SCI is an EPA-approved surrogate for attainment of the ALU and is currently used by VADEQ for that purpose within an EPA-approved Clean Water Act implementation framework. We (AAC) are not in a position to suggest or develop an alternative ALU surrogate for use in developing nutrient criteria. Use of an alternate measure for establishing nutrient criteria would be equivalent to establishing an alternate *de facto* aquatic-life standard. *(See also response to Comment 6).*

30. Lastly how does the OEC compare to the threshold values that Virginia uses for TMDL stressor analysis for TP and TN?

AAC Response: We have conducted this analysis and attached it as an addendum to these responses (Appendix B).

Visual Assessment Section

31. We encourage you to develop thresholds for percent algal cover, etc to make the assessment process more reproducible and less reliant on BPJ. We also strongly encourage you to adopt these thresholds and SCI components into rule. We are willing to work with you on the structure of the WQS so that it works the way you envision without running afoul of CWA 303(d)(1)(A).

AAC Response: Development of a percent-algal-cover metric and threshold would require additional field study. For the visual assessment trials, algal cover was only estimated by categorical class (0-10%, 10-40%, 40-70%, 70-100%). Prior analyses of the relationships of these values with SCI did not produce results that we considered of adequate precision for use in criteria development (e.g., AAC 2009, Figure 7; plus other exploratory analyses of probabilistic monitoring data conducted but not reported). The probabilistic monitoring dataset does contain numeric algal-cover values but only for a fraction of the monitoring sites. Hence, we consider existing data are not adequate to support development of percent-algal-cover thresholds.

32. With inherent uncertainties surrounding SCI sensitivity, synergistic effects of other stressors, and regional or stream size environmental settings, there should be built-in safety factors (e.g., constants, other probability estimates) to prevent the risk of aquatic life degradation long before problems are seen with the naked eye.

AAC Response: VADEQ conducts water quality trend analysis as part of its periodic water quality assessment. Temporal trend analysis, when applied to nutrients either within or without a screening-approach context, can serve as an early warning system.

33. Additionally, the AAC Report speaks to "decisions to set NOECs at relatively low concentrations and OECs at relatively highly concentrations while limiting visual assessments to only those circumstances that produce highly accurate outcomes would require significant resource expenditure for benthic macroinvertebrate assessments at sites defined as 'inconclusive' by the screening process." If this discussion is about setting criteria values, OEC is really not a concern. What is really needed is a determination of nutrient criteria slightly lower than NOEC to protect the designated uses. Once an effect is noted it is already too late.

AAC Response: As noted above, NOECs are not numeric criteria that identify nutrient impaired waters. The purpose of the NOEC is to set a low nutrient-concentration threshold below which impairment of the aquatic-life use is unlikely. The purpose of the OEC is to set an upper nutrient-concentration threshold above which nutrient levels are likely to contribute to impairment of the aquatic-life use. These thresholds are intended to function as triggers that set in motion a process (similar to the EPA-approved process in Florida) for making an accurate determination of nutrient impairment.

If EPA finds the terms "no-observed-effect concentration" and "observed-effect concentration" to poorly describe the concept and were to state a rationale, the committee would reconsider the terms. We see a screening-approach concept as a valid and useful means of approaching nutrient criteria development, but we are open to alternative suggestions for these terms.

34. The AAC Report states that the visual assessment is as a essential screening-approach component because nutrients impair aquatic communities by stimulating excessive in-stream primary production, and the predominant freshwater stream primary producers – photosynthetic algae and macrophytes – are easily visible to competent observers - these correlate with benthic and fish impairments/lack of? Periphyton community structure cannot be determined by gross visual observation.

AAC Response: We do not disagree with this comment. The assessment procedure used in Stage II of the Screening Approach relies on a visual estimation of the percent coverage of the stream bottom by periphyton and macrophytes. We lack data that would enable determination of relationships between periphyton-community-structure metrics and VASCI (which is used by VADEQ, with EPA approval) to define aquatic-life impairments.

35. The AAC Report states "Eighty-eight percent of monitoring events visually assessed as having a high probability of impairment by nutrients." It is not clear if all monitoring events have visual, SCI and nutrient data for comparison.

AAC Response: All of the events reported have visual assessments and SCI data; only a small fraction has nutrient data. We consider the SCI data to be more essential than water quality data in this context because the goal of visual assessment is to correctly determine aquatic-life impairment (or lack of impairment). All monitoring events that pair visual assessments with SCI and/or with nutrient data are reported.

36. The AAC Report states that "[w]here regional biologists visually assessed monitoring events as having either a 'high' or 'low' probability of aquatic-life impairment due to nutrient and non-nutrient combined effects, results of benthic macroinvertebrate sampling conformed to those BPJ ratings for 79% of monitoring events." Again VADEQ will need to demonstrate that this 79% target is protective of applicable designated uses and are based on sound science.

AAC Response: The data referenced by the comment are not relevant to the proposed application of the Screening Approach – we did not recommend the combined (nutrient + non-nutrient) BPJs for use in the Screening Approach. The purpose for reporting these data is to demonstrate that our proposed application (which includes only nutrient-related BPJs) would be more accurate than one incorporating visual assessments of combined nutrient and non-nutrient effects.

37. For high probability of impairment from the BPJ ratings was applied more frequently to evaluate non-nutrient stressor effects. Eighteen percent (133 of 723) of the monitoring events with SCIs scores received a BPJ rating of "high probability" of impairment associated with nutrients, non-nutrient stressors, or both. Can these confounding factors be accounted for?

AAC Response: The data referenced by the comment are not relevant to the proposed application of the Screening Approach – we did not recommend the combined (nutrient + non-nutrient) BPJs for use in the Screening Approach. The purpose for reporting these data is to demonstrate that our proposed application (which includes only nutrient-related BPJs) would be more accurate than one incorporating visual assessments of combined nutrient and non-nutrient effects.

38. Figure IV-3. which speaks to Relationships of TN, upper and TP, lower medians to Stream Condition Index (SCI, left) and best professional judgment (BPJ) of nutrient impairment likelihood ratings (right). High outlier TN and TP values are off scale. Since medium impairments prob with SCI<60 makes up roughly 30% of finding, there has to be weight given to that data in deriving a correlating nutrient value which can become a criteria candidate.

AAC Response: We cannot respond because we do not understand the comment.

39. The tradeoffs between accuracy/certainty and resource allocations described are not unique to the screening approach; they are generally integral to issues concerning nutrient criteria. The expectation of EPA is that nutrient criteria need to be developed against which all other response variables can be compared and correlated to make impairment determinations. OEC/NOEC is a good starting point (the gap should be as small as possible) but it is known that by the time an effect is noted, the nutrient concentration is already higher than it needs to be to protect aquatic life use.

AAC Response: VADEQ conducts water quality trend analysis as part of its periodic water quality assessment. Temporal trend analysis, when applied to nutrients either within or without a screening-approach context, can serve as an early warning system.

Comments in our report concerning resource expenditures were intended for the sponsor of our activities, VADEQ. Fiscal-resource expenditures were not considered in the analyses that derived potential NOEC and potential OEC values.

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Appendix A: Nutrient Reference and Effect Levels from Peer-Reviewed Literature

Over a multiple-year period extending from the late 2000s, the Academic Advisory Committee (AAC) to Virginia Department of Environmental Quality (VADEQ) has been advising VADEQ on nutrient criteria development. The AAC has been recommending that a "Screening Approach" be applied to nutrient criteria development and application and has described a rationale and logic for this recommended approach (AAC 2012c; and earlier reports).

In January 2013, US EPA Region 3 provided a series of comments to the AAC that concerned the AAC's fiscal year 2012 report to VADEQ (AAC 2012a) and a webinar presentation intended to communicate contents of that report to EPA Region 3 (AAC 2012b). Among other comments, US EPA staff recommended that the AAC evaluate potential screening levels developed through those analyses (Observed-Effect Concentration, OEC; and No-Observed-Effect Concentration, NOEC) in light of nutrient-effect levels generated by other studies. This document is a response to that comment.

This document is a brief review and summary of studies from peer-reviewed literature that we see as relevant to development of Virginia nutrient criteria. The emphasis is nutrient reference and effect-level concentrations that can be evaluated to provide perspective on the potential screening levels for Virginia's nutrient criteria development. Potential screening levels derived from analyses described by the AAC (2012a and b) are listed in Table 1.

Method

This review includes only peer-reviewed literature. The review emphasizes studies from Virginia and neighboring states. Studies with relevant nutrient levels from non-neighboring, Mid-Atlantic states and from US regions that include Virginia were incorporated when encountered, but the review did not comprise a targeted search for states other than Virginia and its neighbors. Studies based solely on measured values from coastal areas were not included because the AAC's focus is Mountain and Piedmont areas of Virginia. An initial search was conducted using terms such as "nutrients" and "nutrient criteria" and names of states. The search continued by reviewing references cited by studies found through the initial search when such references appeared as potentially relevant.

Primary results are nutrient levels contained in Tables 2 through 4. Only total nitrogen (N) and total phosphorus (P) concentrations were tabulated if a reviewed study's results were expressed using multiple nutrient concentration measures; if total N and/or total P were not reported, other nutrient concentration measures, as reported, are listed in Tables 2 through 4.

Nutrient criteria studies found in peer-reviewed literature were of two primary types: Those assessing relationships between nutrient levels and ecological conditions, and those taking a distributional approach by calculating arbitrary percentiles of nutrient concentration distributions assembled without discriminating among potential effects. Studies assessing relationships between nutrient levels and ecological conditions were reviewed, but studies based solely on a

distributional approach were not reviewed. Studies identifying reference concentrations from waters with little human influence were also reviewed because potential NOEC values may be evaluated in light of such reference levels.

Results

Reference Conditions

Nutrient levels in reference-condition streams can provide perspective on potential NOECs. Reference-condition streams represent relatively undisturbed areas. Because natural streams and aquatic communities have the capability to assimilate some level of anthropogenic nutrient input without suffering designated use impairment, NOECs would be higher than reference levels.

Clark et al. (2000) summarized nutrient concentration data from 85 streams draining "relatively undeveloped" basins across the US derived from three US Geological Survey (USGS) programs: Hydrologic Benchmark Network (HBN), the National Water-Quality Assessment (NAWQA), and the Research Program. In addition to sites listed in Table 2, several other sites in Virginia and nearby states were tallied with incomplete data or from coastal areas. Clark et al. (2000) noted that total N exceeded 1 mg/L in only four of the 85 undeveloped basins, and that total P exceeded 0.1 mg/L also in only four of the undeveloped basins nationally.

Smith et al. (2003) used data from USGS reference sites to develop empirical models for predicting background concentrations of nutrients within ecoregions for the conterminous United States. Because their underlying dataset exhibited overlap with the dataset described by Clark et al. (2000), it is not surprising that the Smith et al. (2003) background levels are within the range of levels tallied by Clark et al. (2000). Smith et al. (2003) emphasized the variability of their estimated background concentrations, stating that "the range of background nutrient concentrations is very large within some nutrient ecoregions." In light of that variability, Smith et al. (2003) presented ecoregion-specific reference concentrations box-plot distributions in the published work and 75th percentiles (as opposed to means or medians) within the published article's supplementary data. The background concentrations reported for N were of two types: One set based on models that incorporate effects of atmospheric deposition, and another set generated by setting model parameters to eliminate anthropogenic atmospheric deposition effects; the data presentation of Table 2 lists concentrations generated "with" anthropogenic atmospheric deposition effects.

Stevenson et al. (2008) analyzed relationships of algal community structure to total P levels in streams of the Mid-Atlantic Highlands using data from the US EPA Environmental Monitoring and Assessment Program (EMAP). Using land-use data from the EMAP database, they identified reference sites and characterized total P at those reference sites (Table 2).

Denver et al. (2010) compiled groundwater and surface water data collected in the Piedmont, Blue Ridge, and Valley and Ridge physiographic provinces, extending from New York through Virginia to Alabama. These authors described background concentrations of dissolved P for groundwaters within "natural" settings, and they used these concentrations for models that linked

groundwater and surface water concentrations. The study, however, did not describe "natural setting" background concentrations for surface waters.

Single Thresholds

Table 3 summarizes studies describing thresholds as single numeric values for nutrient-concentration effects. A number of different approaches have been applied, and a wide range of potential thresholds have been derived as a result.

Dodds et al. (2002) analyzed data for relationships of benthic chlorophyll to nutrient concentrations from temperate regions of the US and found that about 40% of benthic chlorophyll variability was explained by concentrations of total N and total P; effect-level thresholds were derived using breakpoint regression. The authors offer "…that there is little probability of low benthic algal chlorophyll above the breakpoint value for TN or TP. If TN or TP is below the breakpoint, there is more likely to be low chlorophyll (but not in all cases)."

Ponader et al. (2007) cited their unpublished report that links nutrient thresholds to benthic chlorophyll levels.

Rier and Stevenson (2006) conducted studies in streamside mesocosms that found nutrient-concentration thresholds for algal biomass growth. At concentrations below the thresholds, algal growth rates tended to increase with nutrient concentrations; at concentrations above the thresholds, algal growth rates were roughly asymptotic to an apparent maximum. The authors did not propose these concentrations as in-stream nutrient criteria levels.

Stevenson et al. (2008) analyzed EMAP data from the Mid-Atlantic Highlands to characterize the response of algal community composition metrics to total P concentrations. The authors found response thresholds for various metrics occurring within the range of 10 to 20 µg/L (0.010 to 0.020 mg/L), which is close to reference levels. Hence, they suggested a reference level of total P (10 – 12 µg/L) as a potential criterion that would "constrain productivity to natural levels, maintain resource constraints on species membership, and prevent proliferation of invasive algae …." These authors also noted, however, that "Protection of all [Mid-Atlantic Highland] streams with a TP criterion of 10 to 12 µg/L probably is not practical" and suggested a criterion in the range of 30 to 60 µg/L total P could be "protective of 'fish, shellfish, and wildlife' that would correspond to the lower, interim goal of the US Clean Water Act." We interpret the latter phrase as referring to designated use, with biological integrity referenced implicitly as a "higher" goal although this was not stated explicitly by the authors.

Miltner and Rankin (1998) studied relationships of fish-community metrics to nutrient concentrations in low-order streams throughout Ohio. These authors noted that a "deleterious effect … on fish communities in low-order streams was detectable when nutrient concentrations exceeded background conditions."

Sheeder and Evans (2004) and Morgan et al. (2007) analyzed relationships of in-stream nutrient levels to streams' impairment status, with such status defined using biotic indices applied to water-quality assessment by state agencies in Pennsylvania and Maryland, respectively. Both studies were conducted using agency water-monitoring databases.

Lemly (1998) noted that visible bacterial growth occurs on the bodies of aquatic insects at certain nutrient levels; that the presence of such bacterial growth was highly correlated with reduced insect density; and that induced bacterial growth of this type in the laboratory commonly resulted in insect mortality.

Dual-threshold Studies

Stevenson et al. (2006) studied relationships of algal biomass to in-stream nutrient concentrations in north-central Kentucky, southeastern Indiana, and Michigan. Their dataset included 104 streams sampled repeatedly over a 2-month period. They found that total N and total P explained similar amounts of variation in algal biomass and that soluble nutrient measures were also explanatory. They did not find thresholds for algal-nutrient relationships, as algal biomass responded to nutrient concentrations throughout the measured ranges. Hence, they set a lower threshold based on reference conditions. The data indicated *Cladophora* to be more responsive to nutrient concentrations than diatoms, especially at higher nutrient concentrations; hence, they described upper nutrient-concentration thresholds intended to limit the probability of nuisance *Cladophora* growth.

Ponader et al. (2007) evaluated relationships between benthic diatom community structure and nutrient concentrations in 101 non-coastal, northern New Jersey streams and rivers. Multivariate analysis showed relationships of community structure metrics with nutrient concentrations. They defined diatom community types that corresponded with measured nutrient levels: three community types for total N and four types for total P. The effect levels described by these authors are concentrations that separate the highest- and lowest-concentration community types from community types that are characteristic of mid-range nutrient concentrations.

Smith et al. (2007) also analyzed community structure response to in-stream nutrient concentrations but with benthic macroinvertebrates. Their dataset was comprised of 129 samples obtained over a 10-year period from New York state streams by the state agency. Each sample had both water chemistry and benthic macroinvertebrate data. The authors used multivariate analyses to define Nutrient Biotic Indices (NBIs) for both nitrate-N and total P. One NBI development step was to determine each taxon's nutrient tolerance by analyzing its occurrence in streams of varying nutrient levels. Then, NBI scores were calculated for individual samples as a function of taxonomic tolerances and abundances. Sample NBI scores were highly correlated with nutrient concentrations, which is not surprising given the method of development. Multivariate analyses were conducted to separate sample communities into three groups: oligotrophic, mesotrophic, and eutrophic. Nutrient thresholds were defined at the oligotrophic-mesotrophic, and mesotrophic-eutrophic boundaries.

Summary and Analysis

Collectively, the reference-level studies (Table 2) suggest reference or background water-quality levels in the range of 0.2 to 0.4 mg/L for total N and 0.02 to 0.04 mg/L for total P for the Mountain and Piedmont ecoregions of Virginia. The studies can be interpreted to suggest lower reference levels for total P in the Mountains than in the Piedmont, but no similar differences are

apparent from these data for total N. The reference levels are generally lower than the potential NOEC values of Table 1 but not by much.

It is difficult to derive solid conclusions from the single-threshold studies (Table 3) given the range of metrics studied and parameters reported. To aid interpretation, we can note that nitrate and oxidized N are commonly about half, on average, of total N in Virginia streams; however, this ratio can vary widely among streams and seasons. In Virginia streams at baseflow, measured levels of soluble P forms are commonly close to measured levels for total P; however, that rough equivalence dissipates with increased streamflow and suspended sediment concentration. Although these two "rules of thumb" are imperfect at best, they can be used to view the results of various reported studies in an integrated fashion. With that perspective, it can be concluded that most of the reported effect-level thresholds occur within the ranges that are bounded by potential NOECs and OECs of Table 1. Exceptions for streams on the low side for nitrogen include the studies by Dodds et al. (2002), which monitored streams from a geographic region that encompasses Virginia but is much larger, and the unpublished study cited by Ponader et al. (2007); the thresholds cited by these two studies were derived from analysis of algal biomass. Phosphorus thresholds from stream studies that are less than the potential NOEC values of Table 1 include the effect-level defined by Stevenson et al. (2008), which was derived from analysis of algal community composition.

Most of the dual-threshold pairs (Table 4) occur at lower concentrations than corresponding NOEC-OEC pairs (Table 1). Upper threshold versus OEC differences are especially pronounced.

Table 1. Potential screening levels for Virginia nutrient criteria development (AAC 2012a and 2012b).

Type	Nutrient	Ecoregion	Concentration	Method of Derivation
NOEC	Total N	Combined (9, 11)	≤ 0.6 mg/L	90th %tile of reference distribution, rounded
NOEC	Total N	Piedmont (9)	≤ 0.6 mg/L	90th %tile of reference distribution, rounded
NOEC	Total N	Mountains (11)	≤ 0.6 mg/L	90th %tile of reference distribution, rounded
NOEC	Total P	Combined (9, 11)	≤ 0.04 mg/L	90th %tile of reference distribution, rounded
NOEC	Total P	Piedmont (9)	≤ 0.06 mg/L	90th %tile of reference distribution, rounded
NOEC	Total P	Mountains (11)	< 0.03 mg /L	90th %tile of reference distribution, rounded
OEC	Total N	Combined (9, 11)	>2.6 mg/L	Conditional probability, 6 month data, visual
OEC	Total N	Piedmont (9)	≥1.8 mg/L	Conditional probability, 12 month data, visual
OEC	Total N	Mountains (11)	≥3.2 mg/L	Conditional probability, 6 month data, visual
OEC	Total P	Combined (9, 11)	>0.15 mg/L	Conditional probability, 12 month data, visual
OEC	Total P	Piedmont (9)	≥0.15 mg/L	Conditional probability, 12 month data, visual
OEC	Total P	Mountains (11)	≥0.26 mg/L	Conditional probability, 6 month data, visual

Table 2. Reference nutrient concentrations from Virginia and nearby states.

Parameter	Concentra-tion (mg/L)	Location	Notes on concentration	Citation
Total N	0.16	Little R, TN (Mountains, east TN)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total N	0.21	Holiday Creek, VA (center of state)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total N	0.28	Ecoregion 9, 1st order streams	Upper quartile (75th %tile), natural background, empirical models	Smith et al. 2003
Total N	0.29	Ecoregion 11, 1st order streams	Upper quartile (75th %tile), natural background, empirical models	Smith et al. 2003
Total N	0.335	Young Woman Creek, PA (north central PA)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total N	0.38	Cataloochee Creek, NC (mountains)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total N	1.11	S. Fork Potomac R., WV	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	0.010 - 0.012	Mid-Atlantic Highlands (southern NY to NC)	No evidence of stressors from mining, agriculture, and urban development	Stevenson et al. 2008
Total P	0.02	Ecoregion 11, 1st order streams	Upper quartile (75th %tile), natural background, empirical models	Smith et al. 2003
Total P	<0.03	Young Woman Creek, PA (north central PA)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	<0.03	Cataloochee Creek, NC	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	<0.03	Little R, TN (Mountains, east TN)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	0.031	Holiday Creek, VA (center of state)	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	0.037	S. Fork Potomac R., WV	Flow-weighted mean, undeveloped basin	Clark et al. 2000
Total P	0.05	Ecoregion 9, 1st order streams	Upper quartile (75th %tile), natural background, empirical models	Smith et al. 2003
Diss. P	<0.01	Carbonate rock aquifers, "natural settings" in Piedmont - Blue Ridge - Ridge & Valley, eastern US.	Groundwater concentrations, mean	Denver et al. 2010
Diss. P	0.018	Siliciclastic rock aquifers, "natural settings" in Piedmont - Blue Ridge - Ridge & Valley, eastern US.	Groundwater concentrations, mean	Denver et al. 2010
Diss. P	0.029	Crystalline rock aquifers, "natural settings" in Piedmont - Blue Ridge - Ridge & Valley, eastern US.	Groundwater concentrations, mean	Denver et al. 2010

Table 3. Single-threshold nutrient effect levels defined by peer-reviewed studies.

Parameter	Concentra-tion (mg/L)	Location	Effect Noted	Citation
Total N	0.04	Temperate US streams	At greater concentrations, mean chlorophyll values (indicating algal biomass) were substantially higher.	Dodds et al. 2002
Total N	2.01	Pennsylvania	Midpoint between impaired and non-impaired watersheds, with biological impairments determined with standard state practices.	Sheeder and Evans 2004
Total In-organic N	0.61	Ohio, low order streams	At higher concentrations, "deleterious effect … on fish communities … was detectable."	Miltner and Rankin 1998
Diss. In-organic N	0.086	KY, near Louisville	Algal growth in streamside mesocosms was 90% of maximum rates or higher in nutrient concentrations.	Rier and Stevenson 2006
Nitrate N	>0.2	NJ Piedmont	Higher levels can lead to nuisance algal biomass (Chl.-a > 100 mg/m^2)	Ponader et al. 2007 †
Nitrate N	0.83	Maryland, urban streams	"critical thresholds between fair and poor stream quality" - benthic macroinvertebrates.	Morgan et al. 2007
Nitrate N	0.86	Maryland, urban streams	"critical thresholds between fair and poor stream quality" – fish.	Morgan et al. 2007
Nitrate N	≥1.35	Highland County, VA	Lower bound of concentration range where bacterial growth on stream insects is likely.	Lemly 1998
Total P	0.01 - 0.02	Mid-Atlantic Highlands (southern NY to NC)	Change in algae/diatom composition noted when concentration exceeds these levels. Authors suggest 0.010-0.012 mg/L TP as protective.	Stevenson et al. 2008
Total P	0.03	Temperate US streams	At greater concentrations, mean chlorophyll values (indicating algal biomass) were substantially higher.	Dodds et al. 2002
Total P	>0.05	NJ Piedmont	Higher levels can lead to nuisance algal biomass (Chl.-a > 100 mg/ m^2)	Ponader et al. 2007 †
Total P	0.06	Ohio, low order streams	At higher concentrations, "deleterious effect … on fish communities … was detectable."	Miltner and Rankin 1998
Total P	0.07	Pennsylvania	Midpoint between impaired and non-impaired watersheds, with biological impairments determined with standard state practices.	Sheeder and Evans 2004
Ortho P	≥0.13	Highland County, VA	Lower bound of concentration range where bacterial growth on stream insects is likely.	Lemly 1998
Soluble Reactive P	0.016	KY, near Louisville	Algal growth in streamside mesocosms was 90% of maximum rates or higher in nutrient concentrations.	Rier and Stevenson 2006

† Threshold cited with reference to an unpublished report.

Table 4. Dual threshold studies.

Parameter	Concentra-tion (mg/L)	Location	Effect Noted	Citation
Total N	≤0.4	North-central KY, southern IN, and MI	Streams in both MI and KY/IN with the lowest levels of human disturbance in watersheds.	Stevenson et al. 2006
Total N	≤1	North-central KY, southern IN, and MI	Target to prevent a high probability of nuisance accrual of *Cladophora*.	Stevenson et al. 2006
Total N	<0.7	Northern NJ	Diatom community is characteristic of low nutrient conditions.	Ponader et al. 2007
Total N	>1.5	Northern NJ	Diatom community is characteristic of high nutrient conditions.	Ponader et al. 2007
Nitrate N†	0.24	NY state	Benthic macroinvertebrate communities are differentiated (termed as "oligotrophic-mesotrophic boundary").	Smith et al. 2007
Nitrate N†	0.98	NY state	At concentrations above this level, benthic macroinvertebrates are likely to be characteristic of eutrophic conditions, termed by authors as "impaired" although status does not correspond directly with status as defined by NY State multimetric index.	Smith et al. 2007
Total P	≤0.011	North-central KY, southern IN, and MI	Streams in both MI and KY/IN with the lowest levels of human disturbance in watersheds.	Stevenson et al. 2006
Total P	≤0.03	North-central KY, southern IN, and MI	Target to prevent a high probability of nuisance accrual of *Cladophora*.	Stevenson et al. 2006
Total P	0.0175	NY state	Benthic macroinvertebrate communities are differentiated (termed as "oligotrophic-mesotrophic boundary").	Smith et al. 2007
Total P	0.065	NY state	At concentrations above this level, benthic macroinvertebrates are likely to be characteristic of eutrophic conditions, termed by authors as "impaired" although status does not correspond directly with status as defined by NY State multimetric index.	Smith et al. 2007
Total P	<0.025	Northern NJ	Diatom community is characteristic of low nutrient conditions.	Ponader et al. 2007
Total P	>0.1	Northern NJ	Diatom community is characteristic of high nutrient conditions.	Ponader et al. 2007

†Stated as $NO3^-$ by authors, but close inspection of text [comparison to EPA guidance nutrient criteria] indicates this is measure is expressed as N.

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Appendix B: Review and Summary of TMDL Studies Relevant to Development of Virginia Nutrient Criteria

This summary was conducted by reviewing approved TMDL reports (and two TMDL reports in draft form) available from individual state or EPA's web sites. Whereas the list of reviewed TMDL studies includes all of the published reports for Virginia (as of April 29, 2014), it is not comprehensive for the states of Maryland and Pennsylvania, but it is representative of the most recently published TMDL reports on nutrients in those states. One TMDL study from Delaware was included, as it was referenced in a Maryland study on the downstream portion of the Upper Pocomoke River. None of the states cited have numeric nutrient criteria or standards for rivers and streams. Whereas these studies focus primarily on non-tidal waters, a few of the rivers and streams are tidal, and others are a combination of tidal and non-tidal reaches.

The attached summary table shows information on each of the watersheds in these studies for which TMDLs were developed, either directly or indirectly, for nutrients. Not all of the summary table fields are completed because the review was an iterative process. Fields were included when identified as useful distinctions.

There are differences in the listing information that make comparison between the reports from the different states difficult. Some of these nuances are evident in the table.

TMDLs are always written in terms of loads. Sometimes the target nutrient TMDL loads are simulated directly based on one or more reference watersheds or are set by a concentration from a reference stream. In other studies, nutrient TMDL targets result from iterative simulated reductions to dissolved oxygen (DO), drinking water quality standards, chlorophyll-a, or Trophic State Index (TSI) thresholds. In these latter studies, where a concentration endpoint is identified, it represents a long-term average annual concentration that is back-calculated from simulated load and flow over some period of time.

Virginia has used a variety of approaches in the TMDLs that have used nitrogen or phosphorus either as interim measures or endpoints.

In its most recent TMDL reports, Maryland has relied on the latest Chesapeake Bay Watershed Model (Phase 5.3.2) simulated loads along with a method they developed based on an all-forest normalized load, which was used to set the target TMDL total phosphorus (TP) load for the impaired watershed (MDE 2006, 2009). This method uses the median all-forest normalized load from a group of twelve reference watersheds to set the TMDL target load. No instances of total nitrogen (TN) target loads were found using this newer method.

Pennsylvania has generally relied on the AVGWLF (ArcView Generalized Watershed Loading Function) model and a single reference watershed with the Reference Watershed Approach (RWA) used for setting the target pollutant load. No instances of TN target loads were found for TMDLs in Pennsylvania.

In situations where DO impairments were involved, generally both TN and TP targets were identified in the process of achieving the DO-concentration standard, and the TMDL reports

were written in terms of TN and TP loads. Where nutrients were cited as the impairment but DO was not an issue, the argument was frequently made that TP was the limiting nutrient, and the "nutrient" TMDL was developed solely for TP. In the case of the TMDL for the Chickahominy River unnamed tributary (UT) where DO was a concern, TP was selected as the basis for the TMDL: "The impairment listing and stressor analysis identifies excess phosphorus as the primary cause of biological impairment in the UT Chickahominy. The technical approach used to develop TMDLs for the impaired stream was based on identifying the acceptable nutrient (phosphorus) levels that will lead to a reduction in eutrophic conditions in the UT Chickahominy and the downstream pond, specifically…. Nutrient ratios suggest that the pond may be somewhat more nitrogen limited than phosphorus limited. However, this analysis focuses on phosphorus for the following reasons:

1. Phosphorus is usually easier to control and, if the ratios are fairly close, the lake will become phosphorus limited as phosphorus is removed.
2. If waterbodies are close to phosphorus limitation they have been shown to follow generally the P loading models such as the one used here.
3. Empirical eutrophication prediction models for P loading are much more well-developed and accepted than models for N loading.
4. The pond is nitrogen limited because the phosphorus concentrations are so high."

In the Susquehanna River TMDLs where DO was linked to point sources, TP concentrations from the point sources were reduced until the DO endpoint was met. The TP concentrations that resulted from meeting the DO criteria were used to calculate the TP TMDL loads. The interim TP concentration values for these point-source TMDLs were 0.337 and 0.257 mg/L and were considerably higher than the range of other TP concentration endpoints.

Virginia has an established nitrate-N drinking water numeric concentration criterion of 10 mg/L that was applied as in-stream target in two of the earlier Shenandoah basin TMDLs. Otherwise, TN endpoint concentrations ranged from 0.71 to 3.00 mg/L (n=2). TP endpoint concentrations, excluding the point source dominated TMDLs, ranged from 0.03 to 0.20 mg/L (n = 8; average = 0.076 mg/L; median = 0.062 mg/L).

In reviewing the TMDL studies, reference was made to two EPA studies conducted in cooperation with Pennsylvania Department of Environmental Protection (PaDEP) that developed nutrient criteria for specific physiographic regions in Pennsylvania. These studies appeared to be a refinement of earlier EPA region-specific nutrient criteria documents. The two recent EPA studies used a weight-of-evidence approach based on a combination of percentiles of observed ranges, simulated ranges, and literature review values specific to these areas. The resulting recommended values are included at the bottom of the table, along with recommended values from another published study from Pennsylvania. The Pennsylvania-specific EPA criterion was used in the Goose Creek study, but the Sheeder and Evans recommendations have not been referenced directly in any of the reviewed Pennsylvania TMDLs (to the best of our knowledge).

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Web Sites

Delaware Upper Pocomoke Nutrient TMDL: http://www.dnrec.delaware.gov/swc/wa/Documents/TMDL_TechnicalAnalysisDocuments/18_PocomokeTMDLAnalysis.pdf

Maryland Approved TMDLs Web Site: http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/programs/waterprograms/tmdl/approvedfinaltmdl/index.aspx

Pennsylvania Approved TMDLs Web Site: http://www.epa.gov/reg3wapd/tmdl/pa_tmdl/?delaware%20river/index.htm

Virginia Approved TMDLs Web Site: http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/TMDL/TMDLDevelopment/ApprovedTMDLReports.aspx

Nutrient TMDL Endpoint Summary										
State	Waterbody/Source	Basin	Approval Date	Approach	Model	Pollutant Modeling				Impairment/Comments
						Load or Conc.	Parameter	Value (mg/L)	Endpoint or Interim Measure	
VA	Pitts Creek, UT	Ches. Bay	4/28/2009		LSPC/EFDC	conc.	TN	0.71		DO issue; EPA recommended natural background levels
VA	Pitts Creek, UT	Ches. Bay	4/28/2009		LSPC/EFDC	conc.	TP	0.03		DO issue; EPA recommended natural background levels
VA	Albemarle Canal/ North Landing River	Chowan	6/25/2012	RWA		load	TP			Low DO
VA	Northwest River	Chowan	6/25/2012	RWA		load	TP			Low DO
VA	Spring Branch	Chowan	9/7/2006	TSI=60		conc.	TP	0.0481		Benthic
VA	Chickahominy River, UT	Lower James	3/15/2005		BasinSim (GWLF)	load	Phos.			Benthic - ALU; Reckhow model
VA	South Run	Potomac	3/9/2007	RWA		load	TP			ALU
VA	Upper Blackwater River	Roanoke	8/31/2004	RWA	BasinSim (GWLF)	load	Phos.			ALU
VA	Cooks Creek/Black Run	Shenandoah	3/23/2004	RWA		load	Phos.			ALU
VA	Mill Creek/Pleasant Run	Shenandoah	3/23/2004	RWA		load	Phos.		Endpoint	ALU
VA	Muddy & Holmans Creeks	Shenandoah	3/23/2004	RWA		load	Phos.		Endpoint	ALU
VA	SF Shenandoah River	Shenandoah	9/30/2010	RWA/LDC		load	TP		Endpoint	ALU
VA	South River	Shenandoah	12/9/2010	RWA/LDC		load	Phos.		Endpoint	ALU
VA	Parker Creek	Coastal	4/27/2009	ref. stream		conc.	TP	0.1		ALU
VA	Pettit Branch	Coastal	12/9/2010	RWA		load	TP		Endpoint	ALU
VA	Jackson River	Upper James	12/9/2010		WASP 7.2	conc.	PO4-P	0.038		ALU, DO; periphyton linked to nutrients, TP ≈ 0.063 mg/L
VA	Jackson River	Upper James	12/9/2010		WASP 7.2	conc.	TN			ALU, DO
VA	Folly Creek	Ches. Bay	3/25/2013		LSPC/EFDC	load	TN		Endpoint	ALU linked to DO
VA	Gargathy Creek	Ches. Bay	3/25/2013			load	TN		Endpoint	ALU linked to DO
VA	Mill Creek	Small Coastal	12/9/2010			load	TN		Endpoint	ALU linked to DO
VA	Muddy Creek	Shenandoah	3/23/2004			conc.	Nitrate-N	10	Endpoint	Nitrate
VA	North River & Dry River	Shenandoah	3/23/2004			conc.	Nitrate-N	10	Endpoint	Nitrate
VA	North Creek	James	Draft	ref. stream	GWLF	conc.	TP	0.06	Interim	Lowest measured TP value at a non-impaired downstream section of North Creek
VA	Little Otter River	Roanoke	Draft	ref. stream	GWLF	conc.	TP	0.07	Interim	ALU/ WWTP-dominated
DE	Upper Pocomoke River	Pocomoke	12/1/2005		QUAL2K	conc.	TN	3.0		Nutrients, DO; concentration set as target in lieu of numeric criteria
DE	Upper Pocomoke River	Pocomoke	12/1/2005		QUAL2K	conc.	TP	0.2		Nutrients, DO; concentration set as target in lieu of numeric criteria
MD	Mattawoman Creek	Potomac	11/1/2006		WASP 5.1	load	TN		Endpoint	ALU linked to DO and Chl.-a
MD	Mattawoman Creek	Potomac	11/1/2006		WASP 5.1	load	TP		Endpoint	ALU linked to DO and Chl.-a
MD	Upper & Middle Chester River	Chester	11/1/2006		CBWM 4.3/CE-QUAL-ICM/CH3D	load	TN		Endpoint	ALU linked to DO and Chl.-a; tidal influence

State	Waterbody/Source	Basin	Approval Date	Approach	Model	Pollutant Modeling				Impairment/Comments
						Load or Conc.	Parameter	Value (mg/L)	Endpoint or Interim Measure	
MD	Upper & Middle Chester River	Chester	11/1/2006		CBWM 4.3/CE-QUAL-ICM/CH3D	load	TP		Endpoint	ALU linked to DO and Chl.-a; tidal influence
MD	Antietam Creek	Potomac	9/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	Nutrients, impacts to biological communities; see Note 1
MD	Catoctin Creek	Potomac	9/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	See Note 1
MD	Rock Creek	Potomac	9/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	Nutrients, impacts to biological communities; see Note 1
MD	Upper Pocomoke River	Pocomoke	9/1/2013		CBWM P5.3.2 / EFDC	load	TP		Endpoint	Nutrients, impacts to biological communities; ALU linked to DO and Chl.-a impacts
MD	Lower Monacacy River	Potomac	5/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	See Note 1
MD	Upper Monacacy River	Potomac	5/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	See Note 1
MD	Double-Pipe Creek	Potomac	4/1/2013	MDE	CBWM P5.3.2	load	TP		Endpoint	See Note 1
PA	Anderson Creek	Susquehanna	7/1/2006	RWA	AVGWLF	load	TP		Endpoint	Nutrients, sediment; no DO impacts
PA	Deep Run & Elizabeth Run	Susquehanna	8/1/2004		AVGWLF/QUAL2K	conc.	TP	0.337	Interim	Nutrients, ALU linked to DO; point source dominated loads
PA	Beach Run	Susquehanna	8/1/2004		AVGWLF/QUAL2K	conc.	TP	0.257	Interim	Nutrients; ALU linked to DO; point source dominated loads
PA	Goose Creek	Delaware River	6/1/2008	WOE	BasinSim/WASP 7.2	conc.	TP	0.04		ALU linked to organic and nutrient enrichment; Apr-Oct average, EPA 2007
PA	Stoneycreek River	Conemaugh	8/1/2004	RWA	AVGWLF	load	TP		Endpoint	Nutrients, suspended solids; no DO impacts
PA	Conestoga Headwaters	Susquehanna	8/1/2004	RWA	AVGWLF	load	TP		Endpoint	Nutrients, organic enrichment, DO
PA	Buffalo Creek tributaries	Susquehanna	8/1/2011	RWA	AVGWLF	load	TP		Endpoint	Nutrients, siltation; no DO impacts
PA	Hunters Creek	Juniata	5/1/2012	RWA	GWLF-E (Revised AVGWLF)	load	TP		Endpoint	Nutrients, siltation, ALU; no DO impacts
PA	Little Swatara Creek	Swatara Creek	5/1/2011	RWA	AVGWLF	load	TP		Endpoint	Suspended solids, organic enrichment, nutrients/ALU with DO impacts, but DO was not addressed directly in this TMDL
PA	Allegheny Plateau and Ridge and Valley					conc.	TP	0.035		EPA 2008
PA	Piedmont					conc.	TP	0.04		Apr-Oct average; EPA 2007
PA						conc.	TN	2.01		Sheeder and Evans 2004
PA						conc.	TP	0.07		Sheeder and Evans 2004

Waterbody/Source: UT = unnamed tributary; **Basin**: As listed on state TMDL website; **Approach:** LDC = load duration curve, MDE = Maryland Department of the Environment (all-forest normalized load, based on 12 reference watersheds), RWA = Reference Watershed Approach, TSI = Trophic State Index, WOE = Weight-of-Evidence (weighted average of percentiles of observed ranges, simulated ranges, and literature review values); **Models:** AVGWLF = ArcView GWLF, CBWM = Chesapeake Bay Watershed Model (P5.3.2 = Phase 5.3.2), CH3D = Curvilinear-grid Hydrodynamics Three-dimensional, EFDC = Environmental Fluid Dynamics Code, GWLF = Generalized Watershed Loading Functions, LSPC = Loading Simulation Program in C++, WASP = Water Quality Analysis Simulation Program; **Load or Conc.:** Conc. = concentration; **Parameter:** Phos. = phosphorus, PO4-P = phosphate-phosphorus, TN = total nitrogen, TP = total phosphorus; **Impairment/Comments:** ALU = aquatic-life use, Chl.-a = chlorophyll-a, DO = dissolved oxygen; **Note 1:** DO meeting criteria; impairment related to primary production and possible diurnal fluctuations. Phosphorus loading threshold based on 12 reference, non-impaired watersheds using the MDE all-forest normalized load approach.