Report of the Academic Advisory Committee: Developing Freshwater Nutrient Criteria for Virginia's Streams and Rivers

Fiscal Year 2010 Activity Report

Submitted to

Division of Water Quality Programs
Virginia Department of Environmental Quality

Submitted by

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Summary

Goals and Objectives

The overall goal of the Academic Advisory Committee (AAC) is to provide assistance to Virginia DEQ in developing a scientifically sound and workable approach to nutrient criteria in freshwater streams and rivers. The major objective of the AAC FY10 activities was to continue and build on previous AAC studies conducted during fiscal years 2006 - 2009 on developing freshwater nutrient criteria for Virginia's wadeable and non-wadeable freshwater streams.

The specific objectives for FY10 AAC activities are documented below.

Wadeable Streams

The objectives are to further develop the nutrient criteria screening value approach, including the definition of screening values and analysis of potential effects of nutrient criteria implementation on DEQ water monitoring resources if the Screening Value approach is to be used.

Non-Wadeable Streams

The objectives are to explore documented differences between responses of coastal *versus* non-coastal stream fish assemblages to nutrient and trophic status to evaluate whether or not the geographic differentiation warrants separate nutrient criteria for coastal versus non- coastal streams and rivers, and to expand the limited, existing paired database for non-wadeable streams and rivers through additional data mining and GIS analysis.

Downstream Loading Impacts of Nutrients

The objective was to explore potential and/or develop a rationale for defining critical values for TN and TP that considers and is intended to mitigate the "downstream loading" impacts of nutrients transported by Virginia streams to nutrient-sensitive receiving waters (Chesapeake Bay, Albemarle Sound, Gulf of Mexico via Tennessee and Ohio rivers).

Report Contents

This report is a compilation of study results and three separate AAC progress reports that address three specific objectives noted above.

A Screening Approach to the Development of Nutrient Criteria and Impairment Assessment Methodology for Freshwater Wadeable Streams in the Mountains and Piedmont of Virginia

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1. Introduction

Under the Clean Water Act, criteria are components of water quality standards. The U.S. Code of Federal Regulations (CFR) defines criteria as “elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use” [40 CFR 131.3(b)]. The EPA requires that all states develop criteria to protect waters from impairment by nutrient enrichment using scientifically defensible approaches that consider the effects of nutrients on designated use within the stream segment being assessed (localized effects) and on receiving water bodies located further downstream “downstream loading” effects) (US EPA 2000).

Nutrients (nitrogen and phosphorus), when present in surface water bodies at elevated concentrations, often act as water pollutants. Excess nutrients cause negative effects in surface water bodies nationwide. Recent US Environmental Protection Agency (EPA) reports to the Congress have indicated nutrients to be among the more prominent pollutants that are impairing freshwater rivers and streams nationwide (Table 1).

The Virginia Department of Environmental Quality (DEQ) enforces the Clean Water Act in Virginia under the US Environmental Protection Agency (EPA) oversight. The Virginia DEQ has requested its Water Quality Academic Advisory Committee (AAC) to advise and assist with development of nutrient criteria for freshwater rivers and streams in Virginia. This report documents AAC activities for 2009 - 2010 conducted collaboratively and cooperatively with DEQ for developing nutrient criteria for freshwater wadeable streams and rivers in the Mountain and Piedmont ecoregions of Virginia.

Background: Virginia's Nutrient Criteria Development Process

In Virginia, all state waters are designated to support aquatic life. Virginia water quality standards define the aquatic life designated use as "the propagation and growth of a balanced, indigenous population of aquatic life" (Virginia DEQ 2007). Like many other states and in accord with EPA guidance, Virginia has developed a biological monitoring procedure that employs benthic macroinvertebrates assessment to evaluate the suitability of freshwater streams and rivers for the aquatic life designated use (Tetra Tech 2003; Virginia DEQ 2006).

The AAC has recommended that nutrient criteria for freshwater wadeable streams be defined using a unique approach, termed as the "screening approach" (AAC, 2006). The AAC's recommended approach to nutrient criteria development involves the use of "observed-effect concentrations" and "no-observed-effect concentrations." Nutrient concentrations or indicators greater than observed-effect concentrations would be defined as impaired, while those concentrations less than no-observed-effect concentrations would be defined as not impaired. As shown in Figure 1, the screening approach employs a series of monitoring procedures to determine whether a water body can support the aquatic-life designated use due to nutrient concentrations.

The first stage of the screening approach is based on two sets of threshold N and P concentrations, using the available suite of N and P concentration data from existing ambient water monitoring stations:

- No-Observed-Effect Concentration(s): Streams with nutrient concentrations below the no-observed-effect concentration(s) are assessed as "not impaired by nutrients."
- Observed-Effect Concentration(s): Streams with nutrient concentrations above the observed-effect concentration(s) are assessed as "impaired."

The second stage of the screening approach is based on requirement for additional monitoring. Streams with nutrient concentrations that are not included in no-observed-effect or observed-effect concentrations thresholds will require additional monitoring procedures described below:

- Visual Assessment: Algal biomass, an indicator of nutrient impairment, is often visible to the naked eye. A visual assessment procedure would rely on the presence or absence of visible macrophytes and algae to assess the stream for nutrient impairment. As proposed by the AAC in light of its 2009 studies and findings, the visual assessment procedure can have two possible outcomes: impaired by nutrients or inconclusive.
- Benthic Macroinvertebrate Assessments: If the concentration threshold (stage one) approach and the visual assessment procedure are inconclusive, then a benthic macroinvertebrate assessment would be employed to assess the stream for nutrient impairment.

The AAC recommends the screening approach an alternative to traditional "fixed threshold" criteria because nutrient effects on aquatic systems differ in a fundamental manner from effects of traditional stressors. Whereas traditional stressors generally exert toxic influences at the organism level, nutrient overenrichment effects are systemic. Thus, variations among physical characteristics of river-and-stream systems affect those systems' responses to nutrient enrichment. As a result, biotic responses to nutrient enrichment at specific concentration levels are highly variable among river and stream systems.

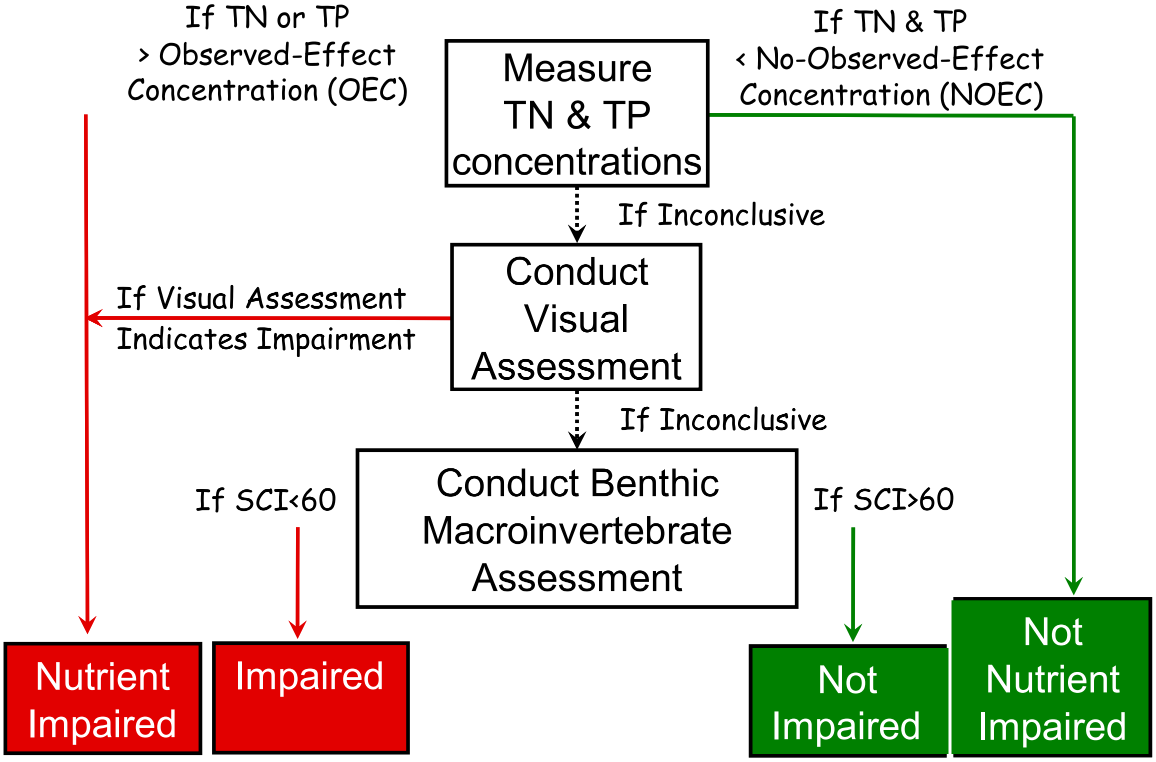


Figure 1. Proposed screening approach to the nutrient criteria and impairment assessment freshwater wadeable streams in the Mountains and Piedmont of Virginia.

		Actual Condition	
		Impaired	Not Impaired
Assessment Outcome:	Impaired	Correct Assessment (true positive)	Incorrect Assessment (false positive, type I error)
	Not Impaired	Incorrect Assessment, (false negative, type II error)	Correct Assessment (true negative)

Figure 2. Type I and Type II errors. The screening approach is being developed with the intention of limiting both Type I and Type II assessment errors.

The screening approach is applied with the intention of limiting assessment errors despite the inherent variability of aquatic systems' responses to nutrients. A secondary goal is to achieve resource efficiency in the DEQ expenditures that are necessary to meet Clean Water Act goals. The AAC has been consistent in recommending that DEQ develop nutrient criteria which limit assessment errors, in recognition of the costs that result from incorrect assessments (Figure 2). When non-impaired streams are incorrectly assessed as impaired (false positive assessment, Type I error), it triggers a TMDL study and using the Clean Water Act enforcement resources that could otherwise be applied elsewhere. False positive assessments can also affect investment decisions by regulated point sources discharging into that stream segment. When impaired streams are not assessed as impaired (Type II error, false negative), costs are borne by the public in the form of lost environmental services that result from failure of that water body to support designated use.

Application of the screening approach as a nutrient impairment assessment procedure requires consideration of tradeoffs, given the inherent variability of streams' responses to nutrient concentrations and the resulting uncertainty of assessment decisions based on fixed nutrient thresholds.

When applied together, the no-observed-effect and observed-effect concentrations define a range of nutrient concentrations for which additional monitoring and assessment resources must be expended for assessment (Inconclusive Nutrient Concentration Range – see Figure 3).

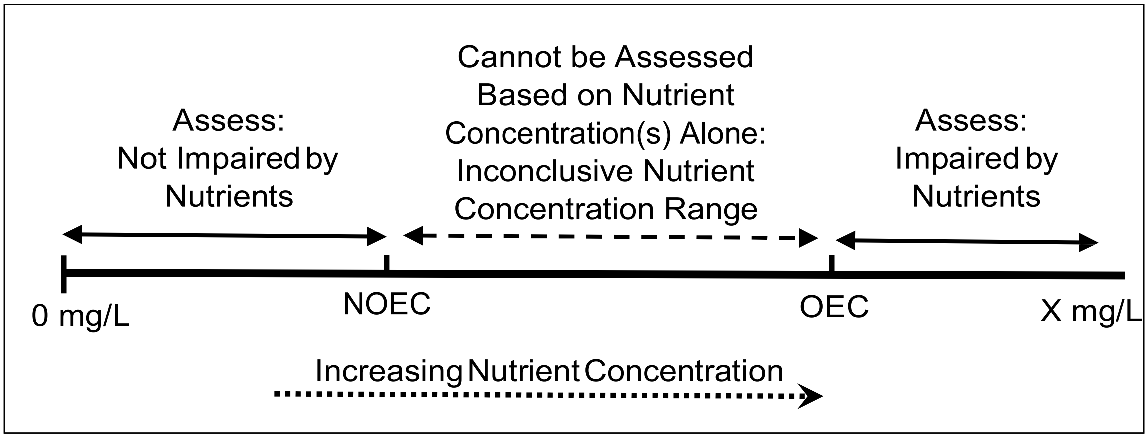


Figure 3. Graphic representation of nutrient concentration ranges defined by the screening approach to nutrient criteria, as recommended by the AAC. NOEC = No-observed-effect Concentration; OEC = Observed-effect Concentration.

A conservative approach to establishing these assessment thresholds – setting the no-observed-effect concentration at a relatively low, and the observed-effect concentration at a relatively high, concentration, with a broad distribution of nutrient concentrations within the "inconclusive" range – would result in a high rate of correct assessments, but at the cost of increasing the monitoring expenditures that must be borne by the Clean Water Act agency in order to complete the assessment process for "inconclusive" concentrations. Given resource limitations that constrain Virginia's DEQ, a taxpayer-supported public agency which must operate its water quality protection programs on limited funds allocated by the state legislature, an expansion of resource expenditures for water monitoring and assessment would be likely to require that the agency's other environmental protection services be reduced. The additional resource expenditures required for a visual assessment of streams that occur within the "inconclusive" concentration range would be relatively modest, but a visual assessment is expected to be adequate for only a fraction of the "inconclusive concentration range" streams; for the remaining streams a benthic macroinvertebrate assessment would be required; each benthic macroinvertebrate assessment requires an additional day of work by a DEQ regional biologist for sampling and analysis. This level of resource expenditure is considered as significant, given that DEQ employs a limited number of regional biologists and that these personnel have a range of responsibilities in addition to whatever additional responsibilities result from nutrient criteria implementation.

An alternative to the conservative approach to no-observed-effect and observed-effect concentration definition that is described above—setting the no-observed-effect concentration at a relatively high, and the observed-effect concentration at a relatively low, concentration, with a narrow inconclusive concentration range—could be expected to reduce agency monitoring expenses relative to the conservative approach, but this cost-savings would be accompanied by an increase in the error rate of no-observed-effect- and observed-effect-concentration assessments. Thus, the screening approach embodies essential trade-offs between public benefits, which require error limitation, and water-monitoring resource expenditures.

2010 Analyses

Three sets of analyses were conducted in 2010:

1. An exploratory derivation of illustrative no-observed-effect and observed-effect concentrations using DEQ Probablistic Monitoring data, applying a method that was described more fully in the 2009 AAC Report to DEQ but with an expanded dataset.
2. Analysis of visual assessment data collected by DEQ Biologists in Spring and Fall of 2009. The analysis is considered as "preliminary" because stream condition index (SCI) concentrations corresponding with all of the visual assessments were not available at the time when this analysis was performed (early March 2010).
3. A preliminary analysis to determine how application of the proposed nutrient impairment assessment procedure might affect DEQ monitoring resources. This analysis uses the illustrative no-observed-effect concentrations derived in Section 2 below.

2. Derive Illustrative No-Observed-Effect and Observed-Effect Concentrations from Reference Conditions

Screening Concentrations

As described earlier, the AAC's recommended approach to nutrient criteria development involves the use of "observed-effect concentrations" and "no-observed-effect concentrations." Nutrient concentrations or indicators greater than observed-effect concentrations would be defined as impaired, while those concentrations less than no-observed-effect concentrations would be defined as not impaired. A site sample with concentrations in between the observed-effect and no-observed-effect concentrations would be assessed, first using a visual assessment procedure to see if impairment is visually evident, and second via benthic macroinvertebrate assessment if the visual assessment results are not definitive (see Figure 1).

As a means of illustrating that approach, we provide the following example. "Observed-Effect Concentrations" and "No-observed-effect Concentrations" in the example are advanced for the purpose of illustrating a possible method for deriving these concentrations from existing datasets. The derived thresholds are intended for the purpose of stimulating discussion, since the sample pool may not represent the range of actual concentrations in the state, as they were obtained from a limited number of sampling sites and conditions. This analysis follows a similar analysis performed and reported by the AAC in 2009, but with an expanded dataset.

This analysis was conducted using DEQ's probabilistic monitoring dataset, 2001-2008, Mountain and Piedmont ecoregions only. Most locations in this dataset are characterized by a single water-quality observation with a suite of laboratory analyses, and two field observations (spring and fall) that included benthic macroinvertebrate and habitat assessment, and field water-quality parameters (pH, conductivity, dissolved oxygen, temperature). Some sites are characterized only by a single field observation.

DEQ has used a set of criteria to define "reference conditions" (i.e. relatively undisturbed, exemplifying a desirable state) in various studies (Table 1), including those which were conducted to develop (Tetra Tech, 2003) and to validate (Virginia DEQ, 2006) the Stream Condition Index (SCI). Initial application of the DEQ reference conditions (Table 1) to the DEQ 2001-2008 Probmon dataset created a subset of those observations with >25% impairment rate (SCI<60), significantly greater than the ≤10% rate that we would consider to be ideal if the reference-filtering method were to be used for screening-concentration definition. As a result, additional reference-filter screens were derived empirically and applied, with the goal of reducing the impairment rate to 10% (Table 2). The result was a reference-filtered dataset comprised of 158 SCI observations at 84 locations (Figure 4). The goal of reducing impairments to ≤10% was not achieved, as 36 of the 158 of the reference-filtered SCIs (23%) were < 60. The 36 impairments included 12 observations with 57.5<SCI<60, meaning that 24 of 158 observations (15%) were SCI<57.5.

The 10th percentile of the SCI distribution at sites satisfying the reference filter conditions is SCI = 52. If DEQ and the AAC were to decide that OEC and NOEC concentrations would be developed with the intent of limiting false negative (Type II) assessment errors to 10 percent or less, the result of this exercise would have been more satisfactory if the 10th percentile for the Reference Sites were SCI=60 or above.

However, it is likely that both nutrient and non-nutrient stressors are responsible for the observed SCI<60 impairments at the reference-filter sites. If nutrients are a primary source of impairment within reference filtered dataset, then the nutrient screens of Tables 1 and 2 would not be appropriate as screening concentrations. If non-nutrient stressors were known to be a primary source of impairment, with nutrients responsible for impairments at fewer than 10% of the sites within the reference-filtered data sets, then it is possible that the nutrient screens of Tables 1 and 2 would be an appropriate basis for defining no-observed-effect concentrations.

We continued the analysis by examining probabilistic monitoring data for the reference-filtered sites with SCI<60 concentrations, seeking evidence that nutrients either were or were not a source of impairment, but those analyses were inconclusive (see Appendix A).

As a means of deriving potential no-observed-effect concentrations for use in subsequent analyses, the reference dataset was expanded by removing the nutrient filters (i.e., deleting the TN < 1 mg/L and TP < 0.05 mg/L requirements) while applying all other Table 1 and Table 2 reference filter conditions (Figure 5). For the sole purpose of continuing the current analysis, TN = 0.75 mg/L and TP = 0.04 mg/L were suggested as illustrative no-observed-effect concentrations. These concentrations were derived empirically and subjectively, considering the data plots of Figure 5??. The AAC is not suggesting that these or any concentrations be applied as no-observed-effect concentrations to implement nutrient criteria at the present time.

AAC and DEQ personnel familiar with the issue agree that it would be advisable for DEQ to obtain additional monitoring data for certain reference-filter sites for the purpose of determining if nutrient enrichment is contributing to the impairments. DEQ will also ask regional biologists to apply best professional judgment to these sites, for the purpose of identifying sites within the reference-filtered datasets with conditions that, in their judgment, would preclude the consideration of such sites as "reference sites" for use in this analysis. The presence of non-nutrient stressors that are not adequately represented by the Probmon data would be a basis for such determination.

Observed-Effect Concentrations

The method of analysis applied to derive illustrative observed-effect concentrations in 2009, using Probmon 2001-2006, was applied again in 2010 to the expanded dataset. Briefly, this analysis is based on the assumption that the probability of a site being impaired (SCI<60) increases with measured nutrient concentrations. The Probmon 2001-2008 dataset supports this assumption (Figure 6), as 90% of Probmon 2001-2008 sites with TN concentrations ≥ 2.0 mg/L, and 90% of Probmon 2001-2008 sites with TP concentrations ≥ 0.13 mg/L are impaired. Thus, these concentrations were selected as illustrative observed-effect concentrations for the purpose of conducting the analyses that follow.

Note that the illustrative observed-effect concentrations selected would allow only a small proportion of water monitoring sites to be assessed as "'impaired," if implemented within a nutrient criteria framework. Both the TN and the TP illustrative observed-effect concentrations occur at approximately the 95th percentile of the probabilistic monitoring data distribution (Figure 6).

As noted elsewhere in the 2010 AAC report to Virginia DEQ, the AAC is also investigating alternative methods for defining Observed-Effect Concentrations which consider downstream loading effects.

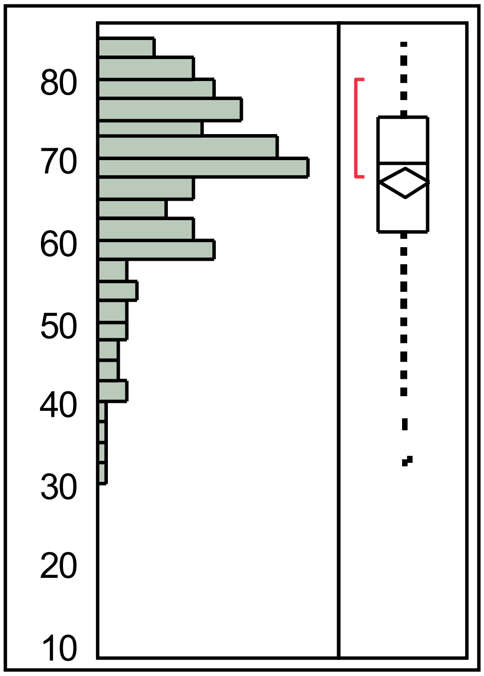
Table 1. Reference filters applied by DEQ (2006).

Parameter	Reference Filter
As Applied by DEQ (2006)	
% Urban *	< 5%
Total Nitrogen	< 1.5 mg/L
Total Phosphorus	< 0.05 mg/L
Specific Conductance ()	< 250 uS/cm
Dissolved Oxygen	> 6 mg/L
pH	> 6 and < 9
Channel Alteration	> 11
Embeddedness (Mountain Ecoregions only)	> 11
Epifaunal Substrate/Cover	> 11
Riparian Vegetative Zone	> 11
Total Habitat Score	> 140

* Preliminary urban land use data were used for this analysis.

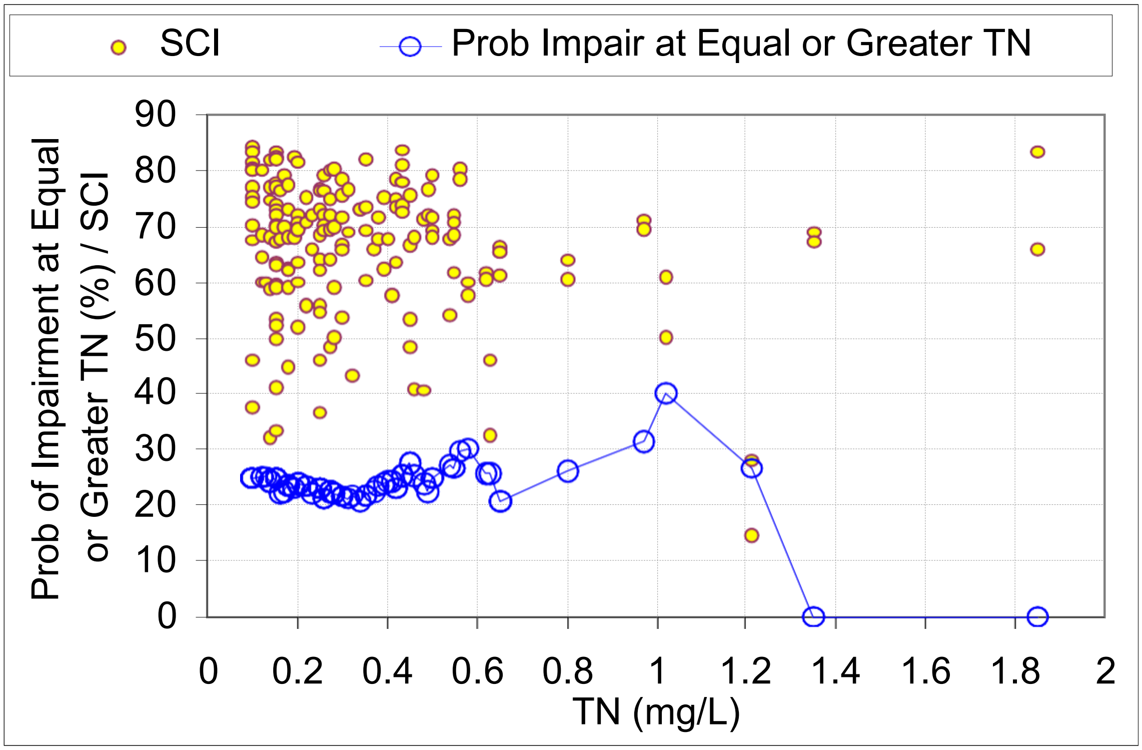
Table 2. Reference filter conditions applied by AAC on 2010 analyses

Condition	Comment
Reference filter conditions applied by DEQ (2006), except TN	See Table 1
Total Nitrogen < 1.0 mg/L	Upper limit re-defined based on empirical observation
Log [Relative Bed Stability] < -1.5	LRBS is a sedimentation indicator calculated for all recent Probmon sites. Threshold was derived empirically.
No Major Point Sources in Watershed	
No water column metals > Water Quality Criteria (WQC)	WQC are defined by Virginia Water Quality Standards, 9VAC25-260-140).
No sediment metals > Probable Effect Concentration (PEC) Values	PEC are Freshwater Consensus- Based Sediment Screening Values, as defined by App. F, DEQ Water Quality Assessment Manual.
No sediment organics > Probable Effect Concentration (PEC) Values).	PEC are Freshwater Consensus- Based Sediment Screening Values, as defined by App. F, DEQ Water Quality Assessment Manual.



Ref %tile	VSCI
0.0%	32.4
0.5%	32.4
2.5%	37.7
10.0%	52.0
25.0%	61.2
50.0%	69.6
75.0%	75.4
90.0%	80.1
97.5%	83.2
99.5%	84.1
100.0%	84.1

Figure 4. Distribution of SCI within the probablisitic monitoring locations defined through application of the reference-filter conditions of Table 2.



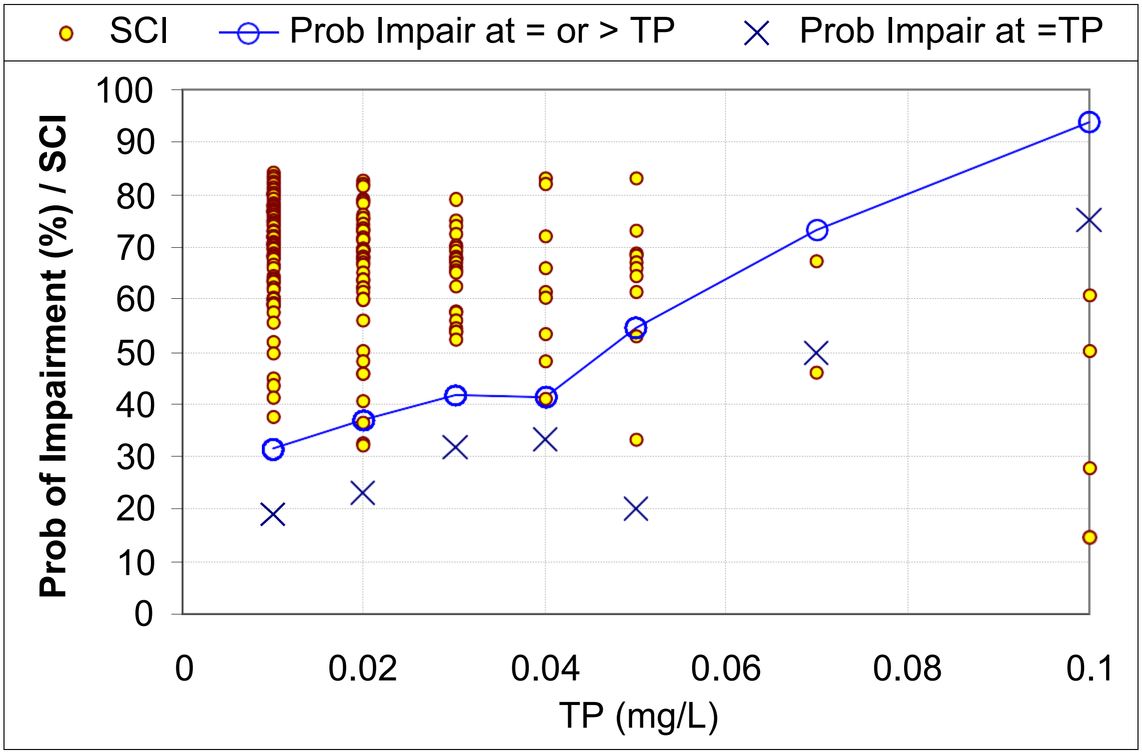
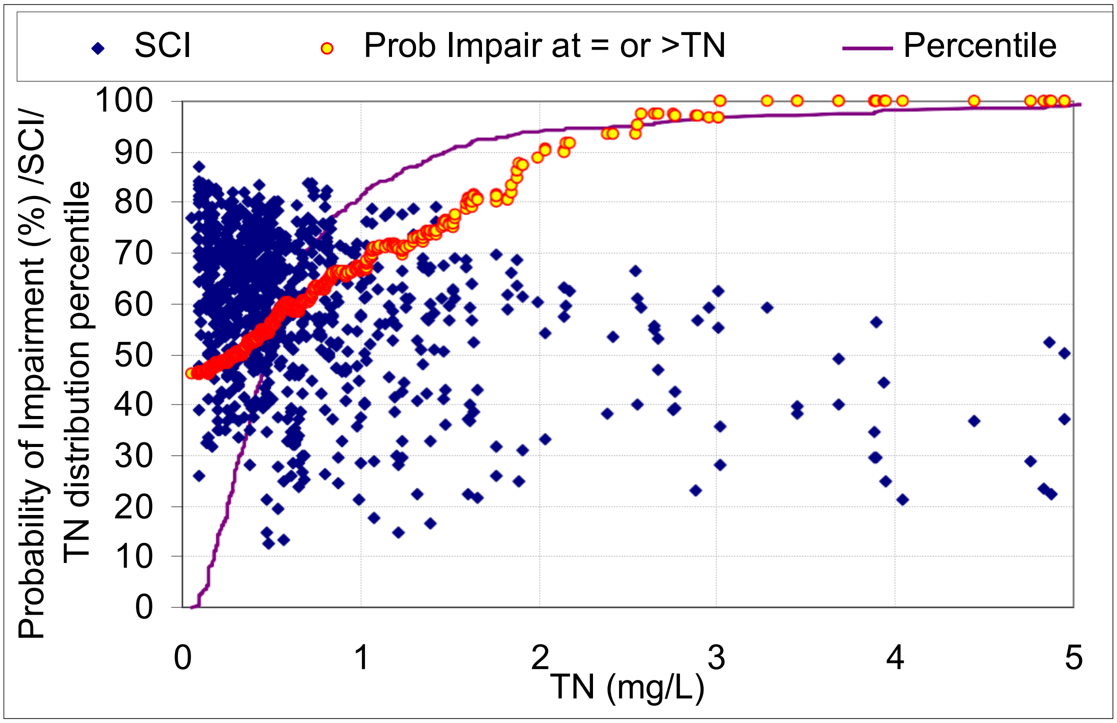


Figure 5. Reference-filtered subsets of 2001-2008 Probmon defined by applying all of the Table 1 and Table 2 reference filters except the TN and TP filters. Data are plotted as raw SCI concentrations; and as probabilities of impairment (SCI<60). See AAC (2009) for further explanation of the "Probability of Impairment" plotting and analysis method.



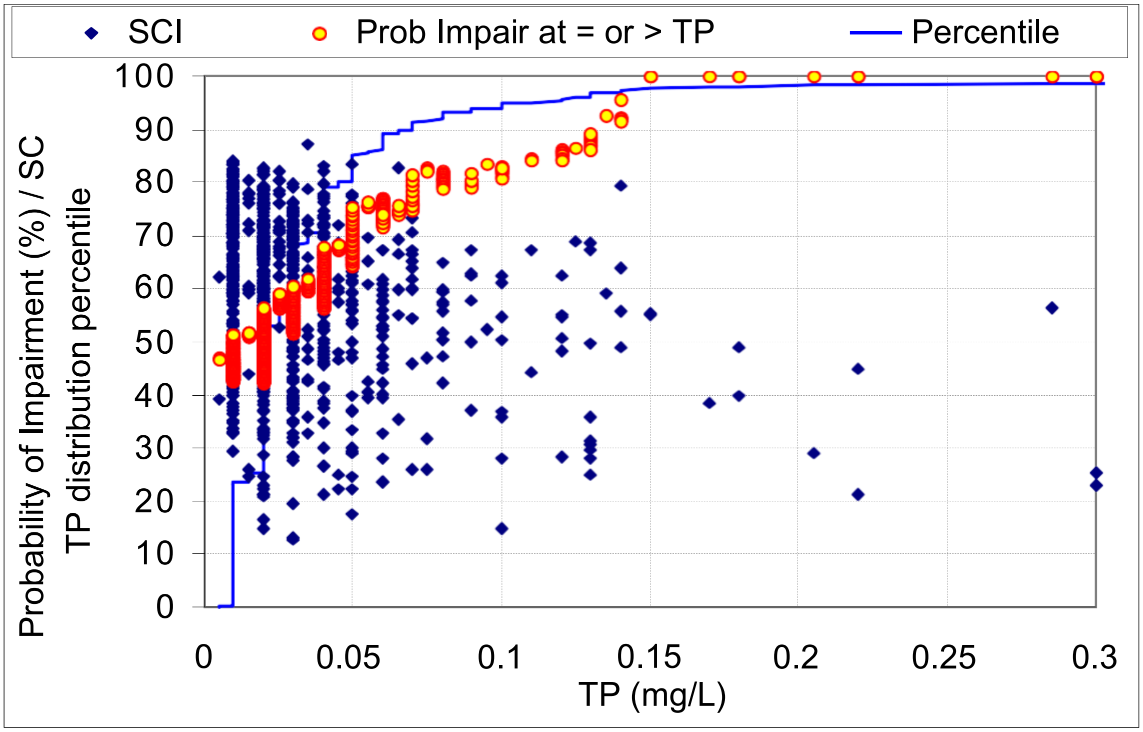


Figure 6. Nutrient concentrations vs. SCI (blue diamonds), and probability of SCI<60 impairment at equal or greater concentrations (red circles). Percentile distributions of nutrient concentrations are also plotted as solid blue lines. Probmon 2001-2008 data are plotted for TN (above) and TP (below). Several very high concentrations for both TN and TP, at impaired sites, are not shown.

3. Visual Assessment Data Analysis

A visual assessment is an essential component of the screening concentration approach to the nutrient impairment assessment procedure. In 2009, the AAC reported results of a "Pilot Program" application of a visual assessment that was applied by Virginia DEQ biologists during Spring and Fall of 2008. Reported outcomes for that activity included a high success rate for visual identification of "impaired" sites, but a low success rate for visual identification of non-impaired sites. In response, the proposed nutrient impairment assessment procedure (Figure 1) was modified to exclude visual assessments of non-impairment status.

In 2009, DEQ biologists applied a modified visual assessment procedure in routine biological monitoring of Mountain and Piedmont sites, as a trial application. The results of this trial procedure were not used for determining Clean Water Act compliance. However, results of the visual assessment are compared to benthic macroinvertebrate assessment and water monitoring results as a means of evaluating the visual assessment process for potential applicability. The visual assessment form used for most of these analyses is included as Appendix C to this report. Some biologists used older versions of the visual assessment form (see AAC 2009) at some sites.

The purpose for the analysis reported here is to assess the accuracy of visual assessment procedures applied by DEQ Regional Biologists during the spring and fall sampling seasons of 2009.

Methods

1. Obtain visual assessment forms completed by DEQ biologists during routine biological monitoring activities during spring and fall, 2009; enter these data manually into a database,
2. Obtain all available EDAS data, including SCI scores, for 2009 in early March, 2010. Link the visual assessments to available SCI scores. Assess the accuracy of visual assessments by comparing assessment results to recorded SCI scores.
3. Obtain DEQ water quality monitoring data for 2009; calculate annual median TN and TP levels; link TN and TP medians, where available, to visual assessments.
4. Calculate an "Algal Biomass Index" from the recorded algal biomass visual assessments. Biomass index was estimated by defining the mid-point of visually assessed stream bottom coverage range as a preliminary estimate of actual coverage by each recorded algae form, and then adjusting component algae coverage percentage-estimates as needed to assure correct total coverage after summing all recorded algal coverage estimates. An algal biomass index score was calculated for each visual assessment by weighting each algae types as follows: film = 1; thin mat = 2; thick mat = 3; short filamentous = 4; and tall filamentous = 5. The stream bottom coverage for each algae type, estimated above, was multiplied by that algae type's weighting; and those products were summed to calculate the biomass index for each site.
5. Assess the factors that contributed to visual assessments by analyzing relationships between visual assessment parameters and measured water quality indicators (median TN and TP) and SCIs, where available.

Results

In 2009, DEQ biologists conducted 329 visual assessments in association with biological monitoring. SCI scores were available at 171 visual assessments at the time of data analysis. 120 visual assessments were conducted at sites with TN concentrations recorded in the DEQ water monitoring database, and 118 visual assessments were conducted at sites with measured TP concentrations. At some sites, biologists used older versions of the visual assessment forms. Visual assessment forms were completed with the full suite of data and information used in this analysis at 312 of the 329 sites.

The visual assessment procedures require DEQ biologists to apply best professional judgment (BPJ) for two separate evaluations: they are asked to assign a probability (high, medium, or low) that the site is impaired by nutrients; and they are asked to assign a probability (high, medium, or low) that the site impaired by non-nutrient stressors. In order to analyze results, the AAC assessed the two BPJ probabilities separately, and combined them by assigning the higher of the two BPJ probabilities of impairment to the site as an overall BPJ indicator.

Biologists were able to discriminate sites by SCI status, generally, as measured SCIs generally corresponded with BPJ probabilities of impairment (Table 3). They had a lower-than-optimal success rate in applying BPJ to discriminate sites with low probabilities of impairment (41% were impaired). Biologists assessed 56 of 312 full visually-assessed sites (18%) as having a "high" probability of impairment by either nutrient or non-nutrient sources, with a success rate of 89% (32 of 36 with SCIs available were impaired).

Both stream bottom coverage by algae (as recorded on visual assessment form, "Total stream-bottom coverage by algae growth") and biomass index were highly correlated with one another (rho = 0.93, p<.0001), and both were highly correlated with SCI, but biomass index correlation with SCI was slightly stronger (rho = - 0.37, vs. - 0.33, both with p<.0001) (Figure 7).

TP and TN demonstrated no significant relationship to stream-bottom algal cover or biomass index in a positive direction, as expected (p<.05), both in Log-Log regressions and non-parametric correlations (Figure 8); TP was negatively correlated with biomass index (p<.05), but the biological significance of this finding is not evident.

When expressed as components of biomass index, only filamentous components of biomass index exhibited significant (p<.05) relationships with SCI (Table 4), with short filamentous being highly significant.

Sediment was commonly cited by regional biologists as a non-nutrient stressor in comments recorded at the visual assessment sites. Citation of sediment as a non-stressor had a significant influence on BPJ ratings (p<.0001), but not on SCI itself (p>.05)

Table 3. Outcomes of visual assessment (VA) procedures. Mean SCI values followed by different letters are significantly different (p<.05) as determined by the Tukey HSD procedure.

BPJ Probab.	n VAs	n SCIs	Mean SCI	Impaired	Not Impaired
A. Impairment by Nutrients					
Low	218	112	60 ^{a}	46	66
Medium	97	53	49 ^{b}	34	19
High	13	6	39 ^{b}	6	0
B. Impairment by Non-Nutrients					
Low	146	75	64 ^{a}	23	52
Medium	110	51	57 ^{b}	25	26
High	50	35	39 ^{c}	31	4
*C. Impairment Overall**					
Low	112	58	65 ^{a}	16	42
Medium	144	70	58 ^{b}	33	37
High	56	36	39 ^{c}	32	4

* Not recorded, but defined as the higher probability of A and B, both of which were recorded.

Table 4. Non-parametric (Spearman) correlations of algae types, expressed as biomass index components, and SCI.

Biomass Index Component	Spearman Rho	p-value
Film	-.1331	.0817
Thin Mat	-.0961	.2099
Thick Mat	-.0711	.3543
Short Filamentous	-.4075	<.0001
Tall Filamentous	-.1777	.0197
Total Biomass Index	-.3679	<.0001

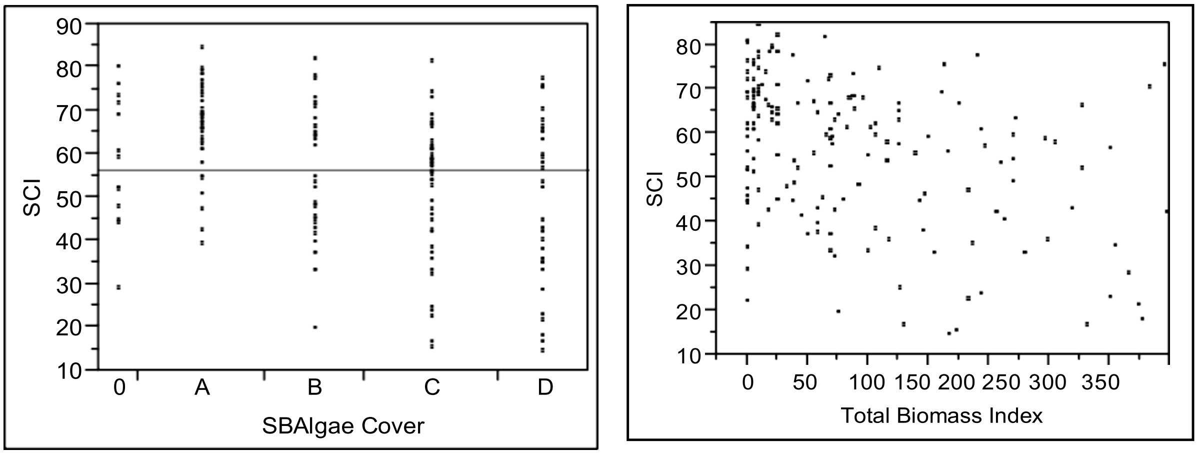


Figure 7. Total stream bottom coverage by algal growth (left) and biomass index (right) vs. SCI for visual assessment sites. Both of these relationships are statistically significant ($p<.0001$).

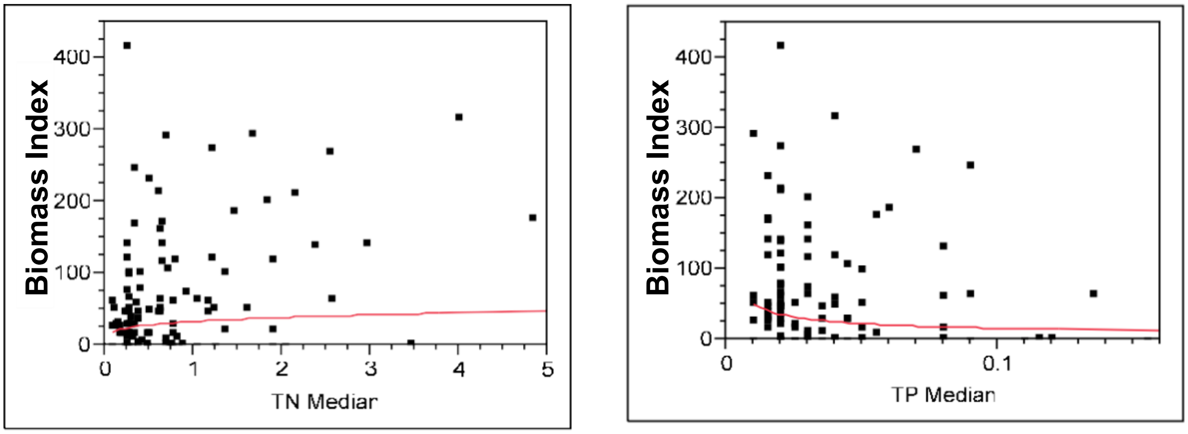


Figure 8. TN and TP median concentrations, calculated from 2009 DEQ water monitoring data vs. biomass index for visual assessment sites where water monitoring data were available. Solid lines were calculated as log-log regressions.

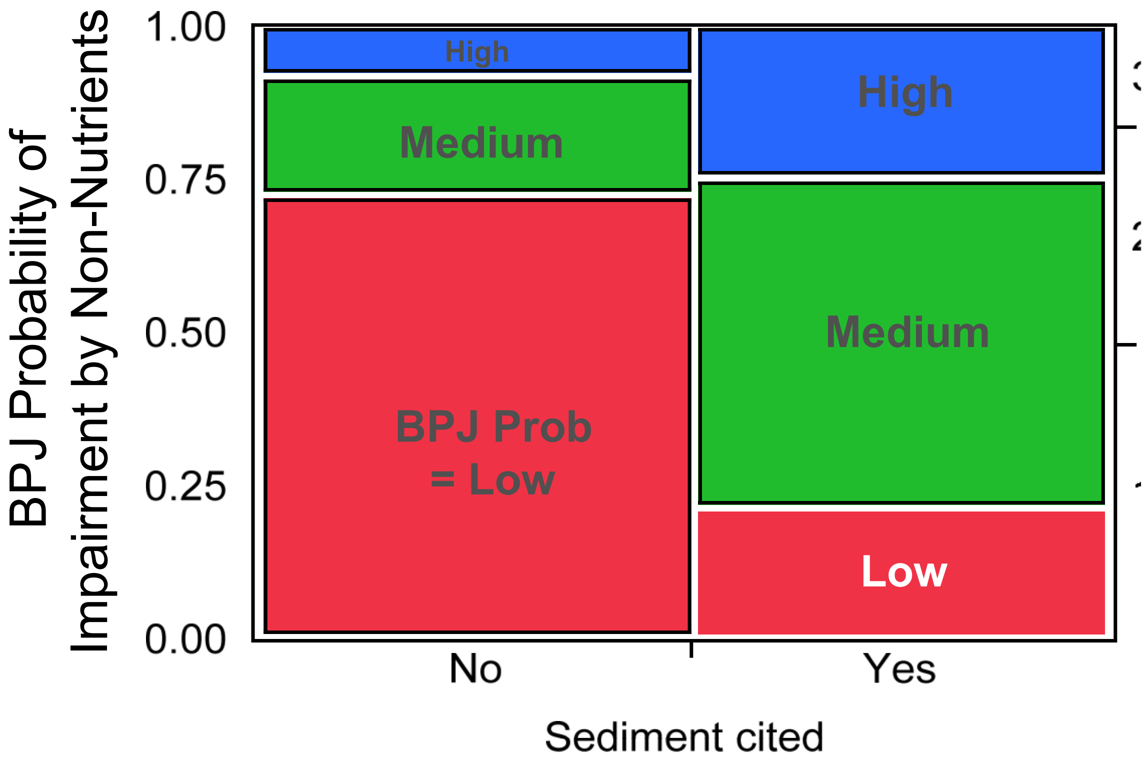


Figure 9. Regional biologists recorded “low” probability of impairment by non-nutrient stressors frequently at sites where excessive sedimentation was not recorded as having been observed.

4. Potential Effects of Nutrient Criteria Incorporating a Screening Approach on DEQ Monitoring Resources

A major concern with the Screening Approach to nutrient criteria is potential effects on DEQ monitoring resources. A major resource limitation is the time available by DEQ regional biologists, who are currently charged with routine biological monitoring and with probabilistic monitoring, along with other duties. In addition to site visitation and sampling, each benthic macroinvertebrate assessment requires a significant time investment in processing the benthic macroinvertebrate samples. If the "inconclusive" range between no-observed-effect and observed-effect concentrations is small (Figures 1 and 3) and/or if a significant number of "inconclusive" sites can be resolved using visual assessment procedures, potential requirements for additional biological monitoring would be modest. If, on the other hand, these conditions were not met, implementation of nutrient criteria using the screening approach would require DEQ biologists to conduct significant numbers of additional benthic macroinvertebrate assessments. Given other duties by the regional biologists and the agency's current resource limitations, this would be a significant concern – especially in the current budget climate which limits the agency's ability to hire additional personnel.

With these facts in mind, we conducted a preliminary analysis for the purpose of determining potential effects of a screening approach on DEQ monitoring resources.

Methods

The illustrative no-observed-effect and observed-effect concentrations derived in Section 1 (0.75 and 2.0 mg/L for TN, 0.04 and 0.13 mg/L for TP) were assumed to be in place and to apply to annual median concentrations, for the purpose of this analysis, as it was applied to water monitoring data from the Mountain and Piedmont ecoregions by DEQ during calendar years 2008 and 2009. The results of the 2009 visual assessment, as reported in Section 2 above, were also applied to the analysis. All other current attributes of the DEQ monitoring programs are assumed to remain in place.

Results

Observation Numbers: The DEQ water monitoring program recorded TN and TP concentrations at about 700 sites each during 2008 and 2009 (Figure 10). However, water was monitored at some of those locations (such as probabilistic monitoring sites) only once or a few times. At about 600 locations each year, 5 or more TN and/or 5 or more TP observations were recorded. The remainder of this analysis applies only to those sites, expecting that DEQ would require some minimum number of water quality observations in order to assess a site for potential nutrient impairments. Five observations was selected for this analysis because of DEQ's monitoring strategy which seeks to obtain 6 or more measurements at all primary monitoring locations (Figure 11). The selection of 5 observations per year as an assessment threshold would allow assessment at routine monitoring sites, even if one of the usual 6 annual monitoring events was not completed.

Preliminary Estimate of Required Visual and/or Biological Monitoring Assessments: The remainder of this analysis is confined to monitoring locations with 5 or more TN and/or TP observations. Of those sites, 36% of measured TP concentrations in 2008, and 42% in 2009, equaled or exceeded the 0.04 mg/L illustrative no-observed-effect concentration, meaning that they would need to be assessed using either visual or biological monitoring procedures (Table 5). Similarly, 33% and 41% of TN observations, in 2008 and 2009 respectively, equaled or exceeded the 0.75 mg/L illustrative no-observed-effect concentration. Only about 5% of total observations exceeded a observed-effect concentration.

However, the DEQ monitoring program shifted a number of watershed monitoring locations in 2009, as per its water monitoring strategy which monitors many locations only 2 out of every 6 years. As a result, nearly 1200 locations were monitored for TN and/or TP during 2008 and/or 2009. A median TN and/or TP concentration equal to or exceeding the NOEC was recorded at about 60% of these locations either or both years. Candidates for visual/bio assessment are those sites with a TN and/or TP concentration that falls between the no-observed-effect and observed-effect concentrations with more than 4 observations either or both years.

The proportion of total monitoring sites, with 5 or more TN and/or TP observations, satisfying the conditions for visual/bio assessment was greater in 2009 than 2008 because general nutrient concentrations were higher. Whether this result occurred because the 2009 monitoring locations are subject to generally higher nutrient concentrations than the 2008 locations; or if a climatic or other factor cause general nutrient levels to be higher in 2009 than in 2008 is unknown. Also unknown is which of the two years should be considered as being the more typical.

Effect of Coincident Biological / Ambient WQ Monitoring: One factor that would reduce the number of additional visual and biological assessments required by nutrient criteria implementation is the fact that certain ambient water quality monitoring are coincident with biological monitoring (Table 6). This analysis was performed only with 2008 data, because the 2009 EDAS (biological monitoring database) was not fully populated by early March 2010. In 2008, DEQ biologists conducted biological monitoring at 346 locations; at most locations, both Spring and Fall samples were collected. At 148 of those locations, water quality data were also collected. Thus, 21% of the water monitoring sites with TN and/or TP data also had biological monitoring data in 2008. However, only 13% of the water quality monitoring sites with 5 or more TN and/or TP observations also had biological monitoring data in 2008. The reason for this difference concerns special studies, such as Probmon, where only one or a small number of water quality samples are collected to supplement biological data. The percentage of sites that would require visual / bio assessment, under the assumptions of this analysis and where biological monitoring data are otherwise available is slightly higher at 15%.

Potential Visual Assessments: Another factor that would reduce the need for biological monitoring, the primary resource demand, is visual assessments. As documented in Table 3, biologists visually assessed 56 of 312 monitoring visits where complete BPJs were recorded (18%) in 2009 by defining a “high” probability of impairment by either nutrient or non-nutrient stressors. SCIs were available for about half of those monitoring events (164), and biologists visually assessed 36 of these (22%) as having a “high” probability of impairment. Biologists achieved a high rate of success in these designations (32 of 36 correct, an 89% success rate).

Therefore, this analysis assumes that visual assessment would be implemented as a component of the nutrient impairment assessment framework, as represented in Figure 1.

Analysis of Increased Biological Monitoring Loads: Table 7 estimates increased resource loads by making assumptions based on the above data. The total number of sites satisfying the requirements for application of visual and/or biological assessments is estimated based on Table 5, assuming the 2008-2009 change is indicative of the effect of the transition between 2-year cycles; these numbers do not include a slight increase within the two-year cycle due to water quality variability at individual monitoring locations; this factor was not incorporated into the analysis because the 2008-2009 monitoring data provide no way to estimate it. However, we expect this intra-cycle increase to be far less than observed for the 2008-2009 monitoring cycle change. General nutrient levels in 2009 were slightly higher in 2009 than 2008, and this effect contributes to the incremental sites satisfying the illustrative criteria for visual/biological monitoring in 2009.

One factor we did not consider is that some of the monitoring sites tallied in Table 5 are non-wadable and therefore would not be subject to the wadeable-streams nutrient criteria. We have no way to estimate the number of monitoring sites listed in Table 5 that are, in fact, non-wadeable. In compiling Table 7, that fraction was assumed to be 10%.

Based on Table 6, we have assumed that 15% of the total number of sites eligible for visual / bio assessment would be coincident with current biological monitoring sites, and therefore would not require additional resources.

Based on the results reported in Table 3, we have assumed that 15% of the sites satisfying criteria for visual/bio assessments would be assessed visually by DEQ's biological monitoring staff, and therefore would not require biological assessments.

Results of these analyses indicate that 77 - 92 sites per year would require biological monitoring assessments in order to implement nutrient criteria via the "no-observed-effect concentration" approach, using the illustrative, hypothetical no-observed-effect concentrations derived in Section 1.

How would this affect DEQ monitoring resources? In 2008, EDAS data report 570 biological monitoring observations at 346 locations. It is not clear whether biological monitoring assessments for nutrient criteria implementation would entail two monitoring visits (both spring and fall), or just one. If the former, the analysis indicates an estimated 22-27% increase in biological monitoring resource demands. If the latter, fewer resources would be required (13-16% increase). Another possibility would be a dual strategy (e.g. both fall and spring assessments if SCI is close to 60 during the first visit, but only one assessment if the SCI's departure from 60 is significant), which would place the increased biological monitoring resource demands somewhere in the neighborhood of 20%.

Table 5. Numbers of DEQ monitoring sites with recorded TN and TP concentrations conforming to various conditions, 2008, 2009, and combined. For this illustration, no-observed-effect concentrations (NOEC) = 0.75 mg/L for TN, 0.04 mg/L for TP; observed-effect concentrations (OEC) = 2.0 mg/L for TN. 0.13 mg/L for TP. Sites defined as eligible for Visual/Bio Assessment are those with ≥ 5 observations for a given parameter (TN or TP) in either 2008 or 2009, and have a median concentration that ≥ the no-observed-effect concentration but < the observed-effect concentration.

	Monitoring Sites	Num Obs ≥ 5	Median ≥ NOEC	Median < OEC	Visual/Bio Assessment
2008					
TN	693	605	230	659	172
TP	691	614	249	666	207
Either TN or TP	711	616	360	692	295
2009					
TN	715	631	294	667	222
TP	723	634	313	700	269
Either TN or TP	725	643	440	711	376
2008 or 2009, TN or TP	1176	1018	658	1152	551

Table 6. Biological monitoring (BioMon) frequency at ambient water quality monitoring sites (coincident) needed to fully apply the Screening Approach for 2008.

	No BioMon	Yes BioMon	Total Sites	BioMon Frequency
Total Biological Monitoring Events	-	570	346	n/a
Total Biological Monitoring Sites	-	346	346	100.0%
WQ Sites with TN and/or TP Observations	563	148	711	20.8%
WQ Sites with TN and/or TP NumObs > 4	536	80	616	13.0%
WQ Sites Requiring Visual / Bio Assessment	250	45	295	15.3%

Table 7. Potential effects of nutrient criteria employing the Screening Approach, given NOEC and OEC assumptions of Table 5, on DEQ Biological Monitoring Program resources. All data are per-year except first data line ("Total satisfying …") which is expressed in a 2-year basis.

Years of Implementation	1 & 2	3 & 4	5 & 6
	(No. of Sites)	(No. of Additional Sites)	
TN &/or TP > NOEC; TN &/or TP < OEC; n > 5			
Total satisfying Visual / Bio Assessment Requirements	300	250	250
Per Year	150	125	125
Wadeable Stream Sites			
Proportion (assumed)	90%	90%	90%
Remaining Visual/Bio Assessment Sites	135	113	113
Sites with Coincident Biomonitoring			
Proportion of Total	15%	15%	15%
Number of sites reduction	-20	-17	-17
Remaining Visual/Bio Assessment Sites	115	96	96
Visual Assessments (- 20%)	-23	-19	-19
Remaining Biological Assessment Sites	**92**	**77**	**77**
Current Biological Monitoring Load:			
Number of Sites in 2008	346	346	346
Number of Biological Assessments in 2008	570	570	570
Increased BioMonitoring Load:			
Relative to Number of Sites	27%	22%	22%
Relative to Number of Biological Assessments	16%	13%	13%

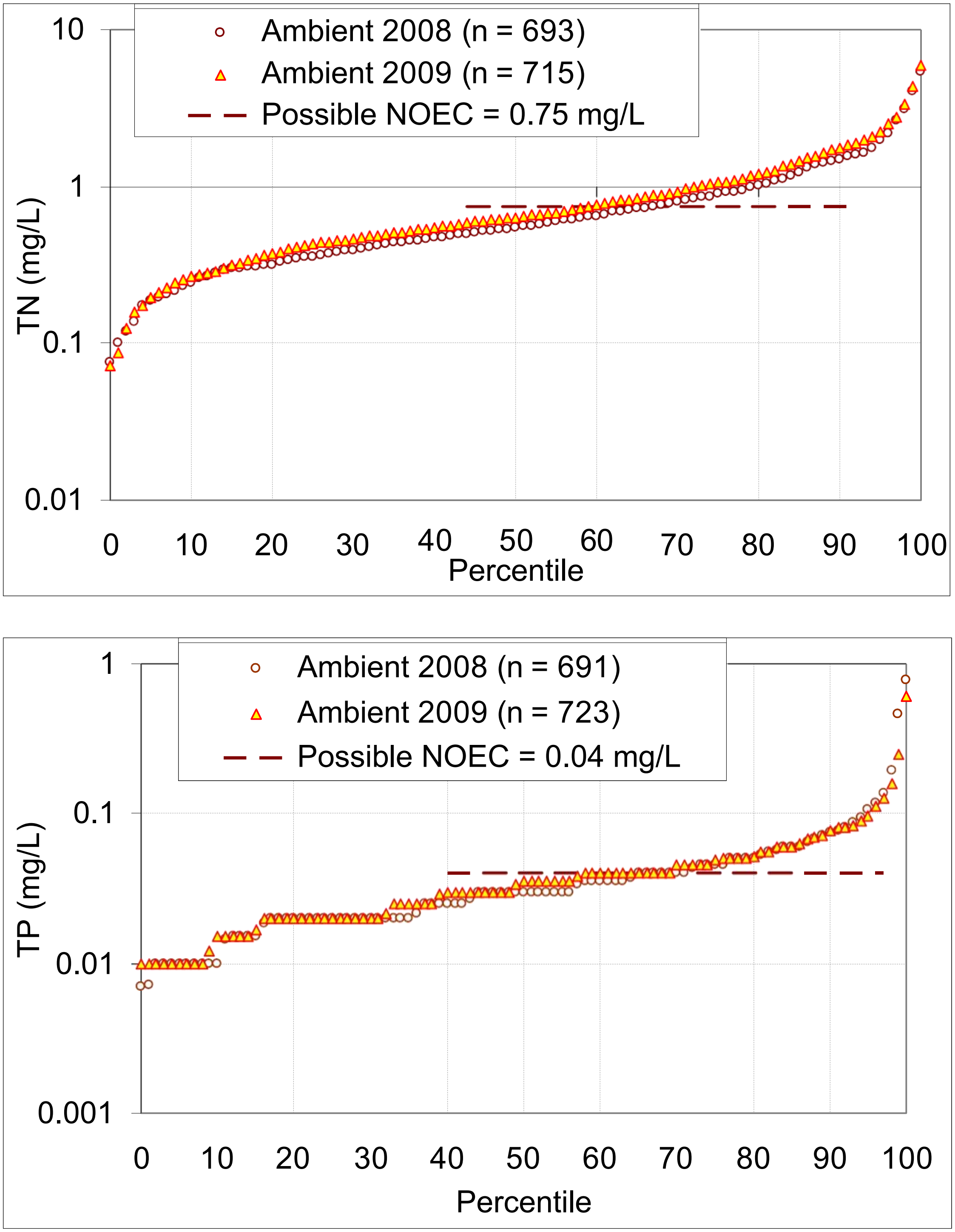


Figure 10. Distribution of DEQ ambient water monitoring sites, by TN (above) and TP (below) median concentrations for 2008 and 2009.

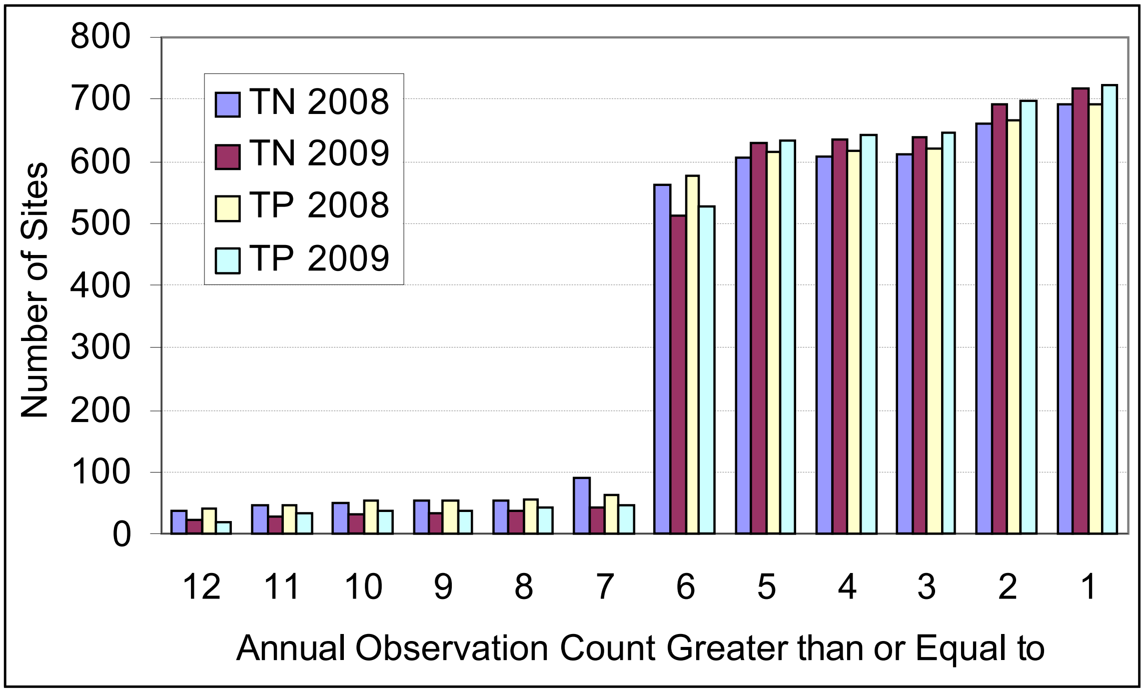


Figure 11. Number of TN and TP observations at DEQ water monitoring sites, 2008 and 2009.

5. General Findings and Conclusions

The potential to use reference filters with probabilistic monitoring data as a means of developing no-observed-effect concentrations is promising. Probablistic monitoring data are well-suited to this analysis because the probmon sites are characterized by a wider range of water quality, site, and attribute data than are DEQ's ambient water monitoring data. DEQ personnel and the AAC have proposed additional monitoring of selected probabilistic monitoring sites that satisfy reference filters for the purpose of gaining additional insight regarding the nature of those impairments. More specifically, the AAC would like to know if those sites that have SCI < 60, despite satisfying the reference filter conditions, are impaired by nutrients. This activity can also include application of best professional judgment by regional biologists concerning whether or not these sites are subject to conditions that would, in their judgment, preclude their consideration as reference sites. Reference sites identified using various criteria are listed in Appendix B.

The approach for identifying observed-effect concentrations as TN and TP thresholds that define a 90% probability of impairment at equal or higher concentration levels does not appear promising as a useful mechanism for application. Although it appears to "work" (in the sense that it reliably identifies sites with a high probability of being impaired), it does not appear to be particularly useful as very few sites exceed these limits with sufficient consistency to enable definitive assessment using the observed-effect concentrations so defined. In Virginia, the majority of the state's freshwater streams drain into water bodies that are known to be nutrient sensitive. An alternative approach to observed-effect concentration designation involving limitation of downstream loading effects is being explored by other AAC members.

The potential for application of visual assessments within the screening approach to nutrient impairment assessment is supported by reported results. In its 2009 report, the AAC reported on a "pilot program" application of visual assessments by regional biologists. The pilot program demonstrated a capability by regional biologists to identify impaired sites visually with consistency, as the accuracy of "high probability of impairment" ratings approached 90%. However, accuracy in identifying non-impaired streams by applying a "low probability of impairment" visual rating was considerably lower. The 2009 visual assessment trial, applied by regional biologists, yielded similar findings. Measured SCI's generally varied with visual assessment ratings, on average; and 89% of "high probability of impairment" ratings applied by biologists where corresponding SCI scores are available were confirmed as correct; but, again, the accuracy of "low probability of impairment" ratings was insufficient to enable that method's application within a regulatory context.

In both 2008 and 2009, the majority of "high probability of impairment" ratings were applied at sites that biologists' best professional judgments indicated to be impaired by non-nutrient stressors. The AAC suggest a minor change in the way visually assessed impairments would be handled within the nutrient impairment assessment framework (Figure 12). The water monitoring data used to evaluate the visual assessment ratings does not allow the cause of impairment to be determined.

The AAC expects that the Screening Approach, if applied as a means of implementing nutrient criteria, would produce more accurate assessments than a conventional fixed-threshold approach. However, that accuracy will come at a cost to DEQ, as it will require the expenditure of resources, primarily in the form of regional biologists' time, in order to conduct the visual and additional benthic macroinvertebrate assessments made necessary by the Screening Approach. The required application of regional biologists' time for additional benthic macroinvertebrate assessments is far more significant than for visual assessments, as the latter procedure is, by design, usually quick and easy. The AAC has conducted an analysis of what those additional resource expenditures might entail, assuming no-observed-effect and observed-effect concentrations in the range of those developed as illustrative examples in Section 1, and found them to be, very approximately, a ~20% additional biological monitoring load. However, this analysis should be considered only as an exploratory and preliminary effort, as the actual increased load would be highly dependent on actual no-observed-effect and observed-effect concentrations.

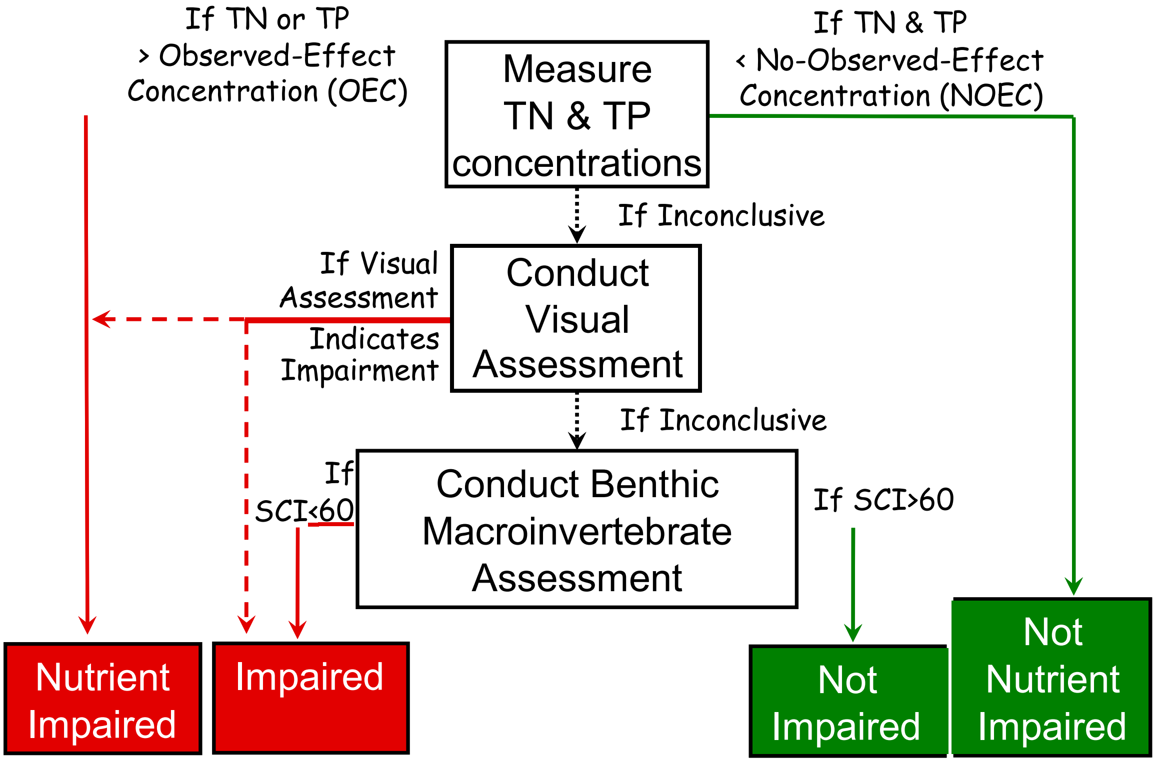


Figure 12. Proposed modification to the nutrient criteria and impairment assessment procedure. When conducting visual assessments, regional biologists are usually correct in assigning "high probability of impairment" as a best professional judgment. In 2009, 89% of such designations at sites with available SCIs were confirmed as impaired by the SCI scores. However, most of these designations were cited as being caused by non-nutrient stressors. As proposed above, visually assessed impairments would only be defined as nutrient impairments if definite evidence of nutrient overenrichment, such as excessive algae, is observed as present; otherwise, visually assessed impairments would be categorized as general impairments.

Acknowledgements

Sincere thanks to DEQ Regional Biologists for performing 329 visual assessment trials in 2009, and for providing those data to the AAC. Thanks to Aimee Budd for providing 2008-2009 EDAS data; to Jason Hill for providing 2001-2008 Probablistic Monitoring data; and to Roger Stewart for providing 2008-2009 ambient water quality monitoring data at our request for use in these analyses.

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Appendix A. Selected Analyses to Assess Stressor Sources at Reference-Filtered Probmon Sites.

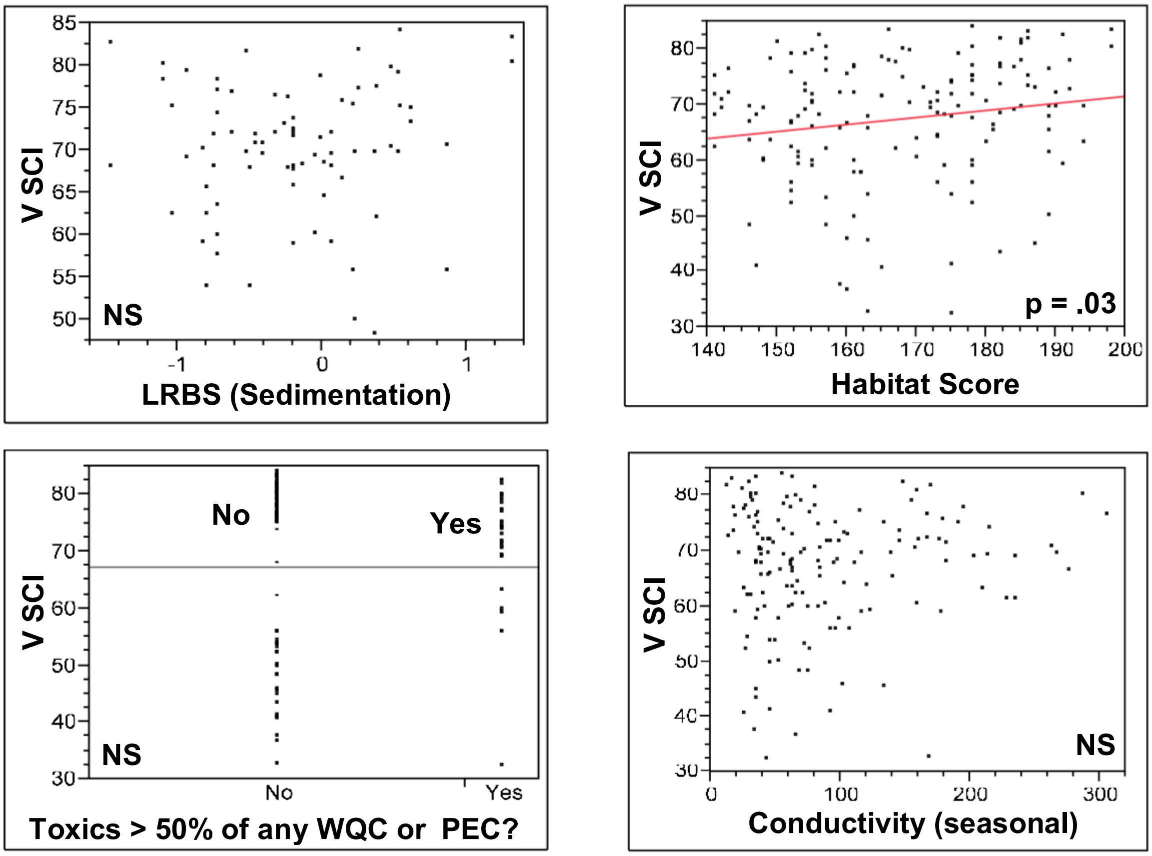


Figure A-1: Reference-filtered Probmon sites showed no significant relationship to Log (Relative Bed Stability), a sedimentation indicator; the presence of metal or organic toxics in water column and sediments of >50% but <100% of WQC or PEC; and conductivity; and only slightly significant relationship to habitat score.

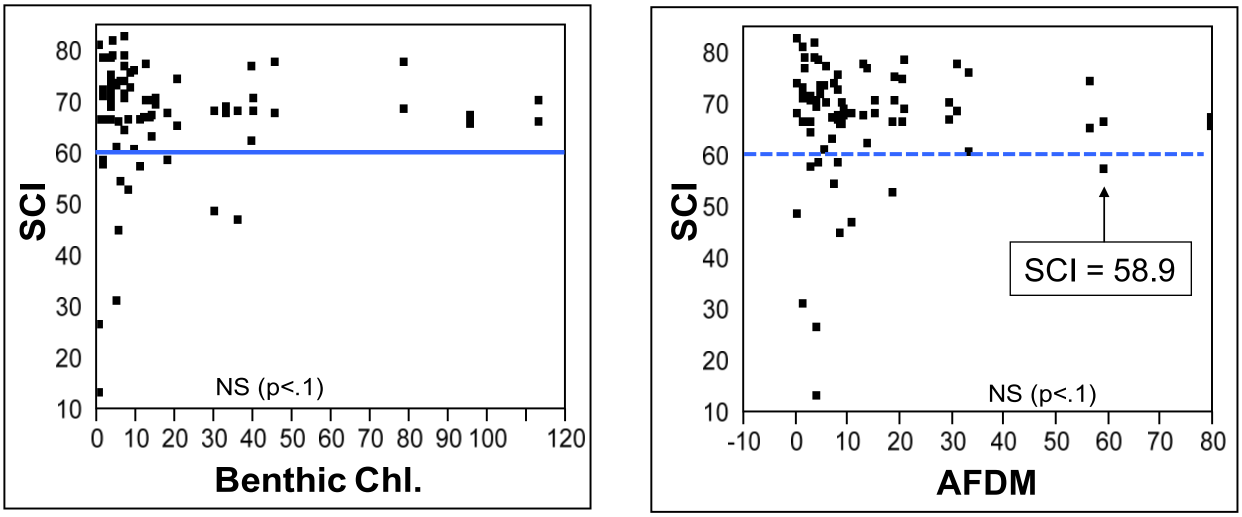


Figure A-2: SCIs at non-nutrient reference-filtered sites (i.e. Probmon sites selected using all of the Tables 1 and 2 reference filters except TN and TP) showed no significant response to two measures of benthic algae in non-parametric (Spearman) correlations.

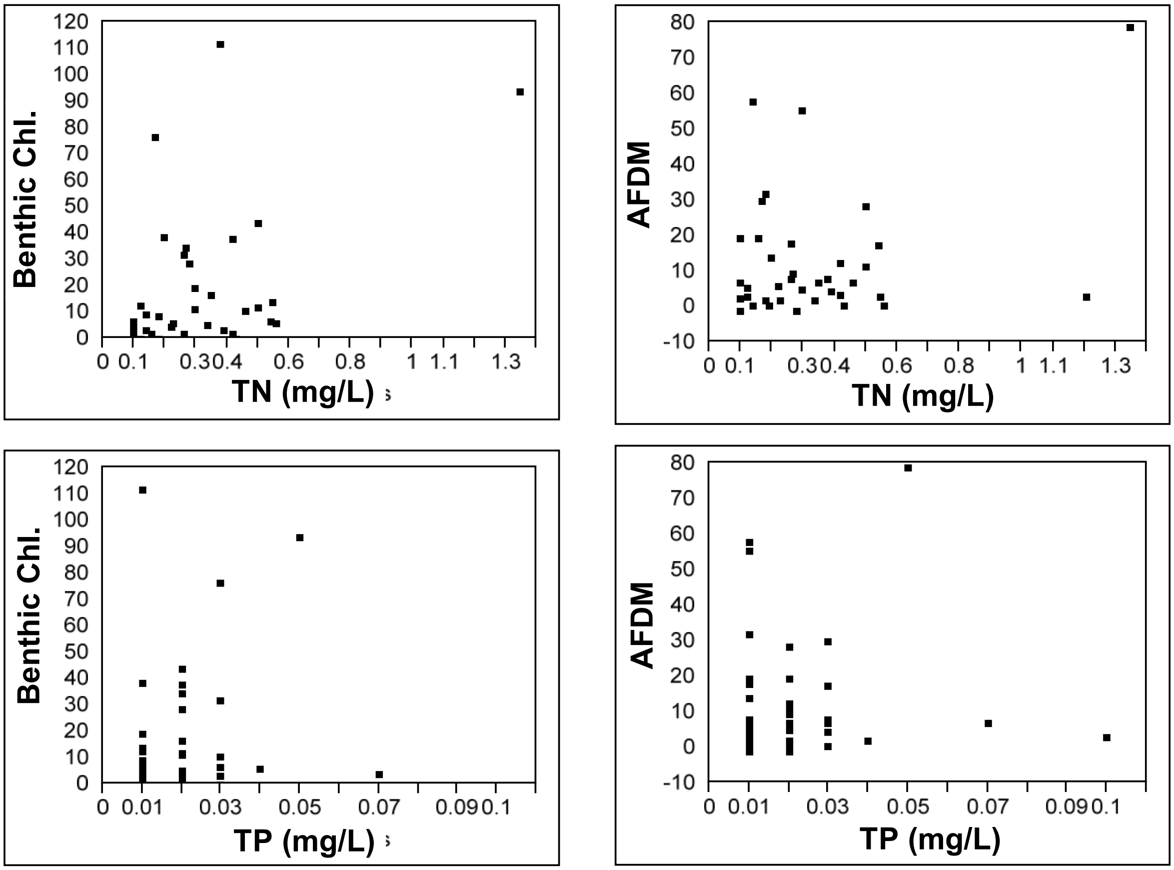
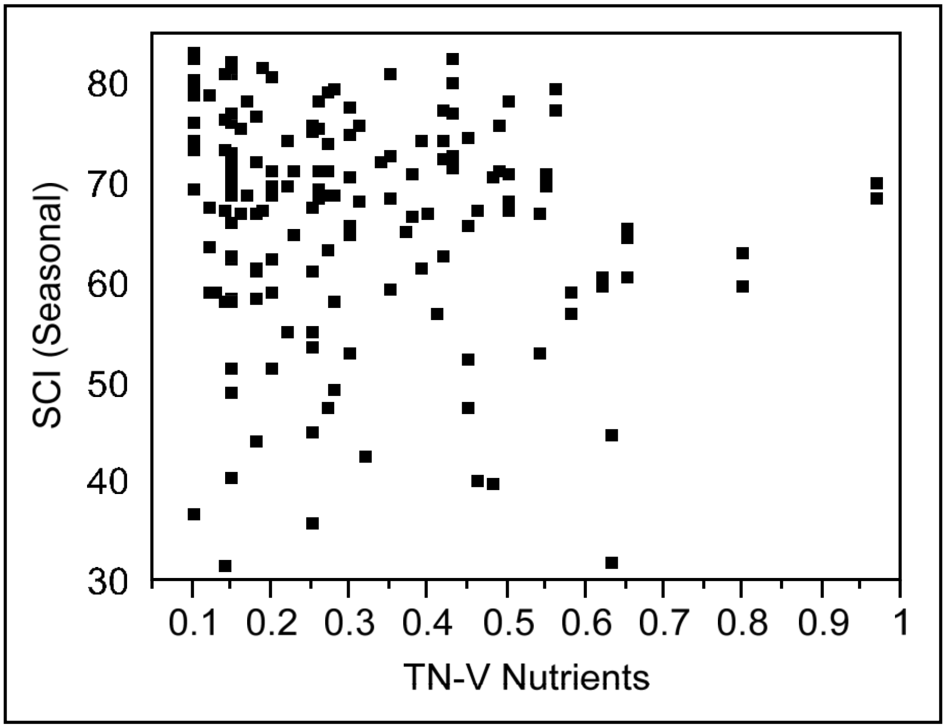


Figure A-3. Measured nutrients (TN, TP) show no influence on measured benthic algae (benthic chlorophyll, ash free dry matter) within the reference filtered dataset. These are “reference” data defined without nutrient filters applied (i.e. all Table 1 and 2 reference filters except TN and TP).



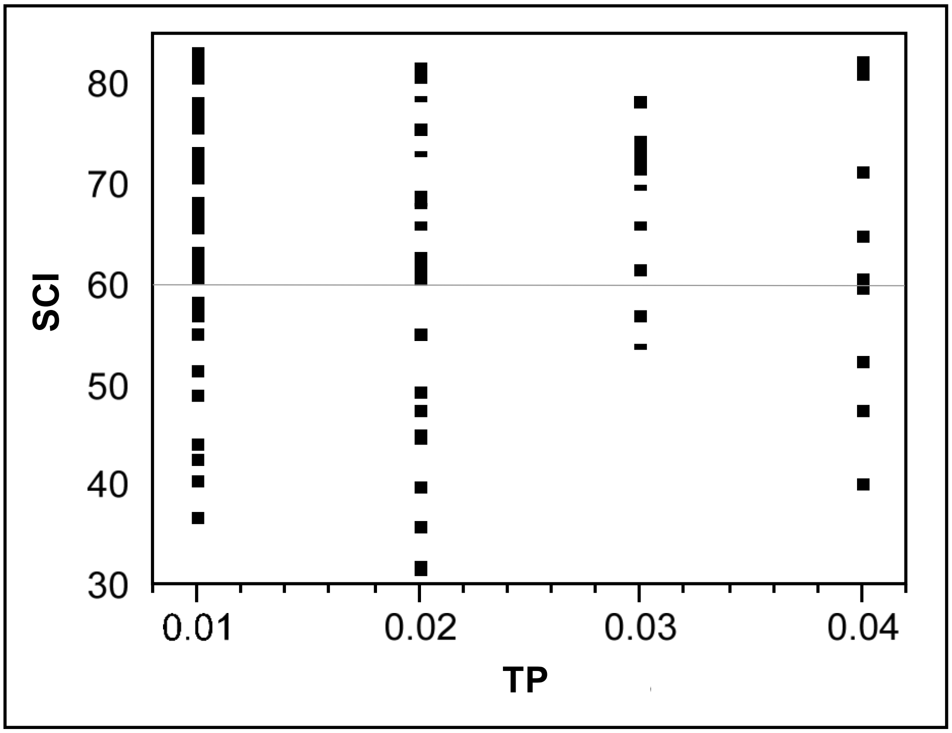


Figure A-4: The presence of numerous SCI<60 observations at very low nutrient levels within the reference-filtered dataset can be interpreted as evidence that nutrients are not a primary source of impairment among these data.

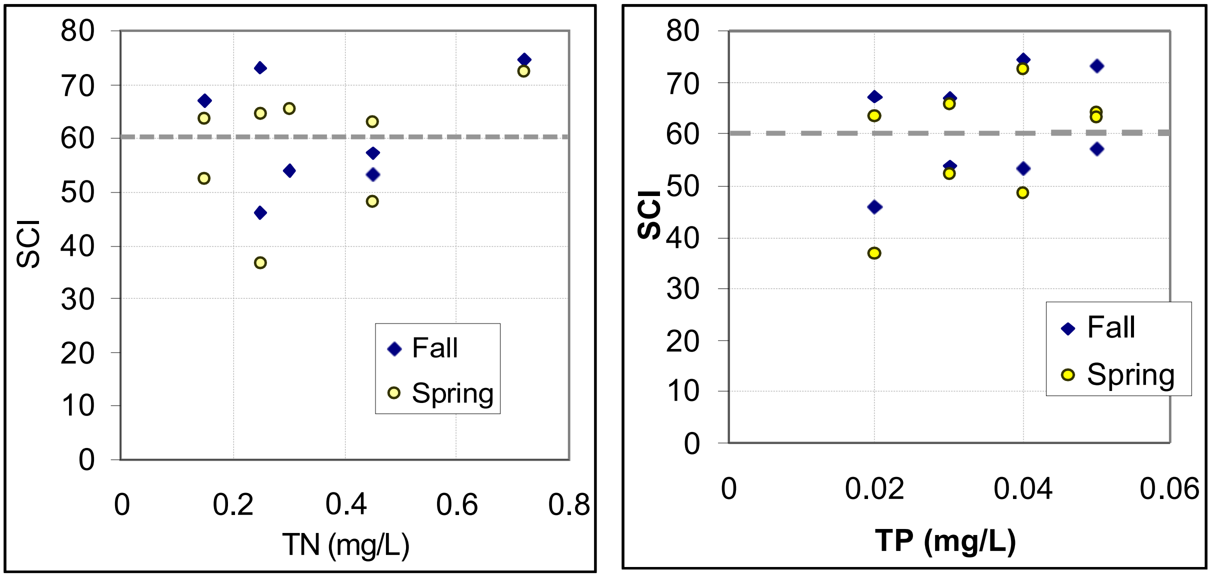


Figure A-5: TN and TP vs. SCI for the few low-gradient streams within the reference-filtered dataset. The majority of the reference-filtered were recorded within the Probmon database as "high gradient." Low-gradient streams are expected to be more sensitive to nutrient effects via an algae stimulation / DO depletion mechanism than high gradient streams.

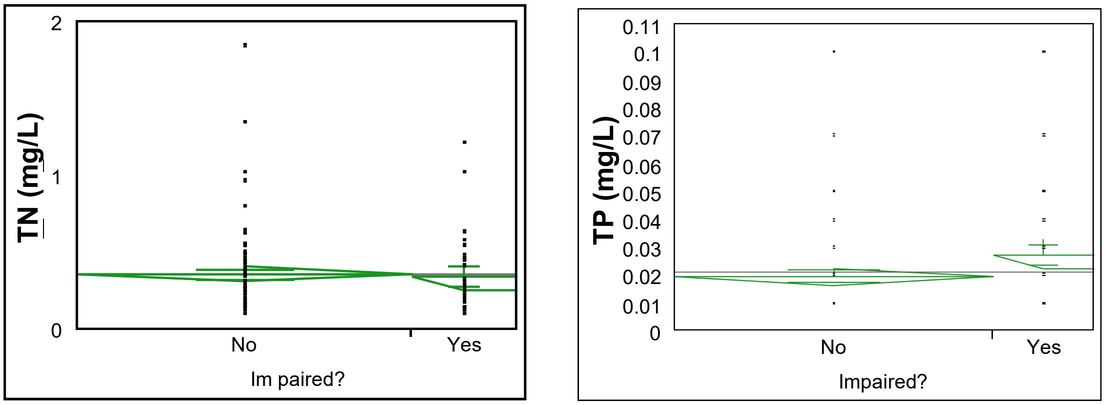


Figure A-6: Non-parametric Wilcoxon analysis reveals in TN between impaired and non-impaired sites (p<.10), but the TP concentrations tend to be higher at impaired sites (p=.05).

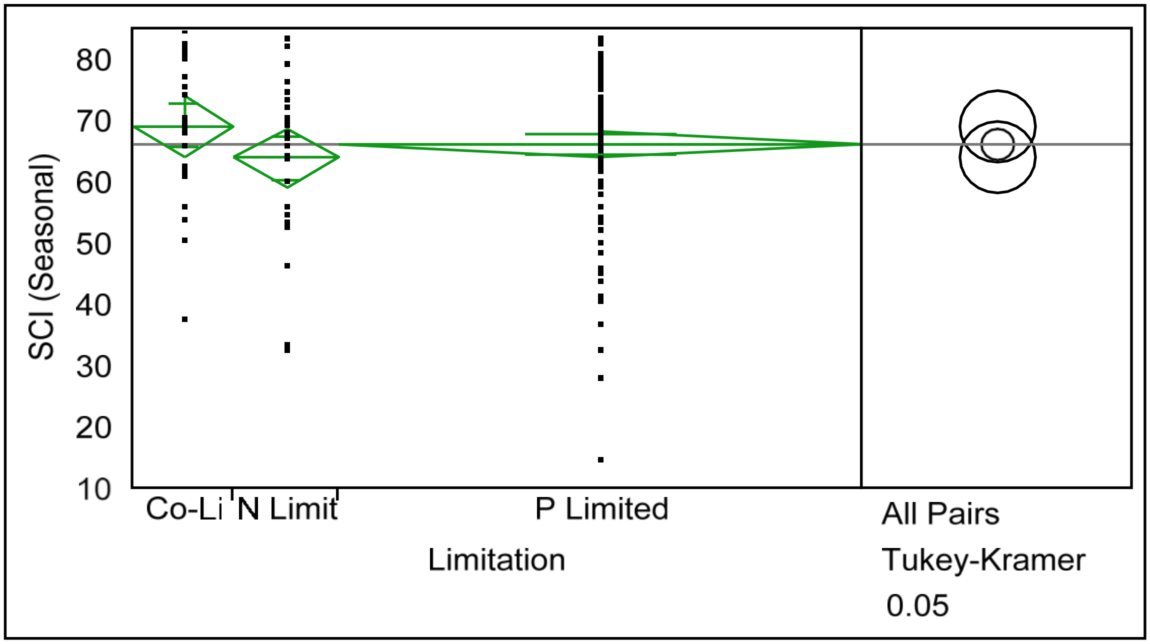
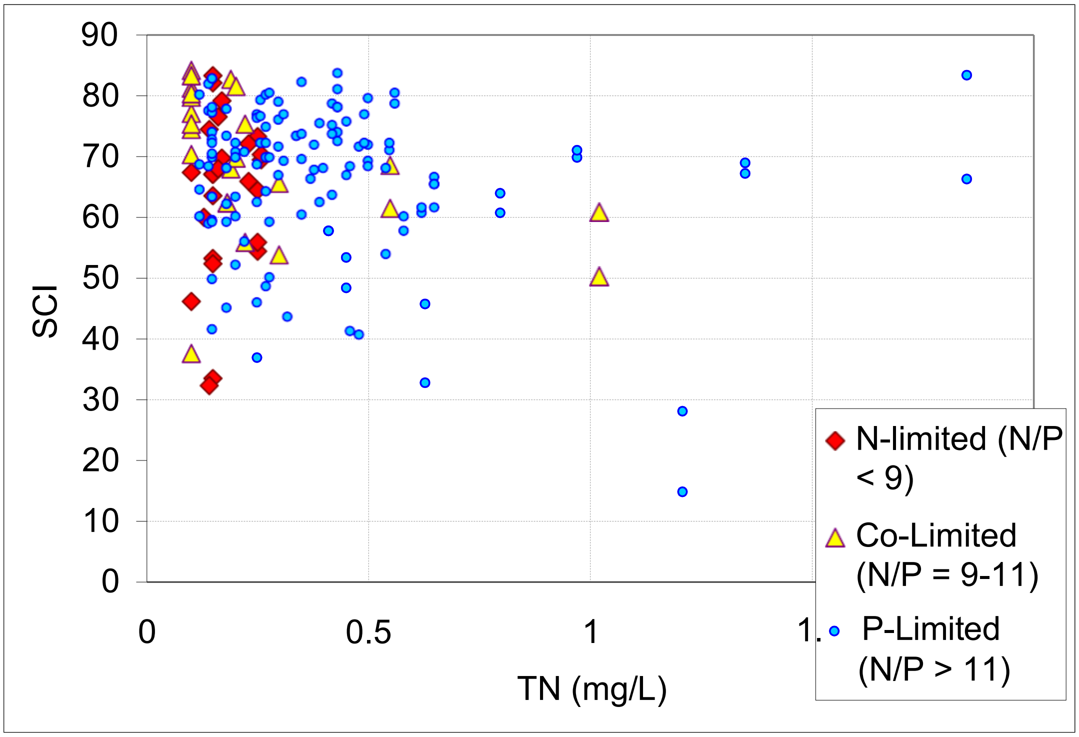


Figure A-7. Both parametric and non-parametric analyses reveal no significant differences in SCI among co-limited, N-limited, and P-limited sites, with limitation-types defined using the following TN/TP ratios:

N Limited: TN/TP ratios < 9
Co-Limited: TN/TP ratios = 9 – 11
P Limited: TN/TP ratios > 11



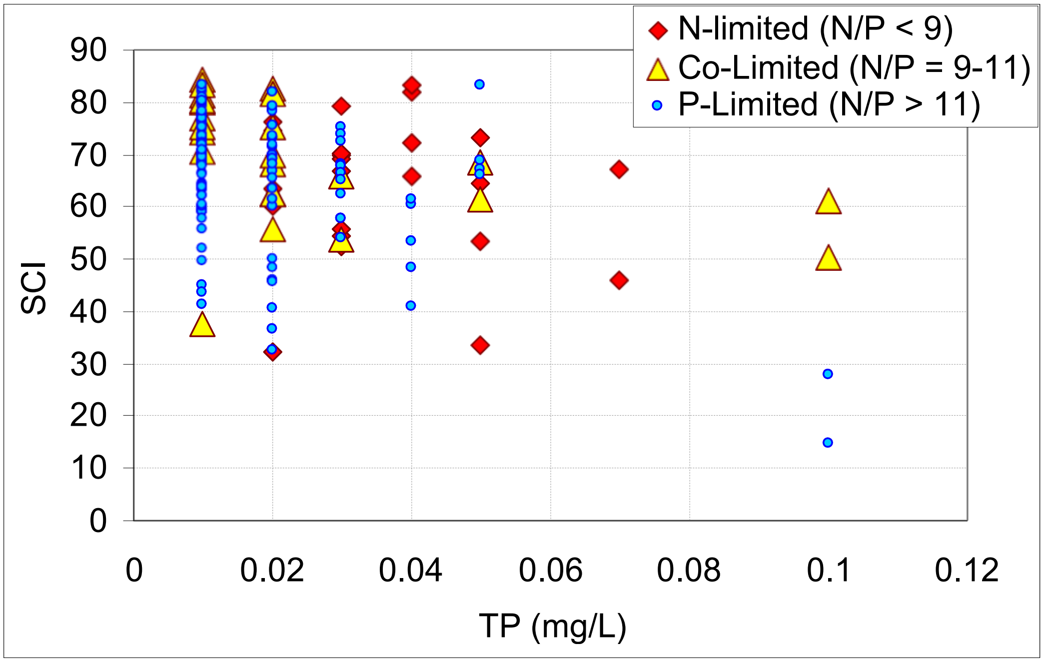


Figure A-8: TN is negatively correlated with SCI only at co-limited Sites; TP is negatively correlated with SCI at both P-limited and co-limited sites. Correlations are non-parametric Spearman (Table A-1).

Table A-1. Non-parametric Spearman correlations among N, P, and SCI for the non-nutrient reference filtered dataset (i.e. Probmon observations satisfying all of the Reference Filter conditions of Tables 1 and 2, except the TN and TP filters), by nutrient limitation status and overall. Within each matrix: upper right data are Spearman correlation coefficients; lower left data are p-values, if p<.10.

N-limited sites (n = 25 SCIs)

	N	**P**	**SCI**
N		0.05	0.25
P			-0.07
SCI			

P-limited sites (n = 125 SCIs)

	N	**P**	**SCI**
N		***0.58***	-0.09
P	<.0001		***-0.27***
SCI		0.002	

Co-limited sites (n = 24 SCIs)

	N	**P**	**SCI**
N		***0.98***	***-0.56***
P	<.0001		***-0.59***
SCI	0.005	0.003	

All Sites (n = 174 SCIs)

	N	**P**	**SCI**
N		***0.32***	***-0.13***
P	<.0001		***-0.29***
SCI	0.08	<.0001	

Appendix B: Probmon sites identified as "Reference" using various criteria.

StationID	Ref Type[a]	Region	Sampled	TN (mg/L)	TP (mg/L)	SCI	Gradient
1ACAA000.83	1, 2	NRO	Spring, 2003	0.63	0.02	45.7	High
1ACAA000.83	1, 2	NRO	Fall, 2003	0.63	0.02	32.7	High
1ANOG000.91	2, 3	NRO	Spring, 2004	1.35	0.05	68.9	High
1ANOG000.91	2, 3	NRO	Fall, 2004	1.35	0.05	67.0	High
1AXJS001.20	1, 2	VRO	Spring, 2004	0.37	0.01	66.1	High
1AXJS001.20	1, 2	VRO	Fall, 2004	0.37	0.01	.	High
1AXKR000.77	2	NRO	Spring, 2005	1.85	0.05	83.3	High
1AXKR000.77	2	NRO	Fall, 2005	1.85	0.05	66.0	High
1AXLB001.49	1, 2	NRO	Spring, 2006	0.46	0.03	68.3	High
1AXLB001.49	1, 2	NRO	Fall, 2006	0.46	0.03	.	High
1BBRY001.78	1, 2	VRO	Spring, 2008	0.32	0.01	43.6	High
1BBRY001.78	1, 2	VRO	Fall, 2008	0.32	0.01	.	High
1BCDR010.21	1, 2, 3	VRO	Spring, 2002	0.27	0.01	64.2	High
1BCDR010.21	1, 2, 3	VRO	Fall, 2002	0.27	0.01	72.1	High
1BCDR027.54	3	VRO	Spring, 2004	0.54	0.01	74.1	High
1BCDR027.54	3	VRO	Fall, 2004	0.54	0.01	80.1	High
1BNFS102.55	1, 2, 3	VRO	Spring, 2002	0.8	0.01	60.6	High
1BNFS102.55	1, 2, 3	VRO	Fall, 2002	0.8	0.01	63.9	High
1BNKW001.97	1, 2, 3	VRO	Spring, 2003	0.2	0.01	52.2	High
1BNKW001.97	1, 2, 3	VRO	Fall, 2003	0.2	0.01	60.0	High
1BNTH046.56	1, 2	VRO	Spring, 2007	0.2	0.01	69.6	High
1BNTH046.56	1, 2	VRO	Fall, 2007	0.2	0.01	72.0	High
2AXQS001.07	1, 2	WCRO	Spring, 2006	0.1	0.01	83.3	High
2AXQS001.07	1, 2	WCRO	Fall, 2006	0.1	0.01	80.3	High
2-BCC001.90	1, 2	VRO	Spring, 2006	0.42	0.01	73.4	High
2-BCC001.90	1, 2	VRO	Fall, 2006	0.42	0.01	75.1	High
2-BNF003.52	1, 2, 3	SCRO	Spring, 2001	0.15	0.04	82.1	High
2-BNF003.52	1, 2, 3	SCRO	Fall, 2001	0.15	0.04	83.2	High
2-BVC003.09	1, 2	VRO	Spring, 2007	0.34	0.02	73.1	High
2-BVC003.09	1, 2	VRO	Fall, 2007	0.34	0.02	73.1	High
2-COO002.35	1, 2, 3	SCRO	Spring, 2001	0.25	0.01	76.8	High
2-COO002.35	1, 2, 3	SCRO	Fall, 2001	0.25	0.01	68.4	High
2-CSR003.94	1, 2	WCRO	Spring, 2005	0.2	0.02	81.6	High
2-CSR003.94	1, 2	WCRO	Fall, 2005	0.2	0.02	69.7	High
2-CWP006.87	1, 2	WCRO	Spring, 2005	0.14	0.01	77.3	High
2-CWP006.87	1, 2	WCRO	Fall, 2005	0.14	0.01	81.9	High
2-CWP023.28	3	VRO	Spring, 2001	0.15	0.01	79.2	High
2-CWP023.28	3	VRO	Fall, 2001	0.15	0.01	75.3	High
2-CWP042.31	1, 2	VRO	Spring, 2008	0.22	0.02	55.9	High
2-CWP042.31	1, 2	VRO	Fall, 2008	0.22	0.02	75.3	High
2-CWP053.78	1, 2, 3	VRO	Spring, 2001	0.15	0.01	59.4	High
2-CWP053.78	1, 2, 3	VRO	Fall, 2001	0.15	0.01	82.6	High
2-DCK003.94	1, 2, 3	WCRO	Spring, 2004	0.16	0.02	76.3	High
2-DCK003.94	1, 2, 3	WCRO	Fall, 2004	0.16	0.02	67.9	High
2-EFK001.55	1, 2	PRO	Spring, 2008	0.12	0.01	59.9	High
2-EFK001.55	1, 2	PRO	Fall, 2008	0.12	0.01	79.9	High
2-HAZ006.34	2, 3	SCRO	Spring, 2001	0.25	0.05	64.3	Low
2-HAZ006.34	2, 3	SCRO	Fall, 2001	0.25	0.05	73.3	Low

StationID	Ref Type[a]	Region	Sampled	TN (mg/L)	TP (mg/L)	SCI	Gradient
2-JKS028.69	1, 2, 3	WCRO	Spring, 2004	0.43	0.01	80.9	High
2-JKS028.69	1, 2, 3	WCRO	Fall, 2004	0.43	0.01	77.9	High
2-JOB001.02	1, 2, 3	WCRO	Spring, 2001	0.15	0.01	73.9	High
2-JOB001.02	1, 2, 3	WCRO	Fall, 2001	0.15	0.01	72.0	High
2-LIJ003.06	3	VRO	Spring, 2004	0.36	0.04	77.7	High
2-LIJ003.06	3	VRO	Fall, 2004	0.36	0.04	77.1	High
2-LOB000.37	2	SCRO	Spring, 2001	0.15	0.05	33.5	High
2-LOB000.37	2	SCRO	Fall, 2001	0.15	0.05	53.3	High
2-MFK002.21	1, 2	VRO	Spring, 2003	0.41	0.03	57.8	High
2-MFK002.21	1, 2	VRO	Fall, 2003	0.41	0.03	57.7	High
2-MIW003.45	1, 2, 3	VRO	Spring, 2004	0.1	0.01	84.1	High
2-MIW003.45	1, 2, 3	VRO	Fall, 2004	0.1	0.01	75.2	High
2-MRY043.42	1, 2	VRO	Spring, 2005	0.22	0.01	55.9	High
2-MRY043.42	1, 2	VRO	Fall, 2005	0.22	0.01	70.7	High
2-OGL005.53	1, 2, 3	WCRO	Spring, 2001	0.27	0.01	80.1	High
2-OGL005.53	1, 2, 3	WCRO	Fall, 2001	0.27	0.01	74.8	High
2-POL010.11	1, 2	SCRO	Spring, 2002	0.15	0.01	77.1	High
2-POL010.11	1, 2	SCRO	Fall, 2002	0.15	0.01	49.8	High
2-PTR005.13	1, 2, 3	WCRO	Spring, 2003	0.2	0.01	63.3	High
2-PTR005.13	1, 2, 3	WCRO	Fall, 2003	0.2	0.01	70.6	High
2-RED003.65	1, 2, 3	WCRO	Spring, 2004	0.54	0.03	67.9	High
2-RED003.65	1, 2, 3	WCRO	Fall, 2004	0.54	0.03	54.0	High
2-RKF026.13	1, 2, 3	VRO	Spring, 2004	0.35	0.02	69.3	High
2-RKF026.13	1, 2, 3	VRO	Fall, 2004	0.35	0.02	60.2	High
2-SMR004.80	1, 2, 3	VRO	Spring, 2001	0.15	0.01	72.8	High
2-SMR004.80	1, 2, 3	VRO	Fall, 2001	0.15	0.01	77.9	High
2-STH000.50	1, 2, 3	VRO	Spring, 2002	0.28	0.01	59.1	High
2-STH000.50	1, 2, 3	VRO	Fall, 2002	0.28	0.01	80.3	High
2-STV000.48	1, 2, 3	WCRO	Spring, 2004	0.1	0.01	79.8	High
2-STV000.48	1, 2, 3	WCRO	Fall, 2004	0.1	0.01	70.4	High
2-SUA001.55	2	SCRO	Spring, 2001	0.55	0.05	61.6	High
2-SUA001.55	2	SCRO	Fall, 2001	0.55	0.05	68.6	High
2-SWS000.90	1, 2	WCRO	Spring, 2008	0.1	0.01	77.0	High
2-SWS000.90	1, 2	WCRO	Fall, 2008	0.1	0.01	74.3	High
2-TYE008.44	1, 2	VRO	Spring, 2006	0.26	0.03	69.3	High
2-TYE008.44	1, 2	VRO	Fall, 2006	0.26	0.03	70.3	High
2-TYE008.77	1, 2, 3	VRO	Spring, 2004	0.17	0.03	79.1	High
2-TYE008.77	1, 2, 3	VRO	Fall, 2004	0.17	0.03	69.8	High
2-TYS000.85	1, 2, 3	VRO	Spring, 2002	0.35	0.02	73.7	High
2-TYS000.85	1, 2, 3	VRO	Fall, 2002	0.35	0.02	82.0	High
2-WIC004.64	1, 2	SCRO	Spring, 2004	0.42	0.02	63.6	High
2-WIC004.64	1, 2	SCRO	Fall, 2004	0.42	0.02	78.4	High
2-WLL001.83	2	SCRO	Spring, 2007	0.1	0.07	67.3	High
2-WLL001.83	2	SCRO	Fall, 2007	0.1	0.07	46.1	High
2-WLN006.90	1, 2, 3	VRO	Spring, 2002	0.18	0.01	45.0	High
2-WLN006.90	1, 2, 3	VRO	Fall, 2002	0.18	0.01	73.1	High
2-XSB000.88	1, 2	VRO	Spring, 2003	0.4	0.03	67.9	High
2-XSB000.88	1, 2	VRO	Fall, 2003	0.4	0.03	.	High
2-XUF000.55	1, 2, 3	WCRO	Spring, 2002	0.15	0.01	41.3	High

StationID	Ref Type[a]	Region	Sampled	TN (mg/L)	TP (mg/L)	SCI	Gradient
2-XUF000.55	1, 2, 3	WCRO	Fall, 2002	0.15	0.01	.	High
2-XZF000.85	1, 2	SCRO	Spring, 2007	0.13	0.02	60.0	High
2-XZF000.85	1, 2	SCRO	Fall, 2007	0.13	0.02	.	High
3-RAP008.71	3	NRO	Spring, 2001	0.45	0.03	71.9	High
3-RAP008.71	3	NRO	Fall, 2001	0.45	0.03	57.8	High
3-RAP028.98	3	NRO	Spring, 2004	0.89	0.03	71.5	High
3-RAP028.98	3	NRO	Fall, 2004	0.89	0.03	.	High
3-ROB005.42	1, 2, 3	NRO	Spring, 2001	0.65	0.03	66.4	High
3-ROB005.42	1, 2, 3	NRO	Fall, 2001	0.65	0.03	65.3	High
4ABEE001.20	1, 2, 3	SCRO	Spring, 2002	0.46	0.04	41.1	High
4ABEE001.20	1, 2, 3	SCRO	Fall, 2002	0.46	0.04	.	High
4ABOR033.22	1, 2, 3	WCRO	Spring, 2003	0.45	0.02	66.7	High
4ABOR033.22	1, 2, 3	WCRO	Fall, 2003	0.45	0.02	75.5	High
4ABWR029.51	2	WCRO	Spring, 2004	1.02	0.1	61.0	High
4ABWR029.51	2	WCRO	Fall, 2004	1.02	0.1	50.3	High
4ACEC000.82	1, 2	WCRO	Spring, 2007	0.12	0.01	64.6	High
4ACEC000.82	1, 2	WCRO	Fall, 2007	0.12	0.01	68.6	High
4AEKH003.18	1, 2, 3	SCRO	Spring, 2001	0.15	0.03	52.3	Low
4AEKH003.18	1, 2, 3	SCRO	Fall, 2001	0.15	0.03	66.9	Low
4AFSF004.02	1, 2	SCRO	Spring, 2005	0.18	0.02	62.4	High
4AFSF004.02	1, 2	SCRO	Fall, 2005	0.18	0.02	62.4	High
4AGSE015.07	1, 2	WCRO	Spring, 2006	0.43	0.03	73.8	High
4AGSE015.07	1, 2	WCRO	Fall, 2006	0.43	0.03	72.4	High
4ALBT003.07	1, 2, 3	WCRO	Spring, 2004	0.26	0.01	72.2	High
4ALBT003.07	1, 2, 3	WCRO	Fall, 2004	0.26	0.01	76.5	High
4AORR002.63	1, 2	WCRO	Spring, 2004	0.28	0.02	50.1	High
4AORR002.63	1, 2	WCRO	Fall, 2004	0.28	0.02	69.7	High
4AOWC004.37	1, 2	SCRO	Spring, 2001	0.25	0.01	62.2	High
4AOWC004.37	1, 2	SCRO	Fall, 2001	0.25	0.01	76.3	High
4APAA000.24	1, 2	WCRO	Spring, 2001	0.25	0.03	54.4	High
4APAA000.24	1, 2	WCRO	Fall, 2001	0.25	0.03	55.9	High
4ARSF007.29	1, 2	WCRO	Spring, 2005	0.49	0.01	72.1	High
4ARSF007.29	1, 2	WCRO	Fall, 2005	0.49	0.01	76.8	High
4ASRV012.19	1, 2, 3	SCRO	Spring, 2001	0.15	0.02	63.6	Low
4ASRV012.19	1, 2, 3	SCRO	Fall, 2001	0.15	0.02	67.1	Low
4AXMX003.62	1, 2	WCRO	Spring, 2006	0.39	0.03	75.2	High
4AXMX003.62	1, 2	WCRO	Fall, 2006	0.39	0.03	62.5	High
4AXMY000.22	1, 2	WCRO	Spring, 2006	0.19	0.02	82.6	High
4AXMY000.22	1, 2	WCRO	Fall, 2006	0.19	0.02	68.1	High
4AXNB000.60	1, 2	WCRO	Spring, 2006	0.14	0.02	74.4	High
4AXNB000.60	1, 2	WCRO	Fall, 2006	0.14	0.02	32.4	High
4AXUO000.49	1, 2	WCRO	Spring, 2004	0.5	0.02	71.8	High
4AXUO000.49	1, 2	WCRO	Fall, 2004	0.5	0.02	68.2	High
5AFON024.32	3	PRO	Spring, 2003	0.72	0.04	72.4	Low
5AFON024.32	3	PRO	Fall, 2003	0.72	0.04	74.5	Low
5ANMR007.11	3	SCRO	Spring, 2002	0.37	0.03	73.6	High
5ANMR007.11	3	SCRO	Fall, 2002	0.37	0.03	.	High
5ANTW093.62	3	PRO	Spring, 2004	0.67	0.04	69.5	High
5ANTW093.62	3	PRO	Fall, 2004	0.67	0.04	73.5	High

StationID	Ref Type[a]	Region	Sampled	TN (mg/L)	TP (mg/L)	SCI	Gradient
5ARSK003.66	3	PRO	Spring, 2004	0.45	0.05	63.1	Low
5ARSK003.66	3	PRO	Fall, 2004	0.45	0.05	57.1	Low
5ARYR001.23	2	PRO	Spring, 2006	1.21	0.1	14.7	High
5ARYR001.23	2	PRO	Fall, 2006	1.21	0.1	28.0	High
5AXEJ001.73	1, 2	PRO	Spring, 2001	0.25	0.02	36.7	Low
5AXEJ001.73	1, 2	PRO	Fall, 2001	0.25	0.02	45.8	Low
5AXHR000.32	1, 2	PRO	Spring, 2008	0.27	0.02	69.7	High
5AXHR000.32	1, 2	PRO	Fall, 2008	0.27	0.02	48.4	High
6AFOX001.69	1, 2, 3	SWRO	Spring, 2004	0.3	0.01	75.8	High
6AFOX001.69	1, 2, 3	SWRO	Fall, 2004	0.3	0.01	66.6	High
6BDRA001.07	1, 2	SWRO	Spring, 2005	0.26	0.01	79.1	High
6BDRA001.07	1, 2	SWRO	Fall, 2005	0.26	0.01	.	High
6BLSR004.78	1, 2, 3	SWRO	Spring, 2004	0.18	0.01	77.6	High
6BLSR004.78	1, 2, 3	SWRO	Fall, 2004	0.18	0.01	62.0	High
6CLAL001.79	1, 2	SWRO	Spring, 2007	0.38	0.01	67.7	High
6CLAL001.79	1, 2	SWRO	Fall, 2007	0.38	0.01	71.8	High
6CSFH084.73	1, 2, 3	SWRO	Spring, 2002	0.62	0.04	60.5	High
6CSFH084.73	1, 2, 3	SWRO	Fall, 2002	0.62	0.04	61.5	High
6CSFH098.10	3	SWRO	Spring, 2004	0.68	0.01	74.3	High
6CSFH098.10	3	SWRO	Fall, 2004	0.68	0.01	75.7	High
8-LOC001.31	1, 2	PRO	Spring, 2004	0.45	0.04	48.3	Low
8-LOC001.31	1, 2	PRO	Fall, 2004	0.45	0.04	53.3	Low
8-PGN002.42	1, 2	NRO	Spring, 2006	0.18	0.01	59.2	High
8-PGN002.42	1, 2	NRO	Fall, 2006	0.18	0.01	68.0	High
8-POR015.70	1, 2	NRO	Spring, 2004	0.3	0.03	65.7	Low
8-POR015.70	1, 2	NRO	Fall, 2004	0.3	0.03	53.9	Low
8-POR024.64	1, 2	NVRO	Spring, 2008	0.23	0.04	65.8	High
8-POR024.64	1, 2	NVRO	Fall, 2008	0.23	0.04	72.1	High
9-CPL009.78	1, 2	SWRO	Spring, 2005	0.97	0.01	69.6	High
9-CPL009.78	1, 2	SWRO	Fall, 2005	0.97	0.01	70.9	High
9-CPL012.73	1, 2	SWRO	Spring, 2006	0.5	0.02	79.3	High
9-CPL012.73	1, 2	SWRO	Fall, 2006	0.5	0.02	69.2	High
9-DDD006.61	1, 2, 3	WCRO	Spring, 2003	0.43	0.01	83.4	High
9-DDD006.61	1, 2, 3	WCRO	Fall, 2003	0.43	0.01	77.9	High
9-DPW002.31	1, 2	SWRO	Spring, 2008	0.1	0.01	81.3	High
9-DPW002.31	1, 2	SWRO	Fall, 2008	0.1	0.01	.	High
9-FRS000.16	1, 2	SWRO	Spring, 2008	0.56	0.01	78.4	High
9-FRS000.16	1, 2	SWRO	Fall, 2008	0.56	0.01	80.3	High
9-LEF005.25	1, 2	SWRO	Spring, 2006	0.55	0.01	70.8	High
9-LEF005.25	1, 2	SWRO	Fall, 2006	0.55	0.01	71.9	High
9-LFK005.39	1, 2	SWRO	Spring, 2005	0.15	0.01	59.1	High
9-LFK005.39	1, 2	SWRO	Fall, 2005	0.15	0.01	70.2	High
9-LRV004.89	1, 2	WCRO	Spring, 2005	0.58	0.01	60.0	High
9-LRV004.89	1, 2	WCRO	Fall, 2005	0.58	0.01	57.7	High
9-MER002.99	1, 2	SWRO	Spring, 2008	0.1	0.01	37.7	High
9-MER002.99	1, 2	SWRO	Fall, 2008	0.1	0.01	.	High
9-SFK002.81	1, 2, 3	SWRO	Spring, 2004	0.14	0.01	68.1	High
9-SFK002.81	1, 2, 3	SWRO	Fall, 2004	0.14	0.01	59.0	High
9-WFC010.66	1, 2, 3	WCRO	Spring, 2001	0.31	0.01	76.8	High

StationID	Ref Type[a]	Region	Sampled	TN (mg/L)	TP (mg/L)	SCI	Gradient
9-WFC010.66	1, 2, 3	WCRO	Fall, 2001	0.31	0.01	69.0	High
9-WLK024.17	1, 2, 3	WCRO	Spring, 2001	0.15	0.01	63.2	High
9-WLK024.17	1, 2, 3	WCRO	Fall, 2001	0.15	0.01	69.8	High
9-WLK026.82	1, 2	WCRO	Spring, 2003	0.65	0.02	65.4	High
9-WLK026.82	1, 2	WCRO	Fall, 2003	0.65	0.02	61.4	High
9-XDP000.65	1, 2, 3	SWRO	Spring, 2003	0.48	0.02	71.5	High
9-XDP000.65	1, 2	SWRO	Fall, 2003	0.48	0.02	40.6	High
9-XEO000.57	1, 2	SWRO	Spring, 2007	0.3	0.02	71.5	High
9-XEO000.57	1, 2	SWRO	Fall, 2007	0.3	0.02	78.7	High

[a] Reference Type 1 satisfies all of the reference-filter conditions of Tables 1 and 2; Type 2 satisfies all Table 1 and 2 conditions except the TN and TP limits; Reference Type 3 were identified as reference sites in the SCI validation study (DEQ, 2006).

Appendix C: Nutrient Criteria Visual Assessment Field Form – 2009

Station ID:	Field Crew:
Stream Name:	Ecoregion:
DEQ Region:	**TP Category**
Location:	**TN Category**

DATE______________ Start Time_________________________Finish Time________

LATITUDE (Decimal degrees) _____________ LONGITUDE (Decimal degrees) ________________________

Stream Physicochemical Measurements

TEMPERATURE:________________ºC

CONDUCTIVITY:________________µS/cm

DISSOLVED OXYGEN:___________mg/L

pH: ____________

Benthic Macroinvertebrate Collection

Method used (circle one) **Single habitat** **Multi-habitat**

Riffle quality (circle one) **Good** **Marginal** **Poor** **None**

Habitats sampled	**Riffle**	**Snags**	**Banks**	**Vegetation**
# jabs	____	____	____	_____

Algae Community and Vascular Plant Growth

Algae community growth (% of stream bottom) **Categories; 1-10; 10-40; 40-70; >70**

Type of growth	bright green	dark green	brown	black	other
Film					
Thin mat					
Thick mat					
Short Filamentous					
Tall Filamentous					

Vascular plant growth (% of stream bottom) **Categories; 1-10; 10-40; 40-70; >70**

Submerged macrophytes	
Emergent macrophytes	
Mosses	
Other	

Total stream-bottom coverage by algae growth _________
(Categories; 1-10; 10-40; 40-70; >70)

Total stream-bottom coverage by vascular plant growth _________
(Categories; 1-10; 10-40; 40-70; >70)

Total stream-bottom coverage by algae and vascular plant growth _________
(Categories; 1-10; 10-40; 40-70; >70)

Observations

Stream Substrate Type Categories; 1-10; 10-40; 40-70; >70	**sand**	**gravel**	**cobble**	**bedrock**	**mud**
	____	_____	_______	_______	____

Estimated average stream width (Meters): ____________________________________

Estimated average stream depth (Meters): ____________________________________

Stream shading: (circle one) **Full shade** **Partial shade** **Full sun**

Stream flow (circle one) **Low** **Normal** **Above Normal**

Estimated stream velocity (Meters/sec): _________________________

Days since last potentially scouring rain: ________________

Photo documentation taken? **YES / NO**

BPJ based on observations of algae and macrophyte biomass; probability of impairment to macroinvertebrate community by nutrients (circle one):

Low **Medium** **High**

Provide a brief explanation for rating: ____

____

BPJ based on general observations: probability of impairment to macroinvertebrate community by non-nutrient stressor (circle one and state suspected non-nutrient stressor(s))

Low **Medium** **High** **Stressor(s)_______________________**

Provide a brief explanation for rating: ____

____

Watershed Features

Land Use: (Indicate the predominant surrounding land use with a "1". If applicable, indicate a secondary land use with a "2".)

____ Forest **____Field/Pasture** **____Agricultural** **____Livestock**

____ Commercial **____Industrial** **____Residential** **____Other**

Local Watershed Pollution (circle one) **No evidence** **Some potential sources** **Obvious sources**

Local Watershed Erosion (circle one) **None** **Moderate** **Low** **Heavy**

Appendix D: Revised Nutrient Criteria Visual Assessment Field Form (2/2010)

Station ID: Field Crew:

Stream Name: Location:

DEQ Region:

DATE Start Time: Finish Time:

Benthic Macroinvertebrate Collection

Method used (circle one) Single habitat Multi-habitat

Riffle quality (circle one) Good Marginal Poor None

Habitats sampled (# jabs): Riffle _____ Snags_____ Banks_____ Vegetation ______

Algae Community and Vascular Plant Growth

Algae community growth: % of stream bottom (0%; 1-10%; 10-40%; 40-70%; >70%)

Film	
Thin mat	
Thick mat	
Short Filamentous	
Tall Filamentous	

Vascular plant growth: % of stream bottom (0%; 1-10%; 10-40%; 40-70%; >70%)

Submerged macrophytes	
Emergent macrophytes	
Mosses	
Other	

Total Stream Bottom coverage: Categories: 0%, 1-10%; 10-40%; 40-70%; >70%

By Algae

Mat and fila-mentious only	
All: inc. mat, filamentous, film	

By Vascular Plants

Macrophytes only:	
Total: Macrophytes and Mosses	

By Algae and Plants

Mat & filamentous algae, macrophytes	
Total: All algae and vascular plant forms	

Best Professional Judgment of Impairment

(† If Visual Assessment Indicates "High" probability of impairment, please take a photograph)

BPJ based on observations of algae and macrophyte biomass; probability of impairment to macroinvertebrate community by nutrients (circle one):

Low **Medium** **High** †

Please provide a brief explanation for rating:

BPJ based on general observations: probability of impairment to macroinvertebrate community by non-nutrient stressor (circle one and state suspected non-nutrient stressor(s))

Low **Medium** **High** † **Stressor(s)**______________________________

Please provide a brief explanation for rating:

Observations

Stream Substrate Type (0%, 1-10%, 10-40%, 40-70%, >70%):

sand ____ gravel _____ cobble_____ bedrock_____ mud_____

Est. average stream width (meters):__________ **Est. average depth** (meters): ________

Shading (circle): Full shade, partial shade, Full sun **Stream flow** (circle): Low, Normal, Above Normal

Development of Freshwater Nutrient Criteria for Non-Wadeable Stream in Virginia: Fish Community Assessment, Phase IV

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Introduction

The complex ecological and biological relationships among nutrient concentrations and fishes in freshwater systems, including streams, lakes, and reservoirs, are documented by a large and diverse literature. Many such studies focus on the role of nutrients in determining rates of secondary production (and, therefore, potential yields) of higher trophic levels, including fishes (e.g. Dodds, et al. 2002), nutrient cycling and spiraling (e.g. Griffiths 2006), and the effects of nutrient releases from aquaculture facilities (e.g. Dalsgaard and Krause-Jensen 2006). The impact of nutrient enrichment (eutrophication) from anthropogenic sources on aquatic systems has also been widely-studied and is considered a serious threat to aquatic ecosystem health and function (EPA 1998). In response, many U.S. jurisdictions have moved to develop and implement regional nutrient criteria, with the goal of protecting aquatic living resources, including fishes. Frequently, measures (indices) of biotic assemblages (fish and macroinvertebrates) are used to assess stream health, integrity, and, indirectly, water quality. However, only a limited number of published studies (e.g. Wang, et al. 2006) have examined *directly* the putative effects of cultural eutrophication on fish community structure and function in streams, and only a few of these reports (e.g. Morgan, et al. 2007) have focused on the mid-Atlantic region.

At a 2006 meeting of an Academic Advisory Committee working group focused on establishing numeric nutrient criteria for Virginia's streams, participants discussed several potential approaches for linking nutrient concentrations and criteria to aquatic life use standards in larger (i.e., non-wadeable) streams and rivers. Specifically, the subcommittee reasoned that fish community structure may be a useful diagnostic of nutrient-related effects in such systems, which are typically too large for standard benthic macroinvertebrate sampling protocols. The subcommittee proposed a preliminary analysis, using existing data, to determine whether statistically significant relationship(s) exist among a limited suite of variables representing nutrient conditions and fish community structure, and at broad geospatial scales. If such a relationship can be demonstrated, based on analyses with archival data alone, additional future analyses and targeted database development may support the establishment and validation of ecologically-based, and scientifically defensible, numeric nutrient criteria for larger (i.e., non-wadeable) lotic ecosystems.

Previous studies for the AAC (Garman, et al. 2007 & 2008; Garman and Shuart 2009) completed preliminary analyses of archived fish community and nutrient data for streams and rivers in the Virginia Coastal Zone. These analyses were based on an extensive database of fish community metrics for Chesapeake Bay freshwater systems and DEQ's nutrient concentration data (TP, TN) and algal biomass data (Chl-a) from that agency's ambient monitoring program. These earlier studies had the following objectives: 1.) create a working database by combining and distilling large amounts of archival data representing nutrient concentrations and fish community structure from multiple sources, and 2.) conduct simple correlation analyses to test the hypothesis that derived measures of nutrient conditions and stream health (fish communities) may be related statistically and could, therefore, be the basis for future predictive models and nutrient criteria thresholds. Previous reports (Garman, et al. 2007 & 2008; Garman and Shuart 2009) demonstrated that statistical relationships among fish community indices (modified Index of Biotic Integrity, mIBI) and nutrient concentrations (DEQ ambient monitoring) may be useful in developing nutrient criteria related to both localized and downstream effects. Unfortunately, these preliminary analyses were constrained limited by several factors, including the lack of temporally and spatially synoptic data for nutrients and fish community health, representation by only a few basins, and the inability to separate wadeable and non-wadeable ambient monitoring stations within the DEQ/STORET database.

2010 Objectives

1.) Provide an expanded explanation of the INSTAR methodology, database, and approach to stream health assessment;
2.) Identify and incorporate new biological and nutrient data—not available in 2009—for both wadeable and non-wadeable and re-run analyses, as appropriate.
3.) Revise draft nutrient criteria for the identification (and assumed protection) of ecologically healthy streams, based on fish community assessment, as appropriate based on new data.
4.) Develop a draft proposal, for eventual submission to EPA, to develop objective and repeatable, ecoregion-specific criteria for the classification of streams as non-wadeable.

Approach and Methods

DEQ monitoring data representing ambient nutrient concentrations (total nitrogen, TN; total phosphorus, TP; mg/l) and algal biomass (as Chlorophyll *a*, Chl-a; ug/l) at georeferenced stream locations were downloaded to a VCU server for post-processing in April, 2009. These data (provided by Mr. Roger Stewart, Virginia DEQ) were 'filtered' by location (Chesapeake Bay drainages), content (availability of all three nutrient parameters and minimum n=10 per station) and other criteria (e.g. stream characteristics, date range), producing a working database of approximately 32,000 records. The final DEQ data were joined to a subset of the fish community database maintained by VCU's INSTAR stream assessment program (http://INSTAR.vcu.edu) , which generates stream health (i.e., biotic integrity) scores at stream reach and watershed spatial scales, based on empirical data and established models for fish community structure and function (described below). Data ranges for TN, TP, and Chl-a in the final dataset were divided into equal categories based on quartiles, i.e., TN category 1 represents the lowest concentrations of the range, while category 4 represents the highest concentrations. Nutrient data were not distributed normally.

Because no objective criteria exist to identify streams as non-wadeable and quantitative and large-river data for fish communities in Virginia are limited, nutrient data and fish community metrics were combined (pooled) to generate descriptive statistics (means and percentiles) for 6th-order watersheds (hydrologic units, HUCs) in the Chesapeake Bay basin for each selected parameter and all stream reaches. Some HUCs did not have sufficient data (nutrients and/or fish) and were eliminated from further analysis. Preliminary analysis suggested that stream fish assemblages in the Coastal Zone may respond differently to nutrient and trophic status. Coastal HUCs were, therefore, separated from non-coastal regions (i.e., Piedmont and Ridge and Valley) for subsequent, watershed-scale analyses. The fall-zone (inferred from Interstate 95) was used as the line of separation for coastal *versus* non-coastal watersheds. Analyses conducted at the watershed scale included fish community data from wadeable and non-wadeable streams. This analysis assumed that DEQ ambient monitoring stations within 500 meters of an INSTAR location represented the same stream reach. The small size of this reach-specific dataset for non-wadeable streams reflects, in part, the lack of relevant, archival data for large streams and rivers in Virginia.

For 2010, a limited number (n=21) new, paired datapoints for nutrients and INSTAR stream health assessment, generated by DEQ's ProbMon program and other VCU data (e.g. Richmond

County Project, Garman, et al. 2009), were incorporated into the prior (2009) assessment of Chesapeake Bay HUCs, and the augmented database was re-analyzed. In 2010, we were also able to expand slightly the previously limited (Garman & Shuart 2009) *paired* dataset of spatially co-incident nutrient values and fish health metrics for putative *non-wadeable* (> 3rd order) streams and rivers within the Chesapeake basin through the inclusion of new synoptic INSTAR and nutrient data generated for Richmond County, Virginia, as part of an unrelated research project funded by Virginia Department of Conservation and Recreation (Garman, et al. 2009). These additions to the database primarily represented coastal streams.

Geospatial analyses were conducted using ESRI's ArcGIS version 9.3. Statistical comparisons across nutrient categories and between 'healthy' and 'compromised' stream fish assemblages were based on nonparametric Chi-square tests (alpha=0.05). More detailed methods and data descriptions are provided below:

Stream Nutrient Concentrations and Trophic Status: The following nutrient parameters were selected from the DEQ ambient monitoring database and developed for further analysis: total nitrogen concentration (TN, mg/l; Figure 1), total phosphorus concentration (TP, mg/l; Figure 2) and chlorophyll-*a* concentration (Chl-a, ug/l; Figure 3). Chlorophyll-a concentration is indicative of the trophic status of a water body and high Chl-a values generally indicate eutrophication. A detailed description of DEQ's ambient monitoring program for nutrients is provided at: http://www.deq.virginia.gov/watermonitoring/aqm.html.

Water chemistry analyses were performed on samples collected from streams within Richmond County during Fall 2008 and Spring 2009. Analyses included dissolved and total fractions of nitrogen and phosphorus (soluble reactive P, nitrate, ammonium, total N and total P) as well as chloride and total suspended solids. Analytical procedures followed standard EPA protocols as described in the VCU Environmental Analyses Laboratory Operating Procedures Guide. An average value for each site was derived from two duplicate samples collected at the top and bottom of the study reach. Variation in nutrient concentrations was used to identify sites experiencing anthropogenic loading associated with agricultural or wastewater sources. Total suspended solids (TSS) were used to identify sites exhibiting elevated inputs of sediment due to land use practices. Chloride was used as an indicator of wastewater inputs for non-tidal streams. Statistical relationships were investigated to assess co-variation in water chemistry, land-use and fish-based indices of stream condition (Virtual Stream Assessment scores; VSA).

Stream Fish Community Assessment: The ***INSTAR*** application (http://instar.vcu.edu) and the extensive aquatic resource database on which it runs, were developed to support a variety of stream assessment and planning activities aimed at restoring and protecting water quality and aquatic living resources throughout the Commonwealth. In addition, regional reference stream models (i.e., *virtual* streams) for both non-tidal and small to medium-sized tidal tributaries are developed as criteria for prioritization of candidate streams and watersheds for protection and restoration, objective and quantitative performance measures, and as a decision support tool for environmental planning and implementation. Currently, *INSTAR* has compiled information on approximately 2,200 Virginia streams and *INSTAR* databases comprise over 245,000 records. Probabilistic study reaches for *INSTAR* sampling were selected through a statistically powerful, stratified (by stream order) random design. Although INSTAR compiles data for both aquatic macroinvertebrates and fishes, only fish community data were included in this analysis. Within each geo-referenced reach (150-500 m), fishes are sampled quantitatively using electrofishing equipment (backpacks, tote barge units, boats) and EPA QAPP methods. Backpack and tote barge sampling is performed throughout the entire reach in a single pass. Boat electrofishing may include additional sampling effort depending on stream width and habitat variability. Fish community data collected as part of DEQ's ProbMon program and other data sources were included, where appropriate.

INSTAR data are compiled into databases and application macros calculated for over 50 separate ecological metrics, including those typically generated for Index of Biotic Integrity (IBI) and Rapid Bioassessment Protocol (RBP) assessments. Variables and metrics will be subjected to ordination and cluster analysis using unimodal models (e.g. correspondence analysis (CA), detrended correspondence analysis (DCA), and canonical correspondence analysis (CCA)) and linear response models (e.g. principal components analysis (PCA), multiple regression techniques). The site scores (i.e., coefficients from the final response model) will be entered as the response variable and significant ($P<0.05$) biotic and abiotic variables and metrics are entered as explanatory variables. Finally, a series of reference stream models (i.e., *virtual* reference streams) will be created for each ecoregion and stream order. We will then use Gower's similarity index to compare empirical scores obtained from sampled stream reaches to the appropriate virtual reference stream, generating an index of stream health as a measure of percent comparability to the appropriate (virtual) reference condition model (i.e., Virtual Stream Assessment, VSA, score; range 0-100%) for all sampled sites in Virginia and Maryland portions of the Potomac River Basin. Fish assemblages with high percent comparability scores (VSA scores > 71%) were assumed to represent streams with high ecological integrity (i.e., healthy and exceptional categories). Conversely, fish assemblages with low VSA scores (< 57%) were assumed to represent biologically degraded streams (i.e., compromised category). These 'healthy' and 'degraded' VSA categories generally represented +/- 1 standard error of the mean VSA score from the distribution of all VSA scores in the database. Only those INSTAR stream locations in upper and lower categories were included in 2009 analyses, based on the assumption that streams representing mid-range VSA scores (58-70%) are less likely to be influenced by ambient nutrient concentrations. For a more detailed description of the INSTAR program, visit http://instar.vcu.edu.

Findings

Stream nutrient concentrations (mg/l) averaged 1.57 and 0.98 and ranged up to 47.22 and 4.42 for TN and TP, respectively. Chlorophyll *a* concentrations averaged 2.97 ug/l and ranged up to 52.58 ug/l). Coastal zone watersheds classified as 'degraded' based on stream fish community assessments were strongly associated (Chi-square test, $p<0.01$; Table 1). For both TN and Chl-a, the relationship was positive, i.e., there were significantly more degraded streams in HUCs with the highest nutrient values (Figure 5). In non-coastal watersheds, only the association between stream health and Chl-a values was significant ($p<0.01$), suggesting that trophic status as inferred from Chl-a concentrations is the best predictor of compromised stream health in both coastal and noncoastal regions. Stream nutrient concentrations and trophic status were also associated statistically (Chi-square test, $p<0.05$; Table 1) with high ecological integrity ('healthy') streams. For example, there were significantly more healthy streams in coastal and noncoastal watersheds with the lowest Chl-a values (Figure 6). In contrast, the relationship between TN concentrations and high biotic integrity was unimodal, with the greatest representation of healthy streams at intermediate TN concentrations. These findings suggest that Chl-a and TN may be better predictors of stream health than TP; the associations between Chl-a and the incidence of healthy or degraded streams in a given HUC were statistically significant for both coastal and noncoastal regions.

Analysis of paired, reach-level data for nonwadeable streams and rivers (Figures 9-11) generally mirrored the statistically significant relationships demonstrated by watershed-scale analyses of wadeable and nonwadeable streams combined (Table 1, Figures 6-8). Specifically, Chl-a mean concentrations were strongly and negatively correlated (Figure 11) and no stream reaches classified as biologically healthy were observed at paired Chl-a values above 0.25 ug/l. The relationship between fish community healthy and TN concentrations was also negative (Figure 9) but depended on a single observation. No streams classified as healthy were observed at paired TN values above 2.0 mg/l. There was no obvious relationship between stream health and TP concentrations (Figure 10).

The limited addition of new data in 2010 did not alter substantially the relationships between nutrient status and stream health described in our earlier (2009) report. In some cases (e.g. Table 1; Fig. 9) the new data significantly strengthened the previous relationships. Research objectives for 2010 continue to be constrained by the relative lack of appropriate (i.e., synoptic and reach-specific) data for large (putative non-wadeable) streams and by the lack of an objective definition of 'non-wadeable.' A likely solution to the latter problem is to develop regression-based models of catchment area and wadeability based on on-site assessments by fish and macroinvertebrate biologists. DEQ's ProbMon program should provide ample data for such an analysis, which is the basis of a proposal currently under development by VCU.

The analyses suggest that nutrient criteria for the protection of biologically healthy streams and rivers are supported by simple, but statistically significant, models of relationships among TN, Chl-a, and VSA scores. For the watershed scale analysis, the proposed 'protection' criteria are as follows: TN < 0.66 mg/l and Chl-a < 0.88 ug/l for coastal and noncoastal streams. The paired, reach-level analysis of nonwadeable streams, based on a much smaller sample size, suggests the following criteria for healthy stream protection: TN < 2.0, Chl-a < 0.25 ug/l. Criteria based on TP concentrations are not supported by this analysis.

Summary

1.) Statistically significant relationships were documented among TN, Chlorophyll-a, and to a lesser degree TP, and fish community-based (INSTAR) stream health metrics using an expanded database (n=35,000 records, DEQ ambient monitoring) of all Chesapeake basin watersheds (6th-order HUCs) in Virginia. Some of these relationships (e.g. Chl-a and VSA score) were relatively strong predictors of both healthy and degraded stream assemblages and might reasonably serve as the basis for establishing biologically valid nutrient criteria. Some of the strong associations between nutrients and trophic status and fish community structure at watershed scales were corroborated by analysis of a much smaller database of paired, nonwadeable streams and rivers. Specifically, fish community metrics were strongly and negatively correlated with TN and Chl-a concentrations in 77 putative nonwadeable streams.
2.) Proposed, *conservative* criteria for the protection of high quality nonwadeable streams are as follows: TN < 2.0 mg/l and Chl-a < 0.88 ug/l. At this time, criteria based on TP may not be warranted.
3.) Differences did exist between responses of coastal *versus* non-coastal stream fish assemblages to nutrient and trophic status, but the geographic differentiation may not warrant separate nutrient criteria for streams. However, this issue should be explored in more detail.
4.) Chlorophyll-*a* concentration appears to be the most promising predictor of ecological health in nonwadeable streams, and therefore the most likely basis for establishing nutrient criteria

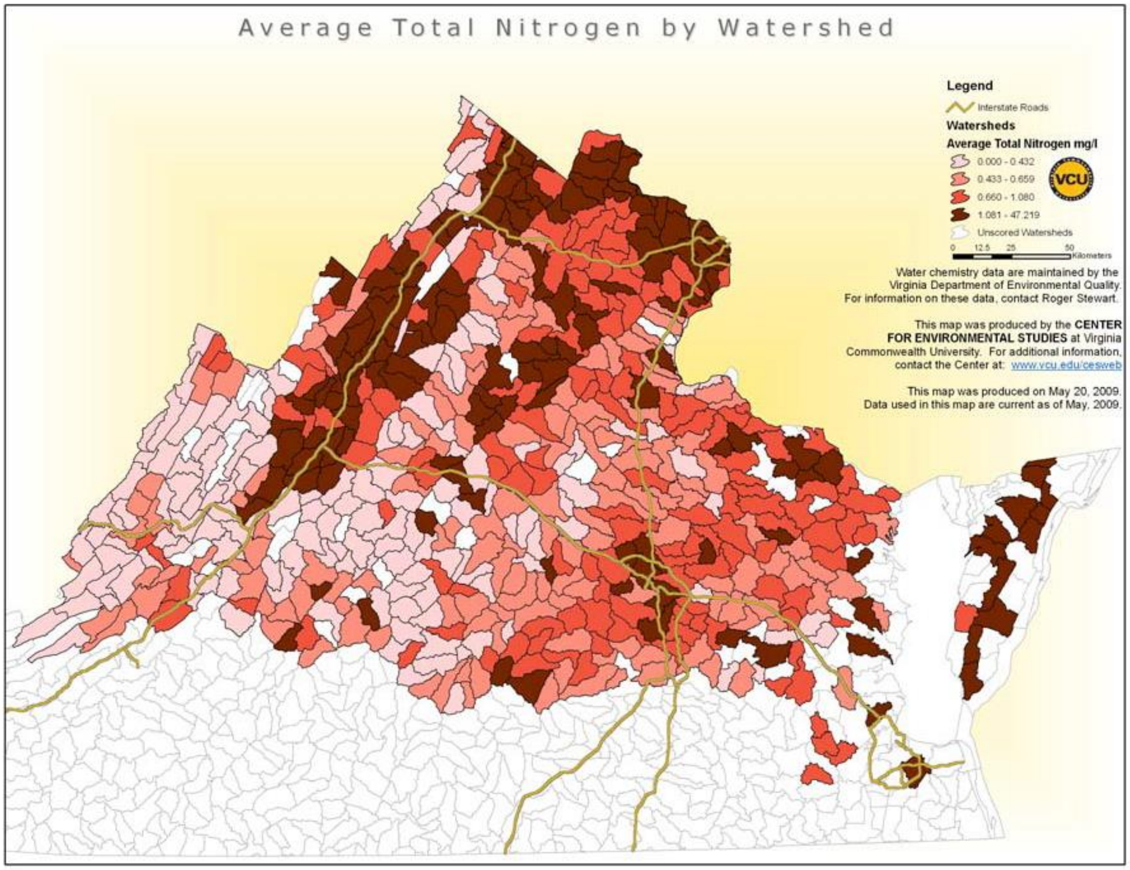
based on fish community structure; however, the availability of Chl-a data is limited, compared to other parameters including TP and TN.

5.) Future efforts should focus on: a.) expanding the paired database for nonwadeable streams and rivers through additional data mining and GIS analysis, b.) refining the proposed nutrient criteria for TN and Chl-a based on this expanded coverage, c.) leverage ongoing fieldwork (e.g. DEQ's ProbMon Program) to develop a separate and synoptic database of nutrient and fish community metrics that can be used to formally validate proposed nutrient criteria for nonwadeable streams in Virginia and d.) expand the discussion statewide into non-Bay drainages.

Table 1. Summary of statistical comparisons across nutrient (TN, TP, Chl-a) categories for watersheds classified as 'healthy' or 'degraded' based on INSTAR assessment of fish communities in coastal and non-coastal streams and rivers (Chesapeake Bay basin). The analyses tested the null hypothesis that classified streams were distributed uniformly or randomly among nutrient categories. Rejection of the null suggests that stream biological health is significantly associated with nutrient or trophic status. All data were pooled by watershed (HUC). Statistically significant relationships are described as 'positive,' 'negative,' or 'unimodal.' Refer to Figures 5-8 for specific comparisons.

	TN		TP		Chl-a	
	Coastal	Noncoastal	Coastal	Noncoastal	Coastal	Noncoastal
Degraded Streams	** positive	n.s.	** unimodal	n.s.	** positive	** positive
Healthy Streams	** unimodal	* unimodal	* positive	n.s.	* negative	* negative

** alpha <0.01, * alpha <0.05, n.s.=not significant



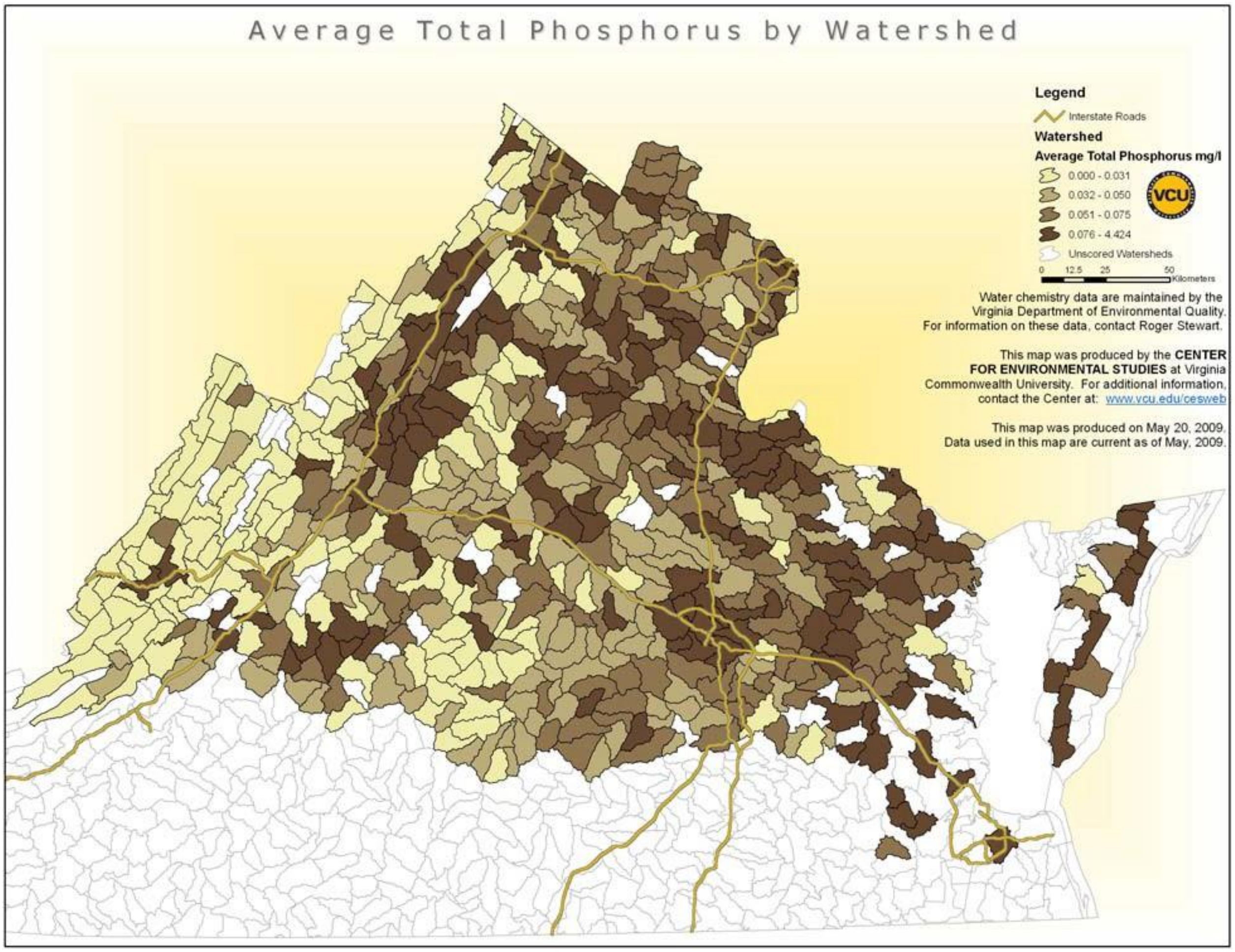
Average Total Nitrogen by Watershed

Water chemistry data are maintained by the Virginia Department of Environmental Quality. For information on these data, contact Roger Stewart.

This map was produced by the **CENTER FOR ENVIRONMENTAL STUDIES** at Virginia Commonwealth University. For additional information, contact the Center at: www.vcu.edu/cesweb

This map was produced on May 20, 2009. Data used in this map are current as of May, 2009.

Figure 1. Distribution of total nitrogen concentrations (TN, mg/l) for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.


Average Total Phosphorus by Watershed

Water chemistry data are maintained by the Virginia Department of Environmental Quality. For information on these data, contact Roger Stewart.

This map was produced by the **CENTER FOR ENVIRONMENTAL STUDIES** at Virginia Commonwealth University. For additional information, contact the Center at: www.vcu.edu/cesweb

This map was produced on May 20, 2009. Data used in this map are current as of May, 2009.

Figure 2. Distribution of total phosphorous concentrations (TP, mg/l) for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.

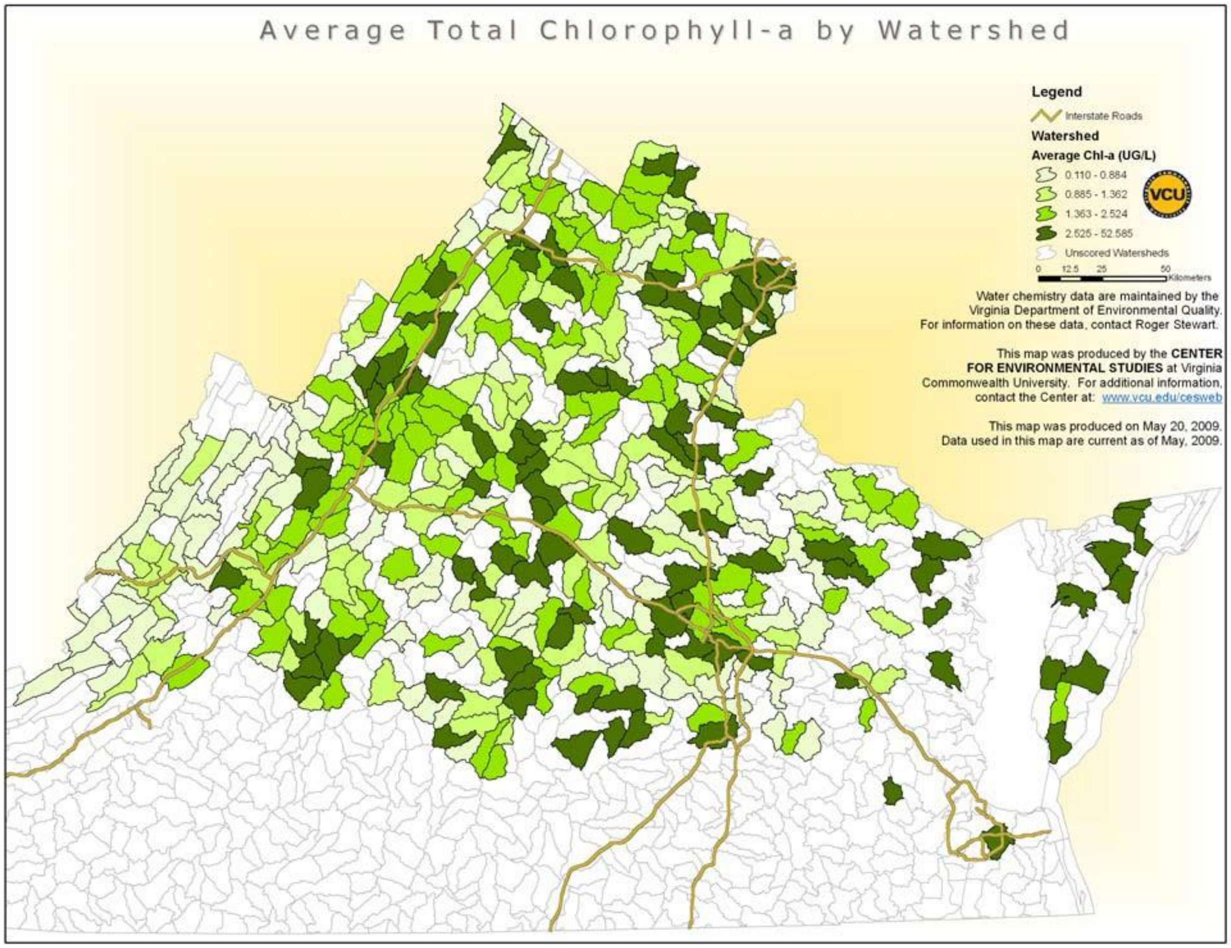


Figure 3. Distribution of Chlorophyll-*a* concentrations (Chl-*a*, ug/l) for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.

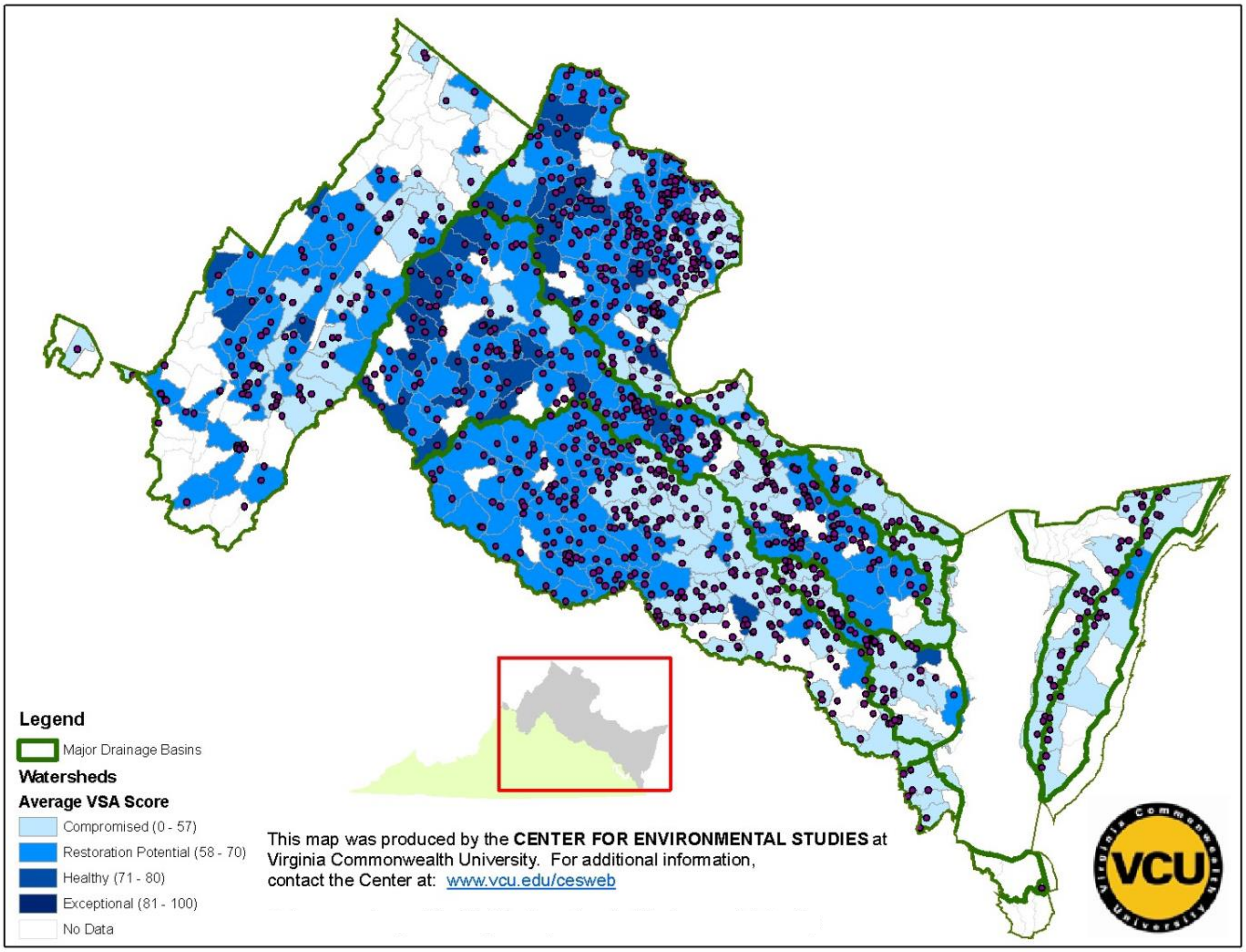


Figure 4. Stream health classification (INSTAR fish assemblage models) for streams in 6th-order hydrologic units in the Chesapeake Bay basin, Virginia. Categories are based on the mean VSA score (percent comparability to appropriate virtual reference condition). Breakpoints for stream health categories are based on the mean, +/-1 standard error, and + 2 standard errors of the distribution of n=1,033 randomly selected VSA scores for INSTAR stream reaches. HUCs in the 'exceptional' and 'healthy' categories are dominated by streams exhibiting high ecological integrity. Points represent individual quantitative (electrofishing) collections for selected HUCs.

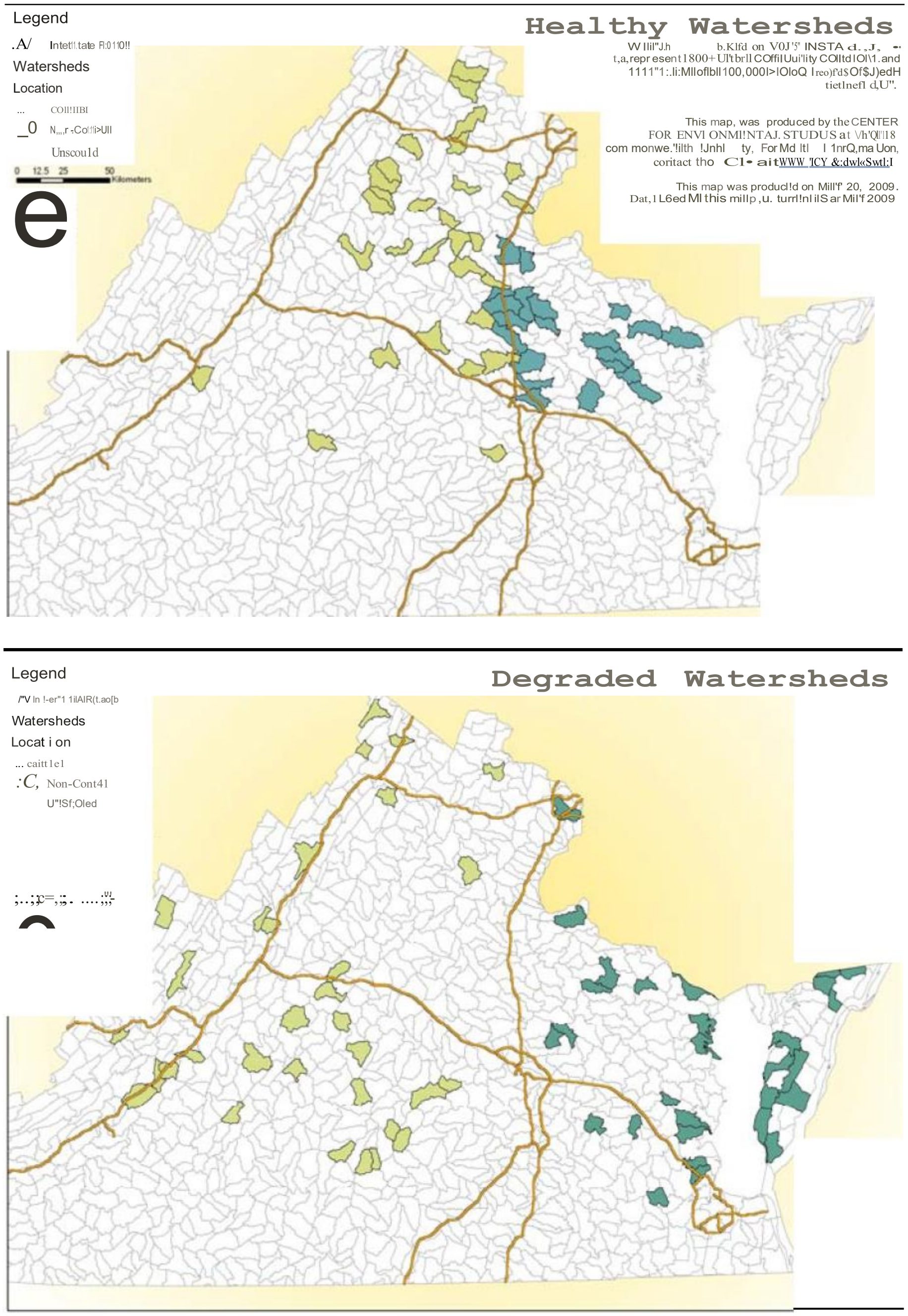
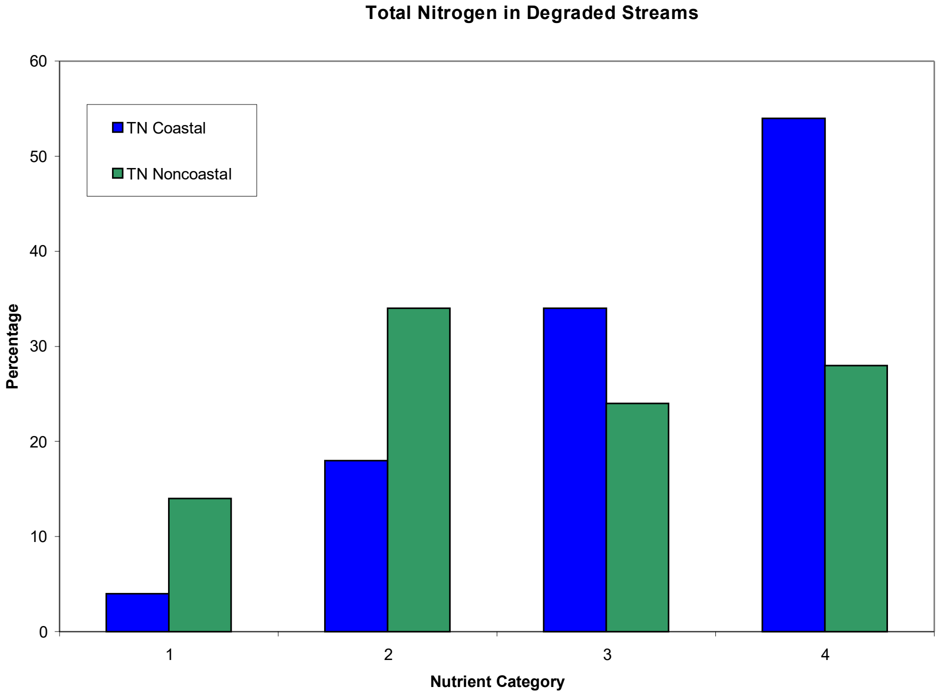


Figure 5. Watersheds (6th-order HUCs) classified as ‘healthy’ or ‘degraded’ based on INSTAR assessment of fish community data. Refer to the text for a more detailed explanation.



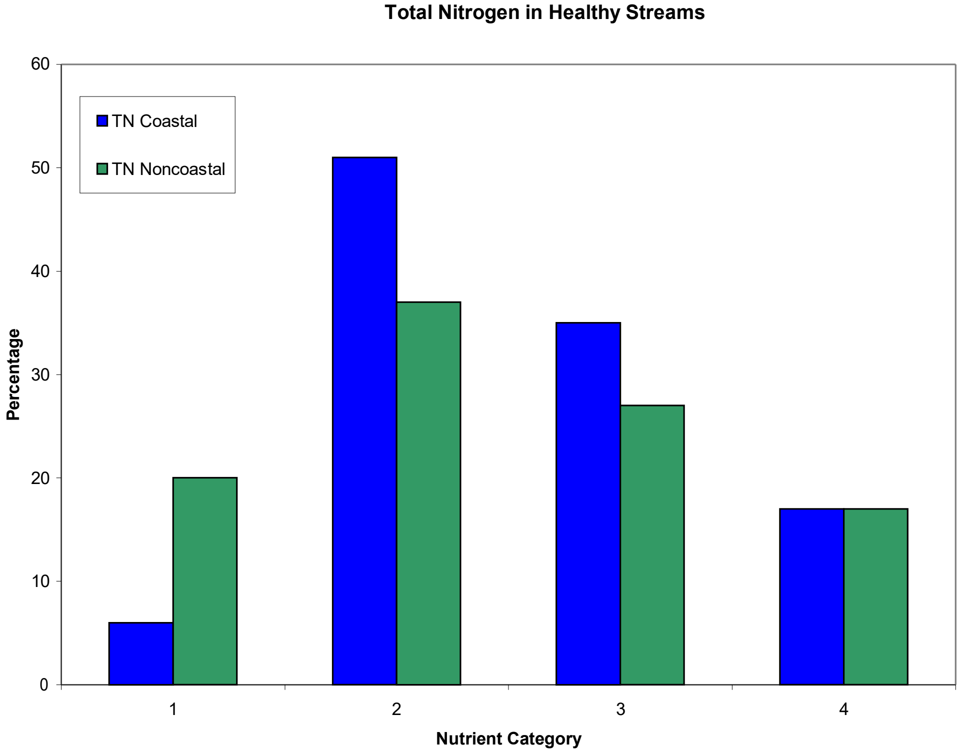
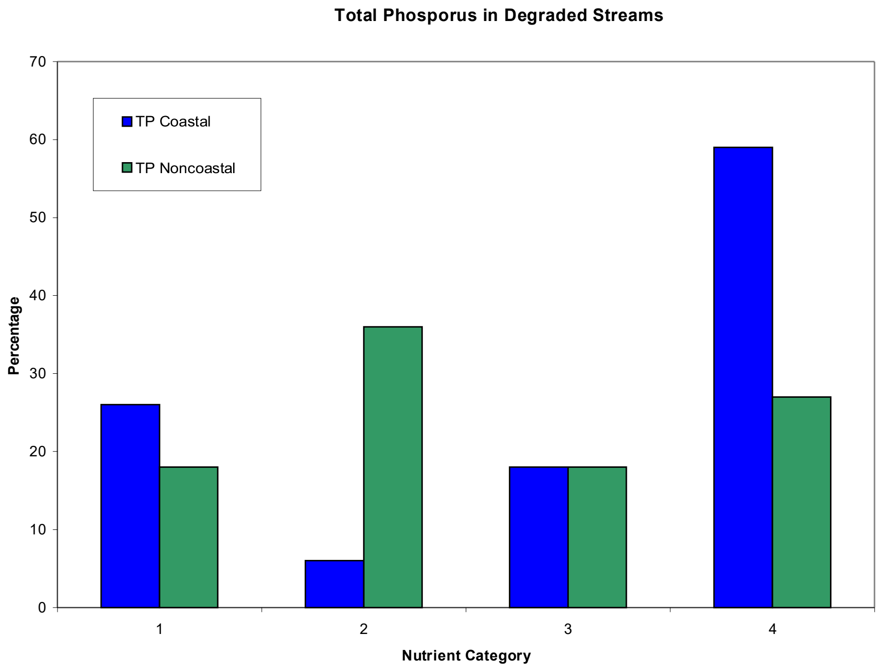
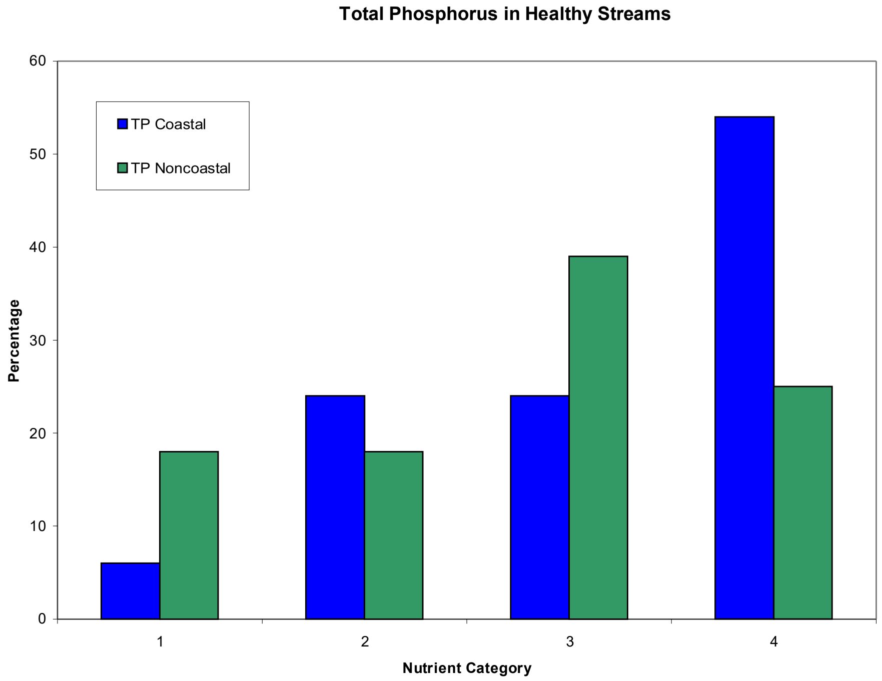


Figure 6. Percent occurrence of biologically degraded (upper plot) and healthy (lower plot) watersheds as a function of TN concentration, where category 1 represents the lowest nutrient concentrations in mg/l. Please refer to Figure 1 for category breakpoints and to Table 1 for results of statistical comparisons.



Total Phosporus in Degraded Streams



Total Phosphorus in Healthy Streams

Figure 7. Percent occurrence of biologically degraded (upper plot) and healthy (lower plot) watersheds as a function of TP concentration, where category 1 represents the lowest nutrient concentrations in mg/l. Please refer to Figure 2 for category breakpoints and to Table 1 for results of statistical comparisons.

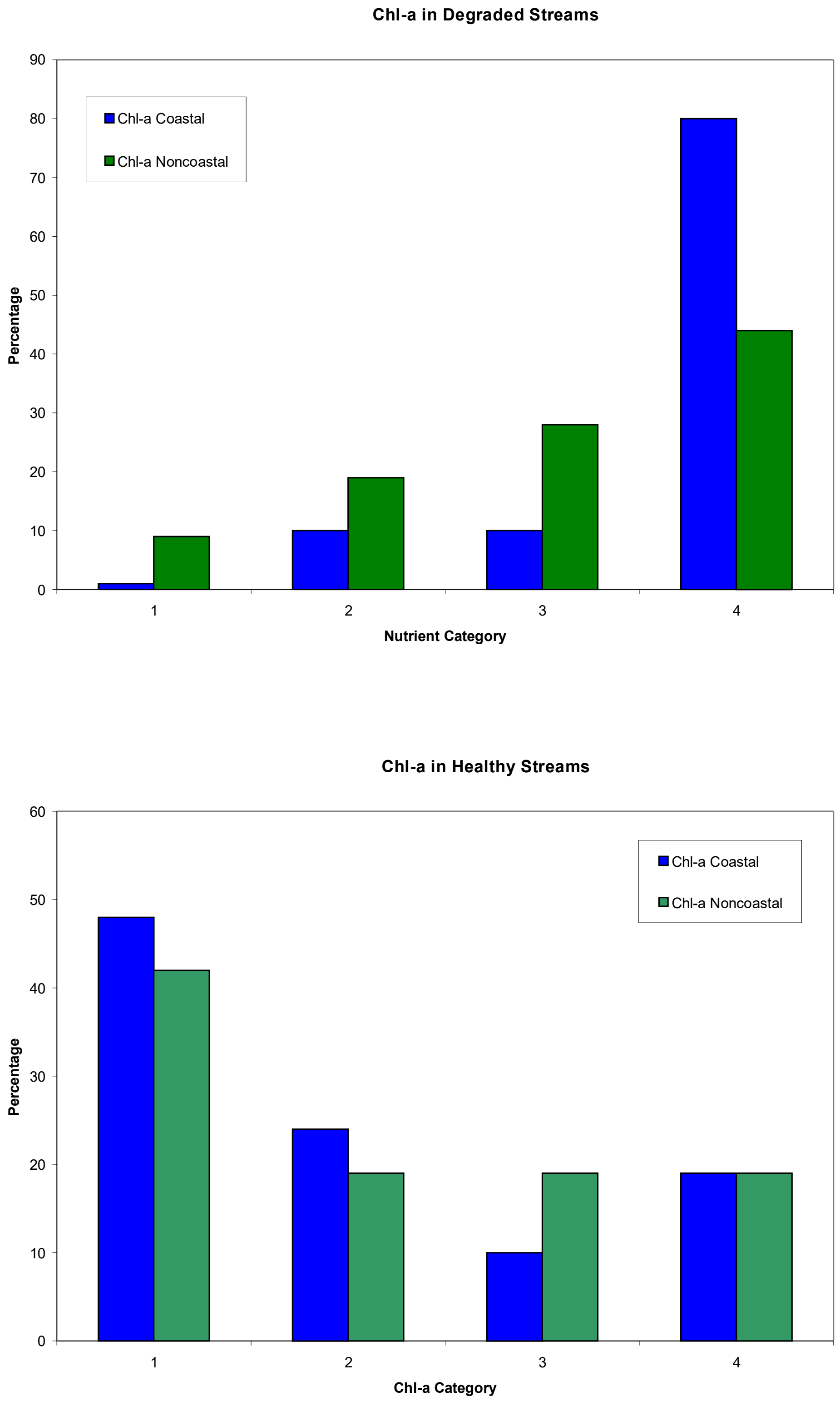


Figure 8. Percent occurrence of biologically degraded (upper plot) and healthy (lower plot) watersheds as a function of Chl-a concentration, where category 1 represents the lowest nutrient concentrations in ug/l. Please refer to Figure 3 for category breakpoints and to Table 1 for results of statistical comparisons.

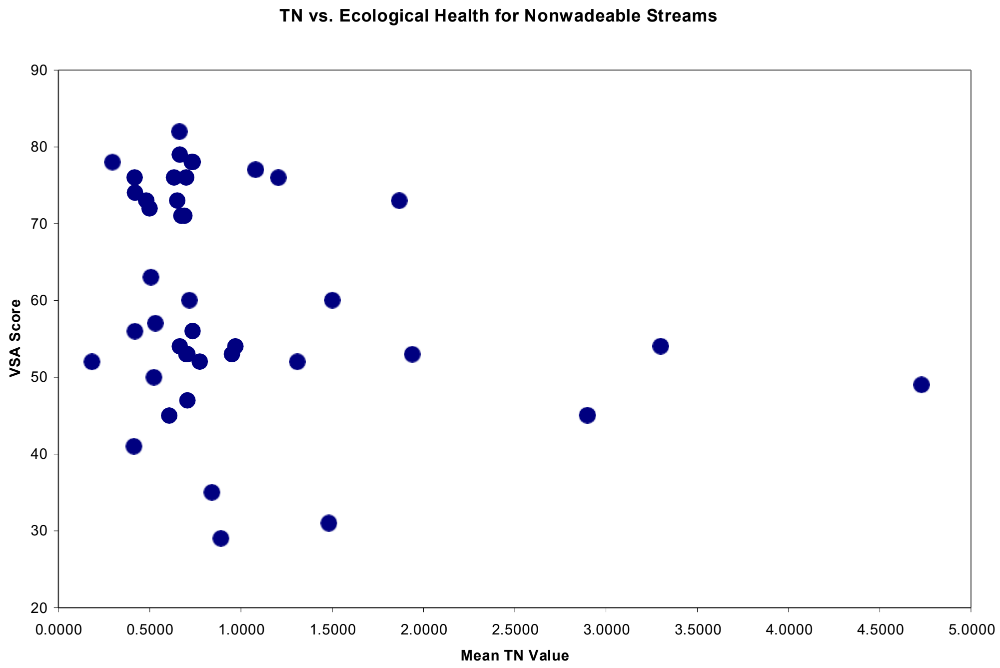


Figure 9. Scatterplot of fish community health score (VSA, % comparability to reference) and TN concentration (mean, mg/l) for paired, non-wadeable stream and river reaches, Chesapeake Bay basin, Virginia. A total of n=4 new data pairs were incorporated from unpublished PROBMON and VCU sources.

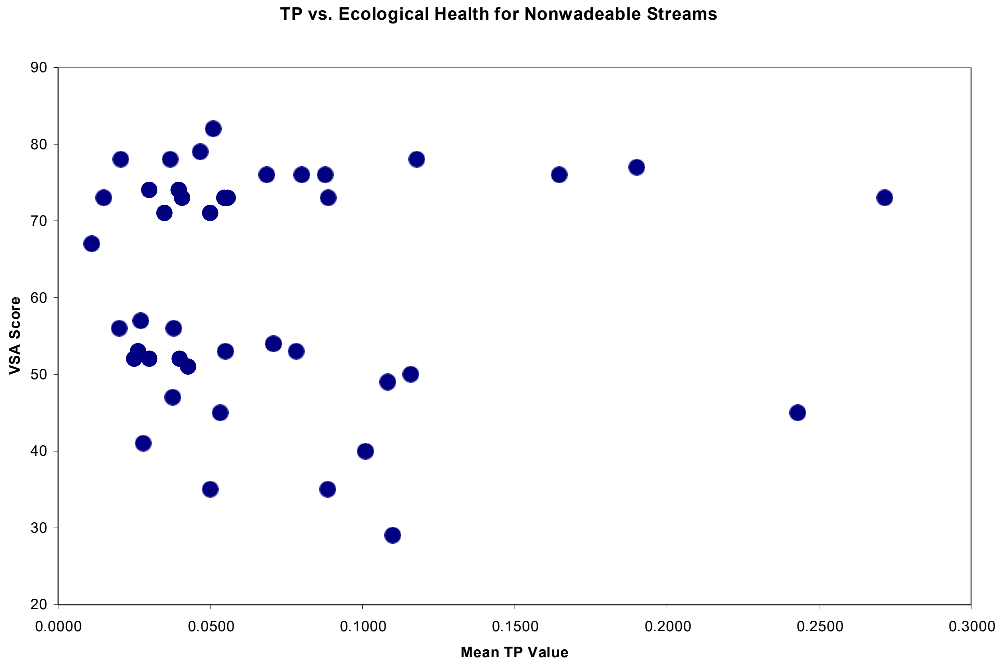


Figure 10. Scatterplot of fish community health score (VSA, % comparability to reference) and TP concentration (mean, mg/l) for paired, non-wadeable stream and river reaches, Chesapeake Bay basin, Virginia. A total of 4 new data pairs were incorporated from unpublished PROBMON and VCU sources.

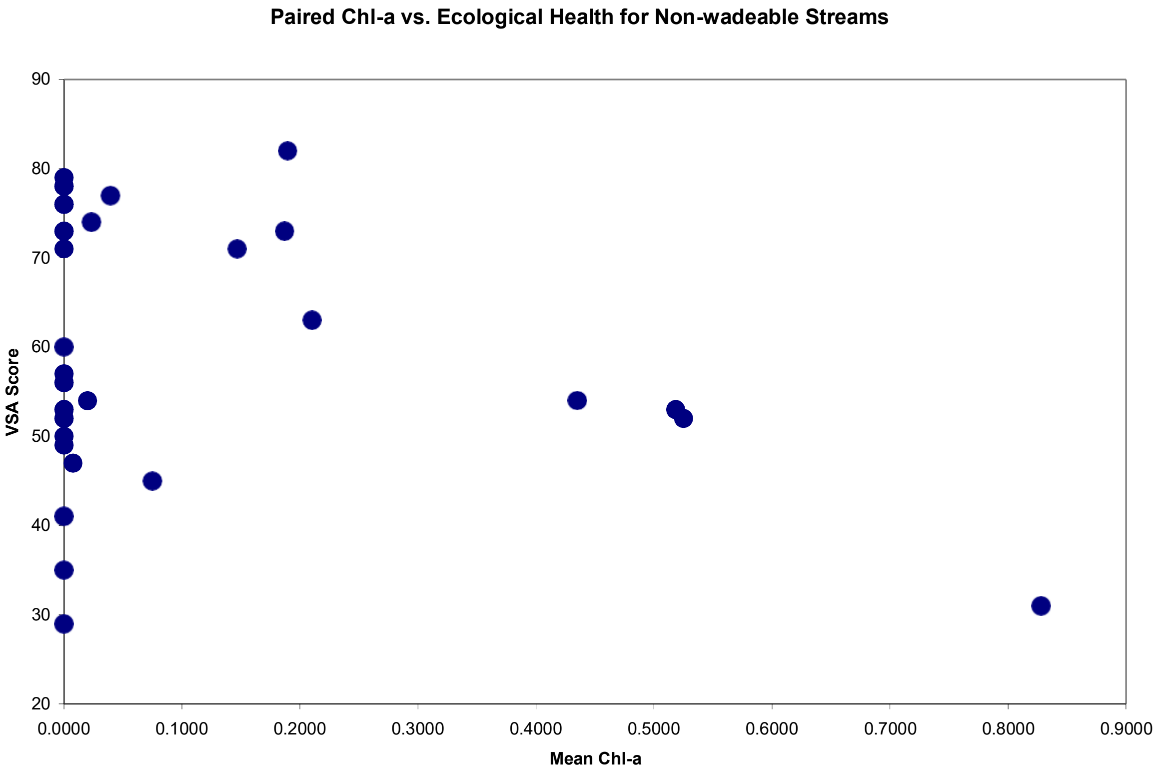


Figure 11. Scatterplot of fish community health score (VSA, % comparability to reference) and Chl-a concentration (mean, ug/l) for paired, non-wadeable stream and river reaches, Chesapeake Bay basin, Virginia.

Downstream Loading Impacts of Nutrients

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Objective

Explore potential and/or develop a rationale for defining critical values for TN and TP that considers and is intended to mitigate the "downstream loading" impacts of nutrients transported by Virginia streams to nutrient-sensitive receiving waters (Chesapeake Bay, Albemarle Sound, Gulf of Mexico via Tennessee and Ohio rivers).

Findings and Recommendations

Key findings from the recent EPA Science Advisory Board report on nutrient criteria guidance states that "a basic conceptual problem concerning selection of nutrient concentrations as stressor variables is that nutrient concentrations directly control only point-in-time, point-in-space kinetics, not peak or standing stock plant biomass. Plant biomass is driven by nutrient supply rates (i.e., nutrient mass loads). Ambient nutrient concentrations are not necessarily good surrogates for nutrient mass loads. Relationships between nutrient mass loads and ambient nutrient concentrations are highly system-specific and depend on many factors including inflows, hydrology, bathymetry, sediment-water exchanges and chemical-biological processes. Consequently, there may be many systems for which nutrient concentrations will not be appropriate stressor variables. For such systems it may be more appropriate, and scientifically defensible, to use site-specific mechanistic models incorporating loading to determine the nutrient controls required to attain designated uses" (Hall & Associates, 2010).

Mass loading in an upstream reach may not cause plant biomass related problems in that reach, but since cumulative mass loading increases progressively downstream, it may contribute to plant biomass related problems in downstream segments. Therefore, for nutrients, it appears to be necessary to set "downstream protective values" that control plant biomass in receiving waters. Therefore, in any stream segment, nutrient criteria will consist of two parts, an in-stream protective value (concentration) and a downstream protective value (load). The most restrictive of these two criteria will be the applicable water quality criterion in any stream segment. These criteria may also vary by distance from a downstream receiving waterbody, by ecoregion, or by some other defining characteristic. Because of the mechanics required for load calculation – simultaneous measurements or estimates of flow and concentration over time at each receiving waterbody, modeling is necessary to calibrate and correlate loads and concentrations and to determine which criteria is applicable to any given stream segment.

The Chesapeake Bay TMDL has set allowable loads of nitrogen and phosphorus for each of the five major river basins in Virginia draining to the Chesapeake Bay. By December

2010, each of the Bay states will have distributed their respective basin nutrient loads to correspond with 92 tidal segments simulated in the Chesapeake Bay estuarine model, of which approximately 35 segments are in Virginia (EPA, 2009). These long-term average allowable nutrient loads together with simulated long-term average annual flow effectively set *defacto* downstream nutrient criteria that should address nutrient-related water quality problems, without the need of formal, less-flexible and cumbersome rule-making usually involved with setting water quality standards and criteria. Since these allowable loads are set at the outlets of all five major basins in Virginia that flow into the Chesapeake Bay, they set effective downstream protective values for both wadeable and non-wadeable streams in this portion of the state.

As a result of a lawsuit brought against EPA claiming unacceptable delays in the establishment of nutrient water quality standards in Florida, EPA has "declared that Florida's existing narrative criteria are insufficient to protect water quality (EPA, 2010). This determination meant that, despite considerable and ongoing nutrient pollution control efforts by state agencies, water quality degradation remains a significant challenge, especially with Florida's projected population growth and land use changes". Therefore, EPA has proposed "numeric water quality criteria" pertaining to nutrient concentrations to protect aquatic life in lakes and waterways, including canals, within the state of Florida. In addition, EPA has proposed regulations to help Florida develop "restoration standards" for impaired waters. These proposed regulations differ substantially from methodologies and approaches being considered by Florida's Department of Environmental Protection (DEP), as discussed in a University of Florida-IFAS guide to the proposed criteria (UF-IFAS, 2010):

> *One difference is that DEP was planning to include a two-tier assessment approach in its rule, with the first tier being numeric nutrient criteria (similar to EPA), and a follow up second tier that was a biological assessment of the water body. It is uncertain if the two-tier system would have been part of a final rule proposed by the State, but the intent was to have "biological confirmation" that nutrient concentrations above the numeric standard actually resulted in biological impairment of the water body. One way to look at this is, EPA's numeric criteria are like a "caution light" on a traffic signal, whereas DEP's biological assessment represents confirmation of the presence or absence of water quality impairment.*
>
> *Another difference between the two rules is that EPA is proposing to use an equation to adjust in-stream total phosphorus criteria to protect downstream lakes, and a different methodology to adjust in-stream total nitrogen criteria to ensure protection of water quality standards for downstream estuaries. DEP's rule prior to the Consent Decree proposed a narrative criteria to protect downstream waters using the best available scientific information to translate this narrative.*

Decisions made in Florida concerning preferred methodologies and approaches may affect future EPA guidelines on how nutrient criteria should be developed in other states, including Virginia.

TMDLs will be set by the Commonwealth of Virginia for each of the 35 tidal segments in Virginia by December 2010. These TMDL loads will represent *de facto* downstream protective loading values at each of these tidal segment outlets, and possibly may be used in lieu of nutrient criteria in these areas of the state. To explore the implications of these target loads on upstream model segments, an analysis will be performed by the AAC using simulated output from the Phase 5.3 Chesapeake Bay Watershed Model (CBWM) and tidal segment TMDLs to be set by the Commonwealth. This analysis will calculate the ranges and variations in protective loads and corresponding mean concentrations upstream from each tidal TMDL segment. Nutrient loads and corresponding flow output will be obtained from individual CBWM model segments. Potential protective loading values in each upstream model segment will then be derived from simulated upstream existing loads by model segment, downstream allowable TMDL loads, and variable in-stream delivery factors by model segment, as used in the Bay Watershed Model.

Streams in other parts of Virginia not addressed by the Chesapeake Bay TMDL are in need of some other basis for downstream protective values. Phase 5.3 of the CBWM unfortunately does not encompass all of Virginia, although in Phase 5.2, model parameters were developed so that loads were simulated not only from the 237 CBWM model segments that drain into the 35 Chesapeake Bay tidal segments in Virginia, but also from 154 additional model segments that cover the remainder of Virginia including boundary watersheds that drain into Virginia. Where the downstream waterbodies are lakes or reservoirs within Virginia, nutrient standards have already been established that set a downstream protective concentration from which a protective load can be derived. Where the downstream waterbodies are in other states, coordination will be needed with other states' downstream protective values or other criteria. Where other states have yet to set nutrient standards or in streams where no impoundments occur on the main channel, a statistical measure will be derived from the simulated nutrient loads outside of the Bay drainage and the "allowable mean values" in the Bay drainage area as affected by ecoregion, physiographic region, or some other definable characteristic. In order to explore potential protective nutrient values in model segments outside of the Bay drainage, an analysis will be performed by the AAC based on Phase 5.2 model outputs to set potential downstream protective load values in the remainder of these model segments. The AAC with the help of DEQ will then summarize for each CBWM model segment the downstream controlling segment and the type of downstream protective value which is applicable: TMDL tidal segment (load), receiving waterbody (concentration), or statistical measure.

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