VIRGINIA WATER RESOURCES RESEARCH CENTER

A “Screening Approach” for Nutrient Criteria in Virginia

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

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Virginia
WATER RESOURCES
Research Center

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FOR
NUTRIENT CRITERIA IN VIRGINIA

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Contents

Executive Summary

Under the Clean Water Act (CWA), criteria are components of water quality standards that are intended to protect designated uses for waters of the U.S. Nitrogen (N) and phosphorous (P) ("nutrients") are common water contaminants that challenge conventional methods for establishing water quality criteria for an essential designated use, the protection of aquatic life. Unlike many water contaminants for which criteria have been established, nutrients typically do not exert primary effects on aquatic life by acting as toxicants. Excess nutrients in freshwater streams stimulate growth of algae that can impair stream communities by causing oxygen depletion and through other pathways. Because excess nutrients in surface waters are well known as stressors that impair aquatic life and impact other uses, the U.S. Environmental Protection Agency (EPA) is requiring CWA agencies throughout the U.S. to establish criteria for nutrients. The Academic Advisory Committee (AAC) to the Virginia Department of Environmental Quality (DEQ) has recommended a screening approach for nutrient criteria in Virginia as an alternative to single fixed-concentration numeric criteria as is commonly employed for conventional toxicants. Here, we investigate the potential to establish nutrient criteria using a screening approach by seeking to derive screening parameters from analyses of Virginia DEQ water monitoring data.

The screening approach is a three-step method that uses (1) threshold concentrations to indicate clear positive or negative effects of nutrients, (2) a visual assessment to further delineate clear positive effects, and (3) in lieu of an inconclusive association with nutrients in the first two steps, a biological assessment to determine impact on the aquatic-life use. The first stage of the screening approach is based on two sets of N and P threshold concentrations:

- No-Observed-Effect Concentrations (NOECs): These are nutrient concentrations, expressed as total nitrogen (TN) and total phosphorous (TP). Freshwater streams with TN and TP concentrations below NOECs would have a low probability of being impaired by nutrients and would be assessed as "not impaired by nutrients." Through analysis of Virginia DEQ monitoring data, we defined a nutrient-criteria reference dataset, and we propose that these data can be used to derive NOEC levels for TN and TP.

- Observed-Effect Concentrations (OECs): These are nutrient concentrations, also expressed as TN and TP. Freshwater streams with a TN or TP concentration equal to or greater than OEC would have a high probability of being impaired by nutrients and would be assessed as "impaired." Through analysis of Virginia DEQ monitoring data, we identified OECs for TN and TP where monitoring data demonstrate a 90% probability of aquatic-life impairment based on the Stream Condition Index (SCI) scores of the benthic macroinvertebrate community.

The second stage of a screening approach is applied to monitoring locations that cannot be assessed conclusively using the NOEC or OEC values. At these sites, regional biologists would conduct visual assessments, observing the presence of algae, macrophytes, and other stream features to apply best professional judgment (BPJ) concerning the site's capability to support aquatic life as required by the CWA. The visual assessment is proposed as an essential screening-approach component because nutrients impair aquatic communities by stimulating excessive in-stream primary production, and the predominant freshwater stream primary producers – photosynthetic algae and macrophytes – are easily visible to competent observers. Virginia DEQ regional biologists conducted trial applications of the visual assessment procedure during >700 monitoring events over three years. Eighty-eight percent of monitoring events visually assessed as having a high probability of impairment by nutrients were found to have SCI scores of <60, demonstrating biological impairment as determined using Virginia's standard assessment protocol for assessing attainment of the aquatic-life use, and 95% of those monitoring events were found to have SCI<65. Regional biologists assigned "high" probability of nutrient-induced impairment ratings to 8% of the visually assessed monitoring events. As a test of the process, they were able to assign definitive assessments (i.e., BPJs as either "high" or "low" probability of aquatic-life impairment) to almost half of visually assessed sites considering both nutrient and non-nutrient stressors. Where regional biologists visually assessed monitoring events as having either a "high" or "low" probability of aquatic-life impairment due to nutrient and non-nutrient combined effects, results of benthic macroinvertebrate sampling conformed to those BPJ ratings for 79% of monitoring events. Furthermore, nearly 90% of the visual assessments were associated with benthic macroinvertebrate SCIs that either conformed to the expected status (i.e., either SCI≥60 or SCI<60 as expected) or, if they did not conform, were within five SCI-units of the SCI<60 impairment threshold.

The third stage is a benthic macroinvertebrate assessment conducted only where the first and second stages yield inconclusive outcomes, meaning that measured nutrient concentrations were >NOEC but <OEC and visual assessments do not conclusively indicate impairment. Under Virginia's established assessment procedure, benthic macroinvertebrate assessments determine the ability of a freshwater stream to support the aquatic-life designated use. Benthic macroinvertebrate assessments, however, are costly to implement as they require significant time expenditure by the agency's professional staff; and that staff is limited in number due to fiscal constraints of a taxpayer-supported agency that faces numerous CWA implementation demands.

A common theme among these results is the tradeoff between accuracy/certainty of screening approach outcomes and potential new resource expenditures that would be required by application. Decisions to set NOECs at relatively low concentrations and OECs at relatively highly concentrations while limiting visual assessments to only those circumstances that produce highly accurate outcomes would require significant resource expenditure for benthic macroinvertebrate assessments at sites defined as "inconclusive" by the screening process. Application of higher NOECs, lower OECs, and a wider suite of visual assessments would reduce demands on the agency's professional field staff but may also produce a greater frequency of inaccurate assessments (i.e., sites defined as biologically impaired, despite SCI≥60; and vice versa).

The tradeoffs between accuracy/certainty and resource allocations described above are not unique to the screening approach; they are integral to issues concerning nutrient criteria, generally. Because nutrients are not direct toxicants, their localized biological effects cannot be managed effectively through numeric criteria applied as fixed thresholds. These analyses demonstrate that application of nutrient criteria as a screening approach can reduce uncertainty and error in identifying impaired waters while at the same time assessing waters in a reasonable time frame and within the budget and capacity of the agency. Specification of essential features (OECs, NOECs, and the role of visual assessments) can be informed by the analyses described here but will also require evaluation of tradeoffs among potential resource expenditures and accuracy/certainty of application.

I. Introduction

Background: Nutrient Criteria and the Clean Water Act

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 U.S. Environmental Protection Agency (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) (U.S. EPA 2000).

Nutrients (nitrogen [N] and phosphorus [P]), when present in surface waters at elevated concentrations, often act as water pollutants. Excess nutrients cause negative effects in surface water bodies nationwide. Reports by EPA to the Congress have indicated nutrients to be among the more prominent pollutants that are impairing freshwater rivers and streams nationwide (U.S. EPA 2011). Analyses by the Virginia Department of Environmental Quality (DEQ) show nutrients to be prominent as stressors within Virginia surface waters (Virginia DEQ 2010).

The Virginia DEQ enforces the Clean Water Act in Virginia under EPA oversight. The Virginia DEQ has requested the Academic Advisory Committee (AAC) to advise and assist with development of nutrient criteria for freshwater rivers and streams in Virginia. This report documents recent AAC activity conducted collaboratively and cooperatively with DEQ for developing nutrient criteria for freshwater wadeable streams and rivers in the Mountain and Piedmont ecoregions of Virginia.

Screening Approach Described

In Virginia, all state waters are designated to support aquatic life. Virginia water quality standards define the aquatic-life designated use to include "the propagation and growth of a balanced, indigenous population of aquatic life… which might reasonably be expected" (Virginia DEQ 2011). To monitor and assess the attainment of the designated aquatic-life use, Virginia has developed a biological monitoring procedure that employs a measure of biological community integrity using benthic macroinvertebrates to calculate a Stream Condition Index (SCI) that was developed for the freshwater streams and small rivers in the Piedmont and Mountain regions (Tetra Tech 2003; Virginia DEQ 2006). Using this assessment procedure, SCI scores of 60 or above are considered to signify healthy benthic macroinvertebrate communities, while water bodies with SCI scores below 60 are assessed as impaired.

The AAC has recommended that nutrient criteria for freshwater wadeable streams be applied as a "screening approach" that would employ observed-effect concentrations (OECs), no-observed-effect concentrations (NOECs), and visual assessments in association with benthic macroinvertebrate assessments (AAC 2006, 2009, 2010). The screening approach would be implemented in multiple stages at water monitoring locations where measured total nitrogen (TN) and total phosphorous (TP) concentrations are available and used to identify waters where adverse impacts on aquatic uses may be occurring due to nutrients (Figure I-1).

The first stage of the screening approach is based on two sets of threshold TN and TP concentrations:

- No-Observed-Effect Concentration (NOEC): Streams with nutrient concentrations equal to or less than (≤) the NOEC are assessed as "not impaired."
- Observed-Effect Concentration (OEC): Streams with nutrient concentrations equal to or above (≥) the OEC are assessed as "impaired."

At each monitoring location, TN and TP data would be evaluated. If both TN and TP are < NOEC, the location would be assessed as not impaired; if TN and/or TP is ≥ OEC, that location would be assessed as impaired. Where both TN and TP occur between the NOEC and OEC, the first stage of assessment would be inconclusive and the assessment process would proceed to the second stage.

For the second stage, a visual assessment would be conducted by the DEQ regional biologists. Excessive algal biomass, an indicator of impairment due to a nutrient stressor, 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 impairment. Monitoring locations defined as inconclusive by the second stage would enter a third stage of assessment.

In the third stage, a benthic macroinvertebrate assessment would be employed to assess the stream for biological impairment. The third stage would produce a definitive assessment for protection of the aquatic-life use.

Screening Approach Rationale

The AAC recommends the screening approach as an alternative to traditional single-numeric fixed criteria because nutrient effects on aquatic systems differ in a fundamental manner from effects of traditional pollutants. Whereas traditional pollutants generally exert primary toxic influences at the organism level so that water-quality criteria for traditional pollutants are established based on species-level toxic effects, nutrient over-enrichment effects are systemic. 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. The screening approach is applied with the intention of limiting assessment errors despite the inherent variability of responses to nutrients by aquatic systems.

A secondary goal of using the screening approach 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 that limit assessment errors in recognition of the costs that result from incorrect assessments (Figure I-2). When non-impaired streams are incorrectly assessed as impaired (false positive assessment, Type I error), it triggers a TMDL study and uses the Clean Water Act enforcement resources that could otherwise be applied elsewhere. False positive assessments can also affect investment decisions by those managing regulated point sources that discharge into the 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 its designated uses.

Application of the screening approach as a procedure for assessing impairment can reduce, but not eliminate, both type I and type II error. To achieve this reduction in error will require additional time and additional monitoring costs before making an impairment decision. This trade-off of additional time and resources in order to reduce the likelihood of making an incorrect impairment decision needs to be evaluated. Of significance in making this evaluation is that the screening process helps to target limited monitoring resources to those areas where the reduction in uncertainty would be the greatest for a given expenditure of funds. First, when applied together, the NOEC and OEC identify the range of nutrient concentrations for which additional monitoring and assessment resources would be expended for a visual assessment. The additional monitoring resource expenditure for the visual assessment is relatively minor, but the increased certainty it adds to the impairment decision is significant. If the visual assessment cannot justify an impairment determination, only then will the screening process proceeds to the greater resource expenditure required by the benthic macroinvertebrate assessment procedure.

Goals of Study Reported in the Current Manuscript

Here, we investigate the potential to establish nutrient criteria using a screening approach by seeking to derive screening parameters from analyses of Virginia DEQ water monitoring data. Specific goals are as follows:

1. Investigate potential to establish NOECs through a “reference filtering” approach using probabilistic monitoring data.
2. Investigate potential to establish OEC’s through a “probability of impairment at equal-or-greater concentrations” analysis applied to Virginia DEQ monitoring data.
3. Evaluate trial applications visual assessment as a potential assessment tool for use in nutrient criteria implementation. Concentrations
4. Estimate potential demands by screening approach on DEQ water monitoring resources.

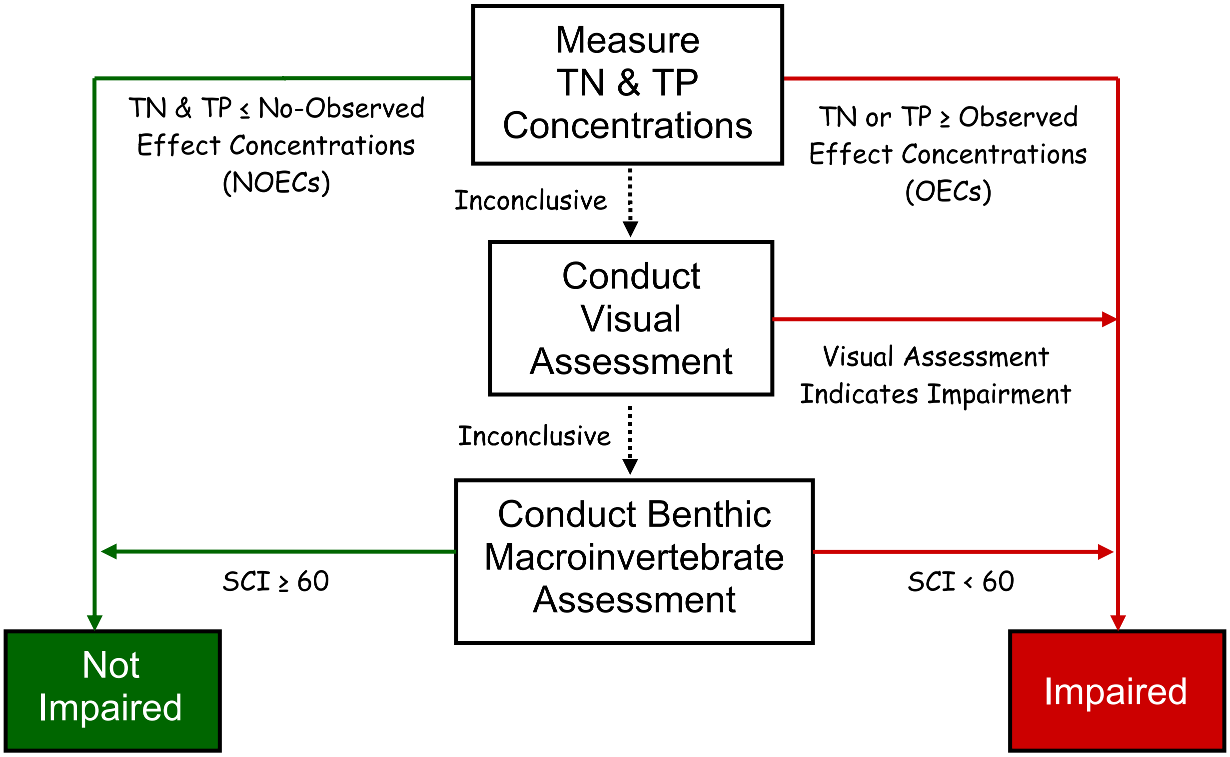


Figure I-1. Nutrient criteria screening approach for assessment of freshwater wadeable streams in the Mountain and Piedmont ecoregions of Virginia as proposed by the Academic Advisory Committee. TN=total nitrogen concentration; TP=total phosphorus concentration; SCI=Stream Condition Index.

		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 I-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.

II. No-Observed-Effect Concentrations

As described earlier, the AAC's recommended approach to nutrient criteria development involves the use of "no-observed-effect concentrations" (NOECs) and "observed-effect concentrations" (OECs). Monitoring sites with concentrations ≤ NOECs would be assessed as not impaired, and those with nutrient concentrations ≥ the OECs would be assessed as impaired. A site or monitoring event with concentrations between the NOEC and OEC concentrations would be assessed using other means: a visual assessment procedure if nutrient impairment is visually evident or benthic macroinvertebrate assessment if the visual assessment results are inconclusive (see Figure I-1).

This analysis is an investigation of the potential to establish NOECs through a "reference filtering" approach using probabilistic monitoring data (ProbMon data).

Approach

The analysis was conducted with the intention of applying the following logic:

1. Define a set of DEQ monitoring observations where non-nutrient stressors are not evident; these are termed as "nutrient-criteria reference" observations.
2. Within the nutrient-criteria reference observations, analyze the response of SCI to TN and TP gradients.
3. If SCI demonstrates a statistically significant response to TN and/or TP: define the nutrient level(s) below which impairments occur at low probabilities. This value would be proposed as an NOEC.

Method

This analysis was conducted using DEQ's probabilistic monitoring dataset, 2001-2009, Mountain and Piedmont ecoregions only. Most locations in this dataset are characterized by a single water-quality observation that has been characterized by numerous laboratory analyses in either the spring or the fall; and two field observations (spring and fall) that include 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 "reference conditions" (i.e., relatively undisturbed streams, exemplifying a desirable state) in various studies (Table II-1), including those which were conducted to develop (Tetra Tech 2003) and to validate (Virginia DEQ 2006) the SCI. These conditions, excluding TN and TP concentrations, were applied as reference filters. Ideally, this application would produce a dataset that eliminates most non-nutrient stressor effects and thus would isolate N and P as aquatic-life stressors – a nutrient-criteria reference dataset.

In fact, initial application of this method (Table II-1) did not yield the expected result. Thus, we applied supplementary screening criteria (Table II-2), expecting that this would eliminate additional non-nutrient stressor effects and reduce the impairment rate to the expected level.

The expectation that reference screen application (Table II-1) would produce a set of monitoring sites that could be considered as "reference" was based on results reported by DEQ

(2006). However, in addition to the reference screen application, that study also employed the best professional judgment (BPJ) of the DEQ's regional biologists who identified some of the sites satisfying the reference filter conditions as stressed due to factors that were visually evident but were not reflected by the reference filter. Because the 2001-2009 ProbMon dataset contains >600 monitoring locations, it was not feasible to ask regional biologists to apply BPJ as a means of identifying significant non-nutrient stressors at all monitoring sites. Hence, regional biologists were asked to visit and apply best professional judgment (BPJ) for the purpose of identifying significant non-nutrient stressor effects only at a subset of the ProbMon sites considered as especially significant for this analysis: those satisfying the DEQ reference filter screen (Table II-1), but impaired for aquatic life (SCI<60).

Based on the observations of the regional biologists, some sites were removed from consideration as nutrient-criteria reference sites. Criteria for removal from the list of nutrient-criteria reference site included:

- An observation that SCI was affected by significant non-nutrient stressors, such as sedimentation, intermittent flows, proximity to a dam, or the like.
- An observation that the site shows no evidence of nutrient-induced impairment. Given that the sites were, in fact, characterized by data indicating impairment, such a statement was interpreted to mean that non-nutrient stressors were likely responsible for the impairment.
- An observation that the site was "inappropriately" defined as impaired for aquatic life for other reasons, such as the presence of a beaver pond or a biologists' statement of observations such as "This site is not impaired." At these sites, the SCI value was not thought to accurately reflect the aquatic-life assessment.

The nutrient-criteria reference dataset was comprised of monitoring observations that satisfied the DEQ reference filter screens (Table II-1), and for which observations by regional biologists showed no reason for removal from the nutrient-criteria reference status.

Within the resulting suite of observations, the nutrient-criteria reference dataset, relationships of TN and TP to SCI were analyzed for the purpose of deriving potential NOECs.

Results

Application of the DEQ reference conditions (Table II-1) to the DEQ 2001-2009 ProbMon dataset created a subset of those observations with 24.1% impairment rate (SCI<60) (Figure II-1, left), and within which no relationships of TN and TP to SCI were apparent.

Application of additional reference filters (Table II-2), in addition to the DEQ reference conditions (Table II-1), created a subset with a 24.2% impairment rate (Figure II-1, right) and within which no relationships of TN and TP to SCI were apparent (data not shown). Although the DEQ TN and TP reference filters (1.5 mg/L and 0.05 mg/L, respectively) were not applied, the maximum TN value within the resulting datasets was 0.97 mg/L, less than the DEQ reference filter maximum, and the maximum TP value (0.06 mg/L) exceeded the DEQ reference filter maximum (0.05 mg/L) only slightly (Figure II-2).

Because application of the additional reference filters (Table II-2) did not result in an improved capacity to discriminate TN and TP effects on SCI, only the dataset produced through application of the DEQ reference filters (Figure II-2, left) was considered in the subsequent analyses. There were two main reasons for this decision: 1) the chosen dataset (Figure II-2, left) had a larger number of observations than did the dataset produced using the supplemental filters, and 2) most of the data elements used to apply the supplementary reference filters were available only for certain segments of the ProbMon dataset and therefore were inconsistently applied.

Observations by the regional biologists for monitoring events with SCI<60 are listed in Table II-3. Application of the process described in the methods to the DEQ reference filtered dataset produced a nutrient-criteria reference dataset (Figure II-3). Within the nutrient-criteria reference dataset, SCIs are higher (ANOVA; $p<0.05$), and TN and TP are lower (Wilcoxon non-parametric comparisons; $p<0.05$) than for other monitoring events that did not pass the reference filter screen (Figure II-4). This latter result occurred despite the fact that TN and TP screens were not applied and likely occurred because TN and TP often covary with other stressors. Measures of benthic algae (benthic chlorophyll, CHLBEN, and ash free dry mass, AFDM) did not differ significantly among nutrient-criteria reference and non-reference sites (Wilcoxon non-parametric comparisons; $p<0.05$).

Within the nutrient criteria reference dataset, no relationships of benthic algae to nutrients or to SCI are evident (data not shown). It is possible that the limited extent of benthic algae data contributed to this finding, as benthic algae data are available only for a portion of the ProbMon data. Benthic algae data are available only for fall collections, and no benthic algae observations were collected prior to 2004.

TN and TP, however, both exhibit negative relationships with SCI within the nutrient-criteria reference dataset (Figure II-5). The TN relationship is significant at $p<0.05$; whereas the p-value for the TP-SCI relationship ($p=0.0598$) is significant at $p<0.10$. However, neither regression line descends below SCI=60 within the TN and TP ranges represented by the nutrient-criteria reference data. "Break even" concentrations (i.e., concentrations where the regression would predict an SCI of 60) are 1.065 mg/L for TN and 0.088 mg/L for TP. The lower bounds of the regression lines' 95% confidence intervals cross SCI=60 at about 0.7 mg/L for TN, and at about 0.05 mg/L for TP.

Discussion:

The above analyses have produced a nutrient-criteria reference dataset that appears suitable for deriving NOEC concentrations for the Piedmont and Mountain regions. This dataset contains monitoring observations where non-nutrient stressor effects are not evident. Within this dataset, about 10% (11 of 111) of the observations are impaired for aquatic life; of these 11 observations, six have SCI scores between 55 and 60, which are very close to the impairment threshold. Within the nutrient-criteria reference dataset, TN and TP show statistically significant relationships to SCI.

The analyses, however, do not provide a clear definition of NOECs; some interpretation is needed to derive NOECs from the reference dataset.

- One possible strategy would be to use the regression line predictions where SCI=60 as NOECs. A problem with that strategy is that those concentrations (TN = 1.065 mg/L; TP = 0.88 mg/L) would be extrapolations beyond the range of available data.
- Another possible strategy would be to select the highest concentrations that occur within the nutrient-criteria reference dataset (0.97 mg/L for TN, 0.06 mg/L for TP) because the regression lines do not descend below SCI=60 within that range. A problem with that strategy would be the fact that very few data points occur at the upper end of the nutrient-criteria reference range: Only two of 60 TN observations occur at concentrations ≥ 0.8 mg/L, and only three of 61 TP observations occur at 0.06 mg/L. Another possible strategy would be to use the lower bounds of the 95% regression line confidence intervals (0.7 mg/L for TN, 0.05 mg/L for TP) intersection with SCI=60. These levels occur within the range of available data, and they do not occur at the extreme upper end.

Another strategy would be to ignore the regression lines, and to use the 90th percentiles of nutrient-criteria reference data. A percentile approach to establishing thresholds is commonly used by EPA. The 90th percentiles of TN and TP values represented within the dataset were 0.599 and 0.05 mg/L, respectively.

Table II-1. Reference filters applied by the Virginia Department of Environmental Quality (2006).

Parameter	Reference Filter
% Urban	< 5%
Total Nitrogen (TN) †	< 1.5 mg/L
Total Phosphorus (TP) †	< 0.05 mg/L
Specific Conductance	< 250 µS/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

† TN and TP screens were not applied in the current analysis.

Table II-2. Supplementary reference filters.

Parameter	Reference Filter	
Log (relative bed stability)	< -1.0	Relative bed stability is a sedimentation indicator used by DEQ's ProbMon program.
Major point sources in watershed above	None	
Water column metals > Water Quality Criteria (WQC)	No measured metals > WQC	WQC as defined by Virginia Water Quality Standards, 9VAC25-260-140.
Sediment metals > Probable Effect Concentration (PEC) Values	No measured metals > PEC	PEC are Freshwater Consensus-Based Sediment Screening Values, as defined by App. F, DEQ Water Quality Assessment Manual
Sediment organics > Probable Effect Concentration (PEC) Values	No measured organics > PEC	PEC are Freshwater Consensus-Based Sediment Screening Values, as defined by App. F, DEQ Water Quality Assessment Manual

Table II-3. Regional biologists' observations of impaired sites in Virginia passing the Table II-1 reference filter screens, and resulting determination.

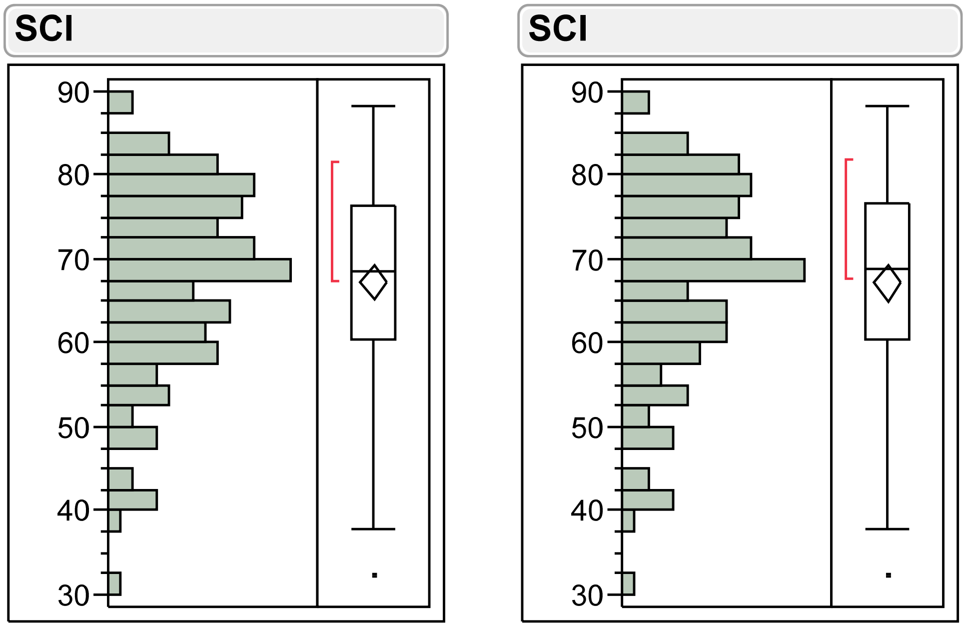
Station ID	Stream Name	Season	Significant non-nutrient stressor or inappropriate impairment?	BPJ: nutrient impair-ment?	Nutrient-Criteria Reference ? †	Comment Quoted
1AKET011.03	Kettle Run	Fall '02		not nutrient impaired	no	"Kettle Run (1aKET011.03) has a series of NPS issues but nutrient impairment is not considered to be a primary cause of lower SCI scores"
1ALUC000.95	Lucky Run	Spring '01		not nutrient impaired	no	"Lucky Run (1aLUC000.95) is a small second order stream subject to very low flows in summer months and at any given time may have a series of beaver dams. The upper watershed is located within the boundary of Quantico Marine Base and as such, MAY be subject to NPS runoff. The site should not be considered a nutrient impaired site."
1ALUC000.95	Lucky Run	Fall '01		not nutrient impaired	no	(same comment as above).
1BBRY001.78	Briery Br	Spring '08	observed		no	"dries up in the summer and early Fall so it can't support a "good" benthic community."
1BNKW001.97	W. Br. Naked Cr	Spring '03		not nutrient impaired	no	"is a mystery. It is draining the Shenandoah National Park, and there is light farming in the immediate area. It has bounced around the cutoff of 60 in follow-up visits as well. The stream has never had high algal productivity, poor in-stream habitat, or poor pH in any of our visits."
1BNKW001.97	W. Br. Naked Cr	Fall '03		not nutrient impaired	no	(same comment as above).
2-CWP042.31	Cow-pasture R	Spring '08		"filament-ous algae present"	yes	"Based on my experience, Cowpasture River, West Branch Naked Creek, and Tye River would not score poorly in visual assessment. Cowpasture and Tye might occasionally get up to 40-70% filamentous growth during periods of low flow, but I don't think they would have nuisance levels of algae. These sites all have good in-stream and riparian habitat, little development in their watersheds, and light agricultural influence."
2-CWP053.78	Cow-pasture R	Spring '01		"filament-ous algae present"	yes	(same comment as 2-CWP042.31 above)

2DAPP015.51	Appomattox R	Spring '09		“filamentous algae present”	yes	"This is a tough one. Both the Spring (51.6) and Fall (57.0) scored less than 60. The lower score in the Spring may be due to higher flows when we could not safely reach all of the habitat. In the Fall we were able to sample more effectively; but we noted that there was not very much cobble. Most of the substrate was large boulders, bedrock, and sand. As a result, limiting substrate may be a factor in the VSCI scores. On the other hand, we also noted a lot of river weed and a substantial amount of filamentous algae coverage in the Fall. It is possible that the VSCI scores are also being lowered by nutrients; but the measured levels of nutrients are low because they are being sucked up by all of the river weed and algae. This is going to be a difficult assessment call for us to make. We have sampled the Appomattox at several other sites both upstream and downstream of this station and have never assessed the Appomattox as impaired."
2DHAW000.81	Haw Br	Spring '09	observed		no	"The x-point for this reach is in the middle of a large beaver-infested swamp. This site is non-target and will not be assessed."
2-EFK001.55	East Fork Kent Br	Spring '08	observed		no	"The Spring 2008 VSCI score was just under 60 and the Fall score was 80.4. In addition, we sampled again during Spring 2010 and the VSCI score was 68.1. This site is not impaired."
2-MRY043.42	Maury R	Spring '05	observed		no	"is close to the confluence with Little Calfpasture River. This stream has been strongly impacted by poor management of the dam at Lake Merriweather, and has periodically had very low DO and serious sediment issues. We have a routine biomon site within a quarter-mile of the probmon site that regularly varies from the 40's to the 70's for VSCI. It is probable that Maury was affected by the lake impacts at the time of our visit."
2-TYE028.94	Tye R	Spring '09		“filamentous algae present”	yes	(same comment as 2-CWP042.31 above)
2-WLN006.90	Wilson Cr	Spring '02	observed		no	"is within a mile downstream of the dam for Douthat Lake. It should be considered non-target due to this proximity. We sampled this before being told to ignore all sites close to dams. "
2-XUF000.55	UT Jackson R	Spring '02	observed		no	"non-perennial (2-XUF & 4AXNB?) have low VSCIs due to intermittent/headwater benthic communities that are actually pretty good but not diverse due to their intermittent location."
4ABEE001.20	Beech Cr	Spring '02			yes	
4ACLB001.90	Coleman Cr	Spring '06			yes	
4ACOX007.73	Cox Cr	Fall '05			yes	
4ACOX007.73	Cox Cr	Spring '05			yes	

4AHRN007.65	Horse Pasture Cr	Fall '03	observed	no	"was a Probmon stations that is below a dam and also impacted by sediment possibly from the dam construction and logging upstream on the mainstem and tribs. I think we had one good score and one low. We have done follow-up benthic sampling at an ambient site several miles downstream where we consistently have low VSCI scores."
4AXNB000.60	X trib Mason Cr	Fall '06	observed	no	(same comment as 2-XUF000.55 above)
5ABTR000.76	Butter-wood Cr	Fall '08	observed	no	"The Fall score for this site was very close to 60 (59.8) and the Spring score was 66.5. During the last assessment cycle, we deemed this stream to be "Fully Supporting" for aquatic life. In addition, if there ever was a "Piedmont" stream that could be classified as a Coastal Plain stream, this one is it. The upstream reaches of Butterwood Creek include lots of swamp waters and beaver impacts and the gradient at the sample reach was measured to be less than 0.1%. Based on sheer physical characteristics, we're somewhat amazed that this stream was able to pass the VSCI at all."
5AFON016.90	Fontaine Cr	Spring '07	observed	no	"Fontaine Creek is one of those streams that starts in the lower Piedmont and then flows into the Coastal Plain. This particular site is located east of I-95 and is actually in the Southeastern Plains ecoregion (Sorry about the mix-up in EDAS – we will correct that.) In addition, the stream gradient for this reach was measured to be 0.03% and there were no riffles. As a result, we felt completely justified in using the CPMI to assess this stream as "Fully Supporting" during the last assessment cycle. As a side note, there was a ProbMon station on Fontaine Creek approximately 8 miles upstream from this site in 2003. The latter stream reach had some riffle areas, a gradient greater than 0.3%, and has been assessed as "Fully Supporting" using the VSCI. In conclusion, all of the evidence indicates that Fontaine Creek is not impaired."
5ALTL001.38	Little Cr	Spring '09		yes	"This stream is very aptly named because it is indeed very "Little" and is probably just barely perennial. When we sampled in Fall 2009, there was very little flow and the DO on a cold November day was 5.6. The Fall sample included lots of *leptophlebiidae* mayflies which seem to be quite common in borderline perennial streams that sometimes go dry. The Spring and Fall VSCI scores of 58.9 and 55.0, respectively, are quite close to the VSCI threshold. If this was a "normal" stream, we would probably assess it as impaired given two VSCI scores below 60. However, in this case, we will probably have a lengthy discussion and may end up concluding there is "Insufficient Information" to make a confident call. We will let you know our final decision next month when we make our final assessments for the upcoming Integrated Report. "
8-LOC001.31	Locust Cr	Spring '04	observed	no	"This stream reach includes some braided channels and substantial impact from beaver activity. In the past, we have not assessed this site due to "Insufficient Information". It turns out that we had another ProbMon site on this stream (8-LOC002.00 in 2007) which has been assessed as impaired. Based on recollections as well as recorded field observations (sedimentation scores in the Marginal range), the most likely stressor is sediment."
8-LOC001.31	Locust	Fall '04	observed	no	(same comment as above).

	Cr					
8-PGN002.42	Pigeon Run	Spring '06		not nutrient impaired	no	"Pigeon Run (8-PGN002.42) is a small stream with low (limited) summer flows. It is not nutrient impaired."
8-POR015.70	Po R	Fall '04	observed		no	Po River (8-POR015.70) is a slow moving stream with limited in- stream habitat that would typically support a more tolerant macroinvertebrate community. Low SCI scores are not indicative of nutrient impairment.
9-LFK005.39	Laurel Cr	Spring '05			yes	"we were unable to identify any obvious reason for the <60 scores at 9-LFK005.39 and 9-SFK002.81. Since both scores are close to 60 we considered possibly a local scouring event which we were unaware of prior to sampling could have occurred."
9-MER002.99	Miller Cr	Spring '08	observed		no	"our records indicate that 9-MER002.99 was dry in the fall of 2008 and we suspect it does so routinely"
9-SFK002.81	Stony Fk	Fall '04			yes	(same comment as 9-LFK005.39 above)
9-XDP000.65	X-trib Rock Cr	Fall '03	observed		no	"is also a first order stream which likely dries up occasionally which could offer the best explanation for the low scores for these two stations."

† sites are used as nutrient-criteria references if a significant non-nutrient stressor was observed, if the biologist expressed a definite BPJ that the site was not nutrient impaired, or, if stream characteristics were observed that caused the biologist to describe an inappropriate impairment.



Quantiles

100.0%	maximum	88.22
99.5%		88.22
97.5%		83.8667
90.0%		80.463
75.0%	quartile	76.35
50.0%	median	68.585
25.0%	quartile	60.5275
10.0%		52.086
2.5%		40.7563
0.5%		32.38
0.0%	minimum	32.38

Moments

Mean	67.396061
Std Dev	11.407155
Std Err Mean	0.9928654
Upper 95% Mean	69.360185
Lower 95% Mean	65.431936
N	132

Quantiles

100.0%	maximum	88.22
99.5%		88.22
97.5%		84.4143
90.0%		81.024
75.0%	quartile	76.6725
50.0%	median	68.795
25.0%	quartile	60.5275
10.0%		49.565
2.5%		40.3918
0.5%		32.38
0.0%	minimum	32.38

Moments

Mean	67.292069
Std Dev	11.862749
Std Err Mean	1.1014286
Upper 95% Mean	69.473787
Lower 95% Mean	65.110351
N	116

Figure II-1. Distributions of Stream Condition Index (SCI) values after applying (left) reference filters used by the Virginia Department of Environmental Quality (DEQ) in prior studies (Table II-1), and (right) additional reference filters (Table II-2) in association with those used by DEQ in prior studies.

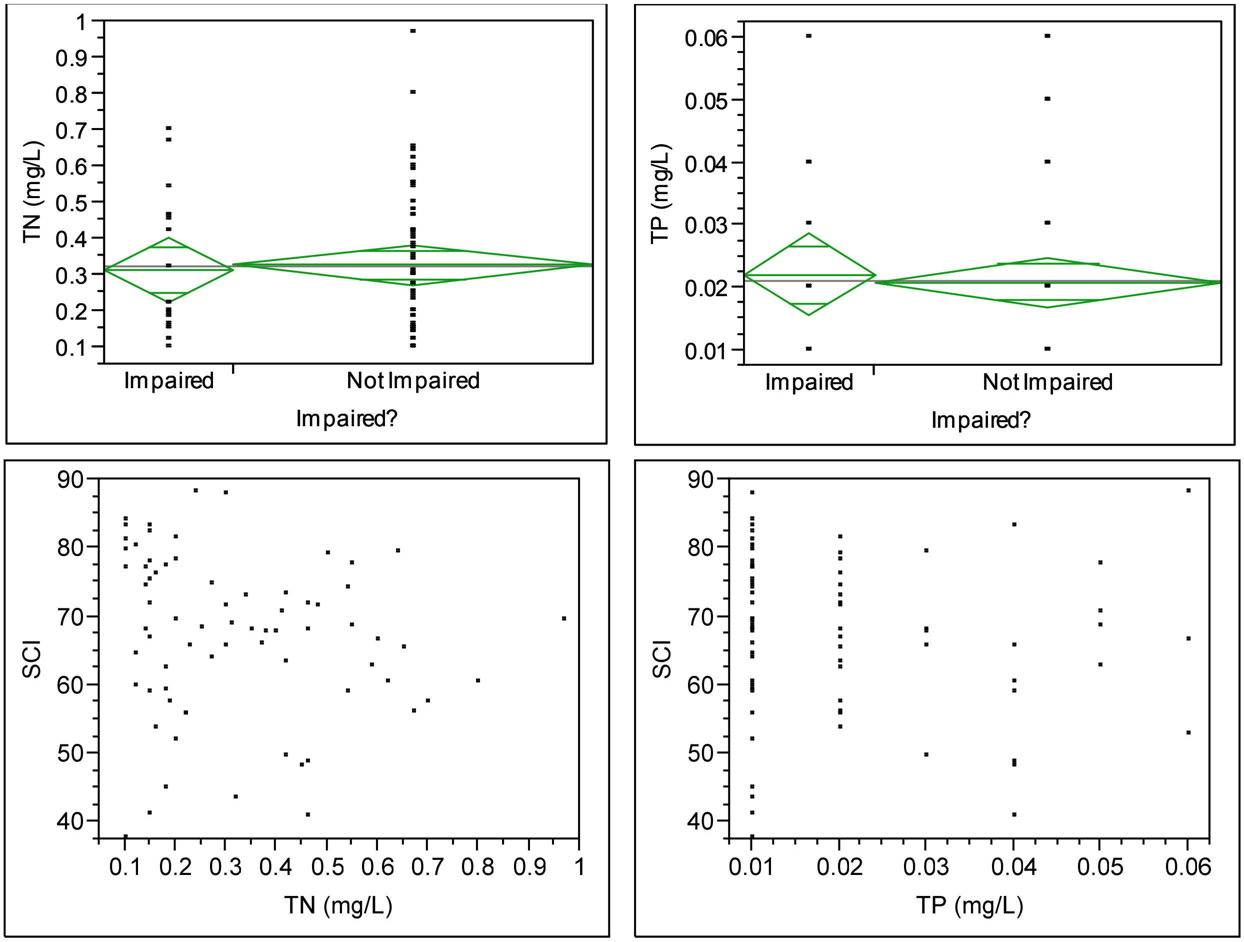
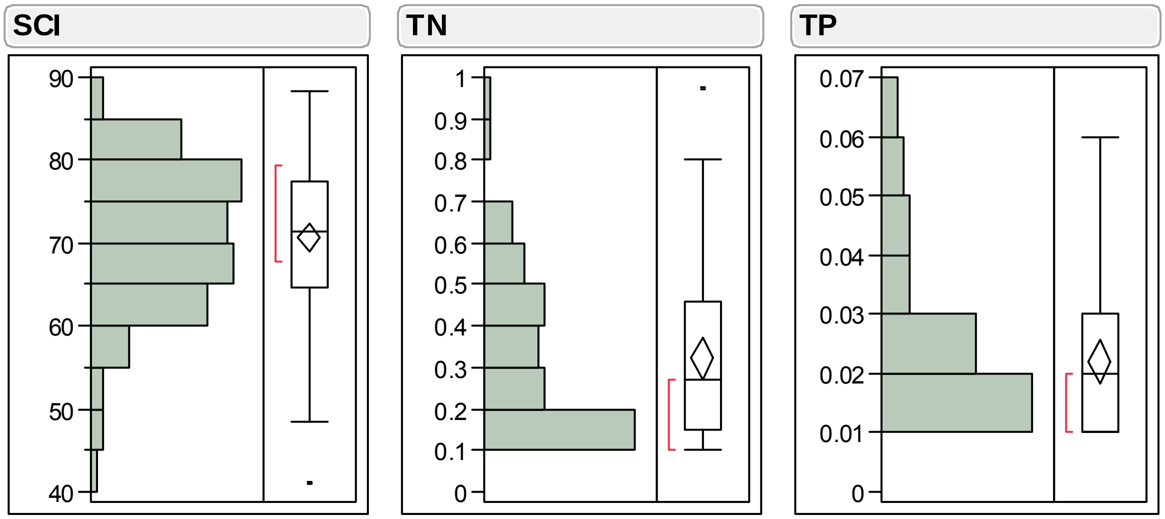


Figure II-2. Relationship of total nitrogen (TN) and total phosphorus (TP) to impairment status (above) and to measured Stream Condition Index (SCI) values (below) at ProbMon sites satisfying the Virginia Department of Environmental Quality reference screens (Table II-1). Regressions of TN and TP against SCI (below) were not statistically significant so regression lines are not shown.



Quantiles

100.0%	maximum	88.22
99.5%		88.22
97.5%		84.888
90.0%		81.214
75.0%	quartile	77.55
50.0%	median	71.51
25.0%	quartile	64.55
10.0%		59.636
2.5%		49.582
0.5%		41.06
0.0%	minimum	41.06

Quantiles

100.0%	maximum	0.97
99.5%		0.97
97.5%		0.88075
90.0%		0.599
75.0%	quartile	0.46
50.0%	median	0.27
25.0%	quartile	0.15
10.0%		0.12
2.5%		0.1
0.5%		0.1
0.0%	minimum	0.1

Quantiles

100.0%	maximum	0.06
99.5%		0.06
97.5%		0.06
90.0%		0.05
75.0%	quartile	0.03
50.0%	median	0.02
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.01

Figure II-3. Distributions of Stream Condition Index (SCI) values, total nitrogen (TN) concentrations, and total phosphorus (TP) concentrations at probabilistic monitoring sites defined as nutrient-criteria references: These sites satisfy the Virginia Department of Environmental Quality reference filters of Table II-1 (TN and TP filters were not applied); and they were found appropriate for nutrient-criteria reference status considering the observations of the regional biologists as recorded in Table II-3.

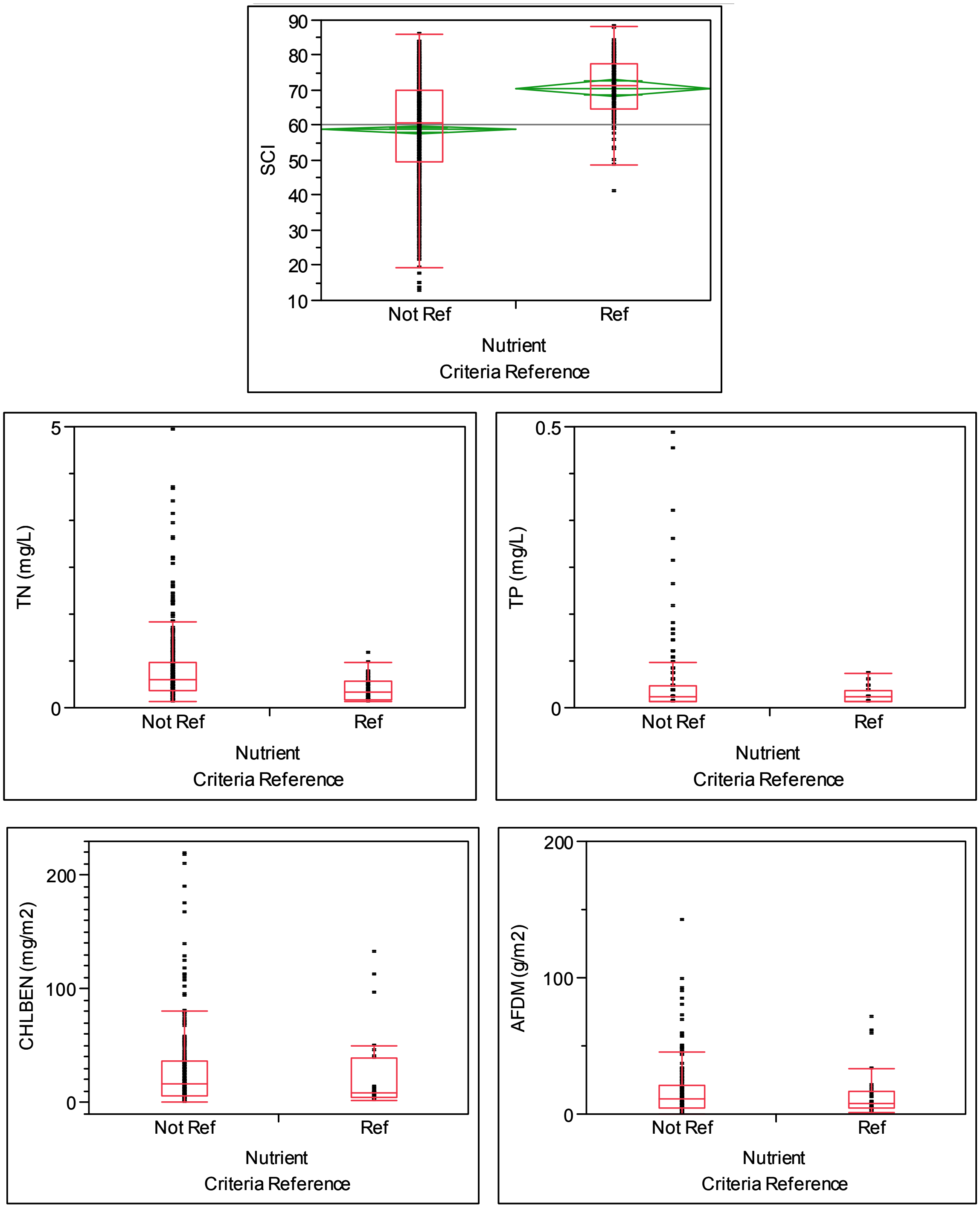
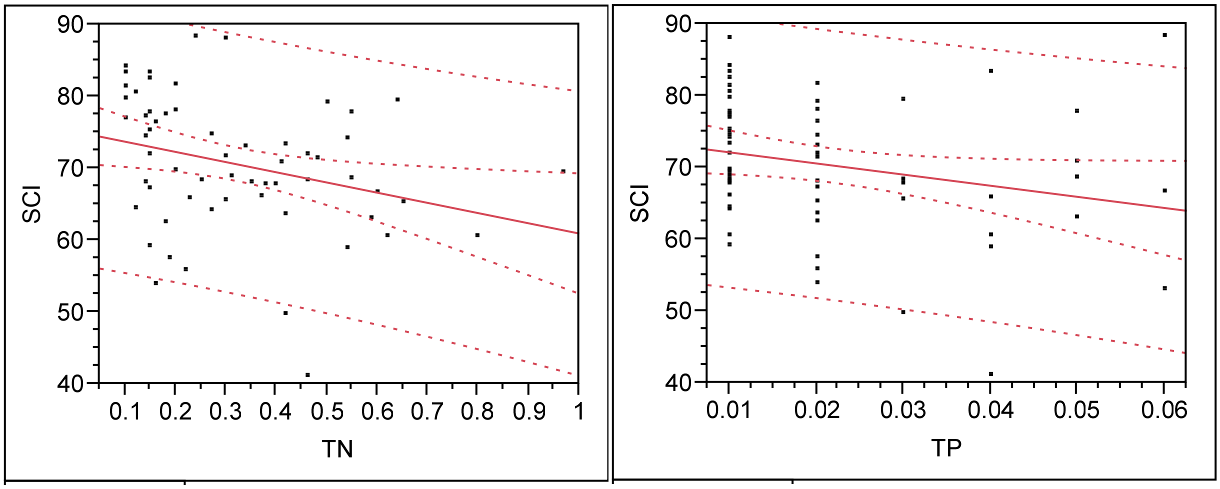


Figure II-4. Comparisons of Stream Condition Index (SCI) values (upper), measured nutrient concentrations (center) and benthic algae metrics (lower) among probabilistic monitoring observations, by nutrient-criteria reference status. Differences between the non-reference and nutrient-criteria reference sites for SCI, total nitrogen (TN) concentrations, and total phosphorus (TP) concentrations are statistically significant a $p<0.05$.



```
Linear Fit
SCI = 75.117623 - 14.197893*TN (mg/L)
  Summary of Fit
  RSquare                          0.090078
  RSquare Adj                       0.07439
  Root Mean Square Error           8.955417
  Mean of Response                   70.553
  Observations (or Sum Wgts)             60
  Analysis of Variance
                          Sum of
  Source        DF       Squares   Mean Square   F Ratio
  Model          1      460.4827       460.483    5.7417
  Error         58     4651.5702        80.199  Prob > F
  C. Total      59     5112.0529                 0.0198*
  Parameter Estimates
  Term         Estimate   Std Error   t Ratio   Prob>|t|
  Intercept   75.117623     2.22834     33.71   <.0001*
  TN (mg/L)   -14.19789      5.9252     -2.40   0.0198*
```

```
Linear Fit
SCI = 73.670854 - 155.0314*TP (mg/L)
  Summary of Fit
  RSquare                          0.059315
  RSquare Adj                      0.043371
  Root Mean Square Error           9.291796
  Mean of Response                 70.26525
  Observations (or Sum Wgts)             61
  Analysis of Variance
                          Sum of
  Source        DF       Squares   Mean Square   F Ratio
  Model          1      321.1986       321.199    3.7203
  Error         59     5093.9111        86.337  Prob > F
  C. Total      60     5415.1097                  0.0586
  Parameter Estimates
  Term         Estimate   Std Error   t Ratio   Prob>|t|
  Intercept   73.670854    2.129068     34.60   <.0001*
  TP (mg/L)   -155.0314    80.37713     -1.93    0.0586
```

Figure II-5. Linear regressions of total nitrogen (TN) and total phosphorus (TP) against Stream Condition Index (SCI) for the nutrient-criteria reference dataset. Residuals from both regressions are normally distributed. The dashed lines adjacent to the regression lines are the 95% confidence intervals for the regression lines. The dashed lines located further from the regression lines bound the 95% confidence intervals for prediction of individual observations.

III. Observed-Effect Concentrations

Observed-effect concentrations (OECs) for N and P are concentrations above which nutrient impairment of the aquatic community can be reasonably expected. Under the nutrient criteria screening approach, monitoring sites with a measured TN and/or TP concentrations ≥ than OECs would be assessed as impaired.

The analyses reported in this chapter were conducted to investigate the potential to establish OEC's through a "probability of impairment at equal-or-greater concentrations" analysis applied to Virginia DEQ monitoring data.

Method

The method of analysis, derived from Paul and McDonald (2005), was applied to estimate potential observed-effect concentrations. The method of analysis is based on the assumption that the probability of a site being impaired for aquatic life (SCI<60) increases with measured nutrient concentrations. Prior AAC reports have validated this expectation at the upper end of the nutrient-concentration range (AAC 2006, 2009, 2010).

The method can be applied to datasets that link measured TN and/or TP concentrations to benthic macroinvertebrate assessments. The SCIs derived from the benthic macroinvertebrate assessments were sorted by the associated nutrient concentration. Then, the number of monitoring observations with SCI<60 at TN and/or TP concentrations ≥ each measured concentration was determined. The resulting frequency was expressed as an impairment probability by calculating the percentage of the total number of observations within that concentration range.

This method was applied to three datasets:

1. Virginia probabilistic monitoring dataset (2001-2009). Only SCI values occurring in association with a TN and/or TP measurement were used for the analysis (i.e., if water quality was measured in the spring, only the spring SCI was used; and vice-versa for the fall).
2. A dataset compiled by linking SCIs recorded in Virginia DEQ's Ecological Data Application System (EDAS) database (2008-2010) with Virginia DEQ's ambient water monitoring data (2008-2010). Each SCI was defined as occurring within a season and year (Spring 2008 or Fall 2010, for example). All monitoring observations for each monitoring location were compiled by 6-month period (January-June and July-December). TN and TP medians were computed for each 6-month period and linked with any corresponding SCI score in EDAS.
3. A second dataset was compiled by linking SCIs recorded in Virginia DEQ's EDAS database (2008-2010) with Virginia DEQ's ambient water monitoring data (2008-2010). TN and TP medians were calculated for each DEQ monitoring station for overlapping 12-month periods: January-December and July-June. The January-December medians were linked with corresponding fall SCI scores, and the July-June medians were linked with corresponding spring SCI scores. The only SCI-TN and SCI-TP pairs used for this analysis were from monitoring locations where four or more nutrient values were available for the 12-month period.

Because an initial application using the three datasets separately did not yield clear interpretations, datasets 1 and 2 were combined after eliminating duplicate observations. This process produced a dataset with a larger number of observations than when datasets were considered independently. The resulting dataset was analyzed as described above, and that result is reported.

All applications were restricted to monitoring data collected from the Mountain and Piedmont ecoregions. Impairment probability curves were plotted for each ecoregion separately and for all data combined.

The probability impairment curves are interpreted visually, referencing the raw data, to estimate potential OECs at the 90% probability-of-impairment level. A logistic inverse prediction approach was applied as an alternative method for interpreting these data. This method is described in Appendix A.

Results

Impairment probability charts for the combined dataset (probabilistic monitoring, 2001-2009, plus 6-month ambient, 2008-2010) yielded a smooth pattern for TN (Figure III-1, upper). The 12-month analysis did not work as well because of five monitoring observations in the Mountains where SCI ≥60 occurred within the 2.5 – 3.2 mg/L range for TN (Figure III-1, below). All visually estimated OECs were in the range of 1.8 – 3.2 mg/L for TN, and the visually estimated TN OEC is higher for the Mountain than for the Piedmont ecoregion (Table III-1). No consistent pattern of difference between the shorter-term combined analysis and the 12-month analysis is apparent.

The impairment probability charts for TP did not yield smooth patterns (Figure III-2). In addition to the data plotted in Figure III-2, an off-scale SCI<60 observation occurs at TP = 0.84 mg/L. Visually estimated OECs for TP range from 0.15 to 0.26 mg/L; and those derived with the 12-month analysis are lower than those derived using short-term data (Table III-1). Interpretation of the ambient 12-month TP data for the Mountain ecoregion was problematic.

The logistic inverse prediction approach was applied only to the 6-month dataset because it contained more observations than the 12-month dataset. It yielded potential OECs of greater magnitude than the manual interpretations (3.66 mg/L for TN, 0.284 mg/L for TP for the two ecoregions combined) while demonstrating significant differences between the Mountains and Piedmont ecoregions (Table III-1).

Discussion

This process did not yield the expected results consistently: smooth and regular patterns of increasing impairment probabilities as nutrient concentrations increase.

The visual interpretation analyses yielded potential OECs for TN ranging from 1.8 to 3.2 mg/L, and for TP ranging from 0.15 to 0.26 mg/L (Table III-1). However, this process proved problematic for several reasons:

- In some cases, the resulting estimates do not appear as robust because they are dependent upon a small number of SCI<60 data points.

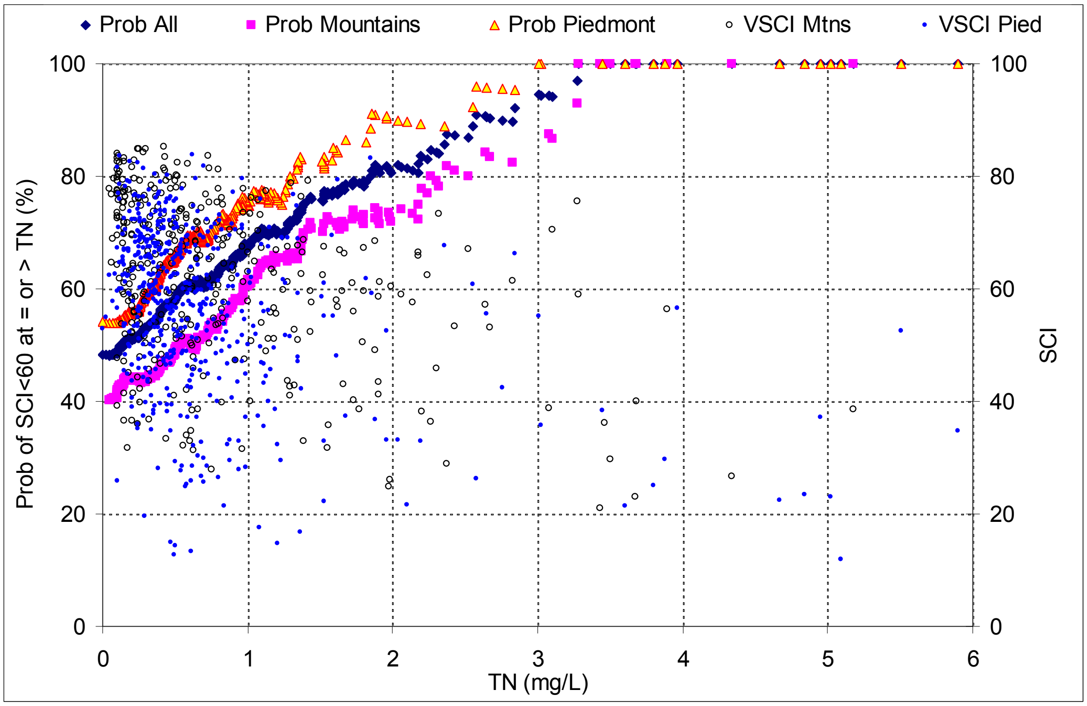
- The OECs are not precise, as the potential values are derived from a manual interpretation process. It would be possible to fit functional forms to these data as a means of estimating OECs more precisely.
- The utility of these potential OECs is limited because they are high relative to most DEQ monitoring data as most occurred beyond the 90th percentile of all TN and/or TP monitoring data. Thus, if implemented, they would be capable of generating assessments for only a small number of monitoring sites.
- The utility of these potential OECs is also questionable because they consider only localized effects. Virtually all Virginia surface waters flow into water bodies that are nutrient sensitive – including Chesapeake Bay, Albemarle Sound, and the Gulf of Mexico. Downstream loading effects for these water bodies must be taken into account by alternative processes.

The statistical interpretations yielded potential OECs of greater magnitudes than those derived from the visual interpretations (3.66 mg/L for TN, 0.284 mg/L for TP, overall) (Figure III-3). This result occurred due to the influence caused by data distributions, as occurring over the full range of impairment probabilities, on the logistic inverse prediction functional forms.

Table III-1. Potential Observed-Effect Concentrations (OECs) derived from the impairment probability curves at 90% probability using visual interpretation and using statistical methods (see Appendix A), by ecoregion (Mtn = Mountain ecoregion; Pied = Piedmont ecoregion) and overall.

Data		- - - - TN (mg/L) - - - -			- - - - TP (mg/L) - - - -		
	n	Mtn	Pied	All	Mtn	Pied	All
Visual:							
ProbMon-Ambient 6 month combined	922	3.2	1.9	2.6	0.26	0.22	0.25
Ambient 12-month	207	n/a	1.8	3.2	n/a	0.15	0.15
Statistical: Logistic Inverse Prediction							
ProbMon-Ambient 6 month combined [†]	922	3.89	3.07	3.66	0.351	0.295	0.284

[†] From Appendix A, Table 3 and Table 6.



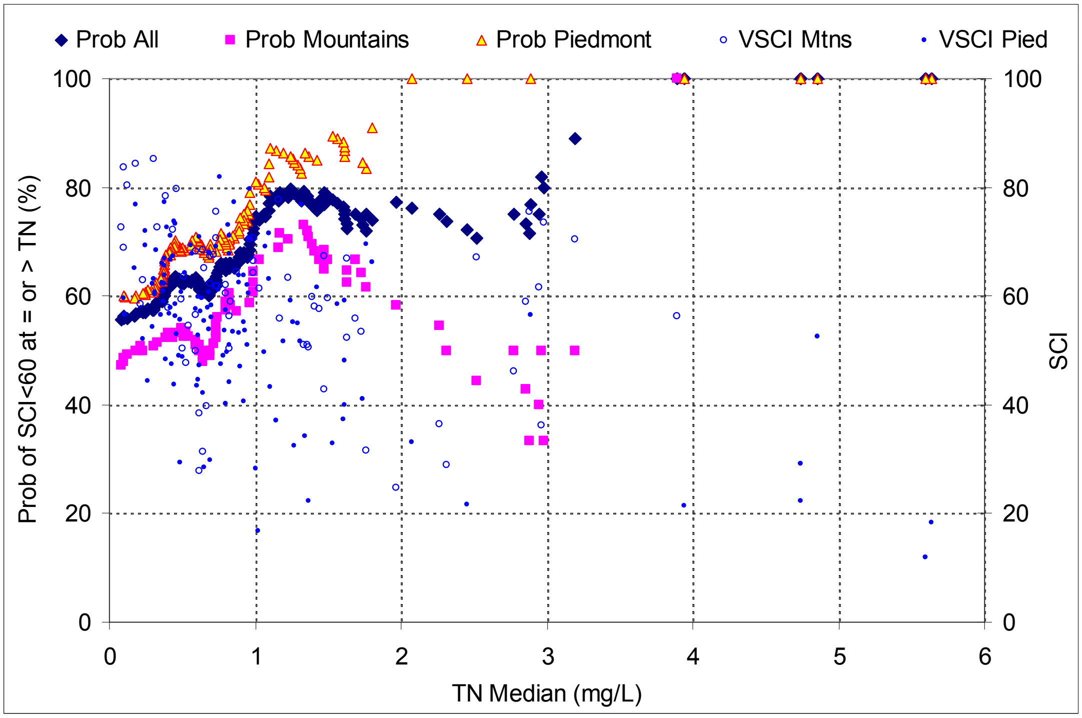
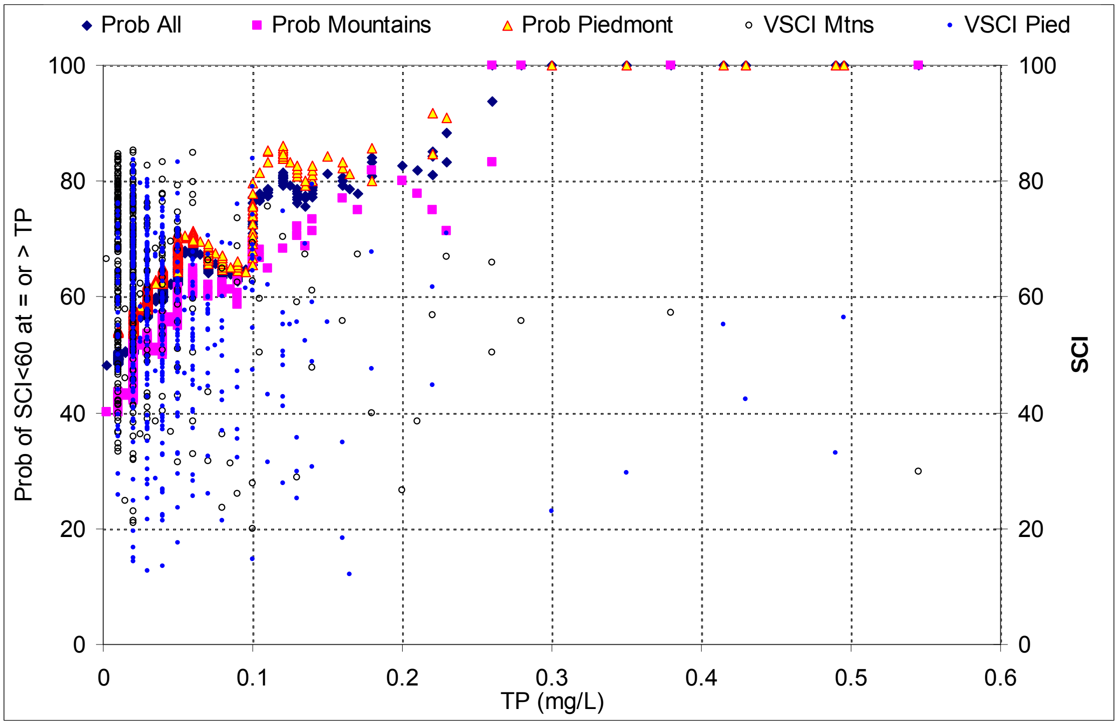


Figure III-1. Impairment probability charts (Mountain ecoregion, Piedmont ecoregion, and overall) for total nitrogen (TN) derived from probabilistic monitoring data -- ambient 6-month medians (above), and ambient 12-month medians (below), with Stream Condition Index (SCI) values. High TN values with SCI<60 are off-scale in both charts.



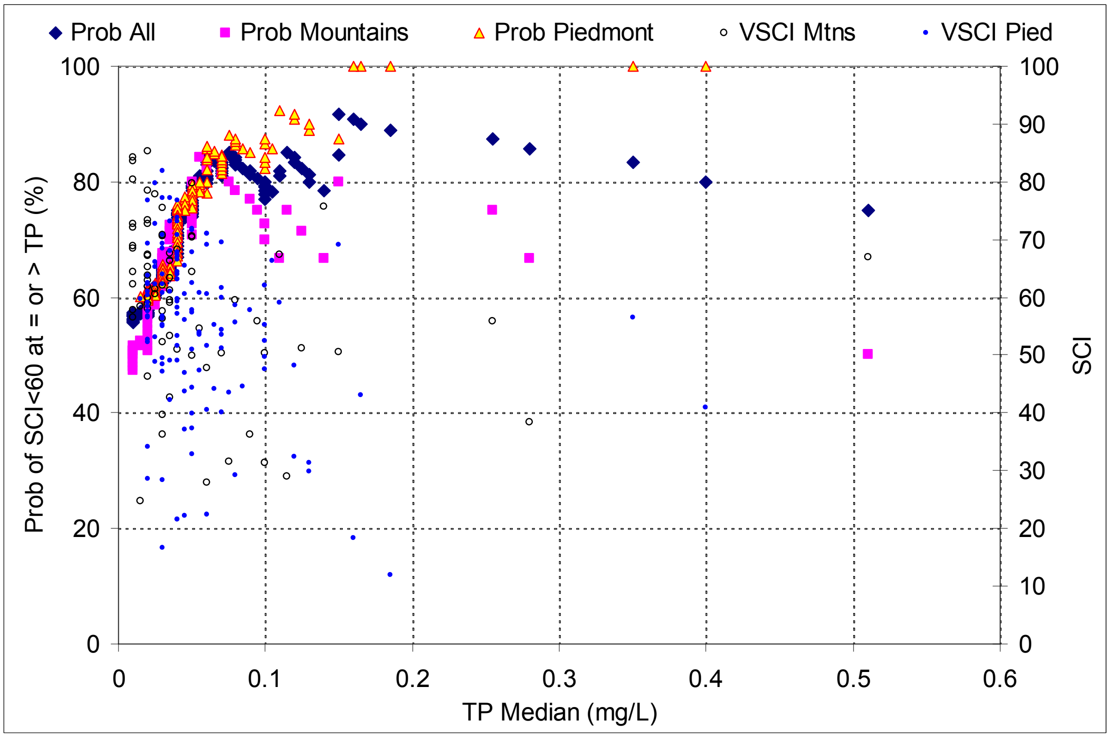


Figure III-2. Impairment probability charts (Mountain ecoregion, Piedmont ecoregion, and overall) for total phosphorus (TP) derived from probabilistic monitoring data -- ambient 6-month medians (above), and ambient 12-month medians (below), with Stream Condition Index (SCI) values. High TP values with SCI<60 are off-scale in both charts.

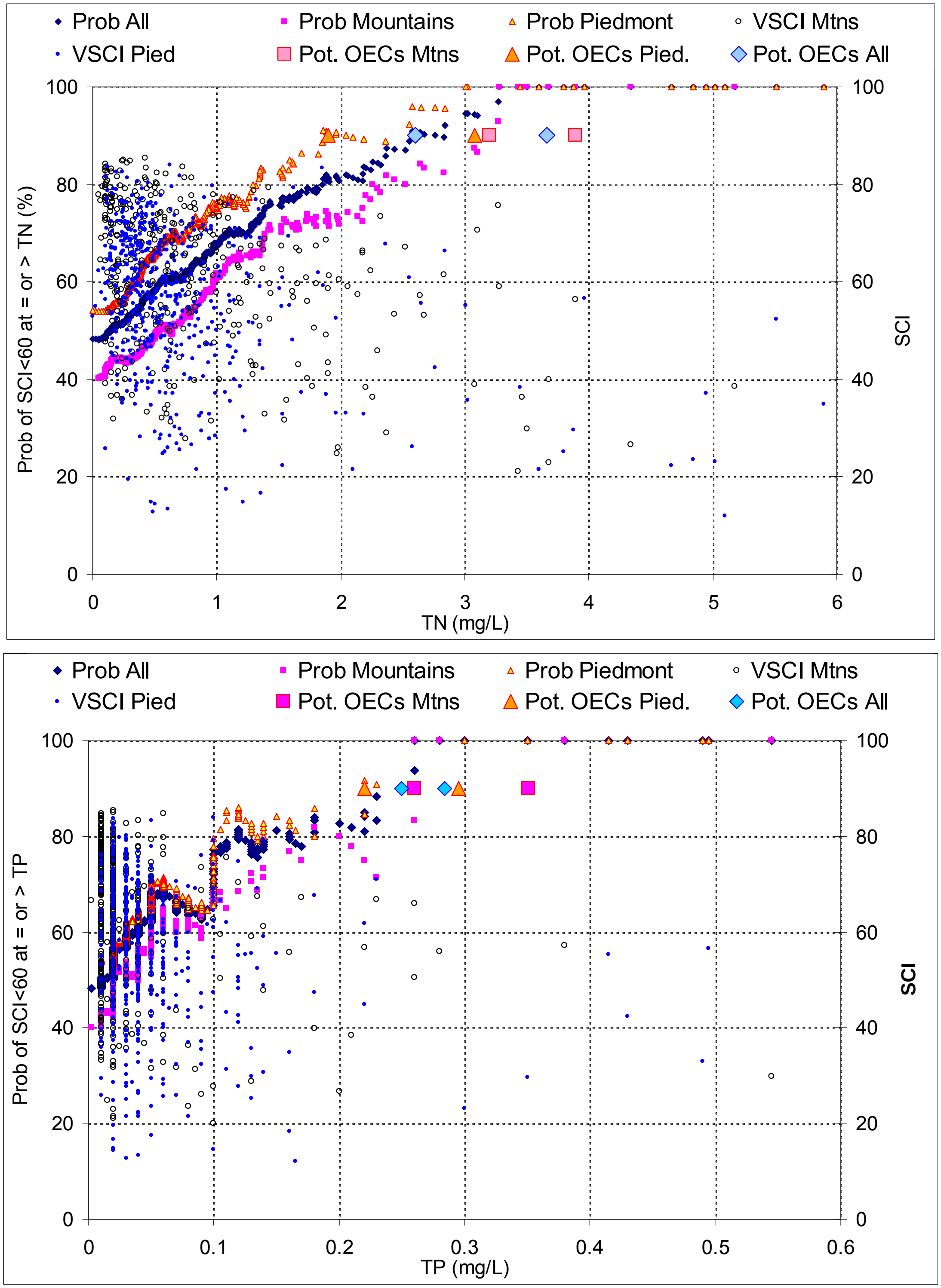


Figure III-3. Probability of impairment plots for the 6-month datasets (Figures III-1 and III-2, upper) replotted with potential Observed-Effect Concentrations (OECs) derived from visual and statistical interpretations (Table III-1). In each case, the potential OEC derived from statistical interpretation occurs to the right (i.e., at higher concentration than the potential OEC derived from visual interpretation).

IV. Visual Assessments

Background

DEQ conducts biological monitoring activities on a twice-per-year basis, for the spring (index period = March 1 – June 15) and fall (index period = September – December 15) seasons.

Virginia DEQ regional biologists conducted visual assessments with biological monitoring in Mountain and Piedmont ecoregions for wadeable streams over three years on a trial basis. During fall and spring of 2008, biologists conducted visual assessments at 62 locations selected for an initial trial, called the "pilot program" (AAC 2009). In 2009 and 2010, regional biologists conducted visual assessments during routine biological monitoring of Mountain and Piedmont wadeable streams. The visual assessment procedure is a structured observation conducted by the regional biologist at a biological monitoring location in association with habitat assessment. Biologists recorded visual assessment observations on data forms prepared for that purpose and sent scanned forms to Virginia Tech for analysis.

Visual assessment forms require biologists to record stream features exerting potential influence on the benthic macroinvertebrate community, including stream-bottom coverage by algae and macrophytes. The form's central feature is the biologist's best professional judgment (BPJ) of whether the stream is impaired by nutrients; responses can be "low" (indicating the biologist's judgment that the stream is unlikely to be impaired by nutrients), "medium," and "high" (indicating the biologist's judgment that the stream is likely to be impaired by nutrients).

Visual assessment forms were updated and changed over the three year trial period due to observations by biologists and by AAC personnel in an effort to create a more effective and time-efficient visual assessment process (see Appendix B). The initial form was implemented in spring 2008. For fall 2008, a "best professional judgment by non-nutrient stressors" response was added for the purpose of improving the capability of the researchers to evaluate the BPJ accuracy of the DEQ biologists. For 2009, the algal stream-bottom coverage approach was simplified by eliminating the coverage-by-algae-color response categories, while maintaining the cover-by-algal-types response. Also in 2009, an "overall" stream-bottom algal cover category was added to the response form as means of recording an estimate for the total stream bottom coverage by algae. For 2010, the form was simplified by removing some of the detail, reducing the form from two sides of a page to one single-sided page.

Here, we evaluate trial applications of the visual assessment as a potential assessment tool for use in nutrient criteria implementation. Because visual assessments can be used for implementation only if they achieve an adequate level of accuracy, our primary focus was to evaluate the accuracy of the visual assessments.

Methods

In conducting the following analyses, only visual assessments with an associated SCI value were considered.

1. Obtain and compile visual assessment forms completed by DEQ biologists over the 2008-2010 period. Manually enter selected data from the forms into a computer database to enable their analysis.

2. Obtain all available EDAS data, including SCI scores, compiled by Virginia DEQ in the Mountain and Piedmont ecoregions for the spring and fall seasons, 2008-2010. Link the visual assessments to the SCI scores and habitat evaluations for each monitoring event. Where replicate benthic macroinvertebrate samples were obtained, use only SCI data for the primary sample.
3. Obtain water quality monitoring data compiled by Virginia DEQ in the Mountain and Piedmont ecoregions for 2008-2010. For each monitoring location, calculate semi-annual median concentrations for TN and TP, with "spring" defined as January-June and "fall" as July-December. Link the semi-annual TN and TP medians to the corresponding visual assessments, SCI values, and habitat scores.
4. Perform manual checks of the above in an effort to ensure completeness. Manually adjust station numbers from the visual assessment forms that failed to match, and install correct linkages to EDAS and nutrient data where appropriate. Check ProbMon and 2008 Pilot Program data so as to ensure that SCI and nutrient concentrations recorded for those activities were included in automated data processing.
5. Calculate an "Algal Biomass Index"(ABI) from the algal biomass recorded as stream-bottom coverages by visual assessments (Table IV-1) for each visual assessment completed in 2009 and 2010 (the 2008 forms did not include an "overall" stream bottom coverage estimate). For each algae type and overall algal coverage, biologists were asked to estimate stream-bottom coverage as a coverage class (Table IV-1). In 2009, algae types were sub-categorized by color (bright green, dark green, brown, black, other), whereas in 2010 no color sub-categories were used. In both years, the "overall" stream-bottom coverage was the primary driver for the Algal Biomass Index calculation: The overall cover was estimated as the mid-point of the recorded cover class; then a preliminary estimate of bottom coverage was made for each algae type as the cover-class midpoint; then, all preliminary algal-type estimates were summed and compared to the overall coverage estimate. An adjustment factor was calculated as the (overall estimate / sum of algal-type preliminary estimates) ratio. Each algae type's preliminary cover estimate was multiplied by the adjustment factor to compute a final estimate of bottom coverage for that algal type, noting that algae-type final estimates summed to the overall coverage estimate. Each algae type's bottom coverage estimate was then multiplied by a weighting factor (Table IV-1) and those products were summed to compute the Algal Biomass Index.

Table IV-1. Factors used in computing algal biomass ratings.

Cover Class	Midpoint of Coverage Estimate	Algae Types	Weighting Factor
None recorded	0	Film	1
A = 0-10%	5%	Thin Mat	2
B = 10-40%	25%	Thick Mat	3
C = 40-70%	55%	Short Filamentous	4
D = 70-100%	85%	Tall Filamentous	5

6. Analyze data to evaluate visual assessment accuracy.

BPJs for nutrient-induced impairment were evaluated; and BPJs for nutrient and non-nutrient-induced impairment were combined and evaluated using the following logic:

- If *both* nutrient and non-nutrient BPJ probability-of-impairment estimates are "low," overall BPJ is "low;"
- If *either* the nutrient or non-nutrient BPJ probability-of-impairment is "high," overall BPJ is "high;"
- Otherwise, overall BPJ is "indeterminate;"
- If a non-nutrient-induced impairment BPJ is not available (as in 2008), combined BPJ is evaluated as if the non-nutrient-induced impairment BPJ was recorded as "medium."

The nutrient and combined BPJs were evaluated on two separate bases:

- A primary evaluation:
  - A "high probability" BPJ for nutrient-induced impairment was interpreted as correct if the site was impaired for aquatic life (SCI<60); and a "high probability" combined BPJ was evaluated as correct if the site was impaired for aquatic life (SCI<60).
  - A "low probability" combined BPJ was evaluated as correct if the site was not impaired for aquatic life (SCI≥60). The nutrient BPJ was not evaluated on this basis, because non-nutrient factors may cause a low-nutrient stream to become impaired.
- A secondary evaluation was also conducted, considering the fact that SCI's reflect the natural variability of the stream community; the secondary evaluation was conducted using ±5 SCI window, but otherwise with rules comparable to the primary evaluation.
  - A "high probability" BPJ for nutrient-induced impairment was interpreted as "within 5 SCI units" if it had an SCI<65 and a "high probability" combined BPJ was evaluated as "within 5 SCI units" if the site had an SCI<65).
  - A "low probability" combined BPJ was evaluated as "within 5 SCI units" if the site had an SCI≥55. The nutrient BPJ was not evaluated on this basis, since non-nutrient factors may cause a low-nutrient stream to become impaired.

7. Analyze data to determine relationships among BPJ nutrient ratings, Algal Biomass Index, habitat score, and stream nutrient concentrations.

   Stream Condition Index and Algal Biomass Index were analyzed for significant differences among BPJ classes using analysis of variance (ANOVA). TN and TP were analyzed for significant differences among BPJ and SCI classes using the non-parametric Wilcoxon procedure. Continuous variables (Algal Biomass Index, SCI, habitat score, TN, and TP) were analyzed for correlation using the non-parametric Spearman correlation procedure. Dependence of SCI upon measured continuous variables (Algal Biomass Index, habitat score, and log-transformed TN and TP) was investigated using a stepwise multiple regression procedure. All statistical analyses were performed using JMP 9.0 (SAS Institute, Cary NC) and interpreted at the $\alpha = 0.05$ level of statistical significance unless otherwise noted.

8. Manually review and characterize monitoring observations that were visually assessed for impairment incorrectly in an effort to determine the source of problems.

Results

Visual Assessment Accuracy Evaluation: During three years of the study, 88% (49 of 56) of sites visually assessed as having a high nutrient-impairment probability had SCIs<60; 79% of sites visually assessed as having a high probability of impairment by either nutrients or non-nutrient stressors were impaired (Tables IV-2 and IV-3). Similarly, 79% of the sites visually assessed as having a "low" probability of impairment for both nutrients and non-nutrient stressors had SCIs≥60.

Using the more relaxed (secondary) criteria for evaluation that consider the variability of SCI, 95% of the sites visually assessed as having a "high" probability of impairment by nutrients and 92% of sites visually assessed as having a high probability of impairment by either nutrients or non-nutrient stressors had SCIs<65. When applying the secondary criteria, 88% of the sites visually assessed as having a "low" probability of impairment for both nutrients and non-nutrient stressors had SCIs≥55.

Monitoring sites visually assessed as having a high probability of impairment based on BPJ for impairment by nutrients and impairment by combined stressors (nutrients and non-nutrients) had lower mean SCI scores (47.7 ± 1.7 for nutrients, 46.1 ± 1.2, for combined stressors) than sites visually assessed as having medium (55.0 ± 1.0 for nutrients, 58.3 ± 0.7 for combined stressors) and low (63.1 ± 0.7 for nutrients, 69.0 ± 0.8 for combined stressors) probabilities of impairment (p<0.05, Figure IV-1).

Relationships Among BPJ nutrient ratings, SCI Values, and Related Factors: The presence of algal biomass clearly influenced regional biologists BPJ nutrient ratings (Figure IV-2). The Algal Biomass Index was higher for sites with a high probability of impairment by nutrients based on BPJ than for medium-rated sites; and it was higher for medium-rated sites than for sites rated with a low probability of impairment by nutrients (Figure IV-2).

TN and TP medians were higher (p<0.05) for sites where SCI<55 and SCI=55-60 than for sites where SCI≥60; and the TN medians were higher for sites where the SCI<55 than where SCI=55-60 (Figure IV-3, left). TN and TP medians were also higher (p<0.05) for sites rated with a high probability of impairment by nutrients based on BPJ than for those rated with medium and low probabilities of impairment by nutrients. Furthermore, TN medians were higher for sites rated with a medium probability of impairment by nutrients based on BPJ than were sites rated with a low probability of impairment by nutrients as assessed using BPJ (Figure IV-3, right). Numerous statistically significant correlations among Algal Biomass Index, SCI, habitat score, and TN and TP medians were noted (Table IV-4, Figure IV-4). TN and TP medians were highly and positively correlated with one another. Habitat score was highly and positively correlated with SCI; whereas TN medians, TP medians and Algal Biomass Index were highly and negatively correlated with SCI. TN median was positively correlated with Algal Biomass Index (ABI) but TP median was not.

Dissolved oxygen was negatively correlated with TP, but exhibited no significant correlations with the other factors; and did not vary significantly with biologists' BPJs or with impairment status (data not shown).

An effort to model SCI yielded the following prediction equation:

$$\mathrm{SCI} = 0.05{*}\mathrm{ABI} + 0.26{*}\mathrm{HabScore} + 17.3{*}(\ln(\mathrm{TN}) + 0.09{*}[\mathrm{HabScore} \times \ln(\mathrm{TN})])$$

The prediction equation generated an R^2 of 0.36 and an adjusted R^2 of 0.35, meaning that 65% of the variation in SCI was associated with non-modeled factors. Habitat score and Algal Biomass Index were included in the model because these factors reflect visual evaluations by biologists.

Incorrect Visual Assessments: Seven monitoring events visually assessed as having a "high" probability of nutrient-induced impairment were found to have SCIs ≥ 60. Of these seven, three occurred at sites with SCIs < 60 during other monitoring seasons (Table IV-5). All had elevated algal biomass indices.

Discussion and Summary

The following text refers to "correct" BPJ visual assessments for nutrient-induced impairments. This interpretation of "correct" indicates only that the site was impaired for aquatic life (SCI<60), as we have no way to evaluate whether or not the site was impaired by nutrients at the time of BPJ application.

Clearly, regional biologists are able to visually discriminate sites impaired for aquatic life with a high degree of accuracy, but their discrimination capability is not perfect. Regional biologists achieved a higher rate of correct "high probability of impairment" BPJ assessments for nutrients (88%) than for all stressors combined (79%). In one sense, this is logical given that the factors that cause nutrient-induced impairment (aquatic algae) are generally visually evident. More than half of their incorrect "high probability of impairment" BPJ visual assessments, both for nutrients and overall, occurred due to SCI scores that exceeded the impairment threshold only slightly (i.e., SCIs in the range of 60 to 65).

Although almost 90% of the biologists' "high probability of nutrient impairment" BPJs were correct, these visual assessments occurred with low frequencies. Only 56 of 723 visual assessments with associated SCIs (about 8%) produced a BPJ rating of "high probability of nutrient impairment." "High probability of impairment" from the BPJ ratings was applied more frequently to evaluate non-nutrient stressor effects. Eighteen percent (133 of 723) of the monitoring events with SCIs scores received a BPJ rating of "high probability" of impairment associated with nutrients, non-nutrient stressors, or both.

Using BPJ, biologists correctly assigned a "low probability of impairment" 79% of the time, meaning that 79% of the combined "low probability" assessments were for monitoring events where SCI≥60. Compared to the high-probability BPJs, a smaller percentage of the incorrect low-probability BPJs (20 of 47, 42%) occurred within five SCI units of the SCI<60 impairment threshold. However, biologists applied the low-probability BPJ rating more frequently, as 31% of monitoring events with SCI scores received "low probability" BPJs.

The potential for application of visual assessments in nutrient criteria development is an important consideration for Virginia DEQ, and for evaluation of the waters of the Commonwealth. A visual assessment can be applied with far fewer resources than a biological assessment. Nearly 50% of the monitoring events were visually assessed as having either a "high" or a "low" probability of aquatic-life impairment, considering both nutrient and non-nutrient factors. The data indicate that regional biologists are able to achieve relatively high levels of accuracy in application of visual assessments.

Table IV-2. Analysis of Correct Classification: Best Profession Judgment (BPJ) of Impairment by Nutrients.

		- - - - - No. of SCI Values - - - -					- - - - - % of SCI Values - - - - -				
Year	BPJ	<55	55-<60	60-65	>65	Total	<55	55-<60	60-65	>65	All
2008	Low	11	4	3	13	31	35%	13%	10%	42%	50%
2008	Med	9	6	4	5	24	38%	25%	17%	21%	39%
2008	High	6	0	0	1	7	86%	0%	0%	14%	11%
						62					
2009	Low	59	24	20	101	204	29%	12%	10%	50%	66%
2009	Med	41	12	14	27	94	44%	13%	15%	29%	30%
2009	High	10	3	0	0	13	77%	23%	0%	0%	4%
						311					
2010	Low	45	21	31	115	212	21%	10%	15%	54%	61%
2010	Med	45	13	17	27	102	44%	13%	17%	26%	29%
2010	High	24	6	4	2	36	67%	17%	11%	6%	10%
						350					
All	Low	115	49	54	229	447	26%	11%	12%	51%	62%
All	Med	95	31	35	59	220	43%	14%	16%	27%	30%
All	High	40	9	4	3	56	71%	16%	7%	5%	8%
						723					

		- - - - - Primary Evaluation - - - - -				- - - - - Secondary Evaluation - - - - -			
Year	BPJ	SCI< 60	SCI≥ 60	Correct[†]	Not Correct[†]	within 5 SCI units[‡]	not within 5 SCI units[‡]	within 5 SCI units[‡]	not within 5 SCI units[‡]
2008	Low	15	16						
2008	Med	15	9						
2008	High	6	1	86%	14%	6	1	86%	14%
2009	Low	83	121						
2009	Med	53	41						
2009	High	13	0	100%	0%	13	0	100%	0%
2010	Low	66	146						
2010	Med	58	44						
2010	High	30	6	83%	17%	34	2	94%	6%
All	Low	164	283						
All	Med	126	94						
All	High	49	7	88%	13%	53	3	95%	5%

[†] for primary evaluation: high probabilities of impairment are "correct" if SCI<60

[‡] for secondary evaluation: high probabilities of impairment are within 5 SCI units if SCI<65

Table IV-3. Analysis of Correct Classification: Combined Best Professional Judgment (BPJ) of Impairment (Nutrients and Non-Nutrients).

		- - - - - No. of SCI Values - - - -					- - - - - % of SCI Values - - - - -				
Year	BPJ	<55	55-<60	60-65	>65	Total	<55	55-<60	60-65	>65	All
2008	Low	1	0	2	4	7	14%	0%	29%	57%	11%
2008	Med	18	7	7	14	46	39%	15%	15%	30%	74%
2008	High	7	0	1	1	9	78%	0%	11%	11%	15%
						62					
2009	Low	18	9	9	70	106	17%	8%	8%	66%	34%
2009	Med	54	24	24	54	156	35%	15%	15%	35%	50%
2009	High	38	1	6	4	49	78%	2%	12%	8%	16%
						311					
2010	Low	8	11	11	83	113	7%	10%	10%	73%	32%
2010	Med	56	32	19	55	162	35%	20%	12%	34%	46%
2010	High	50	9	10	6	75	67%	12%	13%	8%	21%
						350					
All	Low	27	20	22	157	226	12%	9%	10%	69%	31%
All	Med	128	63	50	123	364	35%	17%	14%	34%	50%
All	High	95	10	17	11	133	71%	8%	13%	8%	18%
						723					

		- - - - - Primary Evaluation - - - - -				- - - - - Secondary Evaluation - - - - -			
Year	BPJ	SCI<60	SCI≥60	Correct[†]	Not Correct[†]	within 5 SCI units[‡]	not within 5 SCI units[‡]	within 5 SCI units[‡]	not within 5 SCI units[‡]
2008	Low	1	6	86%	14%	6	1	86%	14%
2008	Med	25	21						
2008	High	7	2	78%	22%	8	1	89%	11%
2009	Low	27	79	75%	25%	88	18	83%	17%
2009	Med	78	78						
2009	High	39	10	80%	20%	45	4	92%	8%
2010	Low	19	94	83%	17%	105	8	93%	7%
2010	Med	88	74						
2010	High	59	16	79%	21%	69	6	92%	8%
All	Low	47	179	79%	21%	199	27	88%	12%
All	Med	191	173						
All	High	105	28	79%	21%	122	11	92%	8%

[†] for primary evaluation: Low-probabilities of impairment are "correct" if Stream Condition Index (SCI) ≥60; high probabilities of impairment are "correct" if SCI<60.

[‡] for secondary evaluation: Low-probabilities of impairment are within 5 SCI units if SCI≥55; high probabilities of impairment are within 5 SCI units if SCI<65.

Table IV-4. Matrix of coefficients for Spearman correlations among total nitrogen (TN) medians, total phosphorus (TP) medians, and related variables. [†]

	ABI	SCI	Habitat Score	TN Median	TP Median
Algal Biomass Index (ABI)		***-0.32***	***-0.15***	**0.14**	0.00
Stream Condition Index (SCI)	***-0.32***		***0.43***	***-0.37***	***-0.24***
Habitat Score	***-0.15***	***0.43***		***-0.20***	-0.07
TN Median (mg/L)	**0.14**	***-0.37***	***-0.20***		***0.53***
TP Median (mg/L)	0.00	***-0.24***	-0.07	***0.53***	

[†] Bold without italics: 0.05>p>0.01; Bold italics: p<0.01

Table IV-5. Incorrect best professional judgment (BPJ)-nutrient visual assessments.

Station ID	Season	SCI	ABI [†]	Comment	Notes [‡]
1ACRF001.18	Spring 2010	75	120	High pH, Lots of algae, some ag/pasture upstream	Fall 2010 SCI = 70, with higher algal index (220).
2RVN015.97	Fall 2008	69	n/a	"Large quantities of plant and algae mass limit substrate interstices, expect community shift to grazers and scrapers"	Spring 2010 SCI = 63. TN and TP medians range from 0.8 - 1.6 for TN, 0.10-0.16 for TP.
1ACLK002.40	Fall 2010	67	275	“Ag/pasture w/ cows just upstream”	Also visually assessed as "high" in Spring 2010, with SCI = 55. 2008 TN (1.6 and 2.2) and TP (0.02 and 0.04) medians are available, but not in 2010.
4ASUC001.31	Spring 2010	64	323	"Abundant long film. algae; bedrock riffles w/ plunge pool habitat."	Fall 2010 SCI = 61. TN median ranges from 0.58-0.95, TP median from 0.03 - 0.04 over 3 sampling seasons.
5ACHS003.42	Fall 2010	64	158	"All rocks covered in algae"	Other SCIs are 50, 52, 56, 61. No TN TP data.
4ATEL001.02	Fall 2010	63	174	">70% of substrate covered in thin mat of periphyton"	Spring 2010 SCI = 52. TN medians range from 0.9 - 1.3, and TP medians from 0.03 - 0.05, over 6 sampling seasons.
2BWTN007.39	Spring 2010	62	107	"All rocks and much of stream bottom covered in algae"	Fall 2010 = 63, visually assessed as "low" BPJ nutrients. Spring & Fall TN median = 0.09 & 0.16, TP median = 0.03 & 0.06.

[†] Algal biomass index; overall mean value = 75. [‡] All total nitrogen (TN) and total phosphorus (TP) median values are mg/L. SCI=Stream Condition Index

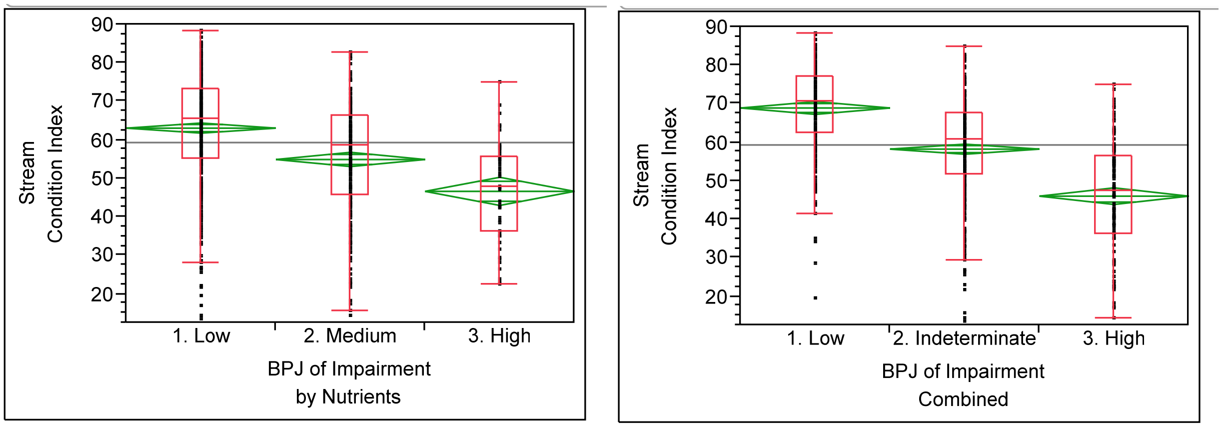


Figure IV-1. Relationship of Stream Condition Index (SCI) to best professional judgment (BPJ) ratings of nutrient impairment likelihood by Virginia Department of Environmental Quality (DEQ) biologists(left) and combined nutrient and non-nutrient stressors (right). Diamonds represent the mean value and its 95% confidence interval. Box plots represent the median, and 25th and 75th percentiles (box). Horizontal line represents the grand mean of all SCI observations for sites with visual assessments (59.4).

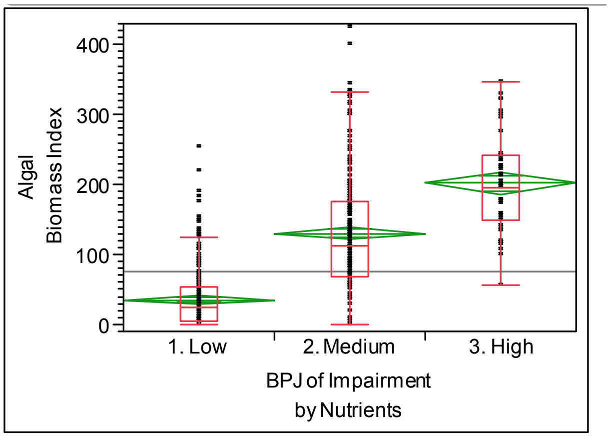


Figure IV-2. Relationship of Algal Biomass Index to best professional judgment (BPJ) ratings of nutrient impairment likelihood by Virginia Department of Environmental Quality biologists. Diamonds represent the mean value and its 95% confidence interval. Box plots represent the median, and 25th and 75th percentiles (box). Horizontal line represents the grand mean of all Stream Condition Index (SCI) observations for sites with visual assessments.

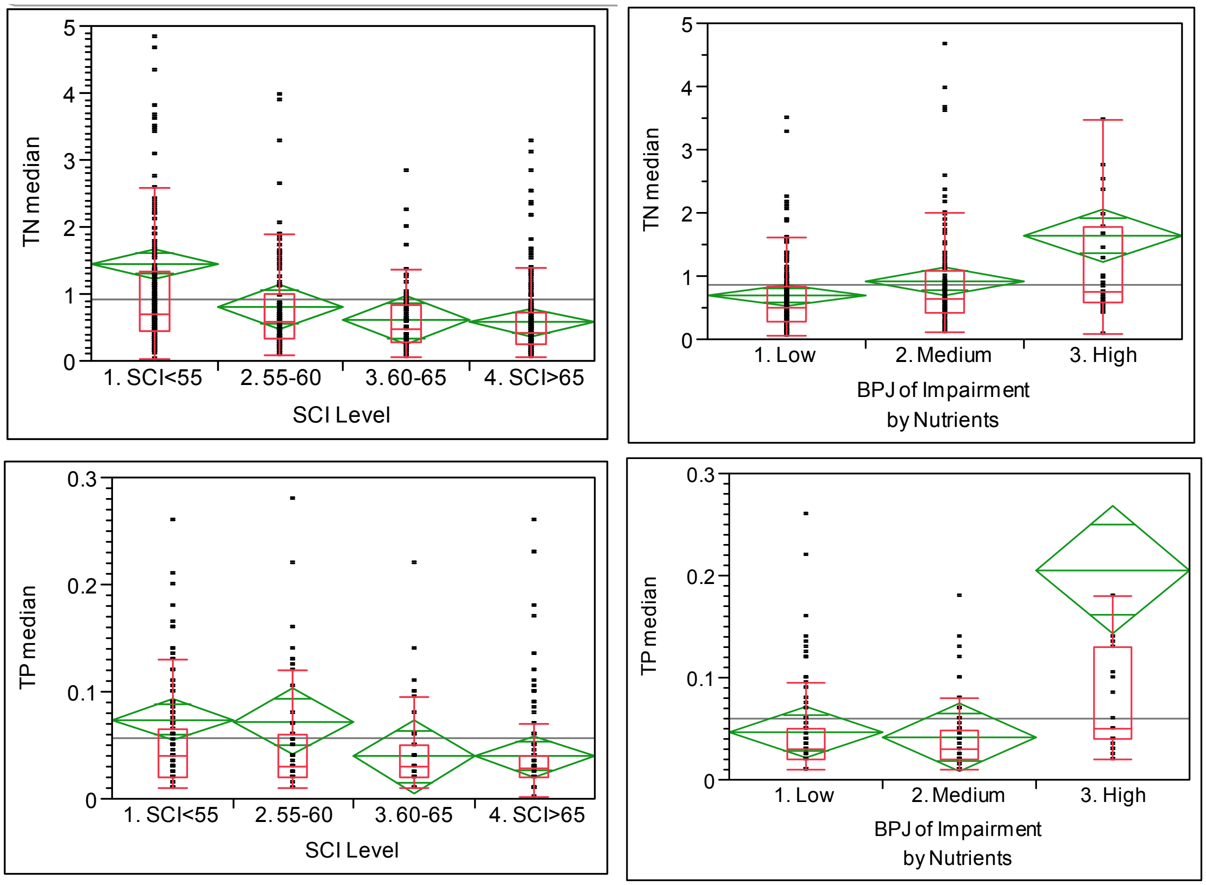


Figure IV-3. Relationships of total nitrogen (TN, upper) and total phosphorus (TP, lower) medians (mg/L) to Stream Condition Index (SCI, left) and best professional judgment (BPJ) of nutrient impairment likelihood ratings (right). High outlier TN and TP values are off scale.

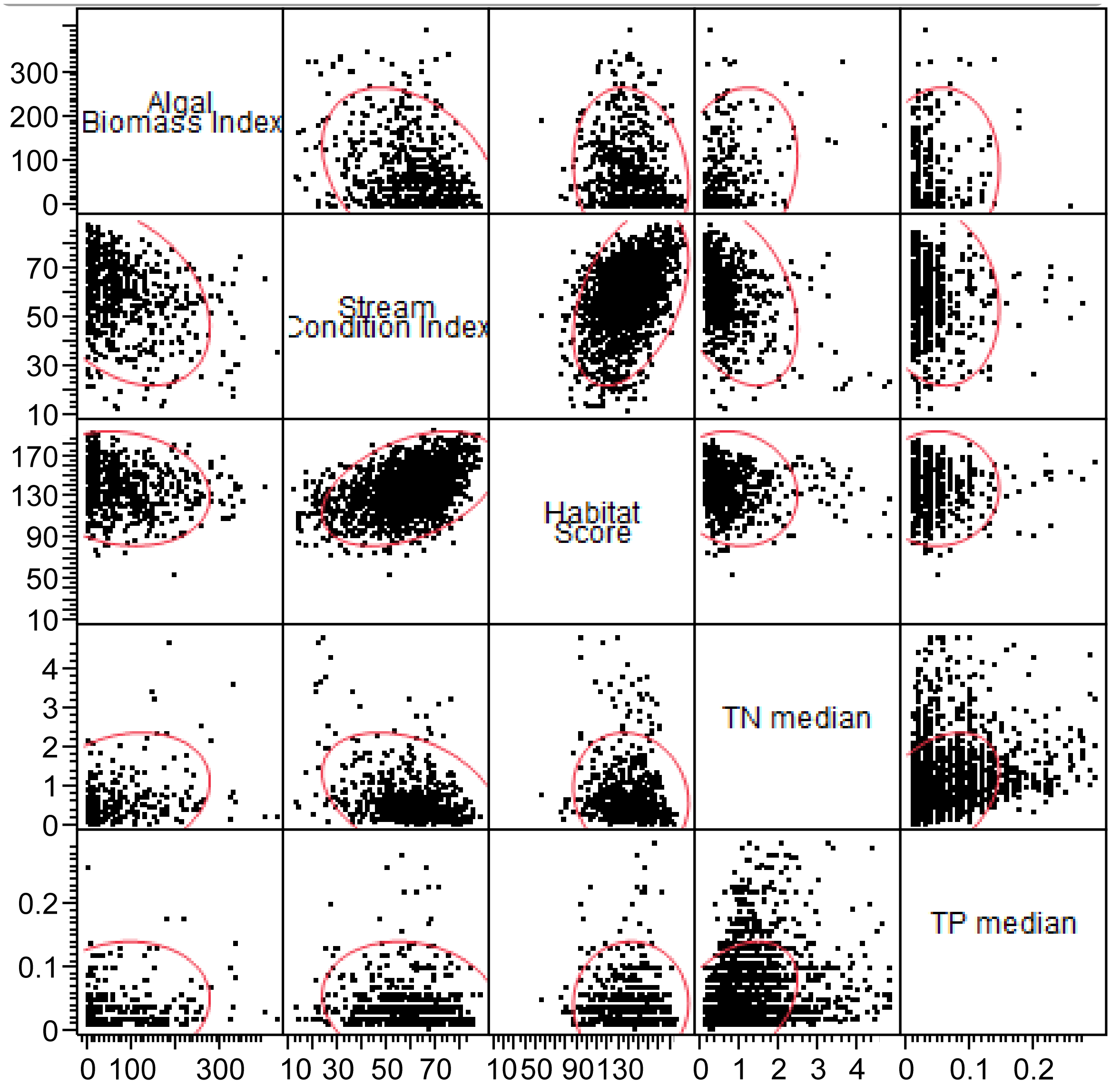


Figure IV-4. Scatterplot matrix among principal nutrients (total nitrogen [TN] and total phosphorus [TP] medians, mg/L) and related variables (Algal Biomass Index, Stream Condition Index, and habitat score). Plots have been truncated to focus on the bulk of the data; high TN and TP outliers are not shown.

V. Resource Effects

The fourth goal of this analysis was to estimate potential demands by the screening approach on DEQ monitoring resources. In order to answer that question, NOECs, OECs, and the role of visual assessments must be defined. As noted, judgments and interpretations are required as a means of translating results of numeric analyses into proposed nutrient criteria components. Here, we provide data analyses that can be applied to estimate the additional benthic macroinvertebrate assessments that would be required by nutrient criteria implementation.

In addition to decisions concerning NOEC and OEC levels and the role of visual assessments, questions that need to be answered in order to estimate resource demands are as follows:

Q1. At how many monitoring sites would freshwater nutrient criteria be applied?

The number of monitoring locations with TN and TP data is tallied in Table V-1. Nearly all TN and TP observations were paired (i.e., very few TN observations were unaccompanied by TP, and vice versa). Screening-approach nutrient criteria may not be suitable for application at all of these locations; some, for example, may not be wadeable, and other exclusions may apply. We have no data to estimate exclusions.

Table V-1. Freshwater Stream Monitoring Locations in the Mountain and Piedmont Ecoregions.

	≥ 4 TN/TP Observations / Year			All Locations		
	2008	2009	2010	2008	2009	2010
Mountains	279	304	275	333	356	321
Piedmont	322	323	320	371	361	364
Total	601	627	595	704	717	685

Q2. How are TN and TP levels distributed among freshwater stream monitoring sites within the Mountain and Piedmont ecoregions?

This is an important question because of the effect of NOEC and OEC levels on resource allocations. If a monitoring location can be assessed definitively using NOECs or OECs, no visual assessment or benthic macroinvertebrate assessment would be required.

Distributions of TN and TP at Virginia DEQ monitoring sites are represented by Figures V-1 and V-2.

Because TN and TP NOECs would likely be applied together (i.e., a non-impairment designation would occur only if both TN and TP were below the NOEC), the relationship of TN and TP to one another at individual monitoring sites must also be considered. TN and TP are highly correlated (Figure V-3). Low TN and TP values tend to be associated with one another. For example, about half (48%) of annual TN medians occur at concentrations ≤ 0.6 mg/L; most of these also occur with TP medians ≤ 0.05 mg/L (Table V-2).

Table V-2. Distribution of annual TN and/or TP medians at monitoring stations with five or more observations per year among magnitude categories, 2008-2010; by frequency (above) and by cumulative frequency at equal or lesser concentrations (below).

TN category (mg/L)	TP Category (mg/L)								
	≤ 0.03	> 0.03 - 0.04	> 0.04 - 0.05	> 0.05 - 0.06	> 0.06 - 0.07	> 0.07 - 0.10	> 0.10 - 0.15	> 0.15	Sum
	- - - - - - - - - - Frequency (% of observations) - - - - - - - - - -								
≤ 0.5	28.8%	5.2%	1.9%	0.3%	0.2%	0.4%	-	-	36.8%
> 0.5 - 0.6	5.2%	3.1%	2.0%	0.6%	0.2%	0.2%	-	-	11.4%
> 0.6 - 0.7	4.1%	1.9%	1.2%	0.7%	0.3%	0.6%	0.1%	0.1%	9.0%
> 0.7 - 0.8	2.7%	1.4%	0.8%	0.7%	0.6%	0.3%	-	-	6.5%
> 0.8 - 1.0	4.2%	1.8%	1.5%	1.2%	0.6%	0.7%	0.1%	0.0%	10.1%
> 1.0 - 1.5	4.7%	2.8%	1.6%	0.9%	0.7%	1.1%	0.7%	0.2%	12.7%
> 1.5 - 2.0	2.4%	1.6%	0.4%	0.4%	0.4%	0.9%	0.4%	0.3%	6.8%
> 2.0 - 2.5	0.8%	0.4%	0.2%	0.2%	0.1%	0.3%	0.5%	0.1%	2.5%
> 2.5	1.0%	0.3%	0.3%	0.3%	0.3%	0.6%	0.4%	1.1%	4.3%
Sum	53.8%	18.5%	9.8%	5.3%	3.5%	5.1%	2.2%	1.8%	100%
	- - - - - - - - - - Cumulative Frequency (% of observations) - - - - - - - - - -								
≤ 0.5	28.8%	34.1%	35.9%	36.2%	36.4%	36.8%	36.8%	36.8%	
> 0.5 - 0.6	34.0%	42.4%	46.2%	47.1%	47.6%	48.2%	48.2%	48.2%	
> 0.6 - 0.7	38.1%	48.3%	53.4%	55.0%	55.8%	57.1%	57.2%	57.2%	
> 0.7 - 0.8	40.8%	52.4%	58.3%	60.6%	62.0%	63.6%	63.7%	63.7%	
> 0.8 - 1.0	45.0%	58.4%	65.7%	69.2%	71.3%	73.5%	73.7%	73.8%	
> 1.0 - 1.5	49.6%	65.8%	74.8%	79.2%	82.0%	85.3%	86.2%	86.5%	
> 1.5 - 2.0	52.0%	69.8%	79.2%	84.0%	87.2%	91.4%	92.7%	93.2%	
> 2.0 - 2.5	52.8%	71.0%	80.6%	85.6%	88.7%	93.3%	95.1%	95.7%	
> 2.5	53.8%	72.3%	82.1%	87.4%	90.9%	96.0%	98.2%	100.0%	

Q3. What fraction of ambient water monitoring sites is co-located with biological monitoring sites?

Monitoring locations that serve as both biological and water monitoring sites (co-located monitoring sites) can be assessed for aquatic-life impairment directly, without using the screening approach (Table V-3).

Table V-3. Number of freshwater stream locations for which four or more TN and/or TP measurements and one or more SCI measurements were recorded, by year.

	2008	2009	2010	Average
Number of Stations	80	44	61	62
Percent of monitoring stations with four or more TN and/or TP observations	13%	7%	10%	10%

Q4. How many benthic macroinvertebrate assessments would be avoided through application of visual assessments, within the context of the screening approach?

Fractions of visually assessed monitoring events where the visual assessments reached definite determinations (i.e., high probability of impairment by nutrients; high probability of impairment by either nutrients or non-nutrient stressors; low probability of impairment by either nutrients or non-nutrient stressors) are listed in Table V-4. Visual assessment determinations are influenced, indirectly, by nutrient concentrations (i.e., when nutrient concentrations are high, there is a higher probability of a "high" BPJ designation).

Table V-4. Distribution of regional biologists' visual assessment BPJs by TN and TP level, for monitoring stations with visual assessments and one or more TN/TP observation during the season when the visual assessment was conducted; by numbers of observations (above) and percent of observations (below).

	TN category (mg/L)					TP Category (mg/L)			
	≤ 0.6	>0.6-1.0	>1.0-2.0	>2.0	Sum	≤ 0.04	>0.4-1.0	> 1.0	Sum
BPJ of Impairment by Nutrients									
Low	106	46	24	8	184	127	43	14	184
Medium	50	29	18	9	106	79	22	5	106
High	8	10	6	6	30	13	8	9	30
Sum	164	85	48	23	320	219	73	28	320
BPJ of Impairment Combined									
Low	55	14	9	1	79	62	13	4	79
Indeterminate	92	50	28	11	181	127	44	10	181
High	17	21	11	11	60	30	16	14	60
Sum	164	85	48	23	320	219	73	28	320

	TN category (mg/L)					TP Category (mg/L)			
	≤ 0.6	>0.6-1.0	>1.0-2.0	>2.0	Sum	≤ 0.04	>0.4-1.0	> 1.0	Sum
BPJ of Impairment by Nutrients									
Low	33%	14%	8%	3%	58%	40%	13%	4%	58%
Medium	16%	9%	6%	3%	33%	25%	7%	2%	33%
High	3%	3%	2%	2%	9%	4%	3%	3%	9%
Sum	51%	27%	15%	7%	100%	68%	23%	9%	100%
BPJ of Impairment Combined									
Low	17%	4%	3%	0%	25%	19%	4%	1%	25%
Indeterminate	29%	16%	9%	3%	57%	40%	14%	3%	57%
High	5%	7%	3%	3%	19%	9%	5%	4%	19%
Sum	51%	27%	15%	7%	100%	68%	23%	9%	100%

Example Applications

As an example, we have produced resource-demand estimates for two sets of assumptions.

The first set of assumptions is conservative and intended to maximize the accuracy of screening-approach outcomes: NOECs of ≤ 0.6 mg/L for TN and ≤ 0.04 mg/L for TP, the 90th percentiles of the nutrient-criteria reference distribution rounded; OECs of >2.0 mg/L for TN and > 0.15 mg/L for TP, which are drawn from the lower end of the range of potential OEC's of Table III-1 but still occur at >90th percentile of all monitoring observations; and application of visual assessments only for high probabilities of impairment by nutrients (Table V-5).

The second set of assumptions is intended to test the effect of a less conservative approach (Table V-6). NOECs are increased to TN ≤ 0.7 mg/L and TP ≤ 0.05 mg/L (lower 95% bounds of confidence intervals of the regression line of the intersection with SCI =60), and OECs remain the same. Also, visual assessments have been expanded to allow "low probability of nutrient impairment" assessments, if the regional biologist's BPJ is a low probability of impairment by nutrient and non-nutrient stressors combined. The effect of this change in conditions is to reduce the number of sites requiring benthic macroinvertebrate assessments by about 1/3.

The third set of assumptions used NOECs identical to the first assumption set (Table V-5) while applying the OECs derived from the logistic inverse prediction. The result increased the number of estimated inconclusive outcomes by 14%, from 247 to 283.

These calculations are advanced recognizing that Virginia DEQ may have other policies and procedures in place that would influence the additional benthic macroinvertebrate assessment demands.

Table V-5. An example estimation of the number of benthic macroinvertebrate assessment sites required when applying the screening approach at given conditions.

Conditions
No-Observed-Effect Concentrations: TN ≤0.6 mg/L; TP ≤0.04 mg/L
Observed-Effect Concentrations: TN >2 mg/L; TP >0.15 mg/L
Visual Assessment: BPJ = "High Probability" of nutrient impairment only

Estimation Step	**% Sites Affected**	**# of Sites**	**Notes**
1-Number of Monitoring Locations		610	Approx Avg over 3 years
2-Number of non-wadeable or other monitoring locations where Nutrient Criteria Screening Approach would not apply		0	In reality, would be greater than 0 but we have no way to estimate.
3-Number of co-located water-biological monitoring locations	-10%	-61	Estimated, Table V-3
4-Monitoring locations where Nutrient Criteria Screening Approach would be applied.		549	
5-Less Locations TN ≤ 0.6 and TP ≤ 0.04	-42.4%	-233	Table V-2, lower
6-Less Locations TN > 2 or TP > 0.15	-7.4%	-41	Table V-2 upper (2.5%+4.3%+1.8%-0.1%-1.1%)
7-Number of Stations for Visual Assessment		275	
8-Stations yielding BPJ "high prob of nutrient impairment" visual assessment	-10%	-28	Estimate, Table V-4, for mid-range TN/TP categories.
9-Number of "inconclusive" screenings indicating need for benthic macroinvertebrate assessments		247	This number can be compared to 1630 total SCIs in EDAS over 3 years, 543 per year.
10-Number of additional sites requiring benthic macroinvertebrate assessments.		?	Additional factors to consider: Current, ongoing TMDLs; potential to extend benthic macroinvertebrate assessments over full water quality assessment cycle.

TN=total nitrogen; TP=total phosphorus; BPJ=best professional judgment

Table V-6. Another example estimation of the number of benthic macroinvertebrate assessment sites required when applying the screening approach at given conditions.

Conditions

No-Observed-Effect Concentrations: TN ≤0.7 mg/L; TP ≤0.05 mg/L
Observed-Effect Concentrations : TN >2 mg/L; TP >0.15 mg/L
Visual Assessment: BPJ = "High Probability" of nutrient impairment only, and
BPJ = "Low Probability" of impairment by nutrients and non-nutrient stressors.

Estimation Step	% Sites Affected	# of Sites	Notes
1-Number of Monitoring Locations		610	Approx Avg over 3 years
2-Number of non-wadeable or other monitoring locations where Nutrient Criteria Screening Approach would not apply		0	In reality, would be greater than 0 but we have no way to estimate.
3-Number of co-located water-biological monitoring locations	-10%	-61	Estimated, Table V-3
4-Monitoring locations where Nutrient Criteria Screening Approach would be applied		549	
5-Less Locations TN ≤0.7 and TP ≤0.05	-53.4%	-293	Table V-2 lower
6-Less Locations TN >2 or TP >0.15	-7.4%	-41	Table V-2 upper (2.5%+4.3%+1.8%-0.1%-1.1%)
7-Number of Stations for Visual Assessment		215	
8-Stations yielding BPJ "high prob of nutrient impairment" visual assessment	-10%	-22	Estimate, Table V-4, for mid-range TN/TP categories.
9-Stations yielding BPJ "low prob of nutrient+non-nutrient impairment" visual assessment	-15%	-32	Table IV-3 shows 226 of 723 visual assessments (31%) received BPJ of this category. Table V-4 shows that these assessments were applied preferentially at low nutrient sites. This figure is a rough estimate.
10-Number of "inconclusive" screenings indicating need for benthic macroinvertebrate assessments		161	This number can be compared to 1630 total SCIs in EDAS over 3 years, 543 per year.
11-Number of additional sites requiring benthic macroinvertebrate assessments		?	Additional factors to consider: Current, ongoing TMDLs; potential to extend benthic macroinvertebrate assessments over full water quality assessment cycle.

TN=total nitrogen; TP=total phosphorus; BPJ=best professional judgment

Table V-7. Another example estimation of the number of benthic macroinvertebrate assessment sites required when applying the screening approach at given conditions. Incorporates results of analysis reported in Appendix A. Otherwise, analysis parameters are identical to those of Table V-5.

Conditions
No-Observed-Effect Concentrations: TN ≤0.6 mg/L; TP ≤0.04 mg/L Observed-Effect Concentrations: TN >3.66 mg/L; TP >0.284 mg/L Visual Assessment: BPJ = "High Probability" of nutrient impairment only

Estimation Step	**% Sites Affected**	**# of Sites**	**Notes**
1-Number of Monitoring Locations		610	Approx Avg over 3 years
2-Number of non-wadeable or other monitoring locations where Nutrient Criteria Screening Approach would not apply		0	In reality, would be greater than 0 but we have no way to estimate.
3-Number of co-located water-biological monitoring locations	-10%	-61	Estimated, Table V-3
4-Monitoring locations where Nutrient Criteria Screening Approach would be applied.		549	
5-Less Locations TN ≤ 0.6 and TP ≤ 0.04	-42.4%	-233	Table V-2, lower
6-Less Locations TN > 3.66 or TP > 0.284	-0.4%	-2	
7-Number of Stations for Visual Assessment		314	
8-Stations yielding BPJ "high prob of nutrient impairment" visual assessment	-10%	-31	Estimate, Table V-4, for mid-range TN/TP categories.
9-Number of "inconclusive" screenings indicating need for benthic macroinvertebrate assessments		283	This number can be compared to 1630 total SCIs in EDAS over 3 years, 543 per year.
10-Number of additional sites requiring benthic macroinvertebrate assessments.		?	Additional factors to consider: Current, ongoing TMDLs; potential to extend benthic macroinvertebrate assessments over full water quality assessment cycle.

TN=total nitrogen; TP=total phosphorus; BPJ=best professional judgment

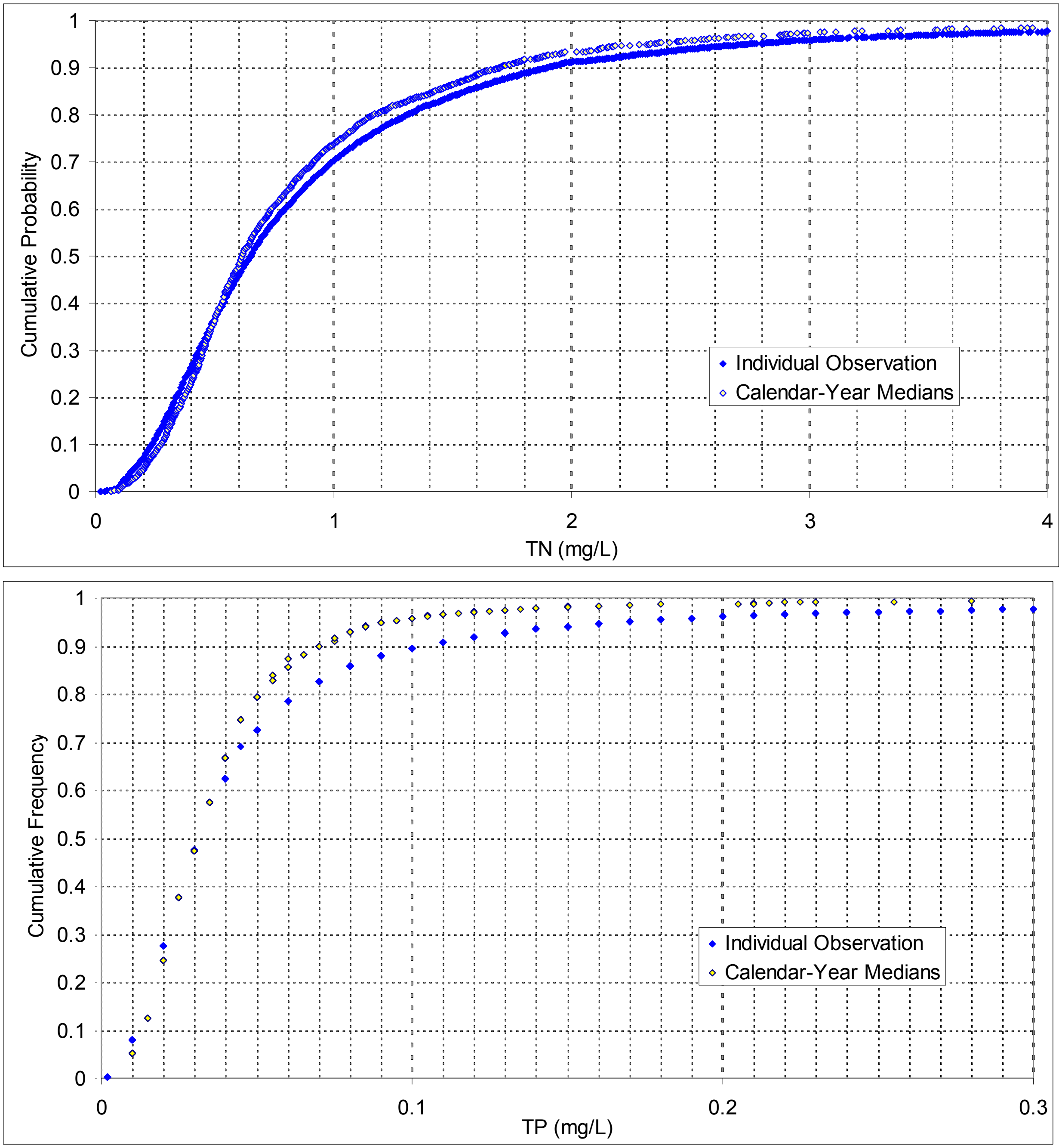
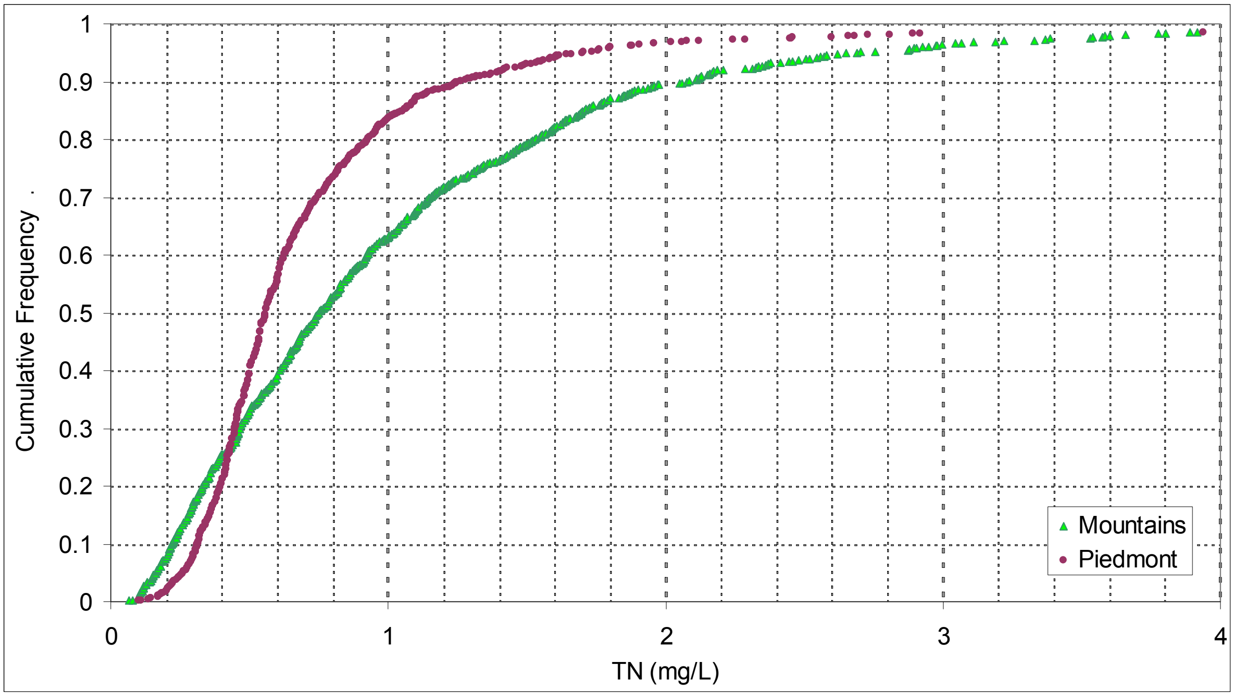


Figure V-1. Cumulative distribution functions for total nitrogen (TN) and total phosphorus (TP) concentrations for individual observations and calendar-year medians in the Mountain and Piedmont ecoregions, 2008 - 2010: all individual observations recorded at all Virginia Department of Environmental Quality monitoring stations, and calendar-year medians at monitoring locations with five or more observations recorded in a given year. High TN and TP values are off scale right.



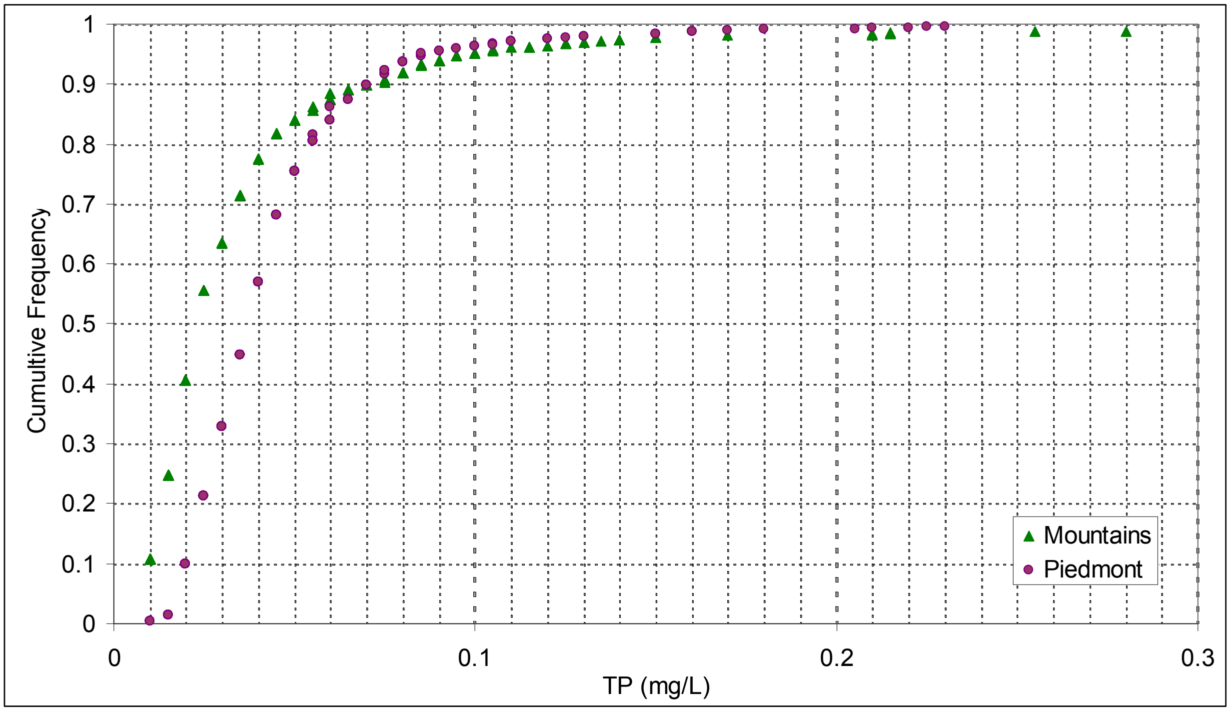


Figure V-2. Cumulative distribution functions for total nitrogen (TN) and total phosphorus (TP) concentrations in the Mountain and Piedmont ecoregions, 2008 - 2010: all individual observations recorded at all Department of Environmental Quality monitoring stations, and calendar-year medians at monitoring locations with five or more observations recorded in a given year. High TN and TP values are off scale right.

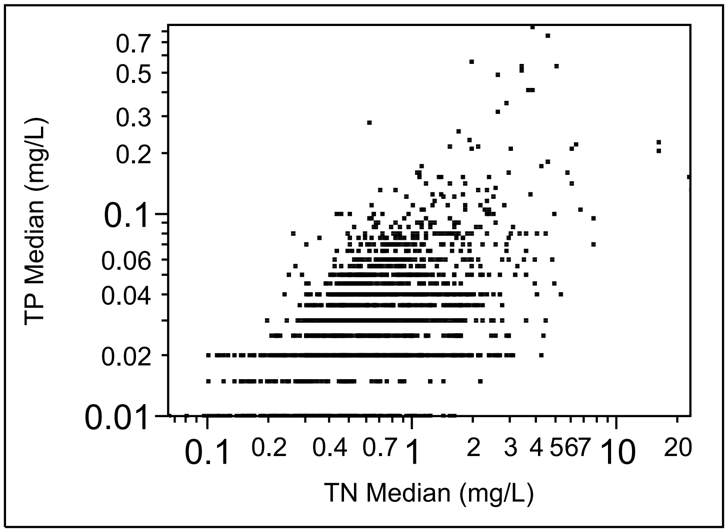


Figure V-3. Scatterplot of total nitrogen (TN) and total phosphorus (TP) concentration annual medians at Mountain and Piedmont monitoring sites with ≥ 5 observations of each per year, 2008-2010, with log scales. The data are highly correlated (Spearman rho = 0.51; p<0.0001).

VI. Summary and Conclusions

Based on recommendations by the AAC, Virginia's DEQ is considering a screening approach to nutrient criteria development. Analyses described in this report have been conducted to aid the agency's evaluation of that process.

Findings and recommendations are summarized below for each of the study goals.

Goal 1. Investigate potential to establish NOECs through a "reference filtering" approach using probabilistic monitoring data.

This analysis was conducted by applying a reference-filter screen to probabilistic monitoring data and the best professional judgments of DEQ regional biologists to identify a set of "nutrient-criteria reference" monitoring events. The sites in this nutrient-criteria reference dataset did not have evident effects by non-nutrient stressors. Within this dataset, nutrient levels and SCI scores were statistically analyzed to propose NOECs for TN and TP. Maximum levels within the resulting nutrient-criteria reference dataset were 0.97 mg/L for TN and 0.06 mg/L for TP. Using these NOECs, only about 10% of the monitoring events within the reference data set had SCI<60.

The analysis found statistically significant negative relationships within the reference dataset, but the regression line produced by that relationship did not descend below the SCI=60 impairment threshold within the TN and TP ranges represented by the dataset. Professional judgment and interpretation are required to derive potential NOEC values from the dataset. The 90th percentiles within the dataset were 0.599 mg/L for TN and 0.05 mg/L for TP.

Goal 2. Investigate potential to establish OEC's through a "probability of impairment at equal-or-greater concentrations" analysis applied to Virginia DEQ monitoring data.

These analyses were conducted with the intent of defining OECs with a ≥90% probability of impairment (SCI<60) if exceeded. We conducted the analyses by Virginia DEQ monitoring data to produce impairment probability charts (Figures III-1 and III-2). Manual interpretations of these data yielded potential OECs for TN ranging from 1.8 to 3.2 mg/L and for TP ranging from 0.15 to 0.26 mg/L. However, this process proved problematic for several reasons:

- In some cases, the resulting estimates do not appear as robust because they are dependent upon a small number of high-nutrient SCI<60 data points. For example: the potential OEC for TN derived from the 6-month dataset (2.6 mg/L) is exceeded by 44 of 922 observations (about 5%), but the potential OEC for TP derived from the same dataset (0.25 mg/L) is exceeded by only 16 of the 922 observations (1.7%).
- They are not precise, as the potential OEC values are derived from a visual interpretation process. It would be possible to fit functional forms to these data as a means of estimating OECs more precisely.
- The utility of these potential OECs may be limited because they are so high relative to most DEQ monitoring data. Thus, if implemented, they would be capable of generating assessments for only a small number of monitoring sites.

- The utility of these potential OECs is also questionable because they do not consider downstream loading effects, and virtually all Virginia surface waters flow into water bodies that are nutrient sensitive – including Chesapeake Bay, Albemarle Sound, and the Gulf of Mexico. When nutrient criteria are established for these nutrient sensitive downstream water bodies, DEQ will have to take these into consideration

A more statistically rigorous approach, logistic inverse prediction, was also applied. This approach yielded potential OECs of greater magnitude than the manual interpretation (3.66 mg/L for TN, vs. 2.6 mg/L for the visual interpretation; 0.284 mg/L for TP, vs. 0.25 mg/L for the visual interpretation) while demonstrating significant differences between potential OECs for the Mountains and Piedmont ecoregions.

The AAC and DEQ will consider the potential utility of these approaches for derivation of OECs, as the process of developing nutrient criteria recommendations moves forward.

Another possible approach to using these data would be interpretation to generate OECs for probabilities of impairment other than 90%.

Goal 3. Evaluate trial applications of visual assessment as a potential assessment tool for use in nutrient criteria implementation.

Three years of visual assessment trial applications demonstrate clearly that Virginia DEQ biologists are able to apply visual assessments accurately most of the time.

Biologists' visual assessments are most accurate when applied to identify sites impaired by nutrients. Eighty-eight percent of sites assessed as having a high probability of being impaired by nutrients had SCI<60, indicating impairment; and 95% of those events had SCI<65. During three years of monitoring, regional biologists found 8% of the visually assessed sites to have a high probability of impairment by nutrients.

Regional biologists' visual assessments were conclusive more frequently when considering both nutrient and non-nutrient stressors; however, they achieved lower levels of accuracy when considering combined effects by nutrient and non-nutrient stressors. Considering both nutrient and non-nutrient stressors, the following results were obtained:

- Regional biologists found almost half (359 of 723) of visually assessed monitoring events to have either a "high" or "low" probability of impairment;
- Benthic macroinvertebrate sampling conformed with regional biologists' expectations for 79% of monitoring events;
- About 90% of benthic macroinvertebrate samplings yielded SCIs within five SCI-units of the expected outcomes.

Goal 4. Estimate potential demands by screening approach on DEQ water monitoring resources.

We have provided tools for estimating the potential resource demands of utilization of nutrient criteria screening approach. It is clear that the level of additional demands for benthic macroinvertebrate assessments is dependent upon the screening levels and tools employed.

General Conclusion

A common theme among these results is the tradeoff between accuracy/certainty and resource allocations. In this discussion, we are considering "accurate" assessments to be those with SCI<60 assessed as "impaired," and those with SCI>60 assessed as "not impaired," by the screening tools.

Based on these results, decisions to set NOECs at relatively low concentrations and OECs at relatively highly concentrations, while limiting visual assessments to only identifying potential nutrient-induced impairments, could be expected to allow implementation of the screening approach with a relatively high level of accuracy. Such an implementation strategy would allow these screening tools to be applied only at a limited number of monitoring events, allowing a large fraction of monitoring events to be defined as "inconclusive" and therefore requiring benthic macroinvertebrate assessments.

The tradeoffs between accuracy/certainty and resource allocations described are not unique to the screening approach; they are generally integral to issues concerning nutrient criteria. Nutrients do not act as direct toxicants at the organism level; thus, we would view potential management of their biological effects by single fixed numeric criteria as problematic. Application of nutrient criteria as fixed numeric thresholds, as per conventional criteria for water contaminants that are direct toxicants, would produce a relatively low-cost regulatory tool – if the cost accounting were to consider only those costs to be borne by the agency. Such a tool could also be expected to have a low level of accuracy as we have defined that term above and, hence, to be costly from a societal standpoint. An alternative would be to apply benthic macroinvertebrate assessments at all monitoring locations; however, that option may not be a practical alternative given the agency's taxpayer-supported funding levels and other resource demands.

These analyses have explored a screening approach to nutrient criteria development that combines elements of both fixed-concentration thresholds and benthic macroinvertebrate assessments along with a visual assessment procedure. The analyses demonstrate that a screening approach is quite feasible if the agency, regulated communities, and the public are willing to accept some less-than-100% assessment accuracy. The definition of essential features (OECs, NOECs, and the role of visual assessments) requires evaluation of resource expenditure vs. accuracy/uncertainty tradeoffs.

VII. References

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Appendix A

Estimation of OEC for TN and TP by Logistic Inverse Prediction

By G.I. Holtzman

Observed-Effect Concentrations

Observed-effect concentrations (OECs) for N and P are concentrations above which nutrient-induced impairment of the aquatic community can be reasonably expected. Under the proposed nutrient criteria screening approach, monitoring sites with measured TN and/or TP concentrations ≥ the OECs would be assessed as impaired.

The analyses reported in this chapter were conducted to investigate the potential to establish OECs through a "probability of impairment at equal-or-greater concentrations" analysis applied to Virginia DEQ monitoring data.

Method

The method of analysis, derived from Paul and McDonald (2005),[1] was applied to estimate potential OECs. The method of analysis is based on the assumption that the probability of a site being impaired (SCI < 60) increases with measured nutrient concentrations. Prior AAC reports have validated this expectation at the upper end of the nutrient-concentration range.

The method can be applied to data sets that link measured TN and/or TP concentrations to benthic macroinvertebrate assessments. OECs will be estimated from the relationship between observed SCIs derived from the benthic macroinvertebrate assessments and the observed potential predictor variables:

- median TN concentration (mg/L)
- median TP concentration (mg/L)
- ecoregion (Mountain, Piedmont)
- season-year (Fall 2001, Spring 2002, etc.)

Log-linear model

The specific model for this relationship will be a log-linear model where the probability of impairment, i.e., the probability that SCI < 60, will be estimated as a function of potential explanatory variables by logistic regression.

This is the model used in medical diagnostic studies. A quantitative diagnostic test is performed on the patient to determine whether he has a specific disease. Here, the patient is a stream site, the disease is impairment (SCI < 60), and the diagnostic test is nutrient level (mg/L), where the nutrient is TN, TP, or both. The result of the diagnostic test is called *positive* if it predicts that the disease is present in the patient and *negative* if it predicts that the disease is absent. Here the test is positive if the nutrient exceeds OEC, and negative otherwise.

Implementation

Based on this model, OECs will be estimated, or *predicted*, by performing the following sequence of steps.

i. **Logistic Model Selection:** Find the optimal configuration of explanatory variables by backward elimination.

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[1] Paul, J.F. and M.E. McDonald. 2005. Development of empirical, geographically specific water quality criteria: A conditional probability analysis approach. *Journal of the American Water Resources Association* 41:1211-1223.

ii. **Inverse Prediction of OEC:** Estimate potential OEC_p levels by inverse prediction of various percentiles of TN and/or TP, where $p = 90, 80, 75, 70, 65, 60$. That is, OEC_{90} will be the 90th percentile of TN concentrations; OEC_{80} will be the 80th percentile of TN concentrations, and so on. Thus, OEC_p will be defined by

$$P\left\{\text{Nutrient} < \text{OEC}_p\right\} = \frac{p}{100}, \quad P\left\{\text{Nutrient} > \text{OEC}_p\right\} = \frac{(1-p)}{100} \tag{1}$$

iii. **False Positive and True Positive Rates:** Calculate the *false-positive rate* and the *true-positive rate* for each percentile. The *false-positive rate* is the probability that an unimpaired site ($\text{SCI} \geq 60$) is misclassified as impaired (Nutrient > OEC). The *true-positive rate* is the probability that an impaired site ($\text{SCI} < 60$) is correctly classified as impaired (Nutrient > OEC). Thus, we measure the nutrient level (mg/L) as a "diagnostic test" of the state of the site (impaired means $\text{SCI} < 60$, unimpaired means $\text{SCI} \geq 60$). The test is called *positive* if it predicts impairment.

iv. **Optimal OEC:** Choose the optimal p and thus the optimal OEC_p according to the false-positive rate and the false negative rate. We will choose OEC such that the false-positive rate is small and the true-positive rate is large. Because a positive test, Nutrient > OEC, results in a stream being classified as impaired, our first priority is to keep the false-positive rate small. However, if the test is negative, i.e., Nutrient < OEC, then the result is considered inconclusive, and further investigation is merited. But the further investigation has a cost, so, if a stream is impaired, i.e., $\text{SCI} < 60$, then we want to detect it, i.e., we want a high true-positive rate to avoid the cost of further investigation.

As the percentile rank p increases, OEC_p increases, the false-positive rate decreases, and the true-positive rate decreases. If we use the 100th percentile of the nutrient as the OEC, then OEC_p will be very large and never exceeded, the false-positive rate will be 0, and the true-positive rate will be 0 also. If we use the 0th percentile, then OEC_p will be 0 and always exceeded, the false-positive rate will be 1, and true-positive rate will be 1.

6-month Analysis ($n = 922$)

Empirical Distribution of TN and TP

TN and TP are highly positively skewed, with a small number of extreme outliers. See Figure 1. Removal, however, of the five outliers for which TN > 10.0 mg/L or TP > 1.0 mg/L makes virtually no difference in the TN and TP OEC estimates, so they have been retained.

Of the 922 sites, 445 (48.2%) are impaired for the aquatic-life use ($\text{SCI} < 60$), and 477 (51.8%) are not impaired ($\text{SCI} \geq 60$). Note that TN (mg/L) is missing at impaired Piedmont site (4ACOX007.73) for spring 2005, and this is the only missing value among TN, TP, and SCI. As a consequence, there are 921 observations of TN, 922 observations of TP, and 922 observations of SCI. See the first two pages of the appendix (below).

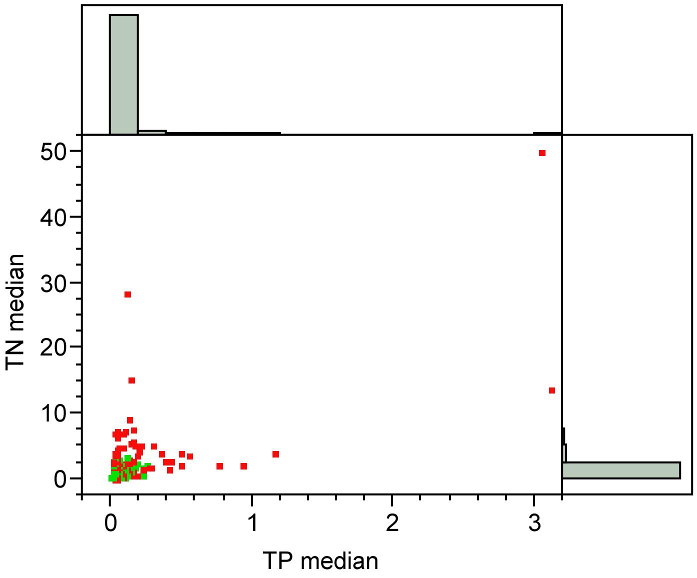

Figure 1 Median total nitrogen (TN) concentrations (mg/L) by median total phosphorus (TP) concentrations (mg/L) of **impaired** and **not impaired** sites (*n* = 922). Red dots represent impaired sites (Stream Condition Index (SCI) < 60). Green dots represent unimpaired sites (SCI ≥ 60). This graph reveals extreme outliers.

(i) Log-linear Model Selection

Table 1 shows the steps of model selection. This process amounts to selecting the explanatory variables to include in the model. The full model that we begin with has the main effects of each of the four potential explanatory variables mentioned earlier, plus the interactions of the six pairwise combinations of the four variables. To obtain stable estimates, all non-statistically-significant parameters must be eliminated from the model. We also considered the Corrected Akaike Information Criterion (AICc) and the Bayesian Information Criterion (BIC), both of which, based on penalized likelihood, are two popular model-selection statistics formulated to obtain their minimum for the "best" model (Burnham and Anderson 2002, 2004).[2] Discarded, not-statistically-significant models are shown in Figure 2, Figure 3, and Table 2.

The result of model selection is the model that estimates the probability of impairment as a function of the TN and eco-region:

$$P\{\text{impairment}\} \equiv P\{\text{SCI} < 60\} = f\left(\text{TN, Ecoregion}\right) \tag{2}$$

The fitted model is graphed in Figure 4 and Figure 5.

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[2] Burnham, K. P. and D.R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag. ISBN 0-387-95364-7.
Burnham, K. P. and D.R. Anderson. 2004. Multimodel inference: understanding AIC and BIC in Model Selection. *Sociological Methods and Research* 33: 261-304.

Table 1 Sequential model building of Probability{Stream Condition Index < 60} = P{Impaired} as a function of total nitrogen concentration (TN or N) (mg/L), total phosphorus concentration (TP or P) (mg/L), ecoregion (Eco or E) (Mountain, Piedmont), season-year (S, as shown in Figure 3 for the TN observed-effect concentration). The full model contains the four first-order effects and six second-order effects of the four factors.

P-value of removed effects	Model	Effects	Effects Retained	AICc[*]	BIC[†]
	Full 2^{nd} degree	4 + 6 = 10	N P E S NP NE NS PE PS ES	1226	1485
0.68	Remove Season*TP	4 + 5 = 9	N P E S NP NE NS PE ES	1209	1412
0.94	Remove Eco*TP	4 + 4 = 8	N P E S NP NE NS ES	1207	1405
0.63	Remove*TN*TP	4 + 3 = 7	N P E S NE NS ES	1205	1399
0.45	Remove Season*TN	4 + 2 = 6	N P E S NE ES	1191	1329
0.44	Remove Eco*TN	4 + 1 = 5	N P E S ES	1189	1322
0.10	Remove TP	3 + 1 = 4	N E S ES	1190	1318
0.04	Remove Season*Eco	3 + 0 = 3	N E S	1187	1259
0.012	Remove Season	2 + 0 = 2	N E	1188	1202
0.72	Add TN^2	2 + 1 = 3		1190	1209

[*] Corrected Akaike Information Criterion

[†] Bayesian Information Criterion

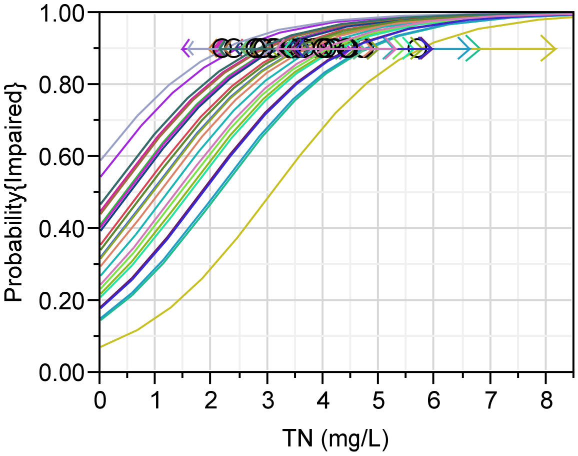


Figure 2 Logistic regression of Probability(Impaired) on TN median (mg/L), showing the inversely predicted TN OEC_{90} with 90% confidence limits, based on the 4-effects model containing season-year (P = 0.02), eco-region (Mountain, Piedmont) (P = 0.70), TN-median (P < 0.0001), and season-year*eco-region (P = 0.035).

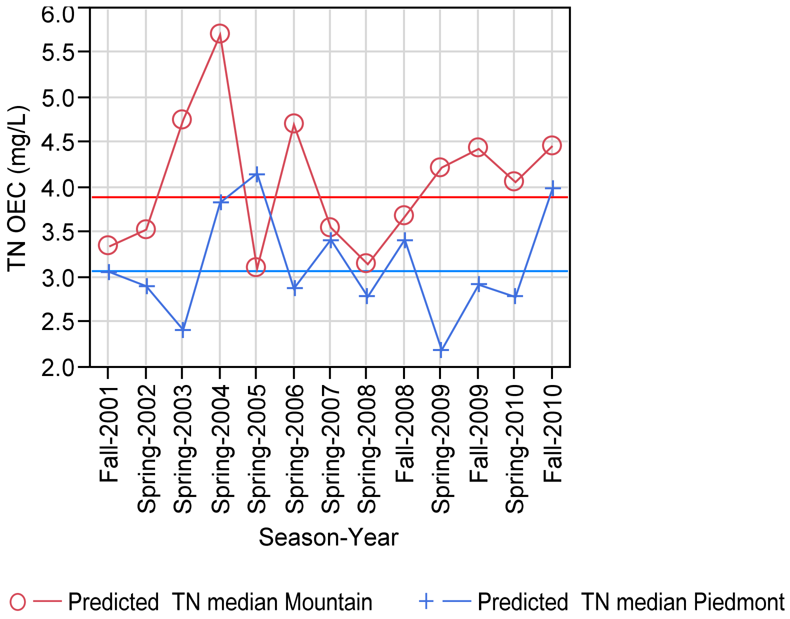


Figure 3 Total nitrogen (TN) observed-effect concentration (OEC)(mg/L) at which there is a 90% probability of impairment as estimated by inverse prediction using the 4-effects model containing season-year (P = 0.02), eco-region (Mountain, Piedmont) (P = 0.70), TN-median (P < 0.0001), and season-year*eco-region (P = 0.035).

Table 2 Total nitrogen (TN) observed-effect concentration (OEC_{90}) (mg/L) at which there is a 90% probability of impairment as estimated by inverse prediction using the 4-effects model containing season-year (P = 0.02), ecoregion (Mountain, Piedmont) (P = 0.70), TN-median (P < 0.0001), and season-year*eco-region (P = 0.035). The bottom line is the best prediction over all season-years, from the 2-effects model with ecoregion (P < 0.0001) and TN (P < 0.0001).

	Predicted TN OEC (mg/L)		90% Confidence Limits			
			Mountain		Piedmont	
Season-Year	Mountain	Piedmont	Lower	Upper	Lower	Upper
Fall-2001	3.35	3.07	2.41	4.68	2.10	4.42
Spring-2002	3.54	2.91	2.53	4.98	1.94	4.18
Spring-2003	4.76	2.42	3.29	6.81	1.47	3.64
Spring-2004	5.71	3.84	3.98	8.16	2.87	5.26
Spring-2005	3.10	4.17	2.07	4.48	3.06	5.78
Spring-2006	4.71	2.88	3.37	6.62	2.02	4.07
Spring-2007	3.56	3.43	2.54	4.99	2.51	4.74
Spring-2008	3.16	2.79	2.42	4.22	2.13	3.77
Fall-2008	3.68	3.43	2.88	4.89	2.69	4.57
Spring-2009	4.23	2.20	3.30	5.62	1.57	3.06
Fall-2009	4.44	2.93	3.43	5.95	2.22	3.97
Spring-2010	4.07	2.79	3.15	5.44	2.14	3.74
Fall-2010	4.47	3.99	3.51	5.93	3.15	5.30
All Season-Years	3.89	3.07	3.24	4.93	2.56	3.90

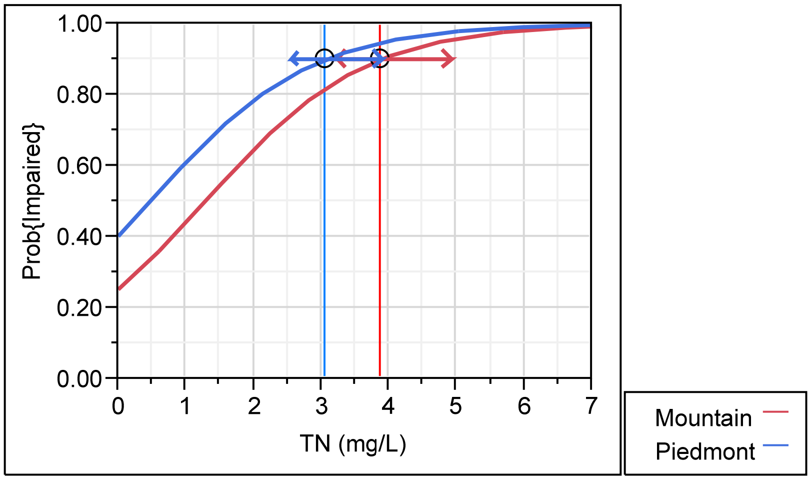


Figure 4 Estimated probability of impairment as a function of total nitrogen (TN) concentration (mg/L) by ecoregion (Mountain, Piedmont). The TN observed-effect concentration is inversely predicted (or estimated) from this log-linear model (logistic regression).

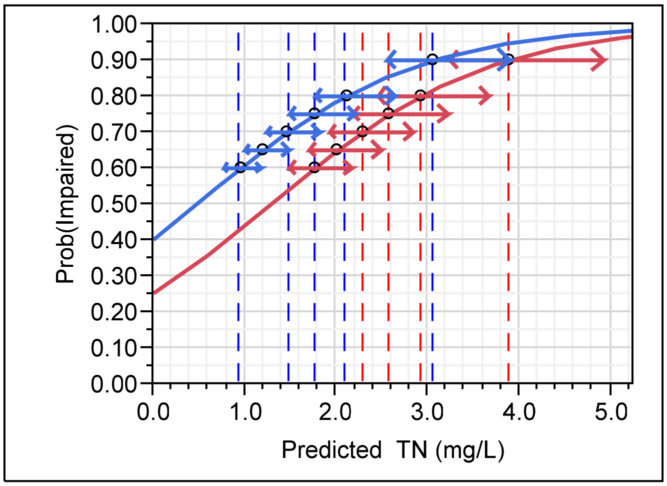


Figure 5 Inverse prediction of OEC_{90}, OEC_{80}, OEC_{75}, OEC_{70}, OEC_{65}, OEC_{60} by ecoregion (Mountain [red], Piedmont [blue]).

(ii) Inverse Prediction of OEC

Figure 4 shows that the TN OEC_{90} (mg/L) is inversely predicted as the 90th percentile of the probability of impairment. Table 3 shows the point estimates and 90% confidence limits. Table 4 shows the same statistics for the 80th percentile, TN OEC_{80} (mg/L). Figure 5 graphs the inverse prediction of OEC at six different percentiles.

Table 3 TN OEC_{90} estimate from nominal logistic regression of the 2-effects model with ecoregion ($P < 0.0001$) and TN ($P < 0.0001$). The *false-positive rate* (1 – *specificity*) is 0.000, i.e., of all unimpaired sites (SCI ≥ 60), none had TN > OEC_{90}. The *true-positive rate* (*sensitivity*) is 0.059, i.e., 5.9% of impaired sites (SCI < 60) are detected by TN > OEC_{90}. The overall statistics were obtained from using a model that excludes eco-region and includes only TN as the explanatory variable. For the overall results the false-positive rate is 0.000, and the true-positive rate is 0.059.

Eco-region	**TN OEC_{90} (mg/L)**	**Lower 90%**	**Upper 90%**
Mountain	3.89	3.24	4.93
Piedmont	3.07	2.56	3.90
Overall	3.66	3.03	4.71

Table 4 TN OEC_{80} estimate from nominal logistic regression of the 2-effects model with ecoregion ($P < 0.0001$) and TN ($P < 0.0001$). The false-positive rate is 0.010.

Eco1	**TN OEC_{80} (mg/L)**	**Lower 90%**	**Upper 90%**
Mountain	2.93	2.46	3.67
Piedmont	2.11	1.77	2.65

(iii) False-Positive and True-Positive Rates

Table 5 lists the OEC estimates and the corresponding false-positive and true-positive rates. The false-positive rate is estimated empirically as the number of sites with TN > OEC among the 477 sites that are not impaired (SCI ≥ 60), whereas the true-positive rate is estimated empirically as the number of sites with TN > OEC among the 444 sites that *are* impaired (SCI < 60).

We see that OEC_{90} is too conservative. Although it generates no false positives, it detects only 5.9% of impaired sites. Using the lower OEC_{80} generates only five false positives for a false-positive rate of 5/477 = 1.04%, but detects 8.8% of impaired sites. It is only when we get down to OEC_{65} that we approach the 5% false-positive rate, one change in 20 of classifying a site as impaired when it actually is not, but for that risk, we expect the correct detection of 16% of the truly impaired sites.

Table 5 False positive and true-positive rate for 90th, 80th, 75th, 70th, 65th, and 60th percentile TN OECs

	TN OEC (mg/L)		False-Positive Rate	True-Positive Rate
	Mountain	Piedmont		
OEC_{90}	3.89	3.07	0.000	0.059
OEC_{80}	2.93	2.11	0.010	0.088
OEC_{75}	2.59	1.77	0.017	0.105
OEC_{70}	2.29	1.48	0.027	0.128
OEC_{65}	2.02	1.21	0.048	0.160
OEC_{60}	1.77	0.95	0.078	0.237

Alternative models to estimate TP OEC_{90}, overall TN OEC_{90}, and overall TP OEC_{90}

Despite the fact that TP does not improve prediction if TN is known, we can entertain a model that includes TP with TN excluded. The result is shown in Figure 6 and Table 6.

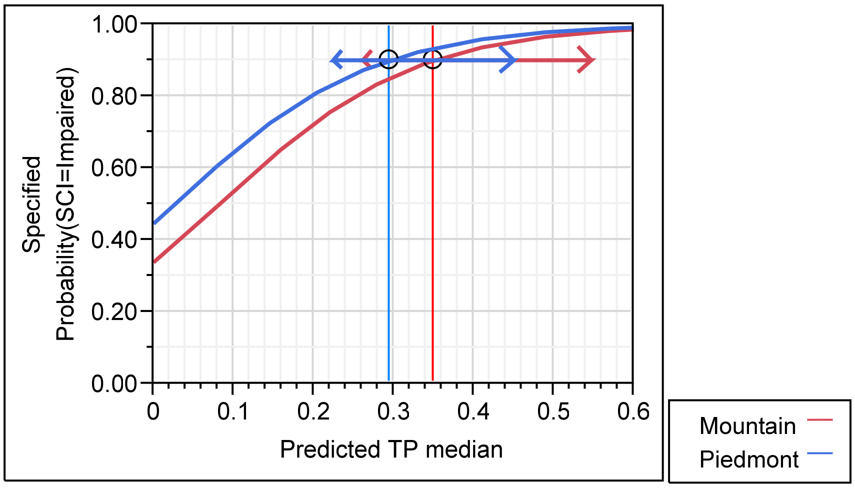


Figure 6 Estimated probability of impairment as a function of median total phosphorus (TP) concentration (mg/L) by ecoregion (Mountain, Piedmont). The TP observed-effect concentration (OEC) is inversely predicted (or estimated) by this log-linear model (logistic regression). The exact values are shown in Table 6.

Table 6 TP OEC_{90} (mg/L) as inversely predicted by logistic regression of Stream Condition Index (Impaired, Not impaired) on ecoregion ($P = 0.001$). If total nitrogen (TN) is added to the model, TP has no significant effects ($P = 0.19$). Likewise, adding TP^2 to the model is not significant. For the model with TP and ecoregion, the false-positive rate is 0.000, and the true-positive rate is 0.0292. The overall statistics were obtained from a model with only TP ($P < 0.0001$). For the overall results, the false-positive rate is 0.000, and the true-positive rate is 0.032.

Ecoregion	**TP OEC_{90} (mg/L)**	**90% Confidence Limits (mg/L)**
Mountain	0.351	(0.261, 0.547)
Piedmont	0.295	(0.224, 0.450)
Overall	0.284	(0.220, 0.415)

We estimate overall TN and overall TP by employing models that include only TN or only TP respectively (both models excluding ecoregion). The model selection step, step (i), showed the "best" model—best in the sense that it produces the highest true-positive rate for a given false-positive rate. At the same time, these alternative models are completely *valid*, statistically, in the sense that they contain no variables that are not statistically significant.

For example, the best model contains TN and ecoregion but not TP because TN and ecoregion are both statistically significant, but TP is not statistically significant when TN and ecoregion are included. However, the model that includes TP and ecoregion but not TN (Figure 6 and Table 6) is *valid* because TP as well as ecoregion are statistically significant when TN is excluded. It does not, however, have quite the *sensitivity* (true-positive rate) as the model with TN and ecoregion (with TP excluded), and therefore is not "best".[3]

The same is true for the models used to estimate Overall OEC_{90} for TN and TP, respectively, in Table 3 and Table 6.

Work in Progress

This methodology can also be applied to the estimation of OEC for TP. For the 6-month dataset, we are in the process of calculating the OECs, false-positive rates, and true-positive rates. For the 12-month dataset, the best model contains both TN and TP. This calls for the joint estimation of the pair of OECs, and the joint calculation false-positive rates, and true-positive rates. The latter calculation is a bit more time consuming as it is not performed routinely by available software.

Finally, there is the decision of exactly where to draw the line. A good way to do so would be to estimate the cost of a false positive and gain of a true positive. The latter is the saving of the cost of further analysis when the first stage is negative for impairment. The former probably has different costs and benefits for different stakeholders.

Further Research

For further research, at least two additional statistical methods could be considered as well. One is cross validation to test the predictive strength of the method proposed above. The other is the use of the bootstrap method of estimation, which is nonparametric and extremely robust.

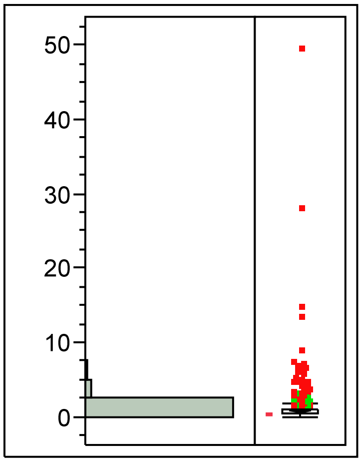
---

[3] The terminology is confusing. Medical biostatistics uses the terms *false-positive rate* and *true-positive rate* for what environmetricians usually call *Type 1 error rate* (or *significance level*) and *power*. *True-positive rate* and *power* are also called *sensitivity*. Regardless, the decision here between "impaired" and "not impaired" is a statistical test of significance of null hypothesis $SCI \geq 60$ against the alternative hypothesis $SCI < 60$. Rejecting the null hypothesis is a "positive" finding of impairment. Not rejecting the null hypothesis is a "negative" of "no statistically significant evidence of impairment."

Appendix

Univariate analysis TN, TP, and SCI of 6-month data (n = 922)

TN (mg/L)



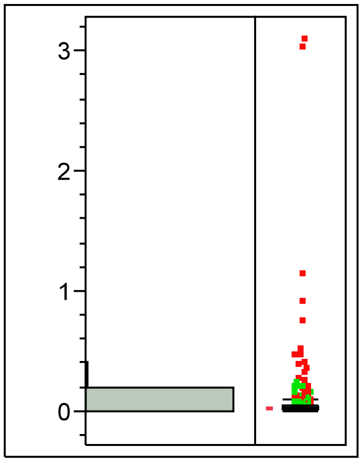
Quantiles

100.0%	maximum	49.95
99.5%		10.8974
97.5%		3.876
90.0%		1.606
75.0%	quartile	0.865
50.0%	median	0.5
25.0%	quartile	0.29
10.0%		0.166
2.5%		0.1
0.5%		0.06
0.0%	minimum	0.02

Moments

Mean	0.8908111
Std Dev	2.1807675
Std Err Mean	0.0718587
Upper 95% Mean	1.0318371
Lower 95% Mean	0.749785
N	921
Sum Wgt	921
Sum	820.437
Variance	4.755747
Skewness	15.400562
Kurtosis	308.67247
CV	244.80696
N Missing	1

TP (mg/L)



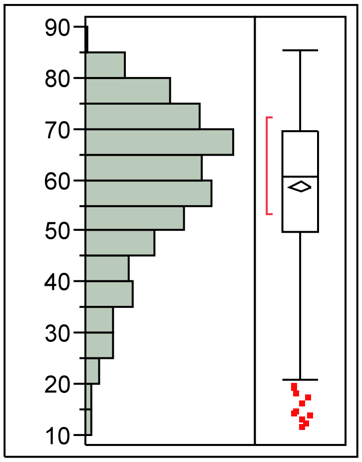
Quantiles

100.0%	maximum	3.11
99.5%		0.83545
97.5%		0.1985
90.0%		0.09
75.0%	quartile	0.05
50.0%	median	0.03
25.0%	quartile	0.02
10.0%		0.01
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.002

Moments

Mean	0.051244
Std Dev	0.159414
Std Err Mean	0.00525
Upper 95% Mean	0.0615474
Lower 95% Mean	0.0409406
N	922
Sum Wgt	922
Sum	47.247
Variance	0.0254128
Skewness	15.730781
Kurtosis	286.39008
CV	311.08786
N Missing	0

VSCI



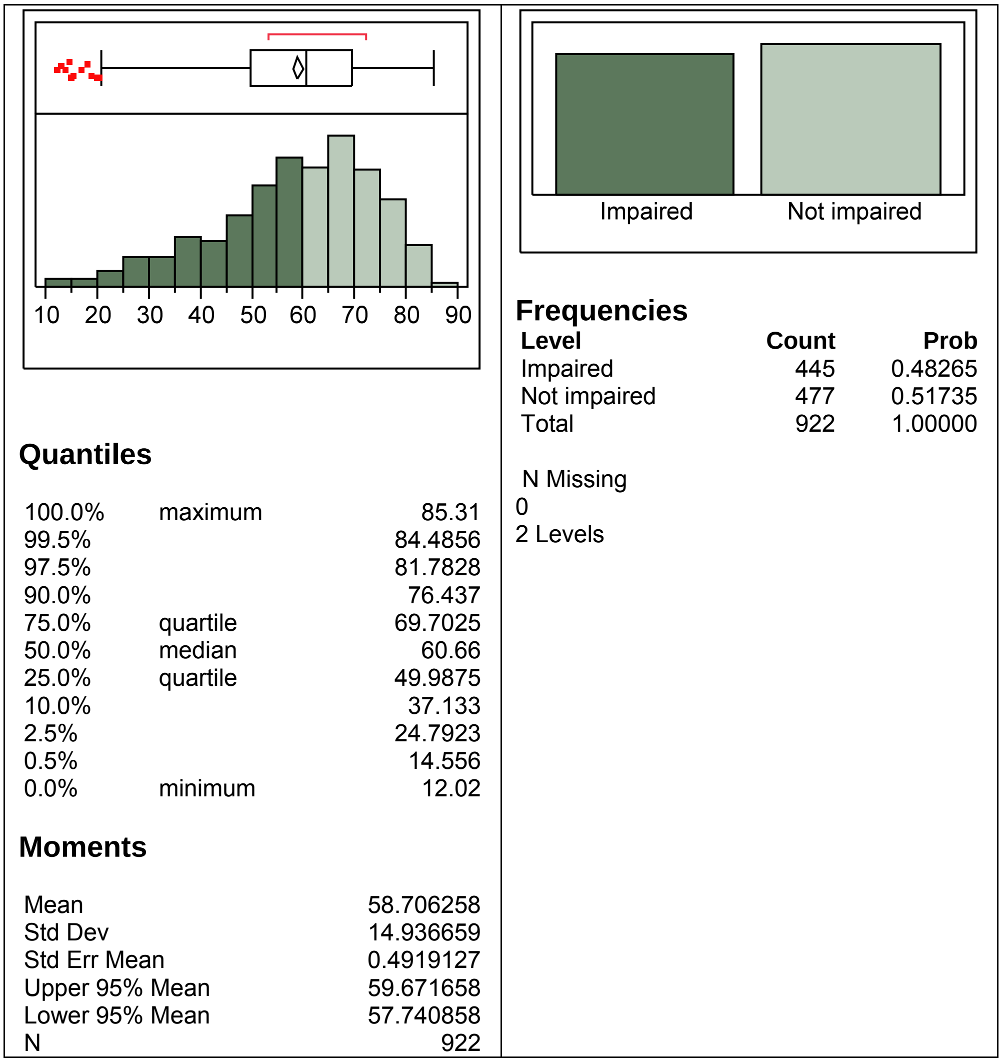
Quantiles

100.0%	maximum	85.31
99.5%		84.4856
97.5%		81.7828
90.0%		76.437
75.0%	quartile	69.7025
50.0%	median	60.66
25.0%	quartile	49.9875
10.0%		37.133
2.5%		24.7923
0.5%		14.556
0.0%	minimum	12.02

Moments

Mean	58.706258
Std Dev	14.936659
Std Err Mean	0.4919127
Upper 95% Mean	59.671658
Lower 95% Mean	57.740858
N	922
Sum Wgt	922
Sum	54127.17
Variance	223.1038
Skewness	-0.659204
Kurtosis	-0.010149
CV	25.443045
N Missing	0

Univariate analysis of SCI for 6-month data (*n* = 922)

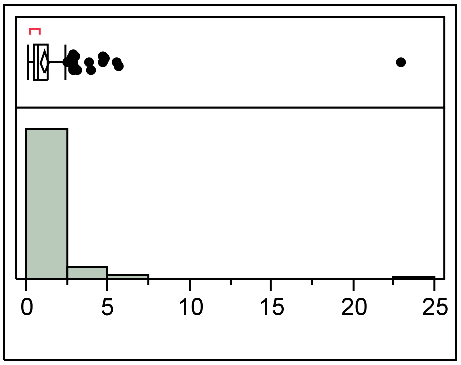


```
Quantiles

100.0%    maximum       85.31
99.5%                 84.4856
97.5%                 81.7828
90.0%                  76.437
75.0%     quartile    69.7025
50.0%     median        60.66
25.0%     quartile    49.9875
10.0%                  37.133
2.5%                  24.7923
0.5%                   14.556
0.0%      minimum       12.02

Moments

Mean                58.706258
Std Dev             14.936659
Std Err Mean        0.4919127
Upper 95% Mean      59.671658
Lower 95% Mean      57.740858
N                         922
```

```
Frequencies
Level           Count      Prob
Impaired          445   0.48265
Not impaired      477   0.51735
Total             922   1.00000

 N Missing
0
2 Levels
```

Univariate analysis TN, TP, and SCI of 12-month data (n = 207)

TN (mg/L)



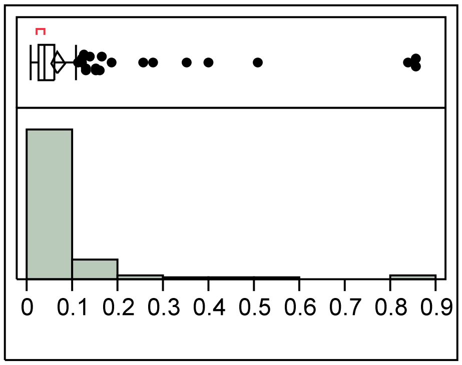
Quantiles

100.0%	maximum	22.9
99.5%		22.2096
97.5%		4.74
90.0%		2.112
75.0%	quartile	1.27
50.0%	median	0.76
25.0%	quartile	0.46
10.0%		0.3132
2.5%		0.112
0.5%		0.0806
0.0%	minimum	0.08

Moments

Mean	1.1419807
Std Dev	1.7893284
Std Err Mean	0.1243669
Upper 95% Mean	1.3871759
Lower 95% Mean	0.8967855
N	207
Sum Wgt	207
Sum	236.39
Variance	3.2016962
Skewness	9.1437493
Kurtosis	106.99339
CV	156.6864
N Missing	0

TP (mg/L)



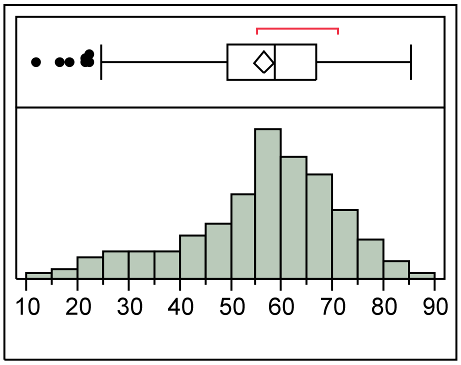
Quantiles

100.0%	maximum	0.855
99.5%		0.855
97.5%		0.39
90.0%		0.111
75.0%	quartile	0.06
50.0%	median	0.04
25.0%	quartile	0.025
10.0%		0.02
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.01

Moments

Mean	0.0667633
Std Dev	0.1123531
Std Err Mean	0.0078091
Upper 95% Mean	0.0821592
Lower 95% Mean	0.0513673
N	207
Sum Wgt	207
Sum	13.82
Variance	0.0126232
Skewness	5.5398922
Kurtosis	34.31755
CV	168.2857
N Missing	0

VSCI



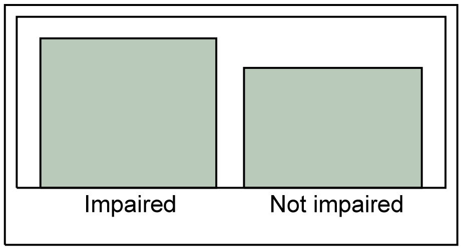
Quantiles

100.0%	maximum	85.31
99.5%		85.2704
97.5%		80.278
90.0%		72.672
75.0%	quartile	66.93
50.0%	median	58.6
25.0%	quartile	49.56
10.0%		33.052
2.5%		21.692
0.5%		12.2076
0.0%	minimum	12.02

Moments

Mean	56.489855
Std Dev	14.438804
Std Err Mean	1.0035662
Upper 95% Mean	58.468433
Lower 95% Mean	54.511277
N	207
Sum Wgt	207
Sum	11693.4
Variance	208.47905
Skewness	-0.709935
Kurtosis	0.3105727
CV	25.559994
N Missing	0

SCI



Frequencies

Level	Count	Prob
Impaired	115	0.55556
Not impaired	92	0.44444
Total	207	1.00000

N Missing 0

2 Levels

Appendix B

Visual Assessment Forms

Nutrient Criteria Visual Assessment Field Form (Spring 2008)

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

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					
Filamentous					

Vascular Plant Growth

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

Submerged macrophytes	
Emergent macrophytes	
Other	

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) **Categories; 1-10; 10-40; 40-70; >70**

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 (circle one)

Low **Medium** **High**

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
Low
Moderate
Heavy

Nutrient Criteria Visual Assessment Field Form (Fall 2008)

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 button coverage by algae and vascular plant growth _________________
(Categories; 1-10; 10-40; 40-70; >70)

Observations

Stream substrate type	**sand**	**gravel**	**cobble**	**bedrock**	**mud**
Categories; 1-10; 10-40; 40-70; >70	_____	_____	______	_______	_____

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 observations of algae and macrophyte biomass; probability of impairment to macroinvertebrate community by non-nutrient stressor (circle one)

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**

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

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

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**

Nutrient Criteria Visual Assessment Field Form (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 filamentious only	
All: inc. mat, filamentious, film	

By Vascular Plants

Macrophytes only:	
Total: Macro-phytes and Mosses	

By Algae and Plants

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

Best Professional Judgment of Impairment

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