VIRGINIA WATER RESOURCES RESEARCH CENTER

A "Screening Approach" for Nutrient Criteria in Virginia

2016 Report of the Academic Advisory Committee for Virginia Department of Environmental Quality

SPECIAL REPORT

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A “SCREENING APPROACH”
FOR
NUTRIENT CRITERIA IN VIRGINIA

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Contents

I. Introduction

The Academic Advisory Committee (AAC) is providing assistance to the Virginia Department of Environmental Quality (VDEQ) in developing a scientifically sound and workable approach to water-quality criteria for Virginia.

This report provides information on development of nutrient criteria for wadeable freshwater rivers and streams. Activities conducted to complete two tasks from the AAC's fiscal year 2016 work plan are described in this report:

- Revisit Observed-Effect Concentration (OEC) analysis (Section III in AAC 2012a) working with advice from a VDEQ contact who is familiar with the agency's water-quality assessment process. Revisit after reconsidering two essential factors: (1) The implementation time frame, and (2) the probability of impairment used to define the OEC. Conduct the analysis for a period that would be compatible with VDEQ's assessment process, likely two years or longer.

- Explore development of No-Observed-Effect Concentrations (NOECs) on an ecoregional basis.

These tasks were conducted within a context established by the AAC's prior reports to VDEQ. Most notably, the July 2012 report of the AAC (2012a) describes a screening approach and its components (including OEC and NOEC) and explores methods for deriving OEC and NOEC values from VDEQ water-monitoring data. The December 2012 AAC (2012b) report describes the technical and policy context for the AAC's proposal that VDEQ adopt a screening approach to nutrient criteria in Virginia's wadeable freshwater rivers and streams. Both reports are available on VDEQ's "Nutrient Criteria Development" web page.[1] The two tasks described here follow analyses described previously by the AAC (2012a) and further explore those approaches.

Specialized acronyms and terms used in this report are stated in Table I-1.

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[1] http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityStandards/NutrientCriteriaDevelopment.aspx (accessed June 3, 2016)

Table I-1. Specialized acronyms and terms used in the report, with meanings and report section where the term is defined.

Acronym/Term	Meaning	Report section where defined
Hypothetical assessment (H-assessment)	An evaluation of VSCI data for a station/period by the AAC. Unlike an actual water-quality assessment conducted by VDEQ, an H-assessment can yield any one of three possible outcomes: H-impaired H-indeterminate H-not impaired	Section II
NOEC	No-Observed-Effect Concentration	Section III (see also AAC 2012a and AAC 2012b)
OEC	Observed-Effect Concentration	Section II (see also AAC 2012a and AAC 2012b)
Station/Period	A single monitoring location during a six-year assessment period (2003-2008 or 2009-2014)	Section II
TPR value	Ten-percent-rule value: the concentration for a given station/period that would be a critical value for water-quality assessment if the 10 percent rule was being applied.	Section II

II. Development of Observed-Effect Concentrations

Development of a screening approach for nutrient criteria requires development of OECs for in-stream nitrogen and phosphorous. The AAC's analyses have focused on total nitrogen (TN) and total phosphorous (TP) as in-stream nutrient concentration measures. *Observed-effect concentrations* (OECs) for TN and TP are concentrations above which nutrient impairment of the aquatic community can be reasonably expected. Under the nutrient criteria screening approach, monitoring sites with measured TN and/or TP concentrations greater than or equal to a corresponding OEC would be assessed as impaired.

The analyses reported in this section were conducted to investigate the potential to establish OECs through a conditional probability analysis applied to VDEQ monitoring data. As per AAC goals for the current year, we attempted to conduct the analysis in a manner that is consistent with VDEQ's water-quality assessment process.

Method

The method of analysis, derived from Paul and McDonald (2005), was applied to estimate potential OECs. The method of analysis is based on the assumption that the probability of a site being impaired for aquatic life (Stream Condition Index <60) increases with measured nutrient concentrations. Prior AAC reports have explored this expectation at the upper end of the nutrient-concentration range (AAC 2006, 2009, 2010, 2012a).

Data Acquisition

The water-quality monitoring data obtained from VDEQ included observations from Virginia streams in the Piedmont, Blue Ridge, Valley and Ridge, and Central Appalachians ecoregions. Observations from ecoregions other than the Piedmont were combined, as per US EPA Level II ecoregion designations, forming a "Mountains" ecoregion designation. The database obtained included measured values for TN and TP and values calculated by VDEQ for those parameters from measured components. The database obtained extended from the 1990s through early 2016.

Biological monitoring data were also obtained from VDEQ. These data included Virginia Stream Condition Index (VSCI) scores, habitat metrics, and ecoregion designations. The three western ecoregions were reclassified as "Mountains" as described above. "Northern Piedmont" observations were reclassified as "Piedmont." Observations from east of the Piedmont ecoregion were not used in the analysis.

Water-Quality Assessments (VDEQ) and Hypothetical Assessments (AAC)

Dr. Tish Robertson of VDEQ was consulted concerning the agency's water-quality assessment practices. Dr. Robertson explained that VDEQ conducts water-quality assessments every two years, and each assessment considers monitoring data for a six-year period. For conventional water-quality parameters with numerical criteria acting as acute stressors, the data from each monitoring location are compared to the criterion using the 10 percent rule (TPR). In accordance with this rule, a monitoring location will be assessed as impaired if >10% of observations, or two observations at minimum, exceed the criterion for the given parameter. At least 10 observations are required from any individual site before it can be assessed as "fully supporting" the water-quality standard.

Dr. Robertson explained that VSCI data are also used for water-quality assessments. If all VSCI observations from a given site are either <60 (indicating impairment) or >60 (indicating not impaired), the site is assessed in accord with those VSCI results. If multiple VSCI scores are available from a given site and are mixed in impairment status (i.e., one or more are <60, and one or more are >60), best professional judgement is applied in the assessment. Factors considered in that judgement include whether or not a majority of the VSCIs are either <60 or >60, and if a site's biological condition appears to be improving or deteriorating through time. In consultation with Dr. Robertson, we developed the following method for assigning *hypothetical assessments* (H-assessments) to water-monitoring locations with VSCI data:

- *H-not impaired* (site passes):
    - If the ratio of passing VSCI scores (VSCI>60) to total number of VSCI scores is > 65%, and the average VSCI > 60; or
    - If the ratio of passing VSCI scores to total number of VSCI scores is ≥ 50% but <65%, and the average VSCI is >65.
- *H-impaired* (site fails):
    - If the ratio of passing VSCI scores to total number of VSCI scores is <35%; or
    - If the ratio of passing VSCI scores to total number of VSCI scores is > 35% but ≤ 50%, and the average VSCI <55.
- *H-indeterminate* (otherwise): All other sites not meeting the definitions above.

The "otherwise" classification was applied with the understanding that VDEQ does not have the option of using this assessment classification. However, this classification helps to avoid subjectivity in applying the hypothetical assessments for the purpose of this analysis.

Analysis

We decided to conduct the analysis using two six-year time frames: 2009-2014 and 2003-2008. The 2009-2014 time frame was selected as a recent period that corresponds with a VDEQ assessment period (currently in process). We used 2003-2008 as a means of increasing the number of data elements that would be available for analysis. We did not use earlier data because many TP observations were recorded ≤0.1 mg/L up through the year 2000, rendering them incompatible for data-analysis purposes with more recent data that has been obtained with greater precision. Also, some pre-2003 habitat evaluation data appeared to be less compatible with current habitat data.

Water-quality and biological data for the two time periods selected were combined into a single database. The first step of analysis was to identify TPR values for TN and for TP for each monitoring station/period with ≥10 observations for that parameter. The *TPR values* are those concentrations that correspond with the 10 percent rule. In other words:

- If 10-19 observations are available, the 2nd- highest value = TPR value
- If 20-29 observations are available, the 3rd- highest value = TPR value
- If 30-39 observations are available, the 4th- highest value = TPR value
- And so forth.

The TPR values were determined by station/period. In other words, if a given monitoring station had ≥10 observations for a parameter (TN, TP) for both the 2003-2008 and 2009-2014 periods, two separate TPR values were calculated for that station, i.e., one for each station/period. Average TN and TP concentrations were also calculated for each station/period.

A hypothetical assessment was applied for each station/period. Then a conditional probability analysis was applied for both TN and TP by ecoregion, using all station/periods with sufficient data to calculate a TPR value.

Impairment probability curves were plotted for each ecoregion separately and for all data combined. As a means of estimating OECs at the 70%, 80%, and 90% probability-of-H-impairment level, LOWESS (locally-weighted scatterplot smoothing) curves were fit to the conditional probability plots. This operation was performed using the software program JMP (v. 11.0) using the "flexible split fit" option, which assigns a smoothing-spline fit lambda = 0.01 value, and which created spline fits with high R^2 values. The spline fit plots were placed in a graphics program and manually interpolated (with graphics' software elements applied to maximize precision) to determine TN and TP concentrations associated with 70%, 80%, and 90% probabilities of H-impairment.

In addition to the median concentrations used in our prior analyses, we analyzed relationships of average and TPR concentrations to median concentrations for the Mountains and Piedmont ecoregions.

Results and Discussion

Hypothetical assessments were applied to 1,086 station/periods with VSCI data that could be linked to measured TN and/or TP concentrations. Of these, 37% were classified as H-impaired, 16% as H-indeterminate, and 47% as H-not impaired (Table II-1).

For both TN and TP, the Piedmont data yielded conditional probability plots closer to what was expected than did the Mountains data (Figures II-1 and II-2). It is possible that this result may have occurred because of greater site-condition differences among streams in the Mountains ecoregion. It is possible that greater variation among such characteristics for streams in the Mountains ecoregion caused greater variation of responses by the stream communities to elevated nutrient concentrations. It is also possible that streams in the Mountains ecoregion are not as responsive to nutrients, generally, compared to those in the Piedmont, perhaps because streams in the Mountains ecoregion are more shaded and generally have higher gradients. Streams with higher gradients and with greater shading can be expected to accommodate elevated nutrient concentrations with lower probabilities of impairment than streams with more open canopies and lower gradients. Regardless of the reason, the Mountains ecoregion failed to generate conditional probability plots of the expected forms.

Conditional probability plots were generated on two separate bases: (1) Probability of H-impairment, and (2) probability of H-impairment or H-indeterminate status. Both approaches produced conditional probability plots with similar forms for high-end probabilities in all cases except for TP in the Piedmont. Hence, most of the potential OEC values generated by the two approaches are either identical or very similar (Table II-2). Based on conversations with Dr. Robertson, we are confident that most or all of the H-impaired and H-Not-Impaired site/periods would have been assessed similarly by VDEQ in formal water-quality assessment, but we have no guidance about how the H-indeterminate site/periods would have been assessed. Potential

OEC values for the Mountains ecoregion should be interpreted with an understanding of the data structures and interpolation methods that generated them (Figure II-3).

For TN in both ecoregions and for TP in the Mountains ecoregion, the basis for constructing the conditional probability curves had essentially no effect on the estimated OEC values (Table II-2). This effect occurred because no H-indeterminate station/periods occurred with TN TPR concentrations giving rise to conditional probabilities >70%. For TN in the Mountains ecoregion, the highest-probability H-indeterminate observation (64%) influenced the shape of the interpolated curves causing a slight difference in the two 90%-probability values. For TP in the Piedmont, derived OECs for 70% and 80% probabilities were influenced by choice of endpoint because a number of H-indeterminate station/periods were associated with conditional probabilities in the ~70% to ~85% conditional-probability range.

Data from the Piedmont ecoregion produced relationships that are consistent with the expectations that underlie the development of the conditional probability method, but results for the Mountains ecoregion did not. Although we have applied the methods described to generate potential/estimated OECs, we do not see the resulting values as suitable for potential application for several reasons, including the sparseness of supporting data. The failure of the data from the Mountains ecoregion to generate usable results was similar to the outcome of previous work by the AAC (2012a).

For both TN and TP, relationships of TPR concentrations to median values are shown in Figures II-4 through II-6. Those relationships enable rough comparisons of results for the analyses described here, which used TPR concentrations, to those conducted previously by the AAC (2012a) using medians. Considering the TPR/median ratios that are evident from Figures II-4 and II-6, it appears that most results of these analyses for the 90%-probability level for the Piedmont ecoregion are roughly similar to those generated in 2012 (AAC 2012a). Informal analyses with these data using site/period average TN and TP concentrations for the Piedmont ecoregion generated 90%-probability potential OECs that were nearly identical to those generated previously by the AAC (2012a) (data not shown).

Considering the variability of TPR/median ratios (Figures II-4 through II-6), we conducted an exploratory and supplemental analysis of potential influences on those ratios. We found no obvious relationships (Figures II-7 and II-8), suggesting that random factors associated with streamflows, seasonality, and other influences on point-in-time TN and TP concentrations influence those relationships.

Given that the TPR is typically applied as an indicator of near-maximum concentrations for conventional toxicants, with the purpose of limiting concentrations to less-than-toxic levels; and given that nutrients do not act as toxicants, these results cause us to question if the TPR is the best possible method for assessing nutrient concentrations for potential in-stream nutrient impairments. One would expect that the average or median concentration experienced during a given season would, perhaps, be a better indicator of in-stream algae levels and influences on dissolved oxygen. It is possible that scientific literature could be consulted to investigate the validity of this expectation, but as of this writing we have not done so.

Conclusions

We applied the conditional probability method to select potential OECs using an analysis framework similar to that applied by VDEQ in water-quality assessments. Although we generated potential OECs for the Mountains ecoregion, the nature of the underlying data would make them difficult to defend. The Piedmont ecoregion data behaved in a manner that was closer to expectations and which enable defensible interpretations of resulting OEC estimates, but the OEC values generated are very high relative to nutrient concentrations in most of the study region’s streams. Hence, their application as a component of a screening approach would enable few definitive water-quality assessments. The analyses described here were conducted using procedures intended to replicate water-quality assessments conducted by VDEQ and produced results that are consistent with those generated previously by the AAC (2012a).

As a means of going forward, we recommend consideration of alternative approaches for developing OECs. For example, VDEQ has conducted a stressor analysis for use in benthic TMDLs (total maximum daily loads; VDEQ 2016). The VDEQ analysis identifies concentrations of TN (≥ 2 mg/L), TP (≥ 0.1 mg/L), and other stressors that indicate “high risk to aquatic life.” As of this writing, that report remains in draft form. It is possible that the report, when completed, may provide an alternative approach for identifying OECs.

Table II-1. Results of hypothetical assessments applied to station/periods.

	-- H-Impaired --		-- H-Indeterminate --		-- H-Not Impaired --	
	n	Mean VSCI	n	Mean VSCI	n	Mean VSCI
Mountains	149	46.6	64	60.0	282	71.5
Piedmont	258	44.3	107	59.7	226	69.0

Table II-2. Potential OEC values generated by the methods described in this report and compared to earlier AAC (2012a) results.

Ecoregion	Probability	H-Impairment	H-impairment + H-Indeterminate	AAC (2012a), 12-month	AAC (2012a), 6-month
		-- TN (mg/L), TPR --		*-- TN (mg/L), median --*	
Mountains	70%	5.0	5.0		
	80%	5.4	5.4		
	90%	6.0	5.9	n/a	3.2
Piedmont	70%	1.6	1.6		
	80%	1.9	1.9		
	90%	3.1	3.1	1.8	1.9
		-- TP (mg/L), TPR --		*-- TP (mg/L), median --*	
Mountains	70%	0.70	0.70		
	80%	0.80	0.80		
	90%	0.90	0.90	n/a	0.26
Piedmont	70%	0.21	0.04		
	80%	0.33	0.19		
	90%	0.46	0.45	0.15	0.22

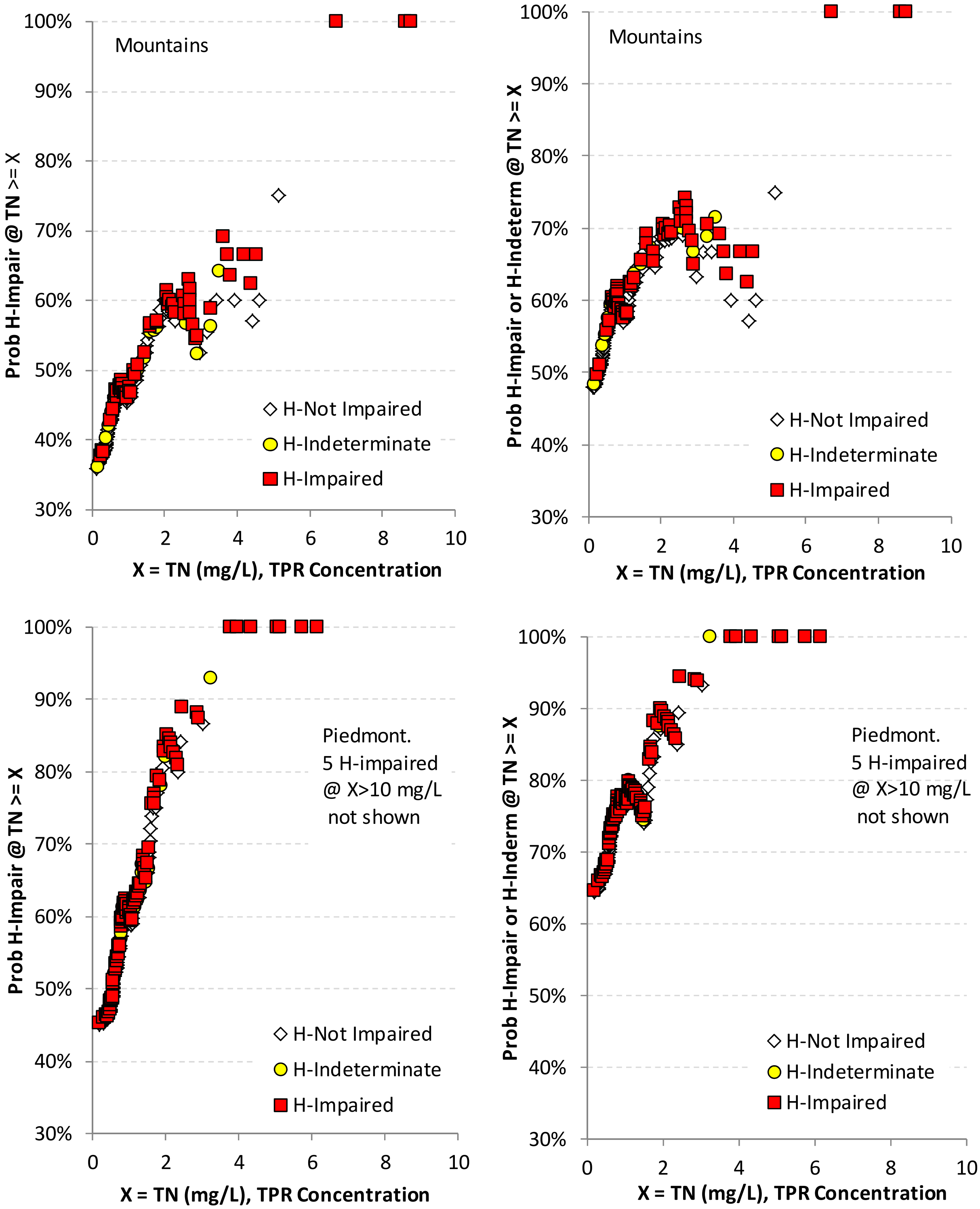


Figure II-1. Conditional probability for TN in the Mountains (above) and Piedmont (below) ecoregions.

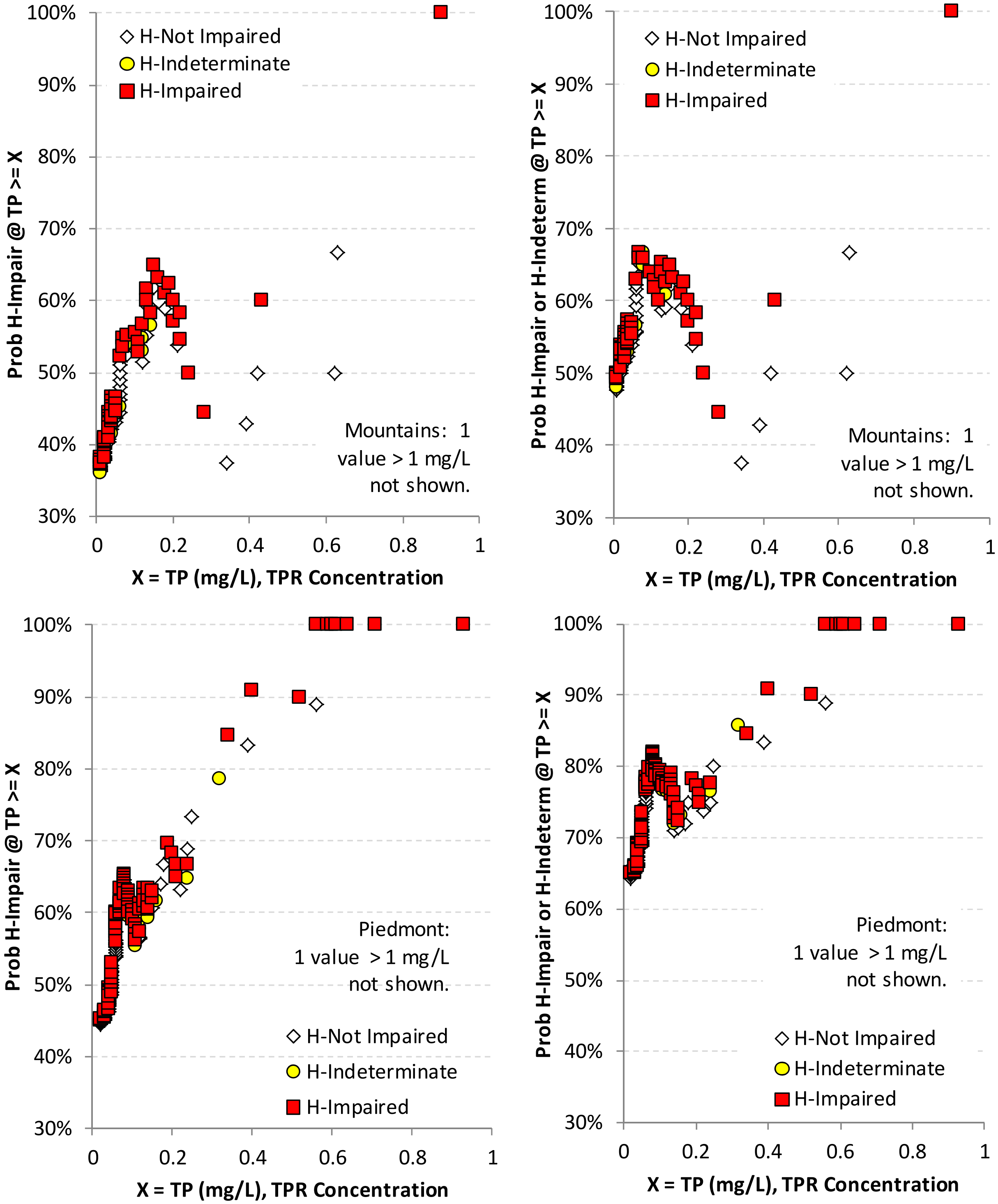
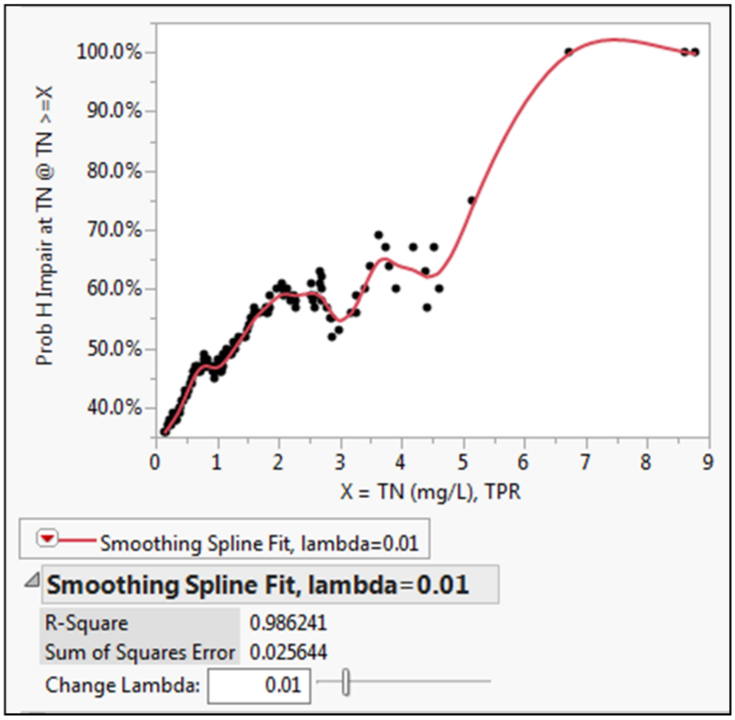


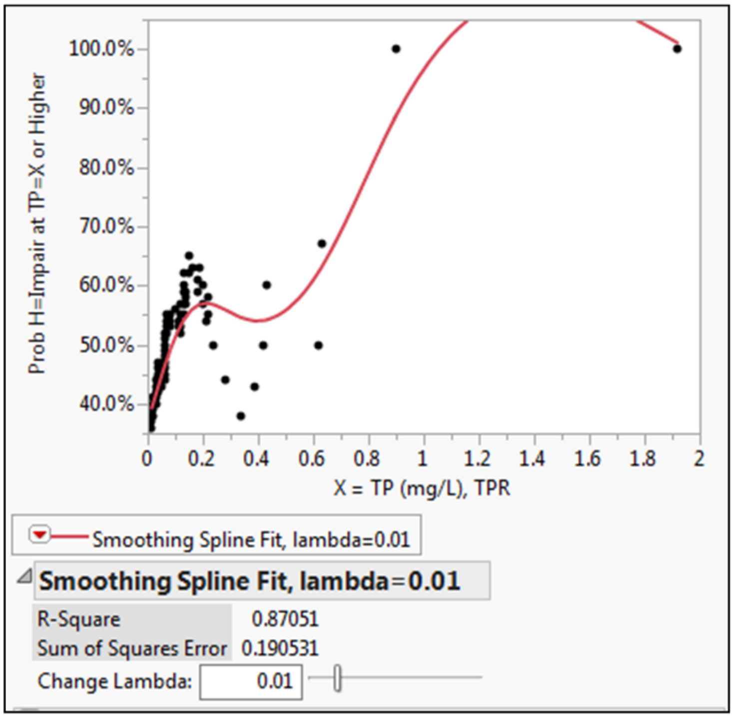
Figure II-2. Conditional probability for TP in the Mountains (above) and Piedmont (below) ecoregions.



Smoothing Spline Fit, lambda=0.01

R-Square	0.986241
Sum of Squares Error	0.025644

Change Lambda: 0.01



Smoothing Spline Fit, lambda=0.01

R-Square	0.87051
Sum of Squares Error	0.190531

Change Lambda: 0.01

Figure II-3. Example of LOWESS spline fits used to interpolate the estimated OEC values of Table II-2. These examples, for the Mountains ecoregion, were selected to demonstrate the poor fit when applying this method.

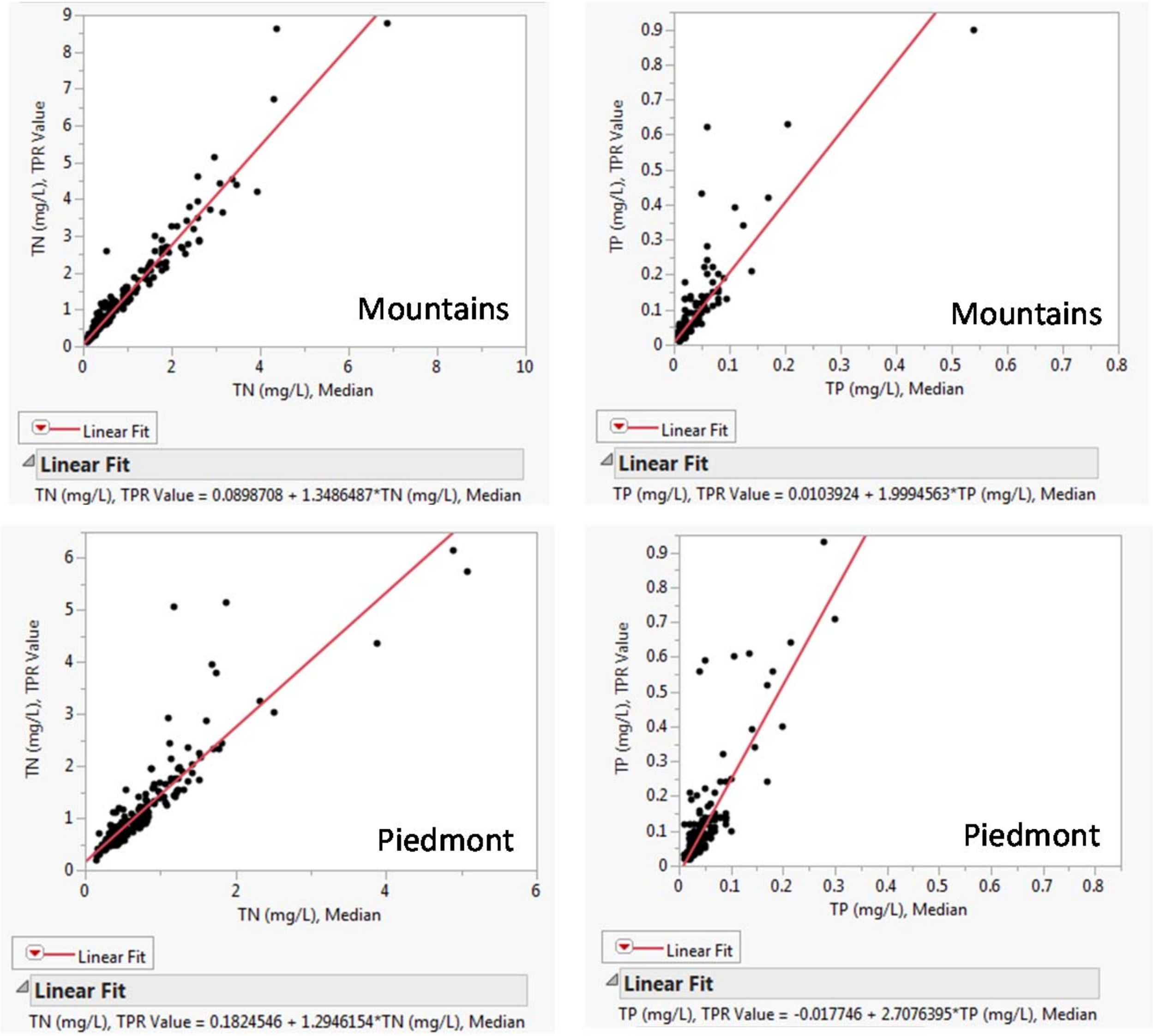
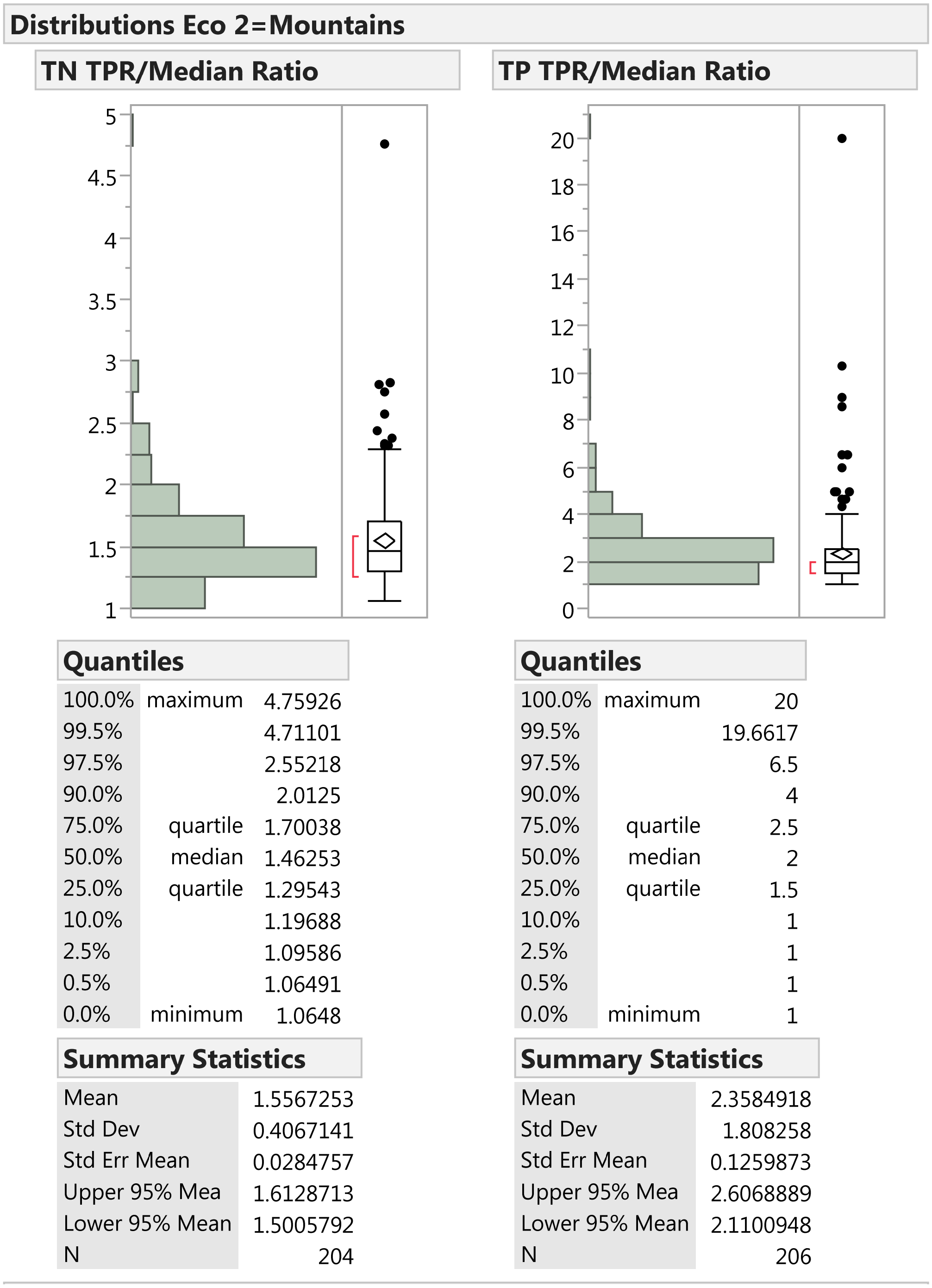


Figure II-4. Linear-function relationships of TPR values for TN and TP vs. corresponding medians, by ecoregion.



TN TPR/Median Ratio

Quantiles

100.0%	maximum	4.75926
99.5%		4.71101
97.5%		2.55218
90.0%		2.0125
75.0%	quartile	1.70038
50.0%	median	1.46253
25.0%	quartile	1.29543
10.0%		1.19688
2.5%		1.09586
0.5%		1.06491
0.0%	minimum	1.0648

Summary Statistics

Mean	1.5567253
Std Dev	0.4067141
Std Err Mean	0.0284757
Upper 95% Mea	1.6128713
Lower 95% Mean	1.5005792
N	204

TP TPR/Median Ratio

Quantiles

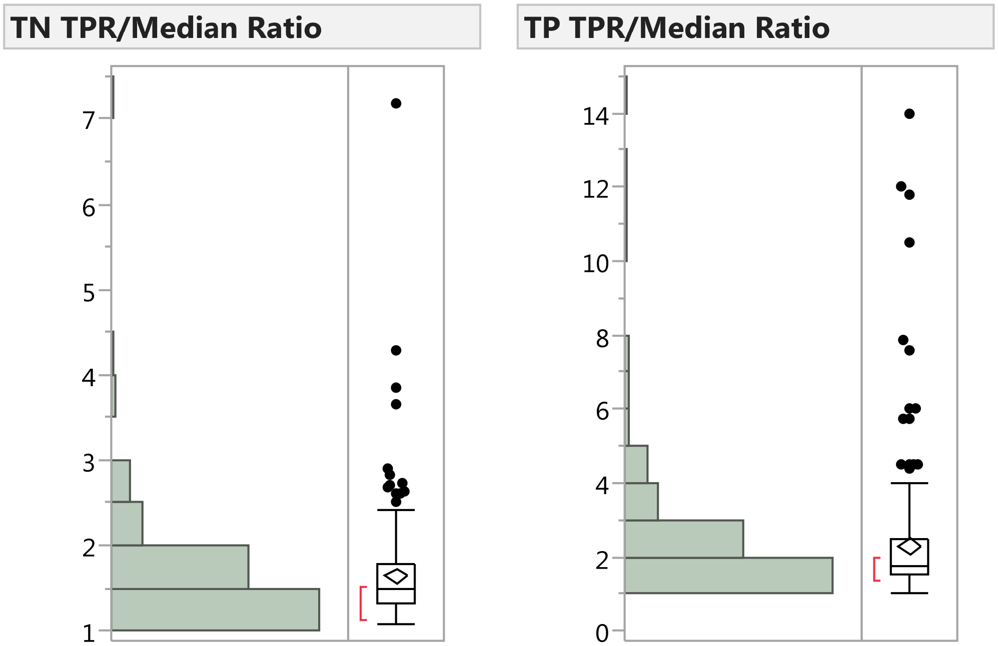
100.0%	maximum	20
99.5%		19.6617
97.5%		6.5
90.0%		4
75.0%	quartile	2.5
50.0%	median	2
25.0%	quartile	1.5
10.0%		1
2.5%		1
0.5%		1
0.0%	minimum	1

Summary Statistics

Mean	2.3584918
Std Dev	1.808258
Std Err Mean	0.1259873
Upper 95% Mea	2.6068889
Lower 95% Mean	2.1100948
N	206

Figure II-5. Relationship of TPR concentrations, which were used for our primary analysis, to median concentrations for TN and TP in the Mountains ecoregion. Each datapoint represents all measured values for a single monitoring station during a 6-year assessment period (station/period). Only data from station/periods with ≥10 observations were used.

Distributions Eco 2=Piedmont



TN TPR/Median Ratio

Quantiles

100.0%	maximum	7.1875
99.5%		7.12951
97.5%		2.88783
90.0%		2.20146
75.0%	quartile	1.7764
50.0%	median	1.48454
25.0%	quartile	1.31579
10.0%		1.20115
2.5%		1.12805
0.5%		1.08155
0.0%	minimum	1.08108

Summary Statistics

Mean	1.6486454
Std Dev	0.6109645
Std Err Mean	0.0428813
Upper 95% Mea	1.7331978
Lower 95% Mean	1.564093
N	203

TP TPR/Median Ratio

Quantiles

100.0%	maximum	14
99.5%		13.83
97.5%		7.738
90.0%		4
75.0%	quartile	2.5
50.0%	median	1.75
25.0%	quartile	1.5
10.0%		1.25
2.5%		1
0.5%		1
0.0%	minimum	1

Summary Statistics

Mean	2.3183216
Std Dev	1.7376451
Std Err Mean	0.1182318
Upper 95% Mea	2.5513635
Lower 95% Mean	2.0852798
N	216

Figure II-6. Relationship of TPR concentrations, which were used for our primary analysis, to median concentrations for TN and TP in the Piedmont ecoregion. Each datapoint represents all measured values for a single monitoring station during a 6-year assessment period (station/period). Only data from station/periods with ≥10 observations were used.

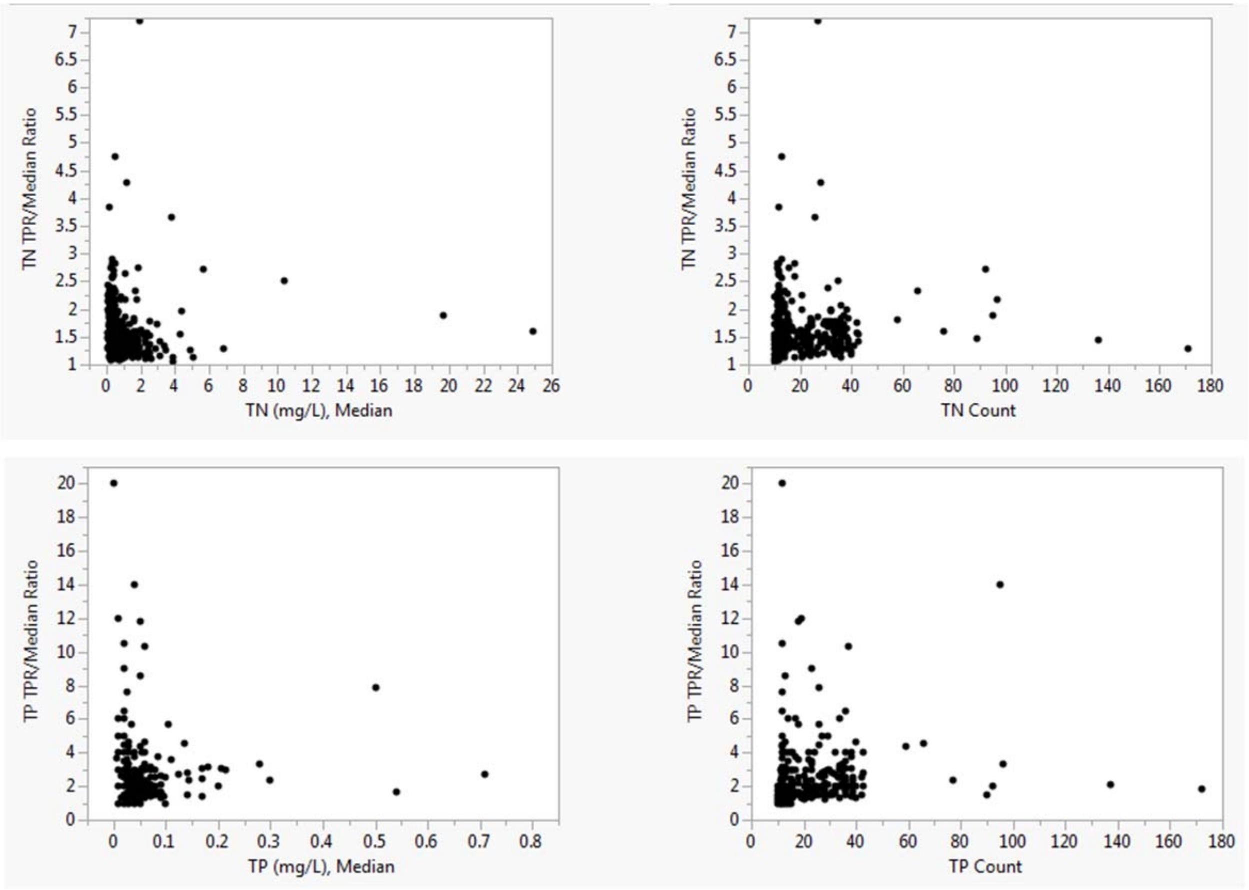


Figure II-7. Relationships of TPR/Median ratios to median concentrations (left) and number of observations, labeled as "counts" (right) for TN (above) and TP (below). Each datapoint represents all measured values for a single monitoring station during a 6-year assessment period (station/period).

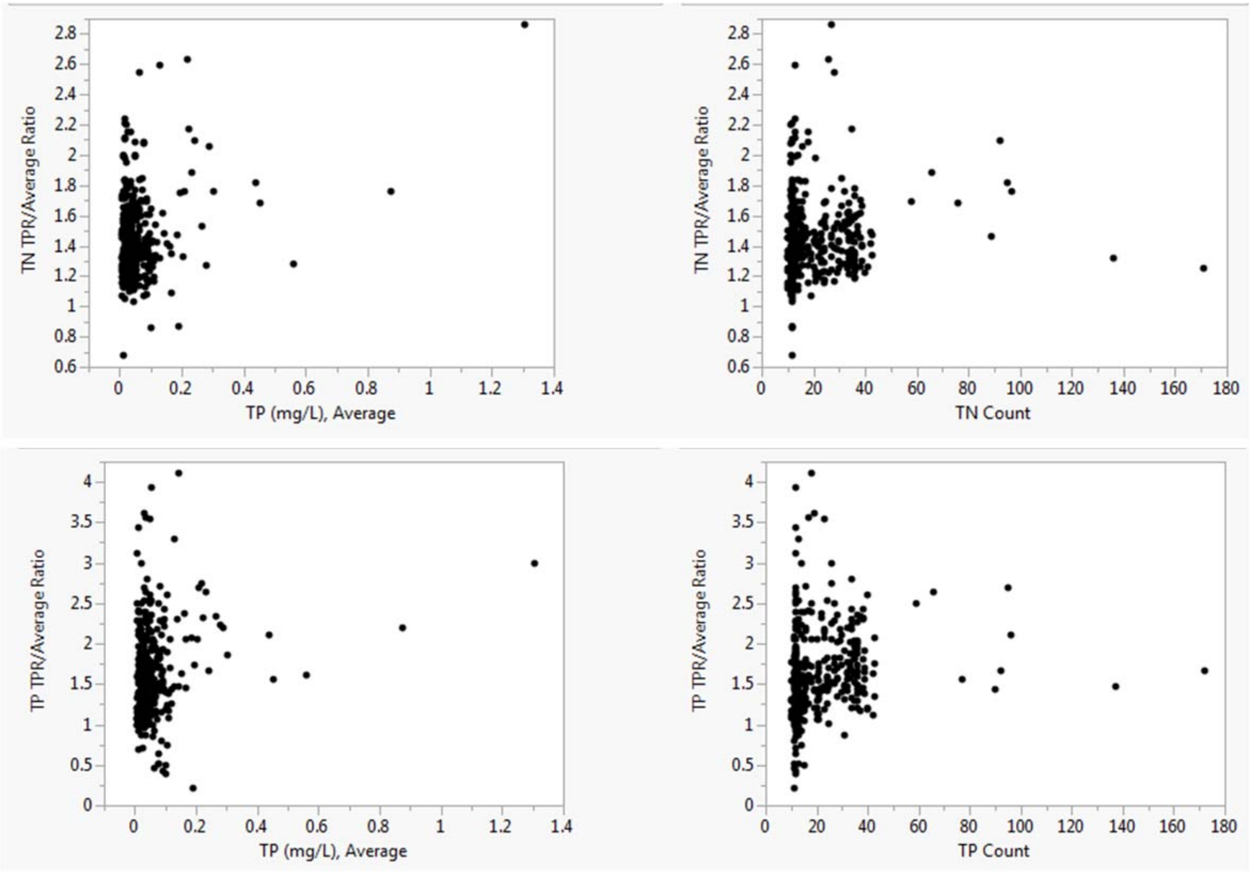


Figure II-8. Relationships of TPR/Average ratios to average concentrations (left) and observation counts (right) for TN (above) and TP (below). Each datapoint represents all measured values for a single monitoring station during a 6-year assessment period (station/period).

III. Development of No-Observed-Effect Concentrations – Probabilistic Monitoring Data

Here, we report activities conducted by the AAC to continue advising VDEQ's development of nutrient criteria for freshwater rivers and streams. This report section describes activities conducted to explore NOEC development on an ecoregional basis.

As the term is used in this report, *no-observed-effect concentrations* (NOECs) are nutrient concentrations expressed as TN and TP concentrations below which freshwater streams have a low probability of being impaired by nutrients. If VDEQ were to adopt nutrient criteria that incorporate a screening approach, as recommended by the AAC (2012a and 2012b), freshwater streams with TN and TP concentrations below the NOECs would be assessed as "not impaired by nutrients."

Our analysis is based on that described by the AAC's July 2012 report to VDEQ (AAC 2012a). We extend that analysis as a means of estimating candidate NOECs for TN and TP on an ecoregional basis.

Goal

Estimate candidate NOECs for the Mountains and Piedmont ecoregions by extending the analysis described previously by the AAC (2012a).

Method

Review of Method Applied Previously by the AAC

The method used by the AAC in 2012 is based on the premise that a nutrient-criteria reference dataset can be extracted from VDEQ probabilistic monitoring data, which can then be used as a basis for defining NOECs for TN and TP. The nutrient-criteria reference dataset would be comprised of data from water-monitoring observations where influence by non-nutrient stressors appears as minimal and, hence, relationships of VSCI scores to TN and TP concentrations can be analyzed to extract NOECs. The nutrient-criteria reference dataset was developed by applying a reference filter that has been used by VDEQ for EPA-approved studies (VDEQ 2006; reproduced here as Table III-1). For our analysis, we did not apply the TN and TP filters; the results of this activity were described as nutrient-criteria reference candidates. VDEQ biologists were then asked to apply their best professional judgement to identify sites that were not appropriate for use as nutrient-criteria references. Because time and other limitations prevent VDEQ biologists from evaluating all candidate sites, those candidates with VSCI scores < 60 were identified, and VDEQ biologists were asked to apply their best professional judgement to those sites. Any candidates judged by the biologists as unworthy of reference status (see Table II-3 in AAC 2012a) were then deleted from the site list to produce a nutrient-criteria reference dataset.

Once the nutrient-criteria reference dataset was defined, we attempted to extract NOECs from TN vs. VSCI and TP vs. VSCI by drawing regression lines. We anticipated that such regressions would have downward slopes (i.e., negative responses by VSCI scores to increasing TN concentrations and to increasing TP concentrations). We also expected that TN values and TP values defined by the intersection of the respective regression line with VSCI = 60 might serve as NOECs. However, application of that method by the AAC (2012a) found such intersections occurred at TN and TP concentrations outside the range of observed values for the nutrient-criteria reference dataset and, hence, were not suitable for use in defining NOECs. Therefore, the 90th percentiles of the nutrient-criteria reference TN and TP values were selected as candidate NOECs.

Method Applied in 2016

We obtained an updated probabilistic monitoring database from VDEQ. Since the prior analysis was based on data from 2009 and earlier, we applied a similar analysis to all observations from 2010 and later to identify additional nutrient-criteria reference data records (i.e., probabilistic monitoring locations with associated VSCI, TN, and TP values) using an identical selection process. We then added the new reference sites to those generated previously by the AAC (2012a) to create an expanded nutrient-criteria reference dataset.

We analyzed the new dataset using the methods described in AAC (2012a) to extract candidate NOECs – but with one major difference: In 2016, we derived candidate NOECs for each ecoregion. In contrast, because of a limited number of observations, the earlier AAC (2012a) analysis derived candidate NOECs for a region comprised of the Mountains and Piedmont ecoregions combined. Other differences between the two analyses are described in the results section below.

We report 90th percentiles of the reference distributions as potential NOECs. Considering EPA documentation describing possible approaches for developing nutrient criteria (see Chapter 7 in US EPA 2000), we have also reported 75th percentiles of the reference distributions.

Results

The new probabilistic monitoring database included 114 observations within the Mountains and Piedmont ecoregions during the 2010-2012 collection periods. The probabilistic monitoring observations reported by VDEQ from 2010-2012 were average values calculated from two complete sampling observations (fall and spring) for biology, water quality, and habitat. Thus, the new data included a single record for each sampling site that had been calculated as an average of the fall and spring samples. In contrast, the pre-2010 dataset included only a single observation, either fall or spring, whichever was associated with water-quality data. Thus, the combined dataset used for the 2016 analysis included single observations for some sites (collected pre-2010) and average observations for other sites (collected during 2010-2012).

Application of the VDEQ reference filter to the 2010-2012 probabilistic monitoring observations identified 26 additional NOEC-reference candidates. Inspection of those data revealed one site that was ill-suited for reference status (5AKIT002.65; VSCI = 35, TN = 1.99 mg/L; TP = 0.19 mg/L). This site was removed from the list of candidate sites, leaving 25 additional nutrient-criteria reference sites (Figure III-1).

Data records for these 25 additional nutrient-criteria reference sites were added to the AAC 2012 nutrient-criteria reference database (61 sites as per AAC 2012a), resulting in 86 total nutrient-criteria reference sites for the two ecoregions combined (Figure III-2, Appendix A). In light of current goals, the 86 nutrient-criteria references were disaggregated into Mountains and Piedmont ecoregion subsets.

As in 2012, attempts to define NOECs by modeling responses of VSCI scores to TN and TP concentrations were not successful. Only one of the resulting relationships was statistically significant, but it produced model TN and TP estimates corresponding with a VSCI = 60 intersect at concentrations higher than any occurring within the reference dataset (Figures III-3a and III-3b).

Therefore, we applied the 90th-percentile method for identifying NOEC candidates, as in the previous work by the AAC (2012a) but for the Mountains and Piedmont ecoregions separately. Also in contrast to the earlier AAC (2012a) procedure, we removed VSCI<60 observations prior to this operation. The 90th percentile values derived from the TN and TP distributions for the nutrient-criteria reference data when VSCI > 60 (Figures III-4a and III-4b) are listed in Table III-2 as candidate NOEC values. The 75th percentile values, alternative candidate NOEC values, are listed in Table III-3.

Discussion and Summary

We see the approach described in this report as a valid and defensible means of estimating candidate NOEC values that would be subject to further investigation. However, the analysis reported here is based on a limited number of data records. Furthermore, each data record is supported by only one (2001-2009 data) or two (2010-2012 data) monitoring observations.

The probabilistic monitoring dataset was selected originally for the NOEC analysis because each data record included additional information that was seen as being of potential value. The prior study (AAC 2012a) attempted to make use of additional probabilistic monitoring data by applying more rigorous reference filters (see Table II-2 in AAC 2012a) and by exploring relationships of nutrient concentrations with benthic algal metrics (see Figure II-4 in AAC 2012a). The probabilistic monitoring database was selected for use in 2012 because it contains measurements that enabled such analyses. However, results of those analyses were not useful in NOEC development. Therefore, the current analysis makes use of data measurements that were available for a much larger segment of the VDEQ water-monitoring observation record. Hence, a similar analysis could be applied using pairings of general biological and water-monitoring data when both occur within similar time frames at specific monitoring locations.

Table III-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 (Mountains 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 III-2. Candidate NOEC values produced by the analysis described in this report using 90th percentiles of TN and TP distributions of Figure III-4.†

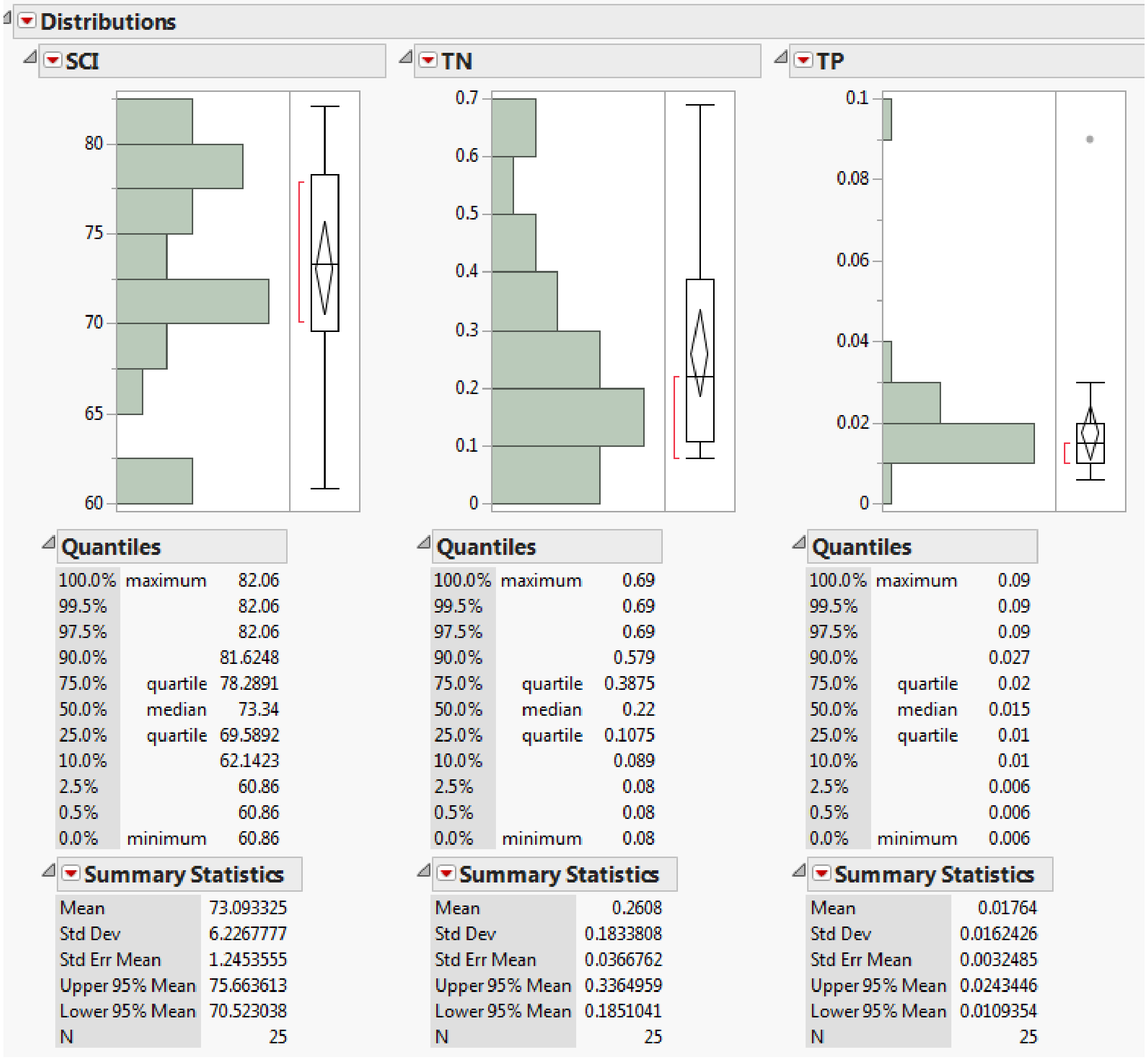
Ecoregion	TN (mg/L)	TP (mg/L)
Mountains	0.59	0.029
Piedmont	0.62	0.054

† Numbers of observations in reference distributions: 53 for Mountains, 25 for Piedmont (see Figure III-4).

Table III-3. Alternative candidate NOEC values produced by the analysis described in this report using 75th percentiles of TN and TP distributions of Figure III-4. †

Ecoregion	TN (mg/L)	TP (mg/L)
Mountains	0.39	0.020
Piedmont	0.54	0.045

† Numbers of observations in reference distributions: 53 for Mountains, 25 for Piedmont (see Figure III-4).



SCI

Quantiles

100.0%	maximum	82.06
99.5%		82.06
97.5%		82.06
90.0%		81.6248
75.0%	quartile	78.2891
50.0%	median	73.34
25.0%	quartile	69.5892
10.0%		62.1423
2.5%		60.86
0.5%		60.86
0.0%	minimum	60.86

Summary Statistics

Mean	73.093325
Std Dev	6.2267777
Std Err Mean	1.2453555
Upper 95% Mean	75.663613
Lower 95% Mean	70.523038
N	25

TN

Quantiles

100.0%	maximum	0.69
99.5%		0.69
97.5%		0.69
90.0%		0.579
75.0%	quartile	0.3875
50.0%	median	0.22
25.0%	quartile	0.1075
10.0%		0.089
2.5%		0.08
0.5%		0.08
0.0%	minimum	0.08

Summary Statistics

Mean	0.2608
Std Dev	0.1833808
Std Err Mean	0.0366762
Upper 95% Mean	0.3364959
Lower 95% Mean	0.1851041
N	25

TP

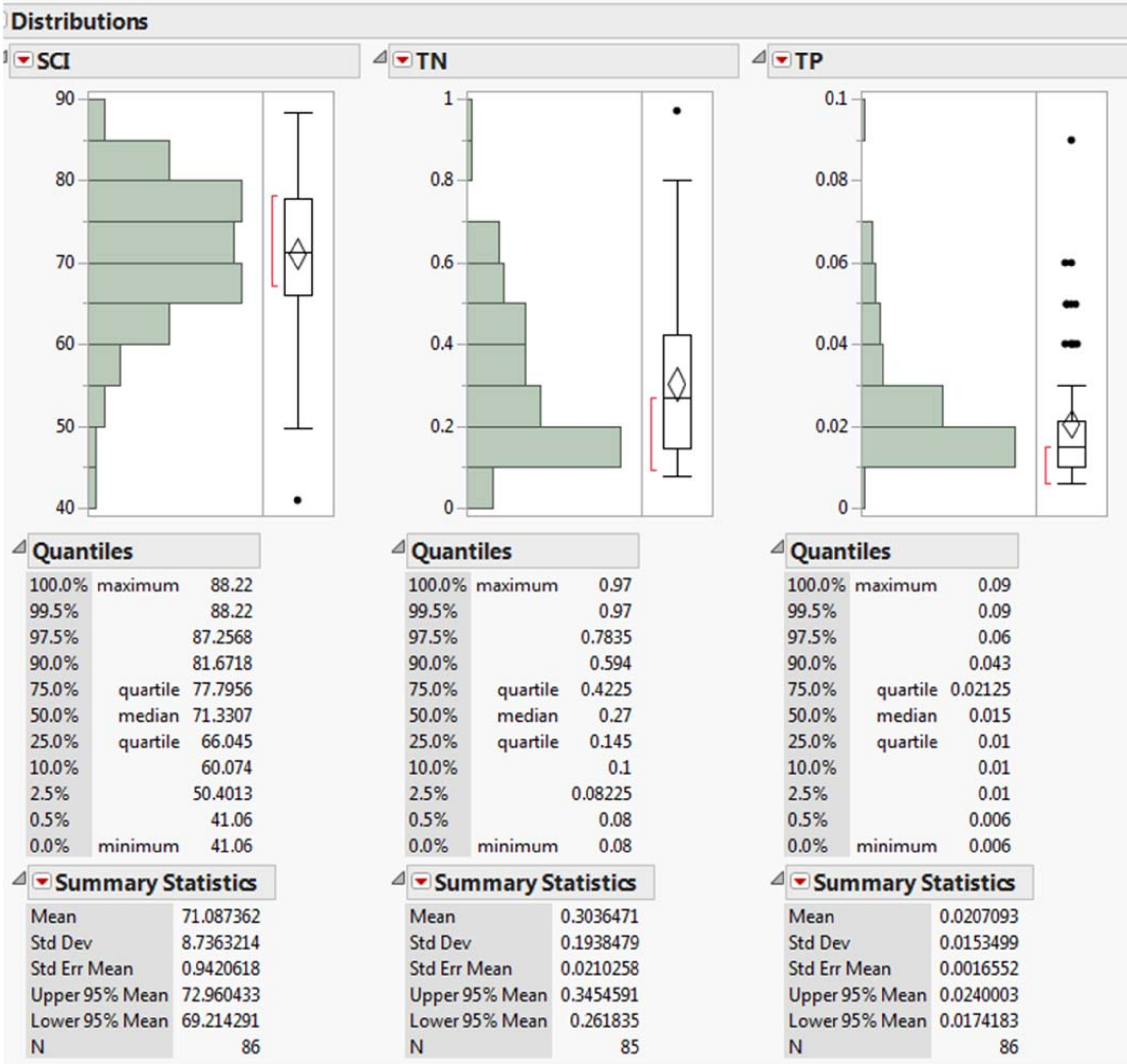
Quantiles

100.0%	maximum	0.09
99.5%		0.09
97.5%		0.09
90.0%		0.027
75.0%	quartile	0.02
50.0%	median	0.015
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.006
0.5%		0.006
0.0%	minimum	0.006

Summary Statistics

Mean	0.01764
Std Dev	0.0162426
Std Err Mean	0.0032485
Upper 95% Mean	0.0243446
Lower 95% Mean	0.0109354
N	25

Figure III-1. VSCI, TN, and TP distributions for nutrient-criteria reference data extracted from 2010, 2011, and 2012 probabilistic monitoring database.



SCI

Quantiles

100.0%	maximum	88.22
99.5%		88.22
97.5%		87.2568
90.0%		81.6718
75.0%	quartile	77.7956
50.0%	median	71.3307
25.0%	quartile	66.045
10.0%		60.074
2.5%		50.4013
0.5%		41.06
0.0%	minimum	41.06

Summary Statistics

Mean	71.087362
Std Dev	8.7363214
Std Err Mean	0.9420618
Upper 95% Mean	72.960433
Lower 95% Mean	69.214291
N	86

TN

Quantiles

100.0%	maximum	0.97
99.5%		0.97
97.5%		0.7835
90.0%		0.594
75.0%	quartile	0.4225
50.0%	median	0.27
25.0%	quartile	0.145
10.0%		0.1
2.5%		0.08225
0.5%		0.08
0.0%	minimum	0.08

Summary Statistics

Mean	0.3036471
Std Dev	0.1938479
Std Err Mean	0.0210258
Upper 95% Mean	0.3454591
Lower 95% Mean	0.261835
N	85

TP

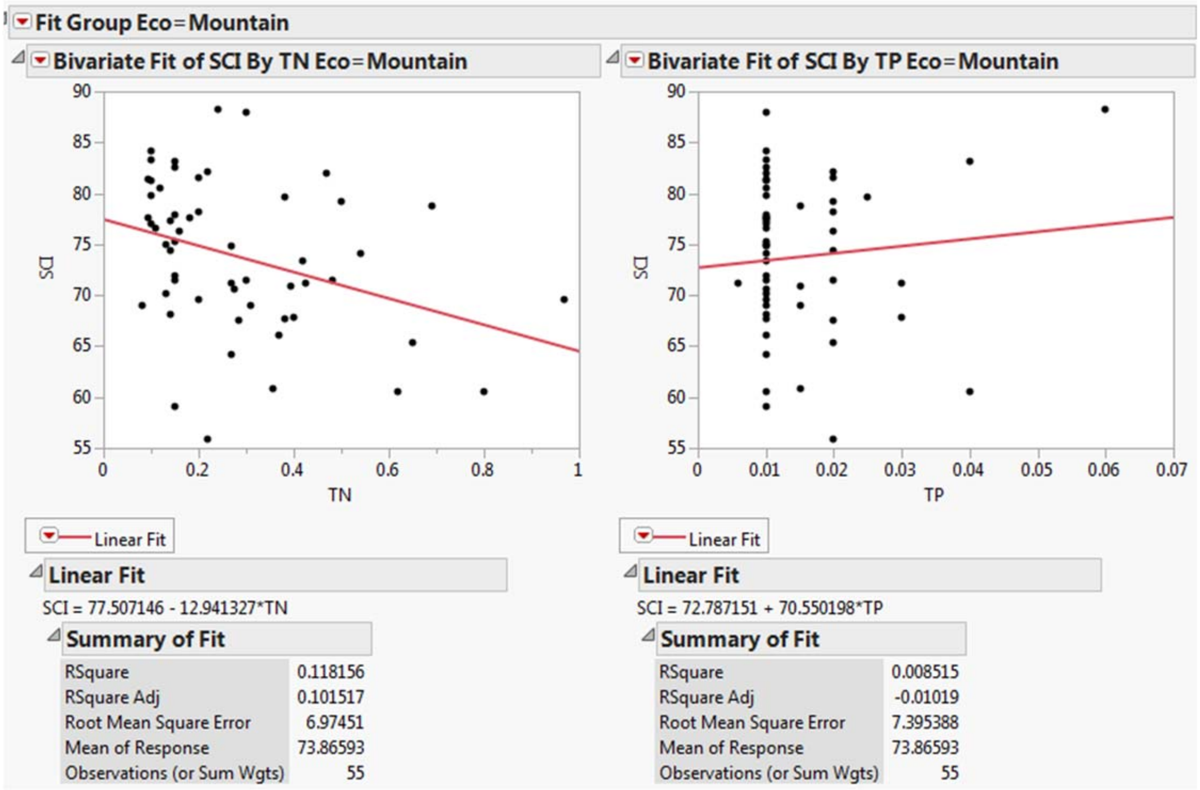
Quantiles

100.0%	maximum	0.09
99.5%		0.09
97.5%		0.06
90.0%		0.043
75.0%	quartile	0.02125
50.0%	median	0.015
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.01
0.5%		0.006
0.0%	minimum	0.006

Summary Statistics

Mean	0.0207093
Std Dev	0.0153499
Std Err Mean	0.0016552
Upper 95% Mean	0.0240003
Lower 95% Mean	0.0174183
N	86

Figure III-2. VSCI, TN, and TP distributions for nutrient-criteria reference data created by combining the AAC (2012a) references with those represented by Figure III-1.



Fit Group Eco=Mountain

Bivariate Fit of SCI By TN Eco=Mountain

Linear Fit

SCI = 77.507146 - 12.941327*TN

Summary of Fit

RSquare	0.118156
RSquare Adj	0.101517
Root Mean Square Error	6.97451
Mean of Response	73.86593
Observations (or Sum Wgts)	55

Bivariate Fit of SCI By TP Eco=Mountain

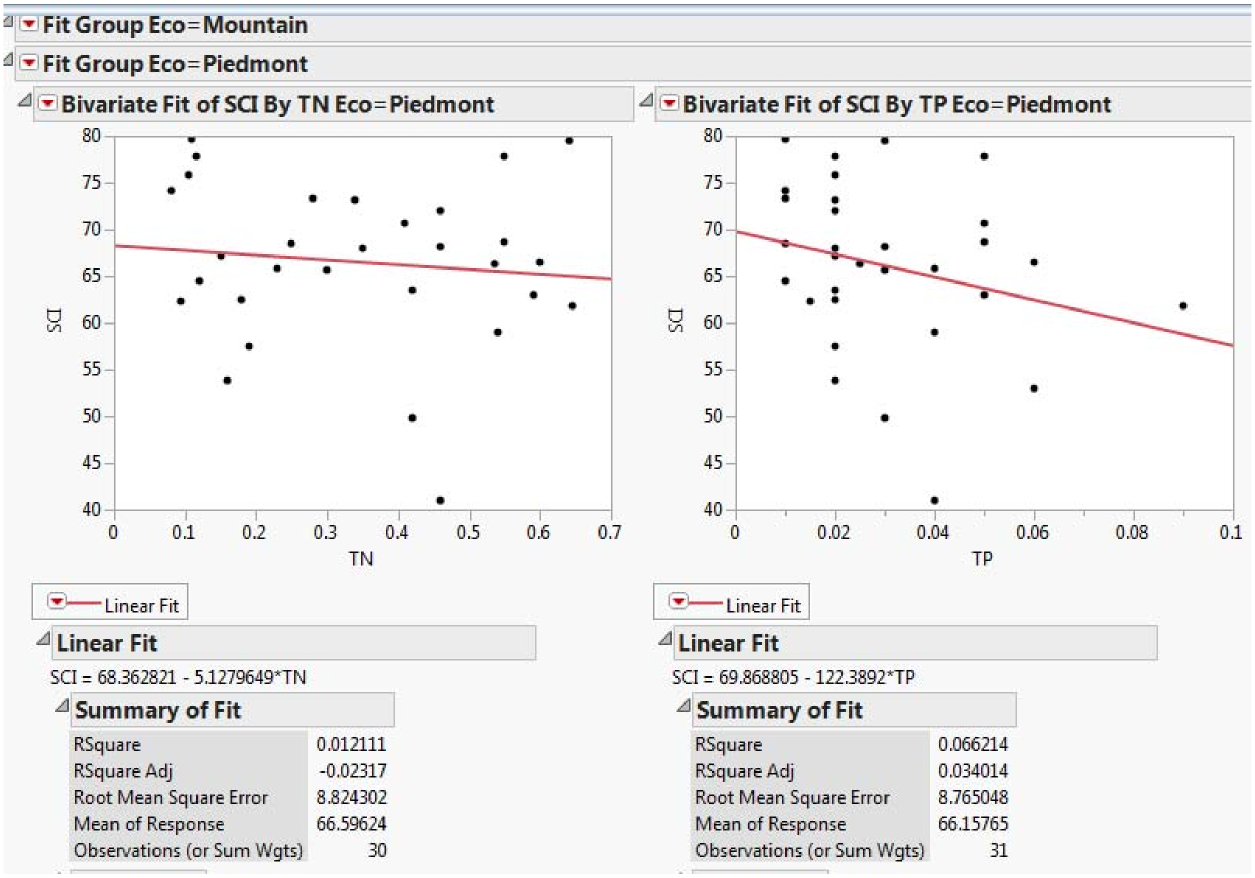
Linear Fit

SCI = 72.787151 + 70.550198*TP

Summary of Fit

RSquare	0.008515
RSquare Adj	-0.01019
Root Mean Square Error	7.395388
Mean of Response	73.86593
Observations (or Sum Wgts)	55

Figure III-3a. Regressions of TN and TP concentrations (mg/L) against VSCI scores for the Mountains ecoregion. The TN regression (left) is statistically significant ($p<0.05$) as shown, but the TP regression (right) is not. More rigorous statistical approaches would employ data transformations so as produce regressions that satisfy statistical assumptions, such as normalized residuals. Explorations of such approaches failed to yield VSCI = 60 intercepts within the range of nutrient-criteria reference TN and TP values.



Fit Group Eco=Mountain

Fit Group Eco=Piedmont

Bivariate Fit of SCI By TN Eco=Piedmont

Linear Fit

SCI = 68.362821 - 5.1279649*TN

Summary of Fit

RSquare	0.012111
RSquare Adj	-0.02317
Root Mean Square Error	8.824302
Mean of Response	66.59624
Observations (or Sum Wgts)	30

Bivariate Fit of SCI By TP Eco=Piedmont

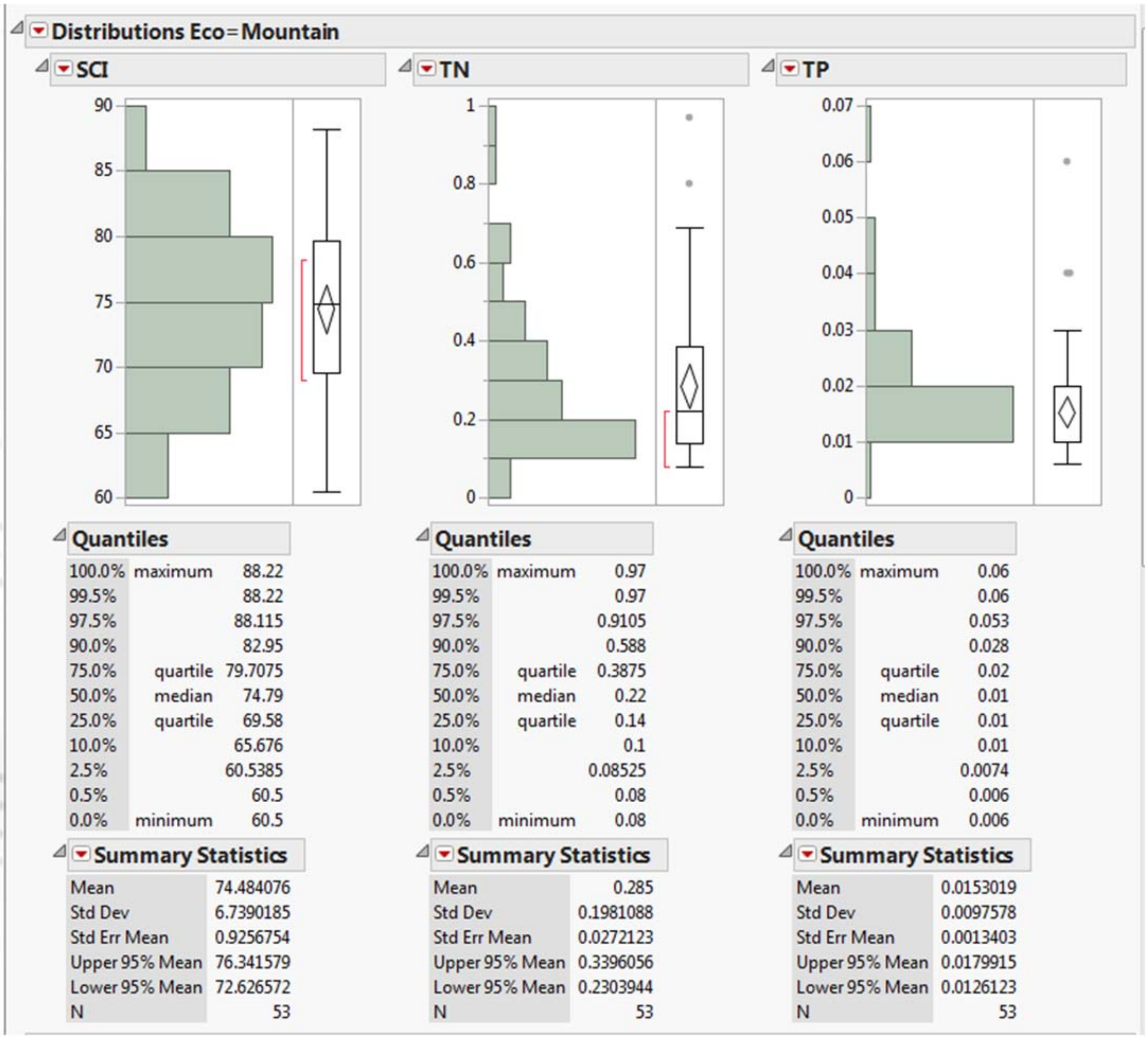
Linear Fit

SCI = 69.868805 - 122.3892*TP

Summary of Fit

RSquare	0.066214
RSquare Adj	0.034014
Root Mean Square Error	8.765048
Mean of Response	66.15765
Observations (or Sum Wgts)	31

Figure III-3b. Regressions of TN and TP concentrations (mg/L) against VSCI scores for the Piedmont ecoregion. Neither regression is statistically significant (p<0.05) as shown. Note that one of the data records is missing a TN value.



Distributions Eco=Mountain

SCI

Quantiles

100.0%	maximum	88.22
99.5%		88.22
97.5%		88.115
90.0%		82.95
75.0%	quartile	79.7075
50.0%	median	74.79
25.0%	quartile	69.58
10.0%		65.676
2.5%		60.5385
0.5%		60.5
0.0%	minimum	60.5

Summary Statistics

Mean	74.484076
Std Dev	6.7390185
Std Err Mean	0.9256754
Upper 95% Mean	76.341579
Lower 95% Mean	72.626572
N	53

TN

Quantiles

100.0%	maximum	0.97
99.5%		0.97
97.5%		0.9105
90.0%		0.588
75.0%	quartile	0.3875
50.0%	median	0.22
25.0%	quartile	0.14
10.0%		0.1
2.5%		0.08525
0.5%		0.08
0.0%	minimum	0.08

Summary Statistics

Mean	0.285
Std Dev	0.1981088
Std Err Mean	0.0272123
Upper 95% Mean	0.3396056
Lower 95% Mean	0.2303944
N	53

TP

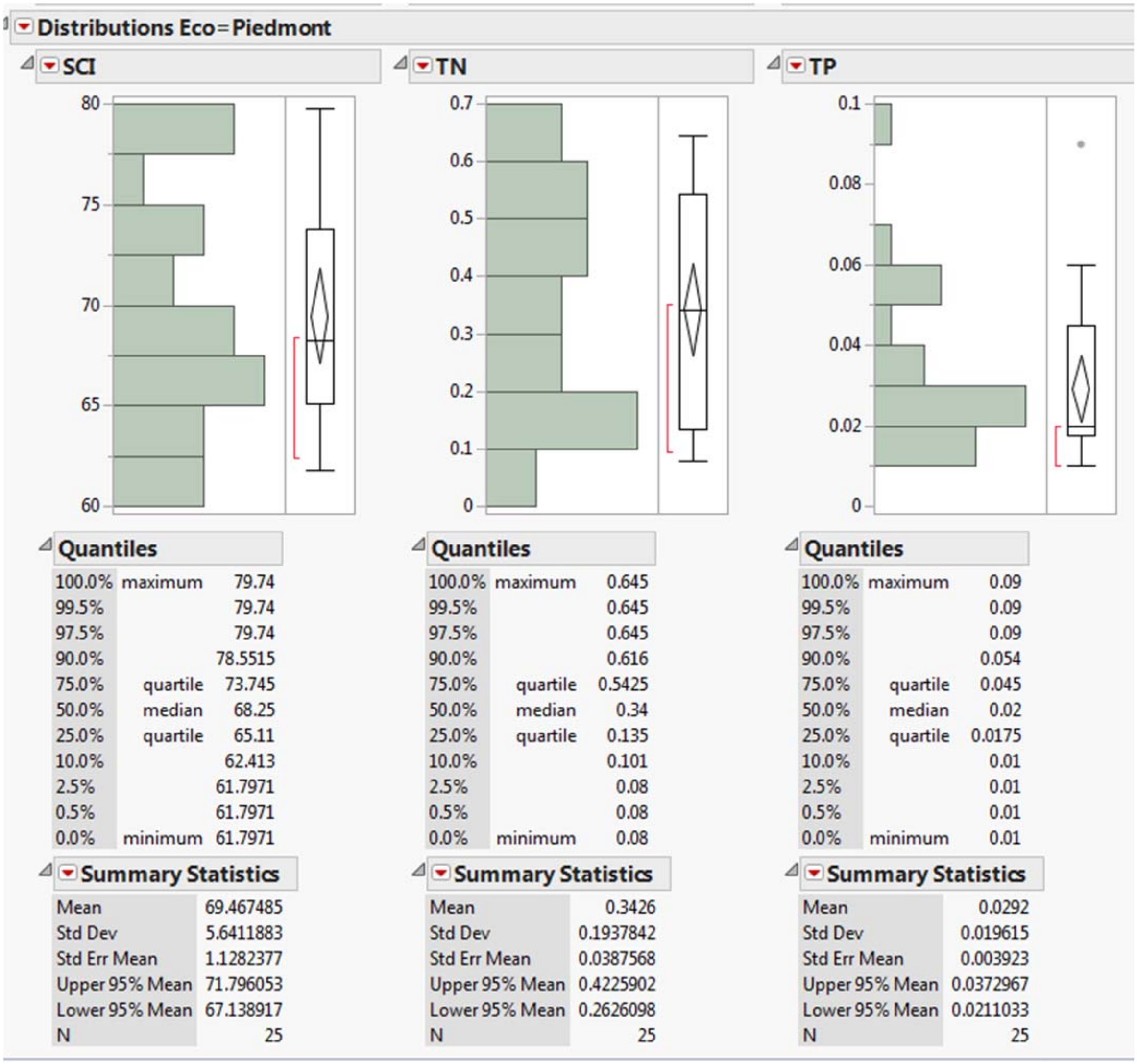
Quantiles

100.0%	maximum	0.06
99.5%		0.06
97.5%		0.053
90.0%		0.028
75.0%	quartile	0.02
50.0%	median	0.01
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.0074
0.5%		0.006
0.0%	minimum	0.006

Summary Statistics

Mean	0.0153019
Std Dev	0.0097578
Std Err Mean	0.0013403
Upper 95% Mean	0.0179915
Lower 95% Mean	0.0126123
N	53

Figure III-4a. Nutrient-criteria reference distributions of VSCI, TN, and TP for the Mountains ecoregion after two VSCI<60 data records were removed.



Distributions Eco=Piedmont

SCI

Quantiles

100.0%	maximum	79.74
99.5%		79.74
97.5%		79.74
90.0%		78.5515
75.0%	quartile	73.745
50.0%	median	68.25
25.0%	quartile	65.11
10.0%		62.413
2.5%		61.7971
0.5%		61.7971
0.0%	minimum	61.7971

Summary Statistics

Mean	69.467485
Std Dev	5.6411883
Std Err Mean	1.1282377
Upper 95% Mean	71.796053
Lower 95% Mean	67.138917
N	25

TN

Quantiles

100.0%	maximum	0.645
99.5%		0.645
97.5%		0.645
90.0%		0.616
75.0%	quartile	0.5425
50.0%	median	0.34
25.0%	quartile	0.135
10.0%		0.101
2.5%		0.08
0.5%		0.08
0.0%	minimum	0.08

Summary Statistics

Mean	0.3426
Std Dev	0.1937842
Std Err Mean	0.0387568
Upper 95% Mean	0.4225902
Lower 95% Mean	0.2626098
N	25

TP

Quantiles

100.0%	maximum	0.09
99.5%		0.09
97.5%		0.09
90.0%		0.054
75.0%	quartile	0.045
50.0%	median	0.02
25.0%	quartile	0.0175
10.0%		0.01
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.01

Summary Statistics

Mean	0.0292
Std Dev	0.019615
Std Err Mean	0.003923
Upper 95% Mean	0.0372967
Lower 95% Mean	0.0211033
N	25

Figure III-4b. Nutrient-criteria reference distributions of VSCI, TN, and TP for the Piedmont ecoregion after six VSCI<60 data records were removed.

IV. Development of No-Observed-Effect Concentrations – Full Database

The OEC analysis (Section II) developed a database comprised of TN, TP, and VSCI data from VDEQ water-monitoring sites in the Mountains and Piedmont ecoregions for two six-year water-quality assessment periods (2003-2008 and 2009-2014). The NOEC probabilistic monitoring analysis (Section III) identified what we refer to as "reference sites" within the probabilistic monitoring dataset, and attempted to derive NOECs from those data by analyzing the relationships between VSCI scores and nutrient concentrations. In Section III, we concluded that it would be possible to apply similar analyses using the complete water-monitoring database. In this section, we apply the analyses described in Section III to the water-monitoring database described in Section II for the purpose of further exploring the development of NOECs.

Methods

The database used for this analysis consisted of joined VSCI (with habitat) and water-quality data described in Section II of this report.

We defined reference station/periods using procedures similar but not identical to those described in Section III of this report. Because GIS data were not available for the majority of monitoring stations, the reference filter based on the percent of urban land was not applied. When multiple observations were available for a given station/period, the dissolved oxygen, pH, and specific conductance reference filters were applied to minimum and/or maximum recorded values as appropriate; i.e., if a single observation for these parameters violated the reference filter, that station/period was defined as "non-reference." The habitat filters were applied with less stringency. For station/periods with five or more habitat evaluations, ≥ 80% of all observations were required to comply with each filter. For station/periods with fewer than five habitat evaluations, 100% compliance was required. Unlike the procedure described in Section III, we did not request best professional judgement by regional biologists as a means of aiding reference designations. Therefore, we made reference designations simply on the basis of the water-monitoring and habitat-evaluation data.

We attempted to develop potential NOECs using procedures similar to those described in Section III: We defined reference sites by ecoregion, evaluated the relationships between VSCI scores and nutrient concentrations for these sites, and defined NOECs as the 90th percentiles of reference sites receiving the H-not impaired classification. For this latter operation, we used results of the H-assessments described in Section II. The term "H-not impaired" indicates station/periods not classified as H-impaired and not classified as H-indeterminate using the methods described in Section II.

For some analyses, we used both median concentrations and TPR concentrations for TN and TP as derived in Section II. We conducted the median analyses for both the entire dataset and for the subset with ≥10 observations. We focused on the station/periods with ≥10 observations because TPR concentrations were derived only for station/periods with ≥10 observations and because VDEQ assessments include sites with ≥10 observations during an actual assessment.

Because we have not analyzed VDEQ's water-monitoring dataset using these techniques previously, we compared certain categories of observations statistically. Statistical comparisons of mean water-quality values were performed using non-parametric Wilcoxon procedures, and mean VSCI comparisons were performed using standard ANOVA (analysis of variance).

Results

A total of 495 station/periods in the Mountains ecoregion were found to have data suitable for use in the analyses, and 591 station/periods were found similarly in the Piedmont (Table IV-1). A small number of station/periods had only TN or TP water-quality data. Less than half of total station/periods had ≥10 observations. Less than a third of all Mountains station/periods and less than a fourth of all Piedmont station/periods were classified as reference. The subsets with ≥10 observations had an even smaller fraction of reference classifications. The reference vs. non-reference classification was successful, as the station/periods classified as reference had lower TN and TP concentrations and higher mean VSCI scores than those that failed to satisfy the reference filters (Table IV-1).

Attempts to identify potential NOECs by defining nutrient concentration vs. VSCI relationships within reference subsets of available data were not successful. Although several of the data segments yielded linear regressions that were nominally statistically significant, were downward sloping, and intersected VSCI=60 within the range of available data (TN medians for all data in both ecoregions, and TN medians for the ≥10 observations subset in the Piedmont), these regressions were performed with datasets that exhibited skewed distributions, and the regressions failed to yield residuals with normal distributions. Application of log-transformations as required to produce residuals with normal-appearing distributions produced regressions that either failed to intersect VSCI=60 or produced intersections beyond the range of measured data (regressions not shown).

Hence, 90th percentile values for TN and TP medians and TPR concentrations for H-not impaired station/periods were calculated (Table IV-2) and were examined as candidate NOECs. The 75th percentiles are also reported for the H-not impaired station/periods (Table IV-3). Selected distributions are displayed as Figures IV-1 through IV-4. In addition, median distributions for all data are reported in Appendix B, and median distributions for ≥10-observation data segments are reported in Appendix C. Distributions of TPR values for TN and TP are provided in Appendix D.

Discussion and Summary

All of the data used to calculate the 90th-percentile values of Table IV-2 are from H-not-impaired station/periods, meaning that station/periods receiving hypothetical assessments as “H-impaired” or “H-indeterminate” were excluded from these analyses. In all cases, the 90th-percentiles of TN and TP data calculated for the entire H-not-impaired segment of the dataset were higher than the corresponding values calculated for reference sites only, and in some cases, they were much higher. Reasons why these results occurred are not clear. However, the mean VSCI scores for the reference station/periods are significantly higher than are those from the non-reference station/periods, both overall (Table IV-1) and at the subset of station/periods that were used to calculate the 90th-percentile nutrient concentrations (potential NOECs; Table IV-4).

The candidate-NOEC values based on the 90th-percentiles of the reference sites yielded by this exercise are of similar magnitudes to those yielded by the probabilistic monitoring NOEC analysis. This analysis is more robust than that based on the probabilistic monitoring data because of the larger numbers of observations. Although the subsets of data with ≥10 observations are generally small, the resulting 90th-percentile values of these medians are similar to those calculated using all data, which had much larger numbers of observations. The 90th-percentile TPR values are higher than the corresponding values calculated for the medians. Possible reasons for this trend are provided in Section II (e.g., random factors such as differences in streamflows, seasonality, etc.). We do not consider the 90th-percentile TPR to be especially robust, given the small numbers of stations/periods at reference sites and the variability of TPR relationships to median and average concentration values (Figures II-4 through II-8). As with prior analyses, we are also reporting 75th percentiles (Table IV-3).

The subset of reference sites classified as H-not impaired is comprised of high-quality monitoring sites. In addition to satisfying most of the VDEQ reference filter criteria (Table III-1), most are characterized by site-mean VSCI scores well above 60 (Figure IV-5).

Table IV-1. Mean values of median and TPR nutrient concentrations (TN, TP) and station/period mean VSCI scores for all station/periods, and reference vs. non-reference comparisons, for the Mountains and Piedmont ecoregions.

Ecoregion	Measure	Obs	-- All --		-- Reference --		-- Non-Reference -	
			n	Mean	n	Mean	n	Mean
- - - Total Nitrogen (mg/L) - - -								
Mountains	Median	all	493	0.82	133	0.34*	360	1.00
Mountains	Median	≥10	204	0.94	35	0.27*	169	1.08
Mountains	TPR	≥10	204	1.36	35	0.42*	169	1.56
Piedmont	Median	all	586	0.85	128	0.45*	458	0.96
Piedmont	Median	≥10	203	1.05	23	0.42*	180	1.14
Piedmont	TPR	≥10	203	1.84	23	0.70*	180	1.98
- - - Total Phosphorous (mg/L) - - -								
Mountains	Median	all	490	0.032	132	0.018*	358	0.037
Mountains	Median	≥10	206	0.034	34	0.017*	172	0.038
Mountains	TPR	≥10	206	0.081	34	0.031*	172	0.091
Piedmont	Median	all	585	0.047	129	0.035*	456	0.050
Piedmont	Median	≥10	216	0.047	23	0.032†	193	0.049
Piedmont	TPR	≥10	216	0.122	23	0.065†	193	0.129
- - - VSCI (Station/Period means) - - -								
Mountains	Mean	all	495	62.5	133	71.2*	362	59.3
Mountains	Mean	≥10	208	60.4	35	70.9*	173	58.3
Piedmont	Mean	all	591	56.5	131	65.0*	460	54.1
Piedmont	Mean	≥10	215	55.9	23	67.3*	192	54.5

* designates reference-site mean values that are significantly different from non-reference site mean values a $p<0.05$; and † designates $0.05<p<0.10$ differences.

Table IV-2. 90th percentile TN and TP concentrations for all station/periods and reference sites that were H-assessed as "not impaired." †

Ecoregion	Measure	Obs	All H-Not Impaired n	All H-Not Impaired 90th %tile	Ref H-Not Impaired n	Ref H-Not Impaired 90th %tile
			- - - - - - Total N (mg/L) - - - - - -			
Mountains	Median	All	280	1.38	111	0.49
Mountains	Median	≥10	101	1.69	30	0.39
Mountains	TPR	≥10	101	2.48	30	0.66
Piedmont	Median	All	224	0.92	87	0.73
Piedmont	Median	≥10	72	1.04	19	0.69
Piedmont	TPR	≥10	72	1.67	19	0.88
			- - - - - - Total P (mg/L) - - - - - -			
Mountains	Median	All	277	0.04	110	0.035
Mountains	Median	≥10	103	0.56	29	0.03
Mountains	TPR	≥10	103	0.13	29	0.06
Piedmont	Median	All	222	0.060	87	0.05
Piedmont	Median	≥10	76	0.06	19	0.055
Piedmont	TPR	≥10	76	0.16	19	0.12

† Values are rounded to 2 significant figures, unless third digit is a "5".

Table IV-3. 75th percentile TN and TP concentrations for all station/periods and reference sites that were H-assessed as "not impaired." [†]

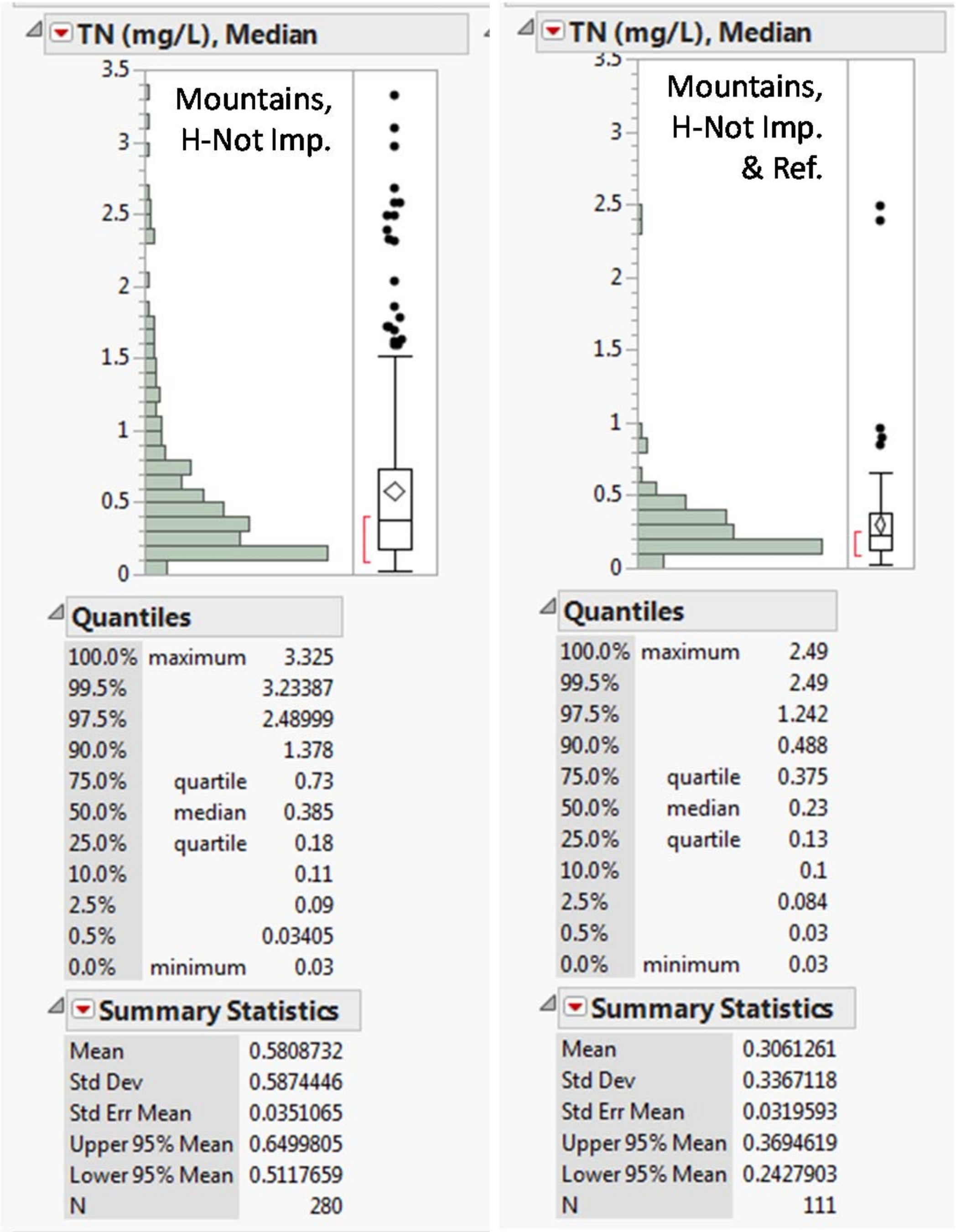
			All H-Not Impaired		Ref H-Not Impaired	
Ecoregion	Measure	Obs	n	75th %tile	n	75th %tile
			- - - - - - Total N (mg/L) - - - - - -			
Mountains	Median	All	280	0.73	111	0.375
Mountains	Median	≥10	101	0.89	30	0.35
Mountains	TPR	≥10	101	1.22	30	0.54
Piedmont	Median	All	224	0.63	87	0.485
Piedmont	Median	≥10	72	0.77	19	0.445
Piedmont	TPR	≥10	72	1.10	19	0.69
			- - - - - - Total P (mg/L) - - - - - -			
Mountains	Median	All	277	0.025	110	0.02
Mountains	Median	≥10	103	0.03	29	0.02
Mountains	TPR	≥10	103	0.06	29	0.04
Piedmont	Median	All	222	0.04	87	0.04
Piedmont	Median	≥10	76	0.04	19	0.04
Piedmont	TPR	≥10	76	0.08	19	0.09

[†] Values are rounded to 2 significant figures, unless third digit is a "5".

Table IV-4. Mean VSCI scores calculated from H-not-impaired station/period means for reference and non-reference station/periods.

Ecoregion	Reference	Non-Reference
Mountains	74.4*	69.6
Piedmont	70.3*	68.1

* designates reference means that are significantly different from non-reference means, p<0.001.



TN (mg/L), Median — Mountains, H-Not Imp.

Quantiles

100.0%	maximum	3.325
99.5%		3.23387
97.5%		2.48999
90.0%		1.378
75.0%	quartile	0.73
50.0%	median	0.385
25.0%	quartile	0.18
10.0%		0.11
2.5%		0.09
0.5%		0.03405
0.0%	minimum	0.03

Summary Statistics

Mean	0.5808732
Std Dev	0.5874446
Std Err Mean	0.0351065
Upper 95% Mean	0.6499805
Lower 95% Mean	0.5117659
N	280

TN (mg/L), Median — Mountains, H-Not Imp. & Ref.

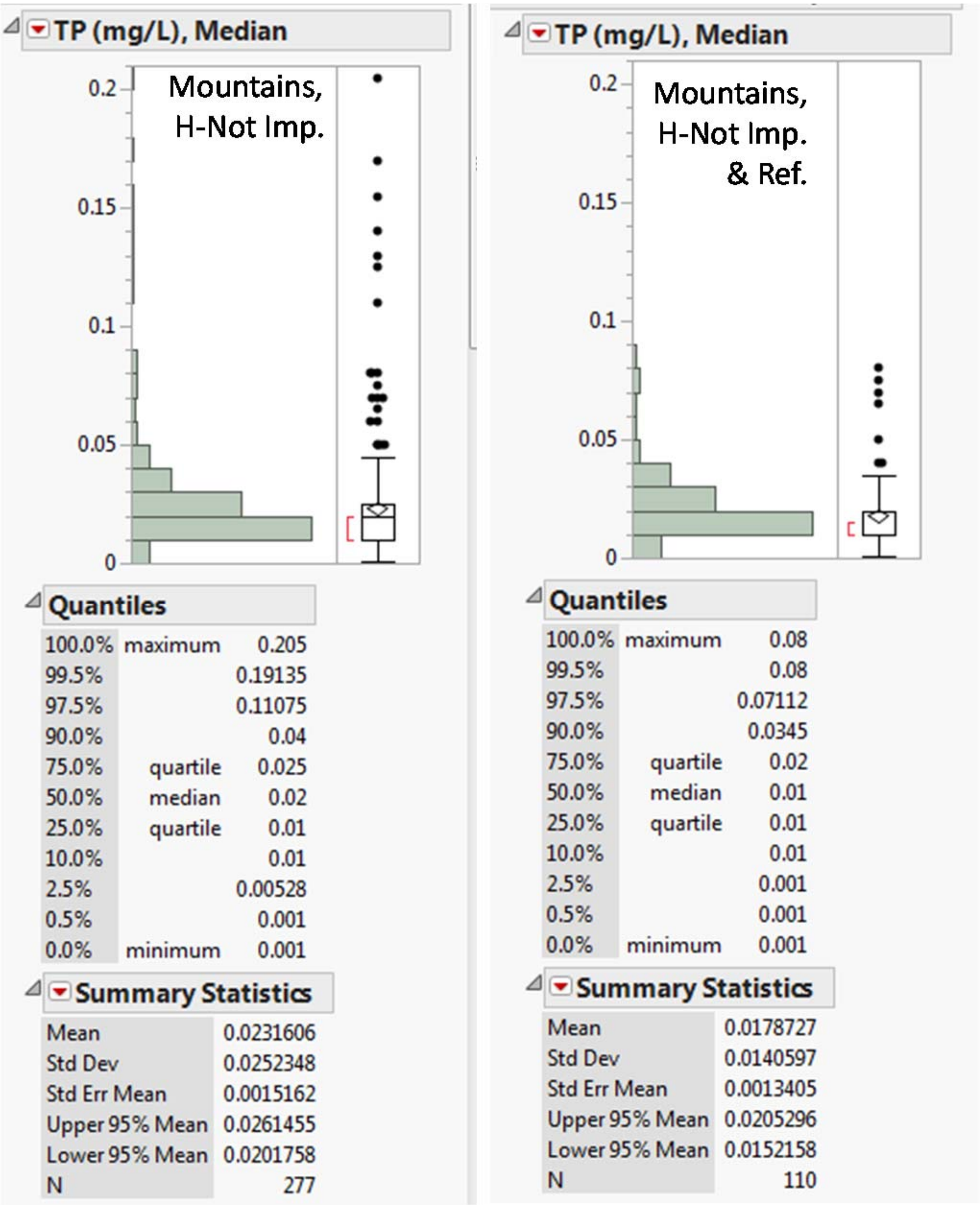
Quantiles

100.0%	maximum	2.49
99.5%		2.49
97.5%		1.242
90.0%		0.488
75.0%	quartile	0.375
50.0%	median	0.23
25.0%	quartile	0.13
10.0%		0.1
2.5%		0.084
0.5%		0.03
0.0%	minimum	0.03

Summary Statistics

Mean	0.3061261
Std Dev	0.3367118
Std Err Mean	0.0319593
Upper 95% Mean	0.3694619
Lower 95% Mean	0.2427903
N	111

Figure IV-1. Distributions of all TN median concentrations (mg/L) for H-not impaired station/periods in the Mountains ecoregion.



TP (mg/L), Median

Mountains, H-Not Imp.

Quantiles

100.0%	maximum	0.205
99.5%		0.19135
97.5%		0.11075
90.0%		0.04
75.0%	quartile	0.025
50.0%	median	0.02
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.00528
0.5%		0.001
0.0%	minimum	0.001

Summary Statistics

Mean	0.0231606
Std Dev	0.0252348
Std Err Mean	0.0015162
Upper 95% Mean	0.0261455
Lower 95% Mean	0.0201758
N	277

TP (mg/L), Median

Mountains, H-Not Imp. & Ref.

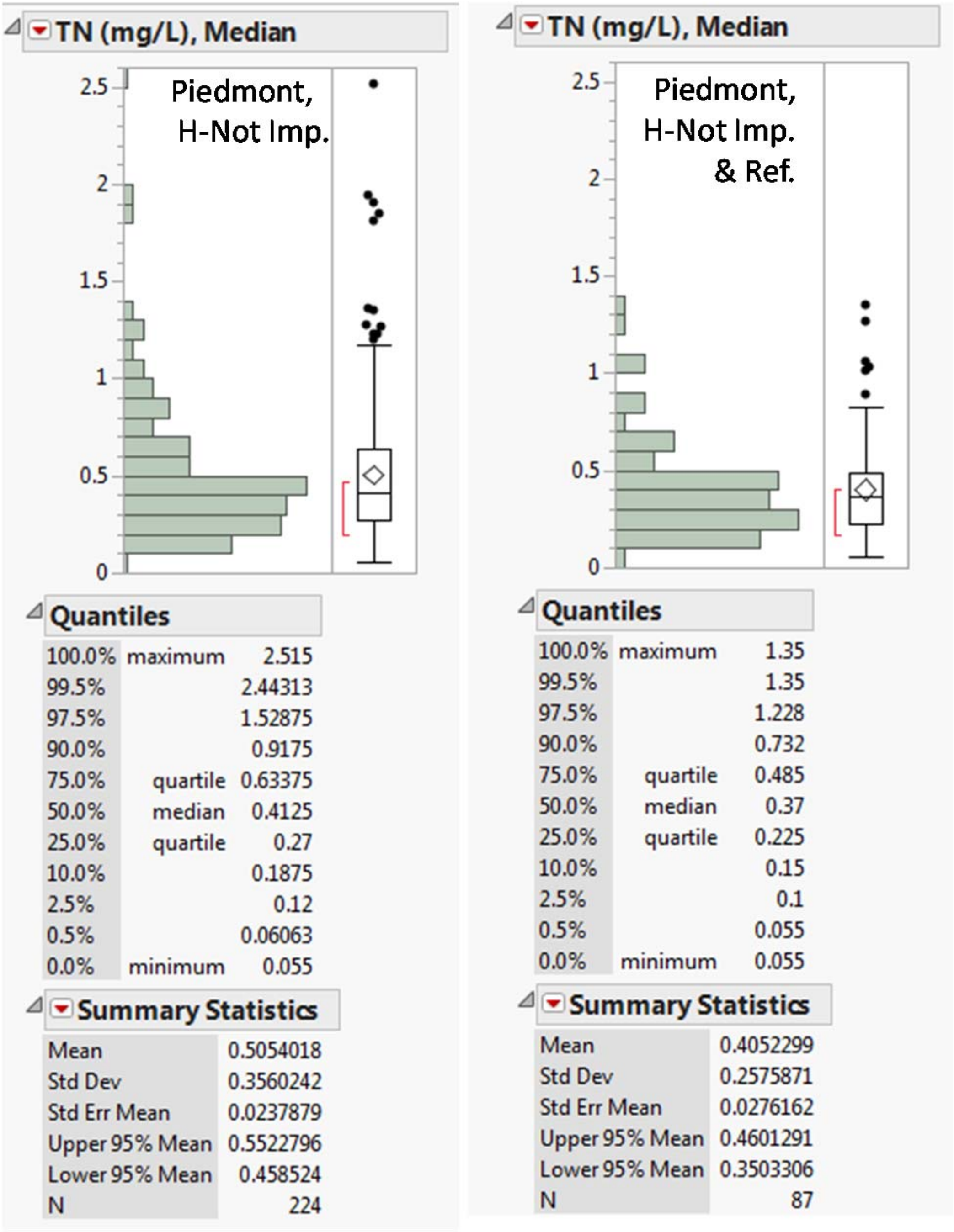
Quantiles

100.0%	maximum	0.08
99.5%		0.08
97.5%		0.07112
90.0%		0.0345
75.0%	quartile	0.02
50.0%	median	0.01
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.001
0.5%		0.001
0.0%	minimum	0.001

Summary Statistics

Mean	0.0178727
Std Dev	0.0140597
Std Err Mean	0.0013405
Upper 95% Mean	0.0205296
Lower 95% Mean	0.0152158
N	110

Figure IV-2. Distributions of all TP median concentrations (mg/L) for H-not impaired station/periods in the Mountains ecoregion.



TN (mg/L), Median — Piedmont, H-Not Imp.

Quantiles

100.0%	maximum	2.515
99.5%		2.44313
97.5%		1.52875
90.0%		0.9175
75.0%	quartile	0.63375
50.0%	median	0.4125
25.0%	quartile	0.27
10.0%		0.1875
2.5%		0.12
0.5%		0.06063
0.0%	minimum	0.055

Summary Statistics

Mean	0.5054018
Std Dev	0.3560242
Std Err Mean	0.0237879
Upper 95% Mean	0.5522796
Lower 95% Mean	0.458524
N	224

TN (mg/L), Median — Piedmont, H-Not Imp. & Ref.

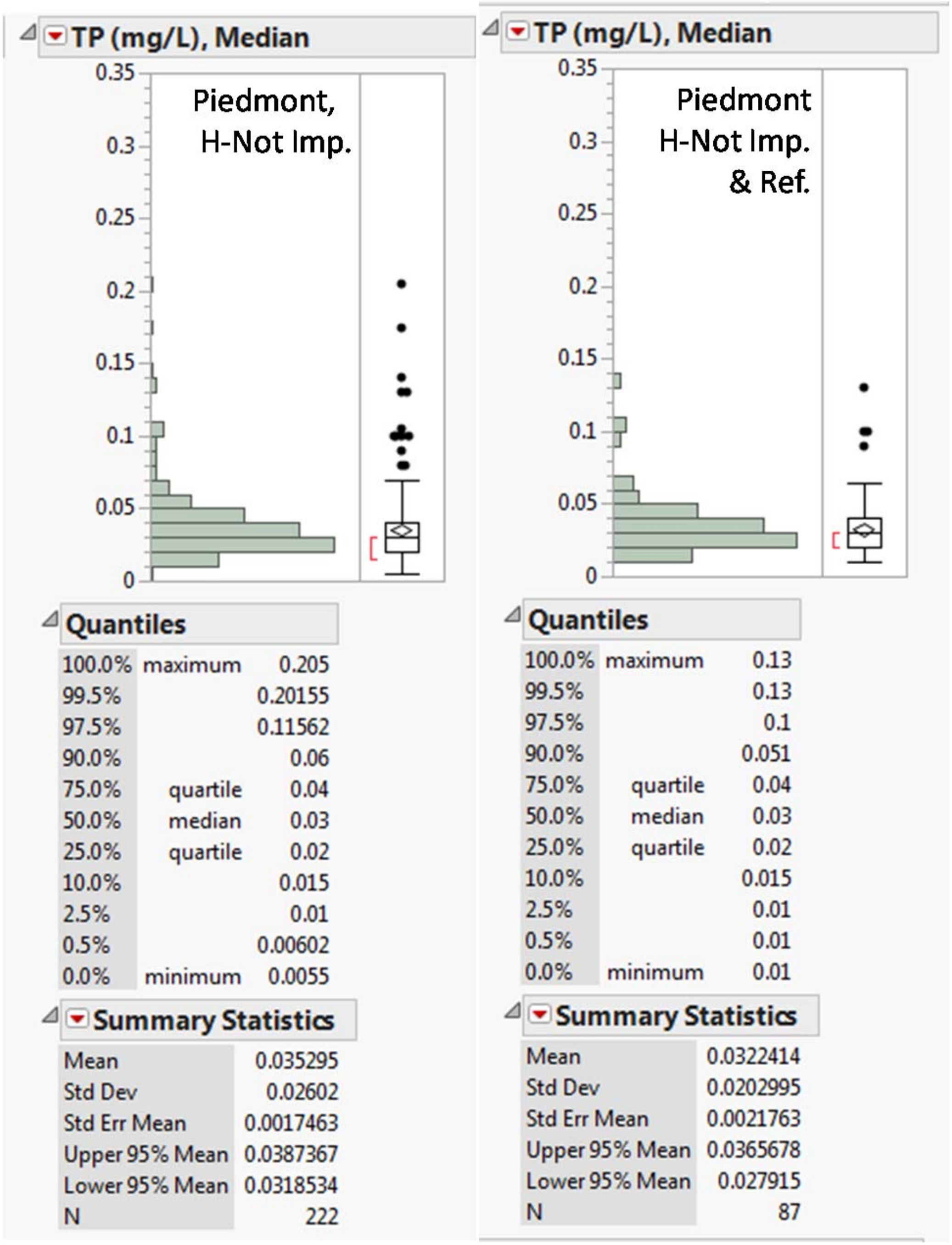
Quantiles

100.0%	maximum	1.35
99.5%		1.35
97.5%		1.228
90.0%		0.732
75.0%	quartile	0.485
50.0%	median	0.37
25.0%	quartile	0.225
10.0%		0.15
2.5%		0.1
0.5%		0.055
0.0%	minimum	0.055

Summary Statistics

Mean	0.4052299
Std Dev	0.2575871
Std Err Mean	0.0276162
Upper 95% Mean	0.4601291
Lower 95% Mean	0.3503306
N	87

Figure IV-3. Distributions of all TN median concentrations (mg/L) for H-not impaired station/periods in the Piedmont ecoregion.



Piedmont, H-Not Imp.

Quantiles

100.0%	maximum	0.205
99.5%		0.20155
97.5%		0.11562
90.0%		0.06
75.0%	quartile	0.04
50.0%	median	0.03
25.0%	quartile	0.02
10.0%		0.015
2.5%		0.01
0.5%		0.00602
0.0%	minimum	0.0055

Summary Statistics

Mean	0.035295
Std Dev	0.02602
Std Err Mean	0.0017463
Upper 95% Mean	0.0387367
Lower 95% Mean	0.0318534
N	222

Piedmont H-Not Imp. & Ref.

Quantiles

100.0%	maximum	0.13
99.5%		0.13
97.5%		0.1
90.0%		0.051
75.0%	quartile	0.04
50.0%	median	0.03
25.0%	quartile	0.02
10.0%		0.015
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.01

Summary Statistics

Mean	0.0322414
Std Dev	0.0202995
Std Err Mean	0.0021763
Upper 95% Mean	0.0365678
Lower 95% Mean	0.027915
N	87

Figure IV-4. Distributions of all TP median concentrations (mg/L) for H-not impaired station/periods in the Piedmont ecoregion.

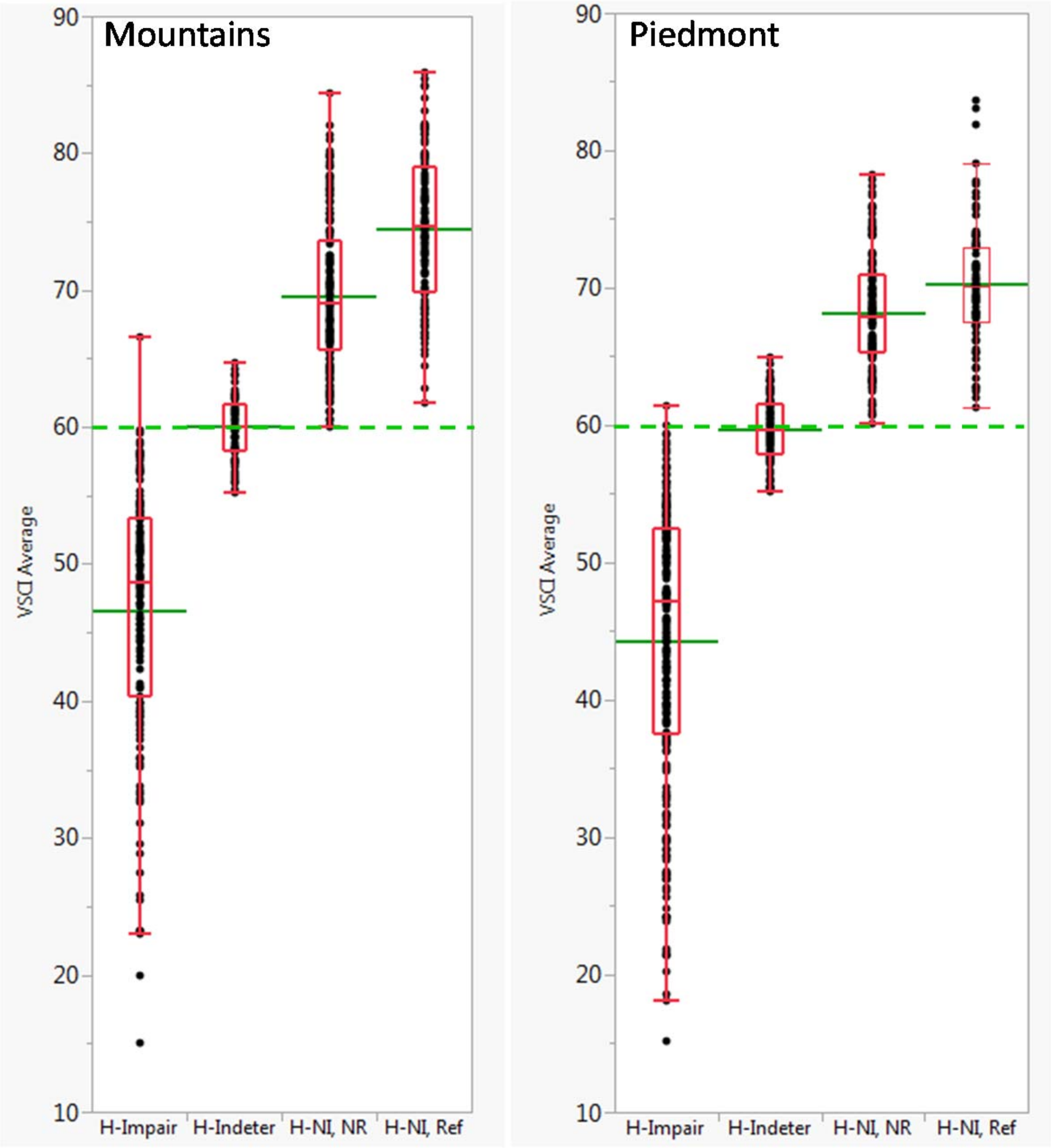


Figure IV-5. Station/period mean VSCI scores for the three H-assessment classes by ecoregion and with the H-not-impaired class disaggregated by reference status. The boxes represent the 25th, 50th, and 75th percentiles. The horizontal lines for each box plot represent the mean value. The dashed horizontal lines represent the VSCI = 60 impairment threshold that is applied to individual VSCI measurements.

Conclusions

The application of conditional probability analysis with the intention of estimating potential OECs did not yield useful results, but the efforts to estimate NOECs from reference datasets was more successful.

We interpret the potential NOECs generated from the full dataset to be more robust than those developed from the probabilistic monitoring dataset for two reasons: (1) The full dataset includes a larger number of aggregated observations (station/periods) than does the probabilistic monitoring dataset; and (2) most of the full dataset's aggregated observations are based on a larger number of water-quality measurements than are those in the probabilistic monitoring dataset, which is populated by TN and TP values derived from only one or two water-quality measurements. Despite those differences, the two data analyses yielded potential NOECs of similar magnitudes.

Based on the results of these analyses and on AAC activities in prior years, we suggest that VDEQ evaluate the following series of actions as a possible way forward in developing a nutrient-criteria framework for wadeable freshwater rivers and streams that incorporates a screening approach:

1. Investigate alternative approaches to OEC development. For example, the analysis described in VDEQ (2016), once published in final form, is one such approach that may merit such consideration.
2. Consider adopting NOECs that are based on the full dataset's reference distributions.

We see NOEC values based on either the 90th or the 75th percentile of reference distributions to be scientifically defensible. The decision concerning which percentile to select is a policy decision, not a scientific decision. Either choice or an intermediate percentile would carry some risk of incorrect assessments.

Because of the nature of the TN and TP distributions in Virginia's waters, there is considerable spread between the 75th and 90th percentiles (i.e., comparison of values in Tables IV-2 vs. IV-3). An advantage of selecting the 90th percentile would be the increased feasibility that VDEQ would be able to implement nutrient criteria as a screening approach, even with the increased demand for biological assessments that would result. VDEQ implementation would be more likely if NOECs were defined based on the 90th percentile because the increased biological-assessment demand would be less with NOECs based on 90th percentiles, relative to criteria with NOECs based on 75th percentiles.

We would expect far fewer incorrect assessments to result from nutrient criteria implemented with a screening approach compared to those that would result from application of conventional single-threshold criteria. The presumed reduced risk of incorrect assessment occurs because benthic macroinvertebrate monitoring would be conducted in stream reaches with inconclusive nutrient assessments and with inconclusive visual assessments, if such were to be applied (AAC 2012a). Thus, the benthic macroinvertebrate assessment would become the basis for assessment for most stream reaches in which an assessment based solely on nutrient concentrations would have the greatest risk of being incorrect.

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Sincere thanks to Jason Hill for providing the updated probabilistic monitoring and EDAS databases, and for answering several questions. Sincere thanks to Dr. Tish Robertson for several phone conversations and for answering e-mail questions that concerned VDEQ water-quality assessment procedures. Sincere thanks to Roger Stewart for providing VDEQ water-monitoring data.

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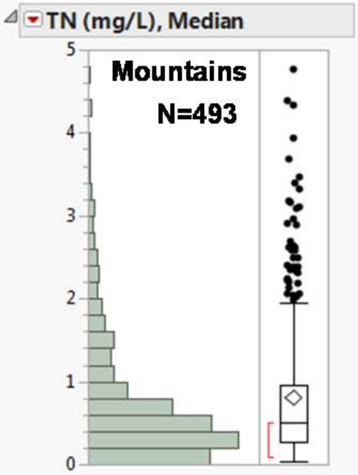
Appendix A: Nutrient-criteria Reference Dataset Developed in Section III

StationID	Year	Lat	Long	Season	Eco	VSCI	TN (mg/L)	TP (mg/L)
2-BNF003.52	2001	37.71877	-79.20181	Fall	Mtns	83.21	0.15	0.04
2-COO002.35	2001	37.51947	-78.52337	Fall	Pdmt	68.42	0.25	0.01
2-CWP023.28	2001	37.93828	-79.72109	Fall	Mtns	75.32	0.15	0.01
2-CWP053.78	2001	38.09981	-79.64977	Fall	Mtns	82.56	0.15	0.01
2-JOB001.02	2001	37.50300	-80.11505	Fall	Mtns	71.96	0.15	0.01
2-OGL005.53	2001	37.83987	-80.12246	Fall	Mtns	74.79	0.27	0.01
2-SMR004.80	2001	37.93492	-79.08797	Fall	Mtns	77.91	0.15	0.01
2-SUA001.55	2001	37.32956	-78.67655	Fall	Pdmt	68.60	0.55	0.05
4ASRV012.19	2001	36.64801	-79.55161	Fall	Pdmt	67.10	0.15	0.02
9-WFC010.66	2001	37.27888	-80.92542	Fall	Mtns	68.99	0.31	0.01
1BCDR010.21	2002	39.06128	-78.34596	Spring	Mtns	64.17	0.27	0.01
1BNFS102.55	2002	38.70317	-78.92056	Spring	Mtns	60.61	0.8	0.01
4ABEE001.20	2002	36.54342	-78.63229	Spring	Pdmt	41.06	0.46	0.04
6CSFH084.73	2002	36.69161	-81.77183	Spring	Mtns	60.50	0.62	0.04
2-XSB000.88	2003	37.72587	-79.56125	Spring	Mtns	67.87	0.4	0.03
4AHRN007.65	2003	36.66096	-80.01521	Spring	Pdmt	68.00	0.35	0.02
9-WLK026.82	2003	37.19857	-80.80576	Spring	Mtns	65.38	0.65	0.02
9-XDP000.65	2003	36.66652	-81.13315	Spring	Mtns	71.51	0.48	0.02
1AXJS001.20	2004	39.32431	-78.26570	Spring	Mtns	66.12	0.37	0.01
1BCDR027.54	2004	39.02172	-78.45979	Spring	Mtns	74.12	0.54	0.01
2-DCK003.94	2004	37.46334	-80.34827	Spring	Mtns	76.35	0.16	0.02
2-MIW003.45	2004	37.99656	-79.71186	Spring	Mtns	84.13	0.1	0.01
2-STV000.48	2004	37.62049	-80.18680	Spring	Mtns	79.80	0.1	0.01
2-WIC004.64	2004	37.47777	-78.88221	Spring	Pdmt	63.58	0.42	0.02
6BLSR004.78	2004	36.87209	-82.47342	Spring	Mtns	77.55	0.18	0.01
8-POR015.70	2004	38.20326	-77.63980	Spring	Pdmt	65.67	0.3	0.03
9-SFK002.81	2004	36.98483	-81.18752	Spring	Mtns	68.12	0.14	0.01
2-APP037.08	2005	37.28548	-77.72863	Spring	Pdmt	70.72	0.41	0.05
2-CSR003.94	2005	37.72799	-80.10520	Spring	Mtns	81.57	0.2	0.02
2-CWP006.87	2005	37.80957	-79.73910	Spring	Mtns	77.25	0.14	0.01
3-RPP150.20	2005	38.58206	-77.87496	Spring	Pdmt	79.57	0.64	0.03
4ACOX007.73	2005	36.72017	-78.25190	Spring	Pdmt	53.00		0.06
4AFSF004.02	2005	37.22043	-78.98518	Spring	Pdmt	62.44	0.18	0.02
8-NAR025.28	2005	37.94938	-77.61710	Spring	Pdmt	72.05	0.46	0.02
9-CPL009.78	2005	36.83265	-81.05106	Spring	Mtns	69.56	0.97	0.01
9-LFK005.39	2005	37.24309	-81.17130	Spring	Mtns	59.08	0.15	0.01
1AXLB001.49	2006	38.44479	-77.49889	Spring	Pdmt	68.25	0.46	0.03
2AXQS001.07	2006	37.71675	-79.77361	Spring	Mtns	83.32	0.1	0.01
2-BCC001.90	2006	38.04966	-79.90579	Spring	Mtns	73.41	0.42	0.01
4ACLB001.90	2006	36.58867	-78.91039	Spring	Pdmt	49.85	0.42	0.03
4AXNB000.60	2006	37.32821	-80.14344	Spring	Mtns	74.42	0.14	0.02
9-CPL012.73	2006	36.83618	-81.08703	Spring	Mtns	79.28	0.5	0.02

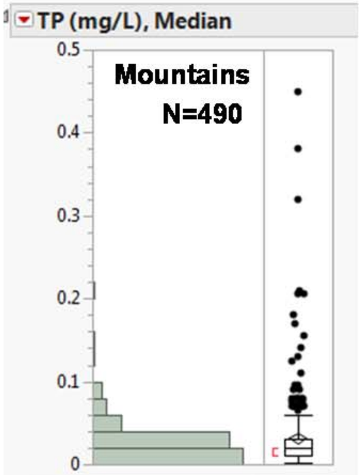
1BNTH046.56	2007	38.33238	-79.23751	Spring	Mtns	69.60	0.2	0.01
2-BVC003.09	2007	37.73594	-78.72230	Spring	Pdmt	73.12	0.34	0.02
4ACEC000.82	2007	36.99435	-79.53321	Spring	Pdmt	64.55	0.12	0.01
6CLAL001.79	2007	36.64236	-81.80495	Spring	Mtns	67.70	0.38	0.01
9-XEO000.57	2007	36.75187	-80.54190	Spring	Mtns	71.54	0.3	0.02
2-CWP042.31	2008	38.01378	-79.63621	Spring	Mtns	55.89	0.22	0.02
2-SWS000.90	2008	37.71363	-79.89366	Spring	Mtns	77.03	0.1	0.01
5ABTR000.76	2008	37.08638	-77.67635	Spring	Pdmt	66.54	0.6	0.06
8-POR024.64	2008	38.22926	-77.73251	Spring	Pdmt	65.82	0.23	0.04
8-SAR058.13	2008	37.87805	-77.90921	Spring	Pdmt	77.77	0.55	0.05
9-DPW002.31	2008	36.91659	-80.63063	Spring	Mtns	81.29	0.1	0.01
2DAPP015.51	2009	37.22422	-77.46174	Spring	Pdmt	59.02	0.54	0.04
2-HKY001.26	2009	37.92418	-80.03744	Spring	Mtns	87.92	0.3	0.01
2-TYE028.94	2009	37.79979	-79.00654	Spring	Pdmt	53.77	0.16	0.02
3-XGR000.95	2009	38.39059	-78.46591	Spring	Mtns	88.22	0.24	0.06
5ALTL001.38	2009	36.59803	-77.74101	Spring	Pdmt	57.50	0.19	0.02
6CLIB001.06	2009	36.95873	-81.47481	Spring	Mtns	78.19	0.2	0.02
8-RIG003.01	2009	38.21874	-77.94060	Spring	Pdmt	63.02	0.59	0.05
9-KNS002.44	2009	36.77292	-81.25101	Spring	Mtns	80.52	0.12	0.01
1BBRY005.09	2010	38.44218	-79.10192	S+F Avg	Mtns	71.24	0.27	0.006
2BXAC000.38	2010	37.58897	-78.75307	S+F Avg	Pdmt	62.37	0.095	0.015
2-CRG074.32	2010	37.33535	-80.32894	S+F Avg	Mtns	69.06	0.08	0.015
2-JKS076.16	2010	38.18453	-79.73117	S+F Avg	Mtns	67.54	0.285	0.02
2-PMC000.59	2010	37.78018	-79.96359	S+F Avg	Mtns	76.61	0.11	0.01
4ACEC001.24	2010	36.98819	-79.55127	S+F Avg	Pdmt	77.87	0.115	0.02
4AXNA001.18	2010	37.16825	-79.76720	S+F Avg	Pdmt	61.80	0.645	0.09
6CSFH082.78	2010	36.67808	-81.79000	S+F Avg	Mtns	78.71	0.69	0.015
6CSFH099.18	2010	36.77460	-81.60880	S+F Avg	Mtns	81.91	0.47	0.01
9-SFK003.38	2010	36.99069	-81.19332	S+F Avg	Mtns	70.11	0.13	0.01
9-SNC008.04	2010	37.41741	-80.60808	S+F Avg	Mtns	77.66	0.095	0.01
1BBGR004.08	2011	38.29140	-78.69940	S+F Avg	Mtns	75.01	0.13	0.01
2-CRG047.95	2011	37.51120	-80.08760	S+F Avg	Mtns	70.59	0.275	0.01
2-DCK003.94b	2011	37.46347	-80.34805	S+F Avg	Mtns	71.42	0.15	0.01
2-DDY000.75b	2011	38.17732	-79.37611	S+F Avg	Mtns	81.44	0.095	0.01
2-RED003.65b	2011	37.50908	-79.38327	S+F Avg	Pdmt	66.28	0.535	0.025
6CLAL000.19	2011	36.64940	-81.82940	S+F Avg	Mtns	70.83	0.395	0.015
9-ECM001.01	2011	36.71690	-81.27070	S+F Avg	Mtns	71.22	0.425	0.03
9-WLK033.29	2011	37.16270	-80.85490	S+F Avg	Mtns	60.86	0.355	0.015
1aXMJ000.42	2012	38.63750	-77.50550	S+F Avg	Pdmt	75.92	0.105	0.02
2BLIR007.16	2012	37.76450	-79.16440	S+F Avg	Mtns	82.06	0.22	0.02
2BXRK001.64	2012	37.81140	-78.72990	S+F Avg	Pdmt	73.34	0.28	0.01
4ASRE063.69	2012	36.84360	-80.16170	S+F Avg	Pdmt	79.74	0.11	0.01
4AXOE001.26	2012	36.64800	-80.38120	S+F Avg	Mtns	79.62	0.38	0.025
4AXOF001.26	2012	36.80200	-79.70090	S+F Avg	Pdmt	74.15	0.08	0.01

Appendix B: Distributions of Median Values for All Station-periods Analyzed



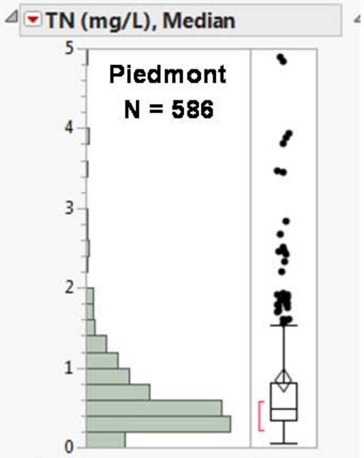
Quantiles

100.0%	maximum	12.93
99.5%		6.99515
97.5%		3.27425
90.0%		1.8854
75.0%	quartile	0.95
50.0%	median	0.5
25.0%	quartile	0.2625
10.0%		0.13
2.5%		0.1
0.5%		0.0447
0.0%	minimum	0.03



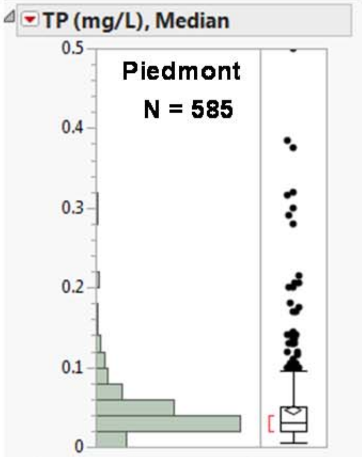
Quantiles

100.0%	maximum	0.76
99.5%		0.63265
97.5%		0.15087
90.0%		0.055
75.0%	quartile	0.03
50.0%	median	0.02
25.0%	quartile	0.01
10.0%		0.01
2.5%		0.0055
0.5%		0.001
0.0%	minimum	0.001



Quantiles

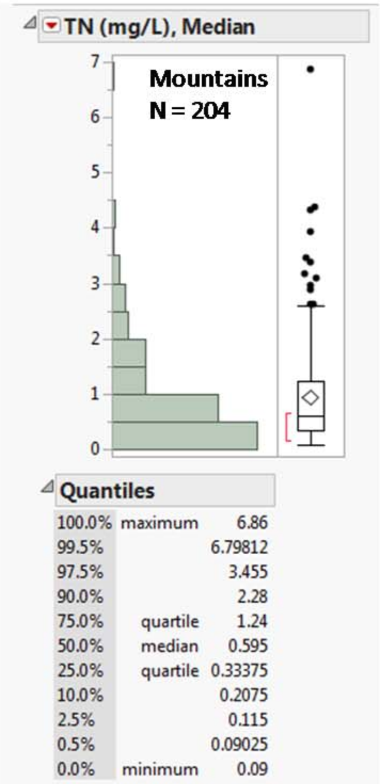
100.0%	maximum	24.88
99.5%		14.5575
97.5%		3.89612
90.0%		1.2715
75.0%	quartile	0.82
50.0%	median	0.49
25.0%	quartile	0.34375
10.0%		0.225
2.5%		0.13838
0.5%		0.09968
0.0%	minimum	0.055



Quantiles

100.0%	maximum	0.82
99.5%		0.39305
97.5%		0.187
90.0%		0.09
75.0%	quartile	0.05
50.0%	median	0.03
25.0%	quartile	0.02
10.0%		0.02
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.0055

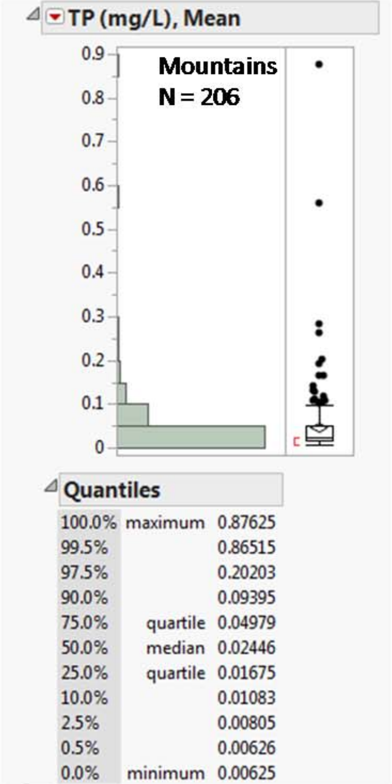
Appendix C: Distributions of TN and TP Median Values (≥10 Observations Only)



TN (mg/L), Median

Quantiles

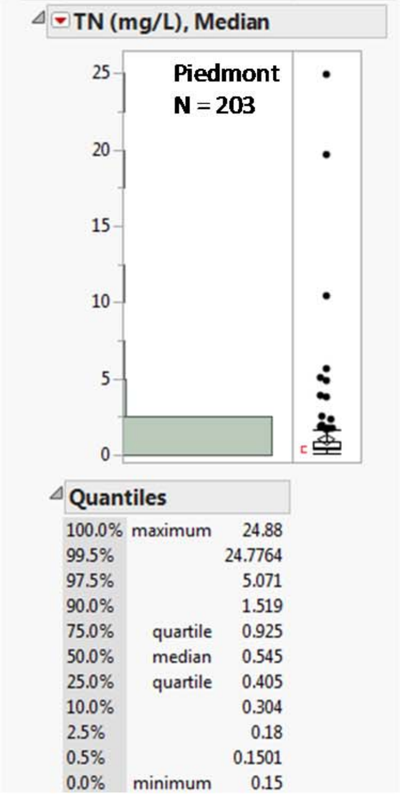
100.0%	maximum	6.86
99.5%		6.79812
97.5%		3.455
90.0%		2.28
75.0%	quartile	1.24
50.0%	median	0.595
25.0%	quartile	0.33375
10.0%		0.2075
2.5%		0.115
0.5%		0.09025
0.0%	minimum	0.09



TP (mg/L), Mean

Quantiles

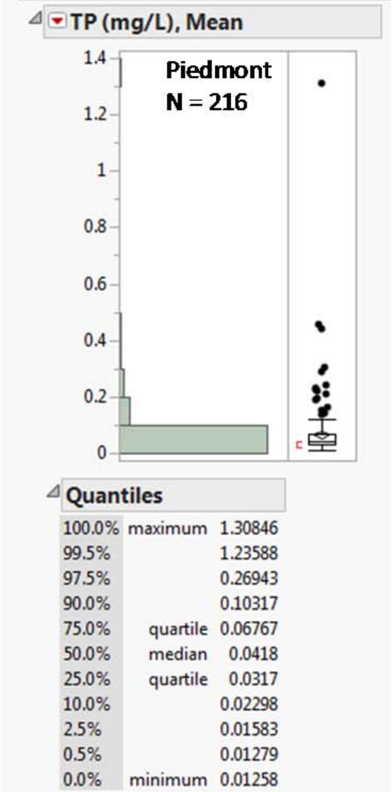
100.0%	maximum	0.87625
99.5%		0.86515
97.5%		0.20203
90.0%		0.09395
75.0%	quartile	0.04979
50.0%	median	0.02446
25.0%	quartile	0.01675
10.0%		0.01083
2.5%		0.00805
0.5%		0.00626
0.0%	minimum	0.00625



TN (mg/L), Median

Quantiles

100.0%	maximum	24.88
99.5%		24.7764
97.5%		5.071
90.0%		1.519
75.0%	quartile	0.925
50.0%	median	0.545
25.0%	quartile	0.405
10.0%		0.304
2.5%		0.18
0.5%		0.1501
0.0%	minimum	0.15

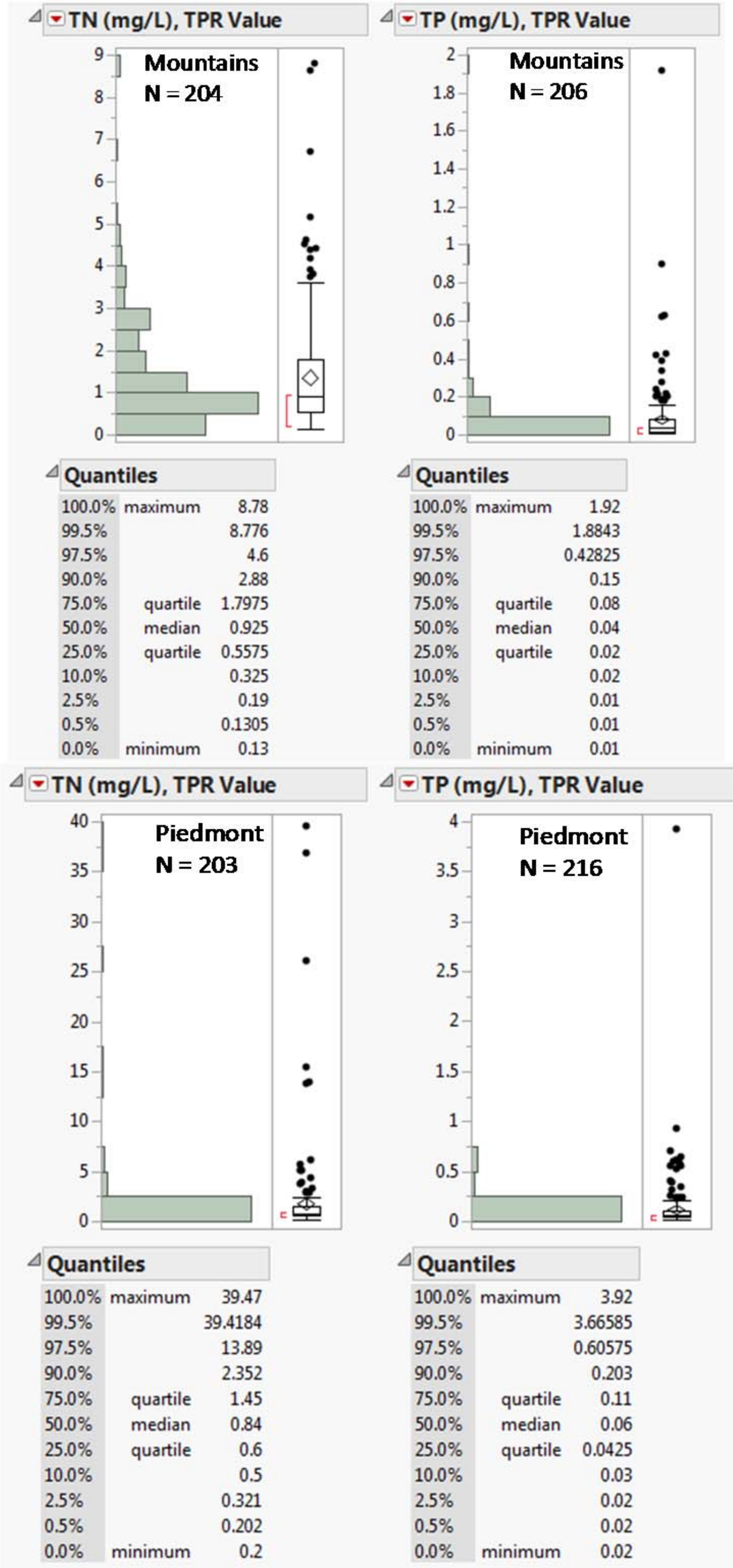


TP (mg/L), Mean

Quantiles

100.0%	maximum	1.30846
99.5%		1.23588
97.5%		0.26943
90.0%		0.10317
75.0%	quartile	0.06767
50.0%	median	0.0418
25.0%	quartile	0.0317
10.0%		0.02298
2.5%		0.01583
0.5%		0.01279
0.0%	minimum	0.01258

Appendix D: Distributions of TPR Values for TN and TP



TN (mg/L), TPR Value — Mountains, N = 204

Quantiles

100.0%	maximum	8.78
99.5%		8.776
97.5%		4.6
90.0%		2.88
75.0%	quartile	1.7975
50.0%	median	0.925
25.0%	quartile	0.5575
10.0%		0.325
2.5%		0.19
0.5%		0.1305
0.0%	minimum	0.13

TP (mg/L), TPR Value — Mountains, N = 206

Quantiles

100.0%	maximum	1.92
99.5%		1.8843
97.5%		0.42825
90.0%		0.15
75.0%	quartile	0.08
50.0%	median	0.04
25.0%	quartile	0.02
10.0%		0.02
2.5%		0.01
0.5%		0.01
0.0%	minimum	0.01

TN (mg/L), TPR Value — Piedmont, N = 203

Quantiles

100.0%	maximum	39.47
99.5%		39.4184
97.5%		13.89
90.0%		2.352
75.0%	quartile	1.45
50.0%	median	0.84
25.0%	quartile	0.6
10.0%		0.5
2.5%		0.321
0.5%		0.202
0.0%	minimum	0.2

TP (mg/L), TPR Value — Piedmont, N = 216

Quantiles

100.0%	maximum	3.92
99.5%		3.66585
97.5%		0.60575
90.0%		0.203
75.0%	quartile	0.11
50.0%	median	0.06
25.0%	quartile	0.0425
10.0%		0.03
2.5%		0.02
0.5%		0.02
0.0%	minimum	0.02