Development of Nutrient Endpoints for Allegheny Plateau and Ridge and Valley Ecoregions of Pennsylvania: TMDL Application

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Region 3

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By

Michael J. Paul and Lei Zheng

Tetra Tech, Inc.

400 Red Brook Boulevard, Suite 200

Owings Mills, MD 21117

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Introduction

The United States Environmental Protection Agency (USEPA) in Region 3 is overseeing the development of nutrient TMDLs to protect aquatic life use for several streams Pennsylvania. Tetra Tech, Inc, (Tt) was approached to establish appropriate and scientifically defensible nutrient endpoints that are protective of aquatic life. Tetra Tech developed endpoints for the Piedmont region as part of this work and published those in a report entitled, "Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application" dated November 30, 2007. That document described the process that was applied in detail, the results of those analyses, and the final recommended TP and TN endpoints. This addendum applies matching methodology to the development of endpoints for streams of the Ridge and Valley and Allegheny Plateau ecoregions of Pennsylvania.

Nutrients affect aquatic systems in diverse ways, and the effects on most non-primary producer aquatic life uses are indirect (Figure 1).

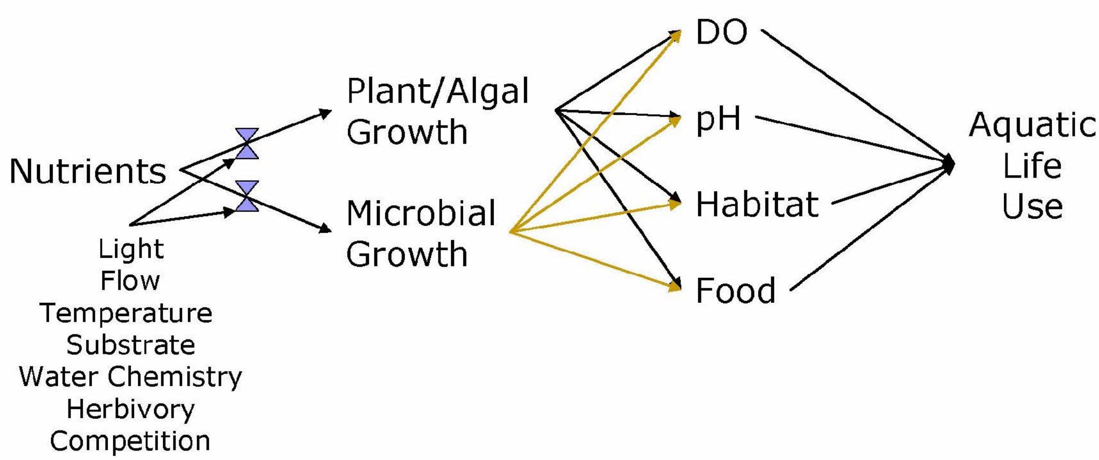

Figure 1 – Simplified diagram illustrating the causal pathway between nutrients and aquatic life use impacts. Nutrients enrich both plant/algal as well as microbial assemblages, which lead to changes in the physical/chemical habitat and food quality of streams. These effects directly impact the insect and fish assemblages. The effects of nutrients are influenced by a number of other factors as well, such as light, flow, and temperature.

Nutrients cause enrichment of primary producer and decomposer biomass and productivity, the increase of which leads to changes in the physical and chemical stream environment (e.g., reduced oxygen, loss of reproductive habitat, alteration on the availability of palatable algal taxa, etc.). It is these effects which directly result in changes to the biological stream community (e.g., loss of disturbance sensitive taxa), and ultimately impair the use of a stream for aquatic life.

Traditionally, water quality endpoints to protect aquatic life use were developed using toxicological approaches. Such approaches have been applied for a range of pollutants to develop water quality endpoints. However, as explained above, nutrient enrichment does not have a direct toxicological effect on non-primary producer aquatic life. It is worth mentioning that nutrients do, however, affect algal and plant aquatic life directly, altering the diversity and composition of those assemblages radically. For insects, fish and other aquatic life, however, the mode of action of nutrients is indirect and through a causal pathway that involves alteration of physical, chemical, and biological attributes of their habitat. As a result, traditional toxicological approaches are not appropriate.

The USEPA has published guidance on nutrient endpoint development for the protection of designated uses for a range of waterbody types including rivers and streams (USEPA 2000a), but also for lakes and reservoirs (USEPA 2000b), estuaries (USEPA 2001), and wetlands (USEPA 2007). The principal method described in those documents is the use of a frequency distribution-based approach (often called the reference approach), where a percentile of a distribution of values is used to identify a nutrient endpoint. The sample distributions were typically either from least disturbed reference sites (sensu Stoddard et al. 2006) or the entire population of sample sites. These documents, however, clearly encourage the use of alternative scientifically defensible approaches and, especially, the application of several approaches in a multiple-lines-of-evidence framework, to establish defensible and protective endpoints. The documents state that, "a weight of evidence approach that combines (multiple) approaches…will produce endpoints of greater scientific validity." The approaches recommended include the frequency distribution approach, stressor-response analyses, and literature based values.

In determining nutrient endpoints for developing TMDLs to protect aquatic life uses of Ridge and Valley and Allegheny Plateau streams in Pennsylvania, we relied on a multiple lines of evidence approach framework considering all of the following approaches: frequency distribution based analysis, stressor-responses analyses, and literature based values. The following sections describe these approaches in detail including the methods used for each and the results. The resulting candidate values were then considered and a weight-of-evidence applied to develop final endpoint recommendations.

Due to the limitation of watershed sizes and the difficulty in obtaining stressor response gradients (especially for reference sites) in the target watersheds, we used an ecoregional nutrient endpoint development approach similar to that applied for nutrient criteria development to identify nutrient targets that would protect aquatic life uses in these watersheds. The USEPA, in their recommendations for nutrient endpoint development, specified that "Ecoregional nutrient criteria will be developed to account for the natural variation existing within various parts of the country." (USEPA 2000a)

They go on to explain the importance of ecoregions:

"Ecoregions serve as a framework for evaluating and managing natural resources. The ecoregional classification system developed by Omernik (1987) is based on multiple geographic characteristics (e.g., soils, climate, vegetation, geology, land use) that are believed to cause or reflect the differences in the mosaic of ecosystems."

The two targeted watersheds for this report, Sawmill Run and Paxon Creek, are located within the Allegheny Plateau and Ridge and Valley ecoregions, respectively. We collected data from the same ecoregions in Pennsylvania, Maryland, West Virginia, and Virginia. We made the assumption that nutrient dynamics in the two watersheds should be similar to nutrient dynamics in sites selected from across these two ecoregions, given similarities in geology, soils, and climate.

Frequency Distribution Based Approach

For this approach, we identified water quality samples collected by a variety of agencies from streams in the Allegheny Plateau and Ridge and Valley ecoregions stored in a variety of databases including the USEPA Storage and Retrieval (STORET) and Environmental Monitoring and Assessment Program (EMAP) databases, United States Geological Survey (USGS) National Water Inventory System (NWIS) and National Water Quality Assessment (NAWQA) program, and the Maryland Biological Stream Survey (MBSS) database (Figure 2). Two populations of sites were developed. The first was all sites for which nutrient samples were available (All Sites). The second was all sites for which watershed land cover was available and for which reference criteria could be applied (Reference Sites).

The All Sites population included samples from all of the agencies described above. For sites with multiple samples, samples were averaged to estimate an average site nutrient concentration. This reduced the influence of any one site on the percentiles.

After all the sites were prepared, we calculated the 25th percentile nutrient concentration of total phosphorus (TP) and total nitrogen (TN).

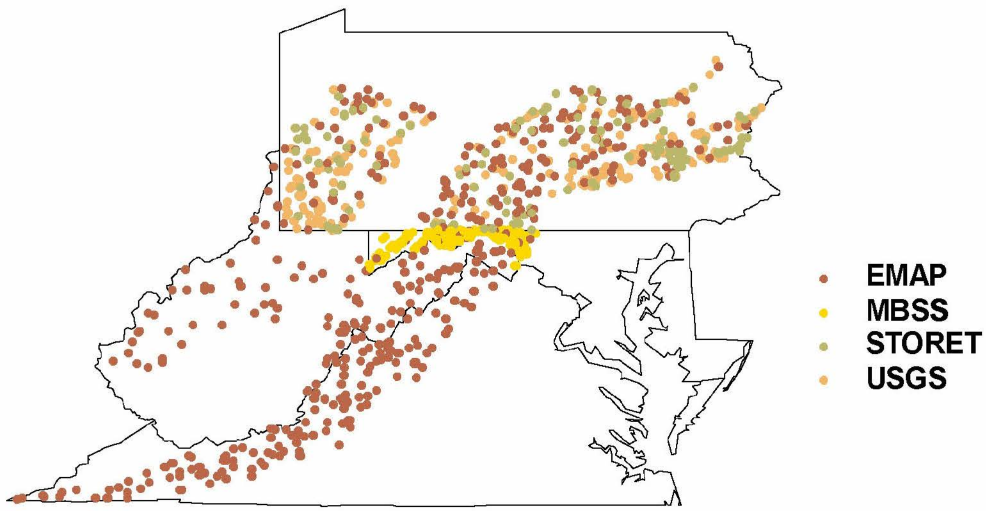

Figure 2 – Map of the sample sites used in the development of nutrient endpoints using the distribution based approach in this study, labeled by agency affiliation.

For sites where land cover information was available (USEPA EMAP, USGS NAWQA, and MBSS), we developed land cover screening criteria to identify least disturbed watersheds (sensu Stoddard et al. 2006). Least disturbed sites represent those watersheds with minimal human disturbance and, therefore, provide the best empirical estimate of chemical integrity. We developed two different reference criteria: >80% Forest, <5% urban (N=7) and >70% Forest, <5% urban (N=24). We then calculated the 75th percentile of total phosphorus and total nitrogen concentrations associated with these populations.

The distribution based analyses resulted in lower endpoints for nutrients from the All Sites population than from the two Reference Site populations in both ecoregions (Figure 3, Table 1). For the Allegheny Plateau ecoregion, total phosphorus endpoints were between 19 and 36 µg/L and total nitrogen endpoints between 260 and 665 µg/L (Table 1). For the Ridge and Valley ecoregion, distribution based total phosphorus endpoints were between 10 and 15 µg/L and total nitrogen endpoints between 280 and 620 µg/L (Table 1).

Table 1 – Values of TN and TP candidate endpoints derived using the distribution based approach.

Parameter	Reference Sites >80% Forest <5% Urban	Reference Sites >70% Forest <5% Urban	All Sites
	75th Percentile	75th Percentile	25th Percentile
Allegheny Plateau			
TN (µg/L)	425	664	260
TP (µg/L)	36	33	19
N	25	39	125 (TN) 185 (TP)
Ridge and Valley			
TN (µg/L)	480	618	281
TP (µg/L)	13	15	10
N	122	147	885 (TN) 1073 (TP)

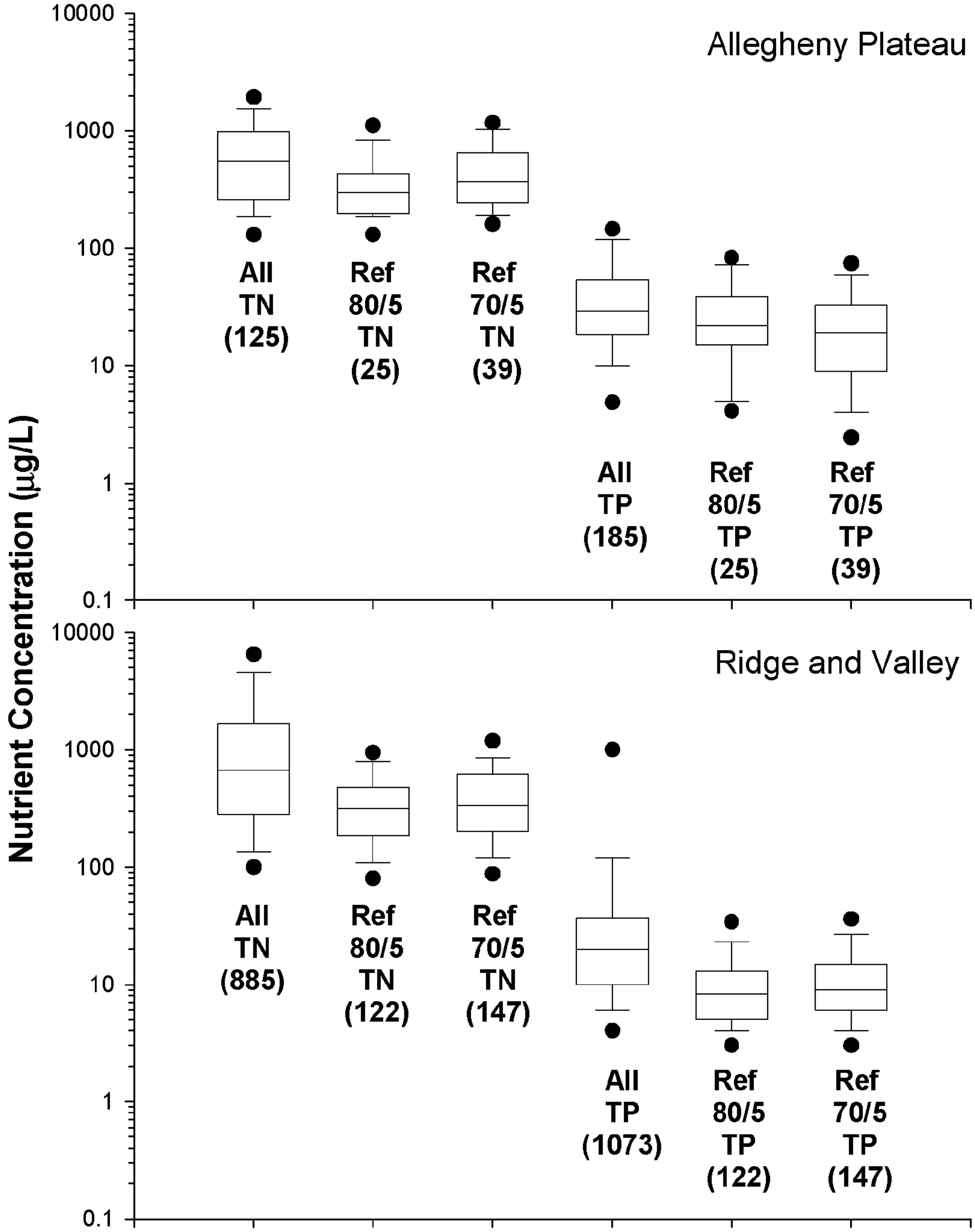

Figure 3 – Plot of TN and TP samples in the All Sites (All) and two Reference Site (Ref) populations used to estimate candidate endpoints with the distribution based approach. Sample sizes are shown below each label. Lines indicate the median values (50th percentiles), boxes are the quartiles (25th and 75th percentiles), whiskers are 10th and 90th percentiles, and symbols are the 5th and 95th percentiles.

Modeled Reference Expectation Approach

Another approach that falls under the rubric of "reference approaches" is the modeled reference expectation approach (Dodds and Oakes 2004). In this approach, multiple regression models of total nutrients versus human land cover (agriculture and urbanization) are built and then solved for the condition of no human land cover (i.e., the intercept). This approach has been used to estimate nutrient concentrations in the absence of human disturbance in the Midwest (Dodds and Oakes 2004).

We developed modeled reference expectation models for the Allegheny Plateau region using data from the USEPA EMAP program, since it was the only one which had both land cover and nutrient data. The final equation for total nitrogen was:

$$\text{Log}_{10}(\text{TN}) = 2.48 + 0.40(\text{arcsine}\sqrt{\%\ \text{Agriculture}}) + 0.94(\text{arcsine}\sqrt{\%\ \text{Urban}});$$

($R^2 = 0.24$, F=9.98, $p<0.001$).

Solving for the undisturbed condition leads to a modeled reference total nitrogen concentration for the Allegheny Plateau of 302 μg/L. No significant model for total phosphorus could be created with the land cover data for the Allegheny Plateau, so we estimated the TP value for this approach using N:P ratios (see below).

Similarly, we developed modeled reference expectation models for TN and TP in the Ridge and Valley ecoregion using data from the USEPA EMAP and Maryland DNR MBSS programs, since they were the only ones which had both land cover and nutrient data. The final equation for TP was:

$$\text{Log}_{10}(\text{TP}) = 0.86 + 0.62(\text{arcsine}\sqrt{\%\ \text{Agriculture}});$$

($R^2 = 0.27$, F=169.0, $p<0.001$)

and for TN was:

$$\text{Log}_{10}(\text{TN}) = 2.32 + 1.01(\text{arcsine}\sqrt{\%\ \text{Agriculture}}) + 0.13(\text{arcsine}\sqrt{\%\ \text{Urban}});$$

($R^2 = 0.51$, F=234.6, $p<0.001$)

Solving for the undisturbed condition leads to a modeled reference Ridge and Valley TP endpoint of 7 µg/L and TN endpoint of 209 µg/L.

N:P Ratios Suggest P Limitation Dominates the Allegheny Plateau Ecoregion

We calculated N:P ratios across all sites in the Allegheny Plateau dataset. The average molar N:P ratio for All Sites was 86:1. We applied this ratio to the TN value estimated from the modeled reference expectation value for TN in the Allegheny Plateau, which yielded a TP value of 8 µg/L TP. The molar ratio of N:P based on the recommended USEPA nutrient criteria for this ecoregion (TP=10 µg/L, TN=310 µg/L) is 68:1. Applying this value, as well as the Redfield molar N:P ratio (16:1), to the value of TN estimated using the modeled reference expectation approach above led to estimated TP values of 10 and 42 µg/L, respectively. We would defend the use of natural ratios rather than Redfield given uncertainties in the applicability of Redfield to freshwater systems combined with the fact that Allegheny Plateau average N:P ratios are much higher than Redfield.

Stressor-Response Approach

Stressor-response approaches refer to a suite of analytical techniques that derive candidate endpoints by exploring the relationships between response variables and nutrient concentrations. Typical response variables in the context of nutrient endpoint development include water chemical aquatic life use indicators (dissolved oxygen, pH, etc.), algal biomass and/or algal assemblage metrics (e.g., percent nutrient sensitive diatoms), and aquatic life use indicators or biocriteria indicators (e.g., algal multimetric indices or individual metrics scores, invertebrate multimetric indices or individual metrics, etc.). The value of these indicators is their direct linkage to aquatic life use designations. They, therefore, provide a way to connect nutrient concentrations directly to aquatic life use protection. We used a few different stressor-response analytical techniques to develop candidate nutrient endpoints using invertebrate response indicators.

We selected two important nutrient variables to examine biological responses: total nitrogen (TN) and total phosphorus (TP). TN and TP are two of the four primary variables EPA recommended for nutrient endpoint development and are likely to limit aquatic primary producers. TP and TN may reflect stream trophic status better than inorganic P and N because nutrient depletion can be partially offset by increases in particulate fractions of TP and TN resulting from drift and suspension in the water column (Dodds 2002). In addition, TN and TP are also measured more frequently in most of the national and state programs than other nutrient variables.

The primary response variable of interest for stream trophic state characterization is algal biomass, which is most commonly reported as mg/m^2 Chl a. Chl a is a photosynthetic pigment and is a sensitive indicator of algal biomass. It is considered an important biological response variable for nutrient-related problems (USEPA 2000a). Periphyton is also often analyzed for dry mass (DM) and ash free dry mass (AFDM), which includes non-algal organisms. The USEPA also recommends a measure of turbidity as the response variable. However, turbidity is often associated with total suspended solids (TSS) and other environmental factors and is less commonly used as a direct response variable. In addition to these, algal species composition often responds dramatically to excess nutrients, including the proliferation of eutrophic and nuisance algal taxa. As a result, algal metrics are frequently used as direct indicators of nutrient enrichment (van Dam et al. 1994, Pan et al. 1996). We did not have sufficient algal endpoints to explore these response variables in the Allegheny Plateau and Ridge and Valley ecoregions, as we did for the Piedmont analysis. The aquatic life response variable for which we had sufficient information to consider was macroinvertebrate metrics from multimetric indices. Macroinvertebrate indices are the most reliable and frequently used bioindicators, and many macroinvertebrate metrics are sensitive to nutrient enrichment.

Data:

We collected data from four different national and state programs, similar to those used in the distribution based analyses:

- USEPA Environmental Monitoring and Assessment Program (EMAP)
- USGS National Water Information System (NWIS)
- USEPA STORET database
- Maryland Biological Stream Survey (MBSS) program

Two projects, the USEPA EMAP and MBSS programs, simultaneously collected nutrients and macroinvertebrate composition data, which were valuable for exploring invertebrate assemblage responses to nutrients. The MBSS collected thousands of macroinvertebrate samples from its statewide stream survey including numerous samples in the Ridge and Valley ecoregion and the EMAP Mid-Atlantic Highlands Assessment collected similar samples across both ecoregions throughout Virginia, West Virginia, Maryland, and Pennsylvania.

Data Analysis: Overview

Establishing definitive stressor-response relationships is a valuable line of evidence in the multiple lines of evidence approach. We first used Spearman correlation analysis to examine relationships between response and stressor variables. Correlation analyses identified significant relationships between biological response and nutrient variables. However, correlation may or may not indicate the real relationship. Numerous relationships were examined; only a subset of which were correlated. There were also results that were considered potentially important but showed weaker relationships.

We selected correlations of interest and performed visual scatter plots to further examine the relationships. We used either linear regression or a locally weighted average regression line to examine the trend of change along the environmental gradients. The locally weighted scatterplot smoothing (LOWESS) technique (Cleveland 1979) models nonlinear relationships where linear methods do not perform well. LOWESS fits simple models to localized subsets of the data to construct a function that describes, essentially, the central tendency of the data. LOWESS fits segments of the data to the model. Tension, which describes the portion of data being used to fit each local function, was set at 0.50 for LOWESS regression.

We also used conditional probability analysis (Paul and MacDonald, 2005) to examine changes in the biological community along stressor gradients. Conditional probability provides the likelihood (probability) of a predefined response when a specific value of a pollutant stressor (condition) is exceeded. Conditional probability is the likelihood of an event when it is known that some other event has occurred. Conditional probability answers the question: for a given threshold of a stressor, what is the cumulative probability of impairment? For example, if the total phosphorus concentration is greater than 30 µg/L, what is the probability of biological impairment (defined as < 8 EPT Taxa) for each site under consideration? All observed stressor values (in this example, all observed values of total phosphorous) are used to develop a curve of conditional probability (Paul and MacDonald, 2005). Because of its ability to identify risks of impact associated with given nutrient concentrations, the approach is suited to identifying nutrient thresholds protective of aquatic biological condition.

To estimate conditional probability of an impairment, we first had to define impairment as a specific value for a response variable (e.g., EPT < 8 genera). We used preexisting biocriteria thresholds as our response thresholds (MDNR 2005). For the Ridge and Valley ecoregion, we used MBSS and EMAP data as well as criteria based on scoring thresholds developed by the state of Maryland for their multimetric index and by EPA EMAP for use in their multimetric index for the Mid-Atlantic Highlands (Klemm et al. 2003). For the Allegheny Plateau, we used EMAP metrics alone because MBSS did not sample in this region. Thresholds used for the EMAP metrics were the 25th percentile of reference site metric scores for metrics declining with stress and the 75th percentile of reference sites for metrics increasing with stress. These thresholds are commonly used to identify metrics that discriminate between reference and stressed sites (Barbour et al. 1999). We used the same reference criteria developed by Klemm et al. (2003) except we excluded the nutrient criteria they used (to avoid circularity) and used only their cutoffs for chloride, sulfate, acid neutralizing capacity, and habitat.

We also used nonparametric deviance reduction (change point analysis) to identify thresholds in biological responses to nutrients (Qian et al. 2003). This technique is similar to regression tree models, which are used to generate predictive models of response variables for one or more predictors. The change-point, in our application, is the first split of a tree model with a single predictor variable (nutrient concentration). The loss function of regression trees can be evaluated by the proportion of reduction in error (PRE), which is analagous to the multiple R^2 of general linear models.

Data Analysis: Metric Calculation

<u>*Macroinvertebrate Metrics*</u>

Numerous macroinvertebrate assemblage metrics were assembled from the MBSS and EMAP programs. We selected a subset of benthic macroinvertebrate indicators, focusing on those that composed the MBSS IBI (Ridge and Valley) and/or Highlands EMAP IBI (Allegheny Plateau). Metrics considered included Ephemeroptera, Plecoptera, Trichoptera (EPT) richness, Ephemeroptera Richness, Plecoptera Richness, Trichoptera Richness, Tolerant Richness, Percent Tolerant, Scraper Richness, Percent Scrapers, Collector-Filterer Richness, and Percent Dominant 5 taxa.

Results: Benthic Macroinvertebrate Metrics – Nutrient Relationships

The largest datasets available for analyzing macroinvertebrate responses to nutrient concentrations were the Maryland Biological Stream Survey (MBSS) and EMAP Mid-Atlantic Highlands Assessment datasets. We found 50 samples from the EMAP database with corresponding macroinvertebrate metric and nutrient data for the Allegheny Plateau ecoregion. In contrast, we found 242 samples with corresponding macroinvertebrate metrics and nutrient samples from the MBSS dataset, and 320 comparable samples from the EMAP database in the Ridge and Valley ecoregion. For each metric, scoring criteria were developed based on the distribution of values from least disturbed reference sites (Table 2). For the MBSS, we selected the middle point of the distribution as the impairment threshold for each metric, since this is consistent with their methodology (Southerland et al. 2005, Table 2). For the EMAP data, we used a standard practice, namely using the 25th percentile of reference site metric scores (for metrics decreasing with stress) or the 75th percentile of reference site metrics cores (for metrics increasing with stress) as our thresholds (Table 2, Barbour et al. 1999).

Of the metrics considered in the Allegheny Plateau, none exhibited a strong enough response to nutrient concentrations to merit development of potential endpoints using the stressor-response approach. For the Ridge and Valley, however, several exhibited a strong response to TP and we used the following metrics: MBSS – EPT Richness, Percent Scrapers, and Number of Taxa; EMAP – EPT Richness, Ephemeroptera Richness, Trichoptera Richness, and Percent Dominant 5 Taxa.

Table 2 – Threshold values for the MBSS and EMAP benthic macroinvertebrate IBI metrics in the Ridge and Valley ecoregion (Southerland et al. 2005, Klemm et al. 2003).

MBSS Scoring criteria	5	3	1	Mid Point
Number of Taxa	≥ 24	15 – 23	<15	19
Number of EPT	≥ 14	8 – 13	< 8	10.5
% Scrapers	≥ 13	3 – 12	< 3	7.5
EMAP Scoring criteria	25th Percentile of Reference		75th Percentile of Reference	
Number of EPT	16			
Number of Ephemeroptera	7			
Number of Trichoptera	4			
Percent Dominant 5 Taxa			60.75	

MBSS Metrics

The three MBSS metrics (Total Taxa, EPT Taxa, and Percent Scrapers) all declined with increased TP concentrations (Figure 4). The scatterplots exhibited a traditional wedge shape decline, while the conditional probability graphs clearly indicated the probability of impairment increasing as TP concentrations increased from 10 to 50 μg/L

TP. Change point analyses indicated thresholds at 14, 14, and 16 µg/L TP for these three metrics, respectively.

EMAP Metrics

Similarly, the first three EMAP metrics all declined with increasing TP concentrations, also exhibiting the typical wedge shaped response (Figure 5). The same data expressed as conditional probabilities exhibited increasing risk of impacts between 8 and 50 µg/L TP. Change point analyses indicated thresholds at 19 µg/L TP for all three metrics. The last EMAP metric, Percent Dominant 5 taxa, increased with increasing TP concentration, as expected (Figure 6). As macroinvertebrate communities become stressed, there is a predictable decline in diversity and evenness, as a few tolerant taxa (e.g., weedy species), take advantage of the loss of more sensitive taxa and begin to dominate the assemblage (Klemm et al. 2003). Change point analyses indicated a threshold at 23 µg/L TP for this metric.

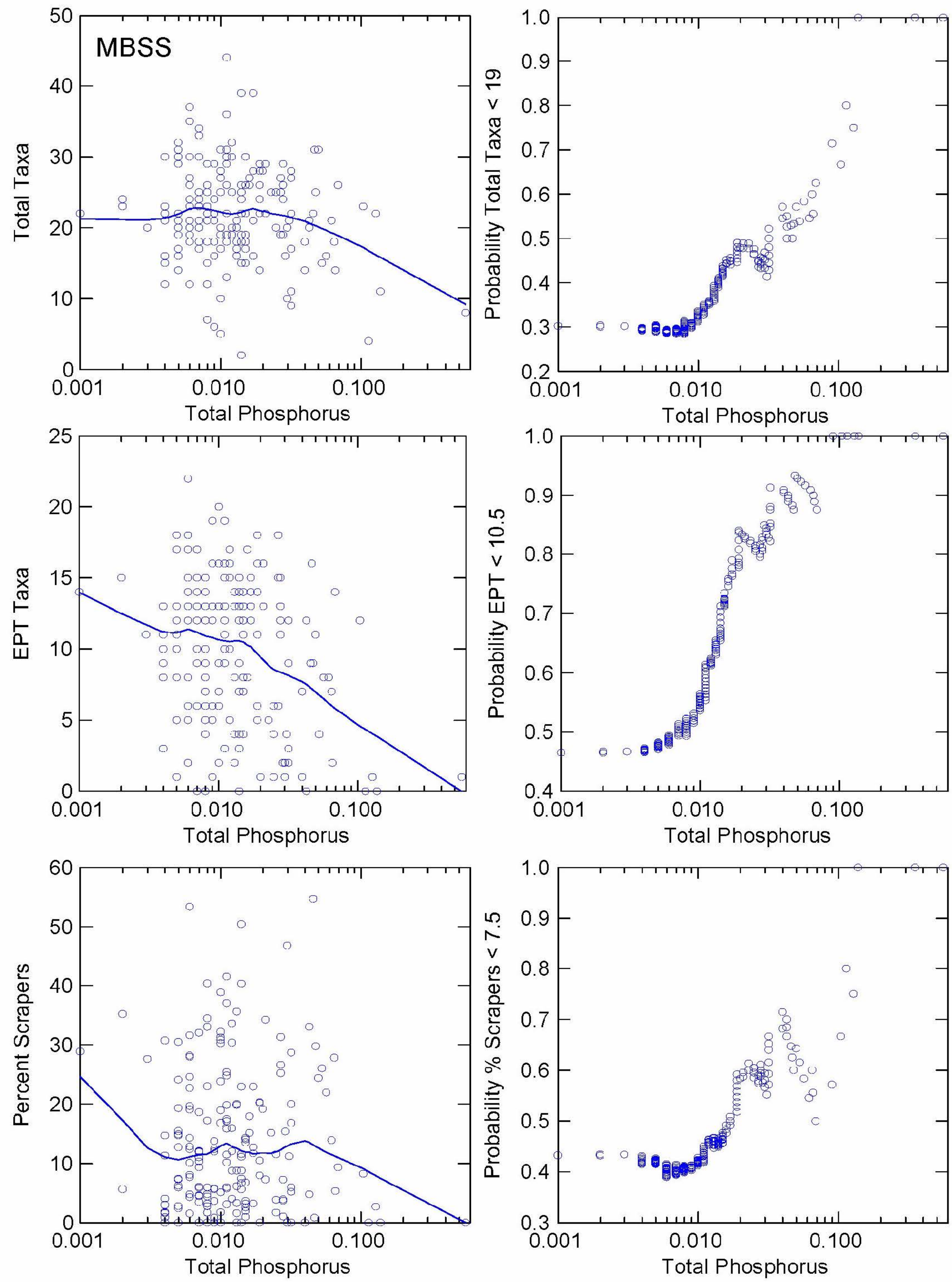

Figure 4 – Response of the three MBSS invertebrate metrics to increases in phosphorus concentration. Plots on the left are raw data with a lowess curve fit. Plots on the right are the same raw data expressed as conditional probabilities.

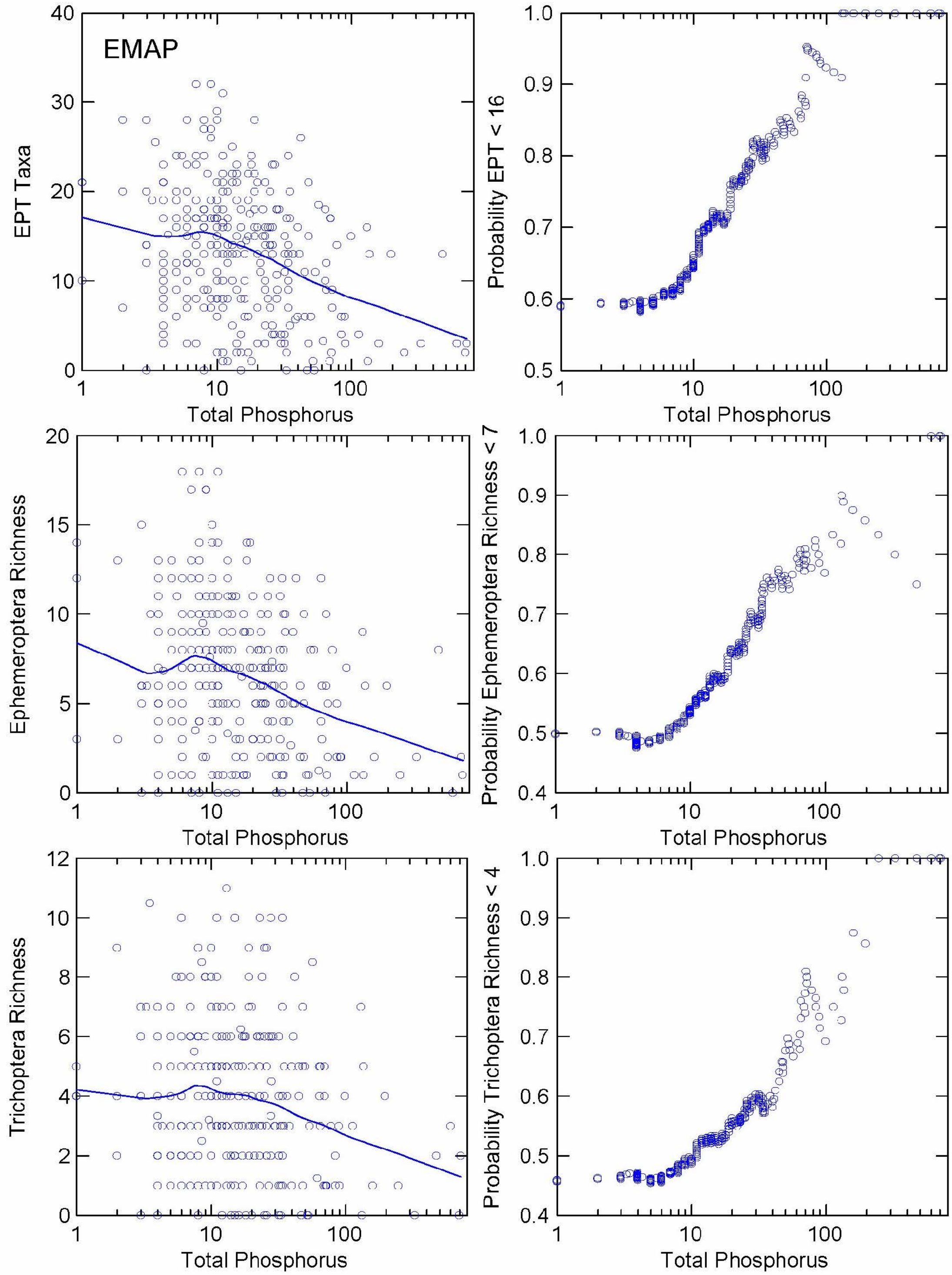

Figure 5 - Response of three EMAP invertebrate metrics to increases in phosphorus concentration. Plots on the left are raw data with a lowess curve fit. Plots on the right are the same raw data expressed as conditional probabilities.

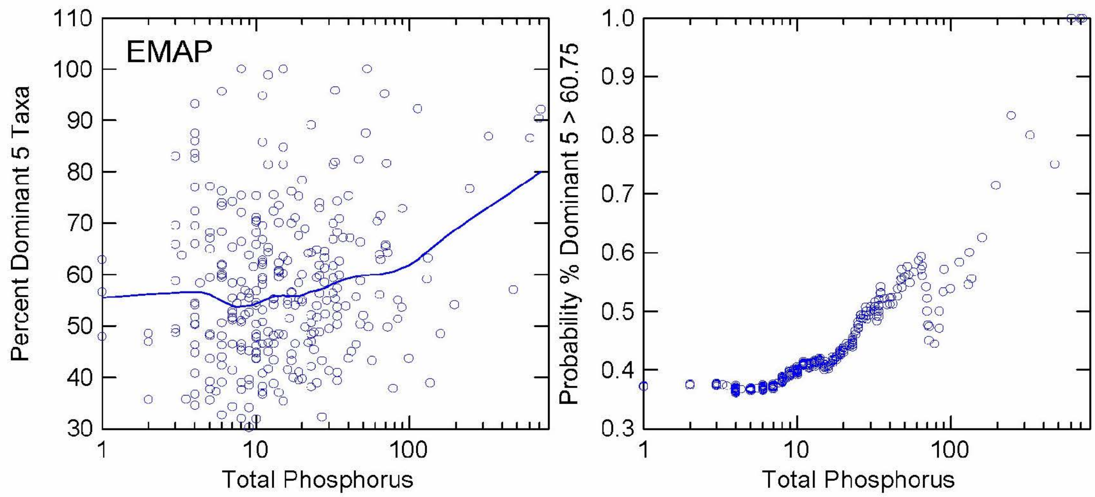

Figure 6 - Response of the last EMAP invertebrate metric to an increase in phosphorus concentration. Plot on the left is raw data with a lowess curve fit. Plot on the right is the same raw data expressed as conditional probabilities.

Literature Based Analysis: Current Existing Endpoints or Threshold Values

In this last analytical section, we present several studies relevant to the development of nutrient endpoints in the Allegheny Plateau and Ridge and Valley ecoregions of Pennsylvania. These are taken principally from the peer-reviewed and federal agency technical literature and reflect increasing experimental and theoretical interest in the impact of nutrients on natural stream systems. We attempted to extract information from these studies that could recommend specific endpoints.

In natural, shaded streams [such as those evaluated in the Dodds et al. (2002) model], it is difficult to assess the full growth potential of algae. Algal growth potential has been evaluated using artificial stream channels that are fully exposed to nutrient and light gradients. Previous studies (Horner et al. 1983, Bothwell 1989) demonstrated that in artificial streams, algal growth could be saturated (i.e., achieved maximum growth rate) at 25–50 μg/l phosphorus. Rier and Stevenson (2006) found that at 16 μg/L soluble reactive phosphorus (SRP) or 86 µg/L dissolved inorganic nitrogen (DIN), algal growth was at 90% of its maximum rate. They also found that saturation concentrations were 3–5 times lower than concentrations needed to produce maximum algal biomass (i.e., 430 µg/L DIN and 80 µg/L SRP for growth saturation). However, these values were derived mostly on the basis of diatom and bluegreen algae growth. We expect that green algae (i.e., *Cladophora*) would have higher nutrient saturation concentrations for peak growth (Borchardt 1996).

USEPA's nutrient threshold recommendations for the Allegheny Plateau and Ridge and Valley nutrient ecoregion were 310 µg/L for TN and 10 µg/L for TP.

Dodds and Welch (2000) conducted a meta-study including values from a range of areas nationwide. These were combined into regression equations to predict chlorophyll. They found that if a mean of 50 mg/m^2 of chlorophyll is the target (thus insuring chlorophyll is less than 100 mg/m^2 most of the time), TN should be 470 µg/L and TP should be 60 µg/L. Even lower numbers should be considered for more pristine waters. These estimates were more general in scope. These authors further noted that lower TN and TP values associated with these chlorophyll concentrations were obtained when using a detailed, smaller data set than those from a larger data set (55 µg/L TP from a large dataset versus 21 µg/L for a more specific, local data set).

USGS conducted a study in 2001 for a broad area of the US, including the New River and Big Sandy River in Virginia (Robertson et al. 2001). They looked at 234 sites using the reference approach and found that a TP of 20 µg/L was appropriate for what they define as Environmental Nutrient Zone 2.

Rohm et al. (2002) conducted a national study to demonstrate how regional reference conditions and draft nutrient endpoints could be developed. They divided the country into 14 regions and analyzed available nutrient data as a case study, using EMAP data from Central and Eastern Forested Uplands, an area that includes much of central Pennsylvania. This case study suggested a criterion of 375 µg/L for TN and 13 µg/L for TP. Rough estimates from the data presented for their Region IX that includes Eastern Pennsylvania gives estimates of 500 µg/L TN and 20 µg/L TP.

Recommended Endpoints

Total Phosphorus (TP)

Endpoint (magnitude) – Allegheny Plateau

Our analyses relied on a weight-of-evidence analysis drawing on many different analytical approaches. Each of the different approaches produced slightly different endpoints and these are summarized in Table 3.

In a weight-of-evidence approach, the different analyses are weighted on their applicability and the strength of the analysis. For the Allegheny Plateau, we had insufficient data to produce significant stressor-response relationships. As a result, we were left weighting the distribution based, modeled reference expectation, and scientific literature lines.

For the distribution based approach, we assembled a large population of nutrient concentration from sites ranging in quality from various databases. We identified the entire population of sites for one estimate, and identified a subset of minimally disturbed sites for a second estimate. The values estimated from these populations were between 19 and 36 µg/L TP.

The modeled reference expectation did not produce a significant model for TP in this ecoregion, but did for TN (302 µg/L). We used the molar ratio of N:P to identify an appropriate TP target associated with this TN concentration. The average Allegheny Plateau stream N:P from our dataset was 86:1. The ratio of N:P based on USEPA's recommended endpoints was similar (68:1). Using these two, and the Redfield ratio (16:1), resulted in TP endpoints of 8, 10, and 42 µg/L respectively.

Finally, literature relevant to nutrient endpoints for this region ranged from approximately 10 µg/L TP (USEPA recommended criteria) to 60 µg/L (Dodds and Welch 2000), but most values were centered around 30 µg/L TP.

We weighted the reference criteria line of evidence most highly of the three lines we had available and we recommend a TP endpoint of 35 µg/L TP for streams of this region.

- **Allegheny Plateau recommended endpoint: 35 µg/L TP**

Table 3 – Summary of candidate endpoints for each of the analytical approaches discussed for the Allegheny Plateau.

Approach		TP Endpoint (µg/L)
Reference Approach		**19-36**
	Reference Site 75th Percentile	33-36
	All Sites 25th Percentile	19
Modeled Reference		**8-42**
Stressor-Response		**NA**
Other Literature		**13-100**
	USEPA Recommended Regional Criteria	10

USEPA Regional Criteria Approach – Local Data	13
Algal Growth Saturation	25-50
Nationwide Meta-Study TP-Chlorophyll	21-60
USGS Regional Reference Study	20
USGS National Nutrient Criteria Study	13-20

Endpoint (magnitude) – Ridge and Valley

As above, our analyses relied on a weight-of-evidence analysis drawing on many different analytical approaches. Each of the different approaches produced slightly different endpoints and these are summarized in Table 4.

In a weight-of-evidence approach, the different analyses are weighted based, essentially, on their applicability and the strength of the analysis. For the Ridge and Valley, we had substantially more data, including abundant data on stressor-response relationships. As a result, we were able to use all four lines of evidence: distribution based, modeled reference expectation, stressor-response and scientific literature based approaches.

Similar to the Allegheny Plateau distribution based approach, we assembled a large population of nutrient concentrations from various databases for sites ranging in quality. We identified the entire population of sites for one estimate, and identified a subset of minimally disturbed sites for a second estimate. The values estimated from these populations were between 10 and 15 µg/L TP in this ecoregion.

The modeled reference expectation produced significant models for both TP and TN in this ecoregion, so we did not have to rely on N:P ratios to estimate a TP endpoint using this line of evidence. The TP endpoint from modeled reference expectation was 7 µg/L. The TN generated from this approach was 209 µg/L. Most streams in the Ridge and Valley ecoregion, similar to the Allegheny Plateau and Piedmont, appear to be P limited systems. The median N:P ratio across the streams sampled was well above Redfield (16:1) and was actually 88:1. Using this ratio along with the TN endpoint, the TP endpoint would be 5 µg/L. Using the more conservative Redfield Ratio (16:1), combined with the TN endpoint, results in a TP value of 29 µg/L.

The stressor-response analyses led to a variety of endpoints that varied between 14 and 23 µg/L TP. The lowest threshold (14 µg/L) was observed in the EPT taxa response for the MBSS data and the highest threshold for the Percent Dominant 5 Taxa metric from the EMAP dataset (23 µg/L).

Finally, literature relevant to nutrient endpoints for this region ranged from approximately 10 µg/L TP (USEPA recommended criteria) to 60 µg/L (Dodds and Welch 2000), but most values were centered around 30 µg/L TP.

We weighted the stressor-response line of evidence most highly of the four lines we had available as it provided a direct linkage to use measures, and these results were higher than the distribution based and modeled reference values. Literature based values were, in terms of central tendency, closer to the upper end of the stressor-response derived values. As a result, we recommend a TP endpoint of 25 µg/L TP for streams of the Ridge and Valley.

- **Ridge and Valley recommended endpoint: 25 µg/L TP**

Table 3 – Summary of candidate endpoints for each of the analytical approaches discussed for the Ridge and Valley.

	Approach	TP Endpoint (µg/L)
Distribution Based		**10-15**
	Reference Site 75th Percentile	13-15
	All Sites 25th Percentile	10

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Modeled Reference			**10-15**
Stressor-Response			**14-23**
	MBSS		
		Total Taxa	14
		EPT Taxa	14
		Percent Scrapers	16
	EMAP		
		EPT Taxa	19
		Ephemeroptera Taxa	19
		Trichoptera Taxa	19
		Percent Dominant 5 Taxa	23
Other Literature			**13-100**
		USEPA Recommended Regional Criteria	10
		USEPA Regional Criteria Approach – Local Data	13
		Algal Growth Saturation	25-50
		Nationwide Meta-Study TP-Chlorophyll	21-60
		USGS Regional Reference Study	20
		USGS National Nutrient Criteria Study	13-20

Sample period

- **Endpoint applies from April to October**

We recommend applying the endpoint over the algal growing season (April to October), which in streams is typically the time during which the greatest risk of deleterious algal growth exists.

Sample duration

Unlike toxics, there is less literature to recommend appropriate sample duration and frequencies for nutrients. Toxics, with chronic and acute criteria, have a longer history of implementation. Their mode of action is also very different than nutrients. As a result, it was more difficult to recommend an appropriate sample period than to derive the endpoints themselves.

Humans tend to sample nutrients at temporal scales that are different than those to which stream organisms respond. Streams respond both to pulsed as well as chronic nutrient concentrations. For example, algae possess mechanisms to store nutrients and use these stored nutrients for growth over time – so they can respond to episodic inputs. Moreover, the responses to episodic inputs include both assemblage responses (for example, development the nuisance algal taxa) as well as population and individual responses (biomass).

The nutrient data we analyzed for the invertebrate and plant responses were based primarily on single grab samples associated with biological sampling. These analyses, therefore, represent a space for time substitution of sorts, estimating what would occur in a piedmont stream as nutrient concentrations increase.

These factors would recommend a not-to-exceed criterion. However, water velocity affects nutrient delivery in streams and elevated nutrients associated with high flows may not be as accessible to benthic algae. We also recognize that there is resistance to not-to-exceed standards and concern about the risk of capturing false positives, even though the risk of false negatives is similarly great. These concerns would recommend averaging multiple samples over some time period. Algal and microbial responses to nutrients can occur rapidly, but these can be offset by floods that scour the bottom and remove algae. At this time, there is limited information and we have had insufficient time to investigate appropriate averaging periods, especially those that result in conditions detrimental to uses.

- **Endpoint is assessed as the average TP concentration during the growing period over one year.**

As a result, for the purposes of these TMDLs, we recommend that the TP endpoint be applied as an average of water samples taken over the growing season. Realize, again, that there is less information to guide this recommendation, which is based principally on our professional judgment and in an attempt to be consistent with other typical duration procedures. A more conservative alternative would be to use the recommended endpoint as a not-to-exceed value, but again, we have had insufficient time to evaluate this.

We feel that this approach will be protective, but we strongly encourage the state and USEPA to investigate this issue more fully for the purposes of regional criteria development. For the TMDLs, this approach is sufficient, but it deserves more attention and resources before being applied to regional criteria.

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