Proposed Nutrient Criteria for Vermont's Lakes and Wadeable Streams

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1. Executive Summary

This report presents a proposal by the Vermont Department of Environmental Conservation for the incorporation of additional nutrient criteria into the Vermont Water Quality Standards. This proposal was developed in concert with the U.S. Environmental Protection Agency's National Strategy for the Development of Regional Nutrient Criteria.

Quantitative relationships were developed between various nutrient-related water quality measurements and the level at which water uses such as aesthetics and aquatic life are supported. Using these analyses, criteria were proposed corresponding to the management objectives defined in the Vermont Water Quality Standards for each water class and management type. The analysis was limited to Vermont inland lakes and reservoirs (not Lake Champlain or Lake Memphremagog) and wadeable streams.

Quantitative relationships between nutrient criteria variables and the level of use support were relatively weak in some cases. This was because of the incremental nature of nutrient impacts where sharp thresholds of response are rare, and because of the large variability among individual waterbodies in their response to nutrient enrichment.

The proposed criteria for lakes include values for spring total phosphorus (0.012 – 0.024 mg/L), spring total nitrogen (0.36 – 0.48 mg/L), summer total phosphorus (0.014 – 0.024 mg/L), summer chlorophyll-a (0.005 – 0.016 mg/L), and summer Secchi disk transparency (2.4 – 3.8 m). All lake criteria are intended to be expressed as long-term mean values based on monitoring of central, open-water locations in each lake.

The proposed criteria for wadeable streams include values for total phosphorus (0.010 – 0.044 mg/L) and total nitrogen (0.30 – 0.75 mg/L). The stream nutrient criteria are intended to be expressed as summer, low-flow values (e.g., as concentrations at low median monthly flow). Separate criteria were derived for each of three stream ecotypes: (1) small, high-gradient streams, (2) medium, high-gradient streams, and (3) warm-water, medium-gradient streams.

In light of the statistical uncertainties inherent in the analysis, the Water Quality Standards should establish a relative priority among the nutrient criteria variables for the purposes of water quality assessment and impairment listing. This is necessary in order to prevent false-positive assessments of use impairment based on phosphorus or nitrogen concentrations alone. It is recommended that causal variables (total phosphorus or nitrogen concentrations) be superseded by response variables (Secchi depth, chlorophyll-a, or stream biological condition) which provide more direct indications of use impairment. Under this hierarchy, phosphorus or nitrogen concentrations would be used to judge compliance with the Water Quality Standards if no other data existed (as in the case of predictive modeling for a new discharge), but if response variable data were available, the actual response measurements would be used to determine compliance with the Standards.

Nutrient criteria were proposed to correspond with the classification system currently in the Vermont Water Quality Standards involving separate management types within each class of waters. While it is possible that the current system of management types may be revised in the future, the establishment of nutrient criteria for tiered levels of use support is a useful approach that should be retained, particularly in the case of aquatic life uses.

Finally, the numeric criteria proposed in this report should be used to define the minimum acceptable water quality conditions necessary to support the uses, except in cases where the

conditions are due to natural background factors. For most Vermont lakes and streams, the existing conditions are much better than the minimum acceptable values. The existing high quality of these waters should be maintained through anti-degradation provisions in the Standards and by implementing strong lake and river protection programs.

2. Background and Purpose

Pollution of lakes, rivers, estuaries, and wetlands by plant nutrients such as phosphorus and nitrogen is a serious water quality problem nationwide. When present in excessive amounts, these nutrients can result in algae blooms, benthic algal mats, slime layers on rocks, poor water clarity, aquatic habitat degradation for other plants and animals, and impairment of drinking water supplies. The adoption of nutrient criteria in state water quality standards is one tool states can use to control nutrient levels in state waters in order to protect the uses of those waters.

The Vermont Department of Environmental Conservation (DEC) has been working to develop nutrient criteria for possible incorporation into the Vermont Water Quality Standards as part of a national effort led by the U.S. Environmental Protection Agency (USEPA). The USEPA issued a *National Strategy for the Development of Regional Nutrient Criteria* in 1998[1]. Key elements of the strategy included the following steps:

- Publication by USEPA of technical guidance manuals for developing nutrient criteria for each of four waterbody types: lakes[2], rivers[3], estuaries[4], and wetlands[5].
- Adoption by USEPA of ecoregion-specific nutrient criteria under Section 304(a) of the Clean Water Act.
- Establishment of Regional Technical Assistance Groups (RTAGs) to guide criteria development by states in each region.
- Adoption of numeric nutrient criteria by the States, based on the technical guidance documents, published Section 304(a) ecoregional nutrient criteria, and consultation with the RTAGs.

The USEPA has published Ecoregional Nutrient Criteria Documents containing Section 304(a) nutrient criteria for lakes, rivers, and estuaries in certain ecoregions. The published criteria include values for lakes and rivers in the three ecoregions applicable to Vermont. Each document presents recommended criteria for causal factors including total phosphorus and total nitrogen, and response variables including chlorophyll-a and either Secchi disk transparency or turbidity. The published Section 304(a) criteria are intended to serve as starting points for states and others to develop more refined nutrient criteria as appropriate, using USEPA waterbody-specific technical guidance manuals and other scientifically defensible approaches.

The Vermont DEC has been participating in the RTAG formed by the New England Region of USEPA. Vermont DEC provided monitoring data for regional and national nutrient databases assembled by USEPA to support the nutrient criteria effort. Vermont DEC staff have exchanged information and technical perspectives on nutrient criteria development with representatives of other states at RTAG meetings and national conferences.

As requested by USEPA, Vermont DEC submitted a draft *Vermont Plan for the Development of Nutrient Criteria for Lakes and Rivers* in 2002[6]. Vermont DEC received a grant from USEPA in 2004 to support the initial portion of the plan, which was to collect lake and stream data in Vermont to help quantify the relationships between nutrient variables and the support of designated water uses. The Department received a second grant from USEPA in 2005 to support the statistical analysis of the data obtained during 2004 along with other information, and to develop methods for deriving nutrient criteria appropriate for Vermont's lakes and wadeable streams.

The Vermont DEC submitted a report to USEPA titled *Developing Nutrient Criteria for Vermont's Lakes and Wadeable Streams*[7] as a draft for technical review in April 2007. The USEPA initiated an external scientific peer review of the report and provided helpful comments from the peer reviewers and USEPA staff to the Vermont DEC in November 2007. The present report includes revisions made by Vermont DEC in response to the review comments and additional analyses.

The Water Resources Panel of the Vermont Natural Resources Board has the statutory responsibility for establishing state water quality standards in Vermont. The Water Resources Panel adopts water quality standards through a public rulemaking process conducted according to the state's Administrative Procedures Act. The Vermont DEC provides technical advice to the Panel.

The purpose of this document is to present the results of the data analysis conducted by Vermont DEC and to provide a technical basis to support the development of nutrient criteria for Vermont's waters by the Water Resources Panel. The scope of this document is limited to Vermont lakes, ponds, reservoirs, and wadeable streams because of limitations in the data and analyses that are currently available. Methods for deriving nutrient criteria for larger rivers and wetlands in Vermont may be developed in the future.

3. Existing Nutrient Criteria in Vermont Water Quality Standards

A. Phosphorus

The Vermont Water Quality Standards[8] contain both narrative and numeric total phosphorus criteria applicable to certain waters (Section 3-01-B-2). The general narrative criterion for phosphorus is as follows:

> *In all waters, total phosphorus loadings shall be limited so that they will not contribute to the acceleration of eutrophication or the stimulation of the growth of aquatic biota in a manner that prevents the full support of uses.*

The general policy for upland streams (all streams above 2,500 feet in elevation) is that *total phosphorus shall not exceed 0.010 mg/L at low median monthly flow.*

The Vermont Water Quality Standards include numeric total phosphorus concentration criteria for each segment of Lake Champlain and Lake Memphremagog. The phosphorus criteria range from 0.010 to 0.054 mg/L among 12 segments of Lake Champlain and two segments of Lake Memphremagog (Table 1). The criteria apply as the annual mean total phosphorus concentration in the photosynthetic depth (euphotic) zone in central, open water areas of each lake segment.

Table 1. Total phosphorus criteria for Lake Champlain and Lake Memphremagog in the Vermont Water Quality Standards.

Lake Segment		Total Phosphorus Criterion (mg/L)
Lake Champlain		0.010
	Main Lake	0.010
	Malletts Bay	0.014
	Burlington Bay	0.014
	Shelburne Bay	0.014
	Northeast Arm	0.014
	Isle LaMotte	0.014
	Otter Creek	0.014
	Port Henry	0.014
	St. Albans Bay	0.017
	Missisquoi Bay	0.025
	South Lake A	0.025
	South Lake B	0.054
Lake Memphremagog		
	Main Lake	0.014
	South Bay	0.025

The phosphorus criteria for Lake Champlain in the Vermont Water Quality Standards were endorsed by the States of Vermont and New York and the Province of Quebec in a 1993 Lake Champlain Water Quality Agreement[9] as a consistent set of management goals for the lake. These joint criteria are incorporated into the basin plan *Opportunities for Action*[10] adopted by the Lake Champlain Basin Program. The criteria also serve as the basis for the Lake Champlain

Phosphorus TMDL[11] prepared by Vermont and New York and approved by the USEPA in November 2002. Since the existing Lake Champlain phosphorus criteria are the foundation for major planning efforts and management agreements on the lake, it is essential to preserve these criteria in the Vermont Water Quality Standards as the process of further nutrient criteria development proceeds under the USEPA initiative.

Lakes, ponds, and reservoirs that have a drainage area less than 40 square miles and a drainage area to surface area ratio less than 500:1 are given special protection from phosphorus discharges in the Vermont Water Quality Standards. In these waters, *there shall be no significant increase over currently permitted phosphorus loadings.* No discharge may increase the in-stream total phosphorus concentration in a tributary by more than 0.001 mg/L at low median monthly flow, and no indirect discharge may increase the total dissolved phosphorus concentration in the groundwater 100 feet from the lake by more than 0.001 mg/L.

B. Nitrates

The general policy in the Vermont Water Quality Standards for nitrates is as follows:

> *In all waters, nitrates shall be limited so that they will not contribute to the acceleration of eutrophication or the stimulation of the growth of aquatic biota in a manner that prevents the full support of uses.*

The Vermont Water Quality Standards include the following numeric criteria for nitrates (Table 2). The nitrate criteria for flowing waters are not to be exceeded at flows exceeding low median monthly flows.

C. Turbidity

The Vermont Water Quality Standards include the following numeric criteria for turbidity (Table 3), depending on the classification of the waterbody.

Table 2. Nitrate criteria in the Vermont Water Quality Standards.

Waterbody Type	Nitrate Criterion (mg/L NO_3-N)
Lakes, ponds, and reservoirs, not including riverine impoundments	5.0
Other Class A(1) and A(2) waters above 2,500 feet elevation	0.20
Other Class A(1) and A(2) waters at or below 2,500 feet elevation	2.0
Other Class B waters	5.0

Table 3. Turbidity criteria in the Vermont Water Quality Standards.

Classification	Turbidity Criterion (NTU)
A(1) Ecological waters	10
A(2) Public water supplies	10
B Waters - cold water fish habitat	10
B Waters - warm water fish habitat	25

4. USEPA Section 304(a) Ecoregional Nutrient Criteria

Vermont lies within three aggregate ecoregions, with one Level III subregion within each aggregate region (Figure 1, Table 4). The Section 304(a) nutrient criteria published by the USEPA include values for lakes and rivers in each of these aggregate ecoregions and subregions.

Table 4. Aggregate ecoregions and subregions in Vermont.

Aggregate Ecoregion		Level III Subregion		Number of Lakes
VII	Mostly Glaciated Dairy Region	83	Eastern Great Lakes and Hudson Lowlands	87
VIII	Nutrient Poor Largely Glaciated Upper Midwest and Northeast	58	Northeastern Highlands	458
XIV	Eastern Coastal Plain	59	Northeastern Coastal Zone	13

There are 820 known lakes, ponds, and reservoirs in Vermont, including segments of Lake Champlain. A total of 558 of these lakes are included in the Vermont lake assessment database where lake impairments are tracked for Clean Water Act sections 303(d) and 305(b) reporting. These 558 waterbodies comprise over 99% of the total lake acreage in the state. Most Vermont lakes are in the Northeastern Highlands Subregion (No. 58), as indicated in Table 4.

The USEPA Section 304(a) nutrient criteria for lakes in the ecoregions applicable to Vermont are listed in Table 5. The criteria for rivers and streams are listed in Table 6.

Table 5. USEPA Section 304(a) lake nutrient criteria for Vermont ecoregions[12,13,14].

	Ecoregion VII		Ecoregion VIII		Ecoregion XIV	
Parameter	**Aggregate**	**Subregion 83**	**Aggregate**	**Subregion 58**	**Aggregate**	**Subregion 59**
TP (µg/L)	14.75	11.25	8.0	7.0	8.0	8.0
TN (mg/L)[a]	0.66	0.42	0.24	0.20	0.32	0.32
Chl-a (µg/L)[b]	2.63	2.84	2.44	2.52	2.9	4.2
Secchi (m)	3.33	4.75	4.93	5.1	4.5	4.9

[a] reported (not calculated) [b] fluorometric technique

Table 6. USEPA Section 304(a) rivers and streams nutrient criteria for Vermont ecoregions[15,16,17].

	Ecoregion VII		Ecoregion VIII		Ecoregion XIV	
Parameter	**Aggregate**	**Subregion 83**	**Aggregate**	**Subregion 58**	**Aggregate**	**Subregion 59**
TP (µg/L)	33.0	24.13	10.0	5.0[c]	31.25	--
TN (mg/L)[a]	0.54	0.48	0.38	0.42	0.71	--
Chl-a (µg/L)[b]	1.54	1.64	0.63	–	--	--
Turbidity (NTU)	1.7	1.50	0.81	0.80	--	--

[a] reported (not calculated) [b] fluorometric technique

[c] This value appears to be incorrectly derived from total ortho-phosphorus (not total phosphorus) distributions.

– indicates criterion not established.

As explained in the USEPA 304(a) nutrient criteria documents, the values in Tables 5 and 6 are the lower 25th percentiles for the frequency distributions of each parameter among all lakes or streams within the ecoregion, including data from all seasons during 1990-1999. This was an approximately equivalent alternative to the preferred approach described in the USEPA technical guidance manuals of selecting the upper 75th percentiles from the distributions among reference (minimally impacted) lakes in each ecoregion.

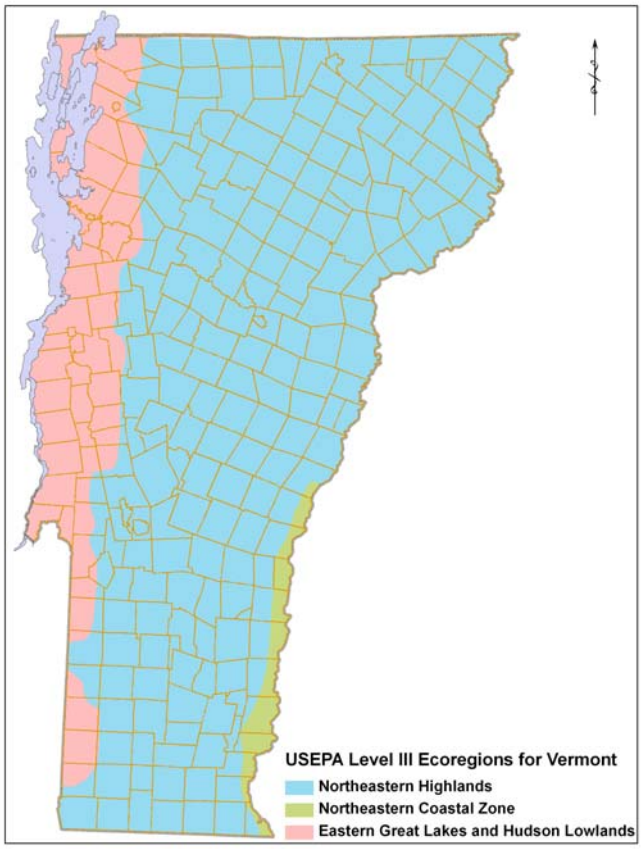

Figure 1. Level III ecoregions for Vermont.

This method of deriving nutrient criteria has the serious disadvantage that the values represent somewhat arbitrarily chosen points on the frequency distributions of each parameter and have no quantified relationships with the water quality characteristics necessary to support the uses for these waters specified in the Vermont Water Quality Standards. Adoption of the EPA 304(a) criteria in state water quality standards would ensure that around 75% of the lakes and streams in these ecoregions would fail to attain the criteria, regardless of whether the uses were supported. For this reason, Vermont DEC chose to take a different approach in most cases to develop nutrient criteria for Vermont waters. Quantitative relationships were developed between nutrient criteria variables and the actual level of use support, as described in later sections of this document.

5. Classification Framework in Vermont Water Quality Standards

The Vermont Water Quality Standards currently classify waters into the following three major categories:

Class A(1)	Ecological waters
Class A(2)	Public water supplies
Class B	All other waters

The Standards also indicate that all Class B waters shall eventually be designated as one of three Water Management Types (1, 2, or 3).

The Vermont Water Quality Standards state that waters shall be managed to achieve and maintain a level of quality that fully supports specific designated uses. The designated uses that must be supported in each class of waters are listed in Table 7.

Table 7. Designated uses applicable to each major water class in the Vermont Water Quality Standards.

Designated Uses	Water Classes
Aquatic Biota, Wildlife, and Aquatic Habitat	A(1), A(2), B
Aesthetics	A(1), A(2), B
Swimming and Other Primary Contact Recreation	A(1), A(2), B
Boating, Fishing, and Other Recreational Uses	A(1), A(2), B
Public Water Supplies	A(2), B
Irrigation of Crops and Other Agricultural Uses	B

This report will focus primarily on developing nutrient criteria to protect the first two designated uses listed in Table 7 (aquatic biota, wildlife, and aquatic habitat; and aesthetics). These two designated uses have the best data available for use in linking nutrient criteria variables to the level of use support in Vermont lakes and streams. In focusing on these two designated uses, we are making the assumption that nutrient criteria that protect aquatic biota, wildlife, aquatic habitat, and aesthetics uses will also be adequately protective of the other uses listed in Table 7. For example, we are assuming that nutrient impacts on recreational uses such as swimming, boating, and fishing are related primarily to the aesthetic condition of the water (e.g., the degree of water clarity and algal growth present). We are also assuming that waters that meet their aesthetics criterion for nutrients will also be free of nutrient-related impairments to public water supplies or agricultural uses (e.g., that aesthetically acceptable water will be suitable from a nutrient standpoint for water supplies with filtration and disinfection).

The Vermont Water Quality Standards define management objectives and criteria for each of the designated uses listed in Table 7. The management objectives and criteria vary for a particular use, depending on the classification and management type. The designated uses and associated management objectives for each class of water are summarized in Table 8 for aquatic biota, wildlife, and aquatic habitat uses, and in Table 9 for aesthetics uses.

Table 8. Management objectives and criteria for aquatic biota, wildlife, and aquatic habitat uses in the Vermont Water Quality Standards (bold emphasis added).

Aquatic Biota, Wildlife, and Aquatic Habitat	
Class	**Objectives**
A(1)	Consistent with waters in their **natural condition**.
A(2)	**High quality** aquatic biota and wildlife sustained by high quality aquatic habitat necessary to support their life-cycle and reproductive requirements.
B	Aquatic biota and wildlife sustained by **high quality** aquatic habitat with additional protection in those waters where these uses are sustainable at a higher level based on Water Management Type designation.
	Criteria
A(1)	Change from the natural condition limited to **minimal impacts** from human activity. Measures of biological integrity for aquatic macroinvertebrates and fish assemblages are **within the range of the natural condition**. Uses related to either the physical, chemical, or biological integrity of the aquatic habitat or the composition or life cycle functions of aquatic biota or wildlife are fully supported. All life cycle functions, including overwintering and reproductive requirements are maintained and protected.
A(2)	Biological integrity is maintained, no change from the reference condition that would prevent the full support of aquatic biota, wildlife or aquatic habitat uses. Change from the reference condition for aquatic macroinvertebrates and fish assemblages shall not exceed **moderate changes** in the relative proportions of taxonomic, functional, tolerant and intolerant components. All expected functional groups are present in a **high quality habitat** and none shall be eliminated. All life cycle functions, including overwintering and reproductive requirements are maintained and protected. Changes in the aquatic habitat shall not exceed **moderate differences from the reference condition** consistent with full support of all aquatic biota and wildlife uses.
B(untyped)	**No change from reference conditions that would have an undue adverse effect** on the composition of the aquatic biota, the physical or chemical nature of the substrate or the species composition or propagation of fishes.
B(1)	Change from the reference condition for aquatic macroinvertebrate and fish assemblages shall be limited to **minor changes** in the relative proportions of taxonomic and functional components; relative proportions of tolerant and intolerant components are within the range of the reference condition. Changes in the aquatic habitat shall be limited to **minimal differences from the reference condition** consistent with the full support of all aquatic biota and wildlife uses.
B(2)	Change from the reference condition for aquatic macroinvertebrate and fish assembledges shall be limited to **moderate changes** in the relative proportions of tolerant, intolerant, taxonomic, and functional components. Changes in the aquatic habitat shall be limited to **minor differences from the reference condition** consistent with the full support of all aquatic biota and wildlife uses.
B(3)	Change from the reference condition for aquatic macroinvertebrate and fish assemblages shall be limited to **moderate changes** in the relative proportions of tolerant, intolerant, taxonomic, and functional components. Changes in the aquatic habitat shall be limited to **moderate differences from the reference condition** consistent with the full support of all aquatic biota and wildlife uses. When such habitat changes are a result of hydrological modification or water level fluctuation, compliance may be determined on the basis of aquatic habitat studies.

Table 9. Management objectives and criteria for aesthetics uses in the Vermont Water Quality Standards (bold emphasis added).

Aesthetics	
Class	**Objectives**
A(1)	Water character, flows, water level, bed and channel characteristics, and flowing and falling waters in their **natural condition**.
A(2)	Water character, flows, water level, and bed and channel characteristics **consistently** exhibiting **(excellent)**[a] aesthetic value.
B	Water character, flows, water level, bed and channel characteristics, exhibiting **good** aesthetic value and, where attainable, excellent aesthetic value based on Water Management Type designation.
	Criteria
B (untyped)	Water of quality that **consistently** exhibits **good** aesthetic value.
B(1)	**Consistently** exhibit **excellent** aesthetic values.
B(2)	**Consistently** exhibit **very good** aesthetic values.
B(3)	Seasonal and temporal **variability** may be allowed provided that **good** aesthetic value is achieved.

[a] The February 9, 2006 and subsequent versions of the Vermont Water Quality Standards omit the word "excellent" from the management objectives for aesthetics for Class A(2) waters. It will be assumed for this paper that this omission was inadvertent, and that the term "excellent" was intended here, as in previous versions of the Standards.

This classification framework in the Vermont Water Quality Standards with its specific management objectives and criteria for multiple water classes and management types for both aquatic life and aesthetics uses presents a major technical challenge in deriving nutrient criteria for Vermont's waters. Numeric distinctions within water quality gradients must be made for terms such as "natural condition," "minor" and "moderate" biological changes, and "excellent," "very good," and "good" aesthetic value.

6. Criteria for Vermont Lakes

A. Data Sources and Nutrient Criteria Variables

USEPA technical guidance for nutrient criteria for lakes and reservoirs suggests considering both causal variables such as total phosphorus and total nitrogen, and response variables such as chlorophyll-a and Secchi disk transparency. The major water quality and biological data sets available to support lake nutrient criteria development for Vermont inland lakes (i.e., lakes other than Lake Champlain and Lake Memphremagog) were derived from long-term monitoring programs such as the Vermont Spring Phosphorus Monitoring Program and the Vermont Lay Monitoring Program, and from the Vermont Lake Bioassessment Project. These programs are described in the Vermont 2008 Water Quality Assessment (305b) Report[18], and all operate according to USEPA-approved quality assurance project plans.

Spring Total Phosphorus and Total Nitrogen

Under the Spring Phosphorus Program, lakes 20 acres or larger in size are sampled during spring overturn on one date per sampling year. The database contains 2,169 lake-year records on 273 different lakes sampled for spring total phosphorus (TP) at least once during 1977-2007. Vertically-integrated, total depth (hose) samples are obtained in triplicate at one to three stations on each lake, and the sample results are averaged to produce a single spring TP concentration value for that year. The program has included sampling for total nitrogen (TN) since 1998 using the same sampling methods. There are 676 lake-year records for spring TN on 237 different lakes.

Summer Total Phosphorus, Chlorophyll-a, and Secchi Disk Transparency

The Vermont Lay Monitoring Program is a citizen volunteer monitoring program that has been operated by Vermont DEC continuously since 1979. Weekly summer (June-August) sampling is conducted for TP, chlorophyll-a (Chl), and Secchi disk transparency (Secchi depth). TP and Chl samples are obtained as vertically-integrated (hose) composites of the photic zone (twice the Secchi depth on the day of sampling). Sample results are averaged by year to produce estimates of mean summer conditions. The Lay Monitoring Program database includes 1,833 lake-year records on 88 different Vermont inland lakes through 2007, although not all variables are measured on each lake every year.

Lake User Survey

A lake user survey[19] was conducted in conjunction with the Vermont Lay Monitoring Program during 1987-1991, and again during 2006-2007. The relationships between total phosphorus measurements and user perceptions of water quality were used to derive phosphorus criteria in Vermont's Water Quality Standards for portions of Lake Champlain, as described in Appendix B (Case Studies) of the USEPA (2000) *Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs*. A similar user survey was conducted on Vermont inland lakes, and the results are available to support criteria development for these lakes, as well. The user survey database includes 2,503 individual user responses paired with simultaneous measurements of one or more nutrient criteria variables (TP, Chl, and/or Secchi depth) on 75 different inland lakes in Vermont.

The user survey form consisted of two parts. Part A sought a description of the physical condition of the lake water, while Part B (shown below) sought an opinion on the suitability of the lake water for recreation and aesthetic enjoyment. The responses to Part B were used for this analysis because they related more closely to the management objectives for aesthetics as defined in the Vermont Water Quality Standards (Table 9). The lay monitors were asked to

provide an evaluation using this form each time they obtained measurements of TP, Chl-a, or Secchi depth.

Vermont Lake User Survey Form (Part B)

Please circle the one number that best describes your opinion on how suitable the lake water is for recreation and aesthetic enjoyment today.

1. Beautiful, could not be any nicer.
2. Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
3. Swimming and aesthetic enjoyment slightly impaired because of algae levels.
4. Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels.
5. Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

Vermont Lake Condition Biological Index

Since 1996, the Vermont Lake Bioassessment Project has developed indicators of aquatic life use attainment for lakes. The project was designed to develop indices of biotic integrity for macroinvertebrates, phytoplankton, and macrophytes. This data set has been periodically re-analyzed with the goal of developing multimetric biological indices for each guild.

Biological indices are typically constructed of a suite of consistently measurable biometrics that discriminates naturally-occurring from degraded ecological conditions. Multimetric indices are constructed to account for natural variation expected across classes within which unimpacted, or reference waterbodies express similar biological characteristics. To date, class-specific multimetric indices assessing phytoplankton[20] and macroinvertebrate[21] guilds have been successfully developed.

The Vermont Lake Condition Biological Indices (VLCBI) for macroinvertebrates and phytoplankton are specific to one of three defined waterbody classes: small low-alkalinity lakes; small well-buffered lakes; and, large lakes, and relate biological condition to the criteria expressed in Table 8. VLCBI scores are reported on a scale of 0-100.

An important premise of using the VLCBI to derive nutrient criteria is that there exists a predictable relationship between the causal variables (TP, TN) and the index scores. The VLCBI for phytoplankton has been shown to respond predictably to changes in spring and summer TP concentrations, but not spring TN (ANOVA, summer: $F_{3, 19} = 4.59$, $p = 0.0168$; spring: $F_{3,44} = 7.93$, $p = 0.0003$). The VLCBI for macroinvertebrates does not vary with summer TP or spring TN ($p > 0.1$). Therefore, only the VLCBI for phytoplankton was considered in the derivation of nutrient criteria for Vermont lakes. In the development of nutrient criteria to protect aquatic life uses, Secchi depth and Chl were considered to be responses to nutrient enrichment rather than stressors of ecological integrity. For this reason, the analysis of nutrient criteria using the VLCBI was limited to TP and TN.

Physical Factors, Land Use, Ecoregion

In addition to the water quality and biological monitoring results, the Vermont DEC Lakes and Ponds Inventory database includes a variety of other information about each lake, including

location, physical characteristics, and watershed land use. This information was available in database format to support lake nutrient criteria analysis.

B. Criteria for Natural Condition

The management objectives in the Vermont Water Quality Standards for both aquatic biota and aesthetics in Class A(1) waters are to maintain water character and biological features in their natural condition (Tables 8 and 9). This is one case where the application of the USEPA approach of defining a criterion from the frequency distributions for minimally impacted reference lakes may be appropriate, since the use to be protected is specifically defined as the "natural condition."

Lakes with primarily natural watersheds were chosen for this analysis, including all sampled Vermont lakes with less than 5% agricultural or developed land in their watersheds. The cumulative frequency distributions for each water quality monitoring variable in lakes with natural watersheds are shown in Figure 2. These curves represent the distributions of long-term means for each variable among these lakes (i.e., the mean of all spring or summer mean values for all years sampled). The long-term mean values for each variable in each lake were $\log_{10}$-transformed for normality, and the normal distribution parameters (mean, variance) were calculated from the log-scale values to produce these plots using the cumulative normal distribution function.

USEPA guidance recommends that nutrient criteria be specific to each ecoregion because natural physical and geological factors that vary among ecoregions may influence the natural or attainable trophic state of lakes and streams. For this reason, separate distributions are shown in Figure 2 for each sub-ecoregion in Vermont (Figure 1) where data existed on a sufficient number of lakes. There were no natural-watershed lakes having monitoring data in the Northeastern Coastal Zone sub-ecoregion, and too few natural-watershed lakes (N=5) sampled for summer TP, summer Chl, or summer Secchi depth in the Eastern Great Lakes and Hudson Lowlands sub-ecoregion to support separate calculation of the cumulative frequency distributions. Consequently, the frequency distributions for summer TP, summer Chl, and summer Secchi depth were combined to include all natural-watershed lakes, regardless of sub-ecoregion.

The distributions of long-term mean spring TP values were significantly different between the Northeastern Highlands and the Eastern Great Lakes and Hudson Lowlands sub-ecoregions (t-test for difference between means, $p<0.05$). Natural spring TP concentrations tended to be higher in the Eastern Great Lakes and Hudson Lowlands sub-ecoregion (essentially the Lake Champlain Valley). There was no significant difference in the spring TN distributions between these two sub-ecoregions. USEPA guidance was followed in using the 75th percentile (25th percentile for Secchi depth) of the frequency distributions for minimally impacted (reference) lakes in order to select criteria values to protect natural conditions. This method resulted in proposed criteria for spring TP (0.012 or 0.016 mg/L depending on sub-ecoregion), spring TN (0.36 mg/L), summer TP (0.014 mg/L), summer Secchi depth (3.8 m), and summer Chl (0.005 mg/L). All proposed criteria are expressed as long-term mean values.

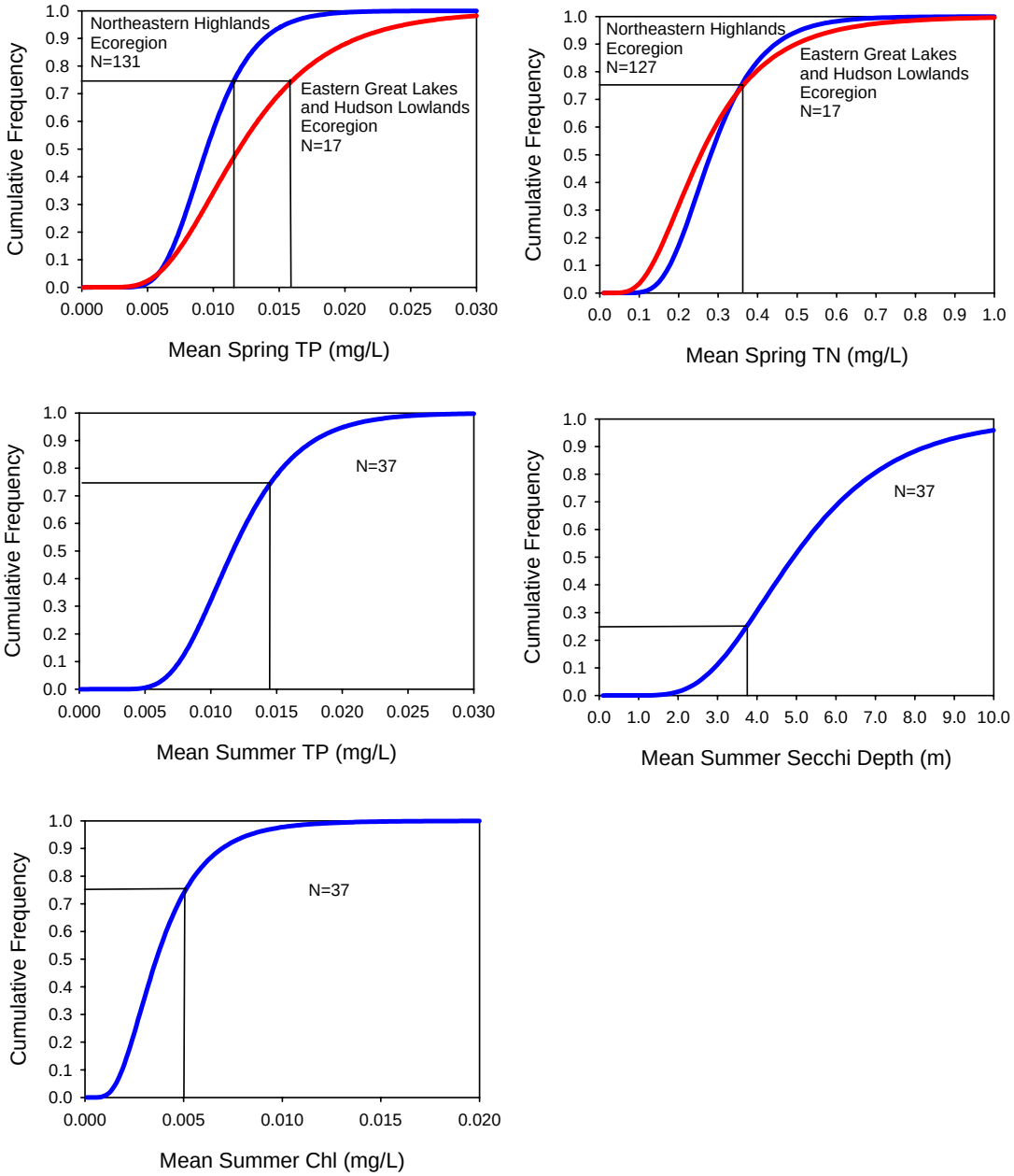

Figure 2. Cumulative frequency distributions of long-term means for lake variables in lakes with natural watersheds (<5% developed or agricultural land). Cumulative normal distribution parameters were calculated from $\log_{10}$-transformed data. Drop lines show proposed criteria values at the 75th percentile (25th for Secchi depth).

C. Criteria for Aesthetics Uses

The responses to the lake user survey form used by the Vermont Lay Monitoring Program provided a measure of the extent to which water quality in the monitored lakes attained the management objectives for aesthetics as defined in the Vermont Water Quality Standards. The correspondence between user survey form responses and the water quality management objectives of "excellent," "very good," and "good" aesthetic value is shown in Table 10.

For the purposes of this analysis, user responses of (1) beautiful or (2) only very minor aesthetic problems were considered to represent attainment of the Class A(2) and B(1) standard of excellent aesthetic value. User responses of (3) no more than slight impairment of enjoyment were considered to represent attainment of the Class B(2) standard of very good aesthetic value and the Class B and B(3) standard of good aesthetic value. The user survey response form did not provide a basis for distinguishing between "good" and "very good" conditions. User survey responses of (4) enjoyment substantially reduced or (5) enjoyment nearly impossible were considered to represent non-attainment of the aesthetic standards.

Table 10. Correspondence between water quality standards for aesthetics and lake user survey responses.

Class (Type)	Water Quality Standard[1]	Lake User Survey Response
A(1)	Natural condition	The user survey was not used to define natural condition.
A(2), B(1)	Excellent aesthetic value	(1) Beautiful, could not be any nicer, or (2) Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
B(2)	Very good aesthetic value	(3) Swimming and aesthetic enjoyment slightly impaired because of algae levels.
B, B(3)	Good aesthetic value	(3) Swimming and aesthetic enjoyment slightly impaired because of algae levels.
	Non-attainment	(4) Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels, or (5) Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

[1] Management objectives and criteria for aesthetics (Table 9)

The lake water quality monitoring data and user survey responses were analyzed using conditional probability analysis as a method to identify thresholds of water quality conditions where attainment of the aesthetics standards becomes unlikely. Conditional probability analysis[22,23] is a procedure that identifies the probability of observing one event, given that another event has occurred. For example, conditional probability analysis answers the question "what is the probability of a user survey response of 'excellent' or better aesthetic conditions in lakes with mean spring TP values above 0.020 mg/L?" In the context of this nutrient criteria analysis, the probabilities of attaining particular aesthetics standards were computed, given the measured lake water quality conditions (e.g., TP, TN, Secchi depth, and Chl values).

The ideal situation for identifying threshold values for water quality criteria would be one in which the response (e.g., the probability of attaining the aesthetics standard) would be relatively insensitive to increasing stressor levels (e.g., increasing TP, TN, or Chl concentrations) until a certain point was reached where higher stressor levels resulted in widespread non-attainment. In

reality, however, the probability of standards attainment usually declines gradually with increasing nutrient concentrations, and the thresholds are not sudden and sharp.

Conditional probability analysis was used to help identify such thresholds where they existed in the data, but the potential criteria values were reviewed in additional ways as well. The steps used to derive proposed criteria for lakes were as follows:

1) Potential criteria values were identified from visually-determined change-points in conditional probability plots.
2) The original data were examined to verify that the change-points derived from the conditional probability plots correctly identified values for the water quality variables beyond which the probability of an adverse response noticeably increased.
3) Professional judgment of Vermont DEC staff and their experience with the management of Vermont's lakes were used to verify that the proposed criteria appropriately distinguished between known problem lakes and those where aesthetics uses seemed well supported.
4) An analysis was done to ensure that lakes having water quality measurements at or better than the proposed criteria had an appropriately high probability of attainment of the use standards.

The software application CProb was used to generate conditional probability plots for each lake water quality monitoring variable. Confidence intervals were generated using a bootstrap resampling procedure in CProb. The conditional probability analysis results for lake aesthetics are shown in Figure 3.

The entire data set of individual user responses was used with long-term mean values for the water quality variables for each lake to generate the conditional probability plots in Figure 3. These plots show the proportion of all user survey responses (Y-axis) representing a particular aesthetic condition among all lakes having mean TP, TN, or Chl values greater than or equal to (or mean Secchi depth less than or equal to) the corresponding values on the X-axis.

Two lake aesthetics conditions are shown on each plot. The lower curve shows the probability of a user response of no worse than "excellent with very minor problems" (user survey form response numbers 1 or 2) corresponding to attainment of the Class A(2) and B(1) aesthetics standards. The upper curve shows the probability of a user response of no worse than "slight impairment" (user survey form response numbers 1, 2, or 3) corresponding to attainment of the Class B, B(2) or B(3) aesthetics standards.

In the case of spring TP and spring TN, the change-point thresholds were fairly well-defined for the Class B, B(2) or B(3) aesthetics standards at about 0.024 mg/L for spring TP and 0.48 mg/L for spring TN. Examination of the underlying data identified thresholds for the Class A(2) and B(1) aesthetics standards at 0.014 mg/L for spring TP and 0.40 mg/L for spring TN. The thresholds for summer TP were less distinct, although there appeared to be a change-point at about 0.014 mg/L for the Class A(2) and B(1) standards, and at 0.030 mg/L for the Class B, B(2) or B(3) standards. However, no lakes in the data set had mean summer TP values between 0.022 and 0.029 mg/L so the actual change-point could have been anywhere within this range. For this reason, and for consistency with the spring TP criterion, a summer TP aesthetics criterion of 0.024 mg/L was chosen for Class B, B(2) and B(3) lakes.

Thresholds for summer Secchi depth were more difficult to discern. However, a slight steepening of the curve was apparent below about 2.4 m for the "no worse than slight impairment" condition, and below about 3.8 m for the "no worse than excellent with very minor problems"

condition. Examination of the original user survey data confirmed that transitions in the frequency of attainment of these uses occurred at these mean Secchi depth values. Similar thresholds for summer Chl occurred at 0.016 mg/L for the “no worse than slight impairment” condition and at 0.009 mg/L for the “no worse than excellent with very minor problems” condition.

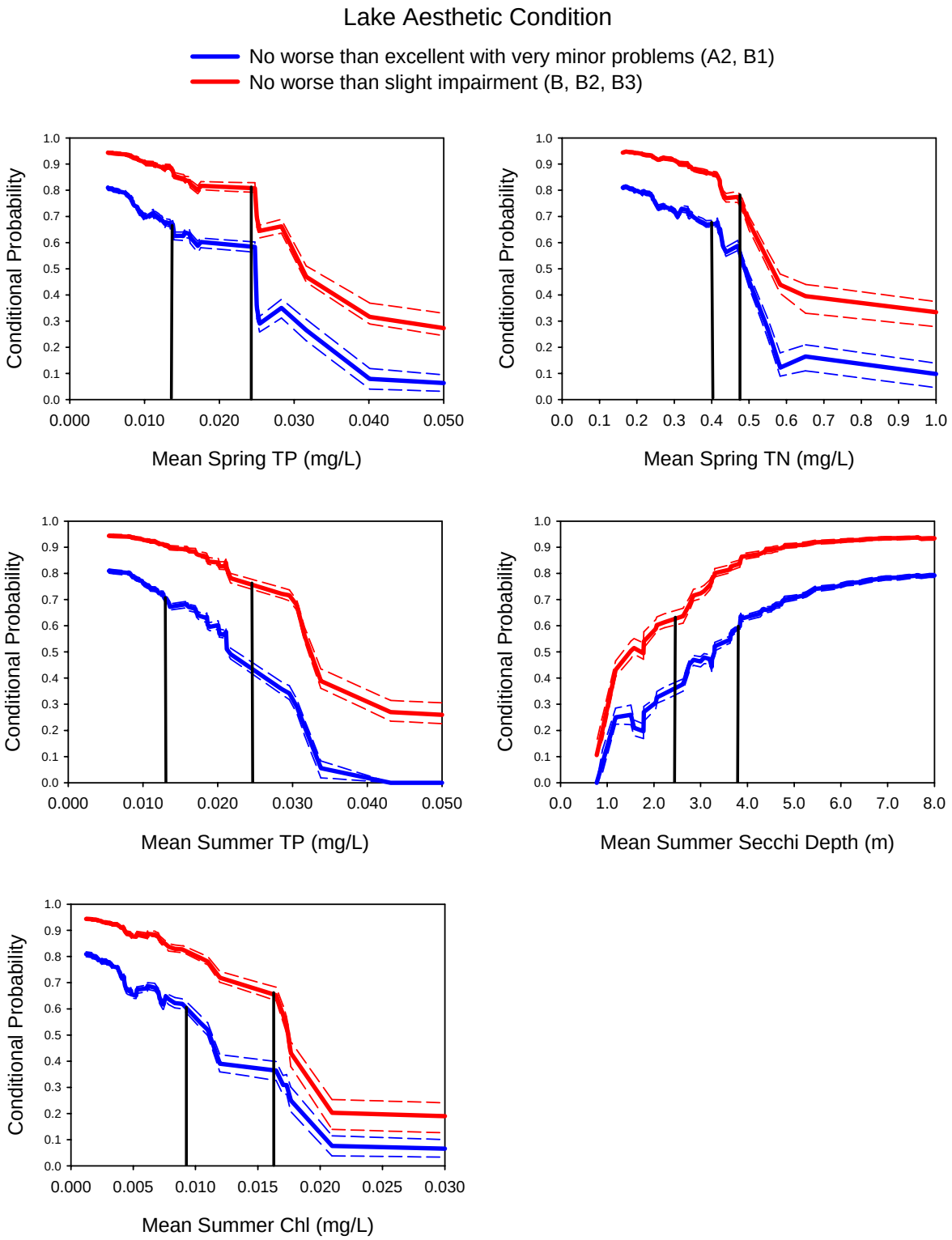

Figure 3. Conditional probability plots for lake aesthetic condition. Curves show the probability of attainment of the indicated aesthetic condition for lakes with water quality long-term mean values greater than or equal to the corresponding value on the X-axis (less than or equal to for Secchi depth). Dotted lines show 95% confidence intervals. Drop lines show proposed criteria values.

D. Criteria for Aquatic Life Uses

The VLCBI scores for phytoplankton in the assessed lakes were used to determine attainment of the management objectives for aquatic life as defined in the Vermont Water Quality Standards. The correspondence between VLCBI scores and the water quality criteria of "natural condition," "minor change from reference," and "moderate change from reference" vary by lake type as shown in Table 11.

Table 11. Vermont Lake Condition Biological Index (phytoplankton) score threshold values in relation to Vermont Water Quality Standards criteria.

Criteria, Class (type)	Lake class		
	Well buffered	Low alkalinity	Large
Natural condition, A(1)	≥57	≥73	≥86
Minor change from reference, B(1)	≥45	≥60	≥64
Moderate change from reference, A(2), B(2), B(3), B	≥33	≥47	≥42
Non-attainment	<33	<47	<42

The lake water quality monitoring data and VLCBI scores were analyzed using conditional probability analysis to identify thresholds of water quality conditions where attainment of the aquatic life criteria becomes unlikely. For this analysis, the probabilities of attaining particular aquatic life criteria were computed given the measured spring TP, summer TP, and spring TN long-term mean values for each lake.

Individual VLCBI score values were paired with long-term mean values for nutrients for each lake to generate the conditional probability plots in Figure 4. Where individual lake data points for summer or spring TP were missing, statistical regression relationships were used to calculate estimated concentrations. These plots show the proportion of assessed lakes (Y-axis) exhibiting attainment of a given aquatic life criterion among all assessed lakes having mean TP or TN value greater than or equal to the corresponding values on the X-axis.

As with the aesthetics analysis, two aquatic life conditions are shown on each plot. The lower curve shows the probability of lakes exhibiting no more than a minor change from reference while the upper curve shows the probability of lakes exhibiting no more than a moderate change from reference. Owing to the small size of this data set (N = 48 lakes) relative to the aesthetics data set, the confidence limits are wide.

In the case of spring TP, change-point thresholds were fairly well-defined at 0.014 mg/L indicating no more than a minor change from reference, and at 0.024 mg/L indicating no more than a moderate change from reference. These values coincided with the criteria derived for lake aesthetics uses. For summer TP and spring TN, change-points were very difficult to discern. Therefore no aquatic life criteria were proposed for summer TP or spring TN, and instead the values derived from the aesthetics analysis were assumed to be protective of aquatic life uses.

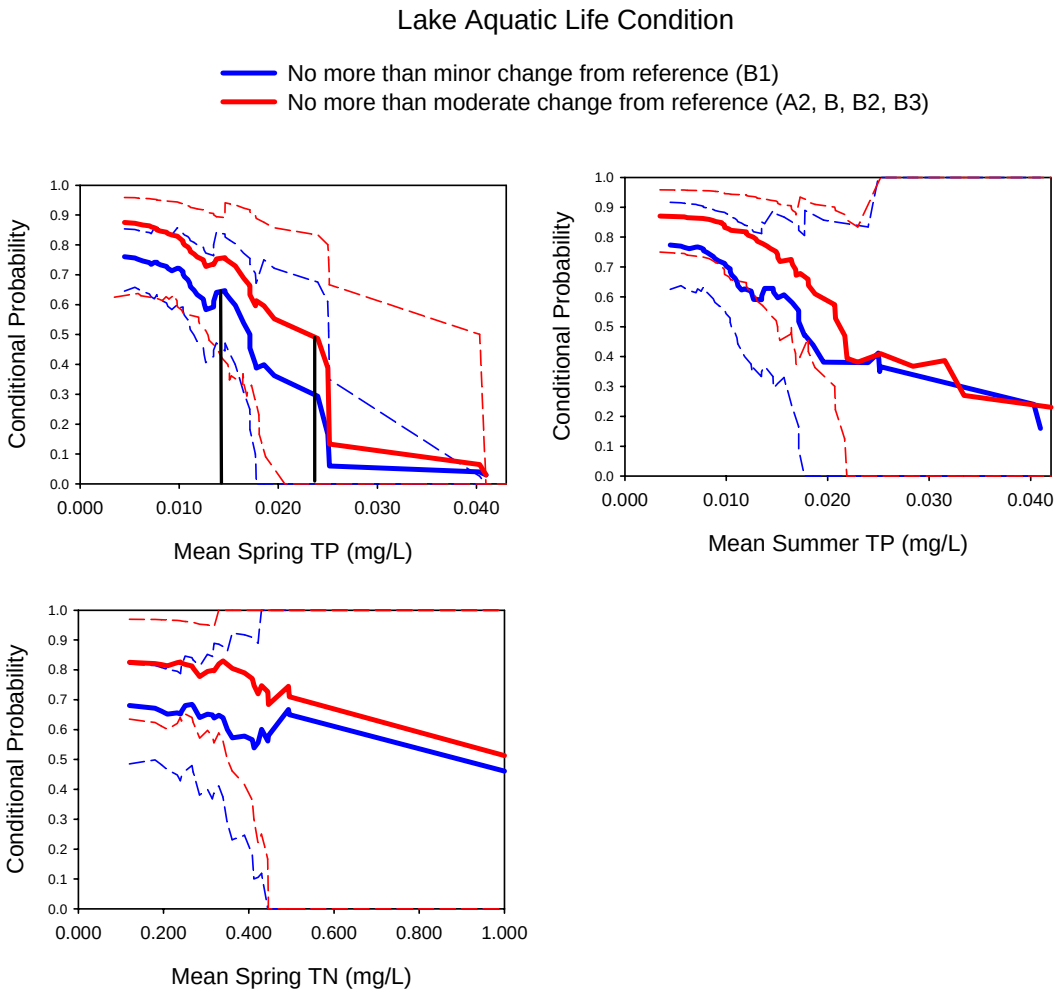

Figure 4. Conditional probability plots for lake aquatic life condition. Curves show the probability of attainment of the indicated biological condition for lakes with water quality long-term mean values greater than or equal to the corresponding value on the X-axis. Dotted lines show 95% confidence intervals. Drop lines show proposed criteria values (Spring TP only).

E. Summary of Proposed Criteria for Lakes

A summary of the proposed nutrient criteria for lakes is provided in Table 12. The criteria for aesthetics and aquatic life uses were derived as explained in previous sections of this report, and both were used to propose "effective criteria" for the Vermont Water Quality Standards.

Where the spring TP values derived for a particular water class differed for aesthetics uses vs. aquatic life uses, the lower of the two values was proposed as the effective criterion (e.g., for Class A(2)). Because the 0.014 mg/L criterion for aesthetics uses in Class A(2) and B(1) lakes was lower than the value of 0.016 mg/L proposed as the Class A(1) criterion for the Eastern Great Lakes and Hudson Lowlands sub-ecoregion corresponding to the "natural condition," the proposed effective spring TP criterion for Class A(2) and B(1) lakes in this sub-ecoregion was adjusted upwards in Table 12 to the "natural condition" value. For other water quality variables where the data were not used to derive aquatic life criteria (spring TN, summer TP, summer Chl, summer Secchi depth), the aesthetics criteria for these variables were proposed as effective criteria for the Standards. The similarity of spring TP criteria values derived for aesthetics and aquatic life uses indicates that this was a reasonable step in the absence of more definitive aquatic life results for the other variables.

An analysis was done to ensure that the criteria derived from the conditional probability analysis (all values in Table 12 except those for Class A(1)) provided a sufficiently high probability of attainment of the corresponding aesthetics and aquatic life uses. As shown in Figure 5, the ranges of lake mean values for each water quality variable were split into three intervals, with the proposed criterion value separating the second and third interval. The midpoint of the data range between the lower analytical detection limit (or the maximum value in the case of Secchi depth) and the proposed criterion value was used to separate the first two intervals.

Figure 5 shows the frequencies with which monitored lakes having mean water quality values within the ranges indicated actually attained the aesthetics or aquatic life standards. These frequencies were calculated from the relative proportion of user survey responses in the case of the aesthetics criteria, and from the proportion of all monitored lakes in the case of the aquatic life criteria. In particular, the results in Figure 5 were used to assess the probability of use attainment for lakes at or immediately below the proposed criterion (i.e., the second interval).

It can be seen from Figure 5 that in most cases the frequency of attaining the indicated aesthetics and aquatic life criteria was relatively high when mean values for the water quality variables were at or immediately below the proposed criteria. These results confirm that the proposed criteria are reasonably protective of the uses.

The management implications of the criteria proposed in Table 12 with respect to the number of Vermont lakes that are likely to violate the criteria if adopted can be evaluated using Figure 6. Figure 6 shows the relative frequency and number of lakes having poorer water quality conditions than the proposed criteria values. For example, a spring TP criterion of 0.024 mg/L would not be attained by about 8% (N=21) of the lakes.

Table 12. Proposed nutrient criteria for lakes.

		Aesthetics Criteria			Aquatic Life Criteria			Proposed Effective Criteria					
Variable	**Units**	**A1 Natural Condition**	**A2, B1 No worse than excellent**	**B, B2, B3 No worse than good or very good**	**A1 Natural Condition**	**B1 No more than minor change**	**A2, B, B2, B3 No more than moderate change**	**A1**	**A2**	**B**	**B1**	**B2**	**B3**
Spring TP	mg/L	0.012[a] 0.016[b]	0.014	0.024	0.012[a] 0.016[b]	0.014	0.024	0.012[a] 0.016[b]	0.014[a] 0.016[b]	0.024	0.014[a] 0.016[b]	0.024	0.024
Spring TN	mg/L	0.36	0.40	0.48	0.36	--	--	0.36	0.40	0.48	0.40	0.48	0.48
Summer TP	mg/L	0.014	0.014	0.024	0.014	--	--	0.014	0.014	0.024	0.014	0.024	0.024
Summer Secchi	m	3.8	3.8	2.4	3.8	--	--	3.8	3.8	2.4	3.8	2.4	2.4
Summer Chl	mg/L	0.005	0.009	0.016	0.005	--	--	0.005	0.009	0.016	0.009	0.016	0.016

[a]Applies to lakes in the Northeastern Highlands and Northeastern Coastal Zone sub-ecoregions.
[b]Applies to lakes in the Eastern Great Lakes and Hudson Lowlands sub-ecoregions.

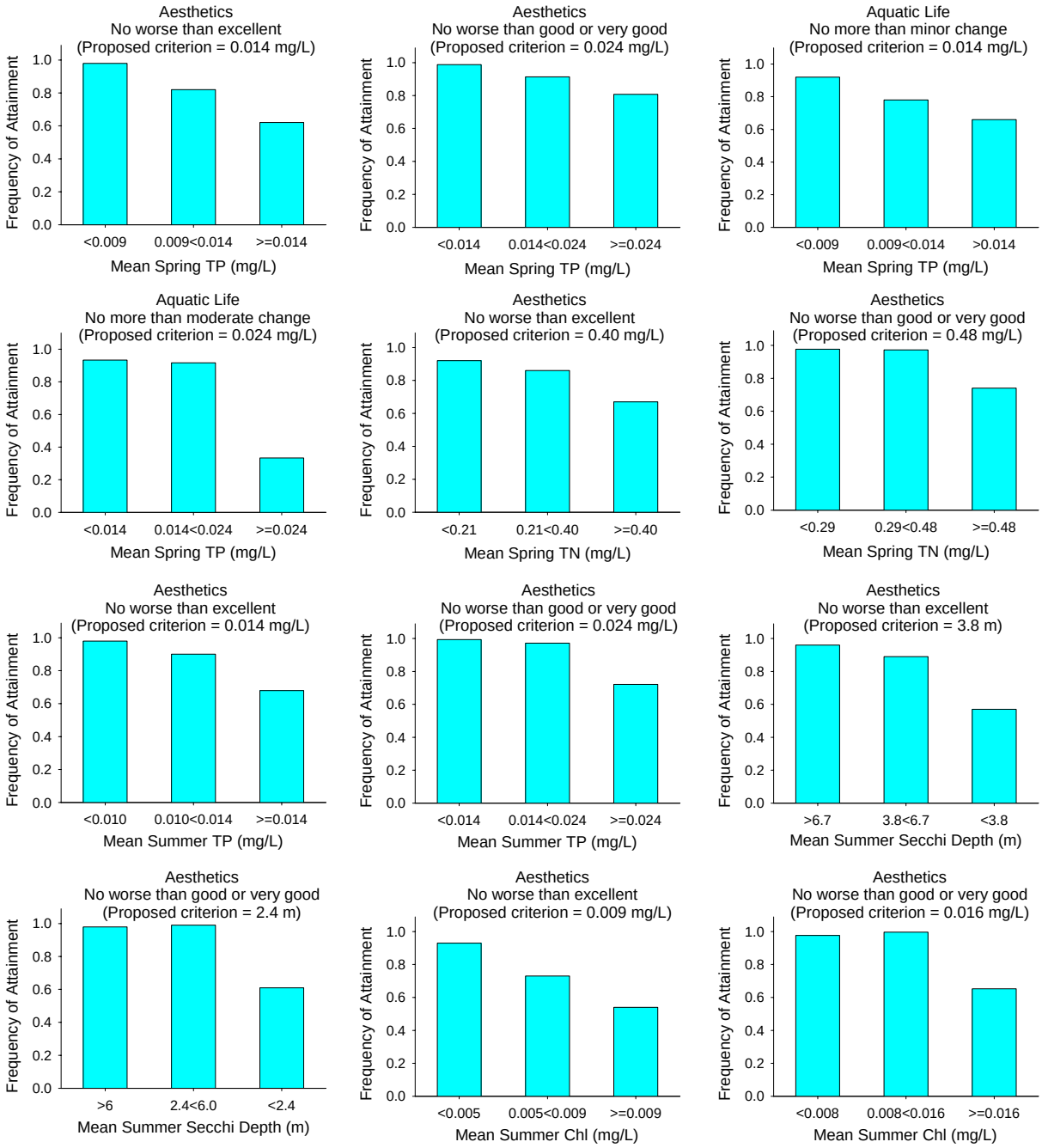

Figure 5. Frequencies of attaining aesthetics and aquatic life use standards for monitored lakes having mean water quality values within intervals above and below the proposed criteria values.

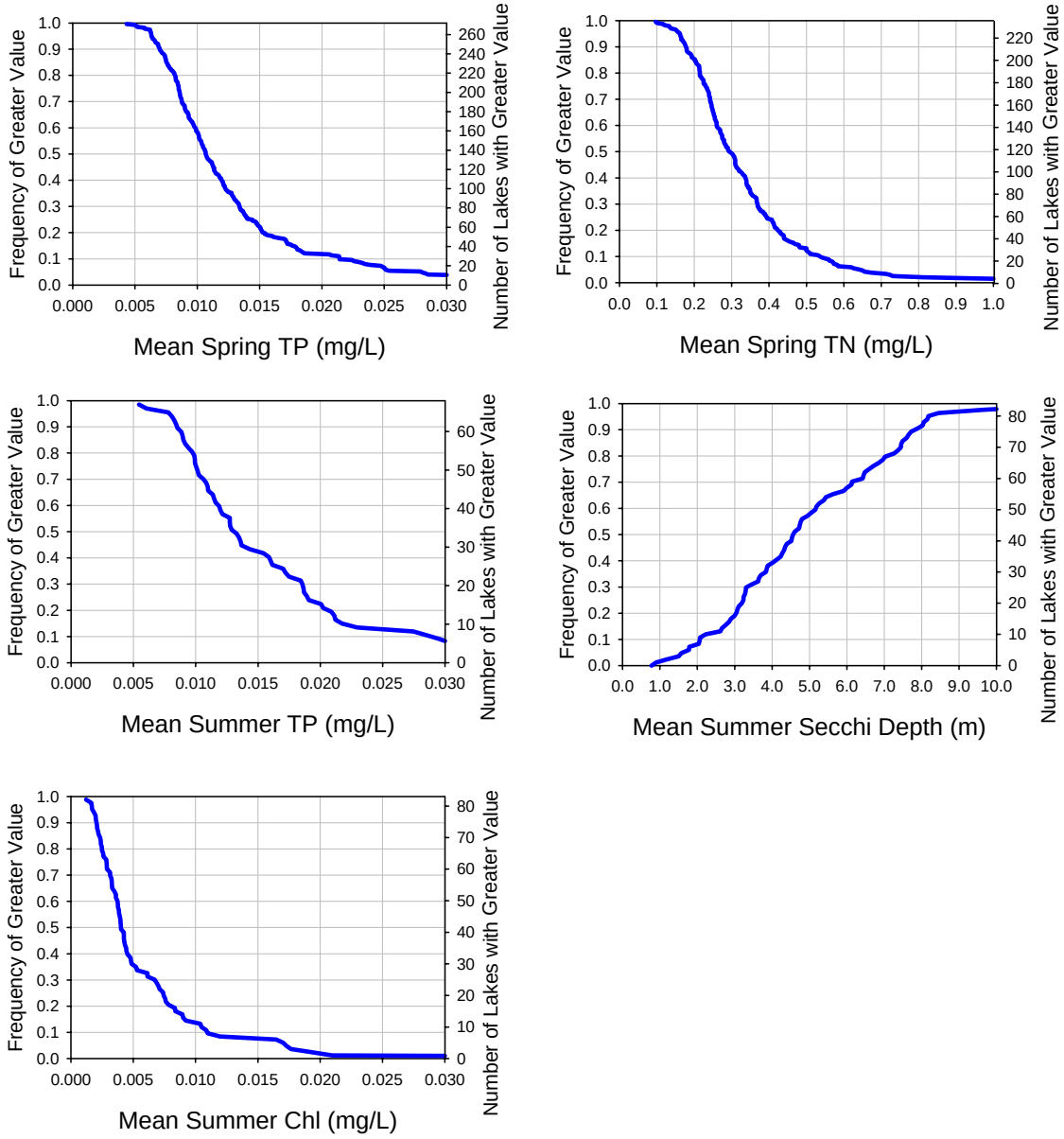

Figure 6. Cumulative frequency distributions of water quality variables among monitored Vermont lakes.

7. Criteria for Vermont Wadeable Streams

A. Data Sources and Nutrient Criteria Variables

Data from Vermont streams come from two major sources, the long-term Vermont DEC Ambient Biomonitoring Program[24] data set, and the 2004 Vermont DEC Nutrient Criteria Project[25] database. Both programs are conducted under EPA-approved Quality Assurance Project Plans. The Vermont DEC Ambient Biomonitoring Program collects chemical, physical and biological data from surface waters throughout the state. Wadeable streams are a prime focus of the program activities. The Ambient Biomonitoring Program has been collecting physical and biological data consistently since the early 1980s. However, it is only recently (starting in 2002) that concerted efforts to collect comprehensive chemical data in conjunction with biological samples have been initiated. Because the objectives of this nutrient criteria project were best served by evaluating concurrently-collected biological and chemical data, mining of the ambient monitoring data set has, for the most part, been limited to data obtained since 2002. The Ambient Biomonitoring Program database contains 268 measurements of biological attainment paired with concurrent nutrient measurements. Not all sampling events in this data set include the full range of observations necessary to evaluate aesthetic condition.

The Vermont Nutrient Criteria Project was carried out in 2004 for the purpose of supplementing the data available from the Ambient Biomonitoring Program by generating concurrent estimates of nutrients (TP and TN) and aesthetic and biological responses at low flows. There are 202 quality-assured observations within the nutrient criteria database used for nutrient criteria analyses. These data are a subset of the Ambient Biomonitoring Database discussed above. In addition, data collected in conjunction with a probability-based assessment of wadeable stream biologic condition in Vermont[26] were used to estimate the statewide distribution of phosphorus concentrations as percent of total stream miles in Vermont (N=78 sites).

Nutrient criteria for natural conditions and aquatic life use have been assessed independently for three pre-defined wadeable stream ecotypes: small high-gradient streams (SHG); medium high-gradient streams (MHG); and warm water medium-gradient streams (WWMG). These stream ecotypes were defined by the structural and functional characteristics of the reference (minimally disturbed) condition macroinvertebrate community and have been used extensively as the basis for biocriteria implementation in Vermont.

Low Flow TP and TN

The objective of the Vermont Nutrient Criteria Project for wadeable streams was to characterize the condition of response variables to TN and TP concentrations expressed as mean values occurring over the “low-flow summer period.” Therefore, the targeted hydrologic condition for sampling was “low” or “base” flow conditions. Hydrologic condition was determined at the time of sampling based on the best professional judgment of the sampling crew. A single grab sample collected concurrently with other chemical, physical and biological information was used to characterize the low flow summer mean concentration. Additional sampling data were used to evaluate the uncertainty associated with using a single value to characterize the mean.

Microalgal Cover

A mean weighted value characterizing microalgal cover, as quantified from pebble-count data, was used as the primary response variable to evaluate aesthetic condition. The derivation of this metric is described in more detail under Section C below. The microalgae represent the component of the periphyton exclusive of larger forms such as filamentous green algae and

mosses, and are evaluated primarily by assessing the thickness of the biofilm on the substrate. The primary components are dominated by diatoms and bacteria and their associated matrices.

Macroinvertebrate Trophic Index (MTI)

A macroinvertebrate trophic index was developed for this project for the purpose of developing a response variable based on trophic signals within the structural and functional characteristics of the macroinvertebrate community that could be related to Aquatic Life Use Support determinations. The macroinvertebrate community was selected as a response variable due to: (1) sensitivity to trophic condition, (2) a long history of macroinvertebrate community assessment by Vermont DEC, and (3) well-developed biocriteria relating macroinvertebrate community condition to the tiered aquatic life use classifications in the Vermont Water Quality Standards. The development of the MTI is described in more detail under Section D below.

B. Criteria for Natural Condition

The management objectives in the Vermont Water Quality Standards for both aquatic biota and aesthetics in Class A(1) waters are to maintain water character and biological features in their natural condition (Tables 8 and 9). Stream nutrient criteria to protect the natural condition were derived in a manner similar to that for lakes, using the USEPA approach of defining a criterion from the frequency distributions for minimally impacted reference streams.

Stream reaches with primarily natural or minimally disturbed watersheds were chosen for this analysis. A total of 97 observations from 88 reference sites were identified from a total pool of 384 observations available in the Ambient Biomonitoring Database. Reference site selection was based on the best professional judgment of Vermont DEC staff. For the most part, watershed characteristics were predominantly undisturbed. In some cases, particularly for some stream types, overall watershed disturbance was greater than minimal (e.g., silviculture, agriculture, roads) but, in the judgment of Vermont DEC staff, unlikely to affect stream condition. The cumulative frequency distributions for TP and TN at these reference stream sites are shown for each stream type in Figure 7. The mean values for TP and TN at each site were $\log_{10}$-transformed for normality, and the normal distribution parameters (mean, variance) were calculated from the log-scale values to produce these plots using the cumulative normal distribution function.

USEPA guidance recommends that nutrient criteria be specific to each ecoregion because natural physical and geological factors that vary among ecoregions may influence the natural or attainable trophic state of lakes and streams. However, the possible effect of ecoregion was taken into account by evaluating the frequency distributions for each stream type. This is because WWMG streams were found primarily within the Eastern Great Lakes and Hudson Lowlands sub-ecoregion, while the MHG and SHG stream types were found mainly in the Northeastern Highlands and Northeastern Coastal Zone sub-ecoregions.

The distributions of TP values at reference sites were significantly different between WWMG streams and the other stream types (t-test for difference between means, $p<0.05$). Natural TP concentrations tended to be higher in the WWMG streams. The TP distributions were not significantly different between MHG and SHG stream types, and there were no significant differences in the TN distributions among stream types.

USEPA guidance was followed in using the 75th percentile of the frequency distributions for minimally impacted (reference) streams in order to select criteria values to protect natural conditions. This method resulted in proposed TP criteria of 0.022 mg/L for WWMG streams,

0.011 mg/L for MHG streams, and 0.013 mg/L for SHG streams. The resulting TN criteria were 0.35 mg/L for WWMG streams, 0.28 mg/L for MHG streams, and 0.33 mg/L for SHG streams.

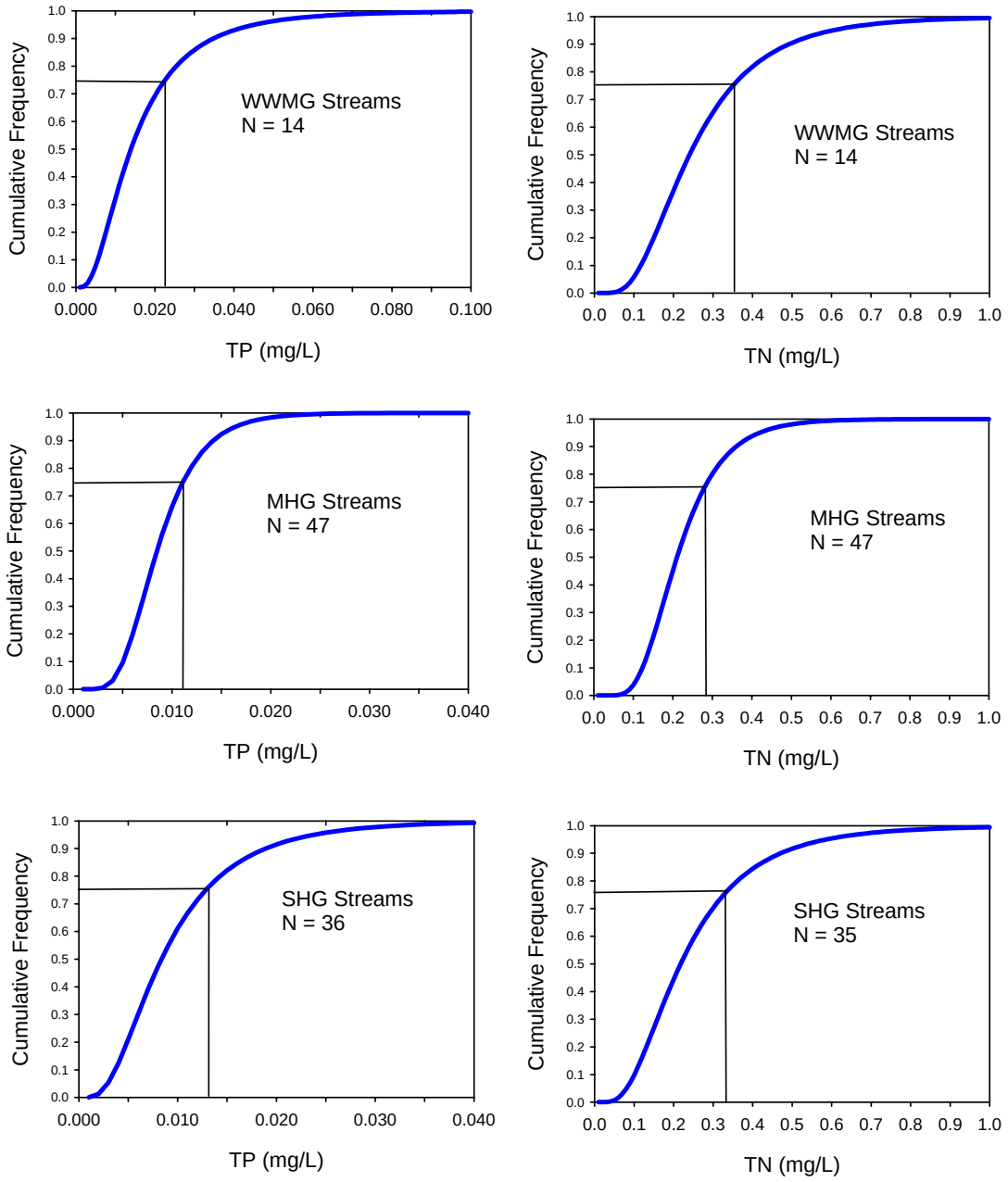

Figure 7. Cumulative frequency distributions of mean TP and TN at stream reference sites. Cumulative normal distribution parameters were calculated from $\log_{10}$-transformed data. Drop lines show proposed criteria values at the 75th percentile. Stream types are warm-water medium-gradient (WWMG), medium high-gradient (MHG), and small high-gradient (SHG).

C. Criteria for Aesthetics Uses

Using the Nutrient Criteria Project data set, several approaches for analyzing the relationship between nutrient concentrations and aesthetic condition were explored, including the evaluation of covariates on aesthetic responses (e.g., antecedent flow, canopy and shading, temperature). This process proved difficult in that strong relationships between aesthetic indicators and nutrient parameters were difficult to discern. After considerable trial and error using various aesthetic indicators, two indicators were identified that best discerned the relationship between in-stream nutrient concentrations and aesthetic condition. One was the "trophic rating," an ordinal score (1-5) assigned by field biologists during the sampling that defined the trophic appearance of the site, where low scores related to more eutrophic appearing conditions. The second quantitative metric was microalgal cover, as measured during the pebble count component of the field sampling program, and modified using the following steps:

1) During the pebble count, each of the 100 observations was scored an ordinal value corresponding to one of seven possible observations, where 0 = stone devoid of biofilm, 1 = stone has thin biofilm, 2 = a line can be drawn in the biofilm, 3 = film thickness is 0.5-1 mm, 4 = film thickness is >1-5 mm, 5 = film thickness is >5-20 mm, 6 = film thickness is >20 mm.
2) A weighted mean value was calculated from these 100 values. The need for a weighting algorithm became evident after several initial attempts to identify a relationship between raw measurements of microalgal cover and nutrient concentrations. The weighting algorithm intentionally emphasized the importance of algae-rich stones in the sample because, overall, substrates in Vermont streams are quite low in algal cover. The weighted means provided a larger range than would have been observed using a simple arithmetic mean or proportional count of observations. The weights attributed to score values were equal to the score values themselves, meaning that stones with scores of 0 (no biofilm) were not included in the weighted mean, while stones with scores of 6 (>20 mm filament) were weighted 6X in the computation of the weighted mean. This yielded a range of weighted mean scores from 0.3 to 2.89.
3) The distribution of scores was divided into the 25th percentile (excellent), 50th percentile (very good aesthetic value), and 75th percentile (good aesthetic value), of the weighted means. Values in excess of the 75th percentile were considered non-attaining aesthetic conditions. This is consistent with the percentile approach used elsewhere in this report to define natural condition.
4) The resulting metric values were related to categories of aesthetic quality defined by the Vermont Water Quality Standards (Table 13).

Table 13. Correspondence between water quality standards for aesthetics and stream aesthetic observations.

Class (Type)	Water Quality Standard[a]	Microalgae weighted mean	Trophic rating
A(1)	Natural condition	The trophic rating and weighted mean microalgae values were not used to define natural condition.	
A(2), B(1)	Excellent aesthetic value	< 0.9, < 25th percentile of values	< 3
B(2)	Very good aesthetic value	0.9 – 1.2, 25th to 50th percentile of values	3
B, B(3)	Good aesthetic value	1.2 – 1.6, 50th to 75th percentile of values	4
	Non-attainment	>1.6, >75th percentile of values	5

[a] Management objectives and criteria for aesthetics (Table 9)

For the purpose of deriving proposed criteria, the individual microalgae values were paired with simultaneously measured values of TP and TN from each site to compute the conditional probability plots in Figure 8, and to facilitate visual examination of the data for potential thresholds (see step 2 of Section 5.C.). The conditional probability plots show the proportion of sites (Y-axis) representing a particular aesthetic condition for streams having TP or TN values greater than or equal to the corresponding values on the X-axis.

Three stream aesthetics conditions are shown on each plot in Figure 8. The lower curve shows the probability of observing excellent aesthetic quality corresponding to attainment of the Class A(2) and B(1) aesthetics standards. The middle curve shows the probability of observing no worse than very good aesthetic quality, corresponding to attainment of the B(2) aesthetics standards. The upper curve shows the probability of attaining at least good aesthetic quality, corresponding to B or B(3) aesthetics standards.

Using the microalgae assessment, the change-point thresholds were fairly well-defined at about 0.030 mg/L for TP corresponding to B(2) conditions, and at 0.044 mg/L TP corresponding to B or B(3) conditions. A visual evaluation of the underlying data values suggested the existence of a threshold for A(2) and B(1) aesthetic conditions (not apparent from the conditional probability plots) at 0.020 mg/L TP.

The thresholds for TN were less distinct, although there appeared to be a change-point at about 0.50 mg/L TN for B(2), and at 0.85 mg/L TN for B or B(3) aesthetic conditions. No thresholds were evident for TN to protect attainment of A(2) and B(1) aesthetic conditions. A statistical analysis of TN concentrations indicated that no significant difference existed in TN concentrations between sites meeting A(2) or B(1) conditions and sites meeting B(2) conditions ($p>0.01$). Therefore no criterion was proposed for TN to protect A(2) and B(1) aesthetic conditions.

To demonstrate that the quantitative microalgae metric successfully identified sites that had the appearance of being trophicly enriched, and therefore aesthetically degraded, the relationship between microalgal cover and trophic score was evaluated (Figure 9). There was a clear progression whereby increasing microalgae scores corresponded to reduced aesthetic quality as assessed using the trophic rating.

Figure 10 shows the frequencies with which monitored streams having low flow water TP and TN values within the ranges indicated actually attained the aesthetics or aquatic life standards. These frequencies were calculated from the relative proportion of monitored sites meeting the aesthetic condition described. In particular, the results in Figure 10 were used to assess the probability of use attainment for streams at or immediately below the proposed criterion (i.e., the second interval). The frequencies of attaining the indicated aesthetics uses were relatively high when mean values for the water quality variables were at or immediately below the proposed criteria. These results indicate that the proposed criteria are reasonably protective of the uses.

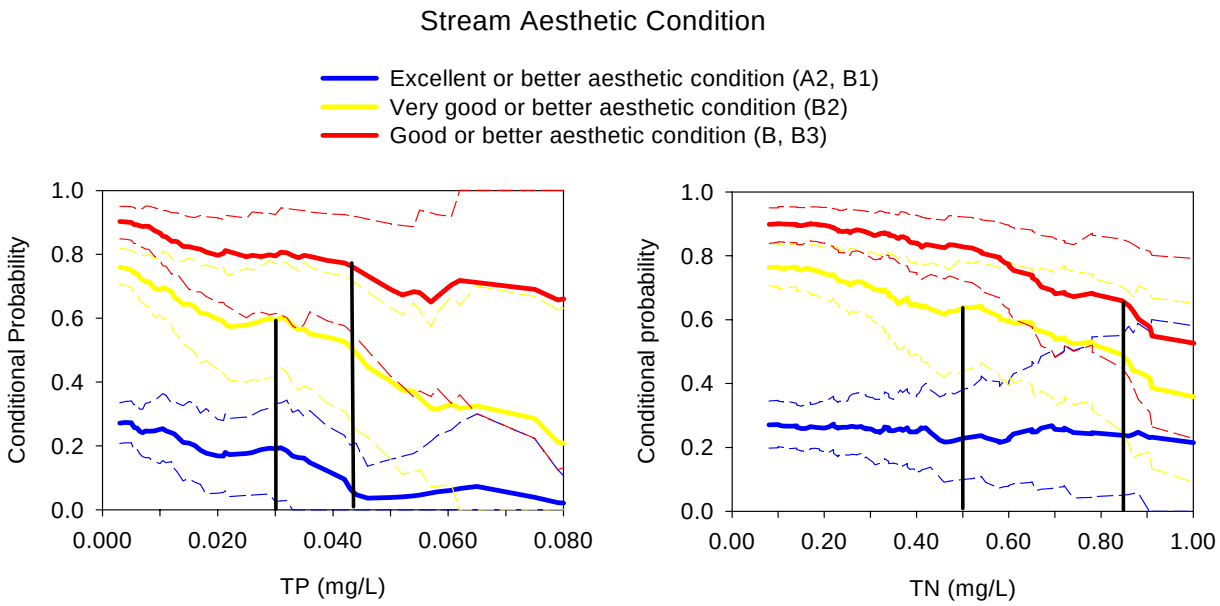

Figure 8. Conditional probability plots for aesthetic condition in wadeable streams. Curves show the probability of attainment of the indicated aesthetic condition for streams with low-flow values greater than or equal to the corresponding value on the X-axis. Dotted lines show 95% confidence intervals. Drop lines show proposed criteria values.

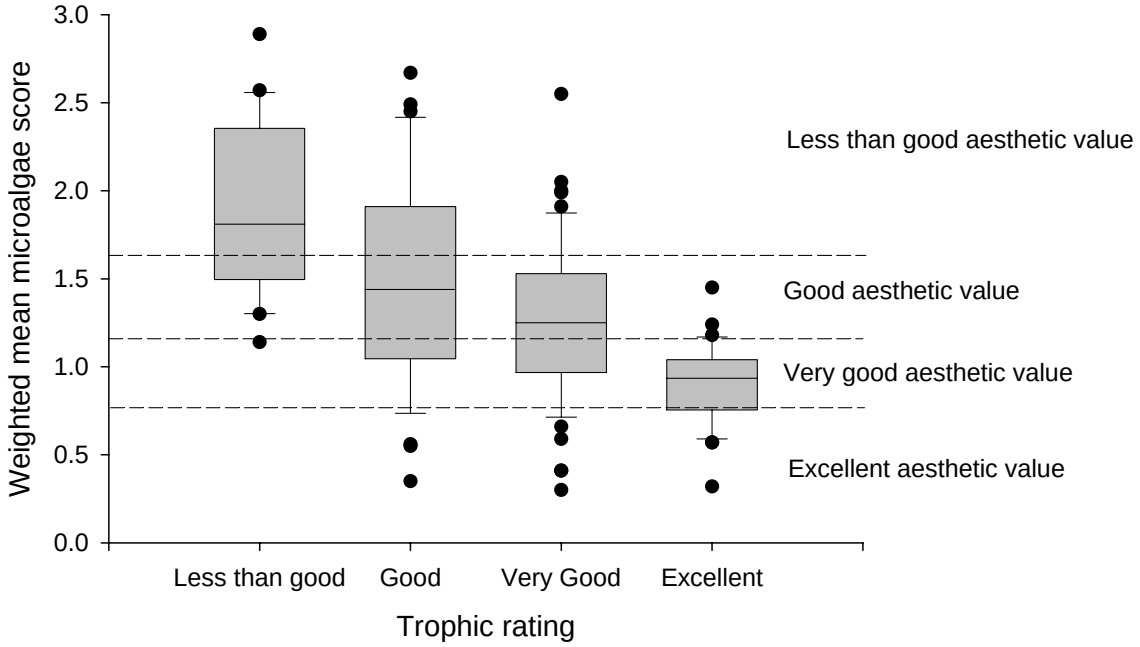

Figure 9. Box-plots showing weighted mean microalgae metric values in relation to trophic appearance scores. Horizontal lines and text correspond to thresholds for aesthetic criteria attainment described in Table 13.

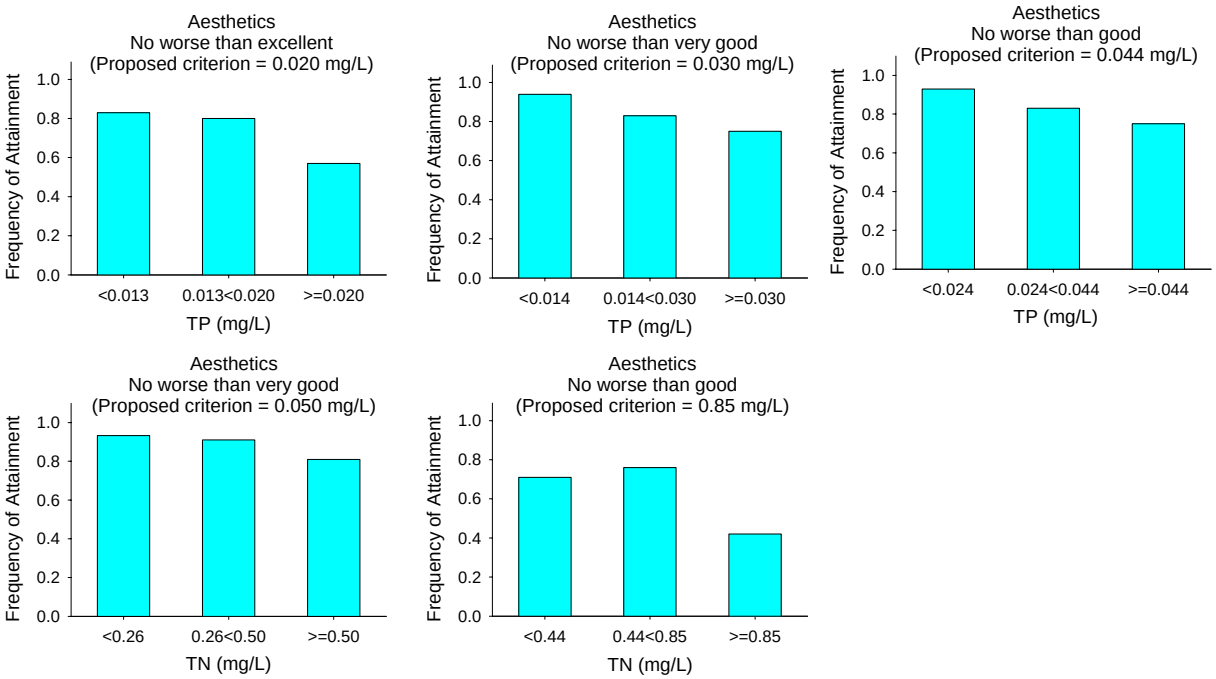

Figure 10. Frequencies of attaining aesthetics and aquatic life use standards for monitored lakes having mean water quality values within intervals above and below the proposed criteria values.

D. Criteria for Aquatic Life Uses

Aquatic Macroinvertebrate Community as the Response Variable

While periphyton is presumed to be the primary response variable to nutrient enrichment in streams, the relationships between measures of periphyton and aquatic life designated use support have not been developed in Vermont. In addition, establishing precise relationships between nutrient concentrations and periphyton biomass is difficult for a variety of reasons, including biomass accrual and loss dynamics mediated by hydrology and grazing, uptake of water column nutrients by benthic organisms, and temporal and spatial water quality and habitat variability.

In contrast to periphyton, the relationships between macroinvertebrate community structure and function and aquatic life designated use support are very well developed for the wadeable stream population in Vermont. For this reason, aquatic macroinvertebrate community structure was used as the response variable for nutrient criteria development for aquatic life in streams, rather than periphyton.

The Vermont wadeable stream macroinvertebrate biocriteria have been calibrated to identify distinctions between natural or "reference" conditions (Class A(1)), and deviations from reference conditions consistent with the aquatic life use "change from reference condition" descriptors "minor" (Class B(1)), and "moderate" (Classes A(2), B(2), and B(3)) found in the Vermont Water Quality Standards for Aquatic Life Use Support (Table 8). Vermont DEC uses eight metrics of macroinvertebrate community structure and function to assess overall biological condition of wadeable streams. Assessment thresholds for all eight metrics, based on comparison to appropriate reference conditions, have been developed to differentiate between natural (Class A(1)), minor change from reference condition (Class B(1)), moderate change from reference condition (Classes B(2)/B(3) and A(2)), or non-attainment of aquatic life use support standards (NA).

Metric thresholds have been derived independently for three stream ecotypes differentiated by natural (i.e., reference) macroinvertebrate community characteristics: Small High-Gradient (SHG) streams, Medium High-Gradient (MHG) streams, and Warm Water Medium-Gradient (WWMG) streams. The primary geophysical gradients that separate the stream ecotypes include slope, elevation, drainage area, temperature and to some extent, ecoregion.

An overall community assessment does not discriminate stressors, and reflects a condition resulting from all chemical, physical and biological stressors operative in the stream system. Relationships between overall biological condition and stressor concentrations document co-occurrence but do not necessarily involve causality. In an attempt to identify a response indicator more related to potential nutrient causality than overall community assessment, a macroinvertebrate trophic community index (MTI) was developed and used to differentiate sites where nutrient enrichment may be implicated as a stressor affecting the macroinvertebrate community.

The procedure used to develop the MTI for Vermont wadeable streams was as follows:

1) Community Assessment Categories. An overall macroinvertebrate community assessment classification was calculated based on aquatic life use class support (natural, minor, moderate, non-support) attainment and each site was assigned to an overall community assessment category (1-4).

2) MTI Scores. Macroinvertebrate metrics were evaluated for correlations with trophic condition indicators, including TP and TN concentrations. For each stream ecotype, selected metrics with the highest correlations to nutrient concentrations and other trophic indicators were used to calculate an MTI score for each site (Table 14).
3) MTI Trophic Assessment Categories. The distribution of MTI scores within overall community assessment categories was used to identify similar trophic categories (1-4) corresponding to aquatic life use designations. Box and whisker plots were used to identify thresholds of MTI values consistent with the overall community assessment categorical rankings.

Table 14. Variables used to derive the macroinvertebrate trophic community index for Vermont wadeable stream ecotypes (PPCS=Pinkham Pearson Coefficient of Similarity; PMAO-Percent Model Affinity-Order; EPT=Percent abundance of mayfly, stonefly and caddisfly taxa). The PPCS and PMAO are based on a comparison of test site conditions to the average conditions found in minimally disturbed (reference) sites.

	Stream Ecotype		
Variable	**SHG**	**MHG**	**WWMG**
Biotic Index (BI)	X	X	X
% Hydropsychid caddis	X		X
Macroinvertebrate community functional similarity (PPCS)	X	X	
Ratio of sensitive organisms to tolerant dipterans (ept/ept + chiro)	X	X	X
Weighted mean macro-periphyton (WMMacro)	X		
Macroinvertebrate community taxonomic similarity (PMAO)			X
Trophy (observational assessment)		X	

Figure 11 shows the distribution of MTI scores with overall macroinvertebrate community scores for all three stream ecotypes. Using medium high-gradient (MHG) streams as an example, MTI score (Y-axis) distributions are shown by overall community assessment category (X-axis). Medians, quartiles, and 90th percentiles are indicated. These plots were used to visually select MTI thresholds. The intent of the threshold selection was, using the "natural/minor" threshold for example, to balance the inclusion of as many of the "natural" sites as possible while excluding as many of the "minor" sites as possible. This methodology was employed throughout this analysis when box and whisker plots were used to identify thresholds. For MHG streams, those thresholds were MTI scores of 0.3, 0.4, and 0.5 for the natural/minor, minor/moderate and moderate/non-attainment (NA) thresholds, respectively. Thus, sites with MTI scores of ≤ 0.3 would be categorized as "natural," >0.30-0.4 as "minor change," >0.40-0.5 as "moderate change," and > 0.5 as "NA." A similar exercise was conducted with small high-gradient and warm water medium-gradient streams to identify MTI categorical thresholds (Table 15). For all three stream types, community assessment and MTI scores were highly correlated ($p<0.001$, Spearman rank correlation). Based on these results, each site was assigned to one of four trophic categories corresponding to aquatic life use support designations articulated in the Vermont Water Quality Standards (natural, minor change from reference, moderate change from reference, and non-attainment).

Categorical rankings based on MTI scores were more highly correlated to TP and TN concentrations than were categorical rankings based on overall community assessments, indicating some success at discriminating the component of designated use attainment related to trophic condition stressors from non-trophic drivers of non- attainment such as sedimentation and toxicity. The MTI trophic thresholds identified in Table 15 for each stream ecotype were used to assign sites to trophic attainment categories (1-4) consistent with the management objectives for aquatic life as defined in the Vermont Water Quality Standards.

Several approaches were used to investigate the relationship between trophic condition as defined by the MTI and nutrient (TP and TN) concentrations: (1) assessment of conditional probability plots, (2) regression analysis of trophic index versus nutrient concentrations, and (3) evaluation of nutrient concentrations within MTI categories. Each of these approaches was used to estimate thresholds of nutrient concentrations consistent with aquatic life use designations.

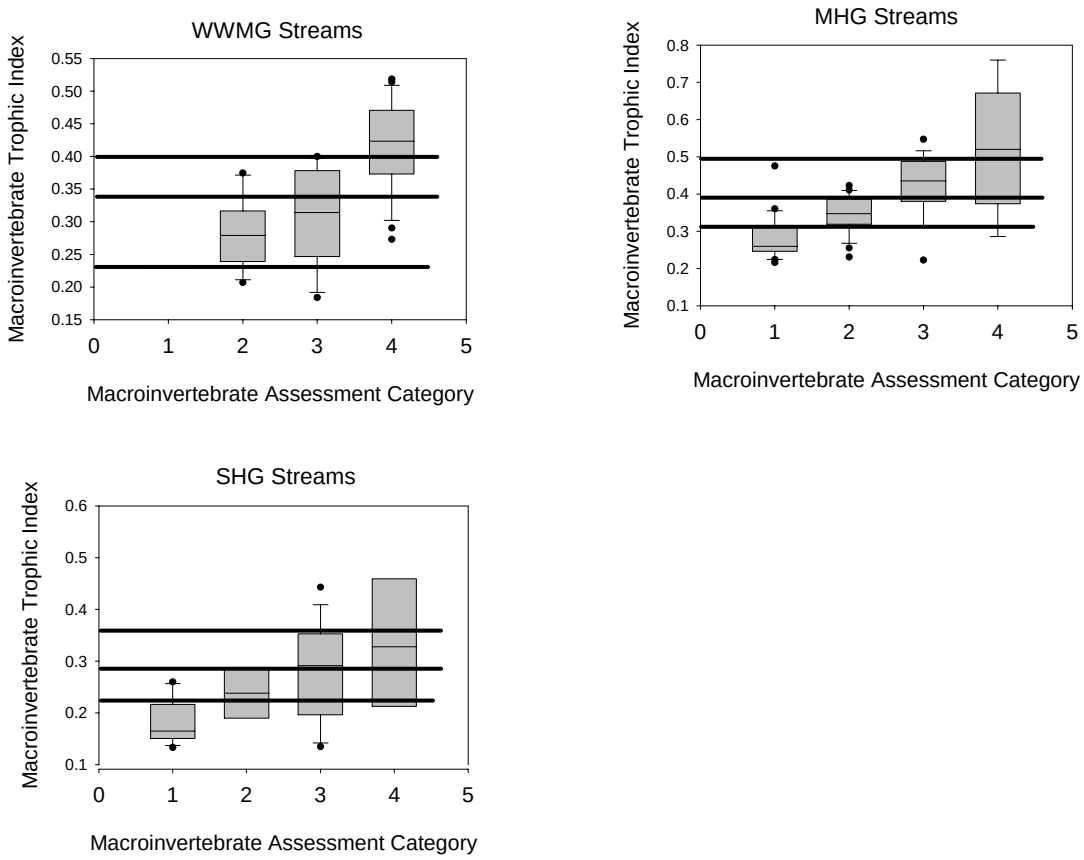

Figure 11. Relationship between Macroinvertebrate Trophic Index (MTI) scores and macroinvertebrate assessment categories. Horizontal lines were visually placed identifying "best visual fit" between four categories: (1) natural, (2) minor change from reference, (3) moderate change from reference, and (4) greater than moderate change from reference (non-support of aquatic life uses).

Table 15. Macroinvertebrate Trophic Index (MTI) score threshold values in relation to Vermont Water Quality Standards criteria.

Criteria, Class (type)	Stream Ecotype		
	SHG	MHG	WWMG
Natural condition, A(1)	≤ 0.21	≤ 0.31	≤ 0.23
Minor change from reference, B(1)	>0.21-0.28	>0.31-0.40	>0.23-0.34
Moderate change from reference, A(2), B(2), B(3), B	>0.28-0.37	>0.40-0.5	>0.32-0.40
Non-attainment	>0.37	>0.50	>0.40

Conditional Probability Analysis

Conditional probability analysis was used to help identify thresholds where they existed in the data. Conditional probability plots were constructed using methods described in previous sections of this report.

The wadeable stream water quality monitoring data and MTI scores were analyzed using conditional probability plots to identify thresholds of water quality conditions where attainment of the aquatic life criteria becomes unlikely. For this analysis, the probabilities of attaining particular aquatic life criteria were computed given the measured low-flow TP and TN concentrations.

Individual MTI score values were paired with low flow values for nutrients for each stream site to generate the conditional probability plots in Figure 12. These plots show the proportion of assessed stream sites (Y-axis) exhibiting attainment of a given aquatic life criterion among all assessed stream sites having a low-flow TP or TN value greater than or equal to the corresponding values on the X-axis.

Two aquatic life conditions are shown on each plot. The lower curve shows the probability of stream sites exhibiting no more than a minor change from reference while the upper curve shows the probability of stream sites exhibiting no more than a moderate change from reference.

No thresholds were apparent from an evaluation of the conditional probability curves in Figure 12. Therefore, no criteria values were derived from the conditional probability analysis of the stream aquatic life data.

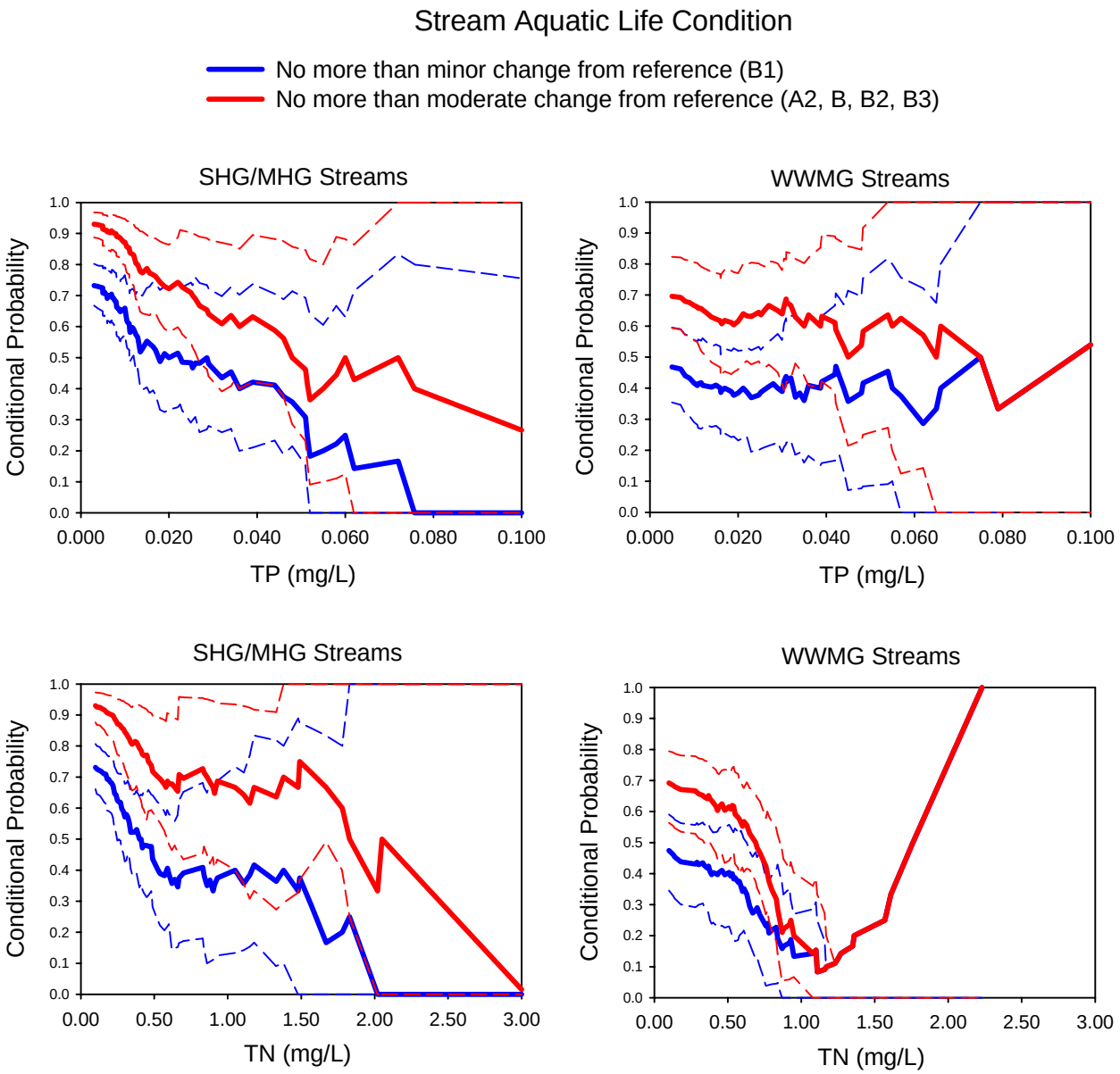

Figure 12. Conditional probability plots for aquatic life condition in wadeable streams. Curves show the probability of attainment of the indicated aquatic life condition for streams with low-flow values greater than or equal to the corresponding value on the X-axis. Dotted lines show 95% confidence intervals. No criteria values were derived from the conditional probability analysis of the stream aquatic life data.

Regression Analysis

For all three stream types, linear regression plots (Figure 13) of MTI versus TP and TN were developed. All regressions, with the exception of MTI and TP for the WWMG stream type, were significant at $p<0.05$. For those regressions that were significant, MTI categorical thresholds (natural, minor change, moderate change) were used to identify predicted phosphorus concentrations for each trophic category for each stream type. The three TP and TN concentrations associated with those aquatic life thresholds were identified. These concentrations were presumed to represent values that provided some discrimination between probable stream trophic condition. For example, for the MHG stream category, a trophic index value of 0.3 is the threshold value for discriminating between natural conditions and minor change from natural, or reference, conditions (Table 15). The corresponding TP concentration is 0.011 mg/L.

TN and TP Distribution Within Trophic Categories

The distributions of TP and TN within trophic categories (natural through non-attainment) for each of the three stream ecotypes were examined for the purpose of evaluating TP and TN concentrations in relation to trophic condition as measured by the MTI (Figure 14). With the exception of TP in warm-water medium-gradient streams, there was a fairly clear distinction between nutrient concentrations between moderate or better and non-attainment trophic condition. Although the upper range of nutrient concentrations tended to expand with trophic category, mean concentrations of TN and TP were not significantly different between the trophic categories natural, minor, and moderate for any stream type (Kruskal-Wallis One-Way Analysis of Variance on Ranks/Dunn's Pairwise Multiple Comparison; $p<0.05$).

Although mean values of TP and TN were not significantly different between trophic categories, distributions of TP and TN within trophic categories suggest that a hierarchy of thresholds would be appropriate to provide increasing levels of protection based on aquatic life use classification. Horizontal lines were visually placed across the plots in order to identify appropriate protective thresholds. Figure 14 shows the plots used to identify thresholds for the three stream types.

Summary of Results for Stream Aquatic Life

Table 16 summarizes the results of the analyses used to derive candidate stream aquatic life criteria for TP and TN. For each method, a candidate criterion for each stream type and management threshold was derived for TP and TN when warranted by the data. The results from regression (Figure 13) and "box and whisker" plots (Figure 14) were combined to calculate mean thresholds. These means, plus review of the raw data, were used to identify thresholds based on an overall weight-of-evidence evaluation. These weight-of-evidence thresholds values are presented in Table 16 as recommendations for TN and TP criteria for the protection of aquatic life uses.

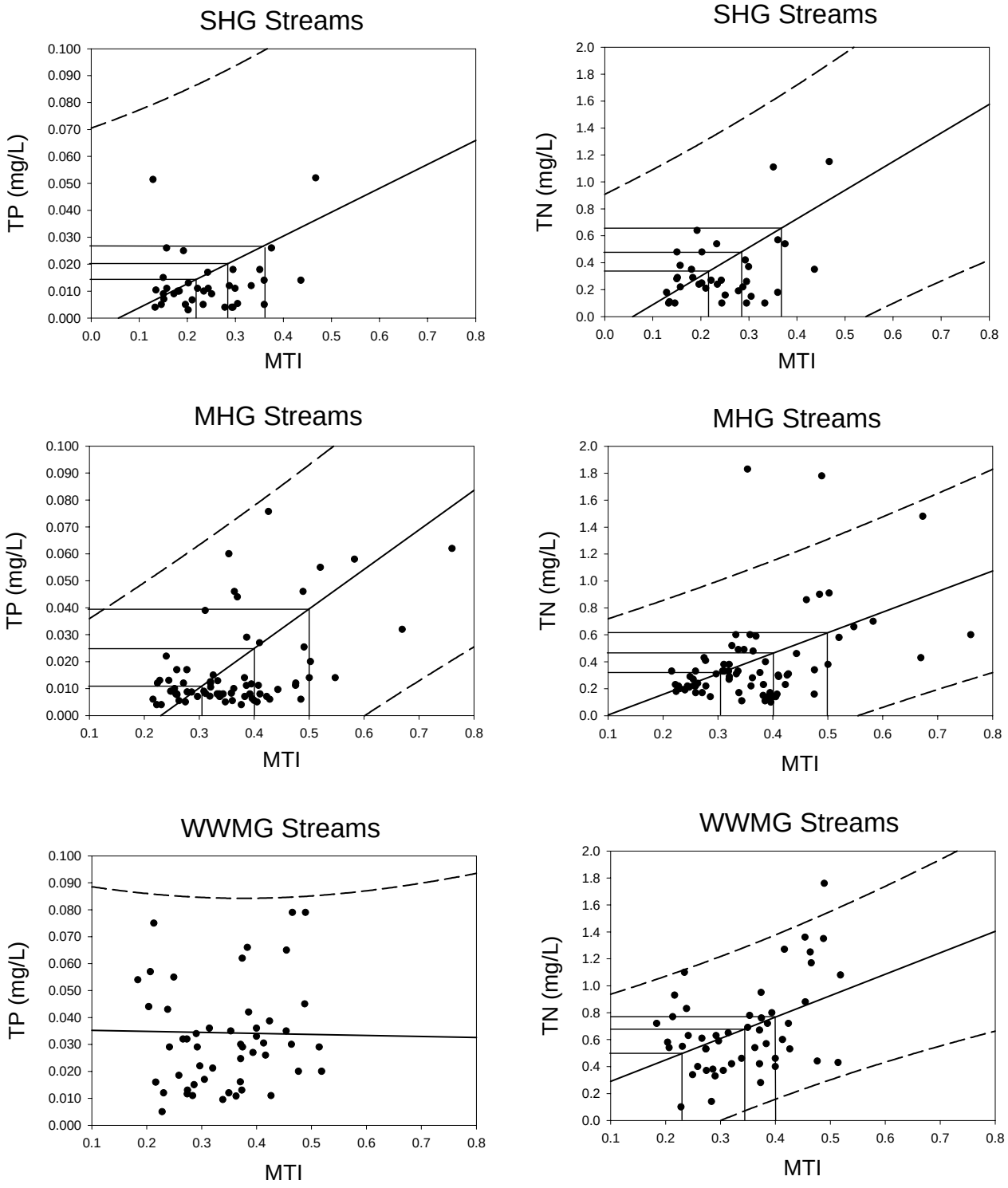

Figure 13. Linear regressions of TP and TN vs. the Macroinvertebrate Trophic Index (MTI) for three wadeable stream types. Dotted lines are 95% confidence intervals for the predicted values. Drop lines show the predicted TP and TN values associated with MTI trophic category thresholds separating aquatic life use support between standards of natural, minor, moderate, and greater than moderate change from reference conditions.

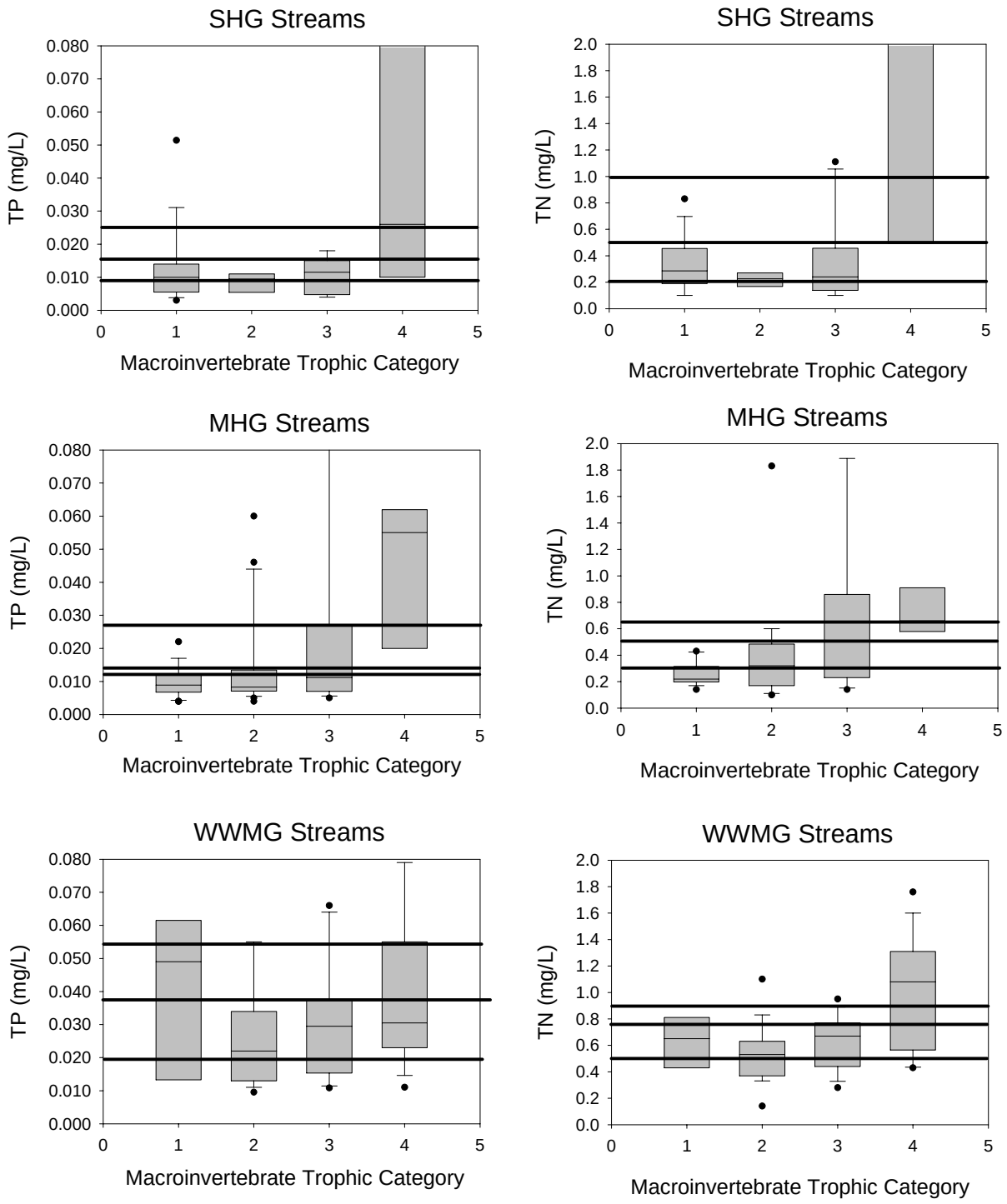

Figure 14. Distribution of TP and TN concentrations within macroinvertebrate trophic categories of (1) natural, (2) minor change from reference, (3) moderate change from reference, and (4) greater than moderate change from reference, or non-support of Class B aquatic life use. Horizontal lines were visually applied to identify "best fit" TP and TN thresholds between trophic categories.

Table 16. Summary of all TP and TN aquatic life use classification thresholds for three wadeable stream types identified using three data analysis methods. The results from this matrix of threshold values were used to develop candidate nutrient criteria based on a weight-of-evidence assessment of all available information. SHG and MHG streams were given the same recommended value as there were no significant differences in threshold values between these two stream types. "NA" indicates that the stressor/response relationship was too weak to identify thresholds. Percentiles from the reference stream distributions were applied only to the natural condition threshold.

	TP Thresholds (mg/L)								
Method	**A1 Natural Condition**			**B1 No more than minor change**			**A2, B, B2, B3 No more than moderate change**		
	SHG	MHG	WWMG	SHG	MHG	WWMG	SHG	MHG	WWMG
75th Percentile of the Reference Distribution	0.013	0.011	0.022	--	--	--	--	--	--
Trophic Category Regressions	0.014	0.011	NA	0.021	0.025	NA	0.027	0.039	NA
Trophic Category Box and Whisker Distributions	0.009	0.012	0.020	0.016	0.014	0.038	0.025	0.027	0.055
Recommended Threshold Value	**0.010[a]**	**0.010[a]**	**0.020**	**0.020**	**0.020**	**0.030**	**0.035**	**0.035**	**0.050**
	TN Thresholds (mg/L)								
Method	**A1 Natural Condition**			**B1 No more than minor change**			**A2, B, B2, B3 No more than moderate change**		
	SHG	MHG	WWMG	SHG	MHG	WWMG	SHG	MHG	WWMG
75th Percentile of the Reference Distribution	0.33	0.28	0.35	--	--	--	--	--	--
Trophic Category Regressions	0.33	0.31	0.50	0.49	0.47	0.68	0.65	0.62	0.78
Trophic Category Box and Whisker Distributions	0.20	0.30	0.50	0.50	0.50	0.75	1.00	0.65	0.80
Recommended Threshold Value	**0.30**	**0.30**	**0.50**	**0.50**	**0.50**	**0.75**	**0.75**	**0.75**	**0.75**

[a] The existing TP criterion of 0.010 mg/L in the Vermont Water Quality Standards for streams above 2,500 feet elevation was recommended here because the existing criterion was close to the mean of the values derived from the three methods. The Standards classify all such streams as A(1) unless specifically classified as A(2)

Stream Aquatic Life Criteria Discussion

There are several aspects of the preceding analyses for stream aquatic life that warrant some further discussion.

1) WWMG Relationships. For the WWMG stream ecotype, relationships between nutrient concentrations and trophic condition as represented by the MTI were ambiguous at best, with no significant differences between TP and TN concentrations between MTI trophic categories, and were confounded by high concentrations of TP and TN at sites rated as "natural" by the MTI. The WWMG ecotype is a relatively heterogeneous group of streams, including streams with relatively large drainage areas as well as small first and second order streams in the Lake Champlain valley. In addition, most of the "stormwater-impaired" streams located in Chittenden County are included in this group. In an effort to generate some meaningful dose/response information within the WWMG stream type, two data stratifications were evaluated.

   - *Drainage area:* The data plotting trophic index vs. drainage area showed very little variation for WWMG streams with a drainage area of greater than 100 km^2, but extreme variability for streams with a smaller drainage area. The data were divided into two groups – drainage area greater than 100 km^2 and drainage area less than 100 km^2. No statistically significant differences were found for median TP and TN values between trophic categories for either group.

   - *Stormwater impact:* Many of the streams with drainage areas less than 100 km^2 are highly impacted by stormwater, possibly confounding nutrient/trophic condition relationships. This set of small streams was divided into two groups: Chloride concentration (an indicator of urbanization and stormwater influence) greater and less than 50 mg/L. Again, no statistically significant differences were found for median TP and TN values between trophic categories for either group.

2) SHG and MHG Similarity. There were no significant differences in TP or TN thresholds between SHG and MHG stream ecotypes for any classification threshold. Therefore, SHG and MHG stream ecotypes were treated as a single class for the purpose of proposing nutrient criteria for aquatic life use support in wadeable streams.

3) Natural Condition. In addition to the three statistical data assessments described above, the 75th percentile of TP and TN distribution in reference sites was used to derive a candidate criterion for natural conditions (Section B: Criteria for Natural Conditions). Current water quality standards have a phosphorus criterion of 0.010 mg/L for streams above 2,500 feet in elevation. The candidate criteria identified by these analyses suggest that the current criterion of 0.010 mg/L TP is appropriate for the protection of natural conditions in SHG and MHG streams. Therefore our recommendation is to apply the current TP criterion for high elevation streams to all SHG and MHG streams designated as Class A waters. Use of the 75th percentile method was supported by these analyses for WWMG streams, and the final recommendation reflects a slight adjustment based on overall weight-of-evidence.

4) Uncertainty Considerations. The process described here for deriving TP and TN criteria for the determination of aquatic life use support was subject to a number of uncertainties that suggest some caution should be exercised when using these criteria to predict impairments resulting from trophic factors. Sources of uncertainty include:

- *Ambient nutrient concentrations:* Instantaneous concentrations of nutrients collected during a representative base-flow period were used in this analysis to characterize the concentration of nutrients available to the primary producer community over the duration of the growing season, and thus represent the potential for periphyton accrual at the test site. There is some uncertainty associated with using an instantaneous value to characterize a mean concentration that should be considered when assessing the precision of the cause and effect relationships observed in this data set. Multiple instantaneous observations of nutrient concentrations collected at discrete sites during base-flow conditions in the same year and season suggest that estimates of the base flow mean seasonal concentration are subject to an average percent standard error in the range of 15-20%. Table 17 summarizes some multiple sampling event data assessed for this analysis.
- *Threshold identification:* The methodologies used here to identify threshold concentrations of TP and TN were all subject to considerable uncertainty related to the imprecision of the dose-response relationships as represented by regression and conditional probability confidence intervals, and with considerable overlap in the categorical distributions as represented by box and whisker plots.

Table 17. Percent standard error summary statistics for mean TP values derived from multiple sampling events at the same site at base flow conditions during the same season. Values represent the potential uncertainty introduced by using a single sample to characterize mean or median seasonal concentrations of TP in streams.

	TP Percent Standard Error of the Mean		
	Mean of the %SE's	**Median of the %SE's**	**Range of the %SE's**
Paired samples (N=52)	18	13	0-71
24 multiple (N=2-8) samples	14	9.5	3.5-42

E. Summary of Proposed Criteria for Wadeable Streams

A summary of the proposed nutrient criteria for wadeable streams is provided in Table 18. The criteria for aesthetics and aquatic life uses were derived as explained in previous sections of this report, and both were used to propose "effective criteria" for the Vermont Water Quality Standards. Where the criteria values derived for a particular water class differed for aesthetics uses vs. aquatic life uses, the lower of the two values was proposed as the effective criterion, with two exceptions. One exception was that a small adjustment to the proposed effective TN criterion for Class A(1) MHG streams was made in order to avoid small and insignificant differences in the Class A(1) criteria between the SHG and MHG stream ecotypes. A TN criterion of 0.30 mg/L for Class A(1) waters was proposed for both stream ecotypes. The second exception involved the use of the higher aquatic life TN criterion of 0.75 mg/L for Class B(2) WWMG streams. This change was justified because the aesthetics analysis was not segregated by stream type, the precision of the analyses used to derive aquatic life criteria was greater than that for aesthetics, and WWMG streams tend to exhibit higher TN concentrations than SHG or MHG stream (Figure 15).

Vermont DEC recently completed a statewide assessment of wadeable stream biological condition conducted over a five-year period (2002-2006). A total of 78 randomly selected wadeable stream sites were assessed. These data were derived from an independent probability-based sample of all wadeable Vermont streams (at the 1:100,000 scale), and are statistically representive of all such streams. This data set was used to show the statewide probability-based frequency distribution of TP and TN in Vermont wadeable streams (Figure 15). The management implications of the criteria proposed in Table 18 with respect to the number of Vermont streams that are likely to violate the criteria if adopted can be evaluated using Figure 15. For example, this analysis shows that a low-flow TP criterion of 0.035 mg/L would currently not be attained by about 5% (~360 miles) of streams.

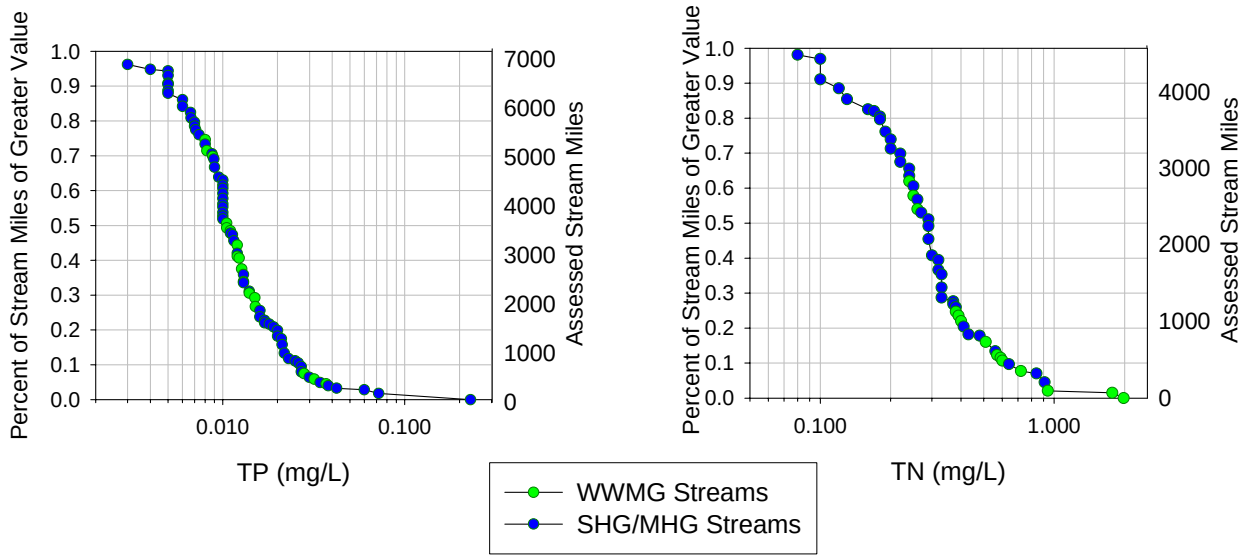

Figure 15. Cumulative frequency distributions of low-flow TP and TN in Vermont streams from the probability-based Vermont Streams Survey. Sites were segregated by stream ecotype. Note that the TN assessment applied to only 65% of the total estimated ~7,200 stream miles in VT (1:100,000 scale).

Table 18. Proposed nutrient criteria for wadeable streams.

			Aesthetics Criteria				Aquatic Life Criteria			Proposed Effective Criteria					
Variable	**Units**	**Stream Type[a]**	**A1 Natural Condition**	**A2, B1 No worse than excellent**	**B2 No worse than very good**	**B, B3 No worse than good**	**A1 Natural Condition**	**B1 No more than minor change**	**A2, B, B2, B3 No more than moderate change**	**A1**	**A2**	**B**	**B1**	**B2**	**B3**
Low-flow TP	mg/L	SHG	0.013[b]	0.020	0.030	0.044	0.010[c]	0.020	0.035	0.010[c]	0.020	0.035	0.020	0.030	0.035
		MHG	0.011[b]	0.020	0.030	0.044	0.010[c]	0.020	0.035	0.010[c]	0.020	0.035	0.020	0.030	0.035
		WWMG	0.022[b]	0.020	0.030	0.044	0.020	0.030	0.050	0.020	0.020	0.044	0.020	0.030	0.044
Low-flow TN	mg/L	SHG	0.33[b]	--	0.50	0.85	0.30	0.50	0.75	0.30	0.75	0.75	0.50	0.50	0.75
		MHG	0.28[b]	--	0.50	0.85	0.30	0.50	0.75	0.30	0.75	0.75	0.50	0.50	0.75
		WWMG	0.35[b]	--	0.50	0.85	0.50	0.75	0.75	0.35	0.75	0.75	0.75	0.75	0.75

[a] SHG = small high-gradient; MHG = medium high-gradient; WWMG = warm-water medium-gradient.
[b] Derived from the 75th percentile of the reference stream distribution (Figure 7).
[c] The existing TP criterion of 0.010 mg/L in the Vermont Water Quality Standards for streams above 2,500 feet elevation was retained here. The Standards classify all such streams as A(1) unless specifically classified as A(2).

8. Nutrient Criteria Implementation Considerations

A. Considerations for Lakes

Lake Size Threshold

Vermont DEC recommends for practical reasons that a lake area cutoff of 20 acres or larger be established for the initial application of nutrient criteria for lakes and ponds. The lake monitoring programs (Spring Phosphorus Program, Lay Monitoring Program, Lake Biocriteria Development Project) providing the data from which criteria were derived have always targeted lakes of 20 acres in size or larger. There are few data from which to assess spring phosphorus concentrations for lakes smaller than this size, and lakes 20 acres or larger represent 95% of all lake acres statewide. As additional lakes are assessed that are below 20 acres in size, or if applications for discharge permits are made that would affect such lakes, then the data necessary to assess compliance with the criteria for these small lakes will be developed.

Definition of Lake

The Vermont Water Resources Panel relies on the Vermont Lake Inventory Database maintained by the Vermont DEC to identify lakes in Vermont. There are 822 inventoried lakes listed in this inventory which is available at http://www.vtwaterquality.org/lakes.html. Periodic updates to the list are made by the Department's Lakes and Ponds Management and Protection Program. This list will be used to establish whether a waterbody is a lake (as opposed to an impoundment on a river or stream) for the purposes of applying nutrient criteria.

Compliance Locations

Where numeric nutrient criteria for lakes are currently defined in the Vermont Water Quality Standards (e.g., Lakes Champlain and Memphremagog), these criteria are to be achieved in the photosynthetic depth (euphotic) zone in central, open water areas of specifically defined lake segments. Vermont DEC recommends the same approach for other lakes and ponds statewide, with the exception that the criteria should apply to individual lakes as opposed to lake segments.

Temporal Considerations

Phosphorus criteria currently defined in the Vermont Water Quality Standards for Lakes Champlain and Memphremagog are expressed as annual average concentrations in each lake segment. However, since Vermont DEC does not presently maintain a winter lake monitoring program, the nutrient criteria variables in Vermont inland lakes are not monitored in a way that can provide true annual average concentrations. Therefore, Spring TP and TN criteria should be expressed as water column averages from samples obtained between the time of ice-out and the onset of thermal stratification in the spring. Summer TP, Chl, and Secchi depth criteria should be expressed as the mean of measurements made within the period of May-October.

Owing to the considerable year-to-year variability in spring TP concentrations, Vermont DEC typically uses a minimum of four years of spring monitoring data in order to report a mean spring total phosphorus concentration with known precision. The precision of the mean is expressed by Vermont DEC as a standardized coefficient of variation (standard error as a proportion of the mean). Adherence to this approach for newly assessed lakes would necessitate a four-year wait before an initial assessment could be completed. Therefore, Vermont DEC recommends that for the purposes of assessing attainment of nutrient criteria, lakes must show a minimum two years where spring TP and/or TN are above the criteria limits before the lake would be considered for listing as impaired. Lakes under such listing consideration would be targeted for summer TP, Secchi depth, and Chl assessments. Where a discharge permit

application is pending for an unassessed lake, appropriate lake water quality models would be used to determine the provisional effluent limits for a discharge. Effluent limits would be open to revision pending the acquisition of sufficient monitoring data.

Hierarchy of Criteria

Numeric criteria are proposed in this report for five lake variables, including spring TP, spring TN, summer TP, summer Secchi depth, and summer Chl. It is likely that some lakes will achieve some but not all of these criteria. It is also possible that aesthetics and aquatic life uses could be supported in some lakes even when criteria values for some of these variables are not attained. Examples would be situations where elevated phosphorus or nitrogen concentrations do not actually lead to excessive algal growth, or where poor water clarity is caused by background factors other than nutrient enrichment, such as naturally-occurring suspended sediments or dissolved organic coloring materials.

In order to avoid conflicting or inappropriate assessments, it will be important to establish a relative priority among the nutrient criteria variables for the purposes of water quality assessment and impairment listing. It is recommended that the causal variables (spring TP, spring TN, summer TP) be superseded by the response variables (summer Secchi depth, summer Chl) which provide more direct indications of use impairment. Under this hierarchy, TP or TN concentrations would be used to judge compliance with the Water Quality Standards if no other data existed, but if Secchi depth and Chl data were available, these response variables would be used to determine compliance. In situations where casual variables indicated an impairment and response measurements were lacking, Vermont DEC would make an effort to obtain additional data on the response variables.

Among the causal variables, it is recommended that summer TP take precedence over spring TP because summer is the season when the adverse effects of eutrophication are most directly felt. Among the response variables, summer Chl should take precedence where available over summer Secchi depth to ensure that a non-compliance determination is based on direct manifestations of excessive algal biomass and not natural background factors causing poor water clarity. However, in instances where the Secchi depth criterion was not achieved as a result of anthropogenically-caused sediment, this should be considered an impairment, as well.

In summary, the following hierarchy of nutrient criteria variables for lakes should be specified in the Water Quality Standards. Compliance with all five criteria should not be required. Instead, water quality assessment and compliance determinations should be based on the highest priority variable for which monitoring data or discharge impact modeling predictions are available.

1) Spring TP (lowest)
2) Summer TP, Spring TN
3) Summer Secchi depth
4) Summer Chl (highest)

Phosphorus Criteria for Lake Champlain and Lake Memphremagog

The phosphorus criteria proposed in this report are not intended to be applied to Lake Champlain or Lake Memphremagog. The existing phosphorus criteria for these lakes in the Vermont Water Quality Standards were derived from a previous analysis using a separate data set. The existing phosphorus criteria for Lake Champlain are serving as the basis for water quality agreements between Vermont, New York, and Quebec, the comprehensive basin plan adopted by the Lake Champlain Basin Program, and the Lake Champlain Phosphorus TMDL. A TMDL for Lake

Memphremagog is in the early stages of development in cooperation with the Province of Quebec. The previously established phosphorus criteria values for Lake Champlain and Lake Memphremagog are in most cases approximately equal to or lower than the phosphorus criteria proposed in this report for Class B inland lakes. For these reasons, the criteria for Lake Champlain and Lake Memphremagog should not be altered as a result of this analysis.

B. Considerations for Wadeable Streams

Stream Ecotypes

The proposed stream criteria will be applicable to all flowing waters of the state considered to be jurisdictional pursuant to the Vermont Water Quality Standards and determined by Vermont DEC staff to be "wadeable." Proposed criteria are applicable to three of four specific wadeable stream "ecotypes" as determined by reference biological characteristics: Small High-Gradient (SHG), Medium High-Gradient (MHG), and Warm-Water Medium-Gradient (WWMG) streams. Criteria for the fourth ecotype, Slow-Winder (SW), are pending the development of appropriate response (i.e., aquatic life and aesthetic) criteria for that stream type. It is likely, based on recent probability-based site selections made in conjunction with a national assessment of flowing waters, that greater than 98% of the stream miles in Vermont would be considered 1st- 4th order streams, the majority of which would be considered "wadeable." Probability-based surveys conducted by Vermont DEC estimate that nearly 47% of wadeable stream miles in Vermont are SHG, 29% are MHG, 10% are WWMG and 14% are SW.

Compliance Locations

The intent of ambient compliance determinations should be to estimate the frequency and duration of exposure to nutrient concentrations during low flow periods when primary production is likely to be optimal. Measurements to determine exceedences of the threshold criteria should be made in a section of the stream representative of well-mixed flow. Standard sample collection procedures should be followed. Below permitted discharges, compliance should be determined at the edge of the mixing zone.

Season and Flow Conditions

The threshold values identified in this document for wadeable streams are based on the presumption that maximum periphyton accrual potential occurs during periods of extended low summer flow. The threshold values are intended to represent mean nutrient concentrations maintained during those low flow periods. Therefore, any assessment of potential threshold value exceedence should be done by assessing mean concentrations at low flows, either through modeling (e.g., determining permit limits for a point discharge) or through analysis of multiple samples collected during periods of low flow.

We recommend that TP and TN criteria be expressed as the concentrations at the lowest median monthly flow that occurs during the summer growing season (generally the August median flow). The summer growing season for streams should be defined as the period of May through September. Vermont DEC biologists have observed algal growth in streams beginning as early as May during years in which stream flows are low in May, and the lack of a fully developed leaf canopy in May creates the potential for sunlight to trigger excessive growth. After September, leaf-fall dominates the stream biological processes and other nutrient sources would be less important.

Recommendations for the number of samples required to determine a mean concentration may be determined on a site-specific basis but should in no case be less than three samples collected

at low flows on separate non-consecutive days. Impairment determinations should be made in a manner consistent with VTDEC assessment and listing guidelines.

Application of Criteria

There are a number of factors that contribute to some uncertainty surrounding the derivation of the proposed criteria for wadeable streams. These factors include: (1) use of a single nutrient data point to represent mean low flow concentrations, (2) lack of precision in the nutrient-response relationships, (3) lack of discrete thresholds of response to nutrients, and (4) difficulties associated with distinguishing co-occurrence from causality in evaluating the nutrient-response relationships.

Given the large degree of uncertainty demonstrated in the derivation of these recommended nutrient criteria for streams, it is our recommendation that these criteria be used primarily as preliminary indicators of impairment and that further evaluation should be used in order to develop a weight-of-evidence determination of designated use support status at specific sites. Therefore, it is recommended that the causal variables (low flow mean TP and TN concentrations) be superseded by the response variables (biological community assessment and aesthetics) which provide more direct indications of use impairment. Under this hierarchy, TP or TN concentrations would be used to judge compliance with the Water Quality Standards if no other data existed, but if biological community and aesthetic assessment data were available, these response variables would be used to determine compliance. In situations where causal variables indicated an impairment and response measurements were lacking, Vermont DEC would make an effort to obtain additional data on the response variables. Where a discharge permit application was pending, appropriate water quality models would be used to determine provisional effluent limits for a discharge based on the probability of "causing or contributing to" an exceedence of water quality criteria. In some instances, where direct assessments of designated use status are unavailable and/or not likely to happen, it may be appropriate, with the application of best professional judgment, to determine designated use support status based on TP and TN concentrations alone.

In summary, when low-flow ambient concentrations of TP and TN can be shown, either by calculation or by direct measurement, to exceed the criteria proposed here, direct assessment of aquatic life and/or aesthetic use support status should be used to confirm the presence or absence of use impairments pursuant to and in a manner consistent with Vermont DEC water quality assessment and listing guidelines.

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