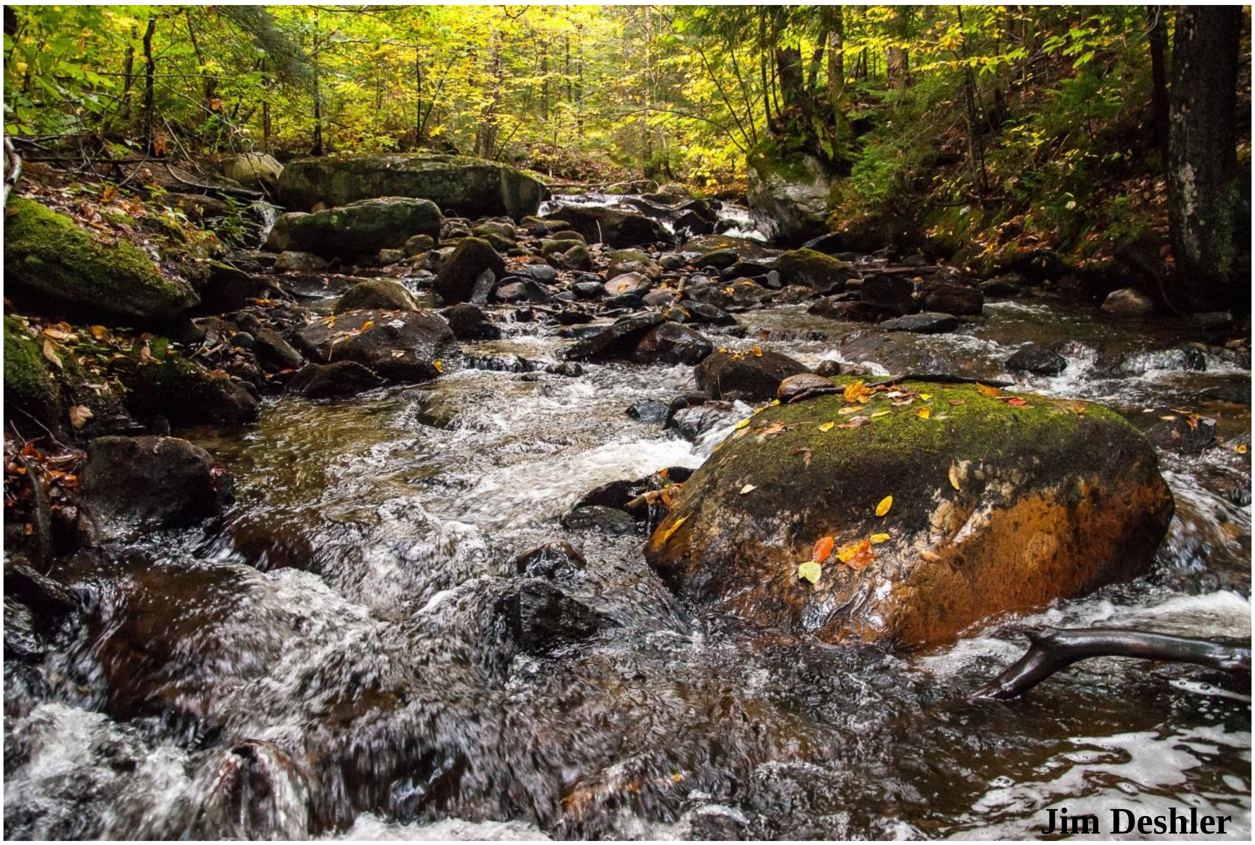
Nutrient Criteria for Vermont's Inland Lakes and Wadeable Streams

Technical Support Document

October 30, 2014

Rev. 2016



Vermont Department of Environmental Conservation
Watershed Management Division
1 National Life Drive, Main 2
Montpelier, VT 05620-3522

CONTENTS

Introduction

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 that states can use to control nutrient levels 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 (EPA). The EPA 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 EPA 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 EPA of ecoregion-specific nutrient criteria under Section 304(a) of the Clean Water Act, including criteria for lakes[6,7,8] and rivers[9,10,11] within three ecoregions in Vermont.
- 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.

Vermont DEC has been participating in the nutrient criteria process within EPA's New England Region, and has received grant assistance from EPA for data collection and analysis supporting the development of nutrient criteria in Vermont. Vermont DEC submitted a report to EPA titled *Developing Nutrient Criteria for Vermont's Lakes and Wadeable Streams*[12] as a draft for technical review in 2007. The EPA initiated an external scientific peer review of the report, and as a result of the peer review and other considerations, the DEC decided to revise the analysis.

Vermont DEC prepared a second report titled *Proposed Nutrient Criteria for Vermont's Lakes and Wadeable Streams*[13] in 2009, and submitted an accompanying rule proposal to the Vermont Water Resources Panel for incorporating the criteria into the Vermont Water Quality Standards. Consideration of the rule proposal was suspended, however, when it could not be reconciled with EPA's directive[14,15] that nutrient criteria must be independently applicable; i.e., that phosphorus or nitrogen concentration data must determine compliance regardless of whether aesthetic or biological measurements indicate support of these uses at the site in question.

Since then, Vermont DEC has acquired considerable additional sampling data for use in nutrient criteria development, and has continued to refine the data analysis methods. This report presents a third technical proposal for nutrient criteria in Vermont, based on the cumulative dataset and additional analyses. A previous draft of this report (April 10, 2013) was submitted to EPA for informal scientific peer review, which resulted in several improvements to the analysis that are incorporated into this present draft.

The issue of independent applicability will need to be resolved before implementing these criteria through rulemaking in the Vermont Water Quality Standards. The EPA's 2013 document on *Guiding principles on an optional approach for developing and implementing a numeric nutrient criterion that integrates causal and response parameters*[16] provides a solution whereby impairment determinations would not need to be based on nutrient concentration data alone. This present draft Vermont nutrient criteria proposal includes revisions made in accordance with this latest EPA guidance.

Classifications, Designated Uses, and Management Objectives in Vermont's Water Quality Standards

The Vermont Water Quality Standards[17] 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 1.

Table 1. 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

The Vermont Water Quality Standards define management objectives and criteria for each of the designated uses listed in Table 1. 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 2 for aquatic biota, wildlife, and aquatic habitat uses, and in Table 3 for aesthetics uses.

Table 2. 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 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 **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 3. 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)*** 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.

* The February 9, 2006 and subsequent versions of the Vermont Water Quality Standards dropped the word “excellent” from the management objectives for aesthetics for Class A(2) waters. However, it was assumed for purposes of this report, pending further clarification, that nutrient criteria should be derived to protect “excellent” aesthetic value in A(2) waters.

Existing Nutrient Criteria in Vermont's Water Quality Standards

The current Vermont Water Quality Standards[17] include both narrative and numeric criteria for total phosphorus and nitrates, but are limited in several ways. The numeric phosphorus criteria are limited to upland streams and Lakes Champlain and Memphremagog. The nitrate concentration criteria do not include other nitrogen fractions that would be part of a total nitrogen analysis and that could be important in promoting eutrophication. With the exception of the criteria for Lake Champlain and Lake Memphremagog, the numeric nutrient criteria for these nutrients were not derived from a direct, quantitative analysis of the relationship between nutrient concentrations and support of designated uses. The existing nutrient criteria in Vermont's Water Quality Standards are summarized below.

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 4). 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 4. 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 general narrative criterion 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 numeric criteria for nitrates listed in Table 5. The nitrate criteria for flowing waters are not to be exceeded at flows exceeding low median monthly flows.

Table 5. 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

Scope and Limitations of the Analysis

Waterbody Types Included

Inland Lakes

Lake nutrient criteria development for this analysis was limited to Vermont "inland" lakes and reservoirs with surface areas of 20 acres or greater, exclusive of Lake Champlain and Lake Memphremagog, and the analysis in this report is therefore most applicable to lakes 20 acres in area or larger. A lake area cutoff of 20 acres was used for practical reasons because the lake monitoring programs used to derive the criteria generally sampled lakes 20 acres in size or larger. There are few data from which to assess nutrient concentrations in lakes smaller than this size, and lakes 20 acres or larger represent 95% of all lake acres statewide.

In order to apply nutrient criteria for inland lakes and reservoirs, a physical distinction must be made between lakes and riverine impoundments. Due to their large drainage areas and rapid flushing rates, riverine impoundments respond less sensitively to nutrient inputs than the more lacustrine environments from which the proposed nutrient criteria were derived. The Vermont Water Quality Standards (Section 3-01 B.2.d) recognize this distinction and provide special protection from discharges for lakes and reservoirs that have drainage areas less than 40 mi^2 and drainage area to surface area ratios less than 500:1. A drainage area to surface area ratio of 500:1 should be used to distinguish lakes from riverine impoundments, and the proposed inland lake nutrient criteria should apply only to lakes with ratios less than 500:1. This would exclude 29 rapidly flushed riverine impoundments from applicability of the lake nutrient criteria. Nutrient criteria for non-wadeable streams, when developed, should apply to these sites.

Changes to the existing phosphorus criteria for Lake Champlain and Lake Memphremagog are not proposed here. The total 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[18] as a consistent set of management goals for the lake. These criteria served as the basis for the Lake Champlain Phosphorus TMDL[19] prepared by Vermont and New York and approved by the USEPA in 2002. The EPA revoked its approval of the Vermont portion of the Lake Champlain TMDL in 2011 and is developing a new TMDL to achieve the same in-lake phosphorus criteria. A phosphorus TMDL for Lake Memphremagog is in the beginning stages of development by Vermont DEC. Since the existing Lake Champlain phosphorus criteria are the foundation for the Lake Champlain TMDL and other major planning and implementation efforts, changes to the nutrient criteria for Lake Champlain and Lake Memphremagog were not considered in this analysis.

Wadeable Streams

Wadeable streams are defined by USEPA as streams, creeks and small rivers that are shallow enough to be sampled using methods that involve wading into the water. They typically include waters classified as 1st through 4th order (and sometimes 5th) in the Strahler Stream Order classification system (based on the number of tributaries upstream). Stream nutrient criteria are proposed here for three wadeable stream types. The currently available data are not sufficient to support nutrient criteria development for non-wadeable streams and rivers in Vermont.

About 98% of the 7,200 mapped stream miles in Vermont (1:100,000 scale) are first through fourth-order streams, and most of these would be considered wadeable. About 47% of the wadeable stream miles are classified by stream ecotype as Small, High-Gradient (SHG) streams, 29% are Medium, High-Gradient (MHG) streams, and 10% are Warm-Water Medium-Gradient

(WWMG) streams. These are the three wadeable stream types for which nutrient criteria are proposed here. A fourth wadeable stream ecotype (Slow-Winder) represents about 14% of the wadeable stream miles in Vermont, but procedures for macroinvertebrate community use attainment determinations have not yet been developed for this stream type, so corresponding nutrient criteria cannot be derived for Slow-Winder streams.

Phosphorus and Nitrogen

Phosphorus has long been regarded as the primary limiting nutrient for phytoplankton in freshwater lakes and streams. There are scientific arguments for reducing phosphorus loading as a priority in order to control eutrophication, and phosphorus reduction has a much stronger lake management record than nitrogen reduction.[20] However, evidence is growing that both nitrogen and phosphorus have additive effects on phytoplankton growth in lakes, and that limitations on nitrogen levels are an important consideration in managing eutrophication in fresh waters.[21,22,23] The EPA has indicated that states should adopt numeric criteria for both phosphorus and nitrogen since generalizations about the limiting nutrient in freshwater are not always appropriate.[15]

The Vermont stream monitoring dataset used to support nutrient criteria development includes both total phosphorus (TP) and total nitrogen (TN) sampling results. The available lake monitoring data during the summer growing season include only TP results, although spring lake data have been collected for both TP and TN.

Correlations between TP and TN concentrations make it difficult to statistically separate the independent effects of each nutrient on designated uses. Because of this uncertainty, the Northeast states[24] have argued that numeric nutrient criteria should be required only for the limiting nutrient in a system, which is generally presumed to be phosphorus in freshwater and nitrogen in marine systems. Unless dual nutrient impacts are demonstrated at a site, unnecessary and expensive treatment requirements for both nutrients should be avoided. Due to remaining scientific uncertainty about the role of nitrogen in eutrophication of fresh waters, adoption of new numeric nitrogen criteria for Vermont lakes and wadeable streams will be deferred until the need for nitrogen criteria is better established.

Vermont’s lake and stream nutrient monitoring programs have focused primarily on total phosphorus and nitrogen. It is possible that consideration of sub-fractions of these nutrients such as dissolved inorganic forms could improve the relationships between nutrient concentrations and algal growth response in some environments, but data on these fractions are not widely available for Vermont waters. Nutrient criteria development for Vermont lakes and wadeable streams was therefore limited to TP, consistent with EPA guidance.[2,3]

Spatial and Temporal Considerations

Inland Lakes

Lake sampling has been conducted for both spring TP and summer TP, but in order to avoid contradictory impairment assessments, criteria for only one of these variables should be specified in the Vermont Water Quality Standards. Spring TP data are more easily obtained by Vermont DEC staff monitoring programs because they entail only one sample date per year on each lake. The existing DEC database includes both spring TP and spring TN records on nearly 300 lakes. However, spring conditions do not always reflect summer nutrient and algae levels in rapidly flushed lakes and reservoirs that are highly affected by spring runoff. Data on nutrient response variables such as chlorophyll-a concentration or Secchi disk depth are not obtained during spring lake sampling sufficiently enough to support a nutrient criteria analysis.

Summer mean TP is more closely related to conditions during the growing season and the season when most recreational use occurs, and summer data exist for nutrient response variables as well. For these reasons, mean summer TP was chosen as the preferred casual variable for deriving nutrient criteria for Vermont lakes. Availability of summer TP data is currently dependent on the efforts of volunteer monitors, and data exist for a limited number (N = 76) of Vermont inland lakes. A significant new programmatic effort would be necessary to provide summer TP assessments on the majority of Vermont lakes. The Spring TP data could be used to identify the highest priority lakes for summer TP assessment.

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, Vermont's inland lake monitoring programs do not extend beyond the spring or summer seasons. For this reason, nutrient criteria should be expressed as the mean of measurements made within the period of June-September.

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 zone in central, open water areas of specifically defined lake segments. The same approach should be used for inland lakes and reservoirs statewide, with the criteria applying to entire lakes as opposed to lake segments.

Wadeable Streams

The existing TP criterion in the Vermont Water Quality Standards of 0.010 mg/L for upland streams is specified to apply at low median monthly flow, which typically occurs during the summer period. The rationale for using this flow condition is that maximum periphyton accrual and associated impacts on the macroinvertebrate community occur during periods of extended low flow when physical scouring is minimal. For this reason, nutrient criteria for wadeable streams should be expressed as the concentration not to be exceeded at the lowest median monthly flow that occurs during the summer growing season (usually the August median flow). The summer growing season for streams should be defined as the period of June through October.

Nutrient sampling to determine compliance with the stream 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 as near as possible to the mixing zone.

The number of samples required for compliance purposes may be determined on a site-specific basis, but should in no case be less than three samples collected on separate non-consecutive days. The flow conditions during nutrient sampling should approximate the low median monthly flow for the site.

Uses Assessed for Nutrient Criteria Development

The Vermont Water Quality Standards list six designated uses that apply to some or all water classes (Table 1). However, data were not available to develop quantitative relationships between nutrient concentrations and the level of support for all six of these uses in all applicable waters. For example, very little information exists for Vermont water supplies regarding the relationship between nutrient concentrations and adverse effects such as filter clogging, taste and odor problems, and formation of disinfection by-products. In many cases, criteria derived to protect one use might protect multiple uses. For example, criteria to protect aesthetic value would be likely to protect swimming, boating, and other recreational uses in most, but perhaps not all cases. Irrigation of crops is not likely to be impaired by nutrients.

This analysis focused on the first two designated uses listed in Table 1, (1) aquatic biota, wildlife, and aquatic habitat, and (2) aesthetics. Lake criteria for aesthetics were derived from an analysis of user perception survey data, as described in the following section. A previous analysis[12] developed lake aquatic life criteria from relationships between nutrient concentrations and a Vermont Lake Condition Biological Index. However, statistically significant relationships between nutrient concentrations and the lake biological index existed only for the phytoplankton community, and not for the macroinvertebrate community. Furthermore, the lake sample size used in the development of the index was relatively small and the relationship between TP and impairment of the lake phytoplankton community as assessed by the lake condition index was highly variable among lakes. For these reasons, after reconsideration of the previous analysis, it was determined that the available data were insufficient to support the development of nutrient criteria to protect aquatic life communities in Vermont lakes.

Wadeable stream criteria for aquatic life support were derived from an analysis of the macroinvertebrate communities and their departure from the reference condition, as described in the following section. Using macroinvertebrate community assessments provides a good evaluation of the status of aquatic biota in the streams.

The previous analysis[12] developed stream aesthetics criteria from measurements of microalgal biofilm thickness on pebbles in the stream. However, no user survey assessment of aesthetic condition was conducted for the streams. Instead, impairment thresholds were defined by somewhat arbitrarily chosen percentiles for the distribution of microalgal film thickness among stream sites. Because of the lack of direct assessment of aesthetic impacts on stream users, and the relatively weak relationships between nutrients and microalgal film thickness, it was determined after reconsideration of the previous analysis that the available data were insufficient to support the development of nutrient criteria to protect aesthetic uses in Vermont streams.

The scope of this analysis and the designated uses for which sufficient data are available to derive nutrient criteria are summarized in Table 6.

Table 6. Scope of the analysis. Shaded cells indicate where sufficient data were available to derive nutrient criteria to support a specific designated use.

Designated Use	Lakes and Reservoirs	Wadeable Streams
Aquatic biota, wildlife, and aquatic habitat	Not analyzed	Evaluated as change in biota from reference condition
Aesthetics	Evaluated from lake user survey	Not analyzed
Swimming and other primary contact recreation	May be supported if aesthetic uses are supported	Not analyzed
Boating, fishing, and other recreational uses	May be supported if aesthetic uses are supported	May be supported if aquatic life uses are supported
Public water supplies	Not analyzed	Not analyzed
Irrigation of crops and other agricultural uses	May be supported if aesthetic uses are supported	May be supported if aquatic life uses are supported

General Data Analysis Approach

Federal regulations derived from the Clean Water Act define water quality criteria as "*elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements,* ***representing a quality of water that supports a particular use****. When criteria are met, water quality will generally protect the designated use*" (40 CFR Part 131 – emphasis added). The first principle of this analysis is therefore that numeric nutrient criteria should be based on quantified, cause-and-effect relationships with the uses they are designed to protect (i.e., stressor-response relationships[25]).

A major technical challenge inherent in developing nutrient criteria for any set of waters is that large variability is to be expected in the relationships between nutrient concentrations and the use response measurements. This variability leads to a high potential for false negative or false positive use impairment determinations. Therefore, a second principle of this analysis is that the analytical methods should consider and quantify the risk of each type of error, and nutrient criteria should be chosen to minimize and optimally balance these errors.

The general data analysis approach used in this report can be described by the following steps.

1. Quantify the level of use support at each site using direct measurements of response variables (e.g., user aesthetic perceptions, biological community status).
2. Verify the existence of statistically significant relationships between nutrient concentrations and response variables.
3. Determine the impairment status (yes/no) at each site from the use support measurements.
4. Select criteria values for nutrient concentrations that optimally minimize and balance the rates of false positive and false negative impairment determinations.

Criteria for Inland Lakes

Data Sources and Nutrient Criteria Variables

Summer Phosphorus, Chlorophyll-a, and Secchi Disk Transparency

The Vermont Lay Monitoring Program is a citizen volunteer monitoring program that has been supported by Vermont DEC continuously since 1979. The program operates according to an EPA-approved quality assurance project plan.

Weekly summer (June-August) sampling is conducted for TP, chlorophyll-a (Chl-a), and Secchi disk transparency. TP and Chl-a 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 data on 87 different Vermont inland lakes during 1987-2012, although not all variables were measured on each lake every year.

Lake User Survey

A lake user survey[26] was conducted in conjunction with the Vermont Lay Monitoring Program during 1987-1991, and again during 2006-2013. The relationships between TP 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 the EPA's Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs.[2] The user survey results for Vermont inland lakes include 5,073 individual user responses paired with simultaneous measurements of one or more nutrient criteria variables (TP, Chl-a, and/or Secchi depth) on 87 different inland lakes during 1987-2013.

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 3). 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.

Derivation of Criteria to Protect the 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 2 and 3). Since "natural condition" is not tied to a specific aesthetic descriptor (e.g., "excellent" or "good"), a different approach to deriving nutrient criteria was used for Class A(1) lakes than was used for lakes in other water classes.

TP criteria for Class A(1) lakes were derived by estimating the nutrient concentrations that should exist in lakes with little or no human disturbance from development or agriculture in their watersheds. Agricultural land uses were defined as those uses in the National Land Cover Dataset that were agricultural in nature (e.g., hay/pasture, row crops, etc.). The developed land category included low, medium, and high-density residential areas, urban uses, quarries, and transportation uses.

The available dataset included only a few high elevation lakes, so deriving statistical relationships specifically for these lakes was not possible. However, the assumption was made for this purpose that nutrient concentrations in undeveloped lowland lakes provide a basis for defining "natural condition" in Class A(1) upland lakes, pending additional data collection on upland lakes.

Figure 1 shows the regression relationships between lake monitoring variables (summer mean values) and the percent of agricultural or developed land in the lake watersheds. The intercepts of these regressions (at zero agricultural or developed land use) were used to derive criteria representing the natural condition. The resulting criteria were 12 µg/L for TP, 2.6 µg/L for Chl-a, and 5.0 m for Secchi depth.

EPA guidance[2] 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. There are three EPA Level III ecoregions that overlap with Vermont, including the Northeastern Highlands, the Northeastern Coastal Zone, and the Eastern Great Lakes and Hudson Lowlands. However, when separate nutrient and land use regressions were developed for Vermont lakes in each ecoregion, there were no statistically significant differences found between the intercepts of the regressions. For this reason, separate criteria for natural condition were not developed for lakes in each ecoregion.

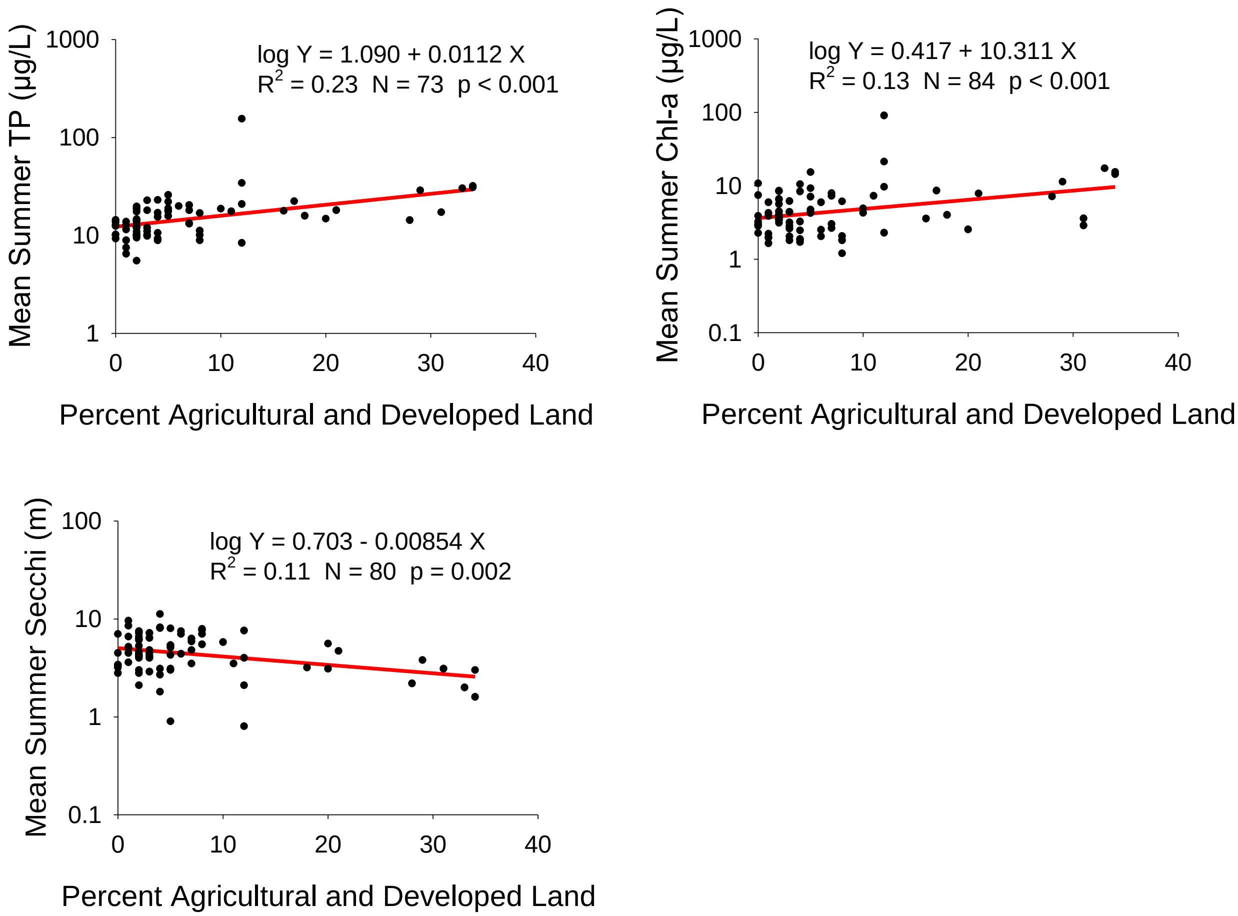


Figure 1. Regressions of lake nutrient variables vs. percent of agricultural and developed land in the lake's watershed.

Derivation of Criteria to Protect 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 lakes attained the management objectives for aesthetics as defined in the Vermont Water Quality Standards. However, the user survey form was created before the aesthetics objectives in Table 3 were incorporated into the Vermont Water Quality Standards and the user survey response choices do not track exactly with the descriptor words used for the aesthetic standards.

For the purposes of this analysis, user responses of (1) “beautiful” or (2) “excellent, very minor aesthetic problems” were judged to represent attainment of the standard of “excellent” or “very good” aesthetic value. User responses of (3) no more than slight impairment of enjoyment were judged to represent attainment of the standard of “good” aesthetic value. User survey responses of (4) enjoyment substantially reduced or (5) enjoyment nearly impossible were considered to be non-attainment of the aesthetic standards. The correspondence between the user survey form responses and the water quality management objectives of “excellent,” “very good,” and “good” aesthetic value that was applied for this analysis is shown in Table 7.

While the survey form used the term “impaired” in response 3, it should be read as a slight reduction in enjoyment and not as an actual impairment of aesthetic use. Assignment of a user response of “slightly impaired” to represent standard of “good” was justified by the fact that this user response choice was the middle of five choices with two lower choices (4 and 5) available to indicate significant impairment. A middle response was very likely interpreted by most respondents to express a midpoint of “good” on a scale of excellent to poor aesthetic condition. In fact, the volunteer monitors were instructed to interpret the scale in this manner.

Table 7. Correspondence between water quality standards for aesthetics and lake user survey responses.

Water Quality Standard	Lake User Survey Response
Natural condition	The user survey was not used to define natural condition.
Excellent or very good aesthetic value	(1) Beautiful, could not be any nicer, <u>or</u> (2) Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
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, <u>or</u> (5) Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

The statistical significance of the relationship between the nutrient criteria variables and the simultaneously recorded user survey responses was verified as shown in Figure 2. The distributions of individual summer TP, Chl-a, and Secchi depth observations associated with each user response category (Table 7) were compared using a Kruskal-Wallis One-Way Analysis of Variance on Ranks. Figure 2 shows that all three water quality measurements varied significantly ($p < 0.001$) in the expected direction with the user response scale, although not all individual pairwise comparisons indicated medians that were significantly different (Dunn's Method, $p < 0.05$).

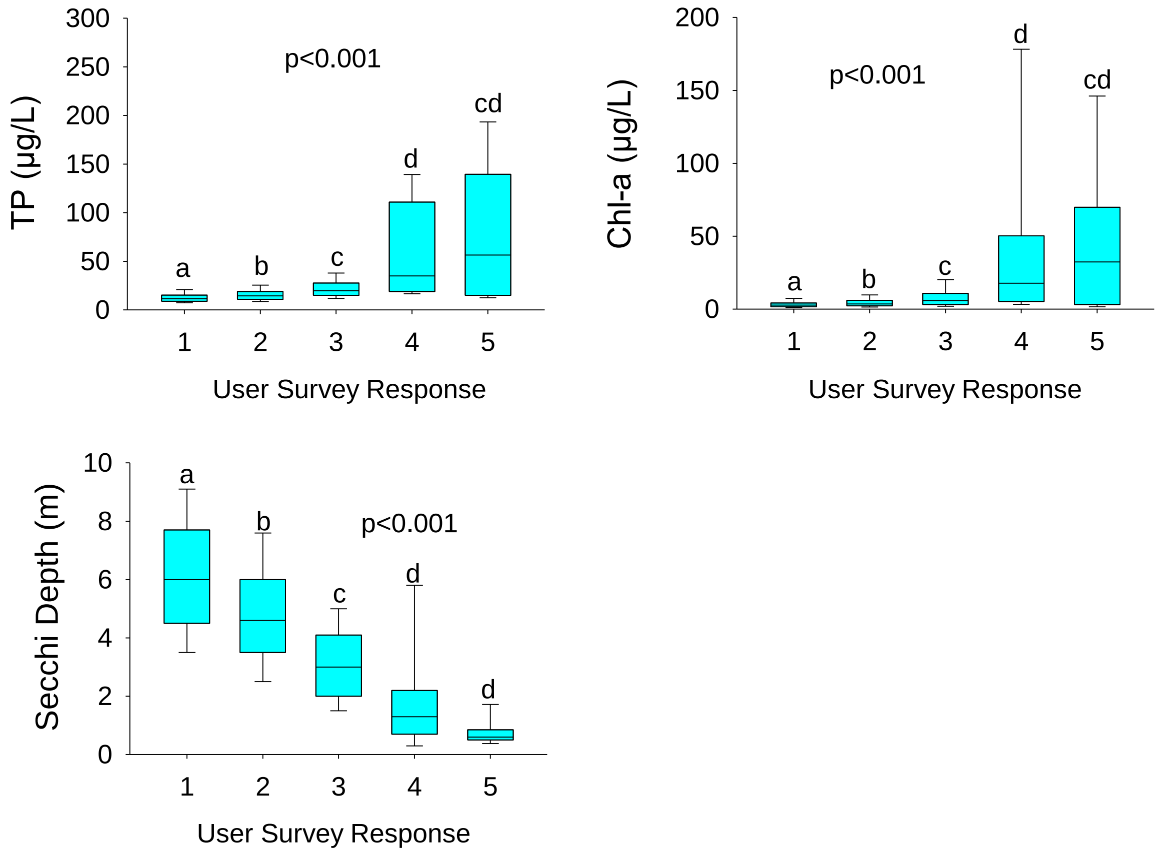


Figure 2. Distributions of individual summer TP, summer Chl-a, and summer Secchi depth sample results associated with each user response category. Box plots show 5th, 25th, 50th, 75th, and 95th percentiles. Overall significance values were based on a Kruskal-Wallis One-Way Analysis of Variance on Ranks. Medians without letters in common were significantly different, based on individual pairwise comparisons (Dunn's Method, p < 0.05).

Lake nutrient criteria are best expressed as season or annual mean values, rather than as instantaneous "not to exceed" values. Means are estimated with greater statistical stability by monitoring programs and are more readily predicted by lake models.[27,28] For these reasons, the analysis used long-term means for the monitored variables to develop relationships between water quality values and the rates of aesthetic use impairment. Long-term means for each lake were calculated as the average of the summer mean TP, Chl-a, and Secchi values across all sampled years.

Application of the lake user survey responses as described in Table 7 allowed for a yes/no impairment determination to be made on each sampling date with respect to attainment of two tiers of aesthetics use: "excellent or very good," and "good." The rates of false positive and false negative impairment determinations associated with potential nutrient criteria values were analyzed as follows.

False positive and false negative (i.e., Type I and Type II) error rates were evaluated using a confusion matrix (Table 8), similar to approaches proposed in Florida[29] and Virginia.[30] For each nutrient criterion cut-off value expressed as a lake mean TP, Chl-a, or Secchi depth, the corresponding numbers of true positives, false positives, true negatives, and false negatives were tabulated from the individual user survey responses. False positive and false negative error rates were calculated as indicated in Table 8 using Receiver Operating Characteristic (ROC) analysis tools[31].

Table 8. Confusion matrix used to calculate false positive and false negative error rates for a specific nutrient criterion test value.

	Site nutrient data indicate no impairment	Site nutrient data indicate impairment
Site response data indicate no impairment	True negatives (TNs)	False positives (FPs)
Site response data indicate impairment	False negatives (FNs)	True positives (TPs)

False positive rate (FPR) = FPs / (TNs + FPs)

False negative rate (FNR) = FNs / (FNs + TPs)

False positive and false negative error rates calculated in this manner are potentially subject to bias when the sampled lake or stream distribution of nutrient criteria variables differs from the true population distribution. To assess this potential bias, the distributions of mean TP, Chl-a, and Secchi depth from the Vermont Lay Monitoring Program lake dataset were compared with the population distributions for these variables in all Vermont lakes larger than 20 acres in surface area, as determined from the National Lakes Assessment project in Vermont.[32,33] The National Lakes Assessment used a probability-based sampling design to produce distributions of the sampled variables that were representative of the true population distribution for the region.

Figure 3 shows that the distributions of nutrient criteria variables in the Lay Monitoring Program dataset differed from the population distributions estimated by the National Lakes Assessment. TP and Chl-a concentrations tended to be higher in the Lay Monitoring lakes than in the full population distribution. Secchi depth was also higher in the Lay Monitoring lakes, a deviation from the expected direction of difference that can be explained by the fact that somewhat different sets of lakes were sampled for TP, Chl-a, and Secchi depth during the course of the Lay Monitoring Program.

In order to provide a basis for calculating false positive and false negative impairment determination rates from representative population distributions of the data, the weights assigned to each lake included in the National Lakes Assessment within Vermont were used to synthesize a larger set of TP, Chl-a and Secchi depth values (N > 7,000) having the same representative population distributions. Each value in these synthetic distributions was randomly assigned an impairment status (0 = no impairment; 1 = impairment) at frequencies corresponding to the probability of impairment determined by logistic regression.[34,31] Since regression provides a way to establish the relationship between nutrient criteria variables and the probability of impairment in a manner that is robust to site selection bias, this procedure was suggested as a way to minimize the effect of such bias on the ultimate nutrient criteria that are proposed.[35]

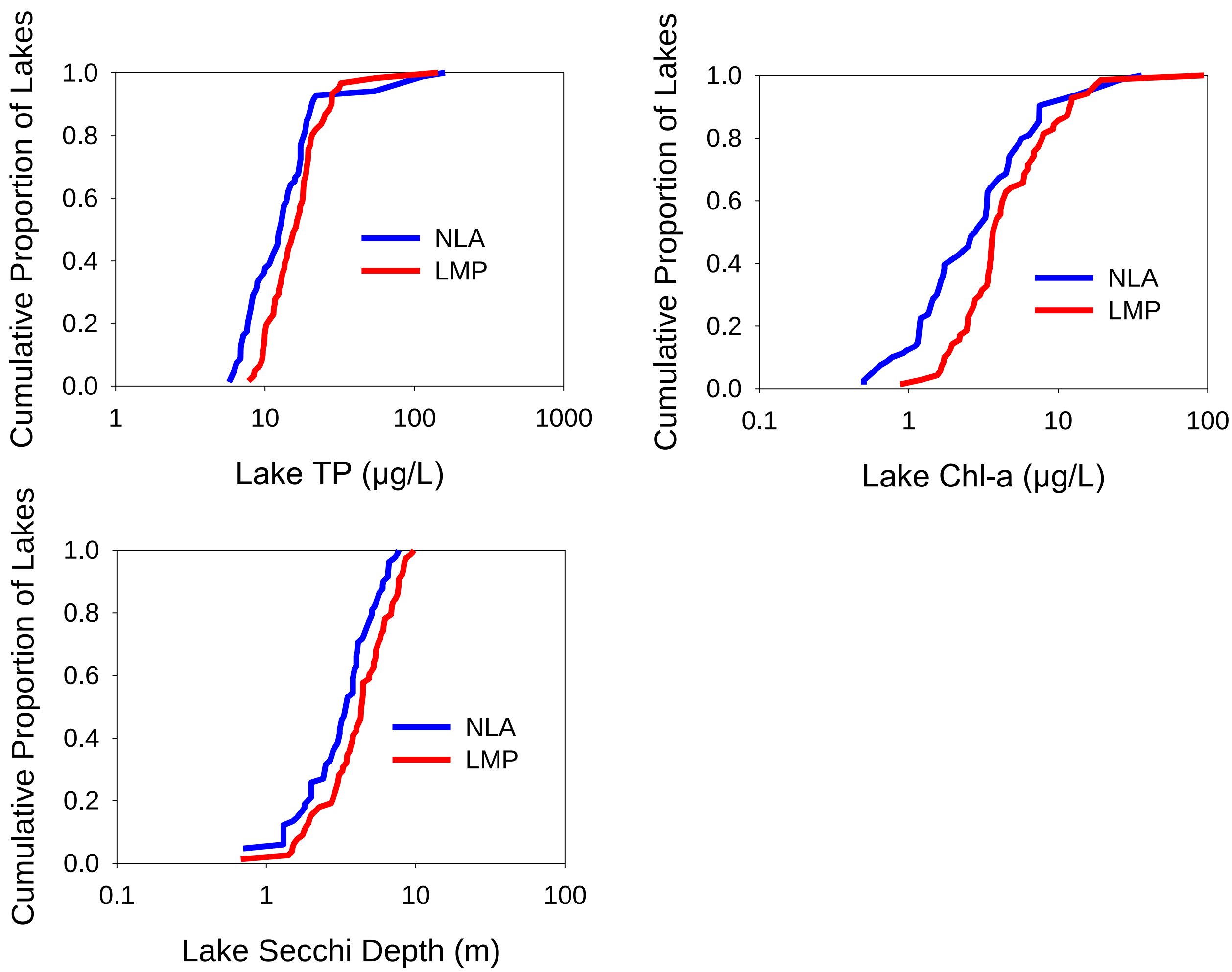


Figure 3. Cumulative frequency distributions of lake nutrient criteria variables. Population distributions derived from probability-based sampling for the National Lakes Assessment (NLA) in Vermont are compared with sampled distributions for the Vermont Lay Monitoring Program lakes (LMP).

The nutrient criteria values (as long-term lake means for the period of record) and the individual user survey responses from the Vermont Lay Monitoring Program dataset were used for the logistic regression analysis. Impairment status was treated as the binary dependent variable in the logistic regression model with the following form:

$$\ln (P / (1-P)) = b_0 + b_1 X$$

Where,

P = probability of impairment
X = lake mean TP, Chl-a, or Secchi depth
b_0, b_1 are the regression coefficients

The logistic regression statistics are provided in Table 9. All regressions had coefficients for the independent variable that were significantly different from zero ($p < 0.001$), based on the Wald statistic The logistic transformation (solving for P) was used for graphing purposes in Figure 4 in order to show probabilities of impairment directly.

Goodness of fit to the logistic model was assessed visually by calculating the frequencies of the user responses within ten intervals (bins) of equal sample size across the range of lake mean TP, Chl-a, and Secchi depth, and plotting these frequencies against the interval mean values as points in Figure 4. High-leverage outlier data for one lake (Shelburne Pond, TP = 144 µg/L, Chl-a = 95 µg/L, Secchi = 0.7 m) were deleted from the dataset used for logistic regression analysis to improve the accuracy of the regression fit over the range of values relevant to nutrient criteria derivation. The results demonstrated a good visual fit of the data to the logistic model.

The logistic regression equations were used to randomly assign impairment status (yes/no) at appropriate frequencies to each TP, Chl-a, and Secchi depth value in the synthetic population distributions derived from the National Lakes Assessment in Vermont. It was then possible to calculate false positive and false negative error rates (Table 8) over the range of mean TP, Chl-a, and Secchi values representative of all Vermont lakes, as shown in Figure 5.

The false positive and false negative error rate curves (Figure 5) illustrate the trade-offs involved in selecting nutrient criteria values. Lower, more stringent nutrient criteria reduce the risk of failing to identify impaired lakes (false negatives), but increase the risk of declaring impairments that do not actually exist (false positives). Both types of error are serious. False negative errors could result in ongoing use impairment without focusing management attention on the pollution sources. False positive errors could lead to inappropriate or excessive management interventions that would be better directed elsewhere.

One method for minimizing and balancing these two types of errors would be to select a nutrient criterion value corresponding to the point where the two error rates are equal (i.e., the point where the two curves cross in Figure 5). This is the method used to derive proposed nutrient criteria in this analysis, and it assumes that each type of error is equally undesirable. Alternate methods could weight one type of error more heavily than the other, or choose a point where the sum of the two error rates is minimized. The curves shown in Figure 5 provide a basis for deriving nutrient criteria with explicit knowledge of the consequences in terms of the risk of these two types of errors.

Table 9. Statistics for logistic regressions of lake user survey response vs. nutrient criteria variables.

TP: Probability of worse than excellent or very good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	p
	4,607	68	Constant	4.932	0.152	1056	<0.001
			TP	-1.180	0.00761	558	<0.001
TP: Probability of worse than good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	p
	4,607	68	Constant	5.718	0.214	711	<0.001
			TP	-1.113	0.00870	170	<0.001
Chl-a: Probability of worse than excellent or very good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	P
	4,791	74	Constant	2.964	0.0819	1308	<0.001
			Chl-a	0.202	0.0103	388	<0.001
Chl-a: Probability of worse than good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	p
	4,791	74	Constant	4.611	0.174	700	<0.001
			Chl-a	-0.160	0.0194	67.9	<0.001
Secchi: Probability of worse than excellent or very good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	p
	4,665	71	Constant	-0.933	0.130	51.2	<0.001
			Secchi	0.644	0.0327	389	<0.001
Secchi: Probability of worse than good aesthetic value							
	N	N unique [a]		Coefficient	Std. Error	Wald Statistic	p
	4,665	71	Constant	0.916	0.298	9.42	0.002
			Secchi	0.791	0.0894	78.3	<0.001

[a] Number of unique independent variable combinations

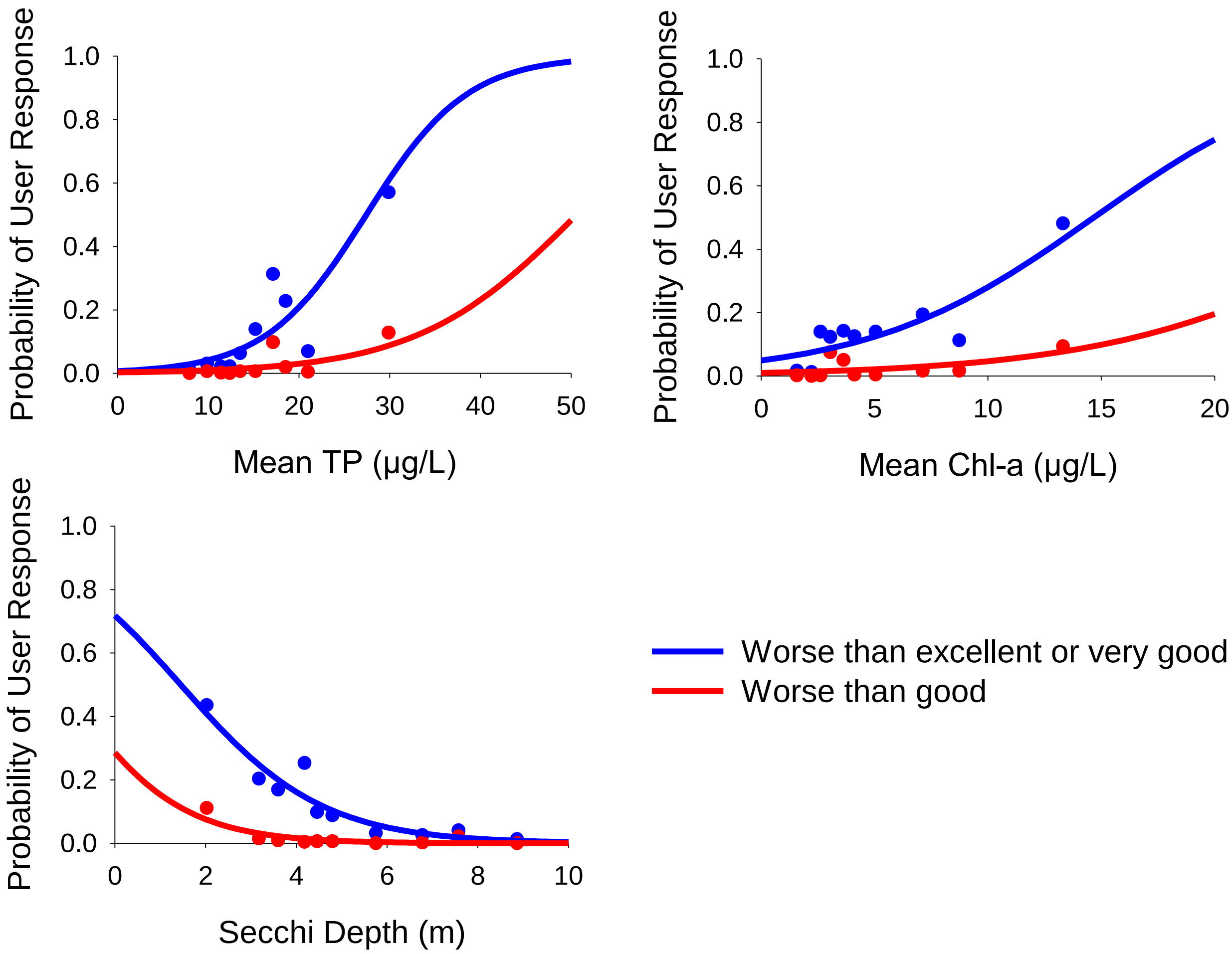


Figure 4. Logistic regression of user survey response vs. lake mean summer TP, Chl-a, and Secchi depth. The data points are frequencies of user responses binned within intervals of the lake means, shown to demonstrate goodness of fit to the logistic model.

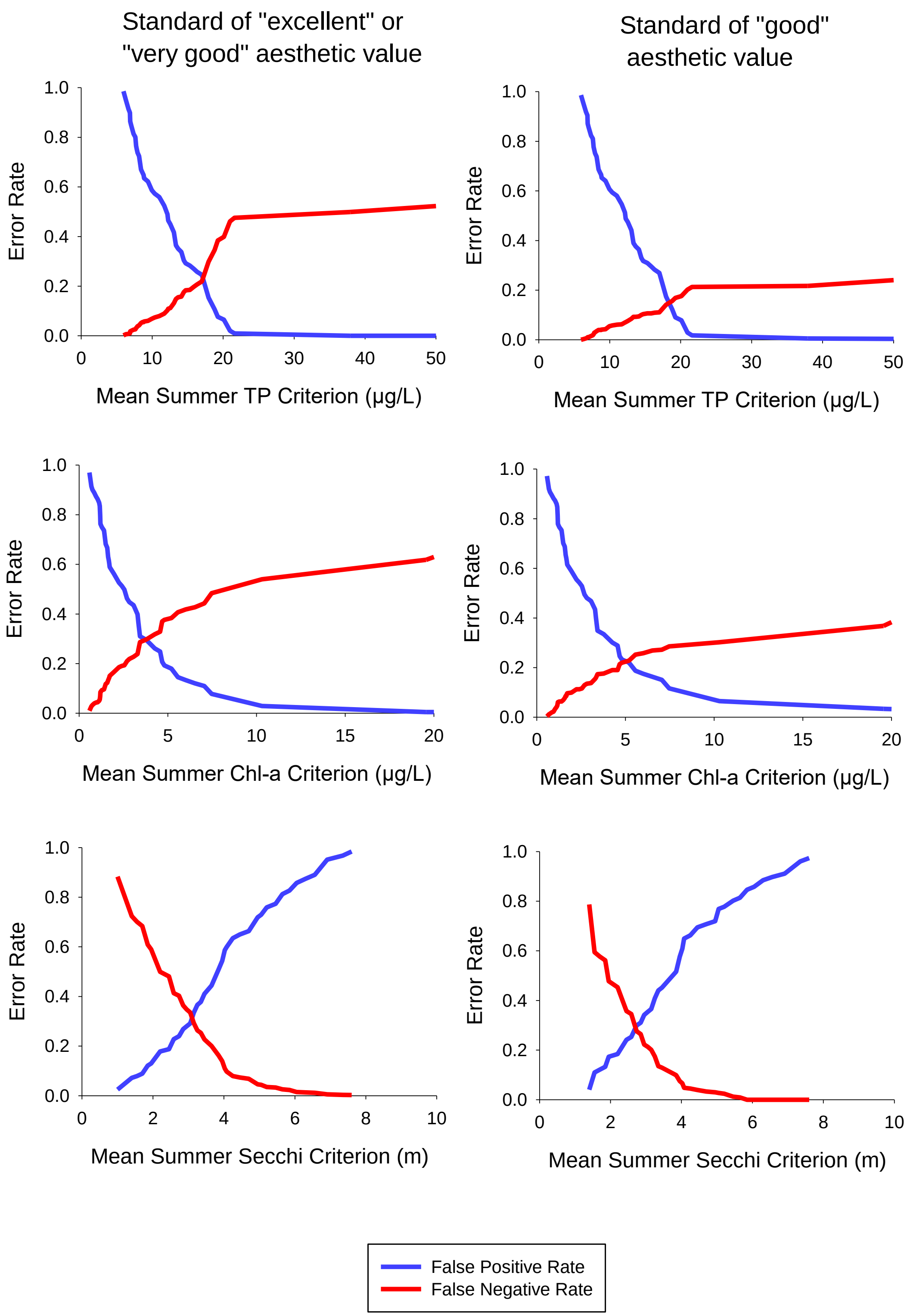


Figure 5. Lake impairment determination error rates associated with potential nutrient criteria values expressed as long-term means.

Proposed Criteria for Lakes

Proposed nutrient criteria to protect the natural condition in Class A(1) lakes and to protect aesthetics uses in Class A(2) and B Vermont inland lakes are summarized in Table 10. The criteria for Class A(1) lakes were derived from the intercepts of the land use regressions (Figure 1) to represent natural conditions. The criteria for Class A(2) lakes were based on the "excellent or very good" aesthetics standard, and the criteria for Class B lakes were based on the "good" standard. The proposed criteria for Class A(2) and B lakes represent the points where the risk of false positive and false negative aesthetic impairment determinations would be equal (Figure 5), except as noted below.

Upon examination of the long-term lake means in relation to the proposed criteria, it was found that there were several lakes where the mean Chl-a value exceeded the value of 5.2 µg/l that would have been derived from the intersection of the false positive and false negative error rate curves in Figure 5 (for "good" aesthetic value), but which had TP and Secchi means below the respective criteria values. It was suspected in most of these cases that concentrated metalimnetic phytoplankton layers were responsible for the disproportionately high Chl-a values in the vertically-integrated euphotic zone samples, while not producing an aesthetic impairment at the lake surface. Adjustment of the Chl-a criterion upwards to 7.0 µg/l would eliminate these inconsistencies between the TP, Chl-a, and Secchi criteria values, and reduce the false positive rate significantly while only minimally increasing the false negative error rate for Chl-a (Figure 5). For these reasons, a Chl-a criterion of 7.0 µg/l is proposed for Class B lakes.

Criteria for individual Class B water management types (1, 2, or 3) are not proposed here because the Vermont DEC does not intend to pursue water management typing. The more stringent criteria proposed for Class A(2) lakes could be applied in the future to high quality Class B waters designated as part of anti-degradation implementation.

Table 10. Proposed nutrient criteria for inland lakes.

	Water Class		
Nutrient Variable	**A(1)**	**A(2)**	**B**
Mean Summer TP (µg/L)	12	17	18
Mean Summer Chl-a (µg/L)	2.6	3.8	7.0
Mean Summer Secchi (m)	5.0	3.2	2.6

Criteria for Wadeable Streams

Data Sources and Nutrient Criteria Variables

Biological and nutrient data from Vermont streams are available from the long-term Vermont DEC Ambient Biomonitoring Program[36] which incorporates a Vermont DEC Nutrient Criteria Project[37] database that was obtained specifically to support nutrient criteria development. These programs were 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, with wadeable streams as a major focus area. Concerted efforts to collect comprehensive chemical data in conjunction with the biological samples began in 2002, and results obtained through 2011 were used to support this nutrient criteria analysis.

While periphyton growth is presumed to be the primary biological response to nutrient enrichment in wadeable streams, the relationships between measures of periphyton and aquatic life 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, the relationships between benthic macroinvertebrate community structure and aquatic life use support are very well developed for wadeable streams in Vermont. Several of the metrics used to assess macroinvertebrate community structure are responsive to stream eutrophication. For this reason, aquatic macroinvertebrate community structure was used as the response variable for nutrient criteria development for aquatic life in wadeable streams, rather than periphyton.

Macroinvertebrate community assessments were conducted at each site according to methods established by Vermont DEC.[38] Macroinvertebrate community assessments were generally conducted during low-flow or base-flow conditions during summer or fall. Single grab samples for TP and TN analysis were collected concurrently with the macroinvertebrate community sampling.

The stream data were screened in several ways in order to eliminate non-nutrient factors that could affect the macroinvertebrate community structure. Since the objective of the analysis was to develop relationships between macroinvertebrate community structure and nutrient concentrations under low or base-flow conditions, data obtained under freshet flow conditions (based on field observations) were removed from the analysis. Sites with known impacts from toxins or other non-nutrient pollutants were eliminated, and sites with greater than 80% forest canopy with potential for light limitation of algal growth were also removed from the analysis.

Nutrient concentration and bioassessment results obtained at the same site on multiple dates during the 2002-2011 sampling period were averaged in order to produce a single value for each site. This data aggregation step affected 76 out of the 385 wadeable stream sites in the dataset and was done in order to prevent sites sampled on multiple occasions from exerting undue influence on the results. Sample sizes in the screened dataset are summarized in Table 11.

Table 11. Number of wadeable stream sites in the screened dataset with macroinvertebrate community assessment results and TP data during 2002-2011.

Stream Type	Number of Sites
Small, High-Gradient	130
Medium, High-Gradient	158
Warm-Water, Medium-Gradient	97
TOTAL	385

Derivation of Criteria to Protect Aquatic Life Uses

The Vermont wadeable stream biocriteria have been calibrated to identify distinctions between natural conditions and either minor or moderate changes from the macroinvertebrate community reference condition, consistent with the aquatic life criteria stated in the Vermont Water Quality Standards (Table 2). Vermont DEC uses eight metrics of macroinvertebrate community structure and function to assess the macroinvertebrate community condition of wadeable streams. Assessment thresholds for all eight metrics have been developed to differentiate between four attainment levels along a tiered aquatic life use gradient, including "natural condition," "minor change from reference condition," "moderate change from reference condition," or non-attainment of aquatic life use support standards.[39]

These metric thresholds were derived independently for three wadeable 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.[39]

Macroinvertebrate community sampling results were used to place each site into one of the four use attainment levels described above. The statistical significance of the relationship between the macroinvertebrate community status and the concurrently measured nutrient criteria variables was verified as shown in Figure 6. The distributions of low-flow TP concentrations associated with each user response category were compared using a Kruskal-Wallis One-Way Analysis of Variance on Ranks. The results indicated that TP varied significantly ($p < 0.001 - 0.02$) with the macroinvertebrate community status generally in the expected direction, although not all individual pairwise comparisons of medians were statistically significant (Dunn's Method, $p < 0.05$).

To assess the potential for site selection bias to influence the estimates of false positive and false negative error rates, the distributions of stream TP values from the Vermont nutrient criteria dataset were compared with the population distribution for all Vermont wadeable streams as determined from the National Wadeable Streams Assessment (WSA) project in Vermont.[40,41] The WSA used a probability-based sampling design to produce distributions of the sampled variables that were representative of the true population distribution for the region, but did not distinguish between wadeable stream categories such as SHG, MHG, or WWMG streams.

Figure 7 shows that the distributions of TP values in the nutrient criteria dataset for the two high-gradient stream categories were very similar to the population distribution estimated by the WSA for Vermont. High-gradient streams represent about 76% of the total wadeable stream miles in Vermont, so it is not surprising that the SHG and MHG distributions were similar to the population distribution for all wadeable streams. Correction for bias as done for the lakes data using logistic regression estimates does not appear to be necessary for the SHG and MHG sites. The TP distribution for the WWMG category was substantially higher than the population distribution for all wadeable streams. Because no probability-based TP distribution specifically for Vermont WWMG streams is available, it is unknown whether there was a site selection bias present in the nutrient criteria dataset for WWMG sites, and no correction was possible.

The rates of false positive and false negative biological impairment determinations associated with potential low-flow TP criteria values were analyzed using the confusion matrix approach (Table 8) previously applied to lakes. The results from the Vermont nutrient criteria dataset were used directly for this purpose. Error rates across the range of potential TP criteria values are shown for each stream ecotype and each attainment level in Figure 8.

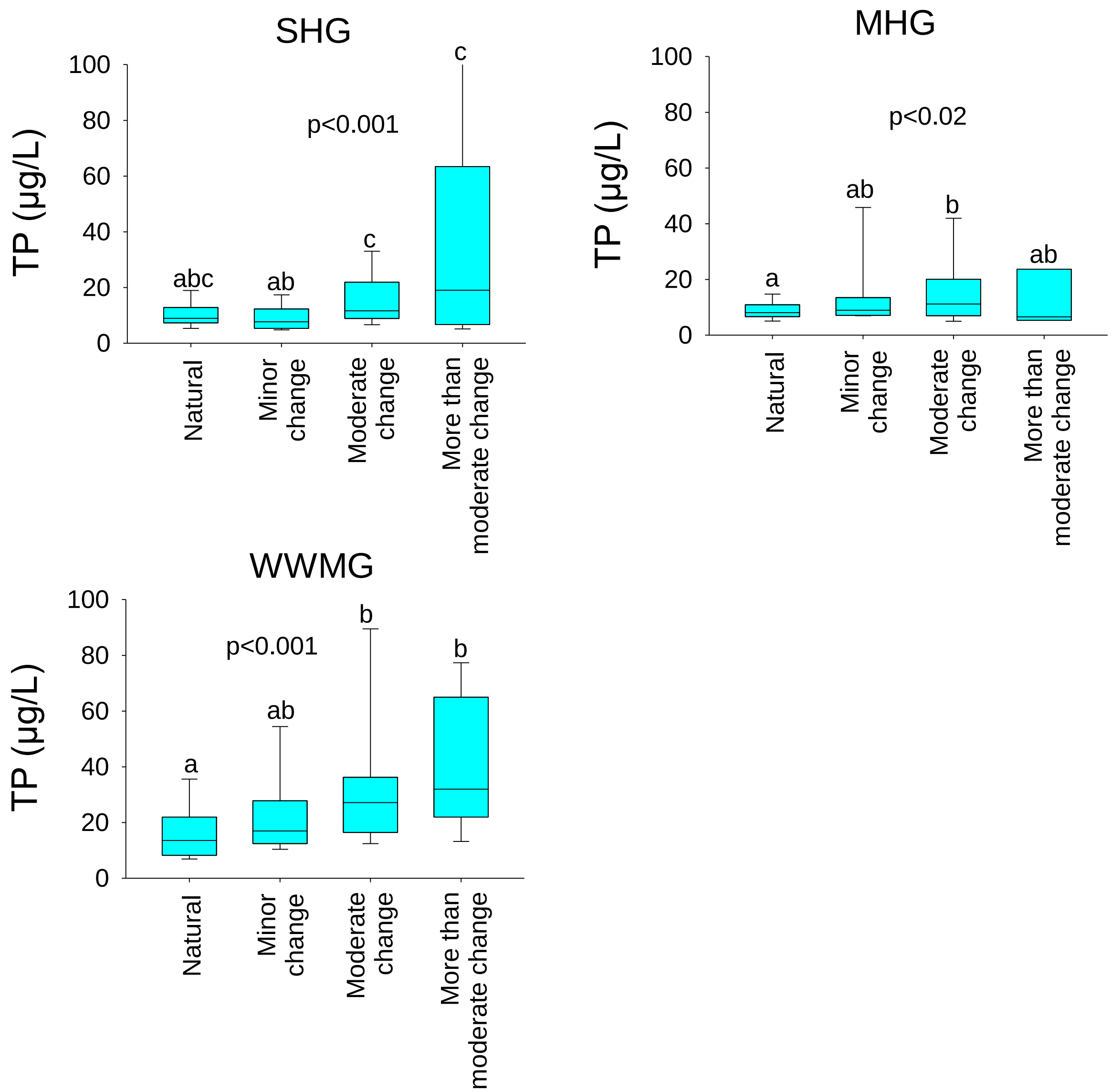


Figure 6. Distributions of low-flow TP concentrations associated with each stream macroinvertebrate community attainment level. Stream ecotypes are Small, High-Gradient (SHG), Medium, High-Gradient (MHG), and Warm-Water, Medium-Gradient (WWMG). Box plots show 5th, 25th, 50th, 75th, and 95th percentiles. Overall significance values were based on a Kruskal-Wallis One-Way Analysis of Variance on Ranks. Medians without letters in common were significantly different based on individual pairwise comparisons (Dunn's Method, $p < 0.05$).

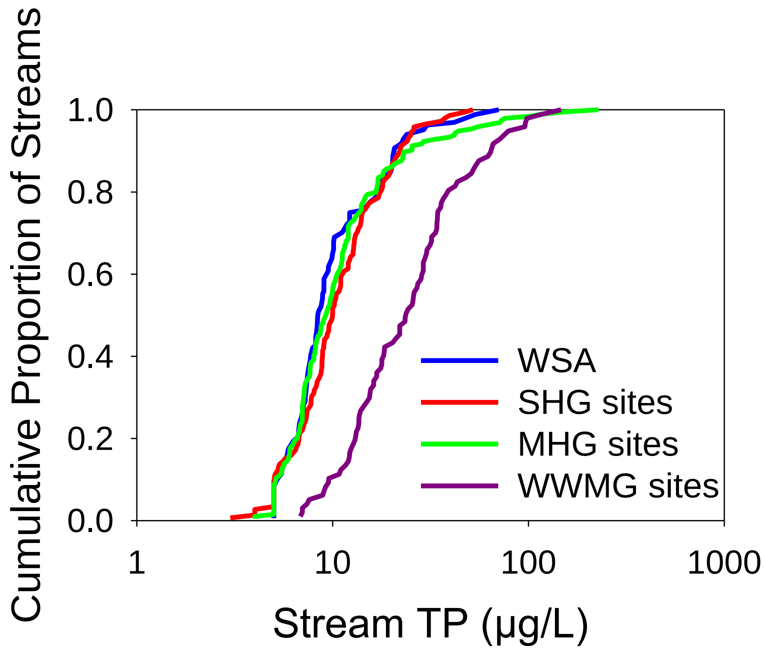


Figure 7. Cumulative frequency distributions of TP derived from probability-based sampling for the National Wadeable Streams Assessment (WSA) in Vermont, compared with sampled TP distributions for small, high-gradient (SHG), medium, high-gradient (MHG), and warm-water, medium-gradient (WWMG) wadeable streams sampled for Vermont nutrient criteria development.

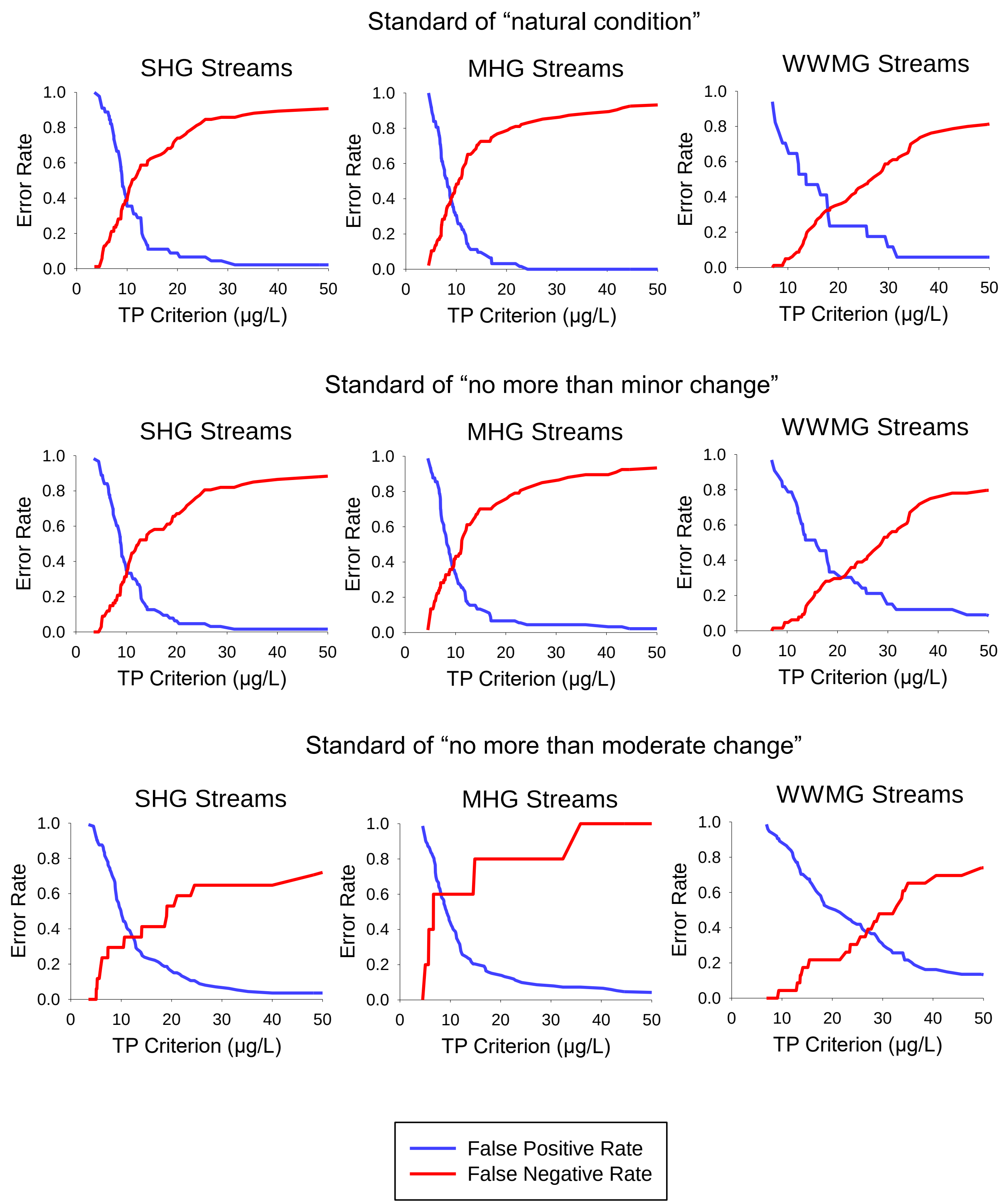


Figure 8. Stream impairment determination error rates associated with potential low-flow TP criteria values. Stream ecotypes are Small, High-Gradient (SHG), Medium, High-Gradient (MHG), and Warm-Water, Medium-Gradient (WWMG).

Proposed Criteria for Wadeable Streams

Proposed nutrient criteria to protect aquatic life uses in Vermont wadeable streams to be expressed as low-flow TP concentrations are summarized in Table 12. The criteria for Class A(1) streams were based on the "natural condition" standard. The criteria for Class A(2) and B streams were based on the "no more than moderate change" standard. These criteria represent the points where the risk of false positive and false negative biological impairment determinations would be equal (Figure 8), except where noted.

Criteria for individual Class B water management types (1, 2, or 3) are not proposed here because the Vermont DEC does not intend to pursue water management typing. More stringent criteria corresponding to the standard of "no more than minor change" could be derived from Figure 8 and applied in the future to high quality Class B waters designated as part of an anti-degradation implementation procedure.

Table 12. Proposed TP criteria for Vermont wadeable streams (μg/L at low flow).

	Water Class	
Stream Type	**A(1)**	**A(2), B**
SHG	10	12
MHG	9	15*
WWMG	18	27

*A higher criterion value was proposed where a lower false positive error rate could be achieved without inflating the false negative rate.

Implementation of Nutrient Criteria

The EPA has historically taken the position that water quality and biological criteria should be independently applicable, i.e., that any type of chemical, toxicity, or ecological assessment results can provide conclusive evidence of non-attainment of water quality standards, regardless of the results from other types of assessment information.[14,15] This policy was based in part on the assumption that conflicts between different assessment approaches would be rare.

The results of the analysis presented in this report have shown that conflicts between different nutrient assessment approaches are not rare, but are in fact very frequent for Vermont lakes and wadeable streams. Even when nutrient criteria were established in this analysis to minimize the rates of false positive and false negative impairment determinations, the percentage of lake or stream sites that would be misclassified in one direction or the other by applying the criteria was typically in the range of 20-40%. These findings indicate that independent application of nutrient concentration criteria alone, without consideration of actual use impairments, would too often result in incorrect impairment determinations and inappropriate management responses in Vermont.

More recently, EPA issued guidance on an approach to nutrient criteria development that integrates causal and response parameters whereby compliance with nutrient criteria may be attained either by compliance with causal parameters (e.g., nutrient concentrations) <u>or</u> by compliance with a set of response variables.[16] A nutrient criteria proposal by the Maine Department of Environmental Protection used this approach and was supported by EPA.[42,43] This integrated approach provides a solution to the concerns regarding independent applicability, and is consistent with the EPA's Nutrient Criteria Guidance Manual for Lakes and Reservoirs which states that using a balanced combination of both causal and response variables in the criteria together should mitigate against false positive and false negative results.[2]

The nutrient criteria derived in this analysis should be implemented in the Vermont Water Quality Standards according to this integrated approach. Under this proposal, compliance with nutrient criteria for lakes and wadeable streams could be attained either by compliance with the applicable total phosphorus concentration values, or by compliance with all specified eutrophication-related response conditions. The response conditions should include eutrophication-sensitive criteria already established in the Vermont Water Quality Standards for pH, turbidity, dissolved oxygen, and aquatic biota, and the new response criteria for chlorophyll and Secchi depth in lakes proposed in this document.

EPA guidance on the integrated approach to numeric nutrient criteria[16] indicates that primary productivity response indicators such as Chl-a are more sensitive to nutrient increases and are therefore preferable to criteria derived from higher trophic level responses (e.g., macroinvertebrates). This proposal includes Chl-a criteria for Vermont inland lakes, but no Chl-a criteria for wadeable streams due to data insufficiency. However, Vermont DEC has a well-developed stream biomonitoring program that has used macroinvertebrate community assessments and biocriteria for many years to evaluate impacts from many stressors including nutrients. The rationale for why the Vermont DEC macroinvertebrate biocriteria assessment procedures provide a sensitive measure of nutrient impacts on wadeable streams is provided in Appendix A.

Use of the integrated approach requires a clear statement of how both water quality assessment and listing decisions and discharge permitting decisions would be made under all possible situations of nutrient concentration values and response conditions in the lake or stream.[16] The proposed nutrient criteria for Vermont inland lakes and wadeable streams should be implemented according to the decision framework presented in Table 13.

Table 13. Proposed Vermont Nutrient Criteria Decision Framework.

	Assessment and Listing Decision	Discharge Permitting Decision
A. Phosphorus concentration less than or equal to criterion. All nutrient response conditions met.		
	Not impaired by nutrients. Rotational basin monitoring on an approximate five-year schedule will be conducted.	If a new or increased discharge is proposed, the permit will limit the phosphorus concentration increase according to the anti-degradation policy. No new or increased phosphorus discharge would be permitted that would cause the phosphorus concentration to be greater than the criterion. If a current discharge at its maximum permitted phosphorus loading rate could produce a mixed, in-stream phosphorus concentration above the criterion value, then representative monitoring will be conducted at the site for phosphorus concentration and all nutrient response conditions. If response conditions are worsening or indicate a likelihood that an impairment will develop, more stringent permit limits will be applied in order to prevent the impairment.
B. Phosphorus concentration greater than criterion. All nutrient response conditions met.*		
	Not impaired by nutrients. Representative monitoring will be conducted for phosphorus concentration and all nutrient response conditions at sites affected by permitted discharges. Rotational basin monitoring on an approximate five-year schedule will be conducted at other sites.	If a new or increased discharge is proposed, the permit will limit the effluent phosphorus concentrations and loads to the existing permitted amounts or less. If response conditions are worsening or indicate a likelihood that an impairment will develop, more stringent permit limits will be applied in order to prevent the impairment.
C. Phosphorus concentration less than or equal to criterion. Not all nutrient response conditions met.		
	Impaired, but not necessarily by nutrients. Site will be studied to determine the cause of impairment. If found to be impaired by nutrients, an alternate (lower), site-specific nutrient criterion may need to be established for permitting purposes.	If the site is determined not to be impaired by nutrients but a new or increased discharge is proposed, the permit will limit the nutrient increase according to the anti-degradation policy. In no case will amounts be permitted that would cause the phosphorus concentration criterion to be exceeded. If the site is determined to be impaired by nutrients, then more stringent permit limits will be applied in order to correct the impairment.
D. Phosphorus concentration greater than criterion. Not all nutrient response conditions met.		
	Impaired by nutrients. Representative monitoring will be conducted for phosphorus concentration and all nutrient response conditions at sites affected by permitted discharges.	More stringent permit limits will be applied in order to correct the impairment. A Total Maximum Daily Load (TMDL) designed to achieve the phosphorus concentration criterion may be required.

* If data are unavailable for any applicable response condition, then the waterbody would be assessed as impaired by nutrients, pending further data collection.

Appendix A. Supplemental documentation providing justification for the use of Vermont's existing stream macroinvertebrate biocriteria as a nutrient response indicator.

Introduction

In conjunction with pre-rulemaking stakeholder outreach regarding VTDEC's proposed nutrient criteria contained in the proposed amendments to the Vermont Water Quality Standards, USEPA's Office of Science and Technology, Health and Ecological Criteria Division (OST), has proposed requiring that VTDEC include a primary productivity indicator for streams. In supporting this proposal, OST cites results of an expert panel workshop that occurred in 2013, which is understood to have concluded that a primary production indicator should be a requirement for an approvable nutrient criteria package. This conclusion is understood to be based on the concern that biological assemblages at next-higher trophic orders may not be sufficiently sensitive to detect nutrient enrichment before impairment becomes established. In this document, VTDEC provides justification for why the macroinvertebrate biocriteria implemented by the State is in fact sufficiently sensitive to nutrient enrichment to detect pre-impairment stress.

Vermont has advanced fish and macroinvertebrate biocriteria for the wadeable streams of Vermont,[39] which are specifically called for by the Vermont Water Quality Standards. The biocriteria are based on the departure in the structure and functional attributes of these communities compared to those found in "reference" watersheds. The "reference" condition in Vermont is defined for regulatory and assessment purposes in the Vermont Water Quality Standards as *"the range of chemical, physical, and biological characteristics of waters minimally affected by human influences (...)"* which *"establishes attainable chemical, physical, and biological conditions for specific water body types against which the condition of waters of similar water body type is evaluated."*

Ecological Foundations of Macroinvertebrate Biocriteria

Vermont's macroinvertebrate biocriteria are proposed, alongside pH, dissolved oxygen, and turbidity, as response variables for the numeric phosphorus components of the proposed nutrient criteria. The macroinvertebrate biocriteria are composed of eight community metrics that have been selected because they are most responsive to alterations in community structure and function which result from environmental stressors. These eight core macroinvertebrate community metrics, as well as others that are computed during VTDEC's assessments, create a "community fingerprint" that is used to determine what environmental stressors are most likely responsible for resulting community alteration. The degree of departure from reference identified by these metrics places the assessed community along a gradient of biological condition,[44] thresholds which have been found to have regionwide applicability in New England.[45]

Based on fundamental ecological principles, excess nutrients have long been known to cause a relatively predictable alteration and eventual degradation of the macroinvertebrate communities of freshwater streams and rivers (Hynes, 1970). Macroinvertebrate community response to increased concentrations of nutrients is due to changes in the type and amount of carbon based food source in the aquatic environment. Small increases in natural levels of nutrients will increase the abundance of most all species of macroinvertebrates due to the increase in the natural primary producers (algae). As greater numbers and taxa of primary producers increase, the macroinvertebrate community will generally continue to increase in abundance, with some increase in species richness that does not affect community structure or function. This is known as “benign enrichment.” Eventually the community begins to show a shift in its composition toward taxa that are competitively advantaged by their ability to consume algae and particulate carbon. Simultaneously, there is an apparent loss or significant reduction in some niche-specific taxa even while richness is maintained. When the amount of carbon based organic material increases to the point at which it cannot be processed biologically and thus begins to accumulate, it creates a number of additional stressors that influence the macroinvertebrate community. These include increased fluctuations in dissolved oxygen (D.O.) and more extended periods of low D.O., and increases in pH associated with enhanced respiration. Eventually only species tolerant of these additional stressors will survive.

Of the eight community metrics are used in VTDEC’s macroinvertebrate biocriteria, most can be used to indicate that nutrient enrichment stresses are evident, and all are relevant to the above discussion of nutrient effects on macroinvertebrates. In the following section of this Appendix, narratives explaining how each metric is expected to respond to nutrient pollution are presented based on ecological first-principles. The responsiveness of these metrics to enrichment is also supported in the literature by nutrient addition experiments that often show dramatic increases in Chironomidae abundance,[46] and reductions in EPT richness and the Hilsenhoff Biotic index (HBI).[47] The HBI, along with ratio metrics among taxa, and certain functional group ratios used by VTDEC, have been shown to be responsive to nutrient enrichment in Wisconsin.[48]

Application of Macroinvertebrate Biocrtieria in Vermont, for Nutrients

In this section, VTDEC presents results of macroinvertebrate bioassessments over time, at a single site subject to a successful restoration effort. The site in question, Crystal Brook, Derby, VT, was subject to an enforcement action followed by implementation using CWA §319 funding. The results are striking, as presented by Table A1, which present biocriteria assessments by year, alongside the striking reductions in phosphorus concentrations. This single site summary is included as but one example of the applicability of Vermont’s biocriteria. A more generalized assessment is presented later.

Table A1. Management-level summary of macroinvertebrate biocriteria assessment of Crystal Brook, Derby, Vermont.

Macroinvertebrate Site Summary											
Location:	Crystal Brook							Location ID:	501650		
Town:	Derby							Bio Site ID:	360300000003		
Description:	Located below Route 5 approximately 0.25mi north of I-91 overpass.							WBID:	VT17-01		
Date	Sample Method	Density	Richness	EPT Richness	PMA O	BI	Oligo.	EPT / EPT + C	PPCS F	Total Phophorus ppb	Community Assessment
9/4/1997	KN	1824	46.0	18.0	46.9	4.92	7.46	0.324	35.0	--	Fair
9/14/1999	KN	2876	38.5	9.0	31.7	5.56	5.95	0.130	32.3	--	Poor
9/16/2004	KN	3280	27.0	5.0	42.3	7.21	14.27	0.288	10.6	36	Poor
9/7/2006	KN	9960	36.0	7.0	32.8	6.84	14.94	0.180	29.5	212	Poor
9/16/2009	KN	2068	37.0	21.0	68.7	4.41	6.96	0.960	36.3	18.6	G-Fair
9/16/2010	KN	2388	43.0	24.0	84.2	3.13	1.34	0.942	53.8	18.8	Ex-Vgood
Full Support		> 350	> 28	> 17	> 50%	< 4.35	< 9.5%	> 0.47	> 45%		
Meets Threshold		≥ 300	≥ 27	≥ 16	≥ 45%	≤ 4.5	≤ 12	≥ 0.45	≥ 40 %		
Near Threshold		≥ 250	≥ 26	≥ 15	≥ 40%	≤ 4.65	≤ 14.5%	≥ 0.43	≥ 35%		
Non-Support		< 250	< 26	< 15	< 40%	> 4.65	>14.5%	< 0.43	< 35%		

Density- The relative abundance of animals in a sample. Relative abundance is a basic measure of a streams secondary productivity. The density criteria was set very conservatively, to ensure some basic level of macroinvertebrate productivity is maintained. Density will generally decrease due to both habitat and toxic impacts. It can also be relatively low in naturally unproductive streams, which is why the minimum criteria is very conservative. Nutrient enrichment will often increase the overall density of a stream. It is an important metric to use in determining the generic cause of the impact on the community, and coupled with other metrics, can point to a nutrient enrichment effect. Tables one shows that density peaked at the Crystal Brook site coincident with peak total phosphorus concentration.

Richness- Species richness is the number of species in a sample unit. It is perhaps the most basic and accepted measure of assemblage diversity. Species richness will decrease when an assemblage is stressed from habitat degradation or poor water quality conditions.[49] It can increase slightly in streams that are moderately enriched, and can also be naturally lower in smaller headwater streams.[50] Tables one shows that richness recovered at the Crystal Brook site following nutrient reduction, although only to a slight degree. Richness is a useful metric when taken in conjunction with other, more nutrient-sensitive metrics.

EPT Index- EPT index is the number of species in the sample in the generally more environmentally sensitive orders Ephemeroptera, Plecoptera, and Trichoptera. EPT richness will decrease when an assemblage is stressed from habitat degradation or poor water quality conditions.[51] The number of EPT taxa will increase from slight enrichment, but are generally the first to decrease from moderate enrichment. Thus, EPT is a sensitive metric to document when a site passes beyond simple “benign enrichment” into a condition that exhibits a reduction in ecological integrity. At Crystal Brook, EPT rebounded strongly post remediation.

Percent Model Affinity of Orders - (PMA-O) A measure of the order level similarity to a model based on the reference streams.[52] The PMA-O decreases with increasing environmental stress on the macroinvertebrate assemblage. This is due to the general trend of decreasing abundance of the more pollution sensitive orders, and increasing abundance of the more pollution tolerant orders in highly polluted streams. Since PMA-O is a measure of similarity to reference, it is not immediately sensitive to nutrients per-se, though it reflects generalized stress when depressed. Tables one shows that PMA-O rebounded significantly once phosphorus concentrations declined at the Crystal Brook site.

Hilsenhoff Biotic Index- BI (0-10) - A measure of the macroinvertebrate assemblage tolerance toward organic (nutrient) enrichment.[53] In many ways this index is both an indicator taxa metric and functional group metric, since those taxa, which become more dominant in moderately enriched streams are those which are taking advantage of shifts in the available food base in the stream. These types of food web shifts have been described in detail in the literature and have come to be known as the river continuum concept.[54,55,56] The HBI declined precipitously once phosphorus concentrations declined at the Crystal Brook site.

% Oligochaeta – A measure of the percent of the macroinvertebrate community comprised of the order Oligochaeta, or aquatic worms. The percent Oligochaeta in the community increases with increased amounts of sedimentation, nutrients, or organic matter in the stream. Many Oligochaeta in streams are burrowers by habit and generally feed on organic particulate that settle on the bottom substrate in streams. The percent Oligochaeta in the reference streams in Vermont is reliably very low. The presence of relatively higher percent Oligochaeta is consistently found in impaired streams associated with high sedimentation indicators such as embeddedness and siltation, which are common co-occurring effects of nutrient enrichment. Tables one shows that Oligochaetes in the Crystal Brook site dropped from 14% of the community at the worst, to approximately one percent, post nutrient reduction.

EPT/EPT & Chironomidae - A measure of the ratio of the abundance of the intolerant EPT orders to the generally tolerant Diptera family Chironomidae. Increased ecological degradation often associated with non-point pollution causing stream warming, habitat impairment from silt/sediment, and enrichment allows the more tolerant species of Chironomidae to dominate the stream community causing the ratio to decrease. This metric is less robust then some, though Tables one shows a major rebound post nutrient reduction.

Pinkham-Pearson Coefficient of Similarity - Functional Groups - (PPCS-F) - A measure of functional feeding group similarity to a model based on the reference streams. It is similar in concept to the PMA-O in that a site is compared to a model of the composition of the functional feeding groups as opposed to order level taxonomic changes. Significant departures in functional group similarity to the reference streams indicate that the energy pathways through the aquatic ecosystem have been significantly altered compared to that of the reference stream model,[57] suggesting modifications in primary production. Table A1 shows the PPCS-F to be low co-incident with high phosphorus concentrations at the Crystal Brook site.

For the reasons listed above, VTDEC's biocriteria metrics are expected to be sensitive to nutrients in other sites. To demonstrate this, Figure A1 shows metric values of nutrient stressed sites compared to reference sites with low nutrient levels. This figure clearly shows discrimination between high and low nutrient sites for all metrics, save richness.

Present Applicability of a Periphyton Indicator for VT Streams

VTDEC cannot presently support inclusion of the proposed OST requirement for an additional periphyton indicator. There are three reasons for this. First, Vermont's Surface Water Management Strategy places primary importance on the maintenance of ecological integrity, which has been measured in Vermont based on macroinvertebrate biocriteria derived from a well-developed reference condition, and implemented for over 20 years. The changes in community noted via these have direct ties to the designated use of *aquatic life and habitat* in the VT Water Quality Standards. VTDEC's regulated community acknowledges the validity of the biocriteria, which have been used in numerous instances to compel or fund restoration. While a periphyton-based indicator may serve these purposes, none yet exists for Vermont, and certainly none with which the regulated community has any experience.

Second, given the available data describing periphyton growth coincident with biological assessments, VTDEC scientists have to date been unable to tie a discernable deviation from the reference condition for a periphyton community to an alteration in the designated use of aquatic life and habitat, absent verification using our existing biocriteria. VTDEC has attempted several such analyses using semi-quantitative observational characteristics of stream periphyton. None have yielded defensible relationships. This finding is substantiated by Bourassa and Cattaneo[58] who found no periphyton biomass increase in receiving waters subject to experimental nutrient addition, but did find a change in benthic macroinvertebrate community composition in response to the same nutrient addition.

Further, VTDEC contends that unlike streams in more lowland settings or hydrologically constrained areas, Vermont's streams are naturally subject to higher-variability hydrology, creating a greater likelihood of periphyton-community disturbance through normal scour and channel adjustment. A nutrient-rich stream may in one week exhibit a high proportion of periphyton cover, yet the next week be quite scoured, simply in response to common-recurrence flow events. The late summer / early fall index period used to assess attainment using macroinvertebrate biocriteria is much more stable and resilient to higher recurrence flows without impact to the assessment outcome.[59] Nonetheless, VTDEC is working with EPA to investigate options for implementing periphyton-based nutrient assessment endpoints. These endpoints may be relevant for assessing aquatic life use, but will primarily be examined for the assessment of aesthetic uses.

Lastly, Vermont macroinvertebrate and fish biocriteria have been successfully used to guide water quality management in Vermont for over 20 years. Vermont has used these biocriteria to list waters as impaired for aquatic life use, and then document their recovery after management actions have addressed the pollutant sources. The biocriteria have also been used to document very high quality waters in our Tactical Basin Planning process. In conformance with Vermont's Surface Water Management Strategy, VTDEC is using these assessments to direct reclassification of select waters to higher classifications within the VT Water Quality Standards. Given this track record of simultaneous restoration of nutrient impairment, and protection of very high quality waters, VTDEC is confident in the use of these biocriteria as the principle response variable in evaluating nutrient stressed rivers and streams in Vermont.

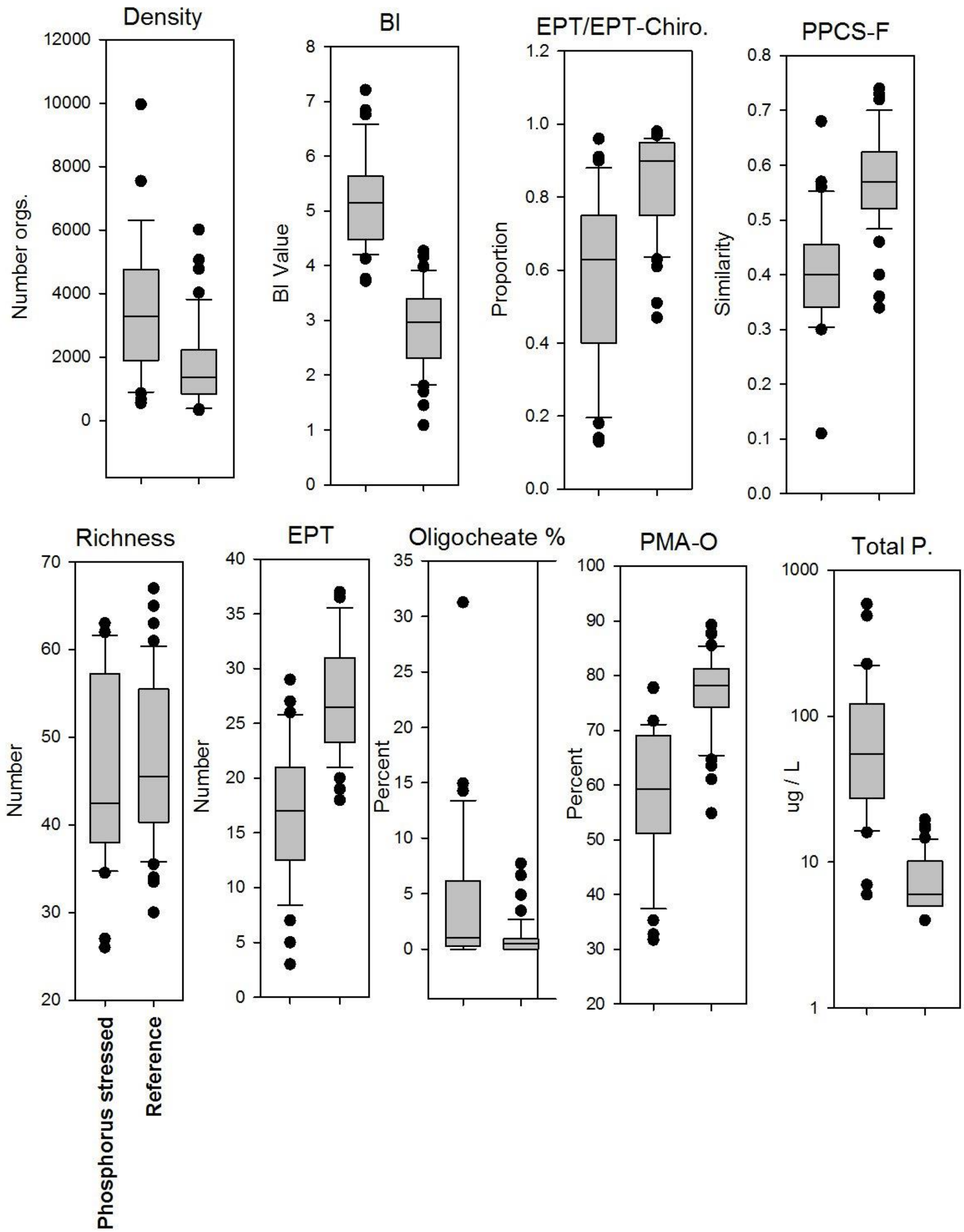


Figure A1. Distribution of Vermont's eight core biometrics in two groups. The first group presents 32 locations identified as nutrient (phosphorus) stressed. The second group presents 46 locations within the reference site network in Vermont. Phosphorus concentrations for each group are also shown.

References

[1] USEPA. 1998. National Strategy for the Development of Regional Nutrient Criteria. EPA 822-R-98-002. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/nutrient_strategy_1998.pdf

[2] USEPA. 2000. Nutrient Criteria Technical Guidance Manual. Lakes and Reservoirs. First Edition. EPA-822-B00-001. Washington, D.C. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/lakes/index.cfm

[3] USEPA. 2000. Nutrient Criteria Technical Guidance Manual. Rivers and Streams. EPA-822-B-00-002. Washington, D.C. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/rivers/index.cfm

[4] USEPA. 2001. Nutrient Criteria Technical Guidance Manual. Estuarine and Coastal Marine Waters. EPA-822-B-01-003. Washington, D.C. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/marine/index.cfm

[5] USEPA. 2007. Nutrient Criteria Technical Guidance Manual. Wetlands. EPA-822-R-07-004. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/wetlands/index.cfm

[6] USEPA. 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Lakes and Reservoirs in Nutrient Ecoregion VII. EPA 822-B-00-009. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_lakes_lakes_7.pdf

[7] USEPA. 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Lakes and Reservoirs in Nutrient Ecoregion VIII. EPA 822-B-00-010. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/upload/2007_09_27_criteria_nutrient_ecoregions_lakes_lakes_8.pdf

[8] USEPA. 2001. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_lakes_lakes_14-2.pdf

[9] USEPA. 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Rivers and Streams in Nutrient Ecoregion VII. EPA 822-B-00-018. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_7.pdf

[10] USEPA. 2001. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Rivers and Streams in Nutrient Ecoregion VIII. EPA 822-B-01-015. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_8.pdf

[11] USEPA. 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria. Rivers and Streams in Nutrient Ecoregion XIV. EPA 822-B-00-022. Washington, D.C.
http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_14.pdf

[12] Vermont DEC. 2007. Developing Nutrient Criteria for Vermont's Lakes and Wadeable Streams. Draft for technical review. Waterbury, VT http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_nutcrit-draftapril07.pdf

[13] Vermont DEC. 2009. Proposed Nutrient Criteria for Vermont's Lakes and Wadeable Streams. Waterbury, VT.
http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_2009nutrientcriteria.pdf

[14] Davies, T.T. June 19, 1991 memorandum to Water Management Division Directors. Transmittal of final policy on biological assessments and criteria. U.S. Environmental Protection Agency. Washington, D.C. http://water.epa.gov/scitech/swguidance/standards/upload/2002_06_11_standards_handbook_handbookappxR.pdf

[15] Stoner, N. March 1, 2011 letter to R.F. Poltak, New England Interstate Water Pollution Control Commission. U.S. Environmental Protection Agency. Washington, D.C. http://water.epa.gov/scitech/swguidance/standards/upload/Letter-to-New-England-Interstate-Water-Pollution-Control-Commission-3_1_11.pdf

[16] U.S. Environmental Protection Agency. 2013. Guiding principles on an optional approach for developing and implementing a numeric nutrient criterion that integrates causal and response parameters. EPA-820-F-13-039. http://www2.epa.gov/sites/production/files/2013-09/documents/guiding-principles.pdf

[17] Vermont Natural Resources Board Water Resources Panel. 2011. Vermont Water Quality Standards. Montpelier, VT. http://www.nrb.state.vt.us/wrp/publications/wqs.pdf

[18] Lake Champlain Phosphorus Management Task Force. 1993. Report prepared for the Lake Champlain Steering Committee. http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_phostaskforce93.pdf

[19] Vermont Agency of Natural Resources and New York State Department of Environmental Conservation. 2002. Lake Champlain Phosphorus TMDL. Waterbury, VT and Albany, NY. http://www.vtwaterquality.org/lakes/docs/lp_lctmdl-report.pdf

[20]Schindler, D.W. 2012. The dilemma of controlling cultural eutrophication of lakes. Proc. R. Soc. B. pp. 1-12. doi:10.1098/rspb.2012.1032. http://rspb.royalsocietypublishing.org/content/279/1746/4322.full.pdf+html?sid=b9e2112a-04b1-4aba-9e3f-bd435c1dac31

[21] Downing, J.A., S.B. Watson, and E. McCauley. 2001 Predicting cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci. 58(10):1905–1908.

[22] Lewis, W.M., Jr., W.A. Wurtsbaugh, and H.W. Paerl. 2011. Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. Environ. Sci. Technol. 45:10300–10305. dx.doi.org/10.1021/es202401p.

[23] Sterner, R.W. 2008. On the phosphorus limitation paradigm for lakes. Internat. Rev. Hydrobiol. 93:433-445.

[24] Poltak, R. January 3, 2011 letter to EPA Administrator L. Jackson. New England Interstate Water Pollution Control Commission. Lowell, MA. http://www.neiwpcc.org/neiwpcc_docs/NEIWPCCCommentLetteronNutrientCriteria1-3-11.pdf

[25] USEPA. 2010. Using stressor-response relationships to derive numeric nutrient criteria. EPA820-S-10-001. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/Using-Stressor-response-Relationships-to-Derive-Numeric-Nutrient-Criteria-PDF.pdf

[26] Smeltzer, E. and S.A. Heiskary. 1990. Analysis and applications of lake user survey data. Lake and Reservoir Management. 6:109-118. http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_lcmusersurveyarticle.pdf

[27] Walker, W.W. 1985. Statistical bases for mean chlorophyll a criteria. pp. 57-62 In Lake and Reservoir Management: Practical Applications. Proceedings of the Fourth Annual Conference and International Symposium. October 16-19, 1984. McAfee, NJ. North American Lake Management Society.

[28] North American Lake Management Society. 1992. Developing eutrophication standards for lakes and reservoirs. Report prepared by the Lake Standards Subcommittee. Alachua, FL. 51 pp.

[29] South Florida Water Management District. 2010. Comments concerning Proposed 40 CFR Part 131 – Water Quality Standards for the State of Florida's Lakes and Flowing Waters. Federal Register. Vol. 75, No. 16. Tuesday, January 26, 2010. Docket No. EPA-HQ-OW-2009-0596. http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/sfwmd%20numeric%20nutrient%20comments.pdf

[30] Zipper, C.E. et al. 2012. A "screening approach" for nutrient criteria in Virginia. Report of the Academic Advisory Committee for the Virginia Department of Environmental Quality. Virginia Water Resources Research Center, Virginia Tech., Blacksburg, VA. http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityStandards/NutrientCriteria/AAC%20Nutrient%20Criteria%20Report%20Final%20July%2011%202012.pdf

[31] SigmaPlot version 12.0. Systat Software, Inc., San Jose CA. www.sigmaplot.com

[32] U.S. Environmental Protection Agency. 2009. National Lakes Assessment: A collaborative survey of the nation's lakes. EPA 841-R-09-001. Washington, D.C. http://www.epa.gov/owow/LAKES/lakessurvey/pdf/nla_report_low_res.pdf

[33] Vermont Department of Environmental Conservation. 2013. Vermont's National Lake Assessment: A survey of Vermont lakes. Montpelier, VT.

[34] Helsel, D.R. and R.M. Hirsch. 2002. Statistical Methods in Water Resources. Techniques of Water Resources Investigations of the United States Geological Survey. Book 4, Hydrologic Analysis and Interpretation, Chapter A3. U.S. Geological Survey. Reston, VA. http://pubs.usgs.gov/twri/twri4a3/pdf/twri4a3-new.pdf

[35] L. Yuan. Personal communication, Aug. 27, 2013. U.S. Environmental Protection Agency. Office of Science and Technology. Washington, D.C.

[36] Vermont DEC. 2005. Water Quality Monitoring Program Strategy. Waterbury, VT. http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_monitoringstrat.pdf

[37] Vermont DEC. 2006. Vermont Nutrient Criteria Development Project, Final Data Report. Waterbury, VT. http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_nutcrit-2005report.pdf

[38] Vermont DEC. 2004. Biocriteria for Fish and Macroinvertebrate Assemblages in Vermont Wadeable Streams and Rivers - Development Phase. Waterbury, VT. http://www.vtwaterquality.org/bass/docs/bs_wadeablestream1b.pdf

[39] Vermont DEC. 2004. Biocriteria for Fish and Macroinvertebrate Assemblages in Vermont Wadeable Streams and Rivers - Implementation Phase. Waterbury, VT. http://www.vtwaterquality.org/bass/docs/bs_wadeablestream2.pdf

[40] U.S. Environmental Protection Agency. 2006. Wadeable Streams Assessment: A collaborative survey of the nation's streams. EPA 841-B-06-002. Washington, D.C. http://water.epa.gov/type/rsl/monitoring/streamsurvey/upload/2007_5_16_streamsurvey_WSA_Assessment_May2007.pdf

[41] Vermont DEC. 2008. Draft Probability-Based Comprehensive Statewide Assessment of Wadeable Stream Biological Condition Vermont 2002-2006. Montpelier, VT. http://www.anr.state.vt.us/dec/waterq/bass/docs/bs_streambiocond.pdf

[42] Maine Department of Environmental Protection. June 12, 2012 working draft of Chapter 583, Nutrient Criteria for Surface Waters. Augusta, ME. http://www.maine.gov/dep/water/nutrient-criteria/index.html

[43] Silva, S.J. December 22, 2011 letter to D. Courtemanch, Maine Department of Environmental Protection. U.S. Environmental Protection Agency. Boston, MA. http://www.maine.gov/dep/water/nutrient-criteria/epa_r1_letter_to_maine_dep_12-22-2011.pdf

[44] Davies, S.P. and S.K. Jackson, 2006. The Biological Condition Gradient: a descriptive model for interpreting change in aquatic ecosystems. *Ecolog. Applic*. 16 (4), pp. 1251-1266.

[45] Stamp, J. and J. Gerritsen. 2009. New England Interstate Water Pollution Control Commission; Methods and Assessment Comparability Among State and Federal Biological Monitoring Protocols; 102p.

[46] Gafner, J. Karin, and Christopher T. Robinson. 2007. J. North Am. Benthol. Soc. 26(1).

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press. xxiv +555 p.

[47] Bryce, S.A. and R. M. Hughes. 2003. Variable Assemblage Responses to Multiple Disturbance Gradients: Case Studies in Oregon and Appalachia, USA. Biological Response Signatures indicator patterns using aquatic communities Edited by Thomas P Simon.

[48] Roberton, D., M. David J. Graczyk, P.J. Garrison, and L. Wang. 2006 .Nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin ; in cooperation with the Wisconsin Department of Natural Resources. USGS Professional paper ; 1722.

[49] Plafkin, J.L. Barbour, M.T. Porter, K.D. Sharon, K.G. and R.M. Hughs. 1989. Rapid Bioassessment Protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. Environmental Protection Agency. Office of Water.

[50] Bode, R.W. and M. A. Novak. 1994. Development and application of biological impairment criteria for rivers and streams in New York state. pp 97-107. in W.S. Davis and T.P. Simon (Eds). Biological Assessment and criteria for water resource planning and decision making. Lewis Publishing Co. Boca Raton Florida.

[51] Penrose, D. Lenat, D and K. Eagleson. 1980. Biological evaluation of water quality in North Carolina Streams and Rivers. North Carolina DEM. Biological Series #103.

[52] Novak, M.A. and R.W. Bode. 1992. Percent model affinity, a new measure of macroinvertebrate community composition. Journal of the North American Benthological Society. 11:80-85.

[53] Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. The Great Lakes Entomologist. 20(1):31-39

[54] Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R., Sedell, C.E.,Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

[55] Culp, J..M.. and R.W. Davies. 1982. Analysis of longitudinal zonation and the river continuum concept in the Oldman-South Saskatchewan River System. Canadian Journal of Fisheries and Aquatic Sciences. 39:1258-1266.

[56] Cummins, K. 1974. Structure and function of stream ecosystems. Bioscience 24: 631-641.

[57] Shackleford, B. 1988.Rapid bioassessments of lotic macroinvertebrate communities: biocriteria development. Arkansas Department of Pollution Control and Ecology, Little Rock.

[58] Bourassa and Cattaneo. 2000. Responses of a lake outlet community to light and nutrient manipulation: effects on periphyton and invertebrate biomass and composition. Freshwater Biol. 44(4).

[59] Moore, A., and S. Fiske. 2014. Macroinvertebrate community impacts, recovery, and resilience at long-term reference streams following flooding from Tropical Storm Irene. Proc. New England Assoc. Environ. Biol. http://www.epa.gov/ region1/neaeb2014/index.html