Comments on

United States Environmental Protection Agency's "Empirical Approaches for Nutrient Criteria Derivation" Science Advisory Board Review Draft of August 17, 2009

The United States Environmental Protection Agency (USEPA) has prepared the above referenced document as an aid to States, authorized Tribes, and other authorized jurisdictions as they consider developing water quality criteria and water quality standards to protect against the adverse effects of nutrient enrichment in surface waters. The approaches presented in this document are meant to be used by authorized jurisdictions as a basis for future development of numeric water quality criteria. It is the USEPA's intention to "improve the progress of State adoption of numeric nutrient criteria into their water quality standards."[a]

USEPA is seeking advice from its Science Advisory Board (SAB) Ecological Processes and Effects Committee regarding the technical soundness of the approaches presented in the above document. The Charge to the SAB includes several questions for the Board's consideration. In general, these questions seek input on the overall utility of the draft document. As part of this exercise, USEPA has provided an opportunity for public comment. The material presented below is provided within that context.

The USEPA is to be commended for its effort to assemble a document of this breadth. It is a thorough compendium of useful statistical tools for data analysis and the consideration of stressor - response variable relationships. For sure, the problem of eutrophication in surface waters is one that involves causal variables (i.e., stressors) and response variables. For any particular waterbody there will be multiple causal variables and multiple response variables. Multiple variables such as nutrients, sunlight, heat (as measured by water temperature) and trace elements combine to *cause a response* in multiple variables such as dissolved oxygen, pH, plant life and higher forms of aquatic life. Some of the response variables, e.g. algae, might be considered primary response variables since they directly respond to changes in the causal variables. Other response variables might be considered secondary response variables, e.g., dissolved oxygen, because their response is a result of changes in the primary response variables. (For example, dissolved oxygen concentration may increase in response to algal photosynthesis and decrease in response to algal respiration and decomposition.) In any system, there may even be tertiary and higher response variables (e.g., fish) whose response may be a result of changes in secondary response variables. (For example, fish may die due to decreases in dissolved oxygen concentration which in turn was due to respiration and decomposition of algae.)

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[a] See page 2 of "Charge to the Science Advisory Board (SAB) Ecological Processes and Effects Committee," September 9th - 11th, 2009.

It is easy to see how even the above simplistic representation of eutrophication related cause and response can quickly become quite complicated by the fact that multiple variables are at play. Many excellent scientists have spent many decades studying these problems. As one of those scientists, I too have spent many years considering problems of nutrient enrichment in surface waters, and in particular the regulation of nutrient discharges from point and nonpoint sources to surface waters. As evidence of my commitment to this matter, I attach two documents which I have authored, both of which deal with the matter of nutrient regulation and the establishment of water quality criteria and water quality standards for nutrients. Appendix A of this submission entitled "Comments on New Jersey's Surface Water Quality Criteria for Total Phosphorus" is a position paper I prepared in 1994. Its concepts are still applicable today, and I believe have served in some small way to positively influence the direction of nutrient regulation in the State of New Jersey. Appendix B is a portion of another document that I authored in the year 2005, "Comments in Support of Amendments to Phosphorus Criteria in New Jersey's Surface Water Quality Standards at N.J.A.C. 7:9B." Both of these documents provide a thorough consideration of the matter of numeric nutrient criteria. Based on my investigations and experience in evaluating and implementing numeric nutrient criteria, I have formed the firm opinion that establishment of Statewide or regional numeric nutrient criteria is inappropriate. I cite multiple reasons in these attached documents. The scientific literature is clear about one thing - the appropriate values for numeric nutrient criteria are unclear. A review of this literature is provided in Appendix B of this document.

Whether or not a particular body of water will experience eutrophication and excessive plant growth is a function of many variables. Flow rate, residence time, depth, ability for solar radiation to penetrate the water column, and a multitude of other factors contribute to whether a specific body of water is at risk with respect to nutrient loading. Consequently, it is not possible to globally establish criteria for nitrogen, phosphorus or for nutrients in general. What Water Quality Standards can do is specify statewide criteria/policies that prescribe how site-specific criteria can be established. I believe that such criteria/policies must include both (a) narrative criteria, and (b) numerical <u>goals</u>. These concepts are further described in Appendix A to this document.

The document for which USEPA seeks comment in this instance stops short of prescribing actual numeric nutrient criteria. It presents a series of tools that States can use to establish numeric nutrient criteria. The illustrations of applications of these tools are hardly convincing. For example, Figure 12 which relates chlorophyll a to total phosphorus has an R^2 = 0.61. Figure 13 which relates total richness to total nitrogen has an R^2 = 0.19. Figure 14 which relates EPT richness to total phosphorus has an R^2 = 0.05! We hope that USEPA is not suggesting that the tools so thoughtfully explained in the document can be used to establish numeric nutrient criteria based on such relationships.

It is not surprising that such poor relationships are calculated. The tools presented may be useful in more narrow circumstances, e.g., segments of watersheds or specific locations. Certainly they will not be successful when applied over larger regions. The heterogeneity in

systems simply makes this impossible. Furthermore, even at specific locations such relationships will often be poor because of the multiple factors that are at play. The problem of confounding variables is so severe when considering nutrient impacts that the use of statistically determined stressor - response variable relationships will often, and I dare say more likely than not, fail.

My comments are not to be taken as a blanket condemnation of the use of stressor - response variable statistically determined relationships. Where sufficient site specific data exist, the development of valid site specific relationships *may* be possible. In such circumstances, these tools would then be used to develop site specific numeric criteria, a valid approach in the matter of nutrient regulation. (As an aside, I would in general prefer the use of mechanistic modeling over statistically based stressor - response relationships, but I also recognize that the former may not be practical in all situations, and the latter may provide a simple useful relationship in some situations.) My firm has illustrated the use of site specific criteria in at least two large TMDL studies that we performed for the New Jersey Department of Environmental Protection (NJDEP). Based on independent mechanistic modeling, one of the studies determined that the use of summer phytoplankton blooms was the appropriate critical end point, while the other determined that dissolved oxygen and pH are the appropriate critical end points. A fixed numeric nutrient criterion would not have been appropriate or sufficient to achieve the proper system response in either case.

My comments can be taken to support an opinion opposed to the use of large scale numeric nutrient criteria, and the use of stressor - response variable relationships to support the adoption of such criteria. It is misleading to suggest that there is a reasonable likelihood that a valid stressor - response variable relationship can be derived in such circumstances. The multitude of variables responsible for system response is just too great, and the scientific literature has supported that conclusion.

APPENDIX A

(circa 1994)

COMMENTS ON NEW JERSEY'S SURFACE WATER QUALITY CRITERIA FOR TOTAL PHOSPHORUS

I. CURRENT CRITERIA

New Jersey's Surface Water Quality Standards contain narrative criteria for nutrients and specific numerical criteria for total phosphorus. These appear at N.J.A.C. 7:9-4.5(g) and 7:9-4.14(c)6, respectively. Furthermore, N.J.A.C. 7:9-5.7(b) contains effluent standards for phosphorus discharges to fresh water lakes, ponds, reservoirs, and tributaries to these water bodies. The narrative criteria, in general, state that nutrient concentrations in fresh waters of the State of New Jersey should be kept to levels such that they do not result in nuisance plant growth, or otherwise render the waters unsuitable for designated uses. These narrative criteria further state that NJDEPE may establish water quality based effluent limitations to avoid such impacts. Such an approach is reasonable, although as currently described it is subjective and ill-defined.

The numerical criteria for phosphorus basically require that the concentration of total phosphorus in impoundments or their tributaries not exceed 0.05 mg/l, and that total phosphorus in free flowing streams not tributary to impoundments shall not exceed 0.1 mg/l when phosphorus is the limiting nutrient. Although we have not been able to specifically identify the basis for these criteria, it appears that they probably have been derived from the USEPA Quality Criteria For Water ("The Red Book" July 1976, or the "The Gold Book" May 1986). In fact, the USEPA decided to not present national criteria for phosphate phosphorus for the control of eutrophication. The USEPA indicated that total phosphates as phosphorus should not exceed 0.05 mg/l in any stream at the point where it enters any lake or reservoir, nor 0.025 mg/l within the lake or reservoir. Although the New Jersey numerical criteria for phosphorus are similar, it is important to point out that the USEPA values are for total phosphate phosphorus whereas the New Jersey criteria are for total phosphorus. The USEPA criteria document goes on further to

indicate that a desired goal for the prevention of plant nuisances in streams or other flowing waters not directly discharging to impoundments is 0.1 mg/l total P. It is unclear whether this numerical value applies to total phosphorus or total phosphate phosphorus. We believe it is the latter since the document is dealing with phosphate phosphorus in its title and throughout its entire discussion. Again, the New Jersey criteria are numerically identical to the USEPA goal although for total phosphorus rather than phosphate phosphorus.

In its desire to control eutrophication in fresh water systems, the State of New Jersey included the numerical criteria for total phosphorus in the water quality standards recognizing that phosphorus is typically the limiting nutrient in fresh water systems. In recent years, it has become widely recognized that strict implementation of the numerical criteria would likely result in water quality based effluent limitations for phosphorus in a large portion of the wastewater discharges to fresh water systems within the State. The consequences of such a program are dramatic with no clearly established corequisite benefit. It is not clear from either a scientific or regulatory basis that the current numerical criteria for total phosphorus in the New Jersey Water Quality Standards are required in order to prevent eutrophication in fresh water systems. As noted above, the USEPA criteria document did not propose criteria for phosphate phosphorus for the control of eutrophication.

It is interesting to note how other states have chosen to prescribe water quality criteria for phosphorus. The USEPA in September 1988 issued a document entitled, "Phosphorus Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria" (EPA 440/5-88-012, NTIS #PB89-141444). Within this document summaries of phosphorus criteria within the water quality standards of various states are presented. Although a number of States have numerical criteria some of which are similar to those in New Jersey, it is interesting to note that a large number of States have no criteria at all for phosphorus. The State of Texas for example notes that, "...sufficient information on nutrient cycling in Texas waters and cause-effect relationships between nutrient concentrations and water quality is not presently available." A number of States rely upon narrative criteria similar to that in N.J.A.C. 7:9-4.5(g) including the provision for specification of site specific nutrient criteria and/or permit limitations to be established to control excessive plant growth. Some States prescribe seasonally varying criteria

or criteria in terms of a frequency distribution (for example see Arizona and Hawaii).

Based upon our review of other State criteria, it is clear that there is a widely diverging opinion as to how and if criteria for phosphorus should be established. This should not be surprising. Whether or not a particular body of water will experience eutrophication and excessive plant growth is a function of many variables. It is widely known that streams can assimilate greater phosphorus loads than impounded bodies of water. Flow rate, residence time, depth, ability for solar radiation to penetrate the water column, and a multitude of other factors contribute to whether a specific body of water is at risk with respect to nutrient loading. Consequently, we conclude that it is not possible to globally establish criteria for phosphorus or for nutrients in general. What New Jersey's Water Quality Standards can do is specify statewide criteria/policies that prescribe how site-specific criteria can be established. Anyone who has been involved in understanding how effluent limitations for nutrients should be established knows that those limitations cannot be established on a statewide basis. Such policies cannot even be implemented on a watershed basis where the watersheds are of the magnitude of "the Raritan" or "the Passaic." It is clear that much smaller segments perhaps subwatersheds as large as for example the Lamington River or the Rockaway River may be feasible for the establishment of nutrient criteria.

In the past year or two, we have been involved in a partnership between NJDEPE and various municipalities in performing "nutrient studies" which we expect will contribute significantly to our further understanding of how nutrients should be regulated within the State of New Jersey. We believe that partnership has been a very valuable and positive experience for both the State of New Jersey and permittees, wherein both sides (the regulated community and the regulatory community) recognized a dilemma which required resources for resolution and which would not be well served by impetuous regulatory decisions stipulating effluent limitations which (a) could not be met, and (b) would only lead to confrontational adversarial arguments.

II. AN ALTERNATIVE APPROACH

We believe that the New Jersey Surface Water Quality Standards should not specifically

focus on establishing narrative or numerical criteria for phosphorus alone. We believe that the present system should be modified to prescribe statewide criteria/policies for control of nutrients. We believe that such criteria/policies must include both (a) narrative criteria, and (b) numerical goals. Our concepts will be presented below. However, initially we wish to present an example of the type of criteria/policies that we envision may be valuable in the State of New Jersey. Such an approach is present in the criteria for the State of Arkansas as repeated here.

> Nutrients - Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation. As a guideline, total phosphorus shall not exceed 100 ug/l in streams or 50 ug/l in lakes and reservoirs except in waters highly laden with natural silts or color which reduce the penetration of sunlight needed for plant photosynthesis, or in other waters where it can be demonstrated that algal production will not interfere with or adversely affect designated uses and/or fish and wildlife propagation. The Commission may establish alternative nutrient limitations for lakes, reservoirs and streams, and shall incorporate such limitations into appropriate water quality management plans.

We believe the Arkansas criteria are particularly interesting in that they first state a set of objectives (i.e., avoiding objectionable algal densities or other nuisance aquatic vegetation). These criteria then present a numerical guideline, albeit for total phosphorus only, which is expected to achieve the objective. We think that such an approach is valuable in that it states an objective and then prescribes a means that, in general, meets that objective, although recognizing that on a case-by-case/site specific basis, alternative numerical criteria may be appropriate.

We suggest that the New Jersey Surface Water Quality Standards delete the numerical criteria for total phosphorus contained in N.J.A.C. 7:9-4.14(c)6 and the effluent standards contained in N.J.A.C. 7:9-5.7(b). In lieu of this, we suggest that the State of New Jersey augment the nutrient criteria/policies in N.J.A.C. 7:9-4.5(g). We believe that the focus should be away from phosphorus criteria to a nutrient criteria/policy. That criteria/policy should include both narrative criteria and numerical goals.

We believe that the narrative criteria should state that nutrients should not be present in quantities sufficient to cause excessive plant growth. Excessive shall be defined as (1) rendering the waterway unsuitable for the designated uses, (2) causing violations of water quality criteria for other parameters (for example, depression of dissolved oxygen due to respiration and decay of plants, exceedences of pH criteria due to photosynthetic activity, etc.), and (3) resulting in significant changes in macroinvertebrate and fish populations. Determination of whether excessive growth has occurred may not always be simple. Criteria (2) above may be fairly easy to determine by monitoring for parameters such as dissolved oxygen and pH. Criteria (1) above may be somewhat more difficult but can be tested via surveys and actual observances of the uses of the waterway. For example, cessation of the use of a waterway as a potable water supply would clearly document that a designated use as a potable water supply is not being achieved; or substantial reductions in recreational fishing by anglers would indicate that a waterway's designated use as a recreational resource is not being achieved. Criteria (3) above is likely more difficult to test because it requires a significant commitment of resources for periodic monitoring of both the macroinvertebrate and the fish community. Such would have to be conducted on some kind of routine basis by state agencies. If this were fiscally impossible, then the definition of whether excessive plant growth has occurred would be determined by using only the first two criteria above.

A second aspect of the nutrient criteria/policy would provide numerical goals for phosphorus and nitrogen. We believe that NJDEPE should conduct additional research into the exact numerical values that should be included in such a criteria. However, as a point of departure for such research, consider the values presented in the attached Table 1. These values are presented for discussion purposes and are not presented as recommendations for adoption. NJDEPE or an authorized agent must conduct current detailed literature and other research in order to prepare a recommendation for adoption.

Several points with respect to Table 1 must be made. In our opinion, it is clear that the biologically available form of nutrients should be regulated and not the total concentration of nutrients. Therefore, we do not recommend a criterion for total phosphorus, but rather for total dissolved orthophosphate phosphorus, i.e., the most convenient and presently available method

for determining the biologically available forms of phosphorus. Similarly for nitrogen, we recommend that the goals be prescribed for total dissolved inorganic nitrogen (i.e., ammonia nitrogen + nitrite nitrogen + nitrate nitrogen) and not for total nitrogen. The numerical values for phosphorus in Table 1 are identical to those currently in the New Jersey Surface Water Quality Standards. Without having conducted any further research, these numbers appear to be reasonable although clearly they should be adopted as goals and not as statewide criteria. We would abandon the specification of a goal of 0.05 mg/l for streams at the point where they enter impoundments.

The values for nitrogen in Table 1 are not nearly as well established as those for phosphorus. Substantial literature research must be conducted, and perhaps NJDEPE may need to conduct algal bioassays to develop numerical criteria. The ratios of nitrogen to phosphorus in Table 1 are in line with the stoichiometric coefficients for nitrogen to phosphorus in aquatic plants.

The numerical goals would not be applicable during periods of the year when light and temperature, not nutrient availability, control plant growth (i.e., approximately November 1st through February 28th). It seems foolish to require effluent limitations for nutrients when it is physically impossible for plants to grow due to other limitations such as temperature and light. Indeed temperature and light may still be limiting in the months between March and October, and further consideration must be given to this aspect of Table 1.

Presentation of recommendations for water quality criteria without consideration of implementation is irresponsible. Consequently, we have addressed this issue below. Determination as to whether the narrative criteria are being met will of course be a more complex problem than determination as to whether the numerical goals are being met. Consequently, we recommend a step-wise implementation approach, starting with an evaluation of whether the numerical goals are being met. If these goals were not met, then it would trigger a determination as to whether the narrative criteria are being met. Determination as to whether the numerical goals are being satisfied can be easily determined. In the case where point sources may be causing exceedence of the goals, simple monitoring upstream, downstream, and in the effluent of the point source can demonstrate whether the goals are being met and whether a point

source is likely to be responsible for exceedence of the goal. We believe it is the responsibility of the permittees within the State of New Jersey to demonstrate at least on a permit renewal time frame (i.e., every five years) that the goal is being met. If no point sources are present within a segment/subwatershed, then we believe it is the responsibility of the State of New Jersey to determine if the goal is being met through periodic monitoring (for example, once every five years).

If the numerical goals are being met, then it is likely that the narrative criteria are being met (although such is not necessarily the case). If the numerical goals are not being met, then a determination must be made as to whether the narrative criteria are being satisfied. Again, the agency/entity responsible for determining whether the narrative criteria are being met will be either the permittee or the State of New Jersey depending upon the presence or absence of point source discharges and their impacts as determined by initial receiving water quality monitoring of nutrient concentrations. For example, if monitoring demonstrates that a point source is causing exceedence of the numerical goals, then it will be the responsibility of the permittee to determine if the narrative criteria are being satisfied. This will require study of the physical, chemical, and biological characteristics of the receiving water, as well as a determination as to whether designated uses are being satisfied. This should not be an inordinate task, and the permittee should recognize that it is their responsibility to acquire such information if they are indeed discharging nutrients in concentrations that exceed otherwise accepted numerical goals. If the permittee demonstrates that the narrative criteria are being met even though the numerical goals are not being met, then no effluent limitations for nutrients would be required. However, periodically (for example, every five years) the permittee would be required to demonstrate that the narrative criteria are being satisfied.

If both the narrative criteria and the numerical goals are not being met, then consideration must be given to setting effluent limitations for point source discharges and/or instituting best management practices for control of nonpoint source inputs. If the criteria and goals are not being met and it has been demonstrated that a point source discharge is contributing to violation of the narrative criteria and the numerical goals as demonstrated by studies performed by the permittee, then two options are available. The permittee may accept effluent limitations

established by NJDEPE in order to satisfy the numerical goals. Such effluent limitations may be determined using reasonable steady-state critical conditions such as MA30CD5 flows and monthly average temperatures. If such effluent limitations as determined by NJDEPE are acceptable to the permittee, then a reasonable compliance period for the permittee to construct the facilities necessary to meet those limitations can be implemented. If the permittee believes that NJDEPE's limitations are excessive and inappropriate, then the permittee shall have the option to perform additional investigations to determine the phosphorus effluent limitations necessary to satisfy the narrative criteria as opposed to strictly satisfying the numerical goals. The permittee may consider use of statistical models that will more reasonably determine effluent limitations. Such limitations would be established to satisfy the narrative criteria only and not the likely more strict numerical goals. However, it would be the responsibility of the permittee to provide a suitable technical basis for such limitations upon which NJDEPE may rely. Furthermore, as part of this investigation, the permittee may consider whether effluent limitations for the point source discharge alone are sufficient to meet the narrative criteria. If nonpoint sources preclude the attainment of the narrative criteria, then effluent limitations for the point source discharge shall not be required until such time as a comprehensive program for control of both point and nonpoint source inputs of nutrients can be established. If the narrative criteria are not being met and point source discharges are absent, not significantly contributing to, or not responsible for exceedence of the narrative criteria, then it will be the responsibility of the State of New Jersey to investigate and institute best management practices for control of nonpoint source inputs in order that the narrative criteria can be attained. We understand that a mechanism does not exist for such a program. We recommend that the State investigate a funding program that might include grants to municipalities for institution of BMPs to reduce nutrient loadings to fresh water systems. Without such a cooperative program between the State and the municipalities, control of nonpoint source nutrient loads will never be effective.

III. CONCLUSION

We believe that it is necessary to control nutrient inputs to the fresh water systems of the State of New Jersey. However, we further believe that such controls are not necessary in every

instance, and that statewide criteria and/or effluent standards should not be prescribed. The problem is site specific and cannot be analyzed and implemented on much greater than a subwatershed basis. Above we have proposed a blueprint that we think is workable. It relies upon a combination of narrative criteria which express the objectives which must be achieved in controlling nutrient loadings, as well as numerical goals which prescribe some minimum level of water quality within which the narrative criteria are expected to be met. We believe that the current system, which prescribes numerical criteria and numerical effluent standards, should be abandoned and that the State's current nutrient policies should be augmented to include the narrative criteria and numerical goals.

We remain available to assist in establishment of this new program for nutrient regulation.

TABLE 1*

Nutrient Numerical Goals for
Control of Excessive Plant Growth
March 1 - October 31

	TOTAL DISSOLVED ORTHOPHOSPHATE PHOSPHORUS (mg/l)	**TOTAL DISSOLVED INORGANIC NITROGEN (mg/l)**
STREAMS	< 0.1	< 1.0
IMPOUNDMENTS	< 0.05	< 0.5

***** These values are presented for discussion only and are not recommended for adoption. Detailed literature and other research must be conducted before a recommendation can be presented. See text for explanation/comments.

APPENDIX B

Portions of

Comments in Support of
Amendments to Phosphorus Criteria in
New Jersey's Surface Water Quality Standards at N.J.A.C. 7:9B

November 17, 2005

Eutrophication

Phosphorus can be characterized as a fertilizer. It is an essential nutrient for plants and, along with other essential nutrients, will support the growth of plants. A host of factors must be of sufficient magnitude in order for plants to grow - there must be sufficient light available, temperature must be sufficiently warm, all essential nutrients must be available in sufficient amounts, etc. When all factors are at their optimum levels, plant productivity will be at its peak leading to something called eutrophication. The term eutrophication was originally coined to describe the natural aging of a lake, transforming the lake from an open waterbody into a marsh and eventually into a meadow, a process which in an undisturbed setting can take thousands of years. The natural input of nutrients and the natural availability of light and heat will cause the natural production of plants in a waterbody. This process can be significantly accelerated through anthropogenic inputs of nutrients like phosphorus. This accelerated aging of a waterbody is called cultural eutrophication, and can result in water quality problems including low dissolved oxygen, nuisance plant growth, and fish kills. Consequently, much focus has been directed toward controlling anthropogenic inputs of nutrients to waterways, particularly lakes, in order to retard the rate of eutrophication in those waterbodies. It is important to note that phosphorus in and of itself is not a problem for aquatic systems. Only when phosphorus in concert with other factors causes excessive plant production in waterways, the adverse consequences noted above can result.

Limiting Nutrient Concepts

As noted above, nutrient enrichment of waterways can lead to excessive plant growth and low dissolved oxygen concentrations. Consequences of this include reduction in aesthetic and recreational value, fish kills and reduction in fish diversity, and interference as a source of raw water supply. The driving force behind all of this is the fact that nutrient supply can stimulate plant productivity. In most water environments, plant productivity is “limited” by one or more factors, one of which may be the availability of “nutrients,” hence the term “limiting nutrient”. More appropriately, one should speak of limiting factors because in many environments other

physical factors (e.g., light, temperature, and hydraulic characteristics) control plant productivity to a greater extent than the availability of nutrients.

New Jersey's Surface Water Quality Standards recognize that control of plant production in waterways can be accomplished by controlling phosphorus levels in those same waterways when the availability of phosphorus is a limiting factor. If the availability of phosphorus is not a limiting factor and hence phosphorus is not a limiting nutrient, then controlling phosphorus levels will have little or no effect on plant production. For this reason, the criteria at N.J.A.C. 7:9B-1.1(c)5 recognize that phosphorus can exceed 0.1 mg/l if phosphorus is not the limiting nutrient.

The definition of limiting nutrient has its roots in Liebig's Law of the Minimum which states that if one essential component is present in limited amounts, then any moderate increase or decrease in the supply of other essential components will have little or no observable influence on the rate of growth of an organism. In effect this concept supports a position that there can be one and only one limiting nutrient at any given time. Screening for the limiting nutrient can be completed by identifying the nutrient present in short supply in the surrounding environment when compared to the ratio at which nutrients are required by the organisms in question (in this case aquatic plants). While there are various formulas for aquatic plant cell composition in the scientific literature, a common mole ratio of carbon to nitrogen to phosphorus in aquatic plants is 106:16:1.[2] This translates to a weight ratio of 41:7.2:1. Typically carbon is plentiful and only nitrogen and phosphorus need be considered. Therefore, the plants in question will use nitrogen and phosphorus in a ratio of approximately 7 to 1.[3] If the ratio of the concentrations of nitrogen to phosphorus in the surrounding water is less than 7:1, then nitrogen would be present in short supply relative to phosphorus, and of the two would be the limiting nutrient. If the ratio of the

[2] For example, see *Aquatic Chemistry*, W. Stumm and J. J. Morgan, Wiley Interscience Publication, p. 562, 1981; *Limnology*, R. Wetzel, Saunders College Publishing, p. 286, 1983; *Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition)*, G. Bowie, et al., USEPA EPA/600/3-85/040, pp. 286 - 287, June 1985

[3] For example, see *Conceptual Approach for Developing Nutrient TMDLs for San Francisco Bay Area Waterbodies*, Peter Krottje and Dyan Whyte, California Regional Water Quality Control Board San Francisco Bay Region Staff, p. 5, June 18, 2003

concentrations of nitrogen to phosphorus in the surrounding water is greater than 7:1, then phosphorus would be present in short supply relative to nitrogen, and of the two, phosphorus would be the limiting nutrient.

A weakness in the above definition of limiting nutrient is that it presumes that there can ***and must*** be one and only one limiting nutrient at all times. It does not consider that all nutrients may be present in ample supply such that no nutrient is limiting plant production. To resolve this dilemma, consideration must be given to the kinetics of plant growth which considers how fast plants can use nutrients to grow relative to the amount of those nutrients available to grow. This relationship is commonly described by the Monod or Michaelis-Menten equation[4]

$$U = U_{max} [S / (K_S + S)]$$

Where:

U = the actual growth rate of the organism

U_{max} = the maximum possible growth rate of the organism

S = the concentration of an essential nutrient in the surrounding environment

K_S = a half saturation constant which is the concentration of the essential nutrient at which the actual growth rate is one-half of the maximum growth rate.

The equation is depicted graphically in Figure 1. This equation demonstrates that as the concentration of the essential nutrient increases, the actual growth rate approaches the maximum possible growth rate. At higher nutrient concentrations, further increases in the supply of the essential nutrient has virtually no effect on the growth rate because the organism can not use the nutrient any faster and therefore can not grow any faster. At concentrations above this point, the essential nutrient is no longer limiting growth and therefore can not be a limiting nutrient. Hence, whether or not a nutrient is "limiting" is a function of its availability relative to the rate at which an organism can use the nutrient to grow. If all nutrients are present in plentiful supply,

[4] These investigators both arrived at the same conclusion. Monod (1942) was studying bacterial growth rates, while Michaelis and Menten (1913) were generally studying enzymatically controlled reactions.

then there are no limiting nutrients, only nutrients that are present in concentrations less plentiful than others. As far as organisms are concerned, this makes no difference. They have as much nutrient as they can use and can not grow any faster.

The difference between the kinetic definition of limiting nutrient and the definition of limiting nutrient based simply on cell composition is that the former demonstrates that when nutrients are in plentiful supply, there is no limiting nutrient. This is reasonable and scientifically accepted. In fact, the Department has adopted this approach in its phosphorus TMDL for the Whippany River.[5] The definition based on cell composition can only tell you ***which nutrient of those you are considering may be limiting***. Consideration of the kinetics of organism growth is necessary to tell you if that candidate nutrient is ***actually*** limiting.

For phosphorus, a simple way to conduct this evaluation is to identify the concentration of phosphorus in the surrounding water when the growth rate is effectively equal to the maximum growth rate. This will occur at a concentration of phosphorus in the surrounding water which is significantly greater than the half saturation constant. The Department has actually taken a position on this in two instances - in the Whippany TMDL and in the Technical Manuals. In the former, the Department noted that when available phosphorus is present at concentrations below 0.002 mg/l it is generally limiting plant growth[6], and concluded that since phosphorus concentrations were significantly greater than this value in the Whippany, then phosphorus was not a limiting nutrient. The Department also noted that the phosphorus half saturation constant is typically in the range of 0.001 to 0.005 mg/l[7], indicating that when phosphorus concentration is greater than 0.05 mg/l, growth rate is 91% to 98% of the maximum growth rate. This finding was reaffirmed in the Technical Manuals where the Department concluded that if DRP is greater than or equal to 0.05 mg/l, phosphorus can be excluded as a limiting nutrient. This approach is

[5] See 32 N.J.R. 2148 - 2151
[6] See 32 N.J.R. 2149, and Lee and Jones, 1998
[7] See 32 N.J.R. 2150. Also see *Principles of Surface Water Quality Modeling and Control*, R. Thomann and J. Mueller, Harper & Row Publishers, p. 427, 1987; and *Surface Water-Quality Modeling*, S. Chapra, WCB McGraw-Hill, p. 607, 1997.

scientifically appropriate and defensible. The May 2005 Addendum deleted this approach to defining whether phosphorus is a limiting nutrient and therefore is scientifically flawed.

The concept of limiting nutrient can be further illustrated via a simple analogy. Consider a carpenter constructing a building with nails (N) and plywood (P). Suppose the carpenter needs nails and plywood in a ratio of 7 to 1, i.e., he needs 7 nails for every sheet of plywood. If he starts working one day with 70 nails and 10 sheets of plywood (a ratio of 7 to 1), he will have nails and plywood in exactly the ratio he needs, i.e., 7 nails for each sheet of plywood. However, if he starts with only 60 nails and 10 sheets of plywood (a ratio of 6 to 1), he will run out of nails before he runs out of plywood, i.e, nails are in short supply relative to plywood and may be the "limiting" factor. His actual N to P ratio is only 6 to 1 when it ideally should be 7 to 1. Conversely, if he starts with 80 nails and 10 sheets of plywood, he will run out of plywood first, i.e., plywood is in short supply relative to nails. His actual N to P ratio is 8 to 1 when it ideally should be 7 to 1. The reader can substitute nitrogen for nails and phosphorus for plywood and quickly understand how the analogy applies to the definition of limiting nutrient based on cell composition only.

However, the above analogy is incomplete in that it does not consider the kinetics of the process, i.e., how fast can the carpenter use the nails and plywood. If he starts with 80 nails and 10 sheets of plywood, one might be tempted to conclude that he is "plywood limited." However, suppose he can only work fast enough to use four sheets of plywood in a day. At the end of the day he will still have plywood left over and he would not have been limited by the availability of plywood. The next morning, the supplier replenishes the materials so that the carpenter starts again with 80 nails and 10 sheets of plywood and begins working. Again, he will not be plywood limited. The process continues in this fashion for the rest of his life. While plywood was always in short supply relative to nails, the availability of plywood never limited the carpenter's ability to work. Therefore, even though the ratio of N to P indicates that P may be limiting, the kinetics of the process confirm that neither P nor N is actually limiting. The analogy to nitrogen and phosphorus for the production of plants in streams is obvious. By failing

to consider the kinetics of nutrient utilization by plants, the May 2005 Addendum is scientifically flawed.

Basis and Background for Criteria

A number of documents have been published by the USEPA to help guide State decision makers in developing nutrient criteria. In 1976, USEPA published Quality Criteria for Water (commonly referred to as the Red Book).[8] This publication provides guidance for a number of parameters. For some parameters, numeric criteria are presented; for others, no numeric criteria are presented. Where numeric criteria are presented, a rationale is also provided. USEPA decided to not present national numeric criteria for the control of phosphorus induced eutrophication, but did provide an evolving rationale for consideration.[9] USEPA's rationale suggested that total phosphates as phosphorus should not exceed 50 ug/l (0.05 mg/l) in any stream at the point where it enters any lake or reservoir. Additionally, a desired ***goal*** of 100 ug/l (0.1 mg/l) was suggested "for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments."[10]

The basis for this goal is cited as a 1973 USEPA publication prepared by Kenneth M. Mackenthun.[11] Two sections in the Mackenthun document discuss the 100 ug/l value. In a section dealing with Water Supplies, a paragraph addressing water quality in impoundments states:

> "Impounded water may result in the leaching of undesirable materials from inundated soils. When present in excessive concentrations, such materials can interfere with the desired water use. …… Phosphorus in excess of 0.1 mg/l may

[8] *Quality Criteria for Water*, USEPA, July 1976 (commonly referred to as "the Red Book")
[9] *Quality Criteria for Water*, USEPA, July 1976, p. 188
[10] *Quality Criteria for Water*, USEPA, July 1976, p. 188
[11] *Toward a Cleaner Aquatic Environment*, Kenneth M. Mackenthun, Director, Technical Support Staff, Environmental Protection Agency Office of Air and Water Programs, 1973

> interfere with coagulation in water treatment plants and in excess of 0.05 mg/l may stimulate the excessive growth of algae and other aquatic plants."[12]

In a section dealing with Limiting Factors and the amount of algae that can result from a given amount of phosphorus, Mackenthun states:

> "A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 ug/l P at any point within the flowing stream, nor should 50 ug/l be exceeded where waters enter a lake, reservoir or other standing water body."[13]

This latter passage is virtually identical to the passage in the Red Book. In Mackenthun, the 100 ug/l value is presented as "a considered judgment," not necessarily his considered judgment and not based on specific scientific studies. As such, to the extent that it is an opinion, it is a net opinion that would not be accepted as a standard by the scientific community. In the Red Book, the 100 ug/l value is presented merely as a desired goal. In neither is it proposed as a numeric criterion, particularly not as a criterion that should be adopted as a hard and fast threshold for noncompliance statewide. In fact, in the opening page of the Red Book the following is noted, "The criteria in this publication should not be used as absolute values for water quality."[14]

Another version of Quality Criteria for Water was published by the USEPA in 1986 (commonly referred to as the Gold Book).[15] USEPA stated that "In a continuing effort to provide those who use EPA's water quality and human health criteria with up-to-date criteria values and associated information, this document Quality Criteria for Water 1986 was assembled."[16] The sections on phosphorus in the Red Book and Gold Book are virtually identical.

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[12] Mackenthun 1973, pp 122 - 123
[13] Mackenthun 1973, pp 175 - 176
[14] *Quality Criteria for Water*, USEPA, July 1976, p. iii
[15] *Quality Criteria for Water 1986*, USEPA, Washington, D.C., EPA 440/5-86-001, May 1986 (The "Gold Book")
[16] Gold Book 1986 in preface "To Interested Parties"

In a response document issued in October 2002, the Department indicated its position regarding the basis for the 0.1 mg/l numeric criterion for total phosphorus at N.J.A.C. 7:9B-1.1(c)5.[17]

> "The 0.1 mg/L total phosphorus criterion has been promulgated in the Department's Water Quality Standards since 1981. The criteria is consistent with the 1986 United States Environmental Protection Agency (EPA) document "Quality Criteria for Water" (known as the Red Book). The origin of the 0.1 mg/l criteria may be found in the 1973 publication "Toward a Cleaner Aquatic Environment" by Kenneth M. Mackenthun, EPA, Office of Air and Water Programs."[18]

Consequently, the Department has adopted a numeric criterion for phosphorus in streams which was presented as "a considered judgment," and portrayed by USEPA as a desired goal that is still evolving, to control the potential for algae and other plants to interfere with coagulation in water treatment plants! Neither the Mackenthun document, the Red Book nor the Gold Book provide a scientifically defensible basis for the Department to adopt a universal numeric criterion of 0.1 mg/l in streams. In fact, the USEPA in the Red Book and the Gold Book purposely decided to not present a numeric criterion for the control of nuisance aquatic plant growth. The Red Book's closing sentence in the section on phosphorus is "No national criterion is presented for phosphate phosphorus for the control of eutrophication."[19]

There are numerous instances in the scientific literature where it is clearly demonstrated that nutrient criteria must reflect differences in waterbodies.[20] In a more recent document,[21] USEPA

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[17] *New Jersey Department of Environmental Protection Water Quality-based Effluent Limits for Total Phosphorus A Synopsis of the Department's Responses to Permittee Comments*, October 2002

[18] *New Jersey Department of Environmental Protection Water Quality-based Effluent Limits for Total Phosphorus A Synopsis of the Department's Responses to Permittee Comments*, October 2002, page 3 of 7

[19] *Quality Criteria for Water*, USEPA, July 1976, p. 190

[20] "Ecologically Based Standards for Nutrients in Streams and Ditches in the Netherlands," Edwin T. H. M. Peeters & Jean J. P. Gardeniers, *Wat. Sci. Tech.*, vol. 37, no. 3. pp 227 - 234, 1998; "Nutrient Concentration Criteria and Characterization of Patterns in Trophic State for Rivers in Heterogeneous Landscapes," Ton H. Snelder, et al., *Journal of the American Water Resources Association*, vol. 40, no. 1, pp 1 - 13 Feb 2004; "Regional Characteristics

recognizes that uniform statewide criteria are not appropriate. This guidance document outlines a complex and somewhat nebulous process for States to use in establishing criteria. One clear conclusion of this document is that there is not a good general relationship between nitrogen or phosphorus and plant biomass in rivers and streams.[22] This is confirmed by Dodds, et al.[23] Dodds and Welch note that "a large amount of the variance in benthic chlorophyll levels in streams is not related to nutrient levels."[24]

The Department's Technical Manuals establish biomass criteria to determine whether there has been excessive nutrient enrichment in a stream. In conducting the test as to whether a waterway has been rendered unsuitable for its designated uses, both phytoplankton and periphyton concentrations are considered. The Technical Manuals prescribe pass/fail metrics in this regard (i.e., if concentration is above a prescribed level, then the waterway is deemed unsuitable for its designated uses). While the Department may argue that the threshold values in the Technical Manuals are representative of the range of the values noted in the scientific literature,[25] these values should not be adopted as absolute pass/fail values. For example, with regard to the 150 mg/m^2 periphyton threshold adopted in the Technical Manuals, USEPA states "the 150 mg/m^2 level can not be supported as an absolute threshold."[26] There is no scientific evidence to support a position that a single periphyton concentration exceeding 200 mg/m^2, or a two week mean phytoplankton concentration exceeding 32 mg/l, or any of the other biomass metrics in the Technical Manuals constitutes a finding that the waterway is unsuitable for its designated uses.

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of Nutrient Concentrations in Streams and Their Application to Nutrient Criteria Development," Christina M. Rohm, et al., *Journal of the American Water Resources Association*, vol. 38, no. 1, pp 213 - 239, Feb 2002, pp 1- 13

[21] *Nutrient Criteria Technical Guidance Manual Rivers and Streams*, USEPA, EPA-822-B-00-002, July 2000

[22] For example see page 77 of *Nutrient Criteria Technical Guidance Manual Rivers and Streams*, USEPA, EPA-822-B-00-002, July 2000

[23] "Developing Nutrient Targets to Control Benthic Chlorophyll Levels in Streams: A Case Study of the Clark Fork River," W.K. Dodds, et al., *Water Research*, vol. 31, no. 7, pp 1738 - 1750, 1997

[24] See page 190 of "Establishing Nutrient Criteria in Streams," *J. North American Benthological Society*, vol 19, no 1, pp 186 - 196, 2000

[25] For example as summarized in Chapter 7 of *Nutrient Criteria Technical Guidance Manual Rivers and Streams*, USEPA, EPA-822-B-00-002, July 2000

[26] See page 102 of *Nutrient Criteria Technical Guidance Manual Rivers and Streams*, USEPA, EPA-822-B-00-002, July 2000

The thrust of the historical information upon which nutrient criteria may be based is clear in that such criteria are not meant to be applied on a wholesale statewide basis, but rather as thresholds which if exceeded would require site specific investigations to determine if there has been excessive nutrient enrichment leading to impairment of the designated uses. There is no consistent evidence to support an opinion or an enforceable regulation that impairment in streams occurs at 0.1 mg/l total phosphorus. To determine that a waterbody is impaired simply based on an observation that some small percentage of the samples have total phosphorus concentrations above 0.1 mg/l is inappropriate and without a scientifically defensible basis.

A Review of Phosphorus Regulation in Other States

It is interesting to note how other States have chosen to prescribe water quality criteria for phosphorus. In this report, a survey of published State regulations with regard to phosphorus specifically and nutrients in general has been prepared. The results of that investigation are summarized in Appendix A. While the survey may not be fully exhaustive, it is quite comprehensive and provides a wealth of information that should be of use to the Department as it considers alternative approaches to regulating nutrient enrichment in New Jersey.

As can be observed in Appendix A, although some States have numeric criteria, a large number of States have no numeric criteria at all for phosphorus. A number of States rely simply upon narrative criteria similar to that in N.J.A.C. 7:9B-1.5(g) including the provision for specification of site specific nutrient criteria and/or permit limitations to be established to control excessive plant growth.[27] Some States prescribe seasonally varying criteria or criteria in terms of a frequency distribution.[28] New Jersey is the only State that has a single numeric criterion for streams statewide and on a year round basis.

[27] For example, see Texas criteria in Appendix A.
[28] For example, see Oregon criteria in Appendix A.

Based upon our review of other States' criteria, it is clear that there is a widely diverging opinion as to how and if criteria for phosphorus should be established. This should not be surprising. Whether or not a particular body of water will experience eutrophication and excessive plant growth is a function of many variables. For example, it is widely known that streams can assimilate greater phosphorus loads than impounded bodies of water. Flow rate, temperature, residence time, depth, ability for solar radiation to penetrate the water column, and a multitude of other factors contribute to whether a specific body of water is at risk with respect to nutrient loading. Consequently, it is not possible to globally establish numeric criteria for phosphorus or for nutrients in general. It is possible to specify statewide narrative criteria and policies that prescribe how site-specific numeric criteria can be established if needed. Coincident with this, effluent limitations for nutrients cannot be established on a statewide basis.

An Alternative Program for New Jersey

The evidence is clear - there is no scientifically defensible basis for adoption of a statewide numeric criterion of 0.1 mg/l for total phosphorus in streams. The document claimed by the Department to be the basis for the criterion (i.e., Mackenthun's 1973 publication) presents "a considered judgment" that phosphorus in excess of 0.1 mg/l in a waterway may interfere with water treatment processes if that waterway is used as a source of water supply. Considering that information, USEPA purposely did not recommend a numeric criterion for phosphorus. Indeed in a later publication, USEPA affirmed that a uniform criterion is not appropriate. Furthermore, USEPA's investigations demonstrate that there is not a good general relationship between nutrients and plant productivity in rivers and streams. The Department has not offered any material which demonstrates scientifically defensible support for the present statewide numeric criterion of 0.1 mg/l.

A better approach to phosphorus regulation, and nutrient regulation in general, can be derived by considering the initial objective for such criteria, i.e., the control of nuisance plant productivity in

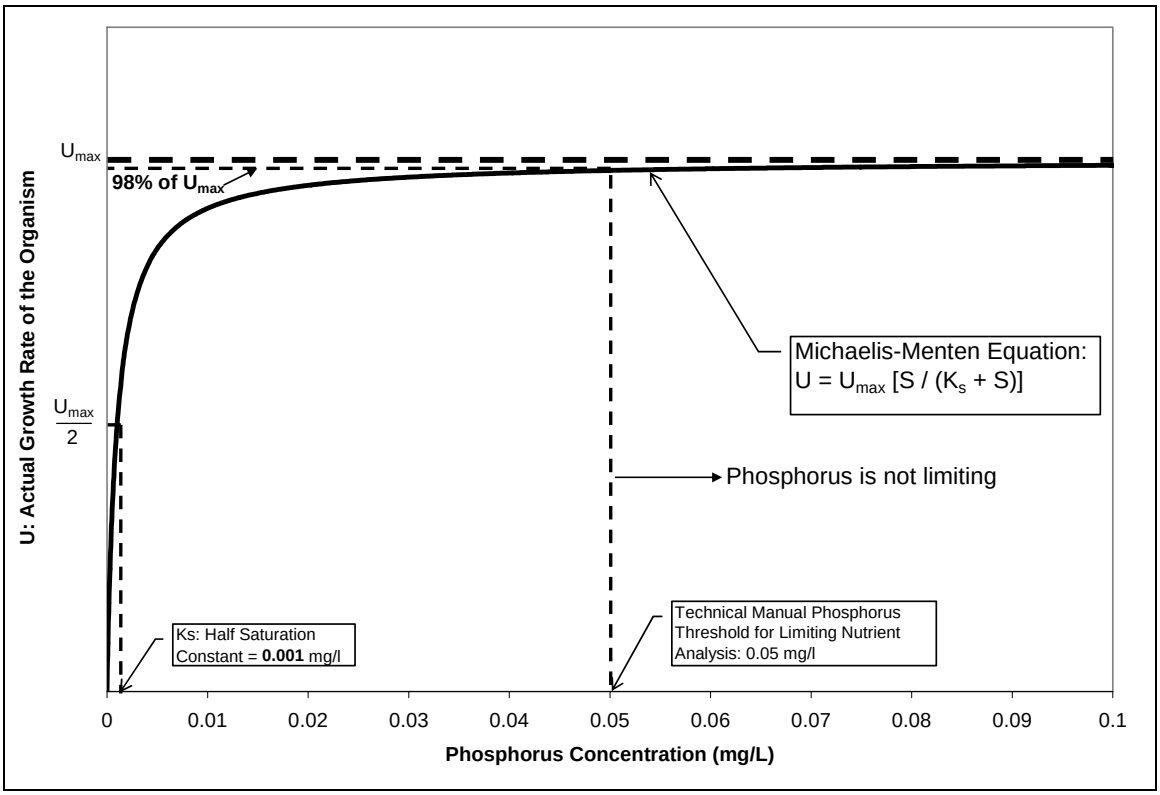
aquatic environments. Such nuisance is akin to the language presently at N.J.A.C. 7:9B-1.14(c)5 regarding rendering the waters unsuitable for the designated uses. Nuisance may occur to aesthetic value, recreational use, fisheries, suitability as a source of water supply, etc. In all instances the nuisance is a result of plant productivity which in itself is a result of a variety of factors, one of which may be phosphorus enrichment but is not always phosphorus enrichment. Therefore regulating phosphorus as the universal cause for such nuisance is incorrect.

The water quality standards and their implementation should be structured to ensure that waterways, except as due to natural conditions, do not experience nuisance aquatic vegetation or violations of numeric criteria for related parameters (e.g., dissolved oxygen and pH). Consequently, a final determination as to whether a waterway complies with the water quality standards must be determined by monitoring for aquatic vegetation and completion of an assessment as to whether that vegetation poses a nuisance (i.e., renders the waterway unsuitable for its designated uses). Recognizing that aquatic vegetation monitoring is expensive, screening level monitoring can be used as a surrogate to determine if it is necessary to conduct aquatic vegetation monitoring. If the screening level monitoring does not indicate that nuisance aquatic vegetation will exist, then monitoring for such is not necessary. One manifestation of nuisance aquatic vegetation is low dissolved oxygen concentrations at night. Another is high pH values during the day. Therefore, before aquatic vegetation monitoring need be conducted, a demonstration that the numeric criteria for minimum DO and high pH at N.J.A.C. 7:9B-1.14(c) should first be made. If the DO and pH numeric criteria are being met, then a presumption that nuisance aquatic vegetation is not occurring can be made. This demonstration requires that monitoring of DO and pH be conducted at the appropriate times of the day. At a minimum, for DO the monitoring must be conducted during the hours before sunrise, and for pH the monitoring must be conducted during the hours in the middle to late afternoon. The Department's ambient water quality monitoring program should be structured to include such monitoring.

If the numeric criteria for DO and pH are being violated, then the waterway should be listed as impaired for DO and/or pH and a determination as to whether those violations are due to nuisance levels of aquatic vegetation is needed. This will require monitoring for phytoplankton and periphyton (and perhaps even macrophytes) along the lines of that presently required by the Department in phosphorus evaluation studies. The information collected can be assessed by comparing the measured values against literature ranges such as those reported in USEPA 2000, and by assessing whether designated uses are actually being impacted - e.g., Has there been interference with water treatment? Have there been objectionable aesthetic and recreational impacts? Have there been fish kills due to depressed dissolved oxygen? If there are impacts which have rendered the waters unsuitable for its designated uses, then the waterway should be listed as impaired for objectionable/nuisance aquatic vegetation and the cause of the excessive plant productivity must be determined. If the cause is determined to be excessive phosphorus enrichment, then site specific criteria for phosphorus can be established along with a program to control phosphorus loads to the system to meet the site specific criteria (i.e., establish TMDLs, WLAs and LAs).

The above approach ensures that designated uses are being maintained which is the ultimate objective of the water quality standards, and addresses the root problem. It also avoids a presumption that in all cases impairment is due to one parameter, i.e., phosphorus, as is the present situation in New Jersey.

FIGURE 1



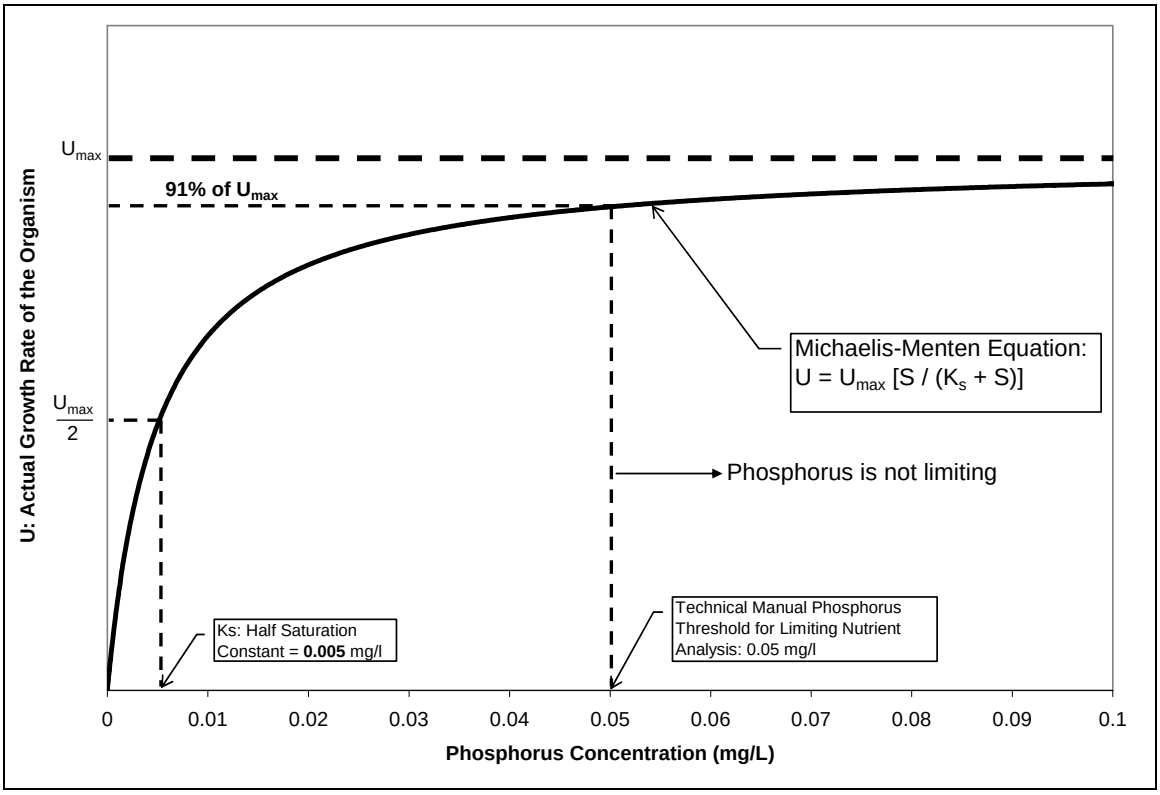


Figure 1. Illustration of Michaelis-Menten Equation for K_s = 0.001 mg/l (top) and 0.005 mg/l (bottom)

APPENDIX A

APPENDIX A

Status of Stream Criteria for Phosphorus in the Fifty States

State	No Criteria	Narrative Criteria	Numeric Target	Numeric Criteria for Select Streams	Basin Specific Criteria	Statewide Numeric Criteria for All Streams
Alabama	x					
Alaska	x					
Arizona				x		
Arkansas		x				
California					x	
Colorado	x					
Connecticut		x				
Delaware				x		
Florida		x				
Georgia	x					
Hawaii						x
Idaho		x				
Illinois		x		x		
Indiana	x					
Iowa	x					
Kansas		x	x			
Kentucky		x				
Louisiana		x				
Maine				x		
Maryland	x					
Massachusetts		x				
Michigan		x				
Minnesota		x		x		
Mississippi	x					
Missouri	x					
Montana				x		
Nebraska	x					
Nevada				x		
New Hampshire		x				
New Jersey		x				x
New Mexico		x				
New York		x				
North Carolina					x	
North Dakota			x			
Ohio		x				
Oklahoma				x		
Oregon	x					
Pennsylvania		x				
Rhode Island		x		x		
South Carolina		x				
South Dakota	x					
Tennessee		x				
Texas		x				
Utah				x		
Vermont		x		x		
Virginia	x					
Washington	x					
West Virginia	x					
Wisconsin		x				
Wyoming		x				

Column Headings:

No Criteria:	No numeric stream criteria for phosphorus is present in the SWQS for the control of eutrophication.
Narrative Criteria:	Narrative criteria for phosphorus or nutrients is present in either the SWQS or effluent standards for the control of eutrophication.
Numeric Target:	A numeric value or percent reduction is presented as a guideline or target.
Numeric Criteria for Select Streams:	Numeric criteria are presented for select streams, such as a certain class of waters or streams in select basins.
Basin Specific Criteria:	Basin specific plans and SWQS are developed to assess water quality.
Uniform Numeric Criteria for All Streams:	Uniform numeric criteria are adopted for all streams in the State.

State	Highlights of Phosphorus Regulation for Control of Eutrophication in Streams	Source
Alabama	No Water Quality Standards for phosphorus.	Alabama Department of Environmental Management Water Division-Water Quality Program Chapter 335-6-10 Water Quality Criteria
Alaska	No Water Quality Standards for phosphorus	Department of Environmental Conservation Water Quality Standards
Arizona	Water Quality Standards are established for individual rivers; multiple rivers with limits based on annual mean, 90th percentile, and single sample max, e.g., Black River, Tonto Creek and their tributaries 0.1 mg/L annual mean, 0.2 mg/L 90th percentile, 0.8 mg/L single sample maximum	Department of Environmental Quality Water Quality Standards
Arkansas	Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation or otherwise impair any designated use of the waterbody. Impairment of a waterbody from excess nutrients are dependent on the natural waterbody characteristics such as stream flow, residence time, stream slope, substrate type, canopy, riparian vegetation, primary use of waterbody, season of the year and ecoregion water chemistry. Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values, dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others. However, when excess nutrients result in an impairment, based upon Department assessment methodology, by any established, numeric water quality standard, the waterbody will be determined to be impaired by nutrients. Effluent Limit for 2.0 mg/l; 3 to <15 MGD = 1.0 mg/l; >15 MGD = case by case. Effluent Limits only apply to dischargers in a watershed of waters officially listed on Arkansas' impaired waterbody list (303d) with phosphorus as the major cause.2	[1] http://www.adeq.state.ar.us/water/303drprt.htm#Table2 [2] Arkansas Pollution Control and Ecology Commission; Regulation No. 2 - Regulation establishing water quality standards for surface waters in the State of Arkansas
California	Basin specific water quality control plans.[1] Basin specific example Cottonwood Creek in west San Diego County 0.1 mg/L in-stream criterion[2]	[1] State of California Water Quality Control Plan [2] Revision of the Clean Water Act Section 303 (d) List of Water Quality Limited Segments; Water Body Fact Sheets Supporting the Listing and Delisting Recommendations; http://www.swrcb.ca.gov/tmdl/docs/303d_update/sr_v3.pdf
Colorado	No Water Quality Standards for phosphorus	Colorado Department of Public Health and Environment Water Quality Control Commission
Connecticut	WQS for phosphorus only exists for existing or proposed drinking water sources. The WQS for this case is "none other than natural origin"	State of Connecticut Department of Environmental Protection Water Quality Standards
Delaware	WQS for dissolved inorganic phosphorus is 0.01 mg/l in tidal portions of selected rivers.	State of Delaware Surface Water Quality Standards
Florida	Narrative: The discharge of nutrients shall continue to be limited as needed to prevent violations of other standards contained in this chapter. Man-induced nutrient enrichment (total nitrogen or total phosphorus) shall be considered degradation in relation to the provisions of Sections 62-302.300, 62-302.700, and 62-4.242, F.A.C.; In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.; The Department finds that excessive nutrients (total nitrogen and total phosphorus) constitute one of the most severe water quality problems facing the State. It shall be the Department's policy to limit the introduction of man-induced nutrients into waters of the State. Particular consideration shall be given to the protection from concentrations or sensitive to further nutrient concentrations and sensitive to further nutrient loadings. Also, particular consideration shall be given to the protection from nutrient enrichment of those waters presently containing very low nutrient concentrations: less than 0.3 milligrams per liter total nitrogen or less than 0.04 milligrams per liter total phosphorus.	Surface Water Quality Standards
Georgia	"Currently, Georgia only has nutrient standards on a limited number of lakes, however nutrient standards for all waters will be established in the near future".	CSREES Southern Regional Water Quality Program; Georgia's Water Quality Standards
Hawaii	Geometric mean of TP not to exceed 50.0 ug/l in the wet season and 30.0 ug/l in the dry season. TP not to exceed 100 ug/l and 60 ug/l (wet and dry) 10% of the time. TP not to exceed 150 ug/l and 80 ug/l (wet and dry) 2% of the time.	Department of Health Amendment and Compilation; Chapter 11-54; Hawaii Administrative Rules Aug. 31, 2004
Idaho	"Surface waters of the state shall be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths impairing designated beneficial uses."	Water Quality Standards and Wastewater Treatment Requirements
Illinois	Water Quality Standard: Phosphorus (STORET number 00665): After December 31, 1983, Phosphorus as P shall not exceed 0.05 mg/l in any reservoir or lake with a surface area of 8.1 hectares (20 acres) or more, or in any stream at the point where it enters any such reservoir or lake.[1] Effluent Standard: No effluent discharge within the Lake Michigan Basin shall contain more than 1.0 mg/l of phosphorus as P. No effluent from any source which discharges to a lake or reservoir with a surface area of 8.1 hectares (20 acres) or more, or to any tributary of such a lake or reservoir whose untreated waste load is 2500 or more population equivalents, and which does not utilize a third-stage lagoon treatment system as specified in Section 304.120(a) and (c), shall exceed 1.0 mg/l of phosphorus as P; however, this subsection shall not apply where the lake or reservoir, including any side channel reservoir or other portion thereof, on an annual basis exhibits a mean hydraulic retention time of 0.05 years (18 days) or less. Narrative: Application for adjusted standard shall, at a minimum, contain adequate deficiencies in the receiving lake or reservoir. For purposes of this subsection, such effluent shall be deemed to contribute to such conditions if phosphorus is the limiting nutrient for biological growth in the lake or reservoir, taking into account the lake or reservoir limnology, morphological, physical and chemical characteristics, and sediment transport. However, if the effluent discharge enters a tributary at least 40.25 kilometers (25 miles) upstream of the point at which the tributary enters the lake or reservoir at normal pool level, such effluent shall not be deemed to contribute to such conditions if the receiving lake or reservoir is eutrophic and phosphorus from internal regeneration is not a limiting nutrient.[2]	[1] TITLE 35: Environmnetal Protection; Subtitle C: Water Pollution; Chapter I: Pollution Control Board; Part 302. Water Quality Standards; Subpart A: General Water Quality Provisions. [2] TITLE 35: Environmnetal Protection; Subtitle C: Water Pollution; Chapter I: Pollution Control Board; Part 304; Effluent Standards; Subpart A: General Effluent Standards.
Indiana	No Water Quality Standards for phosphorus	ARTICLE 2. WATER QUALITY STANDARDS Rule 1. Water Quality Standards Applicable to All State Waters Except Waters of the State Within the Great Lakes System.
Iowa	No Water Quality Standards for phosphorus	ARTICLE 2. WATER QUALITY STANDARDS

State	Highlights of Phosphorus Regulation for Control of Eutrophication in Streams	Source
Kansas	Alternative approach - nutrient reduction target for entire state. Phosphorus target is a 30 percent reduction. Focus on biological nutrient removal (BNR) for larger plants. Technology based legislation - "Based on expected removal efficiencies for BNR, it is feasible for the large WWTFs in Kansas to meet effluent limitations of 1.5 mg/l for TP".	Kansas Department of Health and Environment, Bureaur of Water. Surface Water Nutrient Reduction Plan.
Kentucky	A KPDES permit for an unpermitted or expanded discharge has an effluent limitation of no greater than 1 mg/l TP. " In lakes and reservoirs and their tributaries, and other surface waters where eutrophication problems may exist, nitrogen, phosphorus, carbon, and contributing trace element discharges shall be limited in accordance with the scope of the problem; the geography of the area; and relative contributions from existing and proposed sources."	Natural Resources and Environmental Protection Cabinet Department of Environmental Protection Division of Water
Louisiana	Nutrients. The naturally occurring range of nitrogen-phosphorous ratios shall be maintained. This range shall not apply to designated intermittent streams. To establish the appropriate range of ratios and compensate for natural seasonal fluctuations, the administrative authority will use site-specific studies to establish limits for nutrients. Nutrient concentrations that produce aquatic growth to the extent that it creates a public nuisance or interferes with designated water uses shall not be added to any surface waters.	Environmental Quality Water Quality Water Pollution Control
Maine	For Class A Waters: Nutrients shall not exceed seasonal mean concentration of nutrients in receiving waterbody. This rule limits the discharge of nutrients to the seasonal median concentrations. It is recognized however that impacts from nutrients are dependent on Liebig's Law of the Minimum, that productivity is limited as long as the limiting nutrient is controlled. This rule allows the discharger to exceed the seasonal median concentration for any nutrient if it is demonstrated, that a better condition can occur and that the biological community will still be as it naturally occurs.	Department of Environmental Protection; Rules pertaining to discharges to Class A waters
Maryland	Special advanced wastewater treatment requirement: An effluent limit of 2 mg/l total phosphorus shall be required for all facilities discharging more than 0.5 MGD to the Chesapeake Bay and its tributaires above the Baltimore Harbor and 10 MGD in the vicinity of Baltimore Harbor to the Bay Bridge.	26.08.04.04. 04 Subtitle 8: Water Quality - Sewage Treatment Works
Massachusetts	"Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication". From and after the date 314 CMR 4.00 becomes effective there shall be no new or increased point source discharge of nutrients to tributaries of lakes or ponds that would encourage cultural eutrophication or the growth of weeds or algae in these lakes or ponds.	314 CMR 4.00 Massachusetts Surface Water Quality Standards
Michigan	"Phosphorus which is or may readily become available as a plant nutrient shall be controlled from point source dicharges to achieve 1 mg/l of total phosphorus as a maximum monthly average effluent concentration unless other limits, either higher or lower, are deemed necessary and appropriate by the commission".	PART 4. WATER QUALITY STANDARDS; MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY SURFACE WATER QUALITY DIVISION
Minnesota	"Where the discharge of effluent is directly to or affects a lake or reservoir, phosphorus removal to 1 mg/l shall be required. The limit must be a calendar month arithmetic mean unless…a different averaging period is acceptable. In no case shall the 1 mg/l limit exceed a moving mean of 12 monthly values reported on a monthly basis, or a simple mean for a specified period, not to exceed 12 months. In addition, removal of nutrients from all wastes shall be provided to the fullest practicable extent wherever sources of nutrients are considered to be actually or potentially detrimental to preservation or enhancement of the designated water uses." May apply for variance.	Minnesota Rules, Tables of Chapters; Total Phosphorus Effluent Limits
Mississippi	"No current criteria for phosphorus. Plan for nutrient criteria development submitted in Feb 2004. The strategy was to develop nutrient criteria based primarily on the linkage between nutrient concentrations and impairment of designated uses".	Mississippi's Plan for Nutrient Criteria Development
Missouri	Dischargers to Lake Taneycomo and its tributaries between Table Rock Dam and Power Site Dam shall not exceed 0.5 mg/l of phosphorus. Dischargers permitted prior to adoption of the rule and with a design flow of less than 22,500 gpd are exempt. Also, dischargers to Table Rock Lake watershed shall not exceed 0.5 mg/l of phosphorus as a monthly average.	Rules of Department of Natural Resources Division 20—Clean Water Commission Chapter 7—Water Quality
Montana	River specific criteria. Example: In the mainstem Clark Fork River from below the Warm Springs Creek confluence (N46º11'17", W112º46'03") to the confluence with the Blackfoot River (N46º52'19", W113º53'35"), TP as P must be below 20 ug/l from June 21 to September 21.	ENVIRONMENTAL QUALITY; CHAPTER 30 - WATER QUALITY; Sub-Chapter 6 - Surface Water Quality Standards and Procedures
Nebraska	No Water Quality Standards for phosphorus.	
Nevada	Total phosphorus criteria for individual rivers for maintaining existing or higher quality or standards for beneficial uses. Example: TP<0.1 mg/l for beneficial uses, TP< 0.05 mg/l for maintaining existing higher quality for Jarbidge River: East Fork. Humboldt River Seasonal Average April thru November TP<=0.1 mg/l for beneficial uses, more examples in document.	CHAPTER 445A - WATER CONTROLS
New Hampshire	Narrative criteria. Examples: "(a) Class A waters shall contain no phosphorus or nitrogen unless naturally occurring. (b) Class B waters shall contain no phosphorus or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring. (c) Existing discharges containing either phosphorus or nitrogen which encourage cultural eutrophication shall be treated to remove phosphorus or nitrogen to ensure attainment and maintenance of water quality standards. (d) There shall be no new or increased discharge of phosphorus into lakes or ponds. (e) There shall be no new or increased discharge(s) containing phosphorus or nitrogen to tributaries of lakes or ponds that would contribute to cultural eutrophication or growth of weeds or algae in such lakes and ponds."	State of New Hampshire; Surface Water Quality Regulations; Chapter 1700
New Jersey	Phosphorus as total P shall not exceed 0.1 mg/l in any stream, unless it can be demonstrated that total P is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses. Narrative criteria also.	Surface Water Quality Standards N. J. A. C. 7:9B
New Mexico	Narrative criteria. Plant nutrients from other than natural causes shall not be present in concentrations which will produce undesirable aquatic life or result in a dominance of nuisance species in surface waters of the state.	TITLE 20 ENVIRONMENTAL PROTECTION; CHAPTER 6 WATER QUALITY; PART 1 STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS
New York	Narrative criteria: No phosphorus in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages.	Water Quality Regulations; Surface Water and Groundwater Classifications and Standards; New York State Codes, Rules and Regulations; Title 6, Chapter X Parts 700-706
North Carolina	Basin-Specific water quality control plans.	
North Dakota	Total phosphorus criteria = 0.1 mg/l. "The standards for nitrates (N) and phosphorus (P) are intended as interim guideline limits. Since each stream or lake has unique characteristics which determine the levels of these constituents that will cause excessive plant growth (eutrophication), the department reserves the right to review these standards after additional study and to set specific limitations on any waters of the state.	STANDARDS OF QUALITY FOR WATERS OF THE STATE; NDAC Chapter 33-I 6-02; March 2001; North Dakota Department of Health

State	Highlights of Phosphorus Regulation for Control of Eutrophication in Streams	Source
Ohio	"Total phosphorus as P shall be limited to the extent necessary to prevent nuisance growths of algae, weeds, and slimes that result in a violation of the water quality criteria set forth in paragraph (E) of rule 3745-1-04 of the Administrative Code or, for public water supplies, that result in taste or odor problems. In areas where such nuisance growths exist, phosphorus discharges from point sources determined significant by the director shall not exceed a daily average of 1 mg/l as total P, or such stricter requirements as may be imposed by the director in accordance with the international joint commission (United States-Canada agreement)."	3745-1-07 Water use designations and statewide criteria.
Oklahoma	The thirty (30) day geometric mean total phosphorus concentration in waters designated "Scenic River" in Appendix A of this Chapter shall not exceed 0.037 mg/L.	Revisions to Chapter 45- Oklahoma Water Quality Standards
Oregon	TMDLs have been developed (loads allowed in lakes). River specific criteria: "No wastewater may be discharged to the Yamhill River or its tributaries without the authorization of the Commission that cause the monthly median concentration of total phosphorus to exceed 70 ug/l as measured during the low flow period between approximately May 1 and October 31 of each year."	Revisions to Chapter 340, Division 41- Oregon Water Quality Standards
Pennsylvania	"Regulations contemplate that the Department will evaluate the degree to which phosphorus contributes to the impairment designated uses on a case-by-case basis and may impose more stringent limitations where necessary." DRBC WQ regulations: "The minimum level of wastewater treatment for all new and expanding wastewater treatment projects discharging to Special Protection Waters, including projects approved by the Commission after September 1988, will be "Best DemonstrableTechnology". Equivalent effluent criteria for industrial facilities and seasonal limits, if any, will be developed on a case-by-case basis. The following 30-day average effluent criteria define Best Demonstrable Technology:" TP = 2.0 mg/l	DELAWARE RIVER BASIN COMMISSION; WEST TRENTON, NEW JERSEY; Administrative Manual — Part III; WATER QUALITY REGULATIONS
Rhode Island	"Nutrients - Nutrients shall not exceed the limit specified in rule 8.D. (2) and 8.D.(3) and/or more stringent site-specific limits necessary to prevent or minimize accelerated or cultural eutrophication." Average total phosphorus shall not exceed 0.025 mg/L in tributaries at the point where they enter any lake, pond, kettlehole, or reservoir. Narrative Criteria: "None in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes and ponds.	State of Rhode Island and Providence Plantations Department of Environmental Management; Water Resources; Water Quality Regulations; August 6, 1997
South Carolina	Narrative Criteria: "Discharges of nutrients from all sources, including point and nonpoint, to waters of the State shall be prohibited or limited if the discharge would result in or if the waters experience growths of microscopic or macroscopic vegetation such that the water quality standards would be violated or the existing or classified uses of the waters would be impaired. Loading of nutrients shall be addressed on an individual basis as necessary to ensure compliance with the narrative and numeric criteria." Lakes have numeric criteria.	South Carolina Water Quality Criteria
South Dakota	No Water Quality Standards for phosphorus.	ARTICLE 74:51; Surface Water Quality
Tennessee	Narrative Criteria: "Nutrients - the waters shall not contain nutrients in concentrations that stimulate aquatic plant and/or algae growth to the extent that aquatic habitat is substantially reduced and/or the biological integrity fails to meet regional goals. Additionally, the quality of downstream waters shall not be detrimentally affected." A ecoregional nutrient plan has been drafted, but not implemented.	TENNESSEE'S PLAN FOR NUTRIENT CRITERIA DEVELOPMENT Revised October, 2004
Texas	Narrative Criteria: "Nutrients. Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing."	Revisions to §307 - Texas Surface Water Quality Standards
Utah	WQC = 0.05 mg/l for Class 3B (protected for warm water species of game fish and other warm water aquatic life) and Class 3C (protected for nongame fish and other aquatic life).	R311. Environmental Quality, Water Quality. R317-2. Standards of Quality for Waters of the State. R317-2-1A. Statement of Intent.
Vermont	"a) general policy - 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. b) upland streams - In addition to compliance with the general policy above, for all streams above 2,500 feet in elevation, total phosphorus shall not exceed 0.010 mg/l at low median monthly flow. c) Discharges to tributaries shall not increase in-stream conditions by more than 0.001 mg/l at low median monthly flow. Indirect discharges to lakes, ponds, or reservoirs shall not increase total dissolved phosphorus as measured in the groundwater 100 feet from the mean water level of the lake, pond, or reservoir by more than 0.001 mg/l."	Vermont Water Quality Standards
Virginia	Special standards designation exists for Nutrient Enriched Waters (NEW). For such waters, TP shall not exceed 0.1 mg/l monthly average for all discharges with the exception of Tyson Foods, Inc. which shall meet 0.3 mg/l monthly average and 0.5 mg/l daily maximum in the entire Chickahominy watershed above Walker's Dam.	9 VAC 25-260 Virginia Water Quality Standards.
Washington	No Water Quality Standards for phosphorus.	Chapter 173-201A WAC; WATER QUALITY STANDARDS FOR SURFACE WATERS OF THE STATE OF WASHINGTON
West Virginia	No Water Quality Standards for phosphorus.	TITLE 46; LEGISLATIVE RULE; ENVIRONMENTAL QUALITY BOARD
Wisconsin	Narrative Criteria: In addition to the requirements established in ch. NR 217, any wastewater discharger, regardless of population, volume or type of waste discharge, or geographic location, may be required to remove excess amounts of phosphorus. Effluent limitations for total phosphorus based on surface water quality may be established where, in the best professional judgment of the department, such limitations will result in an improvement in water quality, or preserve the quality of surface waters where long–term discharges may result in impairment of water quality. Such limitations for phosphorus shall include an evaluation of the discharges from point sources, nonpoint sources, background sources, tributaries, and a consideration of a margin of safety.	Chapter NR 102 - WATER QUALITY STANDARDS FOR WISCONSIN SURFACE WATERS
Wyoming	Narrative Criteria: "Class 1, 2 and 3 waters of the state must be free from substances, whether attributable to human-induced point source discharges or nonpoint source activities, in concentrations or combinations which will adversely alter the structure and function of indigenous or intentionally introduced aquatic communities."	WATER QUALITY RULES AND REGULATIONS; WYOMING SURFACE WATER QUALITY STANDARDS