METHODS TO MEASURE PHOSPHORUS AND MAKE FUTURE PREDICTIONS

STUDY BRIEFING

February 20, 2015

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Study Background

- **The objective of the study was to conduct an evaluation and develop recommendations to determine the scientific methods with which to measure the impacts of phosphorus pollution in inland, non-tidal waters**

Note: At the start of the study process, the CASE Research Team and Study Committee, in consultation with DEEP and Working Group #2, considered which inland waters should be included in the study. Most states, including Connecticut, already have numeric standards for nutrients for lakes and reservoirs, and therefore it was decided that these standards are sufficient and do not need to be revisited.

Study Approach

Task 1: How does phosphorus impact water quality in general and what factors are important in Connecticut?

Task 2: What is Connecticut's current approach to addressing phosphorus to comply with water quality standards?

Task 3: How can phosphorus impacts be measured in non-tidal waters such that relevant contributing stressors are considered to comply with water quality standards?

Task 4: What methodologies are appropriate for use in Connecticut to measure phosphorus impacts on water quality and aquatic life and other designated uses?

Brief Statement of Primary Conclusion

- **Setting appropriate standards for limiting the amount of phosphorus discharged into a stream or river is complicated because numerous other factors will likely affect the degree of impact/impairment of the phosphorus on the stream or river**

- **Variation between the amount of phosphorus entering the watercourse and the degree of impairment, coupled with the large amount of variation in stream phosphorus concentration, makes setting a single numerical phosphorus standard inappropriate**

- **Utilization of the "stressor-response model" that links a stressor such as phosphorus pollution to the ecological state of a stream reach can address this complexity**

- **The ecological state or health of the watercourse/body can be linked to the specific "designated uses" incorporated by and upon which the Connecticut Water Quality Standards are based**

Brief Statement of Primary Conclusion (2)

- **The stressor-response model involves using response parameters (i.e., dissolved oxygen, benthic algae, water clarity, pH, diatoms, invertebrates, toxic species, fish) to establish phosphorus impairment**
- **This approach entails measuring a single or multiple response parameters and uses statistical approaches to link the parameter to a desired stream state in order to set a standard**
- **This method consists of building a conceptual model, collecting data through synthesis and monitoring, and creating the stressor-response relationship**
- **The statistical approach used to set response parameters varies; EPA has recently documented an approach that allows for the direct utilization of response parameters as criteria**

Brief Statement of Primary Conclusion (3)

- **Diatoms and dissolved oxygen are very good measures of biotic integrity. Because of their strong correlation to phosphorus impairment, ability to integrate changes over time and space, and cost effectiveness, it is recommended that these two parameters be used by Connecticut as the "response parameters" in developing numeric criteria (or future response parameter standards) for phosphorus**
- **Connecticut has performed an initial analysis of the use of diatoms for determining a concentration-based nutrient criteria in streams, including statistical approaches to evaluate the relationship between diatom species and phosphorus concentrations. DEEP should continue to utilize this approach and their Interim Strategy derived therefrom while continuing to collect data to implement this report's recommendations**
- **The state should continue sampling the diatom community and add diurnal dissolved oxygen measurements. The goal of the state should be to move from the Interim Strategy to a decision framework that includes phosphorus concentrations and these response parameters.**
- **As this is a rapidly evolving area of scientific inquiry DEEP should re-evaluate its approach every 3–5 years in a manner that is transparent to all stakeholders**

Task 1

How does phosphorus impact water quality in general and what factors are important in Connecticut?

Phosphorus in Inland Waters

- **Natural sources are minimal**
- **Human inputs into watersheds can be large**
  - **Detergents, fertilizer, food and feed**
  - **These inputs can be removed before they make it to streams**
- **Once in natural waters P can cause algal blooms**
  - **P often limiting nutrient of inland water plants**
  - **The relationship between P loading and algal blooms in streams and rivers is complex**

Stream Examples

Figure 2-1: Examples of Streams Minimally *(left photos)* and Heavily Impacted by Phosphorus *(right photos); Sources: Biological Monitoring Program, Maine Department of Environmental Protection (top left and top right photos); DEEP (bottom left and bottom right photos)*

Conceptual Model

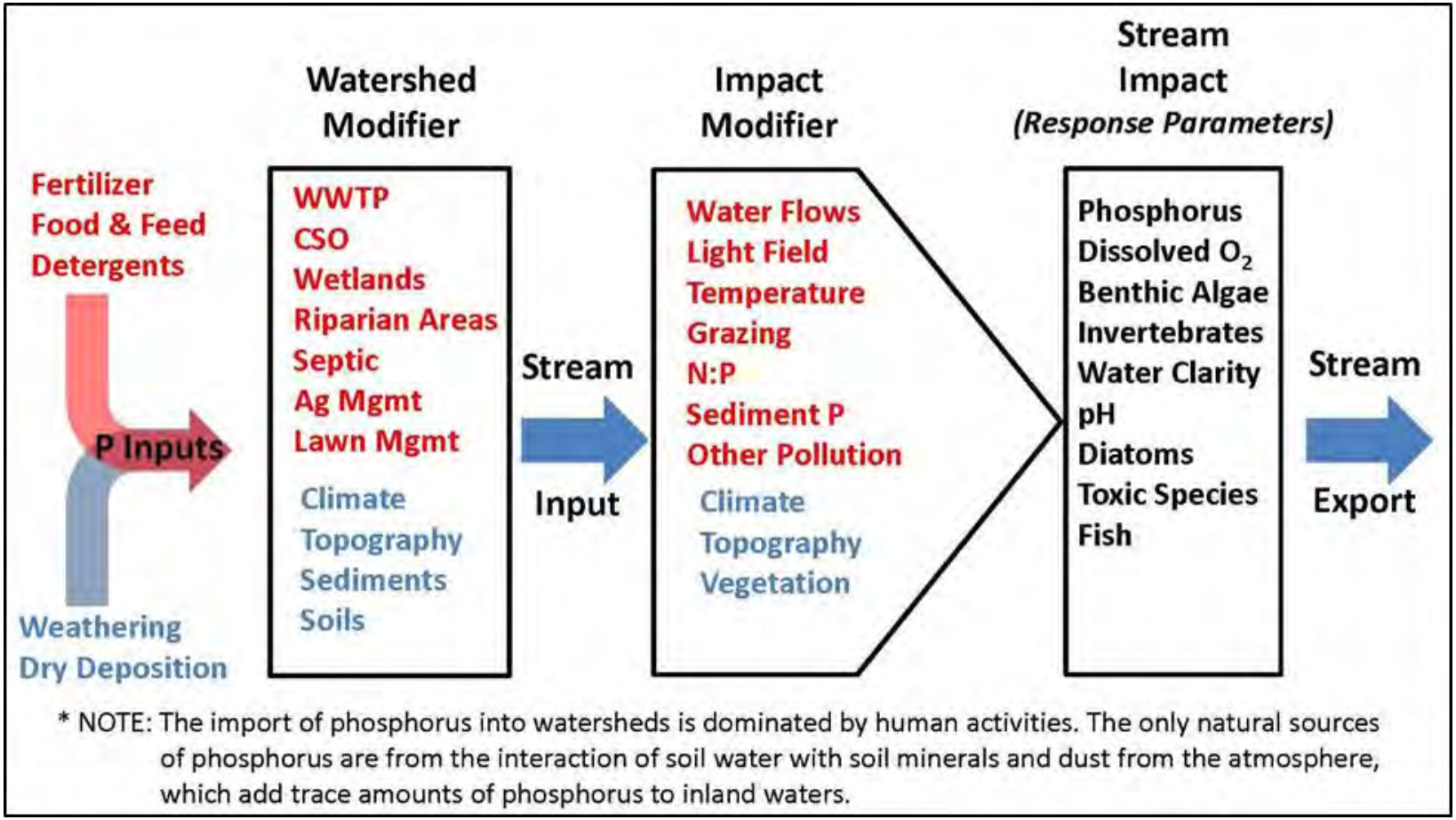


Figure 2-2: Conceptual Model Depicting the Relationship between Sources of Phosphorus and Effects on Aquatic Life and Other Designated Uses in Connecticut

Use of Numeric Standards

- **Difficult for streams and rivers due to the modifiers**
  - **Can be above the limit and not be impaired, or below the limit and be impaired**

With the guidance of EPA states are moving towards response parameters

Conceptual Diagram

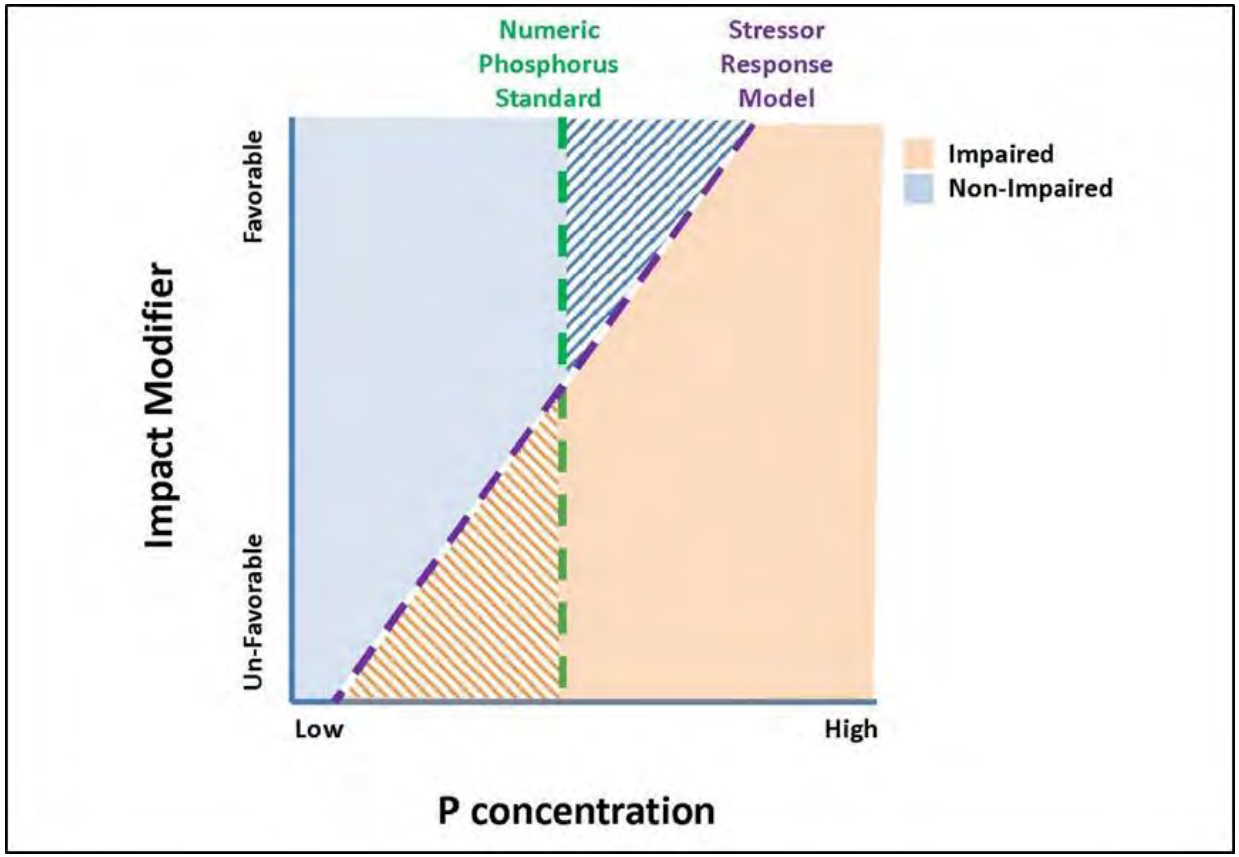


Figure 2-3: A conceptual diagram illustrating the relationship between impact modifiers (y-axis) and numeric standard (dashed green line) and a standard developed using a stressor response model (purple dashed line). A problem with using a single numeric standard arises in some systems with unfavorable impact modifiers that will be falsely deemed non-impaired at concentrations lower than the standards (orange hatches). Also, some systems with favorable impact modifiers will be falsely deemed impaired at moderate phosphorus concentrations (blue hatches)

Task 2

What is Connecticut's current approach to addressing phosphorus to comply with water quality standards?

Existing Regulations

- **Designated uses & narrative nutrient standard**
- **Biological Condition Gradient**
- **Interim Strategy/Standard**

Existing Regulations

- **Designated uses narrative nutrient standard:**
  - **"The loading of nutrients, principally phosphorus and nitrogen, to any surface water body *shall not exceed that which support maintenance or attainment of designated uses*" (CT Water Quality Standards, Section 22a-426-9)**
  - **This statement applies for all classes of inland waters**

Photo Credits: USFWS; JDeeringDavis

Inland Water Classification Designated Uses

- **Class AA**
  - **Designated uses: existing or proposed drinking water supply, fish and wildlife habitat, recreational use (may be restricted,) agricultural and industrial supply.**
  - **Discharges restricted to: discharges from public or private drinking water treatment systems, dredging and dewatering, emergency and clean water discharges.**
- **Class A**
  - **Designated uses: potential drinking water supply; fish and wildlife habitat; recreational use; agricultural and industrial supply and other legitimate uses including navigation.**
  - **Discharges restricted to: same as allowed in AA.**
- **Class B**
  - **Designated uses: recreational use; fish and wildlife habitat; agricultural and industrial supply and other legitimate uses including navigation.**
  - **Discharges restricted to: same as allowed in A and cooling waters, discharges from industrial and municipal wastewater treatment facilities (providing Best Available Treatment and Best Management Practices are applied), and other discharges subject to the provisions of section 22a-430 CGS.**

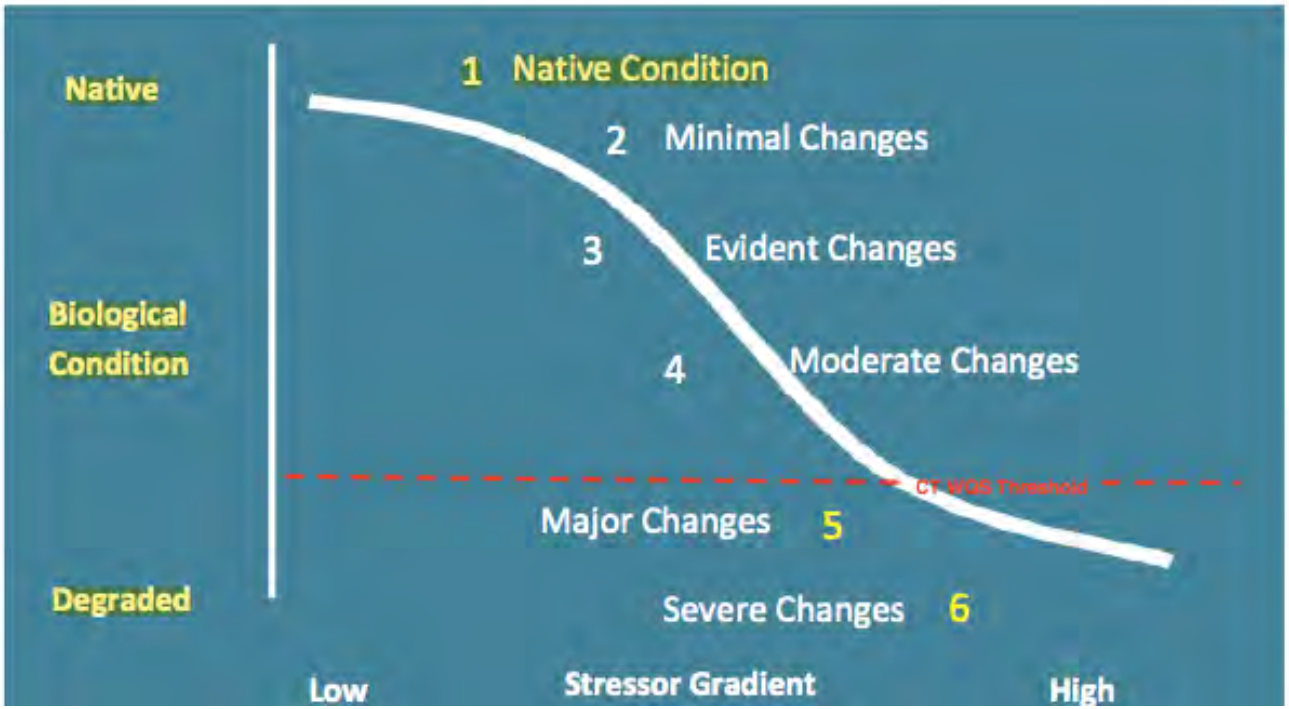
Source: DEEP CT Water Quality Standards and Classifications

CT Consolidated Assessment and Listing Methodology (CALM)

- **To be in compliance with Clean Water Act the stated needs to compile a list of water bodies not meeting standards and prioritize for TMDL**
- **CT publishes and documents its list under CT CALM**
  - **Use an assortment of data types to support assign level of support *(fully supporting, not supporting, insufficient information, or not assessed)***

Biological Condition Gradient (BCG)

- **Biological condition gradient standard:**
  - **"Sustainable, diverse biological communities of indigenous taxa shall be present. Moderate changes, from natural conditions, in the structure of the biological communities, and minimal changes in ecosystem function may be evident; however, *water quality shall be sufficient to sustain a biological condition within the range of Connecticut Biological Condition Gradient Tiers 1-4* as assessed along a 6 tier stressor gradient of Biological Condition Gradient" (CT Water Quality Standards Section 22a-426-9)**



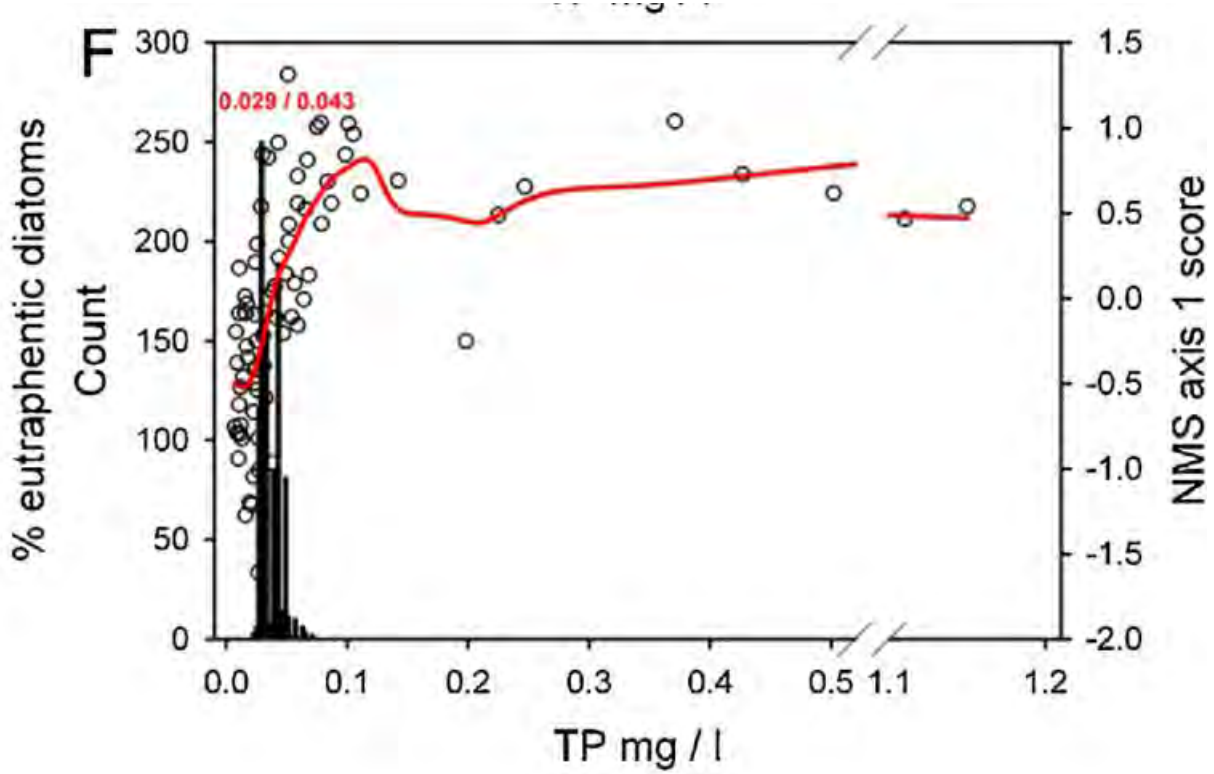
Supporting

Non-Supporting

CT Water Quality Standards: Section 22a-426-5

BCG

- **CT currently recognizes biological communities in its Aquatic Life Use Support (ALUS) as part of the CALM process and has been building a benthic algae community data base to further this effort which is also part of the interim nutrient management strategy**



Smucker, et al. 2013

Threshold Indicator Taxa Analysis

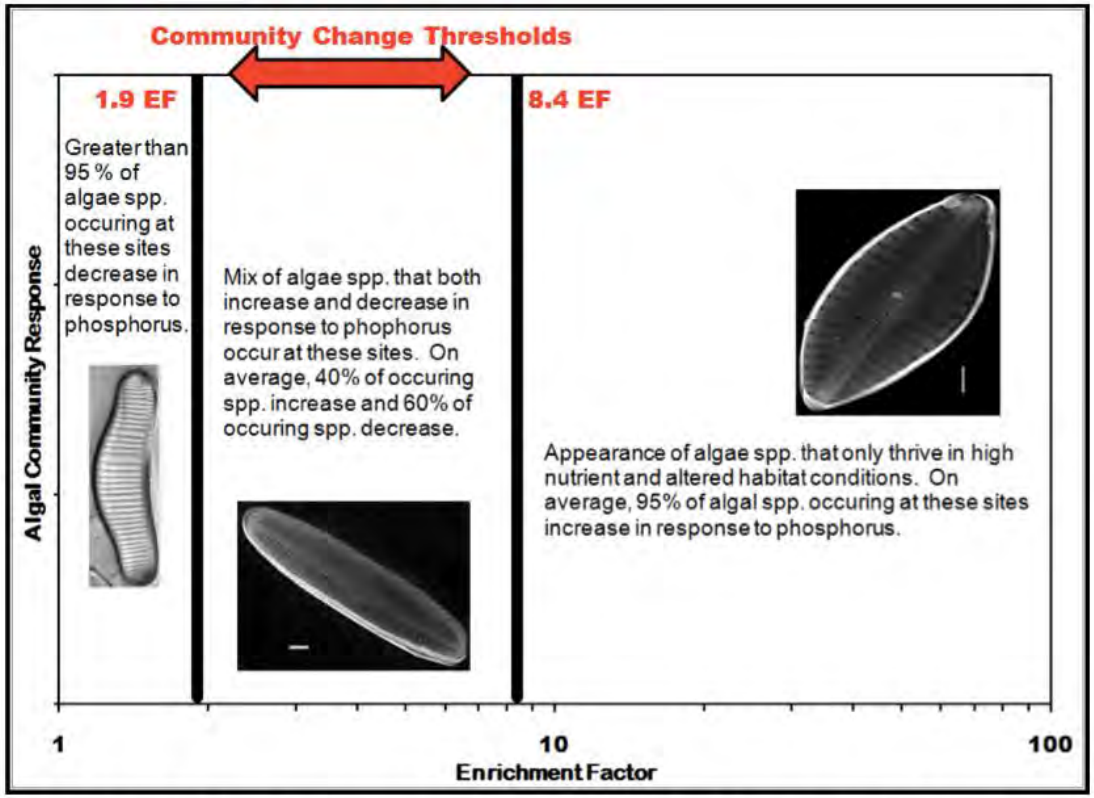


Figure 3. Upper and lower algal community thresholds in response to EF indicated in TITAN analysis

Figure 3-1: Threshold Indicator Taxa Analysis (TITAN) taken directly from the Connecticut Interim Phosphorus Reduction Strategy (Appendix B)

Enrichment Factor = ((Total NPDES Load) + (Land Cover Load))/ (Forested Condition Load) (eq. 1)

Task 3

How can phosphorus impacts be measured in non-tidal waters such that relevant contributing stressors are considered to comply with water quality standards?

EPA Clearly Lays Out Different Methodologies

- Reference stream reaches
- Mechanistic Models
- Stressor-response models
- Scientific Literature Survey

Example for Selecting Reference Values for Total Phosphorus from Stream Phosphorus Measurements

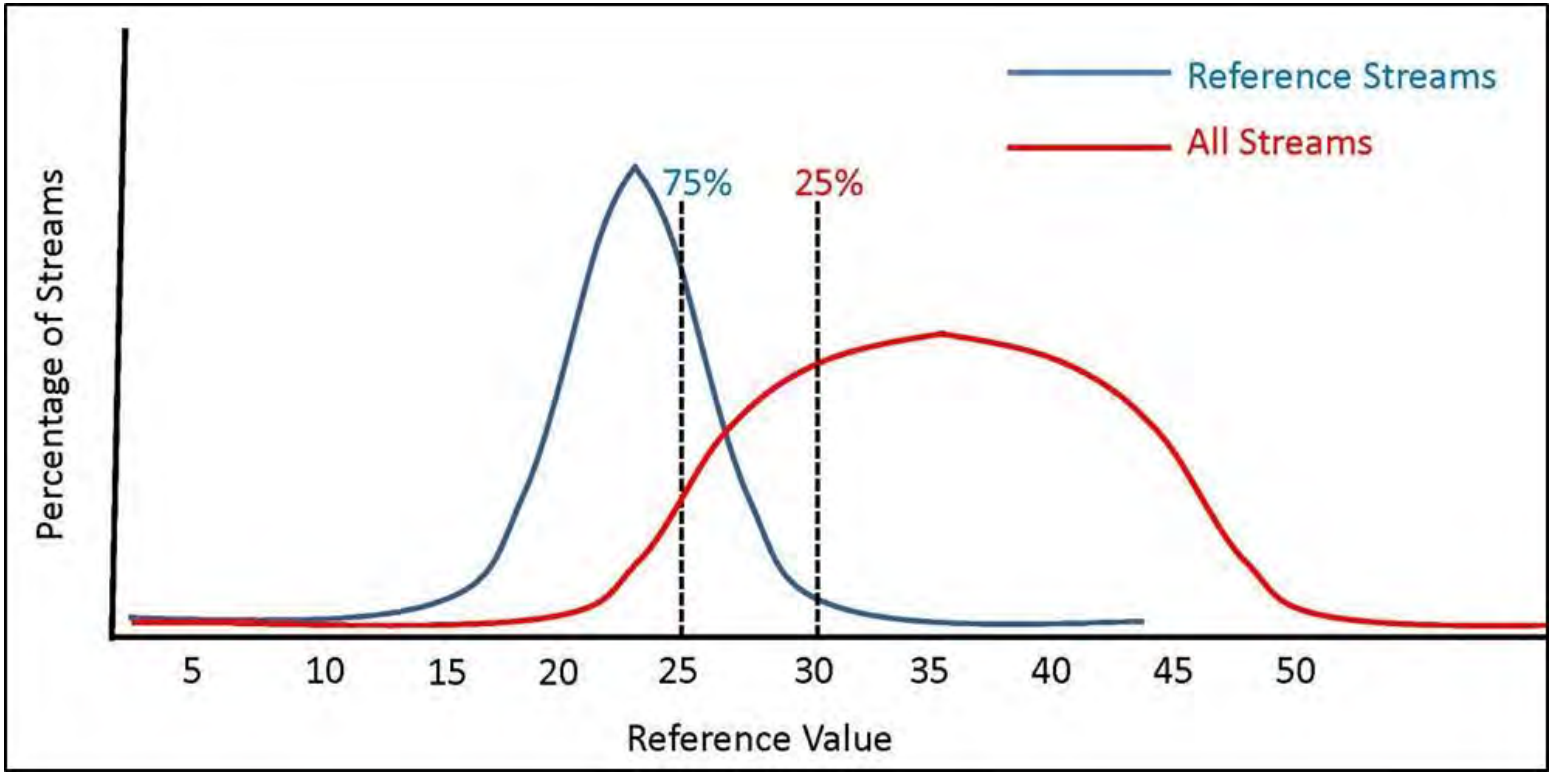


Figure 4-1: An example after (EPA 2000) for selecting reference values for total phosphorus (TP) from stream phosphorus measurements. The x-axis is TP in ug L^{-1}, while the y-axis is percentage of streams in the survey. In the first frequency approach, EPA suggests using the 75th percentile of reference streams. A second frequency distribution uses a percentile (e.g., 25th) from all streams in a class. A state may also look at the TP concentration chosen using both the reference stream and all stream distributions and select an intermediate value.

Rely on concentration

Mechanistic Model

- **Rely on setting a P numeric standard**
- **Relate P concentration with impact**
  - **Can be as simple as a mathematical relationship with a single variable (e.g., chlorophyl)**
  - **Complex as a model with multiple governing equations (e.g., light transmission model, phytoplankton nutrient uptake mdoel) to model a response variable**

Stressor-response Model

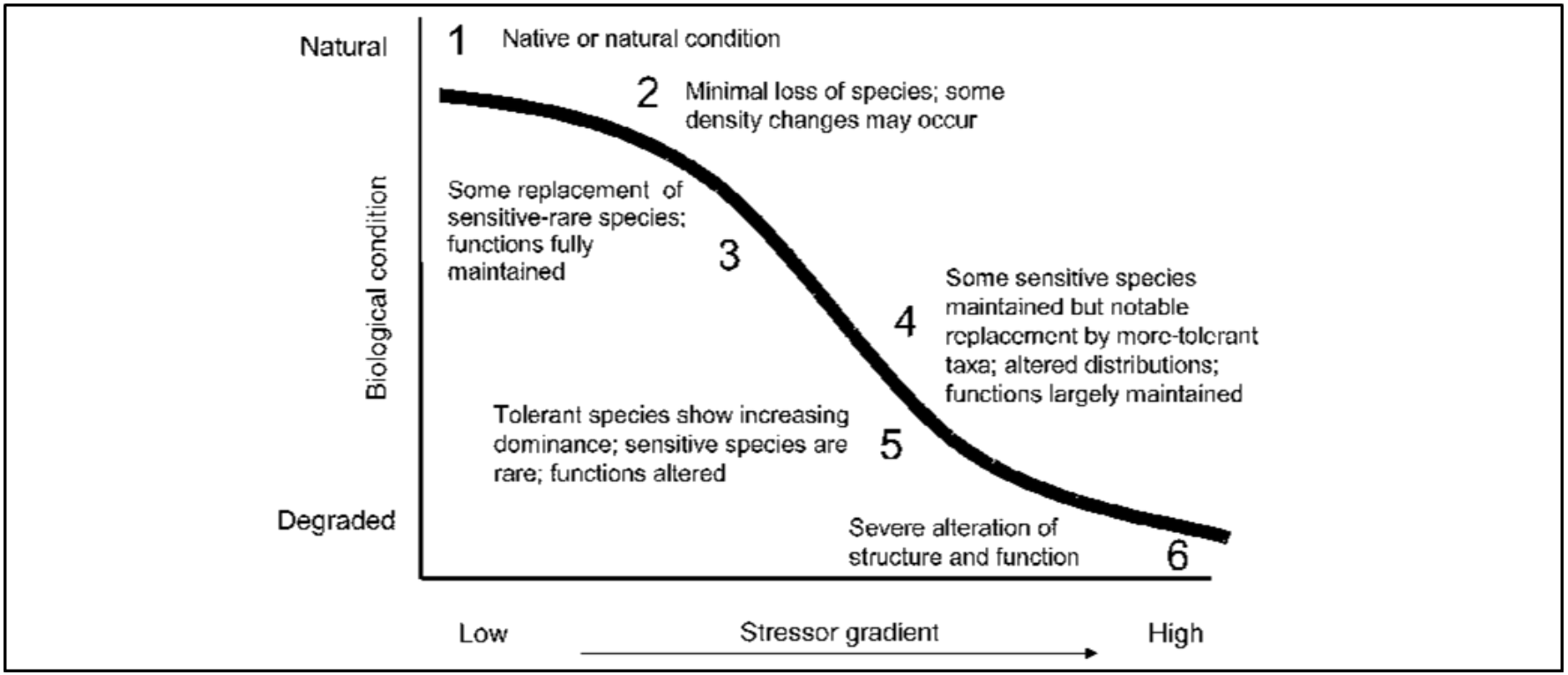


Figure 4-2: Biological Condition Gradient Stressor-response Model
As the stressor increases along the horizontal axis, the biological condition changes from natural to degraded. An expert panel determines the relationship between stressor and biological response that is approximated here by the solid black line (Source: Courtesy of Davis and Jackson, 2006)

Literature Survey Method

- **Rely on setting a numeric standard based on literature values or values set by other neighboring states**

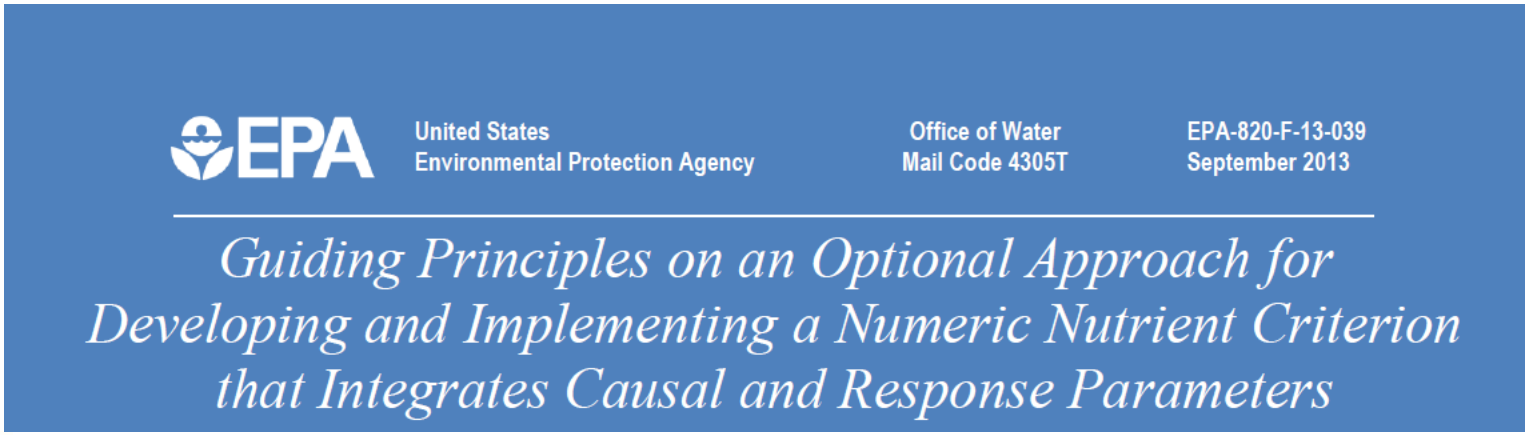
Task 4

What methodologies are appropriate for use in Connecticut to measure phosphorus impacts on water quality and aquatic life and other designated uses?

Recommendations

Recommendations

- **The stressor response model is recommended**
  - **Does not rely directly on P concentration *(uses response parameters)***
  - **Clear EPA guiding document and choice of other states**



Optimization Matrix Used for Ranking Response Parameters

Response Parameters	Strength of Stressor-Response Relationship	Accuracy and Integrative Power	Cost-Effectiveness	Final Ranking
Dissolved Oxygen				
Diatoms				
Algal Biomass – Chl-a				
Phosphorus Concentration				
Macroinvertebrates				
Algal Biomass - AFDM				
% Cover by Nuisance Algae				
Algal Species Composition				
Metabolism				
Toxic Species				
Autotrophic Index				
Algae N:P Stoichiometry				
Macrophytes				
Water Clarity				
Pigment Ratios				
Phosphatase Activity				
Grazers				
Conductivity				
pH				
Fish				
Dissolved Organic Carbon (DOC)				
Temperature				

Recommendation #1

- **Continue using diatom community assemblage as a response parameter, but add diurnal dissolved oxygen**

- **The state should consider partnering with other states for diatom data from other larger streams and rivers and concentrating initial dissolved oxygen data collection on larger streams and rivers**

Recommendation #2

- **Add sites to the state's sampling regime, allowing for further refining criteria via stratification/classification**

- **A large number of sites are needed for stratification and classification of landscape variables such as ecological health (e.g., BCG tiers), geology, stream size or residence time that might allow for better protection of streams and rivers in the future**

Recommendation #3

- **Consider using diatom data and newly collected dissolved oxygen data to develop response parameter standards in addition to numeric criteria standards to allow for a decision framework approach**

Recommendation #3

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 has reasonable potential[45] to produce a phosphorus concentration above the criterion value, then annual 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. Annual 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 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. Annual 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.

Recommendation #4

- **Develop a stratification/classification system**
- **Future efforts need to focus on collecting enough data to determine if stratification based on river size (i.e.,wadeable/nonwadeable) is needed, as there are initial indications that river size influences the diatom community**
- **One potential method is to stratify based on stream order or systems that are seston (suspended matter) or benthic dominated**
- **The state also needs to stratify and set standards that will protect the degradation of healthy streams. This should be done by further stratification under the already established BCG tier system**
- **Standards should be considered for each BCG tier. Possible ways to do this may be stratifying by land use, ecological health (e.g, macroinvertebrate indices - MMI), or the already established enrichment factor**

Recommendation #5

- **Pursue and collect a set of secondary measurements that will further help isolate phosphorus as the cause of impact and potentially help with the stratification process**

- **These measurements are discussed in greater detail in the "Recommendation Details" sub-section of this section of the report**

Recommendation #6

- **Statistical analysis of data to relate response parameters to phosphorus concentrations should be conducted on a rolling basis and reported to the general public**
- **As additional data are collected, the type of statistical analysis applicable and the power of the statistical test chosen may change**
- **The scientific literature is also constantly critiquing and improving statistical methods used for community analysis, and this will allow for the adoption of the most appropriate methods**

Recommendation #7

- **Consider collaborating with neighboring states that use diatoms and dissolved oxygen**
- **Currently each state pursues its own analysis, but multi-state analysis (e.g., EPA Ecoregions) would increase the power of statistical analysis and might provide further insights about the linkage between the diatom community composition and dissolved oxygen or nutrients**
- **States might find it necessary to standardize methods to enable data sharing in the future**

Recommendation #8

- **For impaired watersheds, continue and accelerate the process of creating stream management plans similar to those in the CT IWQR, incorporating these plans into a GIS, and perform response parameter measurements more frequently**
- **An example of stream management plans is the New York City Department of Environmental Protection's efforts for New York City drinking water watersheds (*http://www.catskillstreams.org/Schoharie_Creek_Management_Plan.html*)**

Recommendation #9

- **Begin to collect data on phosphorus import into watersheds and consider collecting additional economic/recreational use data. These are described in more detail in the "Recommendation Details" section of this section of the report.**

Implementation Strategy

Implementation Strategy

- **Utilize new oxygen optodes, which have made the accurate measurement of dissolved oxygen during multi-day deployments possible at a relatively low cost. The diurnal (24-hour period) change in dissolved oxygen offers enough complementary information for it to be incorporated into the current DEEP sampling scheme. A potential strategy would be to place the probes at each site a few days prior to visiting for the involved sampling of variables already measured by the state.**
- **In addition to including dissolved oxygen in the current rotation of sites, DEEP should consider more frequent measurements of response indicators at phosphorus-impacted sites in order to ascertain when an acceptable level of phosphorus abatement has been achieved. This will be particularly pertinent if the response variables are incorporated into a decision framework.**
- **DEEP should strive to increase the number of sites within their database by increasing the number of sites visited, or partnering with neighboring states that already have an active program with similar measurements.**

Implementation Strategy

- **Similar to current practices, a greater percentage of the measurements should be performed in the summer when impacts are greatest. Shoulder season measurements, however, still provide data needed to ascertain range of conditions.**

- **During the next five years, progress on recommendations #5 and #8 can be pursued.**

- **In 3-5 years DEEP should re-evaluate the Interim Strategy depending on the status of the data sets. A new statistical analysis of the data should be pursued with the new, larger data set. This new analysis would be able to determine if sites need to be classified based on landscape variables such as land use, geology or stream size. At this point dissolved oxygen data could be incorporated and the larger data set could be used to create a decision framework (Table 5-3). It is reasonable to expect this re-evaluation to reoccur every 3-5 years.**

- **Finally, during this period, the state should consider mechanisms to facilitate the data collection necessary for recommendation #9.**

Recommendation Details

Other Details

- **Collect suite of secondary measurements (e.g., conductivity and temperature)**
- **Collect human use data to facilitate economic analysis**
- **Collect data on P import into watersheds**

Thank You

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