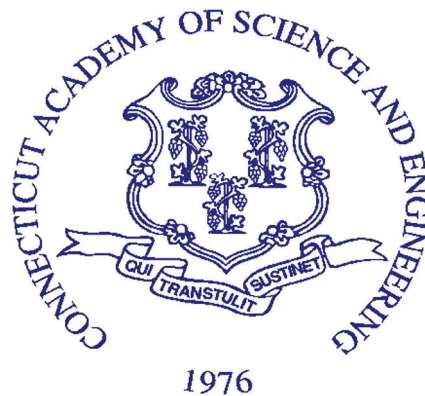


**METHODS TO
MEASURE PHOSPHORUS AND
MAKE FUTURE PROJECTIONS**

DECEMBER 2014

A REPORT BY

**THE CONNECTICUT
ACADEMY OF SCIENCE
AND ENGINEERING**



FOR

**THE CONNECTICUT DEPARTMENT OF
ENERGY AND ENVIRONMENTAL PROTECTION**

METHODS TO MEASURE PHOSPHORUS AND MAKE FUTURE PROJECTIONS

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ORIGIN OF INQUIRY: THE CONNECTICUT DEPARTMENT OF
ENERGY AND ENVIRONMENTAL
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This study was initiated at the request of the Connecticut Department of Energy and Environmental Protection on November 12, 2013. The project was conducted by an Academy Study Committee with the support of Peter A. Raymond, PhD, Study Manager. The content of this report lies within the province of the Academy's Environment Technical Board. The report has been reviewed by Academy Members Senjie Lin, PhD, and Sten Caspersson. Martha Sherman, the Academy's managing editor, edited the report. The report is hereby released with the approval of the Academy Council.

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LIST OF ACRONYMS

AFDM	Ash-Free Dry Mass
ATP	Adenosine Triphosphate
BCG	Biological Condition Gradient
BMP	Best Management Practice
CALM	Consolidated Assessment and Listing Methodology
CGS	Connecticut General Statutes
Chl-a	Chlorophyll-a
CO ₂	Carbon Dioxide
CT WQS	Connecticut Water Quality Standards
DEEP	Connecticut Department of Energy and Environmental Protection
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EF	Enrichment Factor
EPA	US Environmental Protection Agency
CT IWQR	Connecticut Integrated Water Quality Report
MMI	Multi-Metric Index
N	Nitrogen
NPDES	National Pollutant Discharge Elimination System
O ₂	Oxygen
pH	A measure of acidity or alkalinity of a substance
QAPP	Quality Assurance Project Plan
TDI	Trophic Diatom Index
TITAN	Threshold Indicator Taxa Analysis
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
WQS	Water Quality Standards
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

BACKGROUND

Public Act No. 12-155, An Act Concerning Phosphorous Reduction in State Waters, sets forth a process for making recommendations regarding a statewide strategy to reduce phosphorus loading in inland, non-tidal waters to comply with US Environmental Protection Agency (EPA) standards.

The Connecticut Department of Energy and Environmental Protection (DEEP) established working groups and a coordinating committee to address the issues mandated by this legislation. Three working groups were charged with formulating recommendations for the purpose of policy development: Working Group #1: Statewide Response to Phosphorus Non-point Pollution; Working Group #2: Methods to Measure Phosphorus and Make Future Projections; and Working Group #3: Municipal Options for Coming into Compliance with Water Quality Standards. The overarching Coordinating Committee comprises the co-chairs of the three working groups with oversight by a DEEP deputy commissioner and a representative from a Connecticut town. The Coordinating Committee was tasked with guiding the project, with responsibility for overall direction and timing, and addressing cross-cutting issues.

At the request of DEEP, the Connecticut Academy of Science and Engineering (CASE) was engaged to conduct a study of specified tasks regarding the science involved and to make recommendations for the development of methods to measure phosphorus and make future projections for the consideration of Working Group #2.

OBJECTIVE

The overall objective of this study was to meet the legislative intent of Public Act 12-155, which 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. 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.

TASKS

This study focused on conducting research on the following tasks for the purpose of developing recommendations, for consideration of Working Group #2, and the overall project, for setting phosphorus goals:

- 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?

Study research included a comprehensive literature review and interviews, as well as guest speaker presentations to the CASE Study Committee. Additionally, members of Working Group #2 were invited to attend and participate in CASE Study Committee meetings and were provided with an opportunity to comment on the draft study report. This report was provided to Working Group #2 for the state's consideration in establishing site-specific phosphorus goals for Connecticut's streams and rivers.

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 (including, but not limited to, riparian areas, temperature, water flow, topography, vegetation, sediments, and soils) will likely affect the degree of impact/impairment of the phosphorus on the stream or river. The 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 (segment) 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.

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. According to the EPA, 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; the EPA has recently documented an approach that allows for the direct utilization of response parameters as criteria.

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 Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams (Interim Strategy) (see Appendix B) derived therefrom while continuing to collect data to implement this report's recommendations.

The strength of this approach requires a significant amount of data. The state should continue sampling the diatom community and add diurnal dissolved oxygen measurements. These measurements are deemed complementary. 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, with statistical methods used to derive numeric criteria improving over time and with new data as well as scientific and methodological improvements, DEEP should re-evaluate its approach every 3–5 years in a manner that is transparent to all stakeholders.

RECOMMENDATIONS

The following are recommendations for the state's consideration:

1. Continue sampling diatom community assemblage, but add diurnal dissolved oxygen. As presented above, these response parameters are complementary and new dissolved oxygen sensors are highly accurate and relatively cost effective. 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.
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., Biological Condition Gradient (BCG) tiers), geology, stream size or residence time that might allow for better protection of streams and rivers in the future.
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 (See Table 5-3).
4. Develop a stratification/classification system. In particular, the DEEP Interim Strategy (Appendix B) was created for freshwater, non-tidal, waste-receiving rivers and streams, but the diatom analysis was done mostly using data from small streams (Smucker et al., 2013b). 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 (Charles et al., 2010). 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. That is, 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 - Multi-Metric Index [MMI]), or the already established enrichment factor.

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 section (Section 5.3.2) of the report.
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 (e.g., Cuffney and Qian, 2013; Juggins et al., 2013; Baker and King, 2013), and this will allow for the adoption of the most appropriate methods.
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.
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. Stream management plans provide a comprehensive overview of stream characteristics and recommended management strategies. Given the findings in Connecticut and New Jersey that phosphorus impairment is most strongly linked to urban and agricultural land cover and that riparian buffers can modify phosphorus impairment (Charles et al., 2010; Smucker et al., 2013b), management plans would need to focus heavily on the potential impairment from urban and agricultural practices and detail the status of riparian buffers. Having a more detailed understanding of stream reaches will increase the portfolio of options for remediation. The detailed mapping of stream characteristics (e.g., physical characteristics, riparian vegetation) for stream management plans will also benefit efforts to stratify streams when creating criteria, although this will require documenting the plans in GIS and creating variables from the plans for use in statistical analysis.
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 (Section 5.3.2) of the report.

Additional details regarding these recommendations are provided in Section 5.3.2, including Secondary Measurements (Section 5.3.2.1), Economic Approaches (Section 5.3.2.2), and The Import of Phosphorus to Watersheds (Section 5.3.2.3).

Implementation Strategy

As mentioned, the CASE Study Committee deems that the DEEP Interim Strategy (Appendix B) was justified. Although there were some questions with the TITAN model (Cuffney and Qian, 2013), these questions have been addressed in the scientific literature (Baker and King, 2013). Furthermore, when performing the statistical analysis for Connecticut, Smucker et al. (2013) used approaches other than TITAN to evaluate changes in phosphorus concentration

and diatom communities. The approach taken by the state aligns with the guidance provided by the EPA. Thus the Interim Strategy was a reasonable and justified approach for setting numeric criteria. That said, this is still a rapidly evolving area of scientific inquiry. The statistical methods used to derive numeric criteria will continue to improve with time and new data. Furthermore, the response parameters used to set criteria will also change with scientific and methodological advancements. Finally, response variables can also now be used directly in decision making which overcomes some of the problems associated with the standard set using statistical methods.

The proposed set of recommendations should be pursued by the state over the next 3-5 years with the following considerations:

- 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 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.
- 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 occur every 3 to 5 years.
- Finally, during this period, the state should consider mechanisms to facilitate the data collection necessary for recommendation #9.

1.0 INTRODUCTION

1.1 BACKGROUND

Public Act No. 12-155, An Act Concerning Phosphorous Reduction in State Waters, sets forth a process for making recommendations regarding a statewide strategy to reduce phosphorus loading in inland non-tidal waters to comply with US Environmental Protection Agency (EPA) standards. Section 1 of this Act states:

The Commissioner of Energy and Environmental Protection, or the commissioner's designee and the chief elected officials of the cities of Danbury, Meriden and Waterbury and the towns of Cheshire, Southington and Wallingford, and the chief elected official of any other municipality impacted by the statewide strategy to reduce phosphorus, or such chief elected officials' designees, shall collaboratively evaluate and make recommendations regarding a statewide strategy to reduce phosphorus loading in inland non-tidal waters in order to comply with standards established by the United States Environmental Protection Agency. Such evaluation and recommendations shall include (1) a statewide response to address phosphorus nonpoint source pollution, (2) approaches for municipalities to use in order to comply with standards established by the United States Environmental Protection Agency for phosphorus, including guidance for treatment and potential plant upgrades, and (3) the proper scientific methods by which to measure current phosphorous levels in inland non-tidal waters and to make future projections of phosphorous levels in such waters.

The Connecticut Department of Energy and Environmental Protection (DEEP) established working groups and a coordinating committee to address the issues mandated by this legislation. The following three working groups were charged with formulating recommendations for the purpose of policy development:

- Working Group #1: Statewide Response to Phosphorus Non-point Pollution
- Working Group #2: Methods to Measure Phosphorus and Make Future Projections
- Working Group #3: Municipal Options for Coming into Compliance with Water Quality Standards

The overarching Coordinating Committee comprises the co-chairs of the three working groups with oversight by a DEEP deputy commissioner and a representative from a Connecticut town. The Coordinating Committee was tasked with guiding the project, with responsibility for overall direction and timing, and addressing cross-cutting issues.

At the request of DEEP, the Connecticut Academy of Science and Engineering (CASE) was engaged to conduct a study of specified tasks regarding the science involved and to make recommendations for the development of methods to measure phosphorus and make future projections for the consideration of Working Group #2.

1.2 STUDY DESCRIPTION

1.2.1 Objective

The overall objective of this study was to meet the legislative intent of Public Act 12-155, which was to conduct an evaluation and develop recommendations to determine the scientific methods by which to measure the impacts of phosphorus pollution in inland non-tidal waters. 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. It is generally accepted in the literature and in practice that it is more straightforward to set standards and measure phosphorus impacts in lakes and reservoirs than in streams and rivers. Research conducted over decades has demonstrated clear correlations between phosphorus loadings and simple response variables, such as chlorophyll (Vollenweider, 1976; Hecky and Kilham, 1988). Thus, 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. Therefore, this study focused exclusively on the methods for measuring phosphorus in streams and rivers.

1.2.2 Tasks

This study focused on conducting research on the following tasks for the purpose of developing recommendations, for consideration of Working Group #2, and the overall project, for setting phosphorus goals:

- 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?

1.2.3 Study Committee Activities and Research Methodology

The CASE Study Committee met periodically throughout the study process to provide input on draft sections of the study report; provide guidance on issues identified throughout the research phase of the project; develop study recommendations; and hear from experts as guest speakers on the study topics.

The following is a list of presentations provided to the study committee by guest speakers:

- Mary Becker, Environmental Analyst 3, DEEP, and Co-Chair, Working Group #2; Topic: DEEP Phosphorus Project Overview

- Warren Kimball, Watershed Program Manager, Massachusetts Department of Environmental Protection: Massachusetts; Topic: Massachusetts Nutrient Management Framework
- Ralph Abele, Acting Chief, Water Quality Branch and Dave Pincumbe, Environmental Engineer, NPDES, EPA – Region 1; Topic: Nutrient Limits – EPA Region 1
- DEEP Phosphorus Study – Working Group #1 and Working Group #3 Updates
 - Working Group 1: Christopher Malik, Environmental Analyst, Watershed and Non-Point Sources, DEEP and Co-Chair Working Group 1; Topic: State-wide Response to Phosphorus Nonpoint Pollution
 - Working Group 3: Rowland Denny, Senior Sanitary Engineer, DEEP, and Co-Chair Working Group #3; Topic: Municipal Options
- Jeroen Gerritsen, Principal Scientist and Michael Paul, Principal Scientist, Tetra Tech, Inc.: Biological Condition Gradient; Topic: Partitioning Causation of Confounding Variables
- Mike Suplee, PhD, Environmental Science Specialist, Montana Department of Environmental Quality; Topic: Montana’s Approach to Phosphorus: Combined Criteria Implementation Scheme
- Thomas J. Danielson, PhD, Biologist, Maine Department of Environmental Protection; Topic: Maine’s Approach to Phosphorus: Combined Criteria Implementation Scheme
- David Keiser, Yale University and Member, CASE Study Committee; Topic: An Economics Approach to Measuring the Impacts from Phosphorus

Study research included a comprehensive literature review and interviews, as well as guest speaker presentations to the CASE study committee. Additionally, members of Working Group #2 were invited to attend and participate in CASE study committee meetings and were provided with an opportunity to comment on the draft study report.

This report was provided to Working Group #2 for the state’s consideration in establishing site-specific phosphorus goals for Connecticut’s streams and rivers.

1.3 REFERENCES

Hecky, R.E. and Kilham, P. (1988). Nutrient limitation of phytoplankton in fresh-water and marine environments - a review of recent-evidence on the effects of enrichment. *Limnology and Oceanography* 33, 796-822.

Vollenweider, R.A. (1976). Advances in defining critical loading levels for phosphorus in lake eutrophication. *Memorie dell’Istituto Italiano di Idrobiologia* 33, 53-83.

2.0 TASK 1

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

- a. Develop a conceptual model diagram that graphically depicts the relationship between sources of phosphorus and effects on aquatic life and other designated uses.
- b. Provide an explanation of other stressors that may contribute to eutrophication and impairment of aquatic life uses and other designated uses and describe the relative importance of excessive phosphorus to impairment of such uses.

Low concentration of phosphorus in inland waters (lakes, reservoirs, streams and rivers) often limits plant growth (Correll, 1998). Plants need certain elements, like phosphorus, to build their biomass and phosphorus is present in high quantities in plant biomass as RNA and DNA and the central building block of adenosine triphosphate (ATP), one of the most abundant coenzymes in animal and plant cells.

In waters undisturbed by human activity, phosphorus concentrations are low enough that the ability of aquatic plants and algae to grow is often limited by the availability of phosphorus. Similarly, because phosphorus can be a limiting nutrient in backyard gardens, it is a main ingredient in many garden plant fertilizers.

Human activities that add phosphorus to inland waters either directly from point sources or indirectly through non-point sources can cause increased aquatic plant life growth. Levels of plant biomass can be so high due to human-added, limited nutrients such as phosphorus, that inland waters become impaired due to a process known as eutrophication, described in more detail as follows (Figure 2-1).



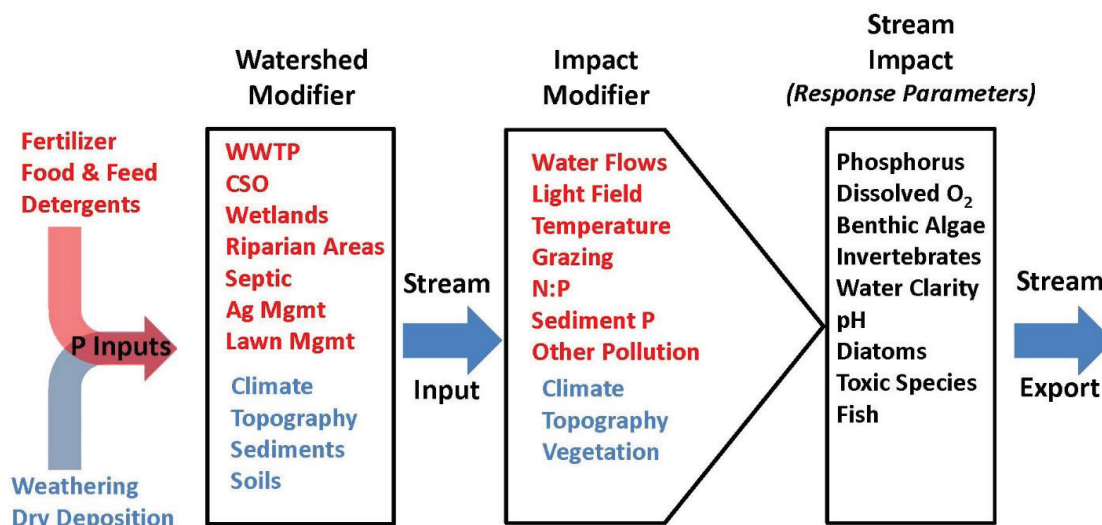
FIGURE 2-1: EXAMPLES OF STREAMS MINIMALLY (LEFT PHOTOS) AND HEAVILY IMPACTED BY PHOSPHORUS (RIGHT PHOTOS); SOURCES: BIOLOGICAL MONITORING PROGRAM, MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION (TOP LEFT AND TOP RIGHT PHOTOS); DEEP (BOTTOM LEFT AND BOTTOM RIGHT PHOTOS)

Human-induced additions of phosphorus to inland waters is one of the leading causes of stream impairment in the United States and globally. A report two decades ago stated that eutrophication accounted for approximately 50% of impaired lake area and up to 60% of impaired river lengths in the United States (EPA, 1996). A more recent assessment found that 25% of stream miles were in fair condition and 42% in poor condition (based on level of disturbance compared to reference sites), and that phosphorus is one of the main stressors, or pollutants, leading to stream damage (EPA, 2013).

Phosphorus pollution can cause fluctuations in the overall productivity of an ecosystem, and alterations to the biomass and composition of shellfish, aquatic plants, algae, and fish, such as desirable finfish species (Dodds and Welch, 2000; Smith, 2003). The changes in algal species due to phosphorus additions to inland waters can also lead to the proliferation of harmful, or toxic species, such as certain cyanobacteria (Downing et al., 2001). Changes in the overall abundance of algal and macrophyte biomass can also impact the filtering capacity of water treatment facilities (EPA, 2000). The structure and chemistry of inland waters are also altered from phosphorus additions, including changes in water transparency, odor, pH, and dissolved oxygen (Smith, 2003). Collectively these alterations can further threaten endangered species and impact the food production and breeding habitats for a wide range of animal and plant species (Carpenter et al., 1998; Mainstone and Parr, 2002). These impacts are all directly relevant to the designated uses outlined in the Connecticut Water Quality Standards (CT WQS) (See Section 3).

Eutrophication can also impact recreational use, as described in the CT WQS, and the economy. Recreational use impairments due to phosphorus additions and resulting eutrophication include decreases in boating, fishing, and swimming opportunities. Other possible economic impacts include decreases in property values, increases in the cost of drinking water treatment due to the production of suspended matter and disinfection by-products, and increases in human health costs (Dodds et al., 2009). These costs have been assessed at \$2.2 billion per year for the United States, with changes in recreational use, drinking water treatment, and water front property leading to the greatest economic loss (Dodds et al., 2009). Perceptions of the risk to human health from harmful algal blooms can also impose economic costs and affect recreational usage (Hunter et al., 2012).

The import of phosphorus into watersheds is dominated by human activities. The only natural source of phosphorus is from the interaction of water with soils, which adds trace amounts of phosphorus to inland waters. The main pathways for phosphorus to enter a watershed are through fertilizer, food for people and pets, and detergents and soaps (Figure 2-2). A recently recognized source of bioavailable phosphorus is organophosphate from herbicides and insecticides (Saxton et al., 2011). Many processes (denoted “Watershed Modifier” on Figure 2-2) can reduce or remove phosphorus before it reaches a water body. The main removal mechanisms, or modifiers, are listed in Figure 2-2 and described in more detail in Appendix A. Some modifiers, such as sediments, may remove phosphorus for a period of time and release it during different seasons or years due to changing environmental conditions. Others, such as wastewater treatment plants, can be responsible for cross-watershed transfers of phosphorus. Studies on the Chesapeake Bay have estimated that less than 10% of the phosphorus entering the watershed through food, feed, fertilizer and detergents makes it to streams and enters the Bay (Russell et al., 2008). Thus, these watershed modifiers provide an important service to inland waters by removing phosphorus. Some of these modifiers are actively managed by humans (Figure 2-2 - listed in red) and therefore can be impacted by policy intervention. Areas in which policy interventions can have impact include agricultural and lawn management, the extent of healthy wetlands and riparian zones, the amount of impervious cover, the type of wastewater treatment, the degree of combined sewer overflow, and the relative state of septic tanks and wastewater pipes (Figure 2-2 and Appendix A). There are also a number of modifiers less directly impacted by humans such as climate, topography, and the type of soils that can impact the overall efficacy of the watershed modifier (Figure 2-2). For example, the same agricultural management practices when applied in areas of steep compared to flat topography may be less effective at keeping phosphorus out of streams.



* NOTE: The import of phosphorus into watersheds is dominated by human activities. The only natural sources of phosphorus are from the interaction of soil water with soil minerals and dust from the atmosphere, which add trace amounts of phosphorus to inland waters.

FIGURE 2-2: CONCEPTUAL MODEL DEPICTING THE RELATIONSHIP BETWEEN SOURCES OF PHOSPHORUS AND EFFECTS ON AQUATIC LIFE AND OTHER DESIGNATED USES IN CONNECTICUT

A combination of the amount of phosphorus added to the watershed and the effectiveness of the watershed modifier determines the amount of phosphorus entering inland waters (arrow denoted “Stream Input”). Not all inland waters that receive phosphorus loadings, however, become impaired (See Figure 2-3). Whether or not a water body becomes phosphorus impaired is also dependent on characteristics of the water body, or impact modifiers (Figure 2-2). Thus, there is a second set of modifiers that determines if phosphorus impairment will occur. The characteristics of these impact modifiers are described in more detail in Appendix A. These modifiers are important because their presence can lead to a large variation between the amount of phosphorus entering inland waters and the degree of impairment for any given stream length. This type of variation makes setting a single numerical phosphorus standard, or concentration, problematic (Figure 2-3) and is a reason why states are moving towards other options, like the Biological Condition Gradient (See Section 4), that measure response parameters of the impairment (Figure 2-3). For example, two streams with similar nutrient loadings but significant differences in the amount of light exposure can have disparate levels of impairment (Dodds, 2006). A stream with high nutrient loadings and high levels of light due to the loss of the riparian zone would fall into the unfavorable category as shown in Figure 2-3. However, a neighboring stream with an intact riparian zone and closed canopy that shades the stream might fall into favorable category, as shown in Figure 2-3. Thus, the impact modifiers (Figure 2-2) also offer a number of opportunities for mitigating impacts caused by phosphorus additions. Continuing the light example, the re-introduction of a canopy to decrease light levels could alleviate the eutrophication response to phosphorus for a given stream length in some instances.

Other forms of pollution can impact stream health and impact designated uses. Examples of other pollutants include nitrogen, pesticides, and pharmaceuticals. Some of these might

interact with modifiers listed in Figure 2-2. Nitrogen pollution, for instance, can sometimes be the primary control on eutrophication in inland waters, or can interact with phosphorus through the Nitrogen:Phosphorus (N:P) ratio and nitrogen-fixing bacteria to control the level of eutrophication (Schindler, 2006). Thus, when attempting to manage and mitigate the impacts of phosphorus additions, it is important to select response parameters that can measure the impacts most directly caused by phosphorus additions and have small interactions with other pollutants. This process and response parameters in general will be discussed in greater detail in Task 2 and Task 3 of this report.

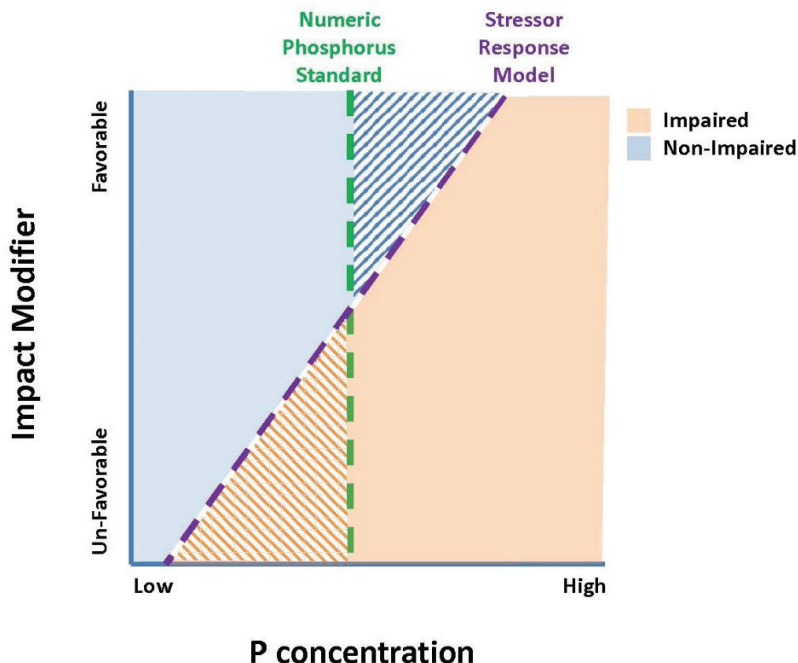


FIGURE 2-3: A CONCEPTUAL DIAGRAM ILLUSTRATING THE RELATIONSHIP BETWEEN IMPACT MODIFIERS (Y-AXIS) AND NUMERIC STANDARD (DASHED GREEN LINE) AND A STANDARD DEVELOPED USING A STRESSOR RESPONSE MODEL (PURPLE DASHED LINE). A PROBLEM WITH USING A SINGLE NUMERIC STANDARD ARISES IN SOME SYSTEMS WITH UNFAVORABLE 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).

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3.0 TASK 2

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

- a. Identify relevant Connecticut Water Quality Standards, such the narrative phosphorus standard and narrative biological condition gradient.
- b. Explain the aquatic life assessment methodology process in CT CALM and how it relates to the narrative biological condition standard. Identify elements of the methodology that may be related to phosphorus.
- c. Provide an overview of the Connecticut Statewide Phosphorus Strategy for Non-Tidal Waste-Receiving Streams

3.1 INTRODUCTION TO CONNECTICUT WATER QUALITY REGULATIONS

Connecticut's surface Water Quality Standards (WQS) were initially developed in 1967. Today, these standards set the overall policy for the state's management of surface and ground water quality in accordance with federal and state clean water programs. Connecticut's surface WQS are required by and consistent with Section 303(c) of the federal Clean Water Act, and address the standards and criteria necessary to support designated uses of Connecticut's surface waters. Since their development in 1967, the standards have been revised many times, and in 2013 the DEEP commissioner codified Connecticut's established WQS into regulations – the Regulations of Connecticut State Agencies Sections 22a-426-1 to 22a-426-9, inclusive.

The CT WQS consist of three elements: the Standards, the Criteria, and a series of Classification Maps.

- The Standards (See Section 3.2; A & B) designate use goals and set the overall policy for management of surface and ground water quality.
- The CT WQS contain narrative and numeric criteria (see Section 3.2; C) that prescribe the allowable parameters and conditions for various water quality classifications required to sustain the designated uses. A numeric criterion defines a precise measurable value for a given metric that is allowable in inland waters (e.g., the maximum allowable concentration of phosphorus), while a narrative criterion describes the desired water quality goal (e.g., phosphorus levels should maintain aquatic life uses).
- The Classification Maps show the water quality class assigned to each surface and ground water resource throughout the state.

3.2 CONNECTICUT WATER QUALITY STANDARDS THAT RELATE TO PHOSPHORUS MANAGEMENT

- A. This report highlights the CT WQS that are most explicitly relevant to the management and regulation of phosphorus in inland surface waters, and should be considered in the development of numeric phosphorus criteria. For a complete list of relevant standards, the CT WQS (Section 22a-426-1 through 9) should be reviewed and referenced in full.

Section 22a-426-3 (a) Purpose and Goals

The purpose of the CT WQS, in addition to the statutory purposes, is to

- (1) provide clear and objective statements for existing and projected water quality and the general program to improve Connecticut's water resources;
- (2) provide water quality for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water, taking into consideration the use and value for public water supplies, propagation of fish, shellfish and wildlife, recreation in and on the water and agricultural, industrial and other purposes including navigation, wherever attainable;
- (3) recognize that surface and groundwater are interrelated and address the issue of competing uses of groundwater for drinking and for wastewater assimilation;
- (4) ensure Connecticut's compliance with requirements of federal law requiring the promulgation of water quality standards and qualify the state and its municipalities for available federal grants for water pollution control;
- (5) establish designated uses for surface and groundwaters and identify the criteria necessary to support those uses;
- (6) focus the department's water quality management activities, including establishment of water quality-based treatment controls and strategies required by 33 USC, Chapter 26;
- (7) protect the public health and welfare and promote the economic development of the state; and
- (8) be consistent with health standards as established by the Department of Public Health.

Section 22a-426-4(a)(5) "Surface waters and sediments shall be free from chemical constituents in concentrations or combinations which will or can reasonably be expected to result in acute or chronic toxicity to aquatic organisms or otherwise impair the biological integrity of aquatic or marine ecosystems..."

Section 22a-426-4 (a) (9) "The Commissioner, pursuant to chapter 446k of the Connecticut General Statutes and regulations adopted thereunder, will regulate discharges to the surface waters to assure that such discharges do not cause acute or chronic toxicity to freshwater and marine aquatic life and wildlife, do not impair

the biological integrity of freshwater and marine ecosystems and do not create an unacceptable risk to human health as determined by the Commissioner. ... (A) In making a determination under chapter 446k of the Connecticut General Statutes as to whether a discharge will or can reasonable [sic] be expected to cause pollution to surface waters, the Commissioner shall consider the numeric criteria for the chemical constituents listed in Table 3 of section 22a-426-9 of the Regulation of Connecticut State Agencies."

Section 22a-426-4(a)(10) "Best Management Practices for control of non-point source pollutants may be required by the Commissioner on a case-by-case basis."

Section 22a-426-4 (a) (11) "The Commissioner shall require Best Management Practices, including the imposition of discharge limitations or other reasonable controls on a case-by-case basis as necessary for point and nonpoint sources of phosphorus and nitrogen, including sources of atmospheric deposition, which have the potential to contribute to the impairment of any surface water, to ensure maintenance and attainment of existing and designated uses, restore impaired waters, and prevent excessive anthropogenic inputs of nutrients or impairment of downstream waters."

Section 22a-426-4(a)(12) "Such use of Best Management Practices and other reasonable controls on nonpoint sources of nutrients and sediment are preferable to the use of biocides to address a trophic state that has been altered due to excessive anthropogenic inputs."

Section 22a-426-4 (a) (13) "Biological Condition criteria may be utilized where appropriate for assessment of the biological integrity of surface waters."

Section 22a-426-4 (e) (1) "The Commissioner may authorize certain treated domestic sewage discharges to Class A surface water provided the Commissioner finds that... (B) such discharge is treated or controlled to the maximum extent practicable in the subsurface and in all cases to a level that in the judgment of the Commissioner, in consultation with the Commissioner of Public Health, protects the environment, public health, safety and welfare."

Section 22a-426-4 (l) (1) The commissioner may, on a case-by-case basis, establish zones of influence when authorizing discharges to surface waters under sections 22a-430 and 22a-133(k) of the Connecticut General Statute in order to allocate a portion of the receiving waters for mixing and assimilation of discharge. In establishing a zone of influence the Commissioner shall consider without limitation: ... (E) "the location of other discharges in the receiving surface water body to insure that the cumulative effect of adjacent zones of influence will not significantly reduce the environmental value or preclude any existing or designated uses of the receiving surface water."

Note: The entire Zone of Influence section is relevant. The above section highlights particularly pertinent aspects of this section.

Section 22a-426-5 (a) "The Biological Condition Gradient Model is a model that describes how ecological attributes change in response to increasing levels of stress..."

Note: Section 22a-426-6 Lake Trophic Categories and 22a-426-7 Ground Waters are also impacted by phosphorus. However, in this assessment the focus is on surface waters, so they have not been included.

Section 22a-426-8 (a) Antidegradation Standards (1) “Existing and designated uses such as propagation of fish, shellfish and wildlife, recreation, public water supply, and agriculture, industrial use and navigation, and the water quality necessary for their protection are to be maintained and protected. (2) Surface waters with an existing quality better than the criteria established in the Connecticut Water Quality Standards shall be maintained at their existing high quality...”

Note: the entire Antidegradation section is relevant. The above section highlights particularly pertinent aspects of this section.

Section 22a-426-8 (c) “The Commissioner shall not issue any permit, water quality certificate or authorization for a discharge or activity unless the Commissioner finds that all existing and designated uses... will be fully protected and the discharge or activity is consistent with the designated uses...”

- B. Management of surface waters in Connecticut is based on protecting and restoring designated uses. The following inland surface water classifications summarize designated uses and allowable discharges to those waters:

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.

- C. The following narrative water quality criteria relate to the management and regulation of phosphorus in inland surface waters in order to maintain designated uses:

Section 22a-426-9 (a) (1) “Surface Waters shall meet the criteria listed in Table 1 (<http://www.cga.ct.gov/2013/rrdata/pr/2013REG2013-031-RC.pdf>) to support the designated uses identified for their particular classification.”

Nutrient Surface Water Criteria - Classes AA, A, and B, all have the same narrative criteria: “The loading of nutrients, principally phosphorus and nitrogen, to any surface water body shall not exceed that which supports maintenance or attainment of designated uses.”

Biological Condition Surface Water Criteria - Class AA, A, and B have the same criteria: “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 (See section 22a-426-5 of the Regulations of Connecticut State Agencies).” The biological condition gradient is explained in detail in Task 3 of this report.

Additionally, CT WQS for dissolved oxygen, color, suspended and settleable solids, turbidity, taste and odor, and pH may be relevant in the management of phosphorus. See Section 22a-426-9 for these specific standards.

3.3 CONNECTICUT CONSOLIDATED ASSESSMENT AND LISTING METHODOLOGY

Section 303(d) of the federal Clean Water Act requires each state to compile a list of water bodies not meeting water quality standards and prioritize each impaired water body for Total Maximum Daily Load (TMDL) development or other management action, and submit that list to the EPA every two years for review and approval. Section 305(b) requires the state to monitor, assess and report on water quality relative to designated uses. Connecticut publishes this list as part of an integrated water quality report (CT IWQR). Connecticut’s Consolidated Assessment and Listing Methodology (CT CALM) documents the decision making process used to assess and report on the quality of surface waters of the state.

In making water quality assessments for CT CALM, each designated use of a water body is assigned a level of support (fully supporting, not supporting, insufficient information, or not assessed), which characterizes whether or not the water is suitable for that use. The level of attainment is based on available data and other reliable information, as further described in this section.

The relevant designated use for aquatic life is “habitat for fish and other aquatic life and wildlife,” which is applicable to all surface water classes. The functional definition of this designated use is “waters suitable for the protection, maintenance, and propagation of a viable community of aquatic life and associated wildlife” (Table 1-1, DEEP 2014 CT IWQR; http://www.ct.gov/deep/lib/deep/water/water_quality_management/305b/2014_iwqr_305b_303d_final.pdf). Another

designated use relevant to phosphorus is recreation, which is also applicable to all surface waters. The functional definition of recreation is “swimming, water skiing, surfing or other full body contact activities (primary contact), as well as boating, canoeing, kayaking, fishing, aesthetic appreciation or other activities that do not require full body contact (secondary contact)” (Table 1-1, DEEP 2014 CT IWQR).

Following guidance from EPA (2005), the following sources of data and information are considered in conducting water quality assessments:

- Results from recent ambient monitoring (primary source)
- Recent federal Clean Water Act compliance documents
- Section 305(b) reports, Section 303(d) lists (lists of impaired waters), and Section 319(a) nonpoint assessments
- Reports of water quality problems from government agencies, volunteer monitoring networks, the public, or academic institutions
- Fish and shellfish advisories, restrictions on watersports or recreational contact
- Reports of fish kills
- Safe Drinking Water Act source water assessments
- Superfund and Resource Conservation and Recovery Act reports
- Results from predictive modeling, dilution calculations, or landscape analysis

A variety of other information may also be included in assessments. Data quality is evaluated for use in assessments using a three-tiered system:

- Tier 1: Data typically are in the form of digital photos or written descriptions of observations. Tier 1 data can provide supporting information when other data exists for a waterbody.
- Tier 2: Data collected may have been collected under a formal Quality Assurance Plan. Tier 2 data can provide supporting information when other data exist for a waterbody.
- Tier 3: Data are collected under a formal monitoring plan that follows a Quality Assurance Project Plan approved by DEEP or EPA. Tier 3 data may be used to support use assessments.

DEEP generally follows guidance provided by EPA (1997) using a variety of information and data types in its assessment methodology. DEEP applies a “weight of evidence” approach when using multiple types of data. A water body is generally considered impaired when one or more sources of data of information indicate a water quality standard is not attained. In resolving discrepancies in information, consideration is given to data quality, age, frequency and site-specific environmental factors. If data reconciliation is not possible, or the data are determined to be insufficient, the assessment unit is flagged for further monitoring.

Importantly, identifying the source of impairment is not a requirement of the Clean Water Act Section 303(d), and is not subject to EPA review and approval. Identifying the sources of impairment is done within a TMDL or similar evaluation (2012 CT IWQR).

DEEP recognizes biological community assessment as the best and most direct measure of Aquatic Life Use Support (DEEP 2014 CT IWQR; *See CASE Report, Table 3-1*). DEEP often uses a combination of information on the benthic macroinvertebrate community, fish community, physical/chemical data, toxicity, and record of water quantity to make use support determinations for wadeable rivers and streams. A project evaluating the use of periphyton for aquatic life assessment is under development (Becker 2014). The periphyton community responds more directly to nutrients than macroinvertebrate or fish communities and therefore is likely to provide a better indicator of nutrient stress in streams.

TABLE 3-1: REPLICATION OF DEEP 2014 CT IWQR TABLE 1-3. AQUATIC LIFE USE SUPPORT (ALUS) CATEGORIES AND CONTRIBUTING DECISION CRITERIA FOR WADEABLE STREAMS

Aquatic Life Use	Criteria / Indicators
Fully Supporting	<p>Biological community with ecological attributes consistent with Biological Condition Gradient Tiers 1-4 as adopted in Connecticut Water Quality Standards Section 22a-426-5 of the Regulations of Connecticut State Agencies.</p> <p>Benthic community: benthic MMI, value >48 (Gerritsen and Jessup, 2007) and meets narrative criteria in CT WQS*.</p> <p>Screening Approach data with 6 or more "Screening Taxa"</p> <p>RBV data submitted to DEEP listed 4 or more pollution sensitive "Most Wanted" invertebrates (see http://www.ct.gov/deep/rbv)</p> <p>Fish community: species composition, trophic structure, and age class distribution as expected for an unimpaired stream of similar watershed size.</p> <p>Conventional physical/chemical criteria are not exceeded.</p> <p>Measured toxicants do not exceed chronic toxicity criteria.</p> <p>No record of episodic events (e.g., chemical spills, fish kills)</p> <p>Biological communities show no evidence of impact from anthropogenic manipulations to stream flow.</p> <p>No evidence of chronic toxicity in ambient waters.</p>
Not Supporting	<p>Biological community with ecological attributes consistent with Biological Condition Gradient Tiers 5-6 as adopted in Connecticut Water Quality Standards Section 22a-426-5 of the Regulations of Connecticut State Agencies</p> <p>Benthic community: benthic MMI < 43 (Gerritsen and Jessup, 2007), and does not meet narrative criteria in CT WQS*.</p> <p>Screening Approach data with 2 or less "Screening Taxa"</p> <p>Fish community: species composition, trophic structure and age class distribution significantly less than expected for a non-impacted stream of similar watershed size; diversity and abundance of intolerant species reduced or eliminated; top carnivores rare or absent; trophic structure skewed toward omnivory.</p> <p>Physical/chemical or toxicant criteria exceeded in $\geq 10\%$ of samples.</p> <p>Biological communities show evidence of impact from anthropogenic manipulations to stream flow.</p> <p>Stream completely enclosed in conduit or cleared concrete trough.</p> <p>Documented episodic event (e.g., chemical spill, fish kill) from anthropogenic cause.</p>
Insufficient Information	<p>Some community data exist, but sampling was very limited and/or the results are ambiguous or conflicting, requiring follow-up monitoring.</p>
<p>* When a bioassessment falls on the border between two use support categories, use support is determined by staff biologists giving consideration to site conditions, certain sensitive taxa present, and other available data. Occasionally, where habitat conditions are not optimal, a non-quantitative sample may be used to infer ALUS as a best professional judgment assessment.</p>	

A fully supported “aquatic life use” designated use in streams is one in which the narrative Biological Condition Surface Water Criteria are met. These decision criteria present current strategies and indicators employed by DEEP to map actionable indicators to a narrative standard.

3.4 Phosphorus Management Interim Strategy

In order to meet the need to issue National Pollutant Discharge Elimination Systems (NPDES) permits that are protective of the environment in the near term, DEEP developed an interim nutrient management strategy for freshwater non-tidal streams (Appendix B) based on the narrative policy statements in the water quality standards. This strategy was developed using benthic algae species composition to assess aquatic life response to phosphorus enrichment levels. Benthic algae were chosen for this analysis because they integrate the effects of stressors over time and space, and respond directly to nutrients. Changes in benthic algae communities in response to anthropogenic phosphorus loading were analyzed within a spatial framework using geographic information systems and statistical techniques.

Surveys were conducted at 78 sites between 2002 and 2004 in July and August. At each site, 15 one-inch diameter samples were scraped from rocks and woody snags. Samples were sent to a taxonomist for diatom – a major group of benthic algae – identification. Additionally, an enrichment factor (EF) was calculated for each of the sites using GIS. An EF is the amount of anthropogenic phosphorus loading that occurs in a river or stream according to

$$\text{Enrichment Factor} = ((\text{Total NPDES Load}) + (\text{Land Cover Load})) / (\text{Forested Condition Load}) \quad (\text{eq. 1})$$

The interim study uses export coefficients, which provide an estimate of nutrient loads for different land classes, from the literature to determine the terms used in equation 1. A statistical technique called Threshold Indicator Taxa Analysis (TITAN) was then used to look at changes in the diatom community in response to varying enrichment factors seen at the sites (Figure 3-1). TITAN detects changes in taxa on specific responses and provides evidence for community thresholds. This analysis indicated that an EF of 1.9 and 8.4 represented a lower and upper threshold at which a significant change was seen in the benthic algal (i.e., periphyton) community.

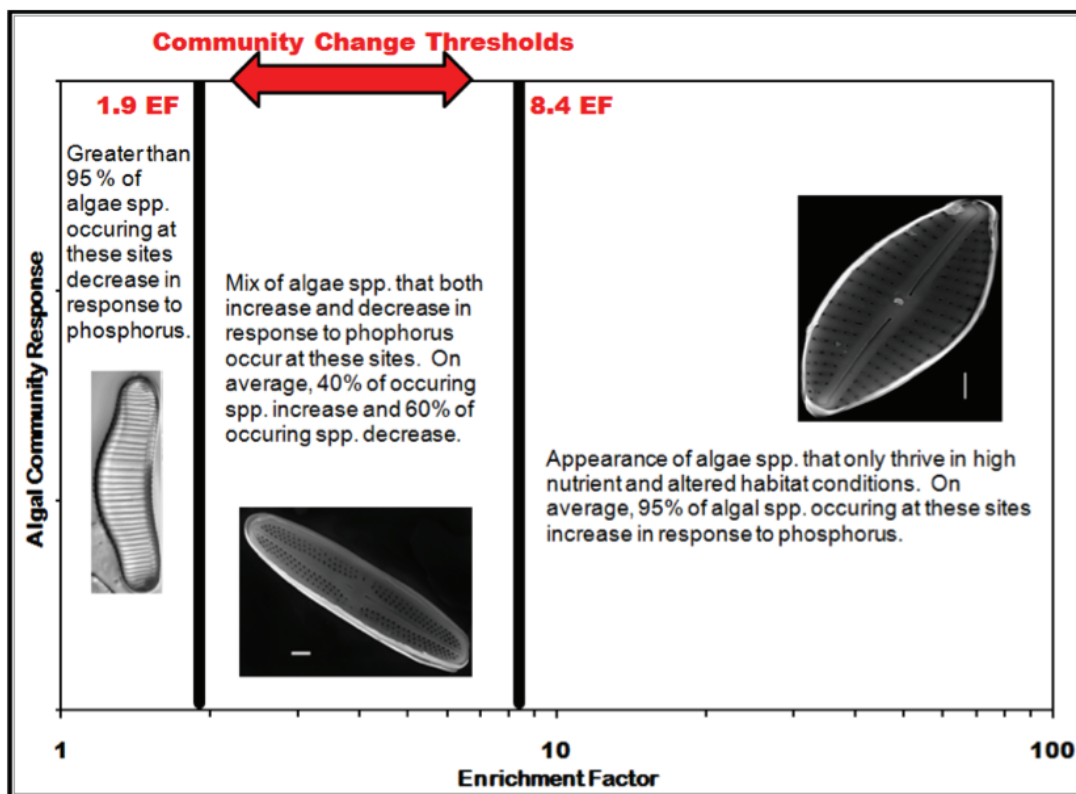


Figure 3. Upper and lower algal community thresholds in response to EF indicated in TITAN analysis

FIGURE 3-1: THRESHOLD INDICATOR TAXA ANALYSIS (TITAN) TAKEN DIRECTLY FROM THE CONNECTICUT INTERIM PHOSPHORUS REDUCTION STRATEGY (APPENDIX B).

The DEEP Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams (Interim Strategy) (see Appendix B) uses this upper threshold of an EF of 8.4 as the aquatic life use goal for water below NPDES facilities. Current EF's below NPDES facilities are as high as 138. DEEP is requiring a reduction in current phosphorus loads to those streams with an EF greater than 8.4 to ensure that aquatic life uses are met. Required load reductions will be incorporated into the facility permits when they are up for renewal. Those facilities discharging to streams with an EF below 8.4 are required to maintain their current load. Once the strategy is fully implemented, it will result in overall watershed reductions of NPDES phosphorus loads up to 95%. Some NPDES permits incorporating new phosphorus limits have already been issued. The Interim Strategy is discussed in more detail in Section 5.

3.5 REFERENCES

2012 State of Connecticut Integrated Water Quality Report. Connecticut Department of Energy and Environmental Protection. Final published December 17, 2012. Chapter 1 – Connecticut Consolidated Assessment and Listing Methodology (CT CALM);

METHODS TO MEASURE PHOSPHORUS AND MAKE FUTURE PROJECTIONS
TASK 2

http://www.ct.gov/deep/lib/deep/water/water_quality_management/305b/2012_iwqr_final.pdf; August 18, 2014.

2014 State of Connecticut Integrated Water Quality Report. Connecticut Department of Energy and Environmental Protection. Final published November 18, 2014. Chapter 1 – Connecticut Consolidated Assessment and Listing Methodology (CT CALM); http://www.ct.gov/deep/lib/deep/water/water_quality_management/305b/2014_iwqr_draft_305b_303d.pdf; November 18, 2014.

Connecticut Department of Energy and Environmental Protection Regulation 22a-426-1 through 9: Water Quality Standards. October 10, 2013; <http://www.ct.gov/deep/lib/deep/regulations/22a/22a-426-1through9.pdf>; August 18, 2014.

Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams Technical Support Document. Mary Becker, Connecticut Department of Environment Protection, Bureau of Water Protection and Land Reuse. Last Revised April 24, 2014. Retrieved from http://www.ct.gov/deep/lib/deep/water/water_quality_standards/p/interimmngntphosstrat_042614.pdf; August 18, 2014; included as Appendix B in this report.

Quality Assurance Project Plan (QAPP) Aquatic Life Response to Cultural Eutrophication in CT Freshwater Wadeable Rivers and Streams (2012-2015). Prepared by Mary Becker, Connecticut Department of Environment Protection, Bureau of Water Protection and Land Reuse for U.S. Environmental Protection Region I, Office of Environmental Measure and Evaluation. Submittal 1. October 24, 2012; http://www.ct.gov/deep/lib/deep/water/water_quality_standards/p/alnutrientqapp_112012.pdf; August 18, 2014.

4.0 TASK 3

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?

- a. Discuss the landscape of methodologies including any existing examples of site-specific applications.
- b. Consider methodologies being used or under consideration
- c. Discuss the pros and cons of each methodology in terms of application in Connecticut

4.1 METHODOLOGIES TO DEVELOP NUMERIC CRITERIA

There are currently four approaches commonly used by the regulatory community and recommended by the EPA to develop numeric criteria: reference, mechanistic models, stressor-response models and scientific literature. These approaches are focused on assessing aquatic life impairment and are described in detail in reports by the EPA (EPA, 2000;2010b). They are summarized briefly as follows.

4.1.1 Methodologies

4.1.1.1 REFERENCE STREAM REACHES

The first common approach is using reference stream reaches. Reference reaches are minimally impacted or relatively undisturbed, and are surveyed for phosphorus concentrations as a baseline for natural conditions. The determination of reference sites is based on professional judgment when assessing chemical and biological data (e.g., dissolved oxygen) and/or by comparing to reference values adopted by neighboring states. A numerical concentration criterion is then developed from the distribution of reference reach phosphorus values (e.g., identifying the 75th percentile of the frequency distribution from reference sites; Figure 4-1). This concentration, presumed to be a reference concentration, is used as numeric criteria.

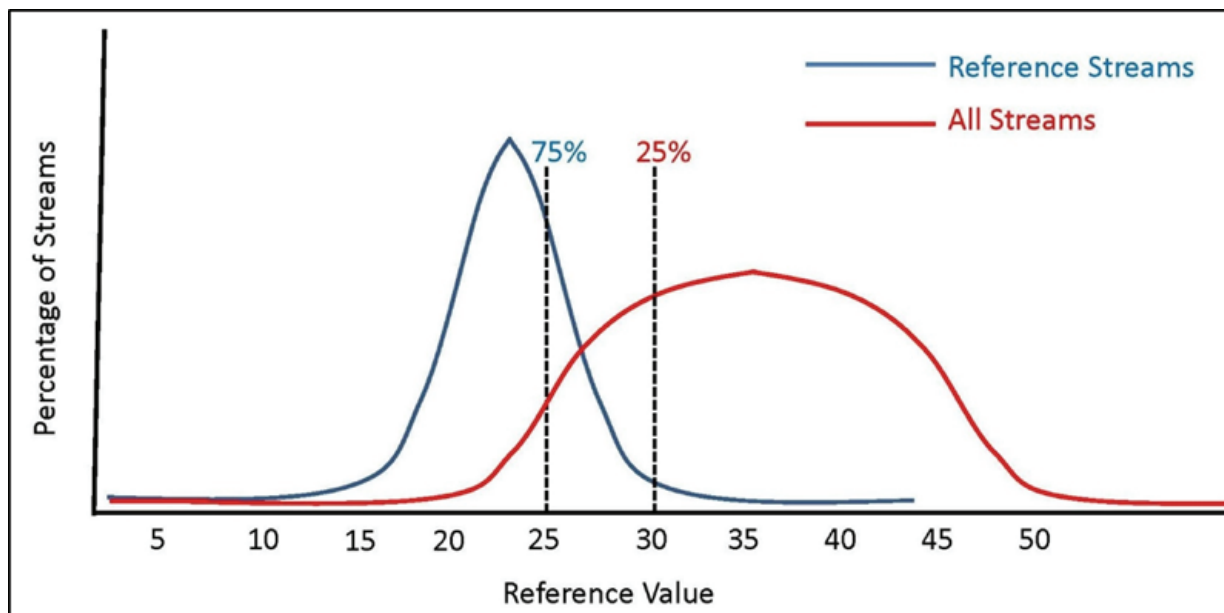


FIGURE 4-1: AN EXAMPLE AFTER (EPA 2000) FOR SELECTING REFERENCE VALUES FOR TOTAL PHOSPHORUS (TP) FROM STREAM PHOSPHORUS MEASUREMENTS. THE X-AXIS IS TP IN $\mu\text{g L}^{-1}$, WHILE THE Y-AXIS IS PERCENTAGE OF STREAMS IN THE SURVEY. IN THE FIRST FREQUENCY APPROACH, EPA SUGGESTS USING THE 75TH PERCENTILE 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.

4.1.1.2 DEVELOPMENT OF MECHANISTIC MODELS

A second method employs the development of mechanistic models. These models, which have been successful in lakes and reservoirs, attempt to correlate the concentration of phosphorus to a form of impairment, such as algal biomass. In their most basic form, they are simple regression models that correlate phosphorus concentrations to one or two variables (VanNieuwenhuysse and Jones, 1996; Jones et al., 2001; Dodds et al., 2002). More complex models that involve dynamic spatial modeling approaches can also be used to isolate the natural concentration of phosphorus in undisturbed or minimally disturbed regions. These models also use stream phosphorus measurements as training data along with more advanced statistical approaches to evaluate the contribution of phosphorus from different terrestrial and up-stream sources and landscape units, including undisturbed sites. More complex models also attempt to determine the impact of climate and landscape variation on phosphorus loads, which is useful when considering management strategies (Smith et al., 1997; Kao et al., 1998; Tong and Chen, 2002).

4.1.1.3 STRESSOR-RESPONSE MODEL

A third statistical approach, the stressor-response model, involves using response parameters (Figure 2.2) to establish phosphorus impairment. This approach entails measuring a single or multiple biological metrics of phosphorus impairment (e.g., diatoms, macroinvertebrates and/or fish) and creating an index, using statistical approaches, to set a standard (Davis and Simon, 1995). According to the EPA, this method consists of building a conceptual model, collecting data through synthesis and monitoring, and creating the stressor-response relationship (EPA,

2010b). The statistical approach used to set response parameters varies, but can include simple linear regressions. More complex non-linear approaches can be used in an attempt to isolate ecological thresholds (Smith et al., 2013). The Interim Strategy, described in Task 2, is an example of this approach. More recently, as discussed in Section 5, the EPA has documented an approach that allows for the direct utilization of response parameters in setting criteria.

4.1.1.4 SCIENTIFIC LITERATURE SURVEY

The final approach outlined by the EPA is a literature survey that can be used to evaluate criteria suggested or developed by other agencies or within the scientific literature. As an example, a state might perform a meta-data analysis of the concentration of phosphorus found in waters with nuisance growth levels of periphyton and adopt criteria from this range of values (EPA, 2010b).

4.1.2 Review of Methodologies

A major problem with the above-mentioned methods is that pristine reference sites, which are needed essentially for all methods, are often non-existent (Smith et al., 2003). In fact, some states establish reference sites with moderately developed watersheds (Yoder and Rankin, 1998). The lack of pristine reference sites may result in some states setting a threshold phosphorus concentration that is too high, leading to a degree of degradation that begins to impact aquatic life uses.

The first two methods—reference and mechanistic models—rely on measurements of phosphorus concentration itself to set a standard. The main difficulties arise from the large amount of temporal and spatial variation in phosphorus concentrations in streams and rivers, and the lack of strong statistical correlations between phosphorus concentration and response parameters (Trench 2004). These problems, which do not generally exist in lakes and reservoirs, have led states to pursue stressor-response models for streams and rivers in recent years.

The high degree of temporal variation in phosphorus is well documented for Connecticut. A study of the Quinebaug basin determined that eight samples per year are necessary to have a 70% probability of detecting a ~75% change in phosphorus concentration (Trench, 2004). There is also considerable seasonal variation. For example, concentrations of pollutants from wastewater treatment plants may be high during low river flow due to a greater proportion of the water originating from these sources (Griffith and Raymond, 2011), while storms can create large variations in phosphorus concentrations regionally (Zhu et al., 2012). Finally, spatial variation in phosphorus concentrations exists. Variation in phosphorus concentrations due to differences in watershed modifiers (Figure 2-2) can cause large ranges in nutrient concentrations regionally (Smith et al., 2003).

The high reactivity of phosphorus also leads to difficulty when using direct phosphorus measurements for establishing numeric criteria. The uptake of phosphorus by autotrophic and heterotrophic organisms can be a source of variation (Mulholland and Hill, 1997). However, the degree of uptake is not controlled simply by the concentration of phosphorus in stream water, but is variable due to variation in impact modifiers (Figure 2-2; (Biggs et al., 1998)). In some cases, the uptake can drive concentrations down, leading to a system that is highly impacted with low phosphorus concentrations.

To summarize, the high degree of spatial and temporal variation in phosphorus concentrations can necessitate a high degree of sampling effort to establish numeric criteria from direct phosphorus measurements. The variation also leads to a high mean error when using these approaches for assigning numeric criteria from phosphorus measurements (Smith et al., 2003). Furthermore, the situation can exist where phosphorus concentrations are low, yet a stream is still impaired due to unfavorable impact modifiers (Figure 2-3, bottom). That is, there is a large variation in the relationship between phosphorus concentration and impairment. As a result, additional sampling of phosphorus alone, without continued sampling of other important response parameters such as those outline in Appendix C, and adoption of appropriate statistical approaches, would make it difficult to establish credible phosphorus criteria for streams as further discussed. The high degree of spatial and temporal variation in phosphorus concentrations and confounding influences by other impact modifiers make it difficult to directly correlate phosphorus measurements with a determination that the stream is, or is not, meeting its designated uses.

In lakes and reservoirs, this spatial and temporal variation is smaller, due to the simpler physical nature of these systems, and thus basic statistical models are more successful at correlating phosphorus concentration to impairment (Vollenweider, 1976). In streams and rivers, these two factors have caused states to consider using stream response parameters (Figure 2-2) to estimate nutrient impacts. Such indicators are typically biotic and are able to overcome the challenges of high spatial and temporal variation because a species presence, abundance, and impact on water quality is defined by the available concentration over time (Porter et al., 2008). Thus, these stream response parameters integrate nutrient loadings over a period of weeks to months, collapsing some of the variation in phosphorus. For example, benthic algae integrate phosphorus concentrations over weeks, while larger organisms such as macroinvertebrates or fish might represent months or years. These indicators are able to overcome the complexities generated by impact modifiers because the stream impact is directly measured (Davies and Jackson, 2006). A final benefit of measuring the stream response parameters is that they capture information that is of great interest to managers, including biodiversity loss and impairment of aquatic life uses. The drawback to stream response parameters is that they reflect the net impact of many variables and it can be difficult to conclusively tie the impact to one causative factor.

4.2 THE BIOLOGICAL CONDITION GRADIENT

The dominant conceptual model related to biological response is the Biological Condition Gradient (BCG). The BCG relates measurable attributes of a stream (e.g., response parameters) to anthropogenic stress and designated uses. It can be calibrated with a single response parameter or multi-metric response parameters. As mentioned in Section 3 (Task 2), currently the CT WQS explicitly mentions the BCG as a narrative water quality criterion. It also includes a benthic multi-metric response parameter in its narrative criteria for the CT IWQR.

The BCG was developed as a conceptual model for assessing the biological health of an aquatic ecosystem (Davies and Jackson, 2006). It is meant to capture the intent of the Clean Water Act's mandate to preserve the "biological integrity" of all aquatic systems, while at the same time providing a standard metric allowing cross-jurisdictional comparison of stream health. The BCG is also designed to overcome some of the issues associated with other major approaches (e.g., reference watersheds, mechanistic models) to develop numeric criteria for water bodies.

The BCG is a “stressor-response model” (Figure 4-2) that attempts to link a stressor such as phosphorus pollution to the ecological state of a stream reach (Davies and Jackson, 2006).

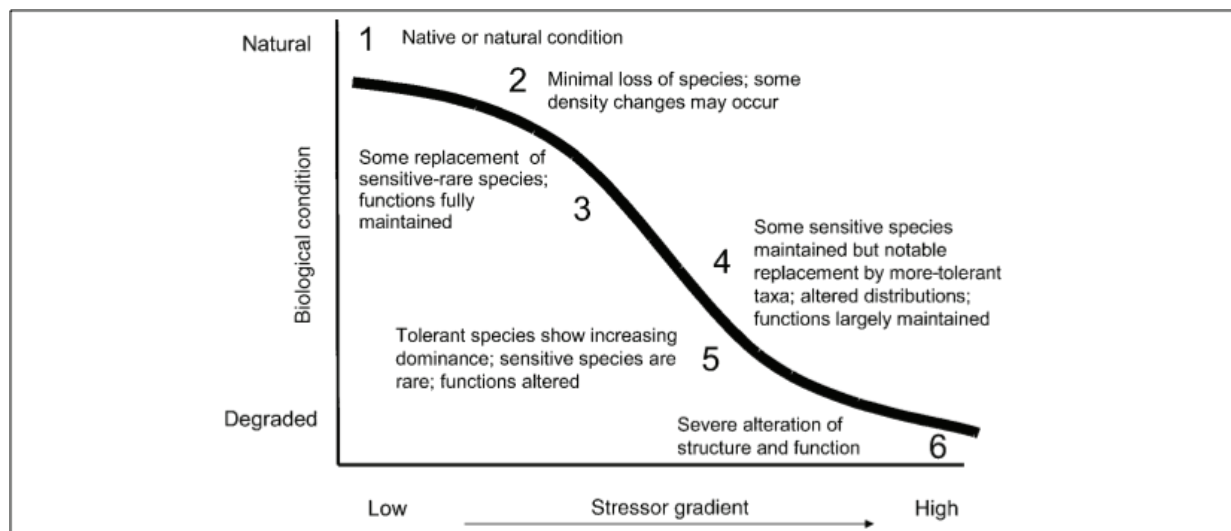


FIGURE 4-2: BIOLOGICAL CONDITION GRADIENT STRESSOR-RESPONSE MODEL

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)

When adopting the BCG, a set of measurable characteristics has to be determined that categorizes the ecological health of a stream or river based on a series of stream response parameters (Figure 2-2). It can be conceived as a more comprehensive version of the well-known “indicator species” approach. Rather than having a single species that identifies degraded sites, a state may decide to use groups of response parameters arranged as an index to determine whether a site is degraded. In so doing, the measurement of phosphorus is made during the calibration stage to create the numerical link between phosphorus concentrations and the stream response parameters (Gerritsen and Jessup, 2007) although as aforementioned, EPA released a guidance document for the direct use of response parameters in standard settings. The continued measurement of phosphorus can then be helpful in evaluating the efficacy of management activities.

The BCG classifies sites into six tiers (Figure 4-2, Table 4-1) meant to capture a range of biological states from pristine to degraded (Davies and Jackson, 2006).

TABLE 4-1: THE SIX TIERS OF THE BCG ADAPTED FROM DAVIES & JACKSON (2006)

Tier	Biotic Community	Ecosystem Function
1	Native Structure, function, and taxonomic integrity is preserved	Preserved within range of natural variability
2	Virtually all native taxa are maintained with changes in biomass/ abundance	Fully maintained within range of natural variability
3	Loss of rare native taxa, shifts in relative abundance, sensitive-ubiquitous taxa common and abundant	Fully maintained through redundant attributes of the system
4	Some replacement of sensitive-ubiquitous taxa by more tolerant ones	Largely maintained through redundant attributes
5	Sensitive taxa markedly diminished, unbalanced distribution of major groups, signs of physiological stress	Reduced complexity and redundancy, increased buildup or export of unused materials
6	Wholesale change in composition, extreme changes in density and distribution of taxa.	Severely altered

Tiers 1 to 4 are considered acceptable in Connecticut for preserving ecosystem function and biological health (DEEP, 2013) (See Section 3). Tier 1 is an undisturbed system with the native taxa assemblage and unchanged functioning. Tier 1 sites are uncommon and were not present in Connecticut or New Jersey when the BCG was developed for macroinvertebrate communities (Gerritsen and Leppo, 2005;Gerritsen and Jessup, 2007). Moving from Tier 1 to Tier 4 represents a loss of sensitive species from the ecosystem and an increase in tolerant species with little to no change in ecosystem function (Table 4-1). Tiers 5 and 6 represent a further shift from sensitive to tolerant species that is now accompanied by a change in ecosystem function. Once you move to Tier 5 and 6 sites, ecosystem functioning changes rapidly. Although the BCG is stressed in both the Aquatic Life Use Support categories in the CT IWQR and the CT WQS, it currently combines Tiers 1-4. This is a current shortcoming, and as noted in this study’s recommendations, Connecticut should consider classifying by stream health when setting standards in order to protect loss of ecosystem function in the top tiers.

A key component for the BCG is choosing a set of response parameters to correlate to the BCG tiers (Figure 4-2). Response parameters used in this effort should be strongly coupled to phosphorus impacts, should integrate over space and time, would be minimally impacted by stressors other than phosphorus, and would not be overly expensive to monitor. A set of response parameters used by other states and suggested by the EPA are provided in Appendix C and discussed further in Section 5.

Once a response parameter or set of response parameters is chosen, it has to be calibrated to the BCG. Calibration of the BCG is often done by an expert panel whose role is to assign stream response parameters (e.g., macro invertebrate populations) to attributes I to VI and develop standardized rules for turning response parameters or species data from a site into a BCG tier ranking (Gerritsen and Leppo, 2005;Gerritsen and Jessup, 2007). Linking stream response parameters can also be done through statistical techniques which are explained in Task 4.

Regardless of the method chosen, calibrating the BCG requires a significant amount of data. The type of data required depends on the stream response parameters used in the gradient. To calibrate the BCG to given response parameters, the experts need reference and disturbed sites where data on response parameters can be sourced. Reference and disturbed sites were identified in Connecticut, and elsewhere, using watershed land use as a proxy for disturbance (Gerritsen and Leppo, 2005; Gerritsen and Jessup, 2007). Using reference and disturbed sites, experts develop the quantitative rules used to place sites within tiers of the gradient. The rule development process is iterative and may require three to four attempts before the rules are sufficiently tested, documented and are deemed satisfactory to the expert panel (Gerritsen and Jessup, 2007). The result of the calibration stage is a decision framework that can quantitatively assign new sites or new samples to one of the six tiers of the BCG.

The BCG is a powerful conceptual model and if properly calibrated can help ascertain which stream reaches are impaired, but it has limitations. An issue with the BCG for some response variables is that for impaired stream reaches, the cause of the impairment is not always known. If stressors other than phosphorus are a major driver of response parameters, additional steps and lines of evidence are needed to confirm that phosphorus is the main stressor. It is therefore imperative to choose response parameters that respond directly to phosphorus, but are minimally impacted by other stressors. The use of fish or macroinvertebrates, for instance, can be problematic because these organisms are sensitive to other stressors such as temperature and pesticides. Diatoms or other algal indicators have been used to overcome some of the problems associated with these organisms (Maine DEP, 2009). Furthermore, the BCG can be a powerful tool for evaluating the impact of phosphorus on the aquatic life component of the designated use, but fails to incorporate recreational uses. Thus, states must consider other approaches to evaluate the relationship between phosphorus pollution and recreation. Finally, by definition, if Tiers 1-4 are considered acceptable, there still will be some loss of sensitive species – species which may be important for designated uses and antidegradation policies – when moving from Tiers 1 to 4. As an example, the loss of sensitive recreational fish species might be acceptable when grouping Tiers 1-4 in the BCG model.

4.3 CLASSIFICATION

Regardless of the method chosen, sampling and analysis need to evaluate the need for stratification or classification (EPA, 2000). Streams can be classified according to geology, geomorphology, ecology, and designated uses. Each approach has impacts on how phosphorous criteria would be set and evaluated. Variability in phosphorus concentrations and impacts can be altered by numerous watershed and impact modifiers (Figure 2-2). Within a state or region, significant variation in a stream response parameters can arise from non-anthropogenic modifiers, such as geology, climate and channel morphology (Figure 2-2). If a dominant non-anthropogenic modifier exists, the sampling and analysis phase should consider stratifying sampling amongst blocks of these modifiers (e.g., high versus low gradient stream reaches) in order to decrease error when correlating impact response parameters to the BCG or phosphorus concentration. In this example, statistical analysis would be performed separately for low versus high gradient streams to evaluate if this modifier should be considered when establishing criteria. The decision to stratify based on non-anthropogenic modifiers is determined by the response parameters chosen. If using pH, for instance, it may be necessary to stratify by surficial soil characteristics, which can cause large regional variation in stream pH (Lauerwald et al., 2013).

A state might also classify based on designated uses. Connecticut already has such a set of stream classes (see Task 2). These stream reach classifications are meant to protect specific and different uses. Thus a state might consider establishing a separate numeric criterion for each class. In the case of Connecticut, lower phosphorus criteria for Class AA and A reaches would protect these systems from the beginning phase of impairment and loss of sensitive species. Finally, in order to explicitly protect more healthy streams against anti-degradation, a state should consider classifying according to stream ecology or health. Stratifying across benthic macroinvertebrate indices or by the already established enrichment factor, for instance, would provide protection between Tiers 1-4 of the BCG model and protect relatively healthy streams from impacts due to phosphorus loading.

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5.0 TASK 4

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

- a. Identify the method or methodologies best suitable for Connecticut. Recommend a method or methodologies.
- b. Identify how the methodology is used to assess the site-specific conditions of a water body and determine the level of phosphorus needed to attain aquatic life uses and water quality standards given the measurement of other relevant response variables.
- c. Identify the method by which to determine that an acceptable level of phosphorus has been achieved in a water body as measured by specific water quality parameters which are related to phosphorus and biological conditions, while recognizing the site-specific conditions of a water body and impacts of other response variables.
- d. Identify the methods, tools and data needed to apply the method identified in (a) above.
- e. Identify what existing available Connecticut data may be relevant and can be used to implement such an approach in an example water body.

5.1 RECOMMENDED RESPONSE PARAMETERS FOR NUMERIC CRITERIA

Of the methodologies recommended by the EPA for setting numeric criteria, the stressor-response model is recommended by the CASE Study Committee. As summarized in the “Review of Methodologies” section of this report (Section 4; Task 3), the lack of consistent correlations between phosphorus concentration measurements and impairment due to variation in phosphorus concentration and variation in impact modifiers precludes the use of methods that rely solely on phosphorus concentrations. Stressor-response models are able to overcome these difficulties because they use response parameters that measure the impact directly; many states are moving towards the use of these models.

Stressor-response models, however, also have potential pitfalls and costs associated with monitoring. A critical component of the stressor-response model is the selection of proper response parameters to measure the impact of phosphorus pollution. The response parameters considered by different states are summarized in Appendix C. In order to recommend response parameters for use by Connecticut, an optimization matrix was developed and used by the CASE Study Committee based on their expertise and as informed by the research team. The use of an optimization matrix is common in decision making. This tool provides experts with the opportunity to weigh options relative to each other in an objective manner. It is important to note that the results of this process represent the opinions of experts, as the data and funds required to quantify the factors were not available. Members of the committee ranked each index for three factors:

- Factor 1. Strength of the stressor response relationship, or the ability to directly link the impact response parameters with impairment from phosphorus. This is the most critical factor in the stressor-response model and was discussed in Task 3.
- Factor 2. Accuracy and integrative power of the response parameters. This factor captures how variable the response parameters are, and their spatial and temporal footprint. Higher scores are given to response parameters that integrate over longer temporal and larger spatial scales and to response parameters that can be measured precisely.
- Factor 3. Cost effectiveness that incorporates the expense associated with use of the response parameters.

Each response parameter was ranked on a scale of 1-5 for each factor and a weighted score was estimated according to the following equation:

$$\text{Strength Relationship} * 1.5 + \text{Accuracy \& Integrative Power} * 1 + \text{Cost-Effectiveness} * 0.5 \quad (1)$$

The committee then used the optimization matrix as shown in Table 5-1 to select a recommended set of response parameters. It is important to note that the matrix was a tool and not an end-product. There were no a-priori agreed upon number of response parameters. The goal was to recommend a small number of response parameters in order to reduce costs and decrease the potential number of outcomes. Thus, the relative strengths of the top ranked response parameters were discussed to avoid overlap in strengths and find complementary response parameters. The recommended response parameters are dissolved oxygen (in particular, diurnal variation in dissolved oxygen) and diatom species that are discussed in more detail, as follows. These recommendations are consistent with EPA results that point to algal assemblage and continuously monitored dissolved oxygen as ideal response parameters (EPA, 2013a). The final ranking of response parameters based on this analysis is presented in Appendix D.

TABLE 5-1: 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				

5.1.1 Diatoms

Diatoms are a well-studied indicator of nutrient degradation in aquatic systems (Danielson et al., 2011). Diatom community structure is sensitive to low amounts of phosphorus loading (Pan et al., 2000; Black et al., 2011; Smucker et al., 2013a) and therefore can capture the gradual degradation of an aquatic system. The diatom community response parameter is also powerful because it integrates stream conditions over days to weeks (Cairns et al., 1993).

The sensitivity of diatom community structure to phosphorus is determined by the degree to which phosphorus limits diatom growth. An extensive body of literature suggests that diatoms

are typically phosphorus limited, especially in New England (Bothwell, 1989;Stevenson and Pan, 1994; Smith et al., 1999; Biggs, 2000;Pan et al., 2000; Rier and Stevenson, 2006; Porter et al., 2008; Black et al., 2011; Porter-Goff et al., 2013). However, many of these studies acknowledge that other factors also limit diatoms, including pH (Stevenson et al., 2008), chloride (Porter-Goff et al., 2013), and nitrogen (Smith et al., 1999; Francoeur, 2001; Dodds et al., 2002). A key benefit of using diatom community structure is that many of these confounding factors can be ruled out when the diatom community is represented by phosphorus-sensitive species (Black et al., 2011;Smucker et al., 2013a).

Community change also helps capture very small changes in the condition of a stream or river that are indicative of a site that is slowly being degraded. Smucker et al. (2013a) identified statistically different diatom community structures at different levels of phosphorus degradation in Connecticut. Evaluating these changes in the diatom community requires a large number of sites to produce a statistical relationship. In Connecticut, it may be difficult to utilize diatoms in large streams, such as the Quinnipiac and Quinebaug Rivers (if the state decides to classify based on stream size), because there is not enough replication of these systems available. Only 8% of the sites in the 2013 Smucker study, for instance, had a watershed area of >500km². This may be overcome by including community data from other large rivers in neighboring states (e.g., Level 3 EPA Ecoregion 58 and 59). Diatoms have been used in large rivers in other states (Fore and Grafe, 2002). As discussed below, dissolved oxygen data from these larger systems will also help determine if a stream reach is non-supporting for designated uses.

Finally, diatom community structure is defined by conditions in a stream currently and in the recent past. Importantly, diatoms have limited mobility and, therefore, cannot migrate away from polluted areas, thus providing confidence that diatom communities represent local conditions over this time period (Lowe and Pan, 1996;Danielson et al., 2011). One downside of this immobility is that diatom communities within a stream reach can be highly variable. Using a metric that integrates over space, such as dissolved oxygen, in conjunction with diatoms can help address this issue.

5.1.2 *Dissolved Oxygen (DO)*

The diurnal variation in DO is sensitive to eutrophication caused by phosphorus impacts. It is also highly spatially integrative, where the placement of a single probe integrates over stream reaches. DO might not work as well in small streams, however, due to rapid re-equilibration with the atmosphere, or in density-stratified systems due to large vertical gradients in DO. DO is also generally measured by the state, although not in a diurnal change framework.

In order to promote healthy aquatic ecosystems, examining the variation in daily DO can provide a rapid assessment of biotic integrity. Several studies have related diurnal variation (the degree of DO change in a day) in DO to other watershed and stream variables to determine the degree of impairment (Heiskary, 2008;Black et al., 2011;Klose et al., 2012;Cohen et al., 2013). Extreme variation between day and night DO concentrations has been found to be strongly correlated with high summer phosphorus levels (Heiskary 2008) and chlorophyll (Klose et al., 2012). Recently, a study found a direct correlation between diurnal DO levels and diurnal phosphorus (Cohen et al., 2013). In addition to metabolic processes, DO is also highly impacted by gas exchange (Raymond et al., 2012) and therefore there is a need to calibrate DO variables (e.g, degree of super saturation, day-night differences) to phosphorus impacts. During this

process there may be the need to stratify by physical factors such as stream slope that can impact gas exchange rates (Raymond et al., 2012).

As described above, the CASE Study Committee finds that these two methods are complementary. The diatom method integrates over long temporal scales (days to weeks), while the diurnal DO method integrates over long spatial scales (tens to hundreds of meters). Diatom species change is sensitive to small changes in phosphorus loading and can therefore document the initial stages of impairment and fulfill anti-degradation policies, particularly in smaller streams. As mentioned, an initial issue with a single state using diatom species is obtaining a statistically relevant data set for deriving nutrient criteria for the small number of moderate to large rivers (i.e, non-wadeable) in the state. Over time, as more data become available, this issue may be overcome. The DO method, however, is particularly sensitive in larger streams and rivers and easier for multi-state comparisons since it is a common measurement. Measuring DO has recently been made easier due to the development of optode probes, which do not have the drift and accuracy problems of older DO probes.

5.2 DERIVING NUMERIC NUTRIENT CRITERIA FROM RECOMMENDED RESPONSE PARAMETERS

As explained in the discussion of the BCG in the previous section, a critical component of using a stressor-response method is deriving numeric nutrient criteria from the chosen stressor response parameters. A recent EPA report guides states through this process using a recommended three-step process (EPA, 2010a).

- Step 1: Development of a conceptual model that links variables to nutrient concentrations, designated uses and impact modifiers (Figure 2-2).
- Step 2: Collection of data on the response parameters used.
- Step 3: Establishment of the relationship between the stressor-response variable and the nutrients of interest. This step involves classification (discussed below) and use of one of a few statistical approaches to determine the accuracy and precision of the stressor-response relationship in order to develop the nutrient criteria.

EPA reviews and discusses multiple statistical approaches in the referenced report. The approaches include simpler linear regressions, multiple linear regression, quantile regression, nonparametric regression curves, and nonparametric changepoint analysis (EPA, 2010a). EPA clearly discusses the pros and cons of these different methods, which are summarized briefly in Table 5-2.

TABLE 5-2: SUMMARY OF EPA REVIEW AND DISCUSSION ON PROS AND CONS OF STATISTICAL APPROACHES TO DETERMINE THE ACCURACY AND PRECISION OF THE STRESSOR RELATIONSHIP.

	Pros	Cons
Simple Linear Regression (SLR)	Easiest to interpret Can incorporate classification	Relationship has to be linear
Multiple Linear Regression	Incorporates more than one response parameter	Relationships have to be linear; Danger of overfitting model
Quantile Regression	Relaxes the SLR assumption of normal distribution of residuals	Estimates at high and low ends are often imprecise; Still relies on linear relationship
Nonparametric Regression	Does not require linear relationship	More data generally required
Nonparametric Changepoint Analysis	Can be used when a threshold exists in data (non-linear response)	More data generally required; Might need to establish that values below threshold support designated uses

Also, Appendix E shows the graphical relationship of the stressor-response parameter relationship. When choosing a statistical approach it is the nature of this relationship (e.g., linear vs threshold) that drives which statistical approach is best. EPA also provides information on diagnostic statistics, distribution of errors, and deriving criteria from the stressor-response relationship.

Connecticut has performed an initial analysis of the use of diatoms for determining concentration-based nutrient criteria in streams (Smucker et al., 2013a). The study examined multiple statistical approaches to evaluate the relationship between diatom species and phosphorus concentrations. It demonstrated that diatom community analysis is sensitive to small amounts of phosphorus inputs and that a nonparametric changepoint analysis, one of the statistical approaches recommended by the EPA, could be used to successfully establish the stressor-response relationship and derive numeric nutrient criteria (Smucker et al., 2013a). Importantly, due to the sensitivity of the diatom community to even low inputs of phosphorus, this method could be used to determine initial impacts on Class AA healthy streams and therefore help establish anti-degradation policies. The state, however, would have to stratify the methodology based on stream class or an ecological attribute and design separate criteria for each.

This analysis also demonstrated that the strongest predictor of phosphorus concentration and the diatom community in Connecticut was the amount of impervious cover – crops and pasture – implicating urban and agricultural management practices as the main watershed modifiers of phosphorus inputs to streams and rivers (Figure 2-2).

EPA has recently provided information on utilizing response parameters in conjunction with numeric criteria to determine if a waterbody is attaining its designated uses (EPA, 2013a). That is, the response parameters themselves can be used in a decision framework to determine the

status of the stream (Table 5-3). In this report the EPA recognizes that diatom assemblages and continuously monitored dissolved oxygen are potential “ideal response indicators.” An example of such a decision framework proposed by the State of Vermont is provided in Table 5-3. Additionally, Appendix F provides a review of the progress of numerous states that are in the process of updating stream phosphorus standards. As discussed in the EPA report (EPA, 2013a) the State of Connecticut would have to meet numerous implementation steps to be able to utilize response indicators in this manner.

TABLE 5-3: PROPOSED VERMONT NUTRIENT CRITERIA DECISION FRAMEWORK (SOURCE: NUTRIENT CRITERIA FOR VERMONT’S INLAND LAKES AND WADEABLE STREAMS, TECHNICAL SUPPORT DOCUMENT, TABLE 13 [REFORMATTED]. VT-DEC (2014); [HTTP://WWW.WATERSHEDMANAGEMENT.VT.GOV/MAPP/DOCS/MAPP_NUTRIENT_TSD.PDF](http://www.watershedmanagement.vt.gov/mapp/docs/mapp_nutrient_tsd.pdf))

	Assessment and Listing Decision	Discharge Permitting Decision
A. Phosphorus concentration less than or equal to criterion. All nutrient conditions met.		
	Not impaired by nutrients. Rotational basin monitoring on an approximate five-year schedule will be conducted.	If a new or increased discharge is proposed, the permit will limit the phosphorus concentration increase according to the anti-degradation policy. No new or increased phosphorus discharge would be permitted that would cause the phosphorus concentration to be greater than the criterion. If a current discharge at its maximum permitted phosphorus loading rate could produce a mixed, in-stream phosphorus concentration above the criterion value, then 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.

Therefore, the CASE Study Committee acknowledges that the using diatoms to evaluate phosphorus impact was an appropriate first step. While the statistical method used was appropriate, the state may consider an evolution of its statistical approach over time, utilizing its response parameters more directly in determining attainment. As the number of observations increase, the opportunity to stratify and refine statistical approaches also increases.

5.3 RECOMMENDATIONS

The following are recommendations for the state's consideration:

1. Continue sampling diatom community assemblage, but add diurnal dissolved oxygen. As presented above, these response parameters are complementary and new dissolved oxygen sensors are highly accurate and relatively cost effective. 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.
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.
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 (Table 5-3).
4. Develop a stratification/classification system. In particular, the DEEP Interim Strategy (Appendix B) was created for freshwater, non-tidal, waste-receiving rivers and streams, but the diatom analysis was done mostly using data from small streams (Smucker et al., 2013b). 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 (Charles et al., 2010). 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. That is, 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.
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.
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 (e.g., Cuffney and Qian,

2013; Juggins et al., 2013; Baker and King, 2013), and this will allow for the adoption of the most appropriate methods.

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.
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. Stream management plans provide a comprehensive overview of stream characteristics and recommended management strategies. Given the findings in Connecticut and New Jersey that phosphorus impairment is most strongly linked to urban and agricultural land cover and that riparian buffers can modify phosphorus impairment (Charles et al., 2010; Smucker et al., 2013b), management plans would need to focus heavily on the potential impairment from urban and agricultural practices and detail the status of riparian buffers. Having a more detailed understanding of stream reaches will increase the portfolio of options for remediation. The detailed mapping of stream characteristics (e.g., physical characteristics, riparian vegetation) for stream management plans will also benefit efforts to stratify streams when creating criteria, although this will require documenting the plans in GIS and creating variables from the plans for use in statistical analysis. 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).
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.

5.3.1 Implementation Strategy

As mentioned, the CASE Study Committee deems that the DEEP Interim Strategy (Appendix B) was justified. Although there were some questions with the TITAN model (Cuffney and Qian, 2013), these questions have been addressed in the scientific literature (Baker and King, 2013). Furthermore, when performing the statistical analysis for Connecticut, Smucker et al. (2013) used approaches other than TITAN to evaluate changes in phosphorus concentration and diatom communities. The approach taken by the state aligns with the guidance provided by the EPA. Thus the Interim Strategy was a reasonable and justified approach for setting numeric criteria. That said, this is still a rapidly evolving area of scientific inquiry. The statistical methods used to derive numeric criteria will continue to improve with time and new data. Furthermore, the response parameters used to set criteria will also change with scientific and methodological advancements. Finally, response variables can also now be used directly in decision making, which overcomes some of the problems associated with the standard set using statistical methods.

The proposed set of recommendations should be pursued by the state over the next 3-5 years with the following considerations:

- 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.
- 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.

5.3.2 Recommendation Details

5.3.2.1 SECONDARY MEASUREMENTS

Connecticut should consider a suite of secondary measurements, some of which are already being collected, in order to both help ascertain if other variables are responsible for facilitating phosphorus impact and to provide data that can be used in the classification process.

Variables that should be considered routine in synoptic sampling include conductivity, temperature, pH, and nutrients.

- Conductivity can help determine if sites might be impacted from salt used to treat roads (Kaushal et al., 2005), and can help stratify the geologic setting (Biggs, 1995), and land cover (Hatt et al., 2004).
- Temperature can impact the degree of the eutrophication response and diatom community structure and dissolved oxygen concentrations (Potapova and Charles,

2002; Kaushal et al., 2010). Temperature can also be impacted by alteration of environmental stream flows, which can interact with nutrient loading to exacerbate phosphorus response (Olden and Naiman, 2010); Figure 2).

- pH is sensitive to changes in surficial geology and may prove helpful when stratifying systems (Hill and Neal, 1997).
- Nutrient measurements are, of course, needed to set nutrient criteria from response parameters.

Collecting nitrogen and phosphorus data together also allows for the calculation of N:P ratios. N:P ratios are often helpful for determining the relative importance of phosphorus versus nitrogen in causing eutrophication (Guildford and Hecky, 2000).

There is also a suite of other variables the state should consider measuring on a less frequent basis. In particular, the state should consider an additional set of measurements in stream reaches that are non-conforming for dissolved oxygen and/or diatoms in order to further document potential management strategies and the relative importance of phosphorus versus other stressors. These include measurements of alkaline phosphatase, in-depth stream management plans, diffusing substrates and bioassays. Algae excrete an enzyme when phosphorus limited, called alkaline phosphatase (USEPA 2000). Thus measuring alkaline phosphatase in non-conforming systems can help confirm changes in phosphorus limitation. Diffusing substrates and bioassays can also be used to confirm and test for the relative importance of different micro- and macronutrients for limiting eutrophication. In-depth stream management plans can help locate contributors to stream phosphorus and nitrogen loading and are useful for managing pollution impacts. These data can also be used to help stratify data for conducting future statistical analyses.

5.3.2.2 ECONOMIC APPROACHES

The biological response parameters discussed in this section of the report can be used to set the maximum allowable phosphorus concentrations for a particular stream or river segment. The results of a biological or ecological (e.g., dissolved oxygen) assessment provide a means of setting standards that help protect aquatic habitats and species. Achieving this level of protection is an important step when setting phosphorus discharge limits. In Connecticut, the standard is a minimum BCG measure of Tier 4 along with a non-degradation clause that prevents the loss of pristine sites (See Task 2).

One weakness of using biological response parameters, however, is that they fail to consider some of the human uses of streams and rivers that water quality standards also hope to protect. As described in this report and referenced by EPA, criteria need to be set that allow for the attainment of designated uses, and a major designated use for Connecticut is recreation. Specifically, biological approaches do not consider the recreational value, amenity value, or human health benefits associated with healthy aquatic ecosystems. Furthermore, quantifying these economic benefits may also help to justify the costs of upgrading water treatment facilities or implementing non-point source reduction programs. As a result, collecting information on economic benefits regarding water quality could help ensure that the human uses of Connecticut waterways are being protected, and could provide a means of reporting the financial value of these improvements. With sufficient data, such an economic analysis

could also help regulators identify streams where easing or imposing stricter requirements on phosphorus levels would provide net economic benefits for a region or municipality. The State of Connecticut should evaluate the status of economic and human use data and facilitate stream valuation studies. A potential benefit of this would be the ability to map the damage and abatement costs of pollution.

5.3.2.3 THE IMPORT OF PHOSPHORUS TO WATERSHEDS

As described in Task 1 there are only a few ways phosphorus can enter watersheds. Phosphorus can enter a watershed through natural weathering, fertilizer, food for people and pets, and detergents. Understanding the relative magnitude of these different sources and how they compare to the fraction of phosphorus entering streams or discharged by wastewater treatment plants can be an important component of management. If, for instance, the import of fertilizer is a large percentage of the phosphorus import in a watershed with stream phosphorus problems, managers might choose to focus on best management practices as opposed to waste water treatment plant abatements. An analysis of how phosphorus enters various watersheds across Connecticut has not yet been undertaken. The state should facilitate this analysis in order to compare stream impairment with watershed phosphorus import. This analysis will be helpful when determining the relative importance of different sources of nutrients to eutrophication, and within Connecticut, may help identify the relative contribution of wastewater in the identified high-priority, non-tidal, waste-receiving streams (DEEP, 2014). It may also potentially create better and more spatially explicit land cover loads, such as those used in the Interim Strategy.

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APPENDIX A DESCRIPTION OF MODIFIERS

Waste Water Treatment Plants (WWTP): Wastewater treatment plants actively remove phosphorus. This is pursued by WWTP's through both abiotic and biotic processes (Morse et al., 1998). The degree of phosphorus removal is dependent on the technologies used.

Combined Sewer Overflow (CSO): Combined sewer overflow systems allow for the direct input of untreated sewage into waterways following storms. Because this sewage bypasses the removal processes that occur in WWTP, it leads to a greater percentage of phosphorus watershed inputs being added to waterways (Buerge et al., 2006). Mitigating CSO can decrease the amount of phosphorus inputs that make it to waterways.

Wetlands and Riparian Zones: Wetlands and riparian zones actively remove phosphorus through burial in soils and uptake into plant material (Vymazal, 2007). Thus these natural or constructed ecosystems can actively remove phosphorus added to a watershed and their historic removal or restoration can impact the removal efficiency of watersheds.

Septic Systems: Well-maintained septic systems filter out phosphorus from the environment. Septic systems, however, can actively leak phosphorus to soils and ultimately inland waters. The degree of septic maintenance in a watershed can thus impact the percentage of phosphorus added from this source (Arnscheidt et al., 2007).

Agricultural and Lawn Management: A large proportion of phosphorus imported to many watersheds is in the form of fertilizer. Ecosystems have some ability to remove a percentage of the phosphorus that enters a watershed through this pathway. Proper management of fertilizer and manure (e.g., Best Management Practices [BMP]) can reduce the amount of fertilizer exported to inland waters from these landscapes (Sharpley et al., 2000; Rao et al., 2012).

Water Flows: The timing and magnitude of freshwater flows are impacted by human activities such as damming and water withdrawals. These actions can impact the temperature, light field and residence time of inland waters and can indirectly alter phosphorus uptake by biota and the expression of eutrophication in inland waters (Schindler, 2006).

N:P Ratio: The ratio of nitrogen to phosphorus determines the degree of nitrogen, phosphorus, or co-limitation in inland waters, and varying N:P ratios can result in different uptake responses given the same phosphorus addition rate, and management of both nutrients (opposed to just one) can result in different system responses (Elser et al., 2007).

Light Field: The uptake of phosphorus in some inland waters, particularly streams, can be limited by light (Pan et al., 1999; Dodds, 2006). Land-use processes that remove tree canopy cover adjacent to streams can remove this light limitation and lead to enhanced algal growth.

Grazing: Grazing can provide top down control on algal growth and alter the response of algae to nutrients in streams and lakes. Thus the types of organisms present in inland waters can impact whether specific systems become eutrophic. Removal of top predators such as bass

has been demonstrated to increase rates of algal growth with phosphorus additions loading (Carpenter et al., 2001).

Sediment Phosphorus: Phosphorus can build up in inland water sediments during years of phosphorus pollution. Sediments can then be a source of phosphorus in years following phosphorus pollution reduction and cause a lag in ecosystem recovery (Sondergaard, Jeensen et al. 2003).

Water Temperature: The biological rates of primary production and decomposition can be regulated by temperature. Oxygen solubility and species diversity are also impacted by temperature, and thus water temperature can have direct and indirect rates on system response to phosphorus additions loading.

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APPENDIX B
INTERIM PHOSPHORUS REDUCTION STRATEGY FOR
CONNECTICUT FRESHWATER NON-TIDAL
WASTE-RECEIVING RIVERS AND STREAMS
TECHNICAL SUPPORT DOCUMENT
LAST REVISED: APRIL 24, 2014

The Interim Strategy can be accessed by web link at:

http://www.ct.gov/deep/lib/deep/water/water_quality_standards/p/interimgntphosstrat_042614.pdf

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APPENDIX C RESPONSE PARAMETERS

The following are potential response parameters that can be used to measure the impact of phosphorus pollution on streams and rivers.

Algal Biomass as Ash-Free Dry Mass: AFDM is an indicator of algal biomass. It measures both living and non-living organic matter, which can be a problem in deciphering only algal biomass (USEPA 2000).

- **Pros:** Can measure biomass more evenly than Chl-*a* measurements, which can be patchy (Stevenson et al. 2006)
- **Cons:** Can consist of non-living organic matter and no satisfactory method exists to separate algae from detrital material; therefore, Chl-*a* is the preferred indicator of algal biomass (USEPA 2000)

Algal Biomass as Chlorophyll *a*: The overall biomass of algae is often used as an indicator of phosphorus loading (USEPA 2000; Stevenson et al. 2006; Miltner 2009). High biomass levels are found in systems that are impaired by phosphorus loading. Chlorophyll *a* (Chl-*a*), a photosynthetic pigment, is often used as an indicator of algal biomass (USEPA 2000). High chlorophyll *a* values are correlated with phosphorus enrichment (USEPA 2000, Stevenson et al. 2006, Miltner 2009).

- **Pros:** Direct measurement of biomass, a main response of nutrient enrichment
- **Cons:** There is a large amount of spatial variation in benthic biomass. Sampling a pool or a nearby riffle, for instance, could lead to contrasting levels. Even with a riffle area, biomass levels can be very patchy (Stevenson et al. 2006). Therefore, designing and implementing sampling and analysis is difficult. Also, Chl-*a* is more strongly correlated with total phosphorus (TP) in lakes and is a better measure for lakes than stream systems (Dodds et al. 1998).

Algal Biomass as % Cover of Bottom by Nuisance Algae: Coverage of a stream bed by nuisance algae is a common response to nutrient enrichment (USEPA).

- **Pros:** Visible indicator of nutrient enrichment
- **Cons:** Thickness of algal mat is not taken into account in measure; therefore, algal biomass can be misinterpreted if a thin layer covers a larger extent than a thicker layer; not a reliable measurement of algal biomass (USEPA 2000)

Algae N:P Stoichiometry: Measuring nitrogen and phosphorus in periphyton can help decipher which is limiting the growth of algae in a system (USEPA 2000, O'Brien, Wehr 2009; Finlay et al. 2011). Cellular N:P ratios in benthic algae provide a more direct method for understanding nutrient limitation than simply measuring N:P ratios in the water column (USEPA 2000).

- **Pros:** Better understanding of nitrogen and phosphorus limitation in the system (O'Brien, Wehr 2009)
- **Cons:** Can provide a more direct suggestion of limitation (Bothwell 1989), but bioassays are still required to examine nutrient limitation relationships (USEPA 2000).

Algal Species Composition: Monitoring algal species composition can aid in assessing a stream's trophic condition. For instance, it is important to note if the algal composition is made up of nuisance algae or if there has been a significant change from the target communities previously present (USEPA 2000). The response of nutrient impairment is often documented through three indicators of algal species composition: diversity, change from baseline reference condition composition, and weighted-average autecological response parameters describing pollution tolerance (USEPA 2000).

- **Pros:** More robust indicator of trophic status and stream health (USEPA 2000)
- **Cons:** Takes more time to identify algal species composition than to measure Chl-*a* (USEPA 2000)

Autotrophic Index: The autotrophic index is the ratio of ash-free dry mass (AFDM) to Chl-*a* (USEPA 2000). This ratio helps clarify if a stream is influenced by organic or inorganic enrichment (USEPA 2000). A stream with a low ratio is relatively free of non-chlorophyll organic matter (e.g., particulate organic matter) while a high ratio indicates a greater amount of organic matter and organic matter decomposers. While ratios over 400 tend to result from organic enrichment, ratios of 250 can indicate the dominance of inorganic pollution and eutrophication problems (USEPA 2000).

- **Pros:** Helpful to distinguish between organic and inorganic enrichment
- **Cons:** Can be artificially influenced by non-living organic detrital material, skewing proportions (USEPA 2000)

Conductivity: Specific conductance, calculated as conductivity, can also serve as a proxy for nutrient impairment (USEPA 2000). Conductance is influenced by the amount of macro-ions in a system, and heavily reflects the geology of the stream (USEPA 2000). Therefore, an abundance of phosphorus dissolved from bedrock can be positively correlated with the concentration of total ions (USEPA 2000).

- **Pros:** Simple to measure; can be used to rule in/out other causes of stream biological impairment, may help identify effluent-dominated segments.
- **Cons:** There may be additional factors, besides nutrients, in streams that can lead to high conductivity. For instance, high amounts of dissolved salts can interfere.

Diatoms: The type of diatom (a specific group of algae) present in streams is determined by a number of different factors (Hill et al. 2001, Gothe et al. 2013). One such factor is the concentration of limiting nutrients, often phosphorus (Black et al. 2011; Gothe et al. 2013). Each species of diatom has a concentration range where it can outcompete other species and become dominant (Black et al. 2011). Thus the type of diatom present with low nutrient concentrations will be different than the type present with high concentrations (Hill et al. 2001; Black et al. 2011; Bae et al. 2014). For example, the mobile rather than sessile (i.e., fixed in space) diatom

species are most strongly correlated with nutrient pollution (Kelly and Whitton 1998, Jarvie et al. 2002). Diatoms have therefore long been used as an index of pollution. The Trophic Diatom Index (TDI), for instance, was created for English streams and rivers to assess the biological integrity of temperate aquatic systems (Kelly and Whitton 1995). These types of indices relating phosphorus loading to diatom diversity patterns require ground-truthing studies that link pollution levels to community presence.

- **Pros:** Less impacted by other stressors than fish or invertebrates. Demonstrated direct link to phosphorus (Charles et al. 2010; Smucker et al 2013). Initial ground-truth work already conducted in Connecticut.
- **Cons:** Time consuming and challenging for a non-expert to identify taxa; therefore, not a useful index for volunteer stream monitoring programs.

Dissolved Oxygen (DO): DO levels are intricately connected to the processes of plant and bacteria growth. During the day photosynthesis adds DO to streams and rivers and lakes, while respiration consumes DO during all hours. The amount of oxygen in a stream is dependent on the balance of these two processes coupled with the ability of the stream to re-equilibrate with atmospheric O₂ (a process often called re-aeration). In many systems, DO follows a pattern of increasing concentrations during the day, and decreasing them at night (Figure C-1; Trench 2004).

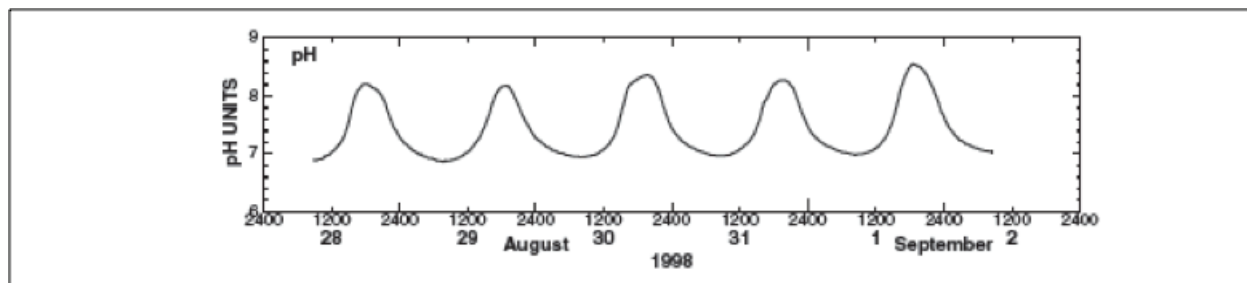


FIGURE C-1: DIURNAL FLUX IN DO IN RESPONSE TO ALGAL PHOTOSYNTHESIS AT THE QUINEBAUG RIVER (COTTON ROAD BRIDGE NEAR POMFRET LANDING, CT, USGS GAGE: 01125520) FROM 8/28/1998-9/2/1998. (SOURCE: TRENCH 2004)

Excess nutrient levels, especially of phosphorus and nitrogen, can fuel algal growth, promoting DO production and increasing respiration due to the respiration of the algae and consumers of the algae. This increased production and consumption of DO leads to larger peaks and troughs in the diurnal pattern shown in Figure C-1. The consumption of DO by algae and algae consumers can also occur over different temporal or spatial scales than DO production, and can lead to hypoxic conditions (especially in stagnant and stratified waters) that can make it difficult for macroinvertebrate and fish taxa to survive (Miranda et al. 2000). The adverse effects of low DO tend to be more evident in low-flowing, less aerated, deeper waterbodies than shallow rivers with high flow and adequate aeration (Allan and Castillo 2007). Typically, an acceptable concentration of DO for a healthy ecosystem is greater than 5 mg/L (Heiskary 2008). However, various species require different levels of DO to thrive; therefore, abrupt changes in DO can significantly alter an entire ecosystem state (Caraco et al. 2006). Extreme day-night swings in DO have been found to be strongly correlated with high summer TP levels (Heiskary 2008). Moreover, low DO stemming from nutrient pollution can lead to other issues that deteriorate ecosystem habitat for macroinvertebrates and fish, including the release of toxic metals from sediments and the ability for harmful ammonia and hydrogen sulfide to be more

readily available (Brick and Moore 1996). Thus, monitoring both the concentration and variation of DO is potentially useful as an indicator of phosphorus loading.

- **Pros:** Due to new sensor technology (e.g., <http://pme.com/HTML%20Docs/miniDOT.html>) it is now fairly simple and relatively cost effective to measure DO (Beaulieu et al. 2013). Diurnal DO variation is a direct result of systems that are suffering from a response to summertime phosphorus (Heiskary 2008; Cohen et al. 2013). Integrate over a stream reach (tens to hundreds of meters).
- **Cons:** Some variation due to strength of re-aeration, which is not as easy to measure (Correa-González et al. 2014).

Dissolved Organic Carbon (DOC): DOC serves as a vital source of energy for the heterotrophic community (USEPA 2000). DOC is associated with the autotrophic index (USEPA 2000). Additionally, nutrient enrichment can lead to high autochthonous (e.g., phytoplankton produced DOC) DOC production rates (USEPA 2000).

- **Pros:** DOC can have an impact on multiple stream modifiers, including light penetration, pH, and stream metabolism.
- **Cons:** It may be challenging to pinpoint a direct response to nutrients.

Fish: Fish are indirectly related to phosphorus levels. The effects of nutrient pollution from phosphorus and nitrogen contribute to a decline in fish diversity through a variety of pathways, such as habitat degradation, reduced DO levels, and changes in food source and quality. Additionally, the fish index of biotic integrity (IBI) scores, usually based on seven metrics of fish sampling at a site, tends to decrease with increases in phosphorus (Heiskary 2008). However, studies have found variation in fish diversity in relation to phosphorus, so it is not as reliable an index as diatoms, for example.

- **Pros:** Easy to identify; of recreational and economic value
- **Cons:** Indirectly instead of directly influenced by phosphorus; can be difficult to eliminate other confounding factors that could lead to impairment. Sampling is resource intensive.

Invertebrate Grazers: Types of grazers present can control the response of the system to nutrient impairment, as discussed in Appendix A. For instance, if grazers that consume algae are highly abundant, there may not be a significant increase in algal biomass from phosphorus enrichment (USEPA 2000).

- **Pros:** Better understanding of the trophic status and biotic integrity of the system
- **Cons:** Grazers may change with the season and appear at unpredictable times

Macroinvertebrates: In streams and rivers that are impaired by phosphorus loadings, the number and type of macroinvertebrates (small animals) present is altered (Heiskary 2008). Macroinvertebrate measurements or macroinvertebrate multimetric Indices (MMI) are bioassessment tools typically used to assess the biological integrity of a stream or river (USEPA 2000). MMI evaluations record multiple attribute measures related to benthic macroinvertebrate condition, such as richness, evenness, and composition.

- **Pros:** Macroinvertebrates are more easily identifiable with training than other response parameters, such as diatoms. Strongly connected to a designated use of aquatic life protection and Connecticut has a well-developed program that includes MMIs and BCG assessment techniques.
- **Cons:** Other stressors in addition to phosphorus enrichment can influence macroinvertebrate communities, potentially masking the primary cause of impairment; indirectly instead of directly influenced by phosphorus. Fairly time consuming to survey.

Macrophytes: Macrophytes include emergent, floating-leaved, submergent, and free-floating aquatic plants that are visible to the eye (USEPA 2000).

- **Pros:** Knowledge of bottom sediment nutrient concentrations, which macrophytes uptake (USEPA 2000)
- **Cons:** Submerged macrophyte growth can be impaired by reduced light availability caused by increased phytoplankton (USEPA 2000); therefore, the relationship between nutrients and macrophytes is not as direct as diatoms, for instance

Phosphorus Concentrations. Phosphorus levels in lakes are strongly correlated with impairment. Studies have demonstrated that the relationship between phosphorus level and impairment can be shown by just controlling for residence time of lake water (Vollenweider, 1976). The flowing nature of streams, coupled with a higher degree of complexity in the amount of light reaching streams, leads to low statistical power between phosphorus concentration and impairment (Figure 2-3: Impact Modifiers and the Water Quality Standard). There could be streams with high phosphorus concentrations, for instance, and no aquatic life impairment. Furthermore, the degree of phosphorus variation in stream systems is much higher than in lakes. Thus, determining the “average” phosphorus concentration in a stream is much more expensive and time consuming than for a lake.

- **Pros:** Measuring pollutant directly. Potentially satisfactory for large rivers.
- **Cons:** High variability in concentration and response (Trench 2004).

pH: Changes in pH, or the concentration of hydrogen ions, can lead to stress on aquatic systems (USEPA 2000). The pH of a stream is partly determined by the concentration of carbon dioxide (CO₂). Therefore similar to dissolved oxygen, pH levels are responsive to respiration and photosynthesis (Figure C-2; Trench 2004).

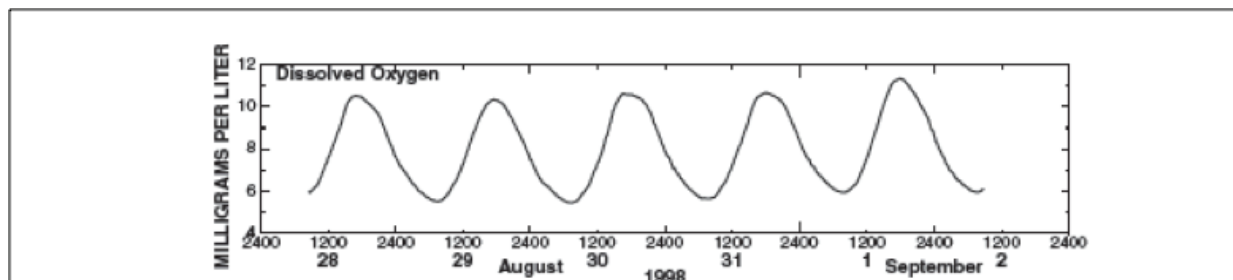


FIGURE C-2: DAILY FLUX IN pH IN RESPONSE TO ALGAL PHOTOSYNTHESIS AT THE QUINEBAUG RIVER (COTTON ROAD BRIDGE NEAR POMFRET LANDING, CT, USGS GAGE: 01125520) FROM 8/28/1998-9/2/1998. (SOURCE: TRENCH 2004)

During excess primary production fueled by nutrients (i.e., phosphorus, nitrogen), CO₂ consumption leads to increased pH levels, which can alter aquatic community structure (USEPA 2010). pH fluctuates daily in relation to algal metabolism.

- **Pros:** Can be easily measured with dissolved oxygen. Integrates over stream segments.
- **Cons:** pH of a stream is strongly regulated by surficial soil chemistry and is highly variable in Connecticut waters. Daily variation in pH is also dependent on the buffering capacity of a stream, which is also partly determined by surficial soil chemistry.

Phosphatase Activity: Algae excrete an enzyme when phosphorus is limited, called alkaline phosphatase (USEPA 2000). This enzyme can be used as a proxy of phosphorus limitation in the water column.

- **Pros:** Better understanding of phosphorus limitation in the system (USEPA 2000)
- **Cons:** Relatively expensive to comprehensively monitor

Pigment Ratios: Two additional ratios for assessing benthic algae include a reverse of the autotrophic index, Chl-*a*:AFDM, and Chl-*a*: phaeophytin (another algae pigment), which is a descriptor of periphyton health (USEPA 2000).

- **Pros:** Provides various tools to analyze benthic algae
- **Cons:** AFDM still can include non-living particulate organic matter (USEPA 2000)

Primary Production: Primary productivity is a direct indicator of nutrient enrichment (USEPA 2000).

- **Pros:** Directly related to nutrient enrichment
- **Cons:** Difficult to measure

Temperature: Higher temperatures speed up the effects of nutrient enrichment (USEPA 2000). Though the maximum algal biomass is controlled by the nutrients available, the rate at which the maximum is achieved will be faster at increased temperatures. Furthermore, temperature in combination with light and nutrients influences the type of algal taxa present, as different taxa have varying optimum thermal thresholds (USEPA 2000). For instance, many types of algae (and blue-green algae, which are actually cyanobacteria) tend to thrive at higher temperatures than diatoms; however, as a general matter, nutrient enrichment is a stronger variable than temperature and plays a larger role in dictating the algal taxa present (USEPA 2000).

- **Pros:** Simple to measure
- **Cons:** Other variables can override temperature effects; weak indicator (USEPA 2000)

Toxic Algal Species: Harmful algal blooms (HAB), mostly due to cyanobacteria in freshwaters, are more frequent with increased nutrients. Blooms of cyanobacteria can form high biomass blooms that can lead to the production of toxins and or taste and odor problems. Blooms of harmful cyanobacteria are often seen as an indicator of nutrient over-enrichment (Lopez et al. 2008).

- **Pros:** Important index for human health (drinking water and recreational designated uses) (Glasgow et al. 1995)
- **Cons:** Difficult and expensive to measure. System can have phosphorus problems without HAB development.

Water Clarity: Reduced water clarity, or increased turbidity, can occur due to a variety of factors that cause changes in color and amount of suspended sediments. Single-celled algae are a form of suspended sediments and therefore increased phosphorus and nitrogen have been associated with increased suspended sediments (USEPA 2000). Furthermore, suspended sediments originating from erosion also contain phosphorus, further linking water clarity to phosphorus loading (USEPA 2000). Finally, decreases in water clarity can limit macrophyte growth and contribute to the formation of dense algal mats, altering stream ecosystems (USEPA 2000).

- **Pros:** Relatively easy to measure; can be used to rule in/out other causes of stream biological impairment.
- **Cons:** Not a clear stressor-response relationship between increased TP and reduced water clarity. Rather, water clarity can be influenced by multiple factors (e.g., geomorphology), one of which is increased phosphorus (USEPA 2000). There are also large differences in water clarity with stream size.

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APPENDIX D
OPTIMIZATION MATRIX RESULTS
BASED ON RANKINGS BY EXPERTS ON THE
CASE STUDY COMMITTEE

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				

APPENDIX E REGRESSION TABLE AND FIGURES

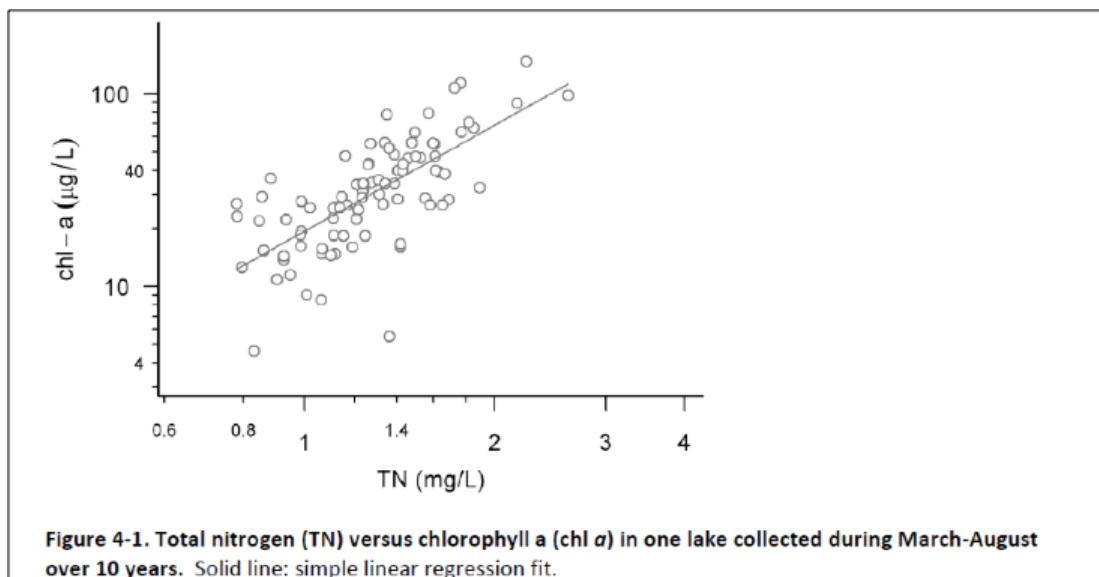
Simple Linear Regression (Table 4-2)

	Pros	Cons
Simple Linear Regression	Easiest to interpret Can incorporate classification	Relationship has to be linear
Multiple Linear Regression	Incorporates more than one response parameter	Relationships have to be linear Danger of overfitting model
Quantile Regression	Relaxes the SLR assumption of normal distribution of residuals	Estimates at high and low ends are often imprecise Still relies on linear relationship
Nonparametric regression	Does not require linear relationship	More data generally required
Nonparametric Changepoint Analysis	Can be used when a threshold exists in data (non-linear response)	More data generally required Might need to establish that values below threshold support designated uses

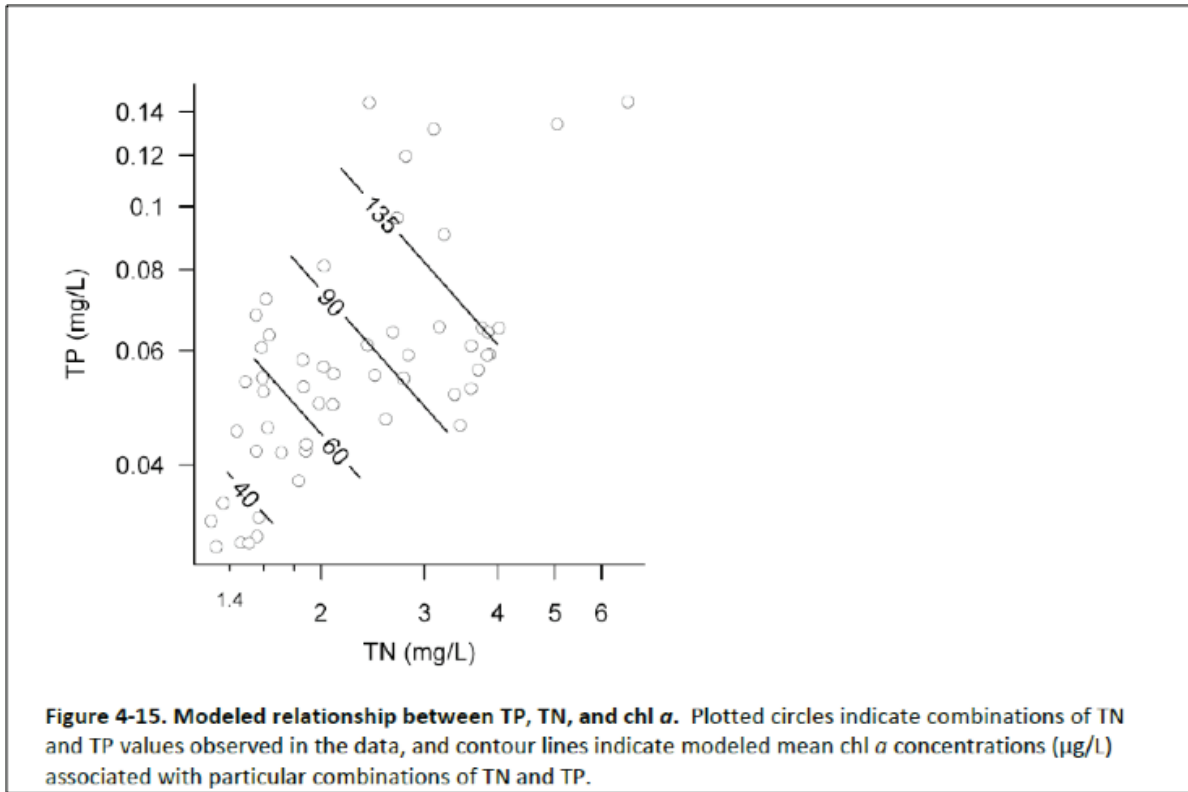
Examples of Regression Approaches Recommended by EPA

All graphs are from EPA report “Using stressor response relationships to derive numeric nutrient criteria” (EPA 2010).

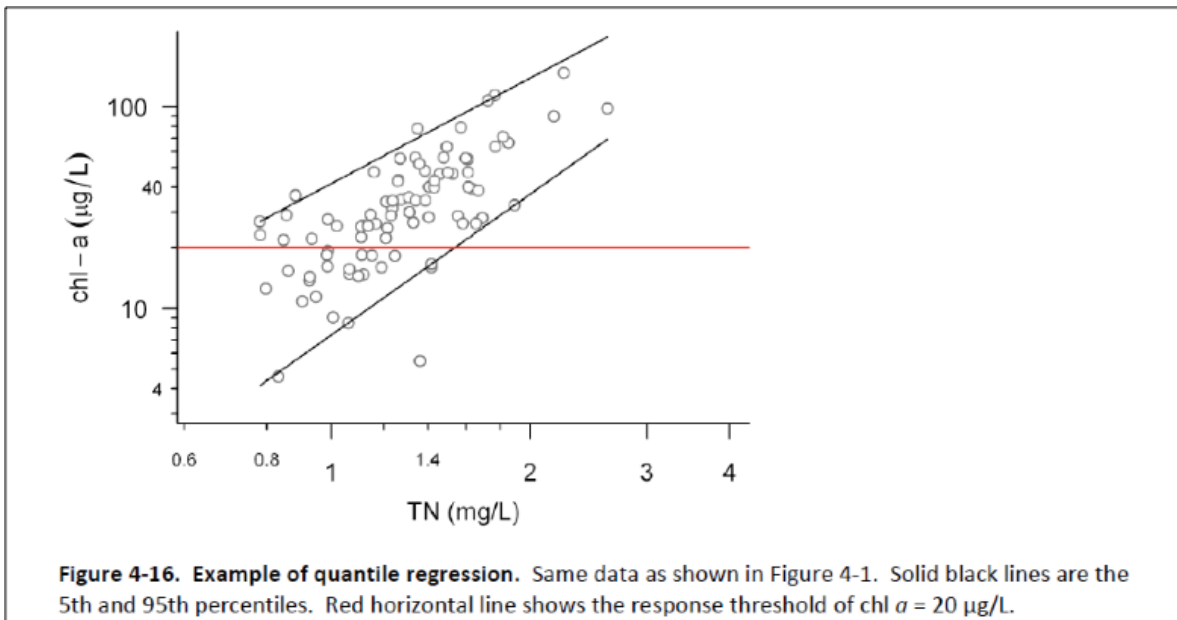
- **Simple Linear Regression**



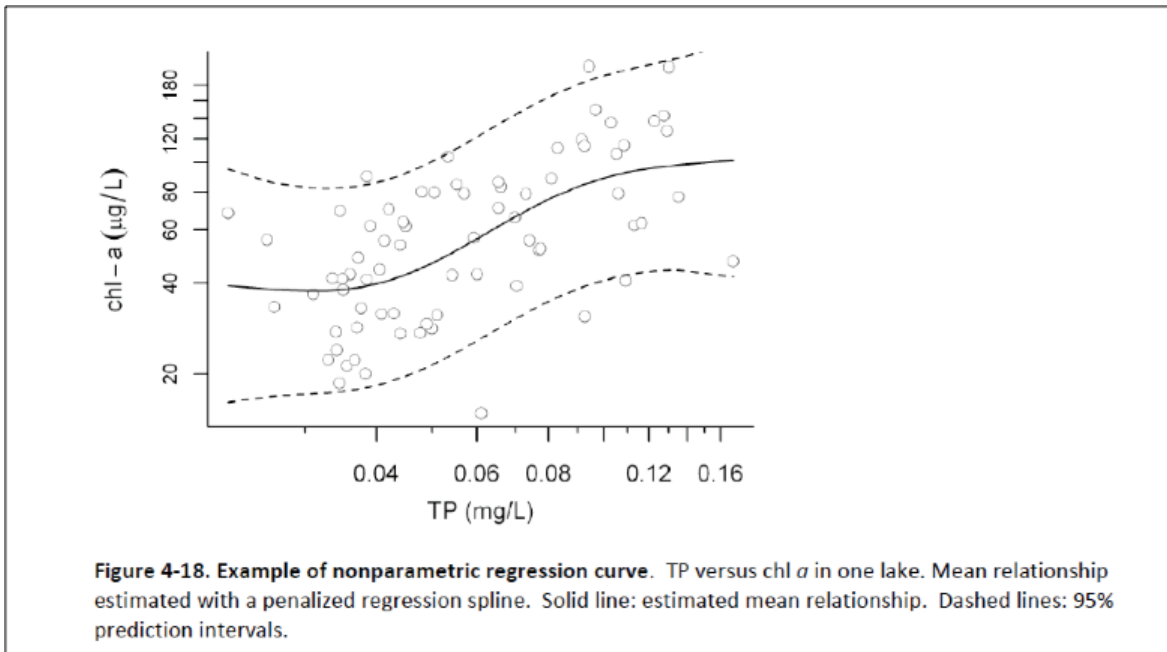
- Multiple Linear Regression



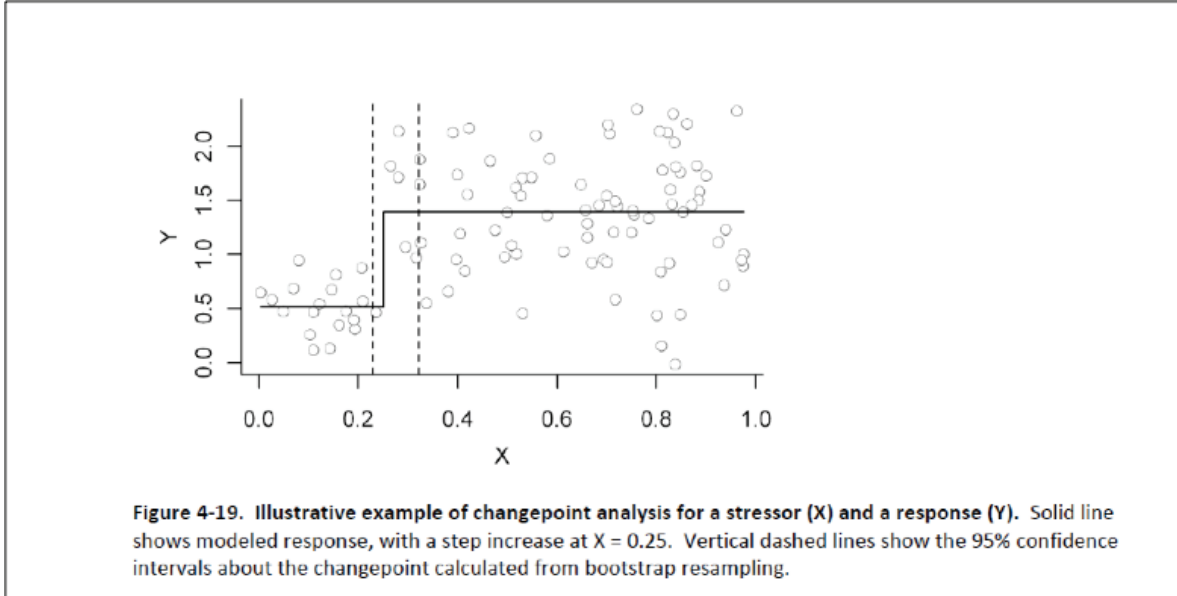
- Quantile Regression



- **Nonparametric Regression**



- **Nonparameteric Changepoint Analysis**



APPENDIX F EXAMPLES OF PHOSPHORUS CRITERIA DEVELOPMENT EFFORTS BY STATES

The following is a listing of phosphorus criteria development efforts by seven states with links provided for additional information.

Maine: Maine uses a multiple regression model called the diatom total phosphorus index (DTPI) to predict phosphorus concentrations based on diatom communities. The DTPI was developed with forward step-wise regression techniques based on a subset of 180 diatom species with TP coefficients collected from 123 samples (Danielson 2009).

For additional information, please access the reference here:
http://www.maine.gov/dep/water/nutrient-criteria/sop_dtpi_dtni.pdf

Massachusetts: Massachusetts released a 2013 map detailing areas for nutrient management efforts.

For additional information, please access the reference here: <http://www.mass.gov/eea/agencies/massdep/water/watersheds/massachusetts-nutrient-management-report-2013.html>

Minnesota: Minnesota developed technical reports for deriving numeric phosphorus criteria and determining the relationship between phosphorus and potential confounding factors.

For additional information, please access the references here:
www.pca.state.mn.us/index.php/view-document.html?gid=14947
www.pca.state.mn.us/index.php/view-document.html?gid=6072

Montana: Montana released technical reports detailing numeric phosphorus criteria development for both wadeable and large rivers. The state developed a combined criteria implementation process.

For a listing of technical reports with additional information, please access the references here:
<http://deq.mt.gov/wqinfo/standards/NumericNutrientCriteria.mcp>

The most recent updated final reports include:
<http://deq.mt.gov/wqinfo/Standards/PDF/LowerYellowstoneModel2013/WQPBDMSTECH22FinalCombo.pdf>
<http://deq.mt.gov/wqinfo/Standards/PDF/ScienceTech2013FnlCom.pdf>

New Jersey: New Jersey developed numeric phosphorus criteria and a technical manual for evaluating phosphorus levels for surface water permits. The New Jersey Department of

Environmental Protection advises sampling during low flows and monitoring diurnal dissolved oxygen and Chl-*a*, among other water quality parameters.

For additional information, please access the reference here:
www.nj.gov/dep/dwq/pdf/p-manual-07-30-08.pdf

Ohio: The Ohio Lake Erie Phosphorus Task Force II Final Report was released in November 2013, as an update to the April 2010 report. The state is developing the Ohio Phosphorus Index, which is being updated and will include results from field studies to evaluate best management practices for agricultural activities. Another study also demonstrated the significance of deriving nutrient criteria in Ohio based on stressor-response relationships (Miltner 2010). In particular, diurnal dissolved oxygen, total phosphorus, and Chl-*a* were considered to be among the most important indicators to measure (Miltner 2010).

For additional information, please access the references here:
http://lakeerie.ohio.gov/Portals/0/Reports/Task_Force_Report_October_2013.pdf
http://epa.ohio.gov/portals/35/lakeerie/ptaskforce/Task_Force_Final_Report_April_2010.pdf

Vermont: Vermont released a draft of proposed nutrient criteria for inland lakes and wadeable streams in February 2014. To derive the phosphorus criteria, the state analyzed the indices of summertime TP, Chl *a*, and Secchi depth readings with a Kruskal-Wallis One Way Analysis of Variance on Ranks, Dunn's method, and logistic regression.

For additional information, please access the reference here:
http://www.watershedmanagement.vt.gov/mapp/docs/mapp_nutrient-tds_2-21-14.pdf

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MAJOR STUDIES OF THE ACADEMY

2014

- Energy Efficiency and Reliability Solutions for Rail Operations and Facilities
- Connecticut Biomedical Research Program: Analysis of Key Accomplishments
- Peer Review of a CL&P/UConn Report Concerning Emergency Preparedness and Response at Selective Critical Facilities
- Connecticut Disparity Study: Phase 2
- The Design-Build Contracting Methodology for Transportation Projects: A Review of Practice and Evaluation for Connecticut Applications
- Peer Review of an Evaluation of the Health and Environmental Impacts Associated with Synthetic Turf Playing Fields

2009

- A Study of the Feasibility of Utilizing Waste Heat from Central Electric Power Generating Stations and Potential Applications
- Independent Monitor Report: Implementation of the UCHC Study Recommendations

2008

- Preparing for Connecticut's Energy Future
- Applying Transportation Asset Management in Connecticut
- A Study of Weigh and Inspection Station Technologies
- A Needs-Based Analysis of the University of Connecticut Health Center Facilities Plan

2007

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- Guidelines for Developing a Strategic Plan for Connecticut's Stem Cell Research Program

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- Evaluating the Impact of Supplementary Science, Technology, Engineering and Mathematics Educational Programs
- Advanced Communications Technologies
- Preparing for the Hydrogen Economy: Transportation
- Improving Winter Highway Maintenance: Case Studies for Connecticut's Consideration

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- Connecticut Stem Cell Research Program Accomplishments

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- Alternative Methods for Safety Analysis and Intervention for Contracting Commercial Vehicles and Drivers in Connecticut

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CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING

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