Recommendations for Phosphorus Strategy Pursuant to PA 12-155

Final Report

February 16, 2017

Coordinating Committee – Phosphorus Reduction Strategy

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1. Executive Summary

Public Act 12-155[1] required the Connecticut Department of Energy and Environmental Protection (CT DEEP) and municipalities impacted by the interim state-wide strategy to reduce phosphorus to collaboratively evaluate and make recommendations regarding a state-wide strategy to reduce phosphorus loading in inland non-tidal waters in order to comply with standards established by the United States Environmental Protection Agency.

This report quotes from, summarizes, and paraphrases the reports of three workgroups that were tasked with providing recommendations to a coordinating committee assembled to oversee the fulfillment of the requirements of the public act.

Information regarding the history and background of phosphorus control in Connecticut is provided, along with a brief explanation of why phosphorus control is important. The full reports of the workgroups, as well as the interim current phosphorus control strategy are included as appendices.

In summary, the Coordinating Committee concurs with the conclusions and recommendations of the three workgroups, which are summarized as follows:

- Connecticut's "Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams" was justified and a reasonable approach based on the state of nutrient science and management options.

- CT DEEP as well as Connecticut's municipalities should continue the regulatory programs already in place to reduce phosphorus, utilizing current and enhanced strategies.

- CT DEEP should carry out the nine recommendations contained in the CASE Report. Among these recommendations, first priority should be

[1] See Appendix A

assigned to the addition of diurnal dissolved oxygen sampling to CT DEEP's sampling of diatom communities.

- CT DEEP should develop a conceptual implementation plan and periodically post on its website a progress report of the efforts being undertaken to implement the CASE Report recommendations.

- CT DEEP, together with partners, should continue, expand and enhance non-regulatory phosphorus reduction programs already in place wherever possible.

- CT DEEP and municipalities should continue to explore cost-effective best management practices and treatment technologies for phosphorus management.

- CT DEEP and municipalities should continue to consider integrated management approaches for managing both point and nonpoint sources of pollution.

2. History of the Project and Background

This report provides the Coordinating Committee's evaluation and recommendations regarding a state-wide strategy to reduce phosphorus loading in inland non-tidal waters in order to comply with standards established by the United States Environmental Protection Agency (EPA).

Public Act 12-155

This report was prepared in accordance with the requirements of Public Act 12-155. Section 1 of PA 12-155 required that:

> 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 state-wide strategy to reduce phosphorus, or such chief elected official's designees, shall collaboratively evaluate and make recommendations regarding a state-wide 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 evaluations and recommendations shall include:
>
> 1. a state-wide 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 phosphorus levels in inland non-tidal waters and to make future projections of phosphorus levels in such waters.

Section 22a-428a

PA 12-155 was codified as Section 22a-428a of the Connecticut General Statutes, and in furtherance of the public act, required the commissioner to submit a report to the joint standing committees of the General Assembly having cognizance of matters relating to municipalities and the environment. The statute requires that the report set forth the recommendations required pursuant to sections 1, 2, and 3 of the Act and detail the collaborative effort through which such recommendations were reached.

Collaborative Process

In order to fulfill the collaboration requirements and meet the goals of Public Act 12-155, a coordinating committee and three subcommittees/workgroups were convened. All municipalities affected by the state-wide strategy were invited to participate in this process.

Coordinating Committee

The Coordinating Committee consists of two co-chairs and the co-chairs of the three sub-committees. The committee met as needed to coordinate and integrate the activities of the three workgroups and to address issues which cut across the scopes of the workgroups.

Workgroup 1: Nonpoint Source (NPS) Phosphorus Workgroup

The charge of this workgroup was to determine a statewide response to address phosphorus nonpoint source pollution. This workgroup utilized the *CT DEEP Nonpoint Source Management Program Plan Update* as a starting point for nonpoint source phosphorus management programs. (http://www.ct.gov/deep/lib/deep/water/nps/planupdate/ct_nps_plan_final.pdf)

Over the course of two years there were 10 workgroup meetings and three subcommittee meetings.

The *Scope of Work for the NPS Phosphorus Workgroup*[2] included assessing existing information, identifying current problems and issues, analyzing the problems, developing goals and objectives, identifying alternative solutions, and recommending next steps.

Workgroup 2: Scientific Methods Workgroup

The charge of this workgroup was to propose scientific methods to measure current phosphorus levels and to make future projections of phosphorus levels. In

[2] See Appendix G

consultation with the workgroup, the Coordinating Committee contracted with the Connecticut Academy of Science and Engineering (CASE) to conduct a detailed study. The workgroup met several times over a two year period and coordinated closely with CASE regarding the study conducted.

The *Scope of Work for the Scientific Methods Workgroup*[3] included determining how phosphorus impacts water quality and what factors are important in Connecticut, describing Connecticut's current approach to addressing phosphorus to achieve Water Quality Standards, determining how phosphorus impacts can be measured in non-tidal waters such that relevant contributing stressors are considered in order to achieve Water Quality Standards and recommending methodologies that are appropriate for use in Connecticut to measure phosphorus impacts on water quality and aquatic life and other designated uses.

Workgroup 3: Municipal Implementation Workgroup

The goal of this workgroup was to propose approaches and guidance for municipalities to comply with DEEP Water Quality Standards based on EPA criteria for phosphorus; in particular, wastewater treatment and treatment plant upgrades. This workgroup met monthly over a two year period.

[3] See Appendix H

3. Phosphorus

The Role of Phosphorus in the Environment and its Impact on Water Quality

Phosphorus is a naturally occurring element that is essential to support plant growth. When present in excessive amounts, phosphorus contributes to a process called “eutrophication.” Eutrophication means excessive richness of nutrients in a lake or other body of water which causes a dense growth of plant life and death of animal life from lack of oxygen.

Eutrophication is a serious threat to water quality in Connecticut. Excessive loading of phosphorus can lead to algal blooms including blooms of noxious blue green algae, reduction in water clarity, and in extreme cases, depletion of oxygen, fill kills, and significant impairment to aquatic life. Nutrient enrichment has been identified as one of the most pressing water quality issues facing the nation as a whole.

Sources and Factors in Connecticut

Excessive loading of phosphorus can occur as a result of point sources such as discharges from municipal water pollution control facilities (WPCFs) or nonpoint sources such as runoff from urban and agricultural lands, or a combination thereof. In addition, erosion can release phosphorus that is contained in soils, allowing release of phosphorus-laden sediments in runoff. Previously deposited phosphorus can also be released from lake and pond bottoms depleted of oxygen when mixing of the bottom layer of these waters with upper layers occurs due to wind or lowering temperatures. This phenomenon is known as internal loading.

Some of the major contributors of phosphorus to these point and non-point discharges are human waste, animal wastes and manures and phosphorus fertilizers. Other sources include leaf litter, yard waste, and pet waste.

4. Connecticut DEEP's Interim Phosphorus Strategy, and the US EPA's Oversight of Water Quality Standards

Background

As a result of the high percentage of water bodies listed for nutrient-related impairments in the United States, the United States Environmental Protection Agency (EPA) has targeted nutrient pollution reduction a priority. EPA encouraged states to accelerate reduction of nutrients by prioritizing watersheds on a state-wide basis and setting load-reduction goals while developing numeric nutrient criteria for state water quality standards. If a discharge is found to cause or contribute to a violation of a water quality standard, NPDES regulations provide that a permit must contain effluent limits to achieve state water quality standards. In order to protect Connecticut water resources and be consistent with EPA guidance and federal regulations, the CT Department of Energy and Environmental Protection (CT DEEP) identified freshwater non-tidal waste receiving streams as a high priority for nutrient loading reductions due to the high phosphorus yields in these water bodies and potential to contribute to water quality impairments.

Connecticut's Interim Strategy

In 2014, CT DEEP released an interim strategy for phosphorus reduction in Connecticut.[4] This strategy was revised from a previous version released in 2009 to address concerns raised by EPA regarding the protection of aquatic life in rivers and streams. The revised strategy identified phosphorus enrichment levels in waste receiving streams that adequately support aquatic life uses. The methodology focused on significant changes in stream algae as the key aquatic life response indicators to excess phosphorus loading.

USEPA review

The methods used to develop the strategy were approved by EPA in a letter dated October 26, 2010[5], as an interim strategy to establish water quality based phosphorus limits in non-tidal freshwaters for industrial and municipal WPCFs National Pollutant Discharge Elimination System (NPDES) permits. EPA's letter

[4] See Appendix B

[5] See Appendix C

states, “We are impressed with the quantity and quality of analyses conducted to date in order to develop the strategy and believe that the approach represents a scientifically sound method for establishing water quality based phosphorus limits for municipal treatment plants and other facilities that discharge pollution.”

Water Quality Standards and Implementation

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. Since their development in 1967, the standards have been revised many times, and in 2013 were codified into regulations.[6] The Water Quality Standards consist of three elements: *Standards*, which designate use goals and set the overall policy for management of surface and ground water quality, *Criteria* that prescribe the allowable parameters and conditions for various water quality classifications required to sustain the designated uses, and *Classification Maps* which show the water quality class use assigned to each surface and ground water resource throughout the state.

The Water Quality Standards are implemented through integration with other statutory and regulatory requirements and programs governing water and waste management. The Water Quality Standards set forth the types of wastewater that can be discharged in various classifications in order to meet statutory goals, and provide the guiding principles concerning waste assimilation, aquatic toxicity and anti-degradation.

The purposes and goals of the Water Quality Standards are laid out in Section 22a-426-3(a) of the Regulations of Connecticut State Agencies:

(1) to provide clear and objective statements for existing and projected water quality and the general program to improve Connecticut’s water resources;

(2) to provide water quality for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water taking into consideration their 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;

[6] See Appendix I

(3) to recognize that surface and ground water are interrelated and address the issue of competing use of ground waters for drinking and for wastewater assimilation;

(4) to 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) to establish designated uses for surface and ground waters and identify the criteria necessary to support those uses;

(6) to 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) to protect the public health and welfare and promote the economic development of the state; and

(8) to be consistent with health standards as established by the Department of Public Health.

Water Quality Standards and Phosphorus

The Connecticut Water Quality Standards (CT DEEP, 2013) incorporate narrative standards and criteria for nutrients. These narrative standards direct CT DEEP to impose discharge limitations or other reasonable controls on point and non-point sources of nutrients which have the potential to contribute to the impairments, to ensure maintenance and attainment of designated uses, and restore impaired waters.

In the absence of numeric criteria for phosphorus, CT DEEP developed the interim phosphorus strategy methodology interpreting the narrative criteria and policy statements in the Water Quality Standards, and to facilitate issuance of NPDES permits to be protective of the environment. These methods were approved by EPA in a letter dated October 26, 2010 as an interim strategy to establish water quality based phosphorus limits in non-tidal freshwaters for industrial and municipal WPCFs NPDES permits until the Department has established numeric nutrient criteria in the Water Quality Standards.

The regulations may be reviewed in full for a complete list of relevant standards.

5. Overview of Current Phosphorus Management Programs and Efforts

Regulatory Programs

Regulatory programs for management of phosphorus focus on both point source discharges and nonpoint source discharges.

Discharge Permits

CT DEEP issues discharge permits in three major categories. While the process for each is similar, specific application requirements may vary.

- **The Surface Water Discharge Permit Program**, also known as the National Pollutant Discharge Elimination System (NPDES) under federal law, regulates discharges into surface waters (either directly or through municipal storm sewer drainage systems, or through other drainage systems such as wetlands or swales).
- **The Ground Water Discharge Permit Program** regulates discharges to ground water from any source, including but not limited to large septic systems, agricultural waste management systems, and waste landfills.
- **The Pre-treatment Permit Program** regulates discharges to a sewage treatment plant through municipal sanitary sewer collection systems, or through combined storm and sanitary sewer systems. All wastewaters (excluding domestic sewage) that are hauled directly to a Wastewater Treatment Plant (WWTP) require either a pre-treatment permit or are regulated under the sewage treatment plant's permit. Domestic sewage hauled directly to a WWTP is regulated by the CT Department of Public Health.

In granting a permit, CT DEEP must determine that the proposed discharges will not cause pollution to the waters of the state. In doing this, a review covers the potential for: 1) any adverse effects on existing and designated uses of the waters of the state as defined in Connecticut's Water Quality Standards and Criteria; 2) any interference with or adverse effects upon the operation of a WWTP; and 3) any treatment systems and control methodologies proposed to counteract such adverse effects and to minimize the discharge of pollutants.

Total Maximum Daily Load (TMDL)

A TMDL is a tool that water quality managers use to address water quality problems through permitting processes. TMDLs provide the framework for restoring impaired waters by establishing the maximum amount of a pollutant that a waterbody can receive without adverse impact to fish, wildlife, recreation, or other uses. This amount is divided up between all potential sources (both point and nonpoint) of that pollutant, and is expressed as: *TMDL = Point Sources + Nonpoint Sources + Background + Margin of Safety.* The end result of the TMDL process is a Water Quality Management Plan with quantitative goals to reduce pollutant loadings to the impaired waterbody. TMDLs can be expressed as concentrations, percent reductions, or mass loads.

Non-Regulatory Programs

CT DEEP Non-regulatory strategies identified by the Nonpoint Source workgroup include the following:

Pollution Prevention

Pollution Prevention (P2), or source reduction, is a logical starting point to reduce nonpoint source phosphorus pollution. P2 emphasizes preventing or minimizing pollution rather than controlling pollution after it is generated. P2 is the most effective nonpoint source pollution control strategy. Numerous P2 practices are available for a variety of land uses and pollution source categories.

Education and Outreach

Where possible, CT DEEP partners with outside groups such as UConn's Nonpoint Source Education for Municipal Outreach (NEMO), often awarding grants to develop outreach programs. In 1992, the University of Connecticut Cooperative Extension System created the NEMO project. Founded on the principles that water quality is a function of land use, and that land use is locally controlled, NEMO uses geographic information systems and other visual aids to provide decision-makers with the information necessary to better protect their water resources.

NEMO delivers research-based, professional technical assistance to Connecticut's 169 municipalities through workshops, publications and the internet. The basic NEMO presentation, *Linking Land Use to Water Quality*, provides training to local land-use decision makers on the connection between land use and water quality, particularly relationships between the amount of impervious surface and degree of water quality impairment. NEMO also provides advanced modules on open space planning and "state-of-the-art" best management practices, which include reducing impervious surfaces, infiltrating runoff on site, and maintaining natural features (e.g. native vegetation, wetlands) to the maximum extent practicable. These programs are delivered on a statewide basis, through targeted efforts in watersheds that are high-priority for Nonpoint Source management.

Agricultural Management and Assistance

Connecticut offers technical and financial support to farm businesses in their farm waste efforts through the "Partnership for Assistance on Agricultural Waste Management Systems." This partnership includes the following agencies: USDA Natural Resources Conservation Service (NRCS), USDA Farm Service Agency, University of Connecticut Cooperative Extension System, Connecticut Conservation Districts, the Connecticut Department of Energy and Environmental Protection and the Connecticut Department of Agriculture.

Through this partnership, a farm business may obtain waste management planning, structure design and qualify for financial assistance as well as help in procuring required permits.

Municipal Technical Assistance

In general, technical assistance is most commonly provided through direct communication with staff, meetings, or correspondence on specific topics, but also through guidance and manuals.

Watershed Based Plans

Watershed based plans are used as a holistic way to assess ambient water quality conditions related to nonpoint sources and propose management measures. Plans generally include modeled assessments of loadings, sources, estimated load reductions, and management measures.

Planning and Implementation Grants

CT DEEP receives yearly Federal Clean Water Section 319 grants. Section 319 of the Federal Clean Water Act is a federal program to control nonpoint sources of water pollution. Funds for matching grants are passed on to communities, regional and local conservation groups, and other stakeholder organizations for nonpoint source projects, plans, and statewide research efforts. Proposals may be submitted by any interested public or private organization. Projects receiving grants may include implementation projects for nonpoint source pollutant load reductions, watershed based plan development, or assessment and implementation of Best Management Practices.

The United States Environmental Protection Agency (EPA) awards small Water Quality Management Planning Grant funds under section 604(b) of the Clean Water Act. Under the federal Clean Water Act, Section 604(b) funds are awarded to State water quality management agencies (CT DEEP) to carry out water quality management planning; performing waste load allocation/total maximum daily loads, point and non-point source planning activities, water quality assessments and watershed restoration plans.

Funding from the Clean Water Fund (CWF) for Phosphorus Removal Projects (PRPs) at Wastewater Treatment Plants

Over the past four years, the Connecticut General Assembly has passed four laws that provide grant funding from the Clean Water Fund (CWF) for municipal phosphorus removal projects (PRP). Currently, the grant funding from the CWF program for PRP is a 30% grant; unless the project meets the conditions in Public Act (PA) 16-57, which makes eleven PRP eligible to receive a 50% grant for a relevant project.

The timeline of phosphorus grant funding from the CWF program is outlined as follows:

- Prior to June 2012, PRPs were eligible for a 20% grant.
- On June 15, 2012, PA 12-155 was passed which increased the grant to 30%.
- On July 1, 2013, PA 13-239 was passed which increased the grant to 50% for three PRPs that met the conditions of the act.
- On May 12, 2014, PA 14-13 passed which expanded the PRP that could receive a 50% grant from three PRPs to 5 PRPs.
- On May 26, 2016, PA 16-57 passed which expanded the PRP that could receive the 50% grant from five PRPs to 11 PRPs.

On May 26, 2016, Public Act 16-57 (*An Act Concerning Phosphorus Reduction Reimbursements to Municipalities*) was passed. This Public Act provided 50% grant funding for eligible PRPs. To qualify for the 50% grant, the municipality must have a permit limit of less than or equal to 0.31 milligrams per liter for phosphorus and enter into a construction contract for the phosphorus reduction project on or before July 1, 2019. This 50% grant funding targeted eleven municipalities with the lowest phosphorus limits. To meet those low limits, the municipality will be using phosphorus reduction treatment processes that have very high capital costs. For PRPs that do not qualify for the 50% grant funding offered through Public Act 16-57, those municipalities qualify for a 30% grant.

6. Workgroup Reports

A. State-wide Response to Address Phosphorus Nonpoint Source Pollution

Background

Workgroup #1, the Nonpoint Source Workgroup, was charged with identifying the relevant sources of nonpoint source phosphorus pollution, identifying reasonable reduction goals, and identifying and assessing methods and strategies to achieve those goals. The report of this workgroup to the coordinating committee[7] dated July 28, 2016, is summarized below.

To develop this statewide response, a Nonpoint Source (NPS) Workgroup made up of municipal representatives, Federal and State environmental professionals, environmental consultants, and academicians was formed to evaluate the sources of phosphorus from NPS pollution. The NPS Workgroup reviewed existing programs that address NPS pollution, studied the status and trends of phosphorus in NPS pollution, and identified and assessed additional methods and strategies to reduce phosphorus from NPS sources. The NPS Workgroup identified and reviewed the sources of phosphorus in NPS sources impacting Connecticut waters. The sources identified by the NPS Workgroup are: urban stormwater runoff, agricultural runoff, fertilizers, soil erosion, internal phosphorus loading from sediments, and on-site wastewater treatment systems. The NPS Workgroup assessed how each identified nonpoint source of phosphorus is currently being addressed and how programs could be implemented or augmented to further reduce phosphorus from NPS sources.

Findings and Recommendations

The NPS Workgroup found that many federal, state, and local programs are in place that address phosphorus in NPS pollution. In some cases additional programs for agricultural waste and septic system upgrades are needed to reduce phosphorus loading to Connecticut waters. In other cases, existing programs could be expanded to further address phosphorus in NPS pollution. Some new or expanded programs will require additional funding and expansion or addition of regulatory programs will require individuals, communities, and businesses to accept a higher level of control than is currently required by existing statutes and regulations.

[7] See Appendix D

Recommendations for Phosphorus Strategy

The NPS Workgroup recommendations are summarized below:

1. Urban Runoff and Soil Erosion. Stormwater runoff is a known conveyer of phosphorus to waterways. The NPS Workgroup found that a number of CT DEEP stormwater permits were in place and that these permits were being enhanced at the time the Workgroup was gathering its information. The Workgroup recommendations for this priority are to:

    - Enhance outreach and implementation of Municipal Green Infrastructure Low Impact Development.
    - Continue research and evaluation of BMPs and development of guidance documents.
    - Enhance CT DEEP's Stormwater Permitting program by targeting sources of phosphorus.
    - Preserve or augment staff resources to inspect and enforce CT DEEP's Stormwater General Permit Programs.

2. Animal Wastes and Fertilizers. Through information provided by UCONN, the NPS Workgroup found that Connecticut produces excess phosphorus in the form of animal manure, feed, and fertilizer. Centrifugal separation of solids from manure can concentrate phosphorus in the solids, allowing liquid manure to be land-applied with less impact to water quality. Anaerobic digestion, paired with solid separation, can further reduce the volume of waste and can produce energy and value-added products like farm animal bedding, soil conditioners, and peat for potting. The Workgroup recommendations for this priority are to:

    - Enhance agriculture animal waste management and technologies that concentrate phosphorus in separated solids
    - Assist with capital costs and organize cooperative agreements to pool resources for centralized/regionalized anaerobic digestion for dairy and food wastes.
    - Incentivize or capitalize private companies to coordinate manure transfer from areas of nutrient excess to areas of soil nutrient need.
    - Identify and incentivize manure management strategies on fields.
    - Provide capital funding for pilot projects to evaluate new technologies for managing manures and agricultural waste such as pelletizing, gasification, and phosphorus recovery.
    - Provide incentives for farms to adopt and apply soil health practices.
    - Support the formation of an NRCS State Technical Committee, Nutrient Management Subcommittee.

- Fund continuing farmer education related to soil nutrient management, manure management, and soil health.

3. Onsite Wastewater Treatment. Onsite wastewater disposal systems, commonly called septic systems, can also be sources of phosphorus. The NPS Workgroup worked with several experts as a subcommittee to assess the extent of phosphorus from septic systems. While current regulatory requirements are effective, old systems; lack of maintenance, improper use, poor sitting, and uneven distribution of effluent in the leaching field can result in phosphorus loading to watercourses. Old systems in high density developments and in environmentally sensitive areas such as those near lakes can be particularly problematic. The Workgroup recommendations for this priority are to:

    - Encourage development of town-wide wastewater management plans.
    - Implement a statewide comprehensive onsite wastewater treatment system management program.
    - Require point-of-sale inspections of all on-site wastewater treatment systems.

4. Statewide NPS Management. The workgroup recommendations for this priority are to:

    - Convene a nonpoint source technical committee to develop and implement more effective policies and procedures to minimize nonpoint source pollution.

Public Act 12-155 restricts the amount and use of phosphorus in fertilizer for residential lawns and gives authority to the Connecticut Department of Agriculture to write regulations and enforce this provision of the act. The NPS Workgroup made recommendations for fertilizer use on lawns and gardens, croplands, container nurseries, and golf courses.

The extent of water quality impacts from phosphorus releases in lake and pond sediments, known as internal loading, were considered by the Workgroup. The NPS Workgroup report includes a discussion on methods to control internal phosphorus loading including chemically binding the phosphorus by treating the water body with aluminum or calcium compounds or adding oxygen to water. Both techniques require active management and are not commonly used in Connecticut.

B. Methods to Measure Phosphorus and Make Future Projections

Workgroup #2, the Scientific Methods Workgroup, was charged with proposing scientific methods to measure current phosphorus levels and to make future projections of phosphorus levels. CT DEEP contracted with the Connecticut Academy of Science and Engineering (CASE) to conduct a study entitled, "Methods to Measure Phosphorus and Make Future Projections." This report[8] was coordinated with and was reviewed by the Scientific Methods Workgroup and is summarized below:

Background

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

Primary Findings

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 can address this complexity.

The stressor-response model involves using response parameters such as dissolved oxygen, algae mass and species, water clarity, pH, diatoms, invertebrates, and fish to establish phosphorus related 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.

[8] See Appendix E for Workgroup report and CASE study

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. CT DEEP should continue to utilize this approach and their Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams 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 additional 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, CT DEEP should re-evaluate its approach every 3–5 years in a manner that is transparent to all stakeholders.

Recommendations

The following is a summary of the recommendations provided to and endorsed by the Scientific Methods Workgroup. The Workgroup also acknowledged that additional staffing and fiscal resources may be needed in order to implement many of the recommendations.

1. Continue sampling diatom community assemblage, but add diurnal dissolved oxygen.

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

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.

4. Develop a stratification/classification system.

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.

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.

7. Consider collaborating with neighboring states that use diatoms and dissolved oxygen.

8. For impaired watersheds, continue and accelerate the process of creating stream management plans similar to those in the CT Integrated Water Quality Report, incorporating these plans into a GIS, and perform response parameter measurements more frequently.

9. Begin to collect data on phosphorus import into watersheds and consider collecting additional economic/recreational use data.

The Scientific Methods Workgroup report lists the following considerations, which should apply to the pursuit of the recommendations above:

- Utilize new oxygen optodes, which have made the accurate measurement of dissolved oxygen during multi-day deployments possible at a relatively low cost.

- 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.

- 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, collect a greater percentage of the measurements 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.

- The state should consider mechanisms to facilitate the data collection necessary for recommendation #9.

The CASE Study Committee concluded that the CT DEEP "Interim Strategy was a reasonable and justified approach for setting numeric criteria" that "aligns with the guidance provided by the EPA." 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.

C. <u>Municipal Options for Coming into Compliance with WQS</u>

The charge of Workgroup #3, the Municipal Implementation Workgroup, was to provide a way of comparing the cost of various methods and approaches so that municipalities can select the most cost-effective path for complying with Water Quality Standards. The report[9] provided from this Workgroup is summarized as follows:

The intent of the report of Workgroup #3 was to provide a cost per pound of total phosphorus removed for different levels of treatment. The information this workgroup reviewed provided simulated cost per gallon treated data with little to no data to support a cost per pound scenario.

Workgroup #3 was unable to produce a meaningful cost per pound comparison of phosphorus removal technologies as that separate specific breakdown of cost was not available. In the absence of such information from this report, it would appear that each municipality should engage an engineering firm to conduct a planning study to better define the range of capital and operation and maintenance costs one should expect at the level of treatment needed for each individual project. This way individual local conditions can be factored into the analysis. Those costs

[9] See Appendix F

could then be compared to the Workgroup 1 costs for non-point reduction projects to provide some direction for specific municipalities.

7. Opportunities for Integration

It is clear from both the findings and recommendations of the three workgroups that integrating the science, wastewater treatment and managing nonpoint sources of pollution (NPS) was essential. A significant number of the lakes, rivers, streams throughout Connecticut are impaired due to phosphorus overloading from both point and nonpoint sources (NPS). Restoring water bodies to federally-mandated fishable and swimmable status means pollution reductions need to continue to come from point sources such as wastewater treatment facilities and NPSs such as urban and agricultural runoff. Integration comes increasingly important as removing nutrients from large municipal wastewater facilities advances and may not by itself achieve our end-goals

The theme of comprehensive watershed planning and management is important to this integration. An inventory and assessment of all pollution sources and management options with participation and commitment from all municipalities in the watershed, is critical to restoring and protecting water quality. Watershed management is a theme used in many DEEP and EPA programs and management efforts. EPA has encouraged states to accelerate reduction of nutrients by prioritizing watersheds on a state-wide basis and setting load-reduction goals. The DEEP Interim Phosphorus Strategy is aligned on holistic and integrated watershed assessment and management of phosphorus.

Integration can help ensure technical, cost-effective and collaborative approaches are considered, and give us reasonable assurances that reductions have a high likelihood of implementation. DEEP and USEPA continue to evaluate integrated and innovative approaches to address both sources in the most effective manner. Integrated management approaches are a theme used in many DEEP programs and management efforts for phosphorus and other concerns. Below are some options:

- Nonpoint Source Permit Strategies- traditional nonpoint source pollution sources such as urban stormwater and agricultural runoff are now being integrated into federal and state general permitting programs.

- Total Maximum Daily Load (TMDL) Program- TMDLs provide the formal framework for restoring impaired waters by establishing the maximum amount of a pollutant that a waterbody can receive. These pollution reduction plans look at all potential pollutant sources, both point and nonpoint, and set out regulatory and non-regulatory reduction measures.

- TMDL Alternatives- USEPA and states agencies are taking a new approach to TMDLs after looking at past practices. This effort will help by focusing state resources and priorities, building on partnerships, and looking at more flexible and efficient ways to restore water quality.

- Watershed Management Plans- Because watershed boundaries are natural, not political boundaries, it allows for more comprehensive assessment of the entire watershed which is critical to restoration of impaired waters. A watershed management plan is also important because the planning process results in a partnership among all affected stakeholders in the watershed. Development and implementation of these plans usually focus on addressing specific nonpoint source pollution.

See Appendix J for a further discussion of integrated management approaches.

8. Conclusion and Recommendations

The conclusions and recommendations of the three Workgroups can be summarized as follows:

- Connecticut's "Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams" was justified and a reasonable approach based on the state of nutrient science and management options.
- CT DEEP as well as Connecticut's municipalities should continue the regulatory programs already in place, utilizing current and revised strategies.
- CT DEEP should carry out the nine recommendations contained in the CASE Report. Among these recommendations, first priority should be assigned to the addition of diurnal dissolved oxygen sampling to CT DEEP's sampling of diatom communities.
- CT DEEP should develop a conceptual implementation plan and periodically post on its website a progress report of the efforts being undertaken to implement the CASE Report recommendations.
- CT DEEP, together with partners, should continue, expand and enhance non-regulatory programs already in place wherever possible.
- CT DEEP and municipalities should continue to explore cost-effective best management practices and treatment technologies for phosphorus management.
- CT DEEP and municipalities should continue to consider integrated management approaches for managing both point and nonpoint sources of pollution.

The detailed workgroup conclusions and recommendations are found in their entirety, with suggestions for implementation, in the text of the workgroup reports.

9. Appendices

Appendix A: Public Act No. 12-155 and CGS Section 22a-428a

Appendix B: Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams Technical Support Document, dated revised 4/24/2014

Appendix C: October 26, 2010 letter to DEEP from the USEPA approving Connecticut's Interim Strategy

Appendix D: Report of the Nonpoint Source Workgroup dated 7/28/2016

Appendix E: Report of Science Methods Workgroup dated and CASE Report dated 12/14/2014

Appendix F: Report of the Municipal Options Workgroup 11/23/2015

Appendix G: Scope of Work for the NPS Phosphorus Workgroup

Appendix H: Scope of Work for the Scientific Methods Workgroup

Appendix I: Water Quality Standards: Regulations of Connecticut State Agencies Sections 22a-426-1 through 9

Appendix J: Integrated Management Approaches

Appendix A: Public Act No. 12-155 and CGS Section 22a-428a

Substitute Senate Bill No. 440

Public Act No. 12-155

AN ACT CONCERNING PHOSPHOROUS REDUCTION IN STATE WATERS.

Be it enacted by the Senate and House of Representatives in General Assembly convened:

Section 1. (*Effective from passage*) 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 state-wide strategy to reduce phosphorus, or such chief elected officials' designees, shall collaboratively evaluate and make recommendations regarding a state-wide strategy to reduce phosphorus loading in inland nontidal waters in order to comply with standards established by the United States Environmental Protection Agency. Such evaluation and recommendations shall include (1) a state-wide 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 nontidal waters and to make future projections of phosphorous levels in such waters.

Sec. 2. (NEW) (*Effective January 1, 2013*) (a) For the purposes of this section:

(1) "Established lawn" means any area of ground that is covered with any species of grass for two or more growing seasons and that is customarily kept mowed;

(2) "Golf course" means an area solely designated for the play or practice of the game of golf, including, but not limited to, surrounding grounds, trees and ornamental beds; and

(3) "Impervious surface" means any structure, surface or improvement that reduces or prevents absorption of stormwater into land, including, but not limited to, porous paving, paver blocks, gravel, crushed stone, decks, patios and elevated structures.

(b) Notwithstanding chapter 427a of the general statutes, no person shall apply fertilizer, as defined in section 22-111b of the general statutes, any soil amendment, as defined in section 22-111aa of the general statutes, or any compost that contains phosphate to an established lawn, except when: (1) A soil testing method approved by the Commissioner of Agriculture and performed within the previous two years indicates the soil is lacking in phosphorus and fertilizer, soil amendments or compost containing phosphate is needed for the growth of such lawn, or (2) such fertilizer, soil amendment or compost containing phosphate is used for establishing new grass or repairing such lawn with seed or sod.

(c) The provisions of this section shall not apply to: (1) Property classified as agricultural land, as defined in section 22-26bb of the general statutes, or (2) a golf course.

(d) Notwithstanding subsection (b) of this section, no person shall apply any fertilizer, as defined in section 22-111b of the general statutes, soil amendment, as defined in section 22-111aa of the general statutes, or compost that contains phosphate to any lawn during the period beginning December first and ending March fifteenth of the following year.

(e) Notwithstanding chapters 427a and 441 of the general statutes and subsections (b) and (d) of this section, no person shall apply any fertilizer, as defined in section 22-111b of the general statutes, soil amendment, as defined in section 22-111aa of the general statutes, or compost that contains phosphate to any portion of a lawn that is located twenty feet or less from any brook, stream, river, lake, pond, sound or any other body of water, except if such fertilizer, soil amendment or compost is applied with the use of a drop spreader, rotary spreader with a deflector or targeted spray liquid, such application may occur on any portion of lawn that is located not less than fifteen feet from any such brook, stream, river, lake, pond, sound or any other body of water.

(f) No person shall apply any fertilizer, as defined in section 22-111b of the general statutes, soil amendment, as defined in section 22-111aa of the general statutes, or compost that contains phosphate to any impervious surface.

(g) For use by the general public or posting and distribution at retail points of sale, the Commissioner of Agriculture may approve consumer information on use restrictions and best practices for fertilizer, soil amendments and compost that contain phosphate.

(h) The Commissioner of Agriculture may adopt regulations, in accordance with chapter 54 of the general statutes, to implement the provisions of this section.

(i) Any person who violates subsection (b), (d), (e), (f) or (g) of this section shall be assessed a civil penalty by the Commissioner of Agriculture of five hundred dollars.

(j) Nothing in this section shall be construed to prohibit the use of any fertilizer, soil amendment or compost that contains 0. 67 per cent or less phosphate.

Sec. 3. Subsection (c) of section 22a-478 of the general statutes is repealed and the following is substituted in lieu thereof (*Effective from passage*):

(c) The funding of an eligible water quality project shall be pursuant to a project funding agreement between the state, acting by and through the commissioner, and the municipality undertaking such project and shall be evidenced by a project fund obligation or grant account loan obligation, or both, or an interim funding obligation of such municipality issued in accordance with section 22a-479. A project funding agreement shall be in a form prescribed by the commissioner. Eligible water quality projects shall be funded as follows:

(1) A nonpoint source pollution abatement project shall receive a project grant of seventy-five per cent of the cost of the project determined to be eligible by the commissioner.

(2) A combined sewer project shall receive (A) a project grant of fifty per cent of the cost of the project, and (B) a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the eligible water quality project costs.

(3) A construction contract eligible for financing awarded by a municipality on or after July 1, **[**1999**]** 2012, as a project undertaken for **[**nitrogen**]** nutrient removal shall receive a project grant of thirty per cent of the cost of the project associated with **[**nitrogen**]** nutrient removal, a twenty per cent grant for the balance of the cost

[ ]

of the project not related to nitrogen nutrient removal, and a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the eligible water quality project costs. [Nitrogen] Nutrient removal projects under design or construction on July 1, [1999] 2012, and projects that have been constructed but have not received permanent, Clean Water Fund financing, on July 1, [1999] 2012, shall be eligible to receive a project grant of thirty per cent of the cost of the project associated with [nitrogen] nutrient removal, a twenty per cent grant for the balance of the cost of the project not related to [nitrogen] nutrient removal, and a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the eligible water quality project costs.

(4) If supplemental federal grant funds are available for Clean Water Fund projects specifically related to the clean-up of Long Island Sound that are funded on or after July 1, [2003] 2012, a distressed municipality, as defined in section 32-9p, may receive a combination of state and federal grants in an amount not to exceed fifty per cent of the cost of the project associated with [nitrogen] nutrient removal, a twenty per cent grant for the balance of the cost of the project not related to [nitrogen] nutrient removal, and a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the allowable water quality project costs.

(5) A municipality with a water pollution control project, the construction of which began on or after July 1, 2003, which has (A) a population of five thousand or less, or (B) a population of greater than five thousand which has a discrete area containing a population of less than five thousand that is not contiguous with the existing sewerage system, shall be eligible to receive a grant in the amount of twenty-five per cent of the design and construction phase of eligible project costs, and a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the eligible water quality project costs.

(6) Any other eligible water quality project shall receive (A) a project grant of twenty per cent of the eligible cost, and (B) a loan for the remainder of the costs of the project, not exceeding one hundred per cent of the eligible project cost.

(7) Project agreements to fund eligible project costs with grants from the Clean Water Fund that were executed during or after the fiscal year beginning July 1, 2003, shall not be reduced according to the provisions of the regulations adopted under section 22a-482.

(8) On or after July 1, 2002, an eligible water quality project that exclusively addresses sewer collection and conveyance system improvements may receive a loan for one hundred per cent of the eligible costs provided such project does not receive a project grant. Any such sewer collection and conveyance system improvement project shall be rated, ranked, and funded separately from other water pollution control projects and shall be considered only if it is highly consistent with the state's conservation and development plan, or is primarily needed as the most cost effective solution to an existing area-wide pollution problem and incorporates minimal capacity for growth.

(9) All loans made in accordance with the provisions of this section for an eligible water quality project shall bear an interest rate of two per cent per annum. The commissioner may allow any project fund obligation, grant account loan obligation or interim funding obligation for an eligible water quality project to be repaid by a borrowing municipality prior to maturity without penalty.

Approved June 15, 2012

22a-428a CGS

Sec. 22a-428a. State-wide strategy to reduce phosphorus loading in inland nontidal waters. 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 state-wide strategy to reduce phosphorus, or such chief elected officials' designees, shall collaboratively evaluate and make recommendations regarding a state-wide strategy to reduce phosphorus loading in inland nontidal waters in order to comply with standards established by the United States Environmental Protection Agency. Such evaluation and recommendations shall include (1) a state-wide 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 phosphorus levels in inland nontidal waters and to make future projections of phosphorus levels in such waters. The commissioner shall submit a report on or before October 1, 2014, in accordance with the provisions of section 11-4a, to the joint standing committees of the General Assembly having cognizance of matters relating to municipalities and the environment. Such report shall set forth the recommendations required pursuant to subdivisions (1), (2) and (3) of this section and detail the collaborative effort through which such recommendations were reached.

Appendix B: Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams Technical Support Document, dated revised 4/24/2014

Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams Technical Support Document

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Last Revised: April 24, 2014

Introduction

Macro nutrients, such as nitrogen and phosphorus, are an essential component of plant and animal nutrition and are naturally occurring in aquatic systems. However, excessive inputs of nutrients from human sources such as discharges from industrial and municipal water pollution control facilities (WPCF) or runoff from urban and agricultural lands can alter primary productivity in aquatic systems and result in impairment to both recreational and aquatic life uses in Connecticut's water resources. Excessive loading of nutrients from anthropogenic sources causes or contributes to accelerated eutrophication, often termed 'cultural eutrophication.' Eutrophication is a process that increases the level of primary production leading to algal blooms, including blooms of noxious cyanobacteria, reduction in water clarity, alteration of habitat and in extreme cases depletion of oxygen, fish kills, and other impairments to aquatic life. Eutrophication is a slow natural process that occurs within a water body, but human activity greatly speeds up the process primarily thorough the addition of excess nutrients.

Excessive nutrient enrichment of surface waters is a widespread issue throughout the United States and the world. Connecticut has identified 21freshwater water bodies on the 2012 Impaired Waters List according to section 303(d) of the Clean Water Act (CT DEEP, 2012) where nutrient enrichment is specifically listed as a contributing cause of the impairment. These waters are primarily lakes that were assessed as impaired due to frequent algal blooms resulting from anthropogenic inputs of nutrients that threaten or impair aquatic life support or recreational designated uses. However, nutrients likely cause or contribute to other water body impairments that are not currently listed specifically for nutrients. Several water bodies have been identified as impaired for aquatic life uses caused by unknown pollutants where high yields of anthropogenic nutrient loading occur (Figure 1). The high yield of phosphorus in many of these water bodies is due to loading from municipal or industrial WPCFs discharging directly to the water bodies.

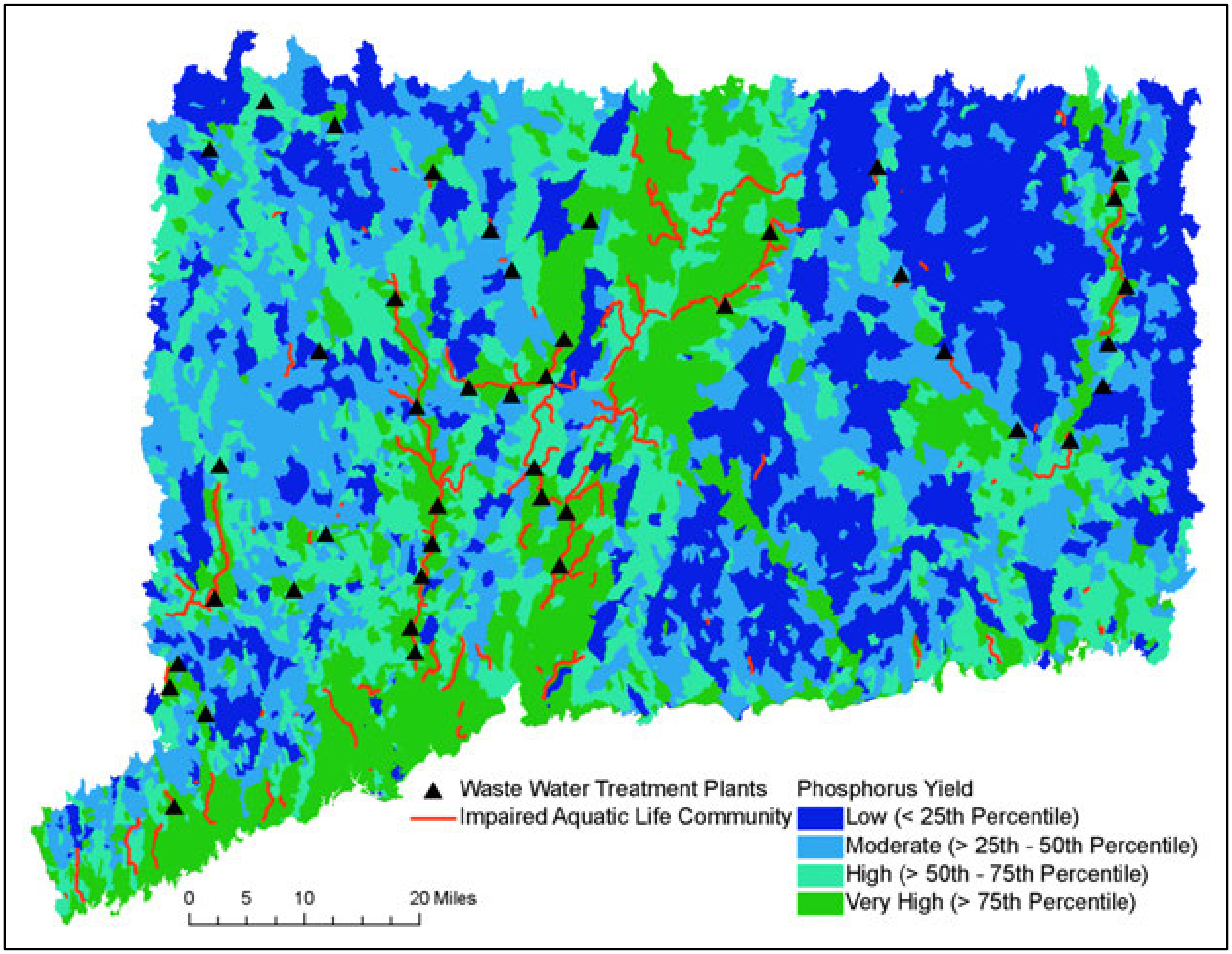

Figure 1. Statewide phosphorus yields calculated using SPARROW (Moore et al., 2011). Aquatic life impairments based on assessments for the 2012 impaired waters list.

As a result of the high percentage of water bodies listed for nutrient-related impairments in the U.S. according to section 303(d) of the Clean Water Act, the U.S. EPA has targeted nutrient pollution reduction a priority and have encouraged states to accelerate reduction of nutrients by prioritizing watersheds on a state-wide basis and setting load-reduction goals while developing numeric nutrient criteria for adoption into state water quality standards (Grubbs, 2001; Grumbles, 2007; Stoner, 2011). In addition, Federal regulations 40 C.F.R. § 122.44(d) indicate that entities issuing permits under the National Pollutant Discharge Elimination System (NPDES) program are required to determine whether a given point source discharge causes or has the reasonable potential to cause or contribute to an in-stream excursion above a narrative or numeric criteria within a state water quality standard. If a discharge is found to cause or contribute to an excursion of a water quality criterion, NPDES regulations implementing sections 301(b)(1)(C) of the Clean Water Act provide that a permit must contain effluent limits to achieve state water quality standards. In order to protect Connecticut water resources and be consistent with U.S. EPA guidance and federal regulations, the CT Department of Energy and Environmental Protection (DEEP) identified freshwater non-tidal waste receiving streams as a high priority for nutrient loading reductions due to the high phosphorus yields in these water bodies and potential to contribute to water quality impairments.

The Connecticut Water Quality Standards (WQS) (CT DEEP, 2013) incorporate narrative standards and criteria for nutrients with no numeric criteria. These narrative policy statements direct DEEP to impose discharge limitations or other reasonable controls on point and non point sources of nutrients 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.

In the absence of numeric criteria for phosphorus, DEEP developed the methodology described below based on the narrative criteria and policy statements in the WQS to meet the pressing need to issue NPDES permits and be protective of the environment. These methods were approved by the United States Environmental Protection (EPA) in a letter dated October 26, 2010 as an interim strategy to establish water quality based phosphorus limits in non-tidal freshwater for industrial and municipal WPCFs NPDES permits until the Department has established numeric nutrient criteria in the CT WQS. The interim strategy is based on best available information at a state-wide level using methods to identify phosphorus enrichment levels in waste receiving rivers and streams that adequately protects aquatic life uses. This strategy results in overall reductions up to 95% of the current watershed load once the strategy is fully implemented.

Phosphorus, healthy streams, and Connecticut's Water Quality Standards

The contribution of phosphorus to eutrophication and aquatic life impairments is difficult to measure directly because phosphorus is a natural element required for biological processes and the effects on the stream vary over time and space. Streams exhibit varying levels of productivity and diversity along longitudinal and lateral dimensions of the river network (Cardinale et al., 2005; Thorp et al., 2006; Vannote et al., 1980). Primary producers in streams include photosynthesizing organisms like algae and macrophytes. The biomass of primary producers may vary greatly throughout a season, from year to year and from one stream reach to another. This natural variation may also result from changes in light availability, temperature and predation due to grazer activity.

This methodology focuses on the contribution of phosphorus loading to cultural eutrophication and its effects on the biological condition of the stream rather than a single numeric criterion value. Threshold based management, or targeting a specific nutrient concentration could impart an unintended consequence of decreasing ecological diversity in rivers and streams if phosphorus was treated like a toxic pollutant (Figure 2). The management approach used for toxic pollutants is based on quantal endpoints that are ineffective for pollutants like nutrients because the ecological impacts of nutrients often occur long before organisms are killed or impaired (Becker, 2013). This approach uses diatoms as a biological endpoint and instead of a having a single threshold, uses anthropogenic phosphorus loading compared to natural levels of phosphorus to drive management activity.

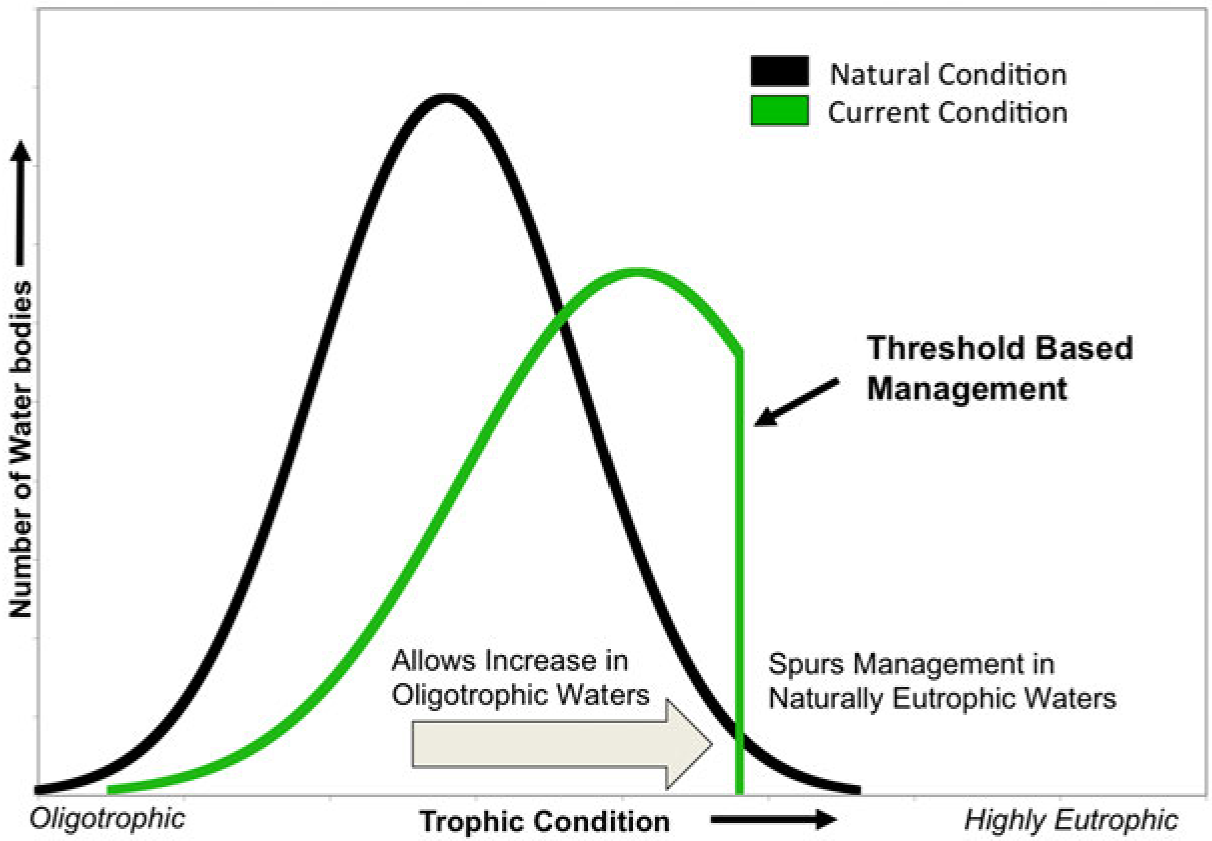

Figure 2. Example of threshold-based approach applied to nutrients using a hypothetical distribution. The black line shows the 'naturally' varying distribution of nutrients in the aquatic environment. The green line shows the current distribution with a threshold criterion applied. (Paul Stacey, Personal Communication, 2010)

Several studies (Danielson, 2009a; Kelly et al., 1998; Potapova and Charles, 2007; Potapova et al., 2004; Winter and Duthie, 2000) have shown that algal species composition provide a reliable indicator of trophic status in rivers and streams. Diatoms, a collection of microalgae in the Bacillariophyta group, are widely recognized and used as indicators of river and stream water quality (Kelly et al., 2008; Pan et al., 1996; Patrick, 1949; Stevenson and Pan, 1999). Several state agencies have identified the effectiveness of diatom trophic indices in aiding the development of nutrient criteria (Danielson, 2009b; Ponader et al., 2007). Studies conducted using CT data have also identified the importance of incorporating diatom responses in the development of nutrient criteria (Smucker et al., 2013). Diatom composition has also been used extensively in Europe as measure of trophic conditions (Kelly et al., 2008; 1998). Lavoie et al. (2008) found that species composition of diatoms is more likely to reflect actual stream conditions than assessment of water chemistry or algal biomass because they integrate the effects of stressors over time and space. Once it enters the stream, phosphorus can be found in the water column, taken up by aquatic organisms or attached to sediment in the water.

Current efforts to manage cultural eutrophication in freshwater in CT are focused on phosphorus because phosphorus is typically found to be the primary limiting nutrient in freshwater systems (Correll, 1998). This means that the level of phosphorus is a limiting factor of biological productivity in streams. In-stream concentrations of phosphorus measured in surface water grab samples (e.g. mg/L) are often used in nutrient criteria studies (U.S. EPA, 2000a). However, phosphorus loads exported to a stream (e.g. lb/ac/yr) may better reflect that the addition of phosphorus over time and space (U.S. EPA SAB, 2010) because stream trophic conditions are affected by the addition of phosphorus over time rather than any one single concentration of phosphorus.

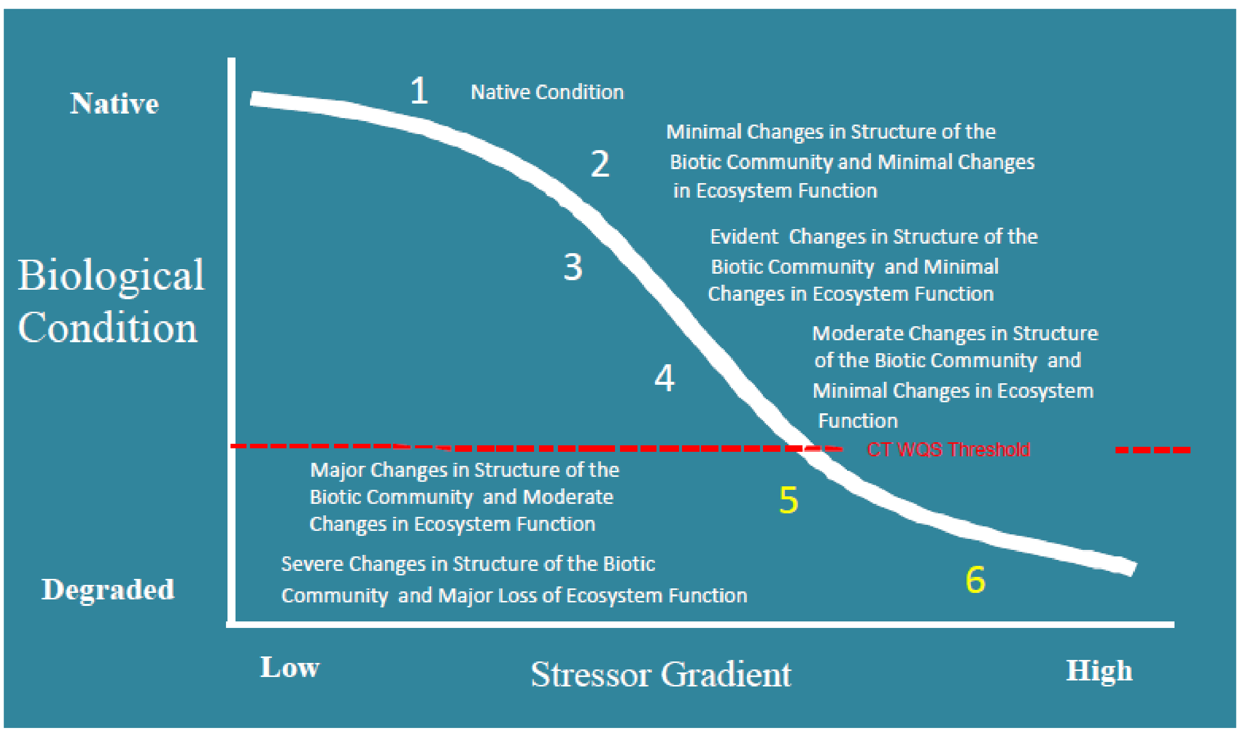

Figure 3: The Biological Condition Gradient (BCG) modified from Davies and Jackson (2006) and applied the CT WQS. The BCG was developed to serve as a common scientific framework that describes how biological communities and ecological attributes change in response to increasing levels of stressors.

The analysis described below is designed to identify where major changes occur in the biological condition of rivers and streams in response to phosphorus. The CT WQS (2013) state that water quality is insufficient when major deviations from the natural condition have occurred in the structure of the biotic community (Figure 3) along the biological condition gradient (Davies & Jackson, 2006). The biological condition gradient illustrates the relationship between the amount of stress in the environment and its effect on biological communities. Major changes are defined as markedly diminished sensitive taxa; conspicuously unbalanced distribution of major groups from that expected; organism conditions showing signs of physiological stress; ecosystem function showing reduced complexity and redundancy; and increased build-up or export of unused materials. Specifically, the analysis identifies changes in trophic condition as indicated by changes in the diatom biological community in response to anthropogenic phosphorus loadings. The analysis includes 4 steps: 1) Identify where diatom community samples were collected across the State; 2) Estimate the seasonal anthropogenic phosphorus loadings at those samples site; 3) Identify changes in the diatom community in response to phosphorus loadings; and 4) Identify loading reductions needed in waste-receiving stream to meet CT WQS biological condition goals.

Methods

Study Area and Sampling Data

Periphyton samples were collected from natural substrates as part of the CT DEEP ambient water quality monitoring program. Periphyton is a complex mixture of microscopic algae (including diatoms), bacteria and fungi that grows on the bottom substrate of a river or stream. It includes the collection of eplithic diatoms. Eplithic diatoms grow on hard relatively inert substrates that are typically bigger than most algae, such as gravel, pebble, cobble and boulder (Stevenson, 1996). Samples were collected in wadable riffle or run sections of the stream. Periphyton surveys were conducted at 85 sites across the State in July and August from 2002 – 2004 using an integrated approach that combined probabilistic and targeted monitoring designs (Wahle, 2003). Stein and Bernstein (2008) demonstrated that an integrated approach provides a more complete assessment of conditions to support water quality management.

Probabilistic designs draw sampling stations randomly from an area or region and are used by the U.S. EPA and states to provide statistically valid assessments of water quality and designated use attainment for spatially diverse regions. Targeted sites focus on describing and quantifying impacts, tracking trends and assessing compliance with regulatory guidelines or limits. Of the 85 sites, 59 were selected using a probabilistic sampling design and 26 selected using a targeted approach. At each site, 15 rocks were randomly selected throughout a 150 m stream reach in riffle and run habitats. Periphyton was removed from within a 5.1 cm^2 area on each rock and composited into one sample. Five ml of the periphyton sample were filtered onto a 47 mm diameter glass fiber filter with a 0.7 µm pore size for chlorophyll *a* analysis. The remaining sample was preserved and sent to a laboratory for diatom taxonomic identification. Diatom samples were processed using acid to remove organic material before mounting on slides using NAPHRAX™. Diatoms were identified to the lowest practical taxonomic level, typically species or lower, and at least 600 valves were enumerated per sample. For the analysis taxon identified below the species level were truncated to the species level. The chlorophyll *a* samples were frozen and sent to a separate lab for quantification using EPA fluorometric method 445.0/AERP 12 and aTurner Design Fluorometer TD-700.

At each site, a surface water chemistry sample was also collected. Nitrogen was determined as $NO_2 + NO_3$ (subsequently referred to as NO_x) using a cadmium reduction technique and an autoanalyzer for colorimetric measurements (EPA method 353.2). Total phosphorus was determined using the colorimetric EPA methods 365.1 and 365.4, which used persulfate and acid digestion. Turbidity was determined by nephelometry using EPA method 180.1.

In some cases, site locations may have been sampled more than once for two reasons: 1) a site was sampled in multiple years or 2) field replicates for samples were collected during the same year to adhere to quality control procedures. In these cases taxa counts were averaged. Taxa abundance was calculated at the species level and any taxa identified at a higher level than species were removed. Rare taxa were defined as those occurring in less than 5% of the samples and were removed from further analysis.

Estimates of Seasonal Phosphorus Loadings

Phosphorus enrichment levels were estimated using a metric called an enrichment factor (EF) (Becker & Dunbar, 2009). An EF is a unitless metric that provides an estimate of the level of anthropogenic phosphorus loading to river and streams. An EF value of 1 would mean that there was no anthropogenic phosphorus loading because current loading is equal to the forested condition. Higher EF values indicate a greater contribution of anthropogenic phosphorus. Phosphorus loadings were used instead of the single grab phosphorus chemistry samples because trophic conditions are affected by the addition of phosphorus over time rather than any one point-in-time single concentration of phosphorus. The EF is calculated by dividing the estimated total seasonal (April through October) phosphorus load by an estimated 'natural' total phosphorus load for any given point along a river or stream (**Equation 1**). The critical 'growing' season (April through October) is targeted for management because this is the time period when phosphorus is more likely to be taken up by sediment and biomass due to low flows, longer periods of sunlight and warmer conditions.

$$\textbf{nrichment Factor (EF)} = \frac{\textbf{Total NPDES Load } \left(\textbf{lbs}/_{\textbf{day}}\right) + \textbf{ Land Cover Load}\left(\textbf{lbs}/_{\textbf{day}}\right)}{\textbf{Forested Condition Load } (\textbf{lbs}/_{\textbf{day}})}$$

Equation 1. Enrichment Factor Calculation

The total current phosphorus load is calculated by adding the total upstream NPDES discharge load to the total upstream land cover load. Phosphorus loads from NPDES discharges were estimated using the flow and phosphorus concentration data from daily monitoring and nutrient analysis reports submitted to the Department from the facilities during April through October, 2001 - 2007. The land cover and 'natural' loads were estimated using land cover export coefficients for urban, agricultural and undeveloped land cover developed by Becker & Dunbar (2009). Land cover export coefficients estimate the average phosphorus export from a given area of land cover type to the river. The land cover export coefficients used for this analysis were within the ranges observed in a recent USGS study within the Northeastern United States (Trench et al., 2012) (Table 1) and generally consistent with the mean phosphorus export observed at sites across New England.

Table 1. Phosphorus export coefficients from Becker & Dunbar (2009) compared to average exports observed in Trench et al. (2012) with a drainage area less than 640,000 Acres (1000 SqMi) without municipal treatment discharges in New England (n = 9) and all throughout the Northeastern U.S. (n = 43).

Source	Undeveloped (lb/ac/yr)	Urban (lb/ac/yr)	Agriculture (lb/ac/yr)
Becker & Dunbar (2009) ***export coefficient used in this study***	**0.038**	**0.158**	**0.721**
Trench et al (2012) New England Sites ***mean*** *(n, range)*	**0.07** *(n= 5, 0.05 – 0.1)*	**0.13** *(n= 3, 0.08 – 0.22)*	**0.77** *(n= 1, NA)*
Trench et al (2012) All Northeastern Sites ***mean*** *(n, range)*	**0.09** *(n=15, 0.02 – 0.22)*	**0.72** *(n= 10, 0.08 – 2.34)*	**0.77** *(n=6, 0.09 – 2.19)*

The total land cover phosphorus load was calculated by multiplying the specified land cover type area (i.e. urban, agriculture or forest) in the upstream drainage basin by the export coefficient and adding all three together. The 'natural' phosphorus load was calculated by multiplying the entire upstream drainage area by the forest export coefficient.

The total upstream drainage basin was delineated for each of the sampling points using the Arc Hydro extension (version 1.4) for ArcGIS (ESRI ArcMap version 9.3.1). Land cover areas were calculated for each of the export coefficient categories in each basin using condensed land cover category grids derived from the University of Connecticut Center for Land Use Education and Research (CLEAR) dataset (Version 1) as described in Becker & Dunbar (2009). NPDES discharges were identified in each basin using GIS point coverage data from CT DEEP. Seven sites were eliminated from the analysis where the majority of the basin was out of state and land cover data or out of state NPDES data was not available leaving 78 sites for further analysis.

Identifying changes in the diatom community in response to phosphorus loadings

Threshold Indicator Taxa ANnalysis TITAN (Baker and King, 2010) was used to identify change points in the diatom species response to phosphorus loadings and community level phosphorus loading thresholds by considering aggregate changes across species. The TITAN method integrates information on the occurrence, abundance, and directionality of taxa responses (Baker and King, 2010) using indicator value (IndVal) scores (Dufrêne and Legendre, 1997). The IndVal scores are calculated and used to associate individual taxa with either a positive or negative response across the observed continuous gradient, in this case a phosphorus enrichment gradient. The TITAN method identifies the point at which the maximum IndVal of the taxon occurs across the observed gradient as the observed change point and assigns the taxa to either a positive or negative partition. Evidence for a diatom community thresholds to phosphorus loadings is identified by synchronous taxa response. The TITAN method standardizes the observed IndVal as z scores and sums the z scores of each individual taxon within each partition for every candidate change point across the observed phosphorus gradient. This standardization ensures that both common and uncommon species contribute equally to the community change analysis (Baker and King, 2010). The largest sums for each positive and negative partition are identified as observed community-level change points. TITAN was written in the programming language R and the code is available as a supplement to Baker and King (2010).

Bootstrap re-sampling was used to estimate uncertainty and identify significant indicator taxa by providing measures of indicator purity and reliability. Indicator purity provides information on the proportion of agreement between the observed change-point response direction (negative or positive) and the bootstrap replicates. Indicator reliability provides an estimate of how significantly different the dataset is from a random distribution. Individual taxa were considered significant if at least 95% of the bootstrap runs indicated the same response direction as the observed response (i.e. high purity) and at least 95% of the bootstrap runs were significantly different from a random distribution at $p \leq 0.05$ (i.e. high reliability). Bootstrap replicates were also used to develop empirical confidence limits around the community level change points. Bootstrap replicates were run 500 times and used to define enrichment thresholds for Connecticut streams. The 95% sum z+ from the 500 bootstrap replicates was used to define the upper most limit where CT WQS are met for the biological community. This approach was chosen because it represents a saturated threshold, beyond which major deviations from the natural condition have occurred in the structure of the biotic community. Beyond this point, an altered community structure is sustained and little change in the biological community is observed.

For comparison non-parametric change point analysis (nCPA) was also run (King & Richardson, 2003, Qian et al., 2003). nCPA and TITAN are similar analyses, however TITAN uses IndVal scores instead of deviance reduction to identify change points. nCPA identifies an aggregate, community level, dissimilarity response, while TITAN incorporates taxon-specific responses. nCPA identifies a point along the independent-variable gradient that produces the greatest reduction in deviance. nCPA uses bootstrap re-sampling with replacement (500 permutations) to estimate uncertainty in the change point values and produces cumulative probability plots for comparison based on the frequency distribution of change points. nCPA was also run using R version 2.10 (R Development Core Team http://www.R-project.org) and source code provided in Baker & King (2010).

Application to Waste Receiving Streams

The locations of NPDES facilities that discharge phosphorus into freshwaters and their receiving waters were identified using the CT DEEP municipal facilities GIS layer and through personal communication with CT DEEP NPDES permitting staff. The upstream EF and the seasonal phosphorus loading contribution from upstream NPDES facilities to the EF were estimated at multiple points downstream of NPDES facilities. The locations for EF analysis downstream of NPDES facilities were defined as stream segment points using the USGS 1:24,000 National Hydrography Dataset (NHD) stream line developed for CT. The Arc Hydro extension in ArcGIS was used to delineate the watershed at each stream segment location and calculate the land cover category areas and NPDES phosphorus loading contributions used to estimate the current EF as described above. In basins that extended out of state where CLEAR data was not available, land cover areas were estimated using the 2001 National Land Cover Dataset (Homer et al., 2004). Out of state NPDES facilities were identified through personal communication with U.S. EPA Region 1 staff and loads were estimated using the phosphorus concentration limits and design flows allocated in facility permits.

In-stream loading reductions needed to meet the maximum allowable EF target necessary to achieve WQS identified by the TITAN analysis at each of the stream segment locations were determined by subtracting the current EF from the WQS target EF. The needed reductions were applied to the NPDES facilities waste load allocation to ensure the target EF was met throughout the stream. In cases where the current NPDES facilities phosphorus load already met the target EF, a cap at the current waste load allocation was applied to ensure future anti-degradation.

Results

The 78 sites for analysis were distributed throughout the State (Figure 3, Table2) and represented a range of human disturbance (percent impervious cover 1.46 – 13.64 %), drainage area (0.45 – 259.25 square miles) and enrichment levels (1.2 to 76 EF).

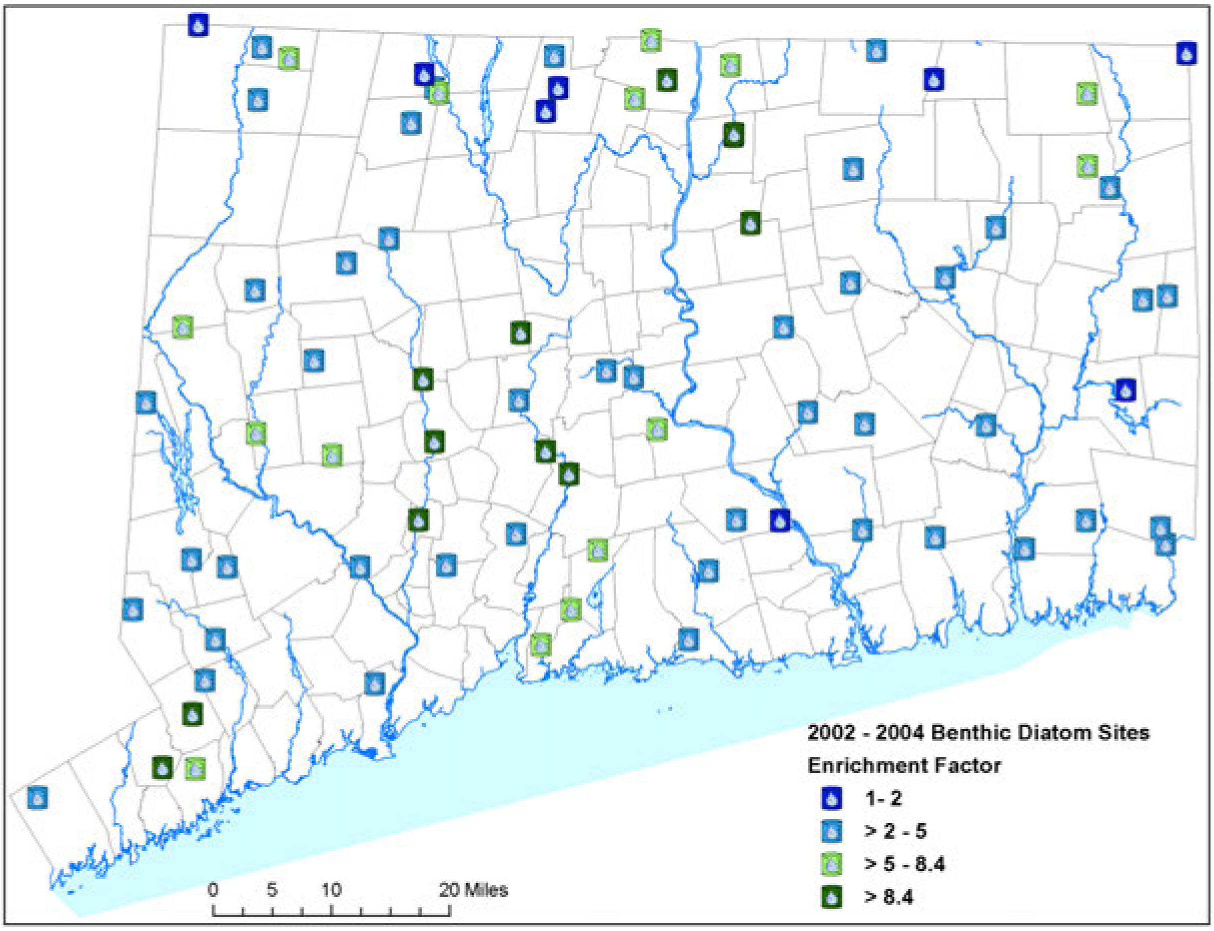

Figure 4. Site locations of where benthic diatom community and nutrient chemistry data were collected from 2002 - 2004. The phosphorus enrichment factor was estimated at each site using land cover data and phosphorus data submitted to CT DEEP from 2002 - 2007 by NPDES permit dischargers.

Table 2: The 78 Sites used in the analysis along with their drainage area (mi^2), percent impervious cover (IC) in the upstream drainage area and enrichment factor.

ID	Stream Name	Location	Municipality	Area (mi^2)	Percent IC	Enrichment Factor
22	Broad Brook	upstream USGS gage at Route 191	East Windsor	15.54	4.93	9.3
28	Coginchaug River	downstream Route 66	Middletown	37.29	5.11	6.24
69	Farm River	downstream Totoket Road	North Branford	12.87	5.33	6.32
77	Five Mile River	under Old Norwalk Road	New Canaan	5.07	13.64	35.14
163	Mattabesset River	downstream Berlin Street	Cromwell	45.28	11.62	4.38
178	Muddy Brook	downstream Route 168 (Main Street)	Suffield	19.43	4.74	8.93
189	Natchaug River	downstream North Bear Hill Road	Chaplin	73.1	2.81	2.83
191	Naugatuck River	upstream Frost Bridge Echo Lake Rd and Route 262	Watertown	137.39	4.31	13.44
192	Naugatuck River	behind Fire Station	Beacon Falls	259.26	8.47	49.77
216	Naugatuck River	at Palmer Bridge Street	Torrington	52.84	6.43	3.17
236	Norwalk River	upstream Perry Avenue	Norwalk	32.81	9.84	6.49
267	Pequabuck River	adjacent USGS Gage upstream of Central Avenue	Bristol	45.69	10.34	76.04
288	Quinnipiac River	downstream small dam behind water company building on Syndall Street	Cheshire	76.2	10.72	41.56
316	Salmon River	downstream 0.7 miles RR bridge	Colchester	82.42	4.62	3.9
317	Sandy Brook	opposite Grange Hall off Riverton Road	Colebrook	36.98	2.18	2.02
319	Saugatuck River	downstream Route 107 & Route 53 Junction	Redding	20.81	3.88	2.62
325	Shepaug River	downstream 100 meters Wellers Bridge Road (Route 67)	Roxbury	132.29	3.31	5.99
336	Still River	adjacent USGS gage off Robertsville Road	Colebrook	85.55	3.21	5.81
337	Still River	downstream Triangle Street	Danbury	30.9	11.31	3.4
340	Stony Brook	upstream South Grand Street	Suffield	10.53	3.74	7.2
424	Mattabesset River	upstream Lower Lane and Belcher Brook Mouth	Berlin	9.92	8.19	4.24
488	Eightmile River	downstream 100 meters Prospect Street	Southington	14.15	8.45	3.32
573	Blackberry River	Behind Elm Knoll Farm at second tractor crossing	North Canaan	38.85	2.7	5.01
574	Blackberry River	adjacent well field south of Route 7 crossing	North Canaan	43.04	2.81	4.97
607	Shunock River	upstream Route 49	North Stonington	16.45	3.49	4.2
739	Muddy Brook	Upstream of private bridge Number 1600 Route 187	Suffield	8.22	4.44	7.57
740	Mountain Brook	adjacent old logging road	Granby	0.86	2.07	1.47
742	Indian Meadow Brook	between Route 44 crossing and end of Loomis Street	Winchester	4.43	2.77	2.75
743	Sandy Brook	250 meters upstream second bridge crossing on Sandy Brk Rd from Rte 8	Colebrook	34.51	2.15	1.99
744	Lake Waramaug Brook	at farm Bridge crossing number 21 route 341	Warren	4.51	3.18	2.48

ID	Stream Name	Location	Municipality	Area (mi^2)	Percent IC	Enrichment Factor
745	Bull Mountain Brook	upstream Camp Flat Rd and Mud Pond Rd intersection	Kent	1.99	3.14	5.59
746	Sawmill Brook	at confluence with spring lake outfall	Sherman	1.66	2.03	2.6
748	Naugatuck River	at RR crossing DS of Mad River Confluence	Waterbury	205.95	8.19	10.18
749	Limekiln Brook	upstream Rockwell Road	Bethel	3.98	8.21	4.17
750	Bladdens River	upstream Sanford Road	woodbridge	1.74	5.57	2.82
751	East Branch Byram River	downstream John Street	Greenwich	2.46	5.34	3.43
752	Pumpkin Ground Brook	upstream cutspring rd	stratford	3.4	11	2.96
753	Norwalk River	adjacent Wilton Jr High/ Middle School	Wilton	18.17	9.25	8.81
755	Neck River	upstream Green Hill Rd	Madison	4.94	7.65	2.27
756	Pond Meadow Brook	Adjacent to Abner Lane (at yellow road marker with dep id)	Killingworth	6.26	3.56	2.45
757	Beaver Meadow Brook	adjacent to Beaver Meadow Road	Haddam	0.46	3.92	2.36
758	Flat Brook	at #30 Finley Hill Rd	Marlborough	2.09	4.42	3.97
759	Shunock River	upstream route 184	North Stonington	14.74	3.18	4.18
760	Flat Brook	upstream Baldwin Hill Road	Ledyard	1.38	7.78	2.81
761	Latimer Brook	between Brook Bend cul-de-sac and Robin Drive cul-de-sac	East Lyme	9.99	3.51	2.93
762	Bentley Brook	at Gifford Lane	Bozrah	1.52	3.14	3.2
763	Rocky Brook	adjacent to East Thompson Road	Thompson	4.83	1.78	1.23
765	Skungamaug River	downstream Old Cathole Road	Tolland	6.18	3.82	3.23
766	Stickney Hill Brook	upstream Brown road	Union	2.28	2.11	1.92
778	Mashamoquet Brook	adjacent route 101	pomfret	28.86	3.18	4.77
779	Hop River	adjacent route 6 at andover auto parts	andover	58.83	4.17	3.88
780	Sages Ravine Brook	500 feet upstream route 41	Salisbury	3.4	1.46	1.27
789	Ekonk Brook	between buildings 6 & 7 at condos Gorman Street	Plainfield	5.31	2.91	4.94
906	Freshwater Brook	behind last parking lot 9 Moody Road	Enfield	7.39	10.67	7.54
907	East Branch Salmon Brook	immediately above small pond Woodhaven Riding Facility #160 rte 189	Granby	5.02	2.79	2.57
908	Still Brook	Upstream Whispering Pine Lane	Stafford	2.6	3.1	3.39
909	North Running Brook	upstream dirt road farm rd below child hill farm property	Woodstock	1.86	3.8	8.07
910	Hollenbeck River	Adjacent to Rte 63 at SNET pole #856	Canaan	22.75	2.1	2.42
911	Beach Brook	adjacent to bend Upstream 100 meters cabin off broad hill road	Granby	1.19	1.63	1.89
913	Wappaquia Brook	at old bridge off RTE 169 on Wappaquia Brook Farm	Pomfret	3.63	4	7.35
915	Bantam River	Upstream Confluence with West Branch Bantam River	Litchfield	10.55	2.69	4.53
916	Hockanum River	behind #440 Rte 83 (Odessey School)	Manchester	49.12	9.86	27.42

ID	Stream Name	Location	Municipality	Area (mi^2)	Percent IC	Enrichment Factor
917	Sawmill Brook	upstream Meadowbrook Lane	Mansfield	3.49	2.97	3.73
920	Cabin Brook	Upstream Cabin Road	Colchester	1.48	10.74	4.45
921	Crooked Brook	DS Rte 201	Griswold	1.65	2.52	1.87
922	Pomperaug River	at Access Rd United Water Company behind Unitarian Church	Southbury	64.09	3.86	6.08
923	Mill River	at first pull-off DS Tuttle Road	Hamden	22.02	8.87	3.56
924	Clark Creek	Upstream RTE 82 Culvert	Haddam	2.51	2.13	1.2
925	Seth Williams Brook	Behind Apartment buildings 10-11	Ledyard	4.32	4.16	3.51
926	Titicus River	behind track Ridgefield High School	Ridgefield	5.08	10.72	3.16
927	Fivemile Brook	50 meters US mouth At old dam structure	Oxford	1.9	4.89	3.03
928	Farm River	Upstream of dirt farm road Schantz farm # 1775 Middletown Ave	North Branford	3.6	7.86	5.31
930	Eightmile River	150 meters downstream Confluence with East branch eightmile R. (rte 156)	Lyme	43.21	3.14	2.99
931	West Branch Saugatuck River	at end of Whiporwill Lane	Weston	1.73	4.36	2.5
932	Farm River	at end of dirt rd off Gloria Place	East Haven	19.3	9.65	5.63
933	Wood Creek	upstream Paddy Hollow Road	Bethlehem	2.53	3.32	4.31
1111	Quinnipiac River	upstream Oak Street	Wallingford	97.55	11.59	52.32
1475	Broad Brook	end of Brookside Drive 500 feet DS Broad Brook Mill Pond	East Windsor	13.59	4.94	8.99

Broad ranges of nutrient chemistry grab sample values were observed among the 78 sites (Figure 5, Table 3). The values in this study for Total Phosphorus, Total Nitrogen and Turbidity were generally in the same ranges as those observed in a 5-year statewide monitoring study conducted from 2006 – 2010 that included 963 samples collected under ambient conditions (CT DEEP, 2011) (Table 3).

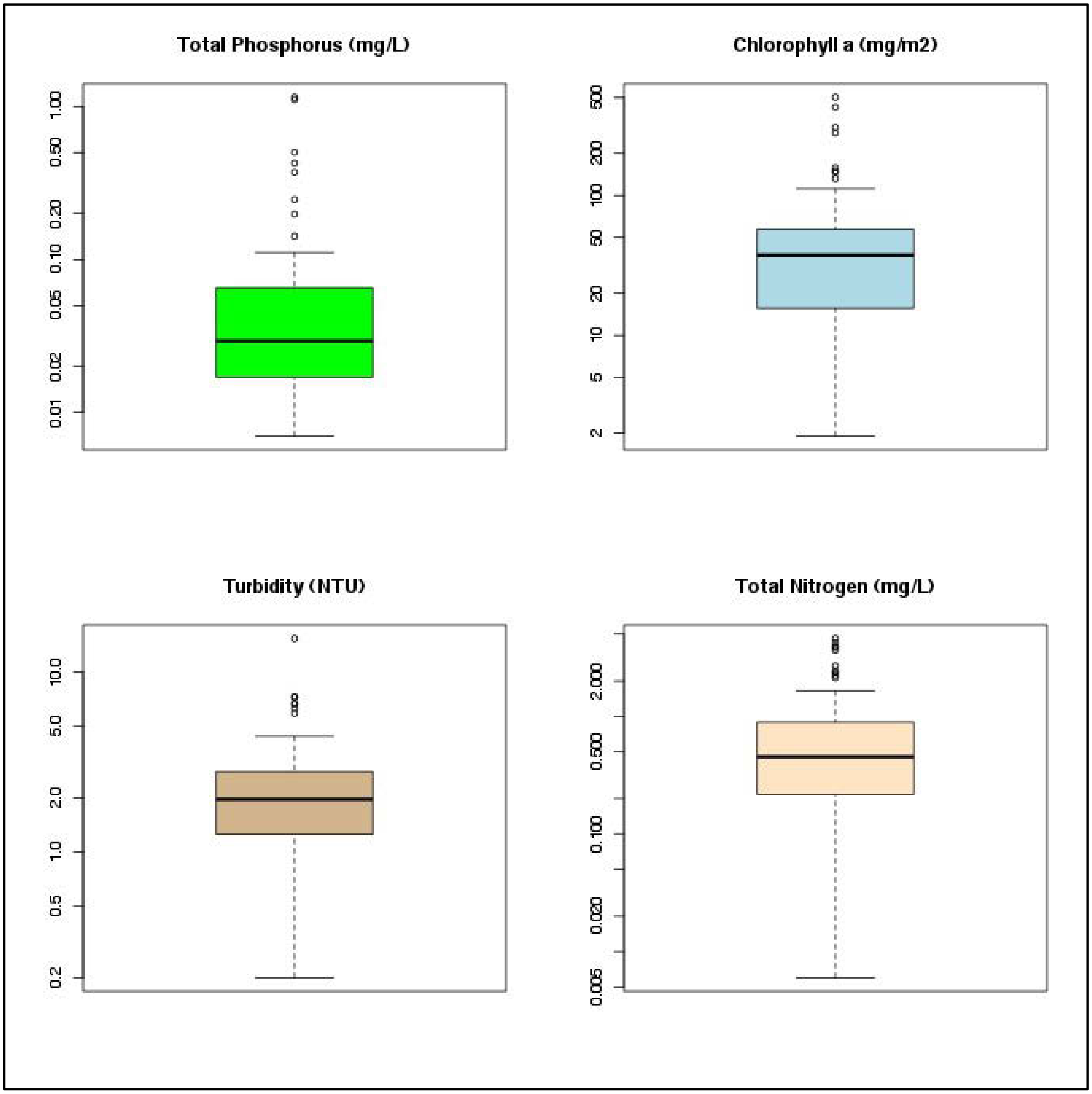

Figure 5: Boxplots of water chemistry ranges observed in chemistry samples collected at the 78 study sites.

Table 3: The minimum (Min), median, mean and maximum (Max) values observed in this study (n = 78) from chemistry grab samples as compared to values observed in a state-wide study conducted from 2006 - 2010 (n = 963) (CT DEEP 2011). Note that chlorophyll a values were not available as part of the state-wide study.

	Study	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Turbidity (NTU)	Chlorophyll *a* (mg/m^2)
Min	This Study (n = 78)	0.007	0.006	0.2	1.903
	Statewide (n = 963)	0.002	0.008	0.1	NA
Median	This Study (n = 78)	0.029	0.454	1.967	37.38
	Statewide (n = 963)	0.021	0.571	1.3	NA
Mean	This Study (n = 78)	0.086	0.838	2.449	59.506
	Statewide (n = 963)	0.06	0.7986	2.27	NA
Max	This Study (n = 78)	1.15	4.585	15.4	504.096
	Statewide (n = 963)	1.558	6.93	29.2	NA

A total of 400 diatom species occurred at the sites. Two hundred fifty-seven occurred in less than 5% of the samples and were removed from the analysis. A total of 143 diatom species were used in the analysis (Table 5). Fifty species were categorized as "decreasers" in response to increasing phosphorus enrichment, while 93 species were categorized as "increasers" in response to increasing phosphorus enrichment. The diatom community change point for decreasers (sum z-) was 1.9 EF with a range from 1.9 to 4.3 for the 5th and 95th confidence intervals, respectively. The diatom community change point for increasers (sum z+) was 6.16 with a range from 4.5 to 8.4 for the 5th and 95th confidence intervals, respectively. Sixteen decreaser taxa and 41 increaser taxa out of 143 total taxa were identified as significant. The overall community change point using nCPA was 5.715 with a range of 2.8 to 6.4 for the 5th and 95th confidence intervals, respectively.

Frequency and abundance of decreaser species sharply declined between the 2 and 4 EF range, with a decline among all significant decreaser species around 6 EF, while increaser species became more prevalent between 6 EF and 8 EF, suggesting a community shift across the phosphorus gradient (Figure 6A & 6B). The upper limit representing a saturated threshold, beyond which major deviations from the natural condition have occurred in the structure of the biotic community, was defined as 8.4 EF.

Table 4: Threshold Indicator Taxa Analysis (TITAN) community-level thresholds estimated from diatom species responses to phosphorus enrichment (EF). The observed change point (CP) corresponds to the value of the x resulting in the largest sum of indicator value (IndVal) z-scores among all negative (z-) and positive (z+) taxa, respectively. Percentages (5%, 50%, 95%) correspond to change points from 500 bootstrap replicates and represent uncertainty around the CP.

Method	CP	5%	50%	95%
TITAN sum (z-)	1.90	1.90	2.31	4.27
TITAN sum (z+)	6.16	4.49	5.89	8.44
nCPA	5.72	2.76	5.15	6.43

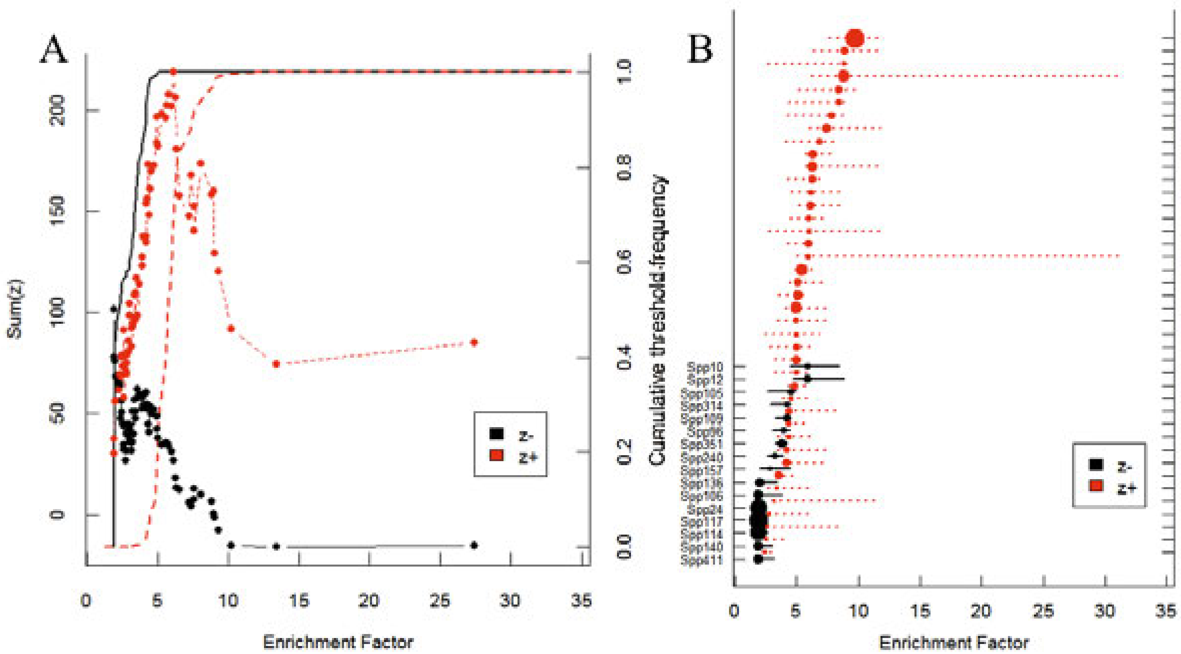

Figure 6. Threshold Indicator Taxa ANalysis (TITAN) outputs. (A) sum (z) scores for decreasers (black circles) and increasers (red circles) across the phosphorus enrichment gradient. Vertical lines are cumulative frequency distributions of change points for negative (solid) and positive (dashed) indicator species across 500 replicate runs. (B) Significant species (purity ≥ 0.95, reliability ≥ 0.95, p < 0.05) in response to increasing (z+) or decreasing (z-) phosphorus enrichment. The circle size represents z-scores and horizontal lines overlapping each circle cover the 5th and 95th percentiles among 500 replicate runs.

Table 5: Threshold Indicator Taxa Analysis (TITAN) changes points of diatom species in response to phosphorus enrichment factor. The observed changes points (CP) corresponds to the value resulting in the largest indicator value (IndVal) z-scores for each taxon either as an increase (+) or decrease (-) to the phosphorus enrichment gradient. Percentiles (5%, 50%, 95%) correspond to change points from 500 bootstrap replicates. Purity is the mean proportion of correct response direction (z- or z+) assignments; reliability (Rel) is the mean proportion of P-values <0.05 among 500 bootstrap iterations.

ID	Species	±	CP	5%	50%	95%	IndVal	P-value	z-score	Purity	Rel
Spp10	Achnanthidium caledonicum	z-	5.89	3.525	5.89	8.955	70.11	0.004	4.99	0.982	0.982
Spp101	Eunotia diodon	z-	1.9	1.9	1.9	4.065	49.39	0.004	8.75	0.974	0.898
Spp104	Eunotia flexuosa	z-	4.485	1.945	3.93	12.231	20.7	0.024	2.32	0.906	0.82
Spp105	Eunotia formica	z-	4.485	2.135	3.885	5.15	39.51	0.004	5.14	1	1
Spp106	Eunotia implicata	z-	1.9	1.9	1.995	4.165	65.64	0.004	7.91	0.99	0.984
Spp109	Eunotia meisteri	z-	4.18	3.09	4.165	4.64	35.71	0.004	5.25	1	1
Spp114	Eunotia paludosa	z-	1.9	1.9	1.945	2.975	82.8	0.004	12.68	0.998	0.994
Spp117	Eunotia praerupta	z-	1.9	1.9	1.945	2.435	99.85	0.004	14.97	1	0.996
Spp12	Achnanthidium exiguum	z-	5.89	4.267	6.405	8.955	80.7	0.004	6.6	0.998	0.998
Spp126	Fragilaria capucina	z-	2.385	1.9	2.485	7.815	29.91	0.164	1.02	0.612	0.404
Spp136	Fragilariforma virescens	z-	1.945	1.9	1.995	4.065	56.42	0.004	6.95	0.988	0.96
Spp138	Frustulia crassinervia	z-	4.18	2.435	3.635	4.64	16.67	0.012	3.05	0.988	0.842
Spp139	Frustulia erifuga	z-	4.18	2.485	3.93	5.605	8.31	0.224	0.97	0.758	0.322
Spp140	Frustulia krammeri	z-	1.9	1.9	1.995	3.80425	65.37	0.004	8.14	0.99	0.962
Spp149	Gomphonema acuminatum	z-	3.385	2.60375	3.385	4.85025	12.01	0.02	2.51	0.94	0.644
Spp152	Gomphonema angustatum	z-	4.21	2.775	3.93	5.89	23.65	0.016	2.79	0.794	0.73
Spp153	Gomphonema angustum	z-	6.28	1.945	3.365	5.72375	8.47	0.28	0.57	0.558	0.254
Spp157	Gomphonema clavatum	z-	2.805	1.945	2.805	4.95175	21.85	0.008	3.3	0.992	0.904
Spp162	Gomphonema gracile	z-	4.485	2.385	4.165	7.435	9.68	0.292	0.58	0.696	0.32
Spp171	Gomphonema pumilum	z-	8.435	1.945	4.41	8.435	25.76	0.048	1.51	0.618	0.342
Spp174	Gomphonema sphaerophorum	z-	3.185	1.995	3.09	5.44	16.53	0.012	3.3	0.906	0.73
Spp176	Gomphonema truncatum	z-	1.9	1.9	1.945	4.6655	31.54	0.012	2.77	0.822	0.628
Spp182	Karayevia clevei	z-	4.18	2.605	3.93	7.435	18.25	0.092	1.47	0.858	0.608
Spp183	Karayevia laterostrata	z-	7.265	1.9	4.34	7.265	12.9	0.252	1.03	0.592	0.172
Spp190	Meridion circulare	z-	3.385	1.945	3.635	8.435	30.36	0.108	1.33	0.616	0.428
Spp193	Navicula angusta	z-	1.9	1.9	1.9	6.16	45.95	0.008	4.96	0.862	0.716
Spp210	Navicula erifuga	z-	3.41	2.385	3.9075	9.8335	10.17	0.24	0.68	0.506	0.34
Spp226	Navicula notha	z-	4.845	2.135	4.27	5.605	24.08	0.02	2.96	0.976	0.884
Spp23	Amphora pediculus	z-	4.27	2.435	3.265	6.84	8.45	0.288	0.72	0.79	0.412
Spp233	Navicula radiosa	z-	2.68	2.52775	3.385	6.16	8.08	0.356	0.22	0.564	0.254
Spp24	Amphora veneta	z-	1.9	1.9	1.945	2.485	83.1	0.004	13.43	0.998	0.988
Spp240	Navicula schmassmanni	z-	3.265	2.48375	3.265	4.07	26.53	0.008	4.87	1	0.99
Spp249	Navicula tenelloides	z-	2.815	2.435	3.635	7.815	13.32	0.2	0.91	0.596	0.368

ID	Species	±	CP	5%	50%	95%	IndVal	P-value	z-score	Purity	Rel
Spp28	Aulacoseira alpigena	z-	4.18	2.485	3.8	4.485	11.9	0.048	2.57	0.98	0.67
Spp293	Nitzschia palustris	z-	3.465	2.805	3.93	7.435	8.3	0.292	0.43	0.692	0.36
Spp300	Nitzschia recta	z-	8.87	2.485	3.8	7.265	16.42	0.156	0.71	0.49	0.17
Spp314	Nupela lapidosa	z-	4.21	2.53	4.165	4.845	32.23	0.008	4.15	1	0.978
Spp351	Planothidium stewartii	z-	3.8	2.975	3.635	4.21	48.38	0.004	6.72	1	1
Spp356	Psammothidium bioretii	z-	4.845	2.68	3.495	8.955	10.47	0.124	0.78	0.684	0.348
Spp361	Psammothidium marginulatum	z-	1.9	1.9	1.945	4.21	32.88	0.016	6.15	0.968	0.76
Spp364	Psammothidium subatomoides	z-	4.27	3.18375	4.165	5.72375	42.52	0.008	3.81	0.934	0.9
Spp378	Sellaphora rectangularis	z-	1.9	1.9	2.435	6.84	22.86	0.056	3.07	0.812	0.58
Spp380	Stauroforma exiguiformis	z-	3.885	2.605	4.165	20.42	15.36	0.16	0.86	0.576	0.344
Spp382	Stauroneis kriegeri	z-	4.21	2.48375	4.065	6.28	14.11	0.076	1.69	0.872	0.524
Spp411	Tabellaria flocculosa	z-	1.9	1.9	1.995	3.41	92.69	0.004	8.04	1	1
Spp6	Achnanthes oblongella	z-	3.385	2.805	3.41	4.985	12.03	0.044	1.74	0.95	0.614
Spp63	Cymbella ehrenbergii	z-	1.9	1.9	3.385	4.985	26.67	0.072	2.58	0.99	0.762
Spp74	Diadesmis confervacea	z-	2.68	1.9	3.1725	31.275	13.44	0.112	1.07	0.622	0.364
Spp96	Epithemia turgida	z-	3.93	2.875	3.8	4.845	39.16	0.004	4.91	0.984	0.976
Spp97	Eucocconeis laevis	z-	1.9	1.9	2.305	5.15	56.97	0.004	6.22	0.942	0.888
Spp11	Achnanthidium deflexum	z+	7.435	5.715	7.815	20.42	64.64	0.004	7.65	1	0.998
Spp13	Achnanthidium minutissimum	z+	31.275	2.4325	8.955	31.275	41.1	0.032	2.35	0.86	0.666
Spp132	Fragilaria sepes	z+	3.01	3.01	3.885	31.275	11.32	0.044	1.52	0.456	0.276
Spp134	Fragilaria vaucheriae	z+	1.995	1.9	2.53	8.45675	58.25	0.048	2.16	0.88	0.78
Spp137	Frustulia amphipleuroides	z+	3.16	2.605	3.525	7.44075	19.62	0.024	2.04	0.956	0.764
Spp143	Frustulia vulgaris	z+	2.135	2.385	3.635	7.815	27.54	0.14	1.13	0.356	0.146
Spp144	Geissleria acceptata	z+	2.945	3.09	4.485	6.16	9.09	0.104	0.9	0.79	0.33
Spp145	Geissleria decussis	z+	3.16	2.605	3.385	20.42	32.31	0.016	3.04	0.986	0.916
Spp164	Gomphonema kobayasii	z+	5.44	2.435	5.605	20.42	30.84	0.02	2.76	0.84	0.726
Spp166	Gomphonema micropus	z+	8.87	1.9	3.465	9.73	12.53	0.104	1.56	0.45	0.31
Spp167	Gomphonema minutum	z+	4.95	2.975	4.485	11.8	46.17	0.004	4.37	0.998	0.994
Spp168	Gomphonema olivaceoides	z+	2.945	3.09	6.16	31.275	9.09	0.22	0.88	0.73	0.402
Spp170	Gomphonema parvulum	z+	9.135	1.945	4.115	11.8	64.09	0.04	2.06	0.968	0.838
Spp18	Amphipleura pellucida	z+	6.03	2.8035	5.44	7.435	26.62	0.02	3.07	0.94	0.82
Spp180	Hippodonta capitata	z+	6.03	3.345	5.15	7.435	54.66	0.004	6.62	1	0.996
Spp188	Mayamaea atomus	z+	8.87	5.14175	8.955	31.275	61.61	0.004	10.09	1	1
Spp189	Melosira varians	z+	4.985	2.305	4.485	7.815	53.21	0.004	4.1	0.996	0.99
Spp197	Navicula canalis	z+	6.84	3.265	6.84	31.275	17.14	0.008	3.41	0.93	0.75
Spp198	Navicula capitatoradiata	z+	4.34	2.815	4.64	6.28	21.3	0.02	2.89	0.902	0.728
Spp203	Navicula cryptocephala	z+	2.605	2.46	2.815	9.8335	50.73	0.012	3.45	0.99	0.962

ID	Species	±	CP	5%	50%	95%	IndVal	P-value	z-score	Purity	Rel
Spp204	Navicula cryptotenella	z+	1.9	1.9	2.435	7.485	77.45	0.004	3.22	0.89	0.824
Spp205	Navicula cryptotenelloides	z+	8.435	4.16	6.405	11.8	29.5	0.008	5.44	1	0.97
Spp214	Navicula gregaria	z+	4.95	2.975	4.64	5.89	76.39	0.004	8.25	1	1
Spp219	Navicula lanceolata	z+	5.44	4.41	5.715	7.265	71.23	0.004	10.31	1	1
Spp22	Amphora montana	z+	3.385	2.485	3.93	6.405	49.46	0.004	3.63	1	0.99
Spp222	Navicula menisculus	z+	3.385	2.605	4.27	20.42	20.27	0.016	2.43	0.972	0.818
Spp224	Navicula minima	z+	4.165	3.525	4.9675	7.815	68.86	0.004	6.63	1	1
Spp227	Navicula peregrina	z+	6.28	2.975	6.16	20.96275	13.6	0.064	2.28	0.814	0.544
Spp229	Navicula perminuta	z+	2.385	2.435	4.065	6.86125	10.45	0.456	0.33	0.558	0.234
Spp231	Navicula praeterita	z+	2.58	2.605	4.065	7.846	9.68	0.372	0.62	0.58	0.3
Spp237	Navicula rhynchocephala	z+	2.775	2.485	2.815	6.405	35.59	0.008	3.14	0.978	0.954
Spp238	Navicula rostellata	z+	6.16	2.775	5.44	7.846	36.19	0.004	3.23	0.974	0.898
Spp242	Navicula schroeterii	z+	7.435	4.6215	7.815	11.8	24.71	0.004	5.59	0.95	0.87
Spp244	Navicula subminuscula	z+	9.73	7.435	8.955	20.42	87.25	0.004	16.79	1	1
Spp250	Navicula tripunctata	z+	4.34	3.885	4.64	6.28	27.7	0.004	5.2	0.996	0.97
Spp251	Navicula trivialis	z+	4.34	4.05825	4.95	11.8	29.37	0.004	5.72	0.998	0.99
Spp252	Navicula veneta	z+	6.84	3.8	6.28	9.135	27.38	0.008	5.27	1	0.952
Spp258	Nitzschia acidoclinata	z+	4.485	3.385	4.845	6.42675	27.15	0.004	4.68	0.996	0.968
Spp26	Astartiella bahusiensis	z+	8.955	3.185	7.815	20.42	28.23	0.012	5.05	0.962	0.8
Spp260	Nitzschia amphibia	z+	5.15	4.17925	5.44	8.87	69.64	0.004	7.16	1	1
Spp268	Nitzschia capitellata	z+	2.875	2.875	3.885	31.275	10.71	0.144	0.85	0.776	0.348
Spp270	Nitzschia dissipata	z+	2.385	1.995	2.875	7.55	43.8	0.064	1.67	0.814	0.686
Spp274	Nitzschia fonticola	z+	4.845	4.18	4.95	7.2735	52.34	0.004	5.81	1	0.998
Spp276	Nitzschia frustulum	z+	2.605	2.67625	4.115	31.275	18.03	0.076	1.43	0.88	0.624
Spp279	Nitzschia heufleriana	z+	3.09	2.815	3.8	11.8	13.46	0.096	1.51	0.92	0.576
Spp282	Nitzschia inconspicua	z+	4.985	3.885	4.95	8.435	75.21	0.004	10.4	1	1
Spp285	Nitzschia liebethruthii	z+	8.955	2.875	8.87	31.275	25.43	0.024	4.32	0.844	0.696
Spp286	Nitzschia linearis	z+	2.775	2.875	4.18	6.03	11.86	0.08	1.14	0.556	0.298
Spp29	Aulacoseira ambigua	z+	8.435	3.265	6.405	11.8	27.14	0.04	2.67	0.96	0.874
Spp290	Nitzschia palea	z+	4.95	2.485	4.41	7.815	70.3	0.004	5.83	1	1
Spp303	Nitzschia sigmoidea	z+	31.275	2.77025	9.73	31.275	35.83	0.024	3.44	0.786	0.596
Spp305	Nitzschia sociabilis	z+	6.16	2.775	4.41	20.42	18.81	0.02	2.42	0.886	0.702
Spp309	Nitzschia supralitorea	z+	3.635	3.09	4.64	8.955	25.43	0.04	2.32	0.914	0.798
Spp311	Nitzschia tubicola	z+	6.28	5.605	6.405	8.435	26.32	0.004	7.56	0.996	0.96
Spp315	Opephora olsenii	z+	8.955	2.945	8.435	31.275	23.86	0.028	3.59	0.878	0.704
Spp317	Parlibellus protracta	z+	7.55	3.8725	7.55	20.42	26.63	0.008	5.11	0.972	0.868
Spp328	Pinnularia subcapitata	z+	3.385	3.16	3.9075	7.56325	10.87	0.084	2.01	0.94	0.512

ID	Species	±	CP	5%	50%	95%	IndVal	P-value	z-score	Purity	Rel
Spp33	Brachysira vitrea	z+	2.53	2.435	2.805	5.44	39.68	0.012	3.07	0.986	0.956
Spp338	Planothidium delicatulum	z+	6.03	3.885	6.16	31.275	22.43	0.008	4.42	0.966	0.864
Spp339	Planothidium dubium	z+	8.435	2.67625	7.6825	31.275	23.81	0.072	1.66	0.738	0.62
Spp340	Planothidium frequentissimum	z+	6.28	3.88075	5.605	7.56325	65.97	0.004	6.84	1	1
Spp341	Planothidium granum	z+	6.84	4.267	7.265	8.955	22.87	0.004	6.11	0.982	0.866
Spp342	Planothidium hauckianum	z+	4.34	3.01	5.0675	31.275	14.1	0.016	2.68	0.922	0.73
Spp344	Planothidium lanceolatum	z+	4.18	2.68	5.15	8.435	56.2	0.004	5.58	1	0.998
Spp350	Planothidium rostratum	z+	6.03	2.435	5.715	9.135	30.75	0.032	2.48	0.92	0.726
Spp354	Platessa hustedtii	z+	31.275	1.995	4.845	31.275	19.73	0.116	2.19	0.574	0.296
Spp365	Psammothidium ventralis	z+	11.8	1.9925	3.525	31.275	14.63	0.18	0.29	0.54	0.314
Spp366	Pseudostaurosira brevistriata	z+	2.945	2.875	3.635	31.275	12.73	0.128	1.66	0.868	0.49
Spp367	Pseudostaurosira parasitica	z+	5.89	4.27	6.405	31.275	23.98	0.008	4.55	0.972	0.918
Spp368	Pseudostaurosira subsalina	z+	8.955	3.185	7.55	20.42	26.79	0.012	4.18	0.902	0.768
Spp369	Reimeria sinuata	z+	7.815	3.88075	7.265	9.135	89.83	0.004	5.87	1	1
Spp370	Rhoicosphenia abbreviata	z+	5.15	3.345	4.34	5.715	78.29	0.004	8.89	1	1
Spp377	Sellaphora pupula	z+	8.87	2.46	6.405	9.73	52.41	0.016	3.63	0.988	0.978
Spp379	Sellaphora seminulum	z+	8.435	4.985	7.265	20.42	83.29	0.004	7.09	1	1
Spp388	Staurosira construens	z+	6.16	2.605	6.405	8.955	57.01	0.004	4.07	0.976	0.954
Spp391	Staurosirella leptostauron	z+	8.955	2.435	7.815	31.275	19.81	0.064	1.97	0.742	0.524
Spp393	Staurosirella pinnata	z+	6.03	2.46	6.28	20.42	50.82	0.004	4.15	0.974	0.942
Spp396	Surirella amphioxys	z+	9.73	1.995	7.55	20.96275	20.35	0.084	1.85	0.616	0.424
Spp398	Surirella brebissonii	z+	6.28	5.44	7.265	20.42	31.58	0.004	8.85	0.996	0.982
Spp404	Synedra acus	z+	2.815	2.945	4.165	9.73	8.77	0.3	0.75	0.612	0.178
Spp407	Synedra rumpens	z+	9.135	1.945	3.41	11.8	45.65	0.236	0.56	0.444	0.26
Spp409	Synedra ulna	z+	1.945	1.9	2.46	11.8	63.38	0.02	2.69	0.932	0.866
Spp44	Cocconeis neothumensis	z+	4.985	3.21	4.985	8.955	36.81	0.004	5.66	1	0.998
Spp45	Cocconeis pediculus	z+	2.485	1.995	2.5075	3.525	77.15	0.004	3.5	0.958	0.908
Spp52	Cyclostephanos tholiformis	z+	9.135	2.305	6.16	31.275	17.46	0.072	1.41	0.586	0.38
Spp54	Cyclotella distinguenda	z+	6.03	3.18375	5.715	7.55	56.67	0.004	5.33	0.998	0.992
Spp68	Cymbella naviculiformis	z+	1.995	2.135	4.115	9.135	24.29	0.252	0.92	0.694	0.41
Spp7	Achnanthes pseudoswazi	z+	3.525	3.185	3.93	4.985	75.92	0.004	6.88	1	1
Spp78	Diatoma tenuis	z+	4.34	3.16	4.845	6.405	37.02	0.004	4.5	0.998	0.99
Spp83	Diploneis parma	z+	6.16	4.64	6.28	9.73	39.32	0.004	6.83	0.996	0.99
Spp84	Discostella pseudostelligera	z+	8.955	5.605	8.435	20.42	52.63	0.004	7.41	0.998	0.984
Spp86	Encyonema brehmii	z+	9.135	2.385	7.265	20.42	53.96	0.04	2.27	0.682	0.586
Spp91	Encyonema prostratum	z+	31.275	2.45875	6.22	31.275	58.81	0.02	2.86	0.978	0.896

Application: Reductions in CT Waste-Receiving Streams

Forty-five NPDES facilities were identified as discharging phosphorus to non-tidal freshwaters in CT. Forty-three are WPCFs and two are industrial plant discharges. The 45 facilities discharge to 20 rivers and streams across the state (Figure 7). The drainage basin size below the facilities ranged from 0.67 square miles below the Ridgefield Main WPCF in Ridgefield Brook to 1080.85 square miles below the New Milford WPCF in the Housatonic River.

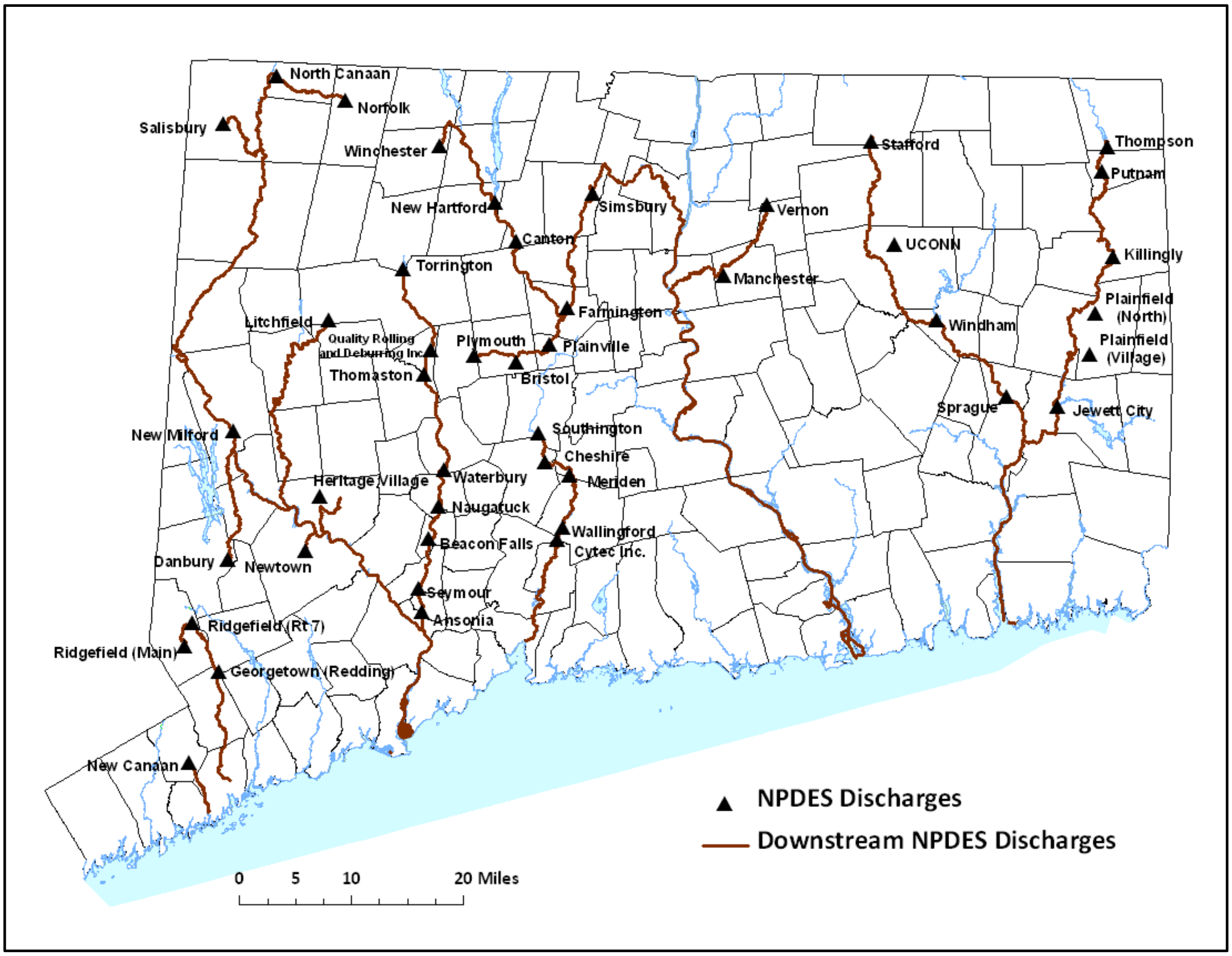

Figure 7: Locations of the 45 NPDES facilities and waste receiving streams included in the analysis

Table 6: Comparison of observed phosphorus yields in the Trench et al. (2011) study compared to this analysis at available USGS gaging stations with watersheds primarily within CT.

USGS Station	Drainage Area (SqMi)	Years of Record	Min (Lbs/SqMi)	Mean (Lbs/SqMi)	Median (Lbs/SqMi)	Max (Lbs/SqMi)	This Study
SHETUCKET RIVER AT SOUTH WINDHAM, Conn.	408	11	68	110	110	150	126
HOCKANUM RIVER NEAR EAST HARTFORD, Conn.	73.4	11	730	1000	1000	1200	1003
QUINNIPIAC RIVER AT WALLINGFORD, Conn.	115	11	550	1000	1100	1500	1121
NAUGATUCK RIVER AT BEACON FALLS, Conn.	260	11	720	1200	1300	1600	1195
NORWALK RIVER AT WINNIPAUK, Conn.	33	11	64	130	120	220	158

Phosphorus loadings and EFs were estimated using land cover export coefficients and NPDES facilities data as described above at multiple points in waste receiving streams. The estimated phosphorus yields in waste-receiving streams in this study fell within the range of estimated phosphorus yields in a recent USGS study (Trench et al., 2011) using 11 years of data at available USGS gage stations (Table 6). The estimated yields generally approximated the mean and median yields observed in the study. The EFs in the 20 waste receiving streams ranged from 3.3 below the New Hartford WPCF in the Farmington River to 138 below the Ridgefield WPCF in Ridgefield Brook. The Naugatuck River had the largest estimated phosphorus load of 955.01 lbs/day below the Ansonia WPCF discharge where an estimated 92.16 % of the in-stream load is attributed to NPDES discharges (Table 7).

Table 7: Estimated In-Stream Phosphorus Load (lbs/day) and EF at the discharge point of each NPDES facility and the estimated percent contribution of sources to that load.

NPDES	Watershed	Estimated In-Stream Phosphorus Load (lbs/day) at Discharge Point	EF	Estimated Percent Contribution to Phosphorus Load at Discharge Point			
				% NPDES	% Forest	% Urban	% Ag
LITCHFIELD WPCF	Bantam River Watershed	27.11	9.5	48.21	7.22	5.27	39.3
NORFOLK SEWER DISTRICT	Blackberry River Watershed	5.8	7.2	59.8	11.23	5.87	23.09
NORTH CANAAN WPCF	Blackberry River Watershed	19.1	6.3	40.32	12.29	6.09	41.3
SALISBURY WPCF	Factory Brook Watershed	8.97	19.8	79.63	3.62	2.94	13.81
WINSTED WPCF	Farmington River Watershed	26.74	9.4	74.92	8.6	6.46	10.02
NEW HARTFORD WPCF	Farmington River Watershed	67.34	3.3	45.96	27.14	9.18	17.72
CANTON WPCF	Farmington River Watershed	103.53	4.3	53.85	20.56	7.75	17.85
FARMINGTON WPCF	Farmington River Watershed	543.55	18.3	87.4	4.53	3	5.06
SIMSBURY WPCF	Farmington River Watershed	642.03	19.5	87.39	4.13	3.16	5.31
NEW CANAAN WPCF	Fivemile River Watershed	11.72	35.5	89.2	0.96	7.14	2.7
VERNON WPCF	Hockanum River Watershed	82.19	46.5	87.83	1.19	2.02	8.95
MANCHESTER WATER & SEWER	Hockanum River Watershed	205.54	42.4	88.83	1.08	3.98	6.1
New Milford WPCF	Housatonic River Main Stem Watershed	381.28	5.3	20.84	14.2	6.68	58.29
DANBURY WPCF	Limekiln Brook Watershed	82.21	89.8	95.5	0.6	1.62	2.28
TORRINGTON WPCF	Naugatuck River Watershed	76.24	21	84.9	3.57	3.14	8.39
QUALITY ROLLING AND DEBURRING INC.	Naugatuck River Watershed	87.87	13.1	74.28	5.67	4.96	15.09
THOMASTON WPCF	Naugatuck River Watershed	113.31	15.5	77.62	4.71	4.29	13.39
WATERBURY WPCF	Naugatuck River Watershed	679.21	49	92.44	1.33	2.07	4.16
NAUGATUCK WPCF	Naugatuck River Watershed	849.15	52.2	92.78	1.22	2.04	3.96
BEACON FALLS WPCF	Naugatuck River Watershed	860.29	48.7	92.5	1.32	2.17	4.01
SEYMOUR WPCF	Naugatuck River Watershed	909.68	45.4	91.99	1.43	2.32	4.27
ANSONIA WPCF	Naugatuck River Watershed	955	46.2	92.16	1.39	2.31	4.13
RIDGEFIELD MAIN WPCF C/O OMI	Norwalk River Watershed	6.14	137.9	97.63	0.41	1.13	0.82
RIDGEFIELD RTE 7 C/O OMI	Norwalk River Watershed	6.83	24.2	87.65	2.23	7.34	2.77
REDDING WPCF	Norwalk River Watershed	9.73	9.9	72.66	6.62	12.93	7.79
PLYMOUTH WPCF	Pequabuck River Watershed	32.06	30.9	89.33	2.26	2.85	5.56

NPDES	Watershed	Estimated In-Stream Phosphorus Load (lbs/day) at Discharge Point	EF	Estimated Percent Contribution to Phosphorus Load at Discharge Point			
				% NPDES	% Forest	% Urban	% Ag
BRISTOL WPCF	Pequabuck River Watershed	229.04	75.4	95.17	0.74	1.97	2.12
PLAINVILLE WPCF	Pequabuck River Watershed	312.44	95.5	96.12	0.56	1.65	1.66
SOUTHBURY HERITAGE VILLAGE WPCF	Pomperaug River Watershed	39.39	7.8	27.74	8.06	7.12	57.08
NEWTOWN WPCF	Pootatuck River Watershed	10.87	7.33	36.87	8.25	13.38	41.5
THOMPSON WPCF	Quinebaug River Watershed	43.4	5.8	40.9	11.88	14.94	32.27
PUTNAM WPCF	Quinebaug River Watershed	123.59	5.7	36.75	12.7	11.37	39.18
KILLINGLY WPCF	Quinebaug River Watershed	197.19	6.5	43.64	11.29	9.47	35.59
PLAINFIELD NORTH WPCF	Quinebaug River Watershed	237.29	6.4	43.77	11.21	9.34	35.69
PLAINFIELD WPCF	Quinebaug River Watershed	266.99	6.4	42.82	11.17	9.12	36.89
GRISWOLD WPCA	Quinebaug River Watershed	292.29	6.2	41.01	11.65	9.26	38.09
SOUTHINGTON WPCF	Quinnipiac River Watershed	114.6	30.8	87.26	1.66	5.51	5.57
CHESHIRE WPCF	Quinnipiac River Watershed	206.96	44.9	90.94	1.11	3.83	4.12
MERIDEN WPCF	Quinnipiac River Watershed	336.24	52.7	92.15	0.9	3.47	3.48
WALLINGFORD WATER & SEWER	Quinnipiac River Watershed	486.43	66.2	93.54	0.67	2.95	2.85
CYTEC INDUSTRIES INC.	Quinnipiac River Watershed	506.9	67.6	93.6	0.65	2.89	2.87
SPRAGUE WPCF	Shetucket River Watershed	161.39	5.2	33.51	14.53	9.91	42.05
STAFFORD WPCA	Willimantic River Watershed	17.6	5	48.93	16.35	10.5	24.21
UCONN WPCF	Willimantic River Watershed	53.4	7.3	60.56	10.85	7.73	20.85
WILLIMANTIC WPCF	Willimantic River Watershed	101.8	6.8	50.12	11	8.47	30.41

An 8.4 EF was identified in the TITAN analysis as a saturation threshold, beyond which major deviations from the natural condition have occurred in the structure of the biotic community. This threshold was identified by the Department as the maximum allowable EF target necessary to achieve WQS in waste receiving streams. The Department is requiring a reduction in current phosphorus loads from NPDES facility discharges to those streams with an EF greater than 8.4. The reductions at these facilities will ensure that an 8.4 EF is maintained throughout the stream so that water quality management goals are achieved and aquatic life uses are met (Table 8). The required load reductions will be incorporated into the facility NPDES permits when they are up for renewal. Those facilities discharging to streams with an EF below 8.4 will be required to maintain their current phosphorus load to ensure anti-degradation. Any increases in flow at the facilities in the future will require that the facilities reduce their phosphorus concentration. Compliance schedules may be incorporated into the permit to allow for planning, design, financing and construction of any treatment facilities necessary to achieve performance levels. The minimum performance concentration limit was set at 0.1 mg/L based on available technology to achieve phosphorus reductions at the time of the analysis. Permit limits for WPCFs that require a reduction below 0.1 mg/L to achieve 8.4 EF were set at a loading of 0.1 mg/L times their current flow rate and will be re-evaluated during the next permit cycle.

Table 8: The current average phosphorus load (lbs/day) and the phosphorus load after reductions are met, as well as the proposed performance limit needed to meet reductions at the 45 NPDES facilities.

NPDES	Watershed	Current Average Phosphorus Load (lbs/day) 2001 - 2007	Phosphorus Load After Reductions to meet EF goal (lbs/day)	Proposed Performance Limit (mg/L)
LITCHFIELD WPCF	Bantam River Watershed	13.07	9.97	2.39
NORFOLK SEWER DISTRICT	Blackberry River Watershed	3.45	3.45	Cap
NORTH CANAAN WPCF	Blackberry River Watershed	4.29	4.29	Cap
SALISBURY WPCF	Factory Brook Watershed	7.14	1.97	0.62
WINSTED WPCF	Farmington River Watershed	20.03	17.16	1.49
NEW HARTFORD WPCF	Farmington River Watershed	10.92	10.92	Cap
CANTON WPCF	Farmington River Watershed	24.8	24.8	Cap
FARMINGTON WPCF	Farmington River Watershed	119.01	70.11	2
SIMSBURY WPCF	Farmington River Watershed	85.99	46.95	2.5
NEW CANAAN WPCF	Fivemile River Watershed	10.45	1.47	0.19
VERNON WPCF	Hockanum River Watershed	72.19	4.56	0.14
MANCHESTER WATER & SEWER	Hockanum River Watershed	110.4	13.21	0.25
New Milford WPCF	Housatonic River Main Stem Watershed	5.76	5.76	Cap
DANBURY WPCF	Limekiln Brook Watershed	78.51	7.55	0.1
TORRINGTON WPCF	Naugatuck River Watershed	64.73	17.29	0.4
QUALITY ROLLING AND DEBURRING INC.	Naugatuck River Watershed	0.54	0.53	0.7
THOMASTON WPCF	Naugatuck River Watershed	22.68	7.35	1
WATERBURY WPCF	Naugatuck River Watershed	539.92	34.26	0.2
NAUGATUCK WPCF	Naugatuck River Watershed	159.97	16.43	0.4
BEACON FALLS WPCF	Naugatuck River Watershed	7.91	2.67	1
SEYMOUR WPCF	Naugatuck River Watershed	41.09	7.54	0.7
ANSONIA WPCF	Naugatuck River Watershed	43.32	11.92	0.7
RIDGEFIELD MAIN WPCF	Norwalk River Watershed	5.99	0.52	0.1
RIDGEFIELD RTE 7 *	Norwalk River Watershed	0	1	1
REDDING WPCF	Norwalk River Watershed	1.08	1.08	Cap
PLYMOUTH WPCF	Pequabuck River Watershed	28.64	4.38	0.5
BRISTOL WPCF	Pequabuck River Watershed	189.33	7.48	0.1
PLAINVILLE WPCF	Pequabuck River Watershed	82.35	3.49	0.2

NPDES	Watershed	Current Average Phosphorus Load (lbs/day) 2001 - 2007	Phosphorus Load After Reductions to meet EF goal (lbs/day)	Proposed Performance Limit (mg/L)
SOUTHBURY HERITAGE VILLAGE WPCF	Pomperaug River Watershed	10.92	10.92	Cap
NEWTOWN WPCF	Pootatuck River Watershed	4.01	4.01	Cap
THOMPSON WPCF	Quinebaug River Watershed	6.29	2.1	0.7
PUTNAM WPCF	Quinebaug River Watershed	19.69	8.41	0.7
KILLINGLY WPCF	Quinebaug River Watershed	40.64	18.23	0.7
PLAINFIELD NORTH WPCF	Quinebaug River Watershed	17.82	3.86	0.7
PLAINFIELD WPCF	Quinebaug River Watershed	10.51	2.51	0.7
GRISWOLD WPCA	Quinebaug River Watershed	5.52	2.92	0.7
SOUTHINGTON WPCF	Quinnipiac River Watershed	100	7.53	0.2
CHESHIRE WPCF	Quinnipiac River Watershed	88.2	4.06	0.2
MERIDEN WPCF	Quinnipiac River Watershed	121.64	8.71	0.1
WALLINGFORD WATER & SEWER	Quinnipiac River Watershed	145.16	8.95	0.2
CYTEC INDUSTRIES INC.	Quinnipiac River Watershed	19.44	1.49	0.1
SPRAGUE WPCF	Shetucket River Watershed	3.11	3.11	Cap
STAFFORD WPCA	Willimantic River Watershed	8.61	8.61	Cap
UCONN WPCF	Willimantic River Watershed	23.76	23.76	Cap
WILLIMANTIC WPCF	Willimantic River Watershed	18.63	18.63	Cap

* Current phosphorus loading data was not available for the Ridgefield Rte. 7 WPCF at the time the analysis was conducted.

The Quinnipiac River, an urbanized waste-receiving stream located south central portion of CT (Figure 8), is provided as a detailed example. The Quinnipiac contains 4 municipal WPCFs (Southington, Cheshire, Meriden & Wallingford) and one industrial (Cytec, Inc.) discharge of phosphorus (Figure 8). The EF was calculated at 52 points in the Quinnipiac River downstream of NPDES facilities (Figure 8).

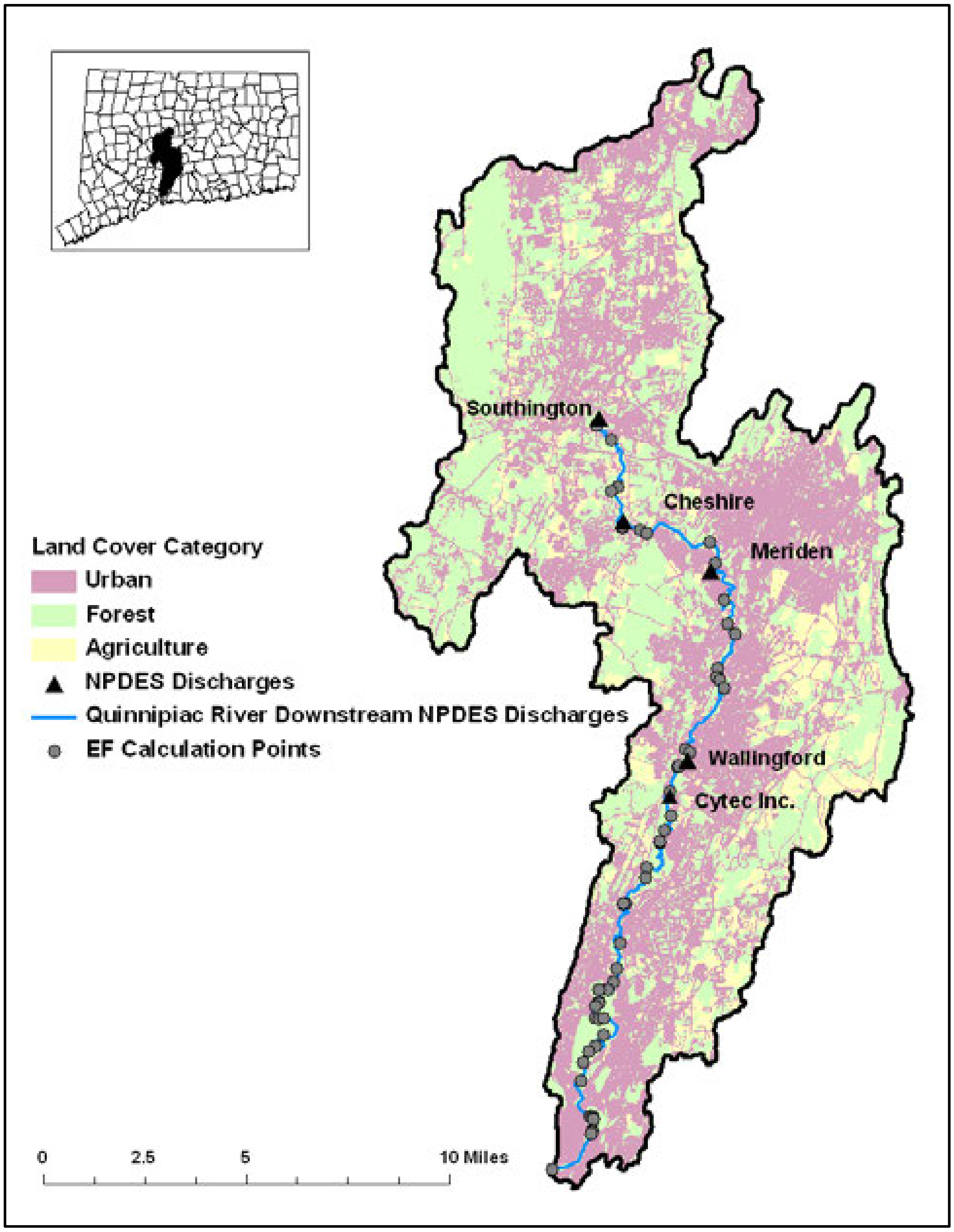

Figure 8: Quinnipiac River Watershed Land Cover and Points for Analysis

The in-stream phosphorus load at the most downstream discharge point, Cytec Inc., is an estimated 108,479 lbs / season while the estimated load under 'natural' conditions is 1,605 lbs / season making the EF 67.6 (i.e. 108,479 / 1,605 = 67.6). The in-stream EF below the facilities ranges from 30.8 below the Southington WPCF to 67.6 below the Cytec Inc. discharge in Wallingford. Loading reductions at each of the plants were made to ensure an 8.4 EF throughout the river (Table 9). Note that in the in-stream EF required to meet CT WQS is lower than an 8.4 EF below the Southington, Cheshire, Meriden and Wallingford WPCFs (Table 9). These reductions are needed to ensure downstream protection of an 8.4 EF consistently throughout the river. The Appendix contains details of loading reductions and permit requirement for all facilities discharging to a freshwater non-tidal waste-receiving stream in CT by watershed.

Table 9: Reductions needed at NPDES facilities discharging to the Quinnipiac River to achieve EFs consistent with CT WQS

NPDES	Flow (MGD)	Current NPDES Load (lbs/day)	Required NPDES Load (lbs/day)	Percent Load Reduction Needed	Current In-Stream EF At Discharge	Required In-Stream EF At Discharge
SOUTHINGTON WPCF	4.51	100	7.53	92.50%	**30.8**	**6**
CHESHIRE WPCF	2.43	88.2	4.06	95.40%	**44.9**	**6.6**
MERIDEN WPCF	10.44	121.64	8.71	92.80%	**52.7**	**7.3**
WALLINGFORD WATER & SEWER	5.36	145.16	8.95	93.80%	**66.2**	**8.3**
CYTEC INDUSTRIES INC.	1.79	19.44	1.49	92.30%	**67.6**	**8.4**

Future Work

Ongoing study in CT rivers and streams (Becker, 2012) is currently being conducted to refine this approach through additional data collection and by expanding the methodology to include non-waste receiving streams. The current approach provides for a major statewide advancement in the level of phosphorus control that is expected to meet all freshwater designated uses in waste-receiving streams. The adaptive nature of Connecticut's strategy allows for revisions to permit limits in future permit cycles without delaying action that we know needs to be taken today. It also provides an opportunity to monitor and research the responsiveness of the aquatic systems to these initial steps to manage phosphorus from NPDES permitted sources.

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Appendix. Enrichment Factor Watershed Analysis Overview and Limits for NPDES Facilities Discharging to Freshwater Rivers and Streams

Nutrient Enrichment Analysis Watershed Overview

Last Updated: 7 Nov. 2011

INTRODUCTION

A geo-spatial modeling analysis was conducted in the following watersheds below facilities discharging phosphorus to assess the level of nutrient enrichment in the river. The goal of the Connecticut interim nutrient management strategy is to achieve or maintain an enrichment factor (EF) of 8.4 or below throughout a watershed. An EF represents the ratio of the total seasonal phosphorus load (April through October) at the point of complete mixing downstream of a National Pollutant Discharge Elimination System (NPDES) discharge to that load calculated for the same location from a fully forested upstream watershed with no point discharges. The total current load includes the current load from the NPDES facility and any additional NPDES facilities upstream plus the load from current land use export.

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left({}^{\text{lbs}}/_{\text{day}}\right) + \text{Land Cover Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}{\text{Forested Condition Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}$$

The EF quantifies the cumulative influence of anthropogenic activity (point and non point) on current phosphorus loads. The goal of an 8.4 EF represents a threshold at which a significant change is seen in stream algal communities indicating highly enriched conditions and impacts to aquatic life uses. The analysis was conducted using stream algae collected in rivers and streams throughout CT under varying enrichment conditions. The approach targets the critical 'growing' season (April through October) when phosphorus is more likely to be taken up by sediment and biomass because of low flow and warmer conditions. During winter months aquatic plants are dormant and flows are higher providing constant flushing of phosphorus through aquatic systems with a less likely chance that it will settle out into the sediment. Limiting the phosphorus export from industrial and municipal facilities offers a targeted management strategy for achieving aquatic life designated uses within a waterbody.

Nutrient Enrichment Analysis Watershed Overview

Bantam River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
LITCHFIELD WPCF	CT0100803	LITCHFIELD	0.80	AS, Nitr, DNitr,UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
LITCHFIELD WPCF	0.50	3.29	13.07	**2.39**	9.97

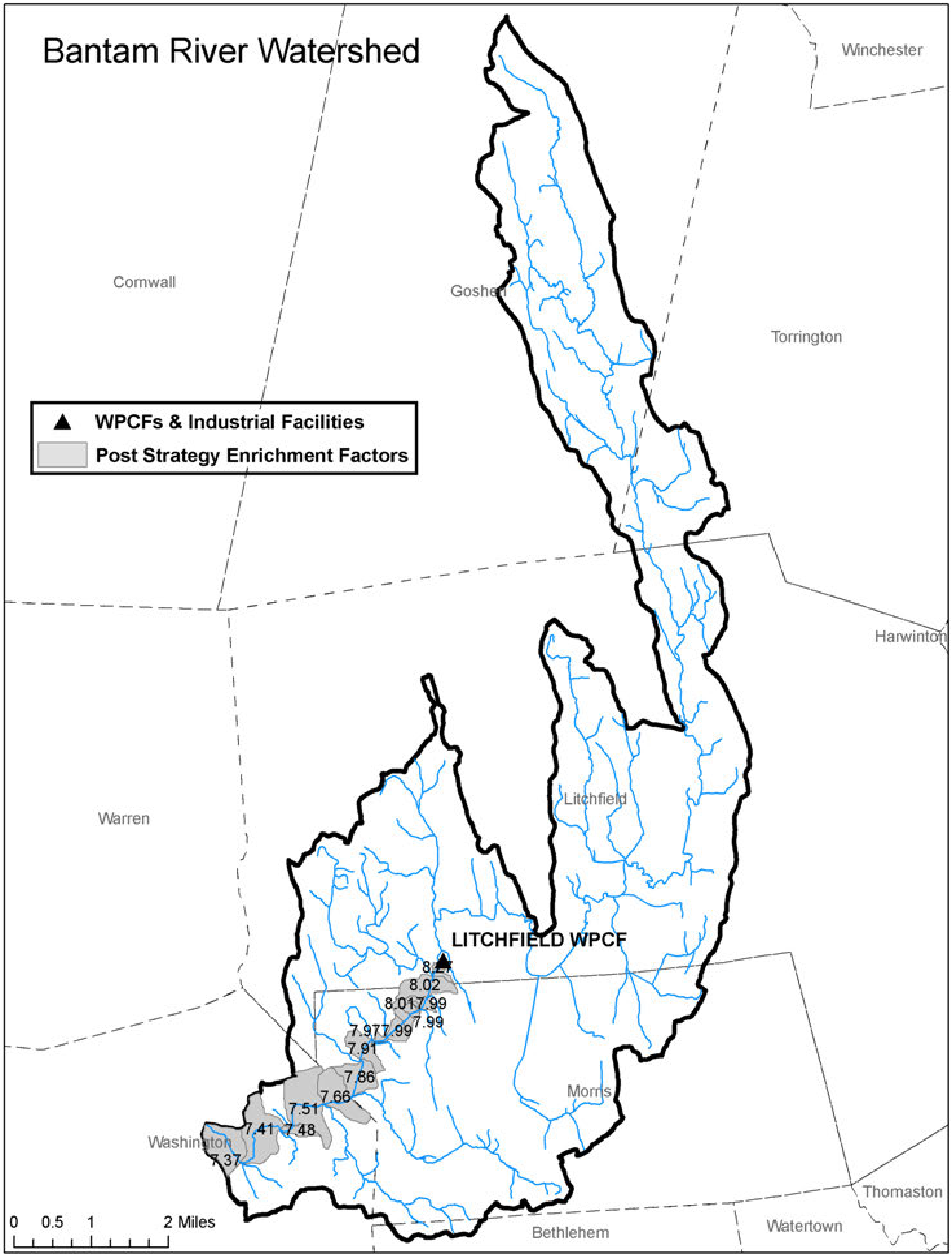
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load } \left({}^{\text{lbs}}/_{\text{day}}\right) + \text{ Land Cover Load} \left({}^{\text{lbs}}/_{\text{day}}\right)}{\text{Forested Condition Load } \left({}^{\text{lbs}}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
LITCHFIELD WPCF	13.07	14.04	2.86	**9.50**	9.97	**8.40**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Blackberry River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
NORFOLK SEWER DISTRICT	CT0101231	NORFOLK	0.35	AS, EA, DChlor, SFilt
NORTH CANAAN WPCF	CT0100064	CANAAN	0.40	AS, UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
NORFOLK SEWER DISTRICT	0.31	1.70	3.45	**Cap**	3.45
NORTH CANAAN WPCF	0.32	1.88	4.29	**Cap**	4.29

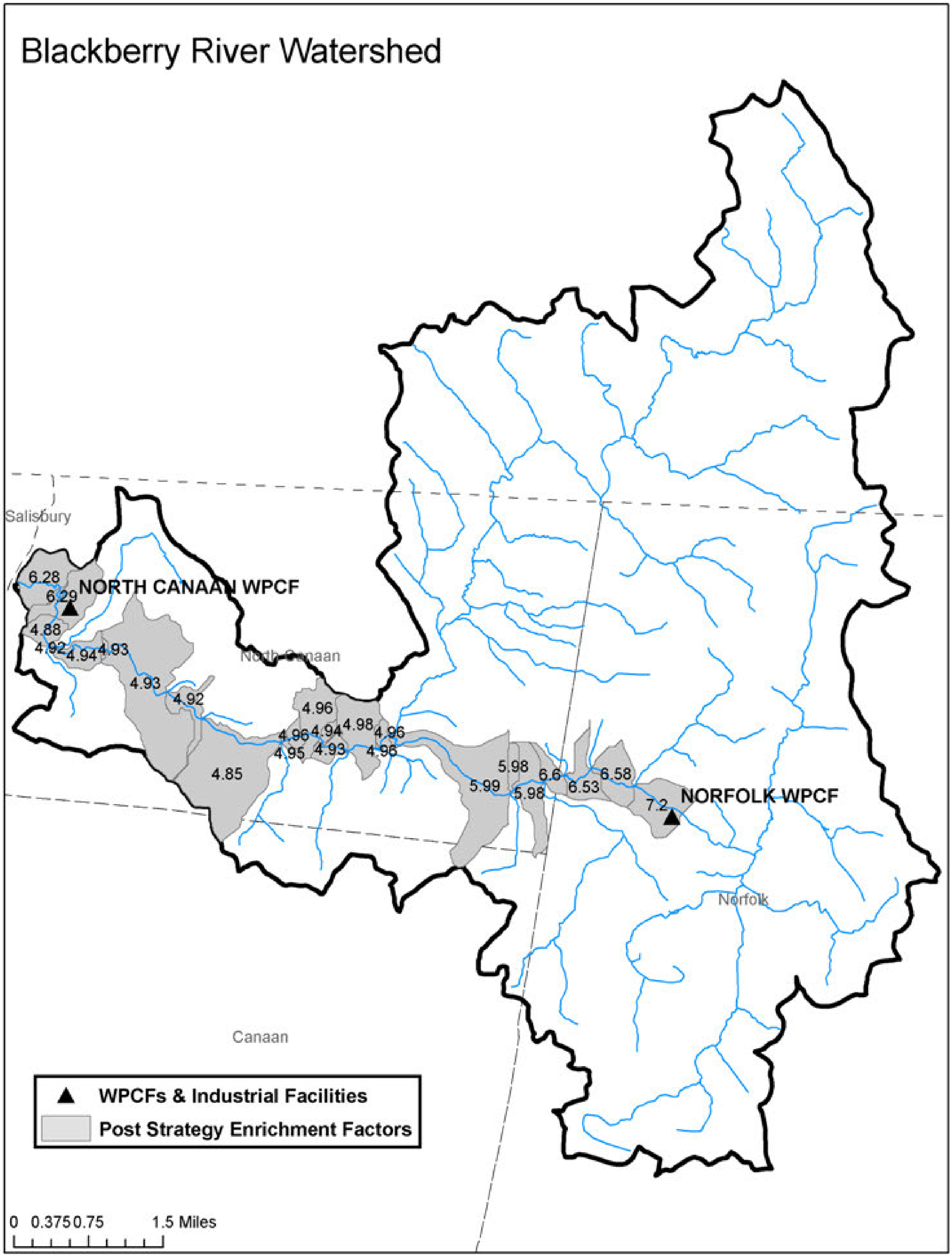
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left({}^{\text{lbs}}/_{\text{day}}\right) + \text{Land Cover Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}{\text{Forested Condition Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
NORFOLK SEWER DISTRICT	3.45	2.33	0.80	**7.20**	3.45	**7.20**
NORTH CANAAN WPCF	7.74	11.40	3.04	**6.30**	7.74	**6.30**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Factory Brook Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
SALISBURY WPCF	CT0100498	SALISBURY	0.67	AS, SFilt, UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
SALISBURY WPCF	0.38	2.40	7.14	**0.62**	1.97

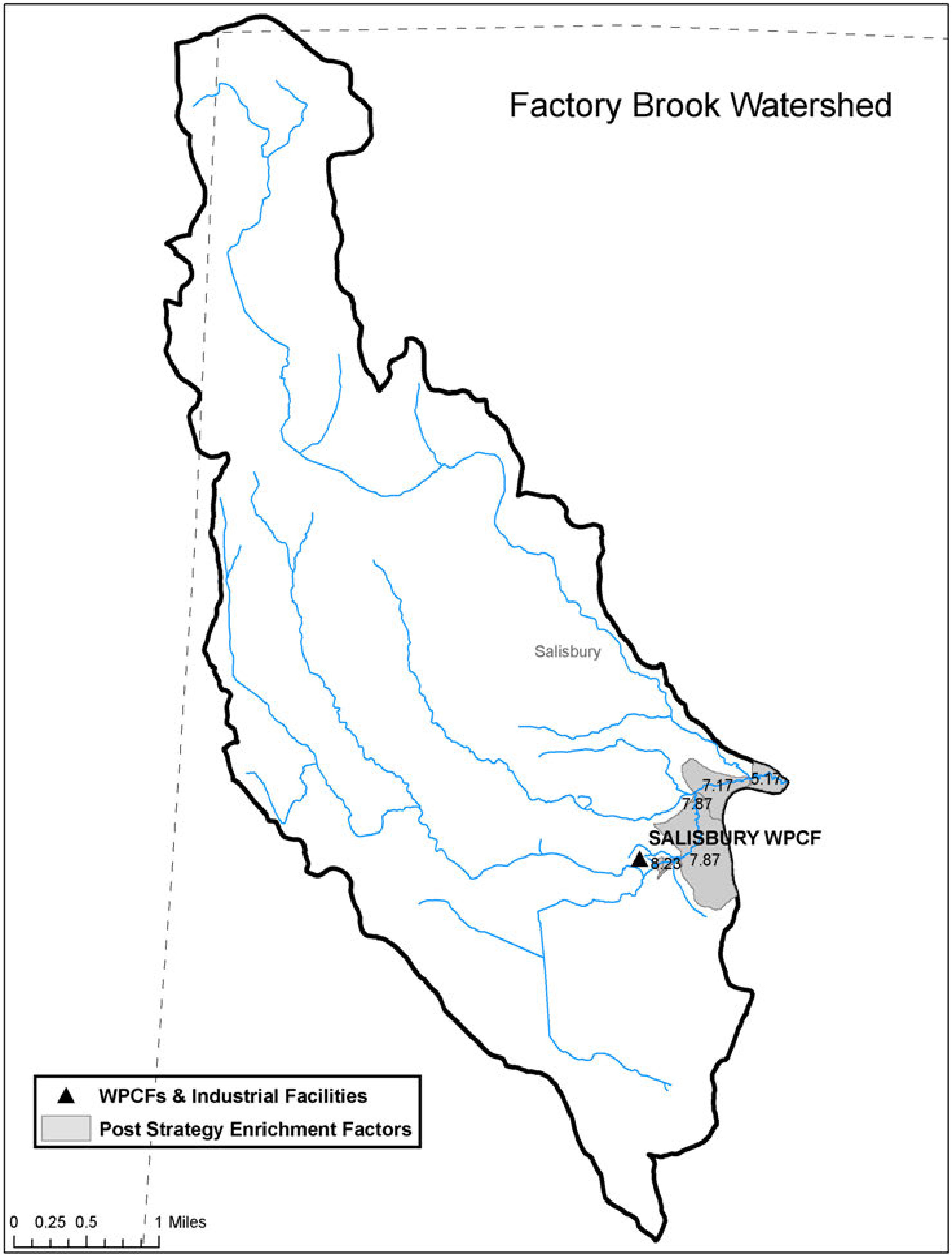
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/\text{day}\right) + \text{Land Cover Load}\left(\text{lbs}/\text{day}\right)}{\text{Forested Condition Load}\left(\text{lbs}/\text{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
SALISBURY WPCF	7.14	1.83	0.45	**19.80**	1.97	**8.40**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Farmington River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
PLYMOUTH WPCF	CT0100463	TERRYVILLE	1.75	AS, AdvTr, Nitr, DNitr, UV
WINSTED WPCF	CT0101222	WINSTED	3.50	AS, AdvTr, Nitr, DChlor
BRISTOL WPCF	CT0100374	BRISTOL	10.75	AS, AdvTr, Nitr, UV
PLAINVILLE WPCF	CT0100455	PLAINVILLE	3.80	RBC, SFilt, UV, AdvTr, Nitr
NEW HARTFORD WPCF*	CT0100331	NEW HARTFORD	0.40	AS, EA
CANTON WPCF	CT0100072	CANTON	0.80	RBC, SFilt, TFilt, UV
FARMINGTON WPCF	CT0100218	FARMINGTON	5.65	AS, TFilt, AdvTr, Nitr, DNitr, DChlor
SIMSBURY WPCF	CT0100919	SIMSBURY	2.85	AS, OD, Nitr, DNitr, UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration,
OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification
DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
PLYMOUTH WPCF	1.05	3.47	28.64	**0.5**	4.38
WINSTED WPCF	1.38	1.87	20.03	**1.49**	17.16
BRISTOL WPCF	8.96	2.62	189.33	**0.1**	7.48
PLAINVILLE WPCF	2.09	5.08	82.35	**0.2**	3.49
NEW HARTFORD WPCF*	0.40	3.27	10.92	**Cap**	10.92
CANTON WPCF	0.60	5.44	24.80	**Cap**	24.80
FARMINGTON WPCF	4.20	3.55	119.01	**2**	70.11
SIMSBURY WPCF	2.25	4.57	85.99	**2.5**	46.95

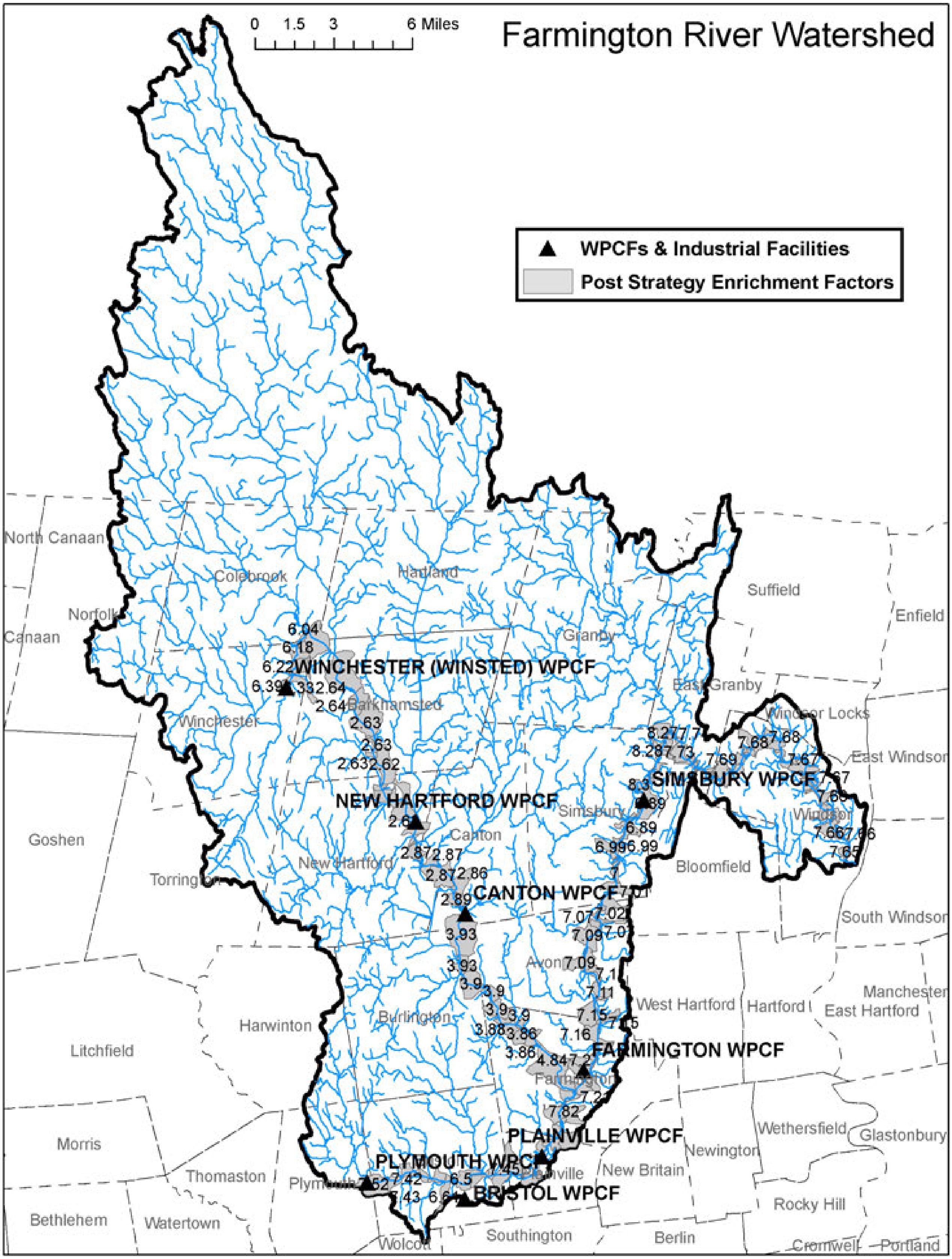
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(^{lbs}/_{day}\right) + \text{Land Cover Load}\left(^{lbs}/_{day}\right)}{\text{Forested Condition Load}\left(^{lbs}/_{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
PLYMOUTH WPCF	28.64	3.42	1.04	**30.90**	4.38	**7.50**
WINSTED WPCF	20.03	6.70	2.85	**9.40**	17.16	**8.40**
BRISTOL WPCF	217.97	11.07	3.04	**75.40**	11.86	**7.60**
PLAINVILLE WPCF	300.32	12.13	3.27	**95.50**	15.35	**8.40**
NEW HARTFORD WPCF*	30.95	36.38	20.15	**3.30**	28.08	**3.20**
CANTON WPCF	55.75	47.77	23.94	**4.30**	52.88	**4.20**
FARMINGTON WPCF	475.08	68.46	29.75	**18.30**	138.34	**7.00**
SIMSBURY WPCF	561.07	80.96	32.97	**19.50**	185.29	**8.10**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Fivemile River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
NEW CANAAN WPCF	CT0101273	NEW CANAAN	1.70	AS, OD, EA, AdvTr, Nitr, DNitr, UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
NEW CANAAN WPCF	0.93	1.42	10.45	**0.19**	1.47

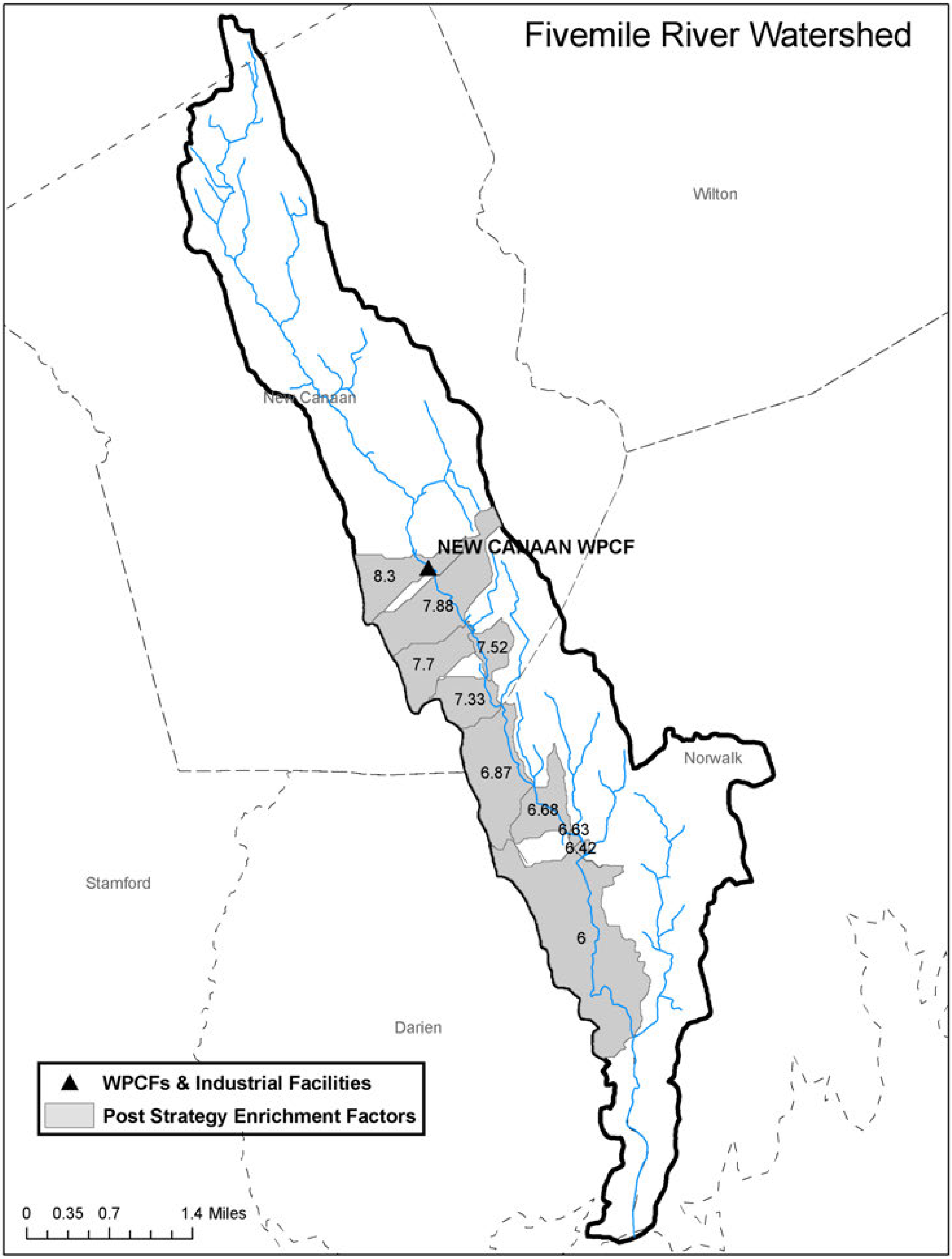
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left({}^{lbs}/_{day}\right) + \text{Land Cover Load}\left({}^{lbs}/_{day}\right)}{\text{Forested Condition Load}\left({}^{lbs}/_{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
NEW CANAAN WPCF	10.45	1.26	0.33	**35.50**	1.47	**8.30**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Hockanum River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
VERNON WPCF	CT0100609	VERNON	7.10	PAC, AdvTr, Nitr, SFilt, DChlor
MANCHESTER WATER & SEWER	CT0100293	MANCHESTER	8.25	AS, AdvTr, Nitr, UV

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
VERNON WPCF	3.90	2.30	72.19	**0.14**	4.56
MANCHESTER WATER & SEWER	6.33	2.15	110.40	**0.25**	13.21

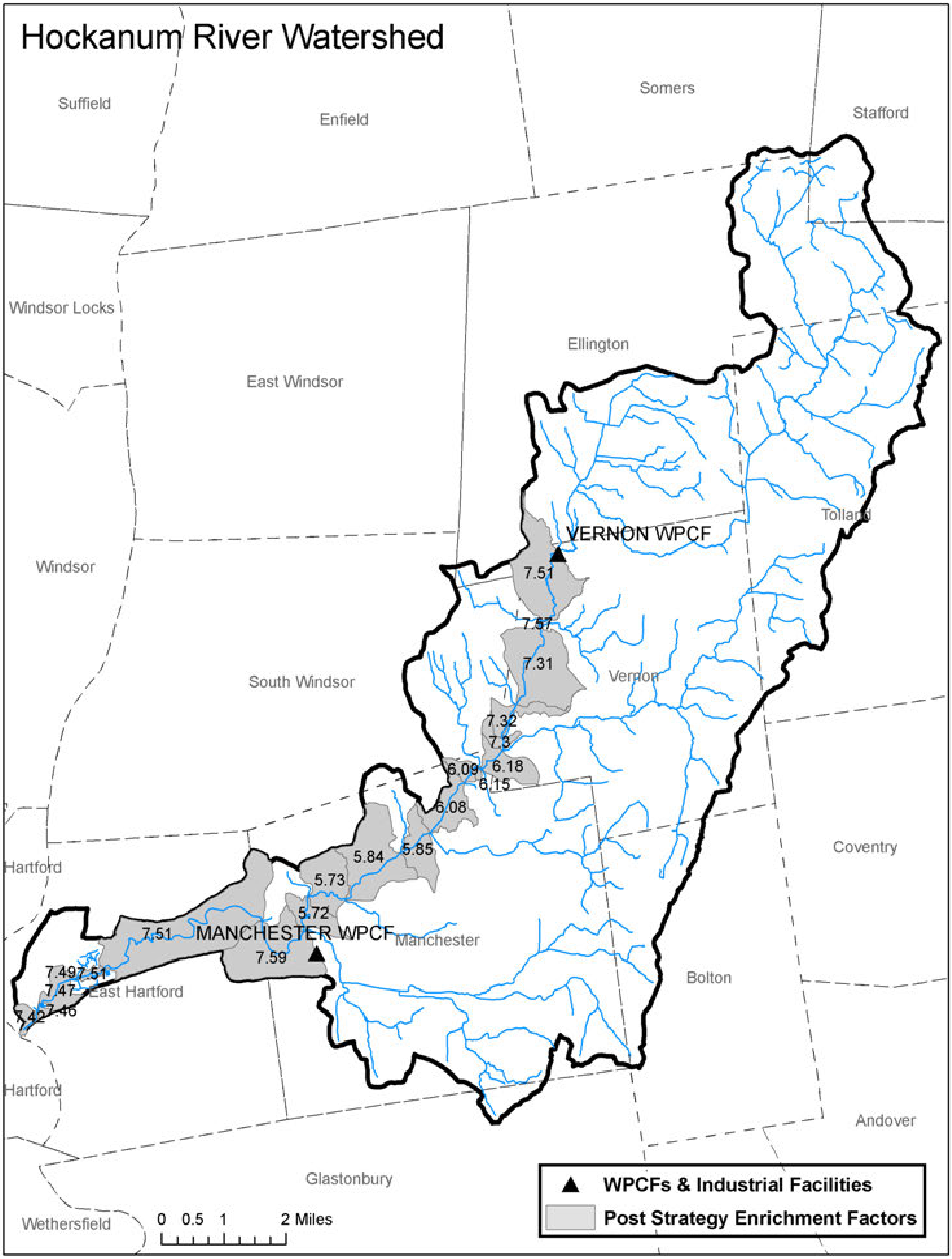
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load } \left(\text{lbs}/\text{day}\right) + \text{ Land Cover Load} \left(\text{lbs}/\text{day}\right)}{\text{Forested Condition Load } \left(\text{lbs}/\text{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
VERNON WPCF	72.19	10.00	1.77	**46.50**	4.56	**8.20**
MANCHESTER WATER & SEWER	182.59	22.96	4.85	**42.40**	17.77	**8.40**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Housatonic River Main Stem Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
New Milford WPCF*	CT0100391	NEW MILFORD	1.02	AS, AdvTr, PRem

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
New Milford WPCF*	0.69	1.00	5.76	**Cap**	5.76

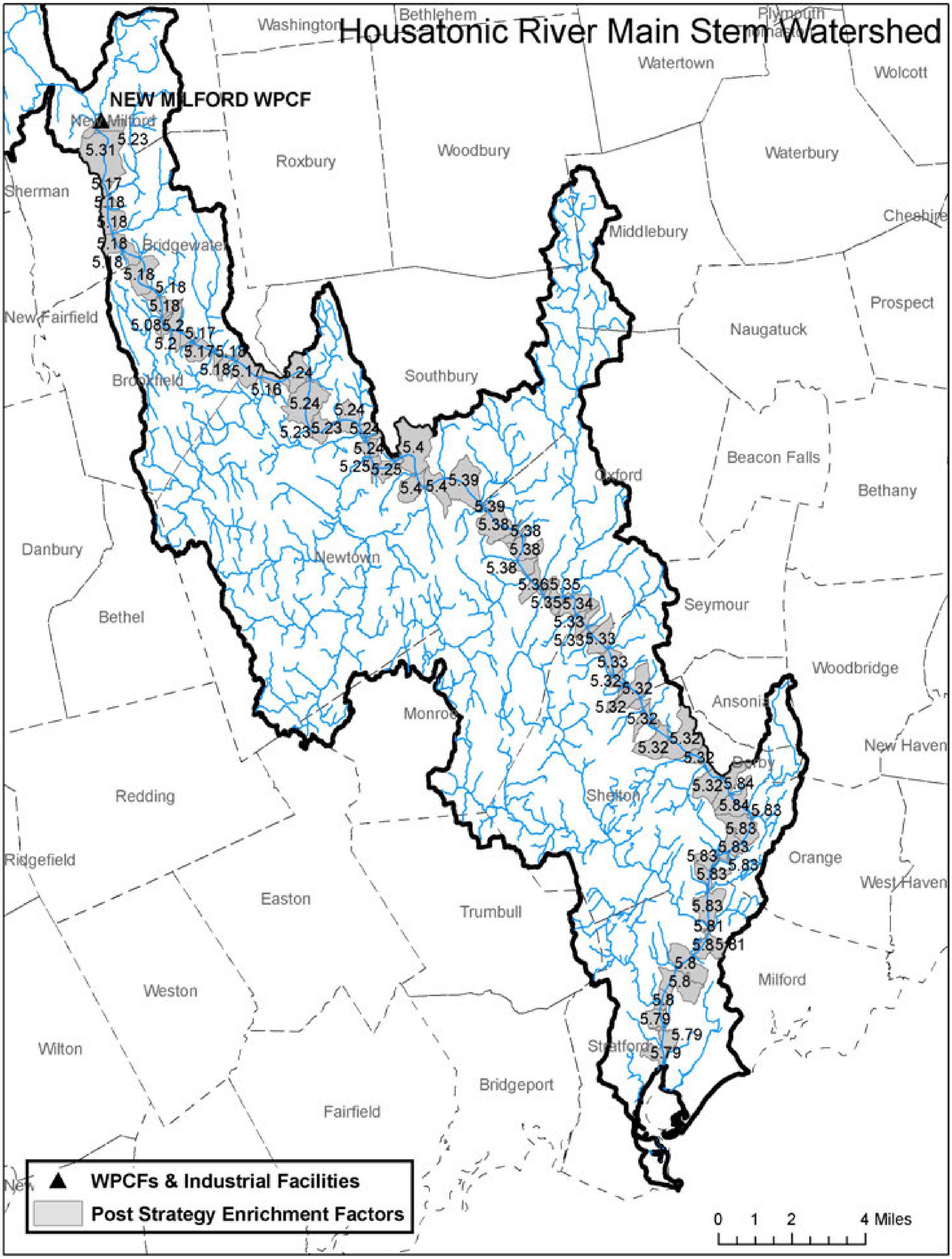
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left({}^{\text{lbs}}/_{\text{day}}\right) + \text{Land Cover Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}{\text{Forested Condition Load}\left({}^{\text{lbs}}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
New Milford WPCF*	79.49	301.85	71.87	**5.30**	79.49	**5.30**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Limekiln Brook Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
DANBURY WPCF	CT0100145	DANBURY	15.50	AS, TFilt, AdvTr, Nitr, DNitr, PRem, DChlor

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
DANBURY WPCF	9.05	1.04	78.51	**0.1**	7.55

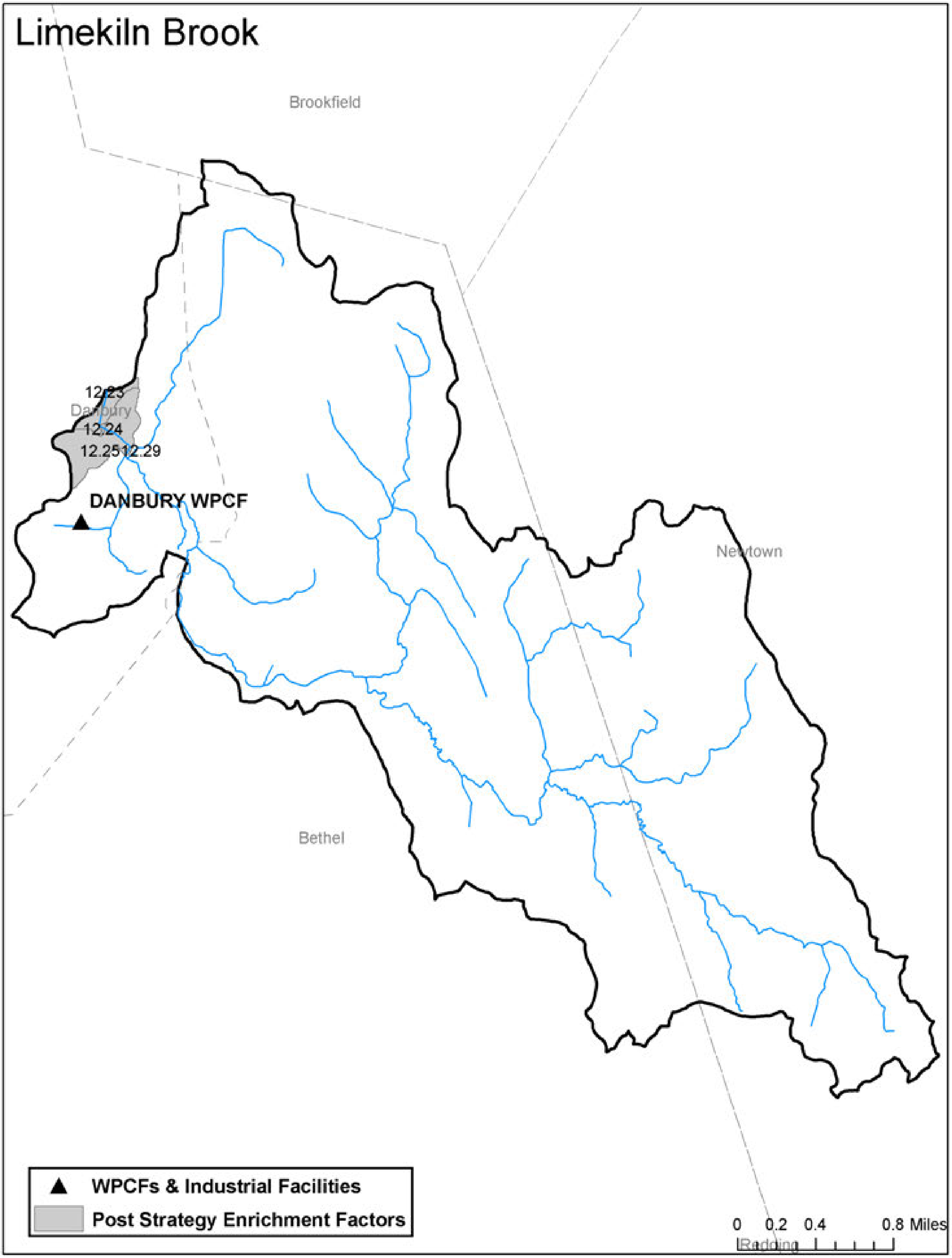
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load} \left({}^{lbs}/_{day}\right) + \text{Land Cover Load} \left({}^{lbs}/_{day}\right)}{\text{Forested Condition Load} \left({}^{lbs}/_{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
DANBURY WPCF	78.51	3.70	0.92	**89.80**	7.55	**12.30**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Naugatuck River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
TORRINGTON WPCF	CT0100579	TORRINGTON	7.00	AS, AdvTr, Nitr, DNitr, DChlor
QUALITY ROLLING AND DEBURRING INC.	CT0025305	THOMASTON		
THOMASTON WPCF	CT0100781	THOMASTON	1.38	SBR, AdvTr, UV, Nitr, DNitr
WATERBURY WPCF	CT0100625	WATERBURY	27.00	AS, AdvTr, Nitr, DNitr, UV
NAUGATUCK WPCF	CT0100641	NAUGATUCK	10.30	AS, AdvTr, Nitr, DNitr, DChlor
BEACON FALLS WPCF	CT0101061	BEACON FALLS	0.71	AS, UV
SEYMOUR WPCF	CT0100501	SEYMOUR	2.93	AS, Nitr, DNitr, DChlor
ANSONIA WPCF	CT0100013	ANSONIA	3.50	AS, DChlor

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
TORRINGTON WPCF	5.18	1.68	64.73	**0.4**	17.29
QUALITY ROLLING AND DEBURRING INC.	0.09	0.70	0.54	**0.7**	0.53
THOMASTON WPCF	0.88	3.29	22.68	**1**	7.35
WATERBURY WPCF	20.52	3.19	539.92	**0.2**	34.26
NAUGATUCK WPCF	4.92	4.30	159.97	**0.4**	16.43
BEACON FALLS WPCF	0.32	3.19	7.91	**1**	2.67
SEYMOUR WPCF	1.29	3.98	41.09	**0.7**	7.54
ANSONIA WPCF	2.04	2.89	43.32	**0.7**	11.92

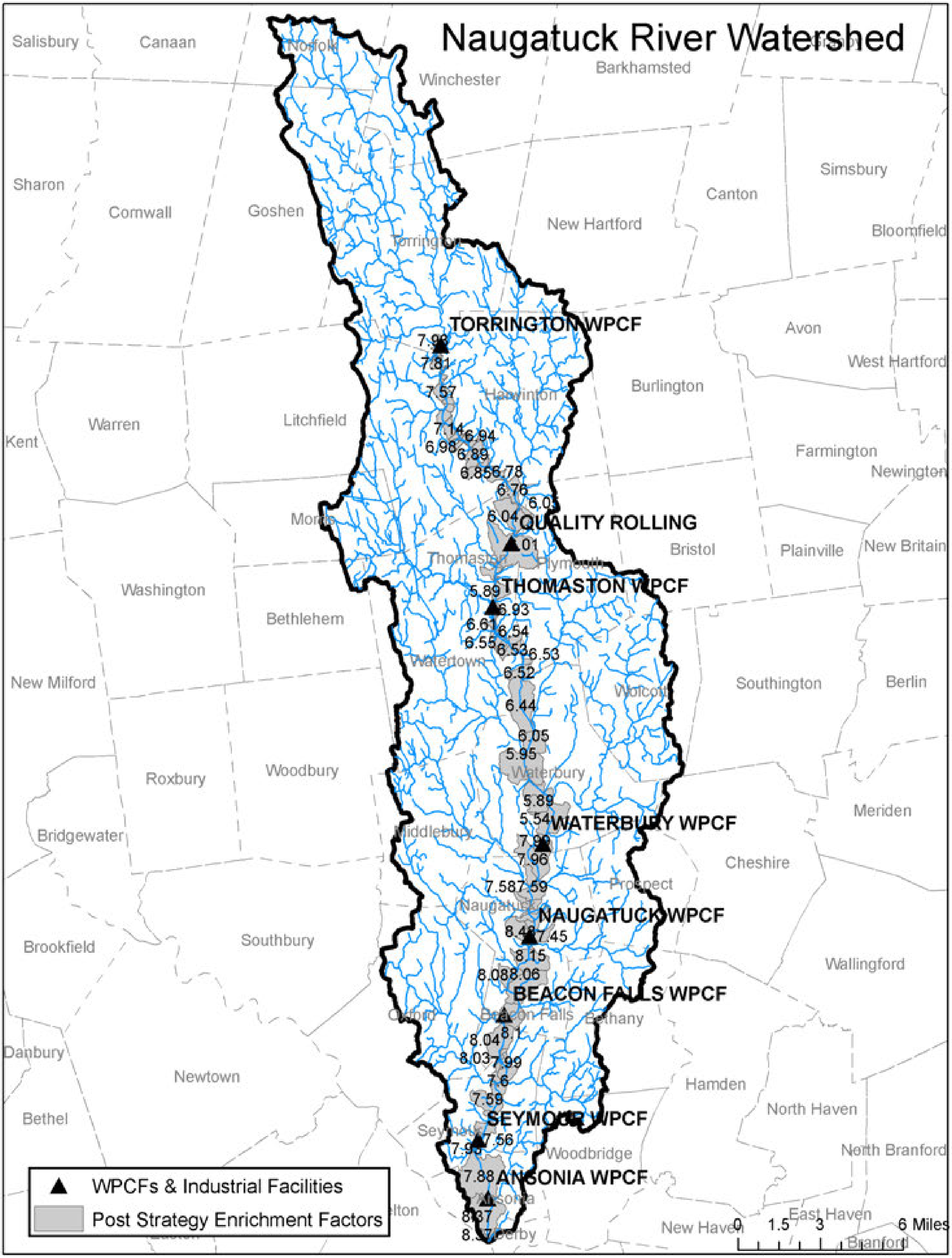
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/\text{day}\right) + \text{Land Cover Load}\left(\text{lbs}/\text{day}\right)}{\text{Forested Condition Load}\left(\text{lbs}/\text{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
TORRINGTON WPCF	64.73	11.52	3.63	**21.00**	17.29	**7.90**
QUALITY ROLLING AND DEBURRING INC.	65.27	22.60	6.72	**13.10**	17.82	**6.00**
THOMASTON WPCF	87.95	25.36	7.29	**15.50**	25.17	**6.90**
WATERBURY WPCF	627.87	51.35	13.87	**49.00**	59.42	**8.00**
NAUGATUCK WPCF	787.84	61.32	16.26	**52.20**	75.85	**8.40**
BEACON FALLS WPCF	795.75	64.55	17.66	**48.70**	78.52	**8.10**
SEYMOUR WPCF	836.84	72.85	20.05	**45.40**	86.06	**7.90**
ANSONIA WPCF	880.16	74.85	20.65	**46.20**	97.98	**8.40**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Norwalk River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
RIDGEFIELD MAIN WPCF C/O OMI	CT0100854	RIDGEFIELD	1.00	AS, AdvTr, Nitr, DNitr, PRem, Sfilt, UV
RIDGEFIELD RTE 7 C/O OMI*	CT0101451	RIDGEFIELD	0.12	RBC, UV, Nitr
REDDING WPCF	CT0101770	REDDING	0.25	SBR, UV, AdvTr, Nitr, DNitr

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
RIDGEFIELD MAIN WPCF C/O OMI	0.62	1.38	5.99	**0.1**	0.52
RIDGEFIELD RTE 7 C/O OMI*	0.12		0.00	**1**	1.00
REDDING WPCF	0.05	3.38	1.08	**Cap**	1.08

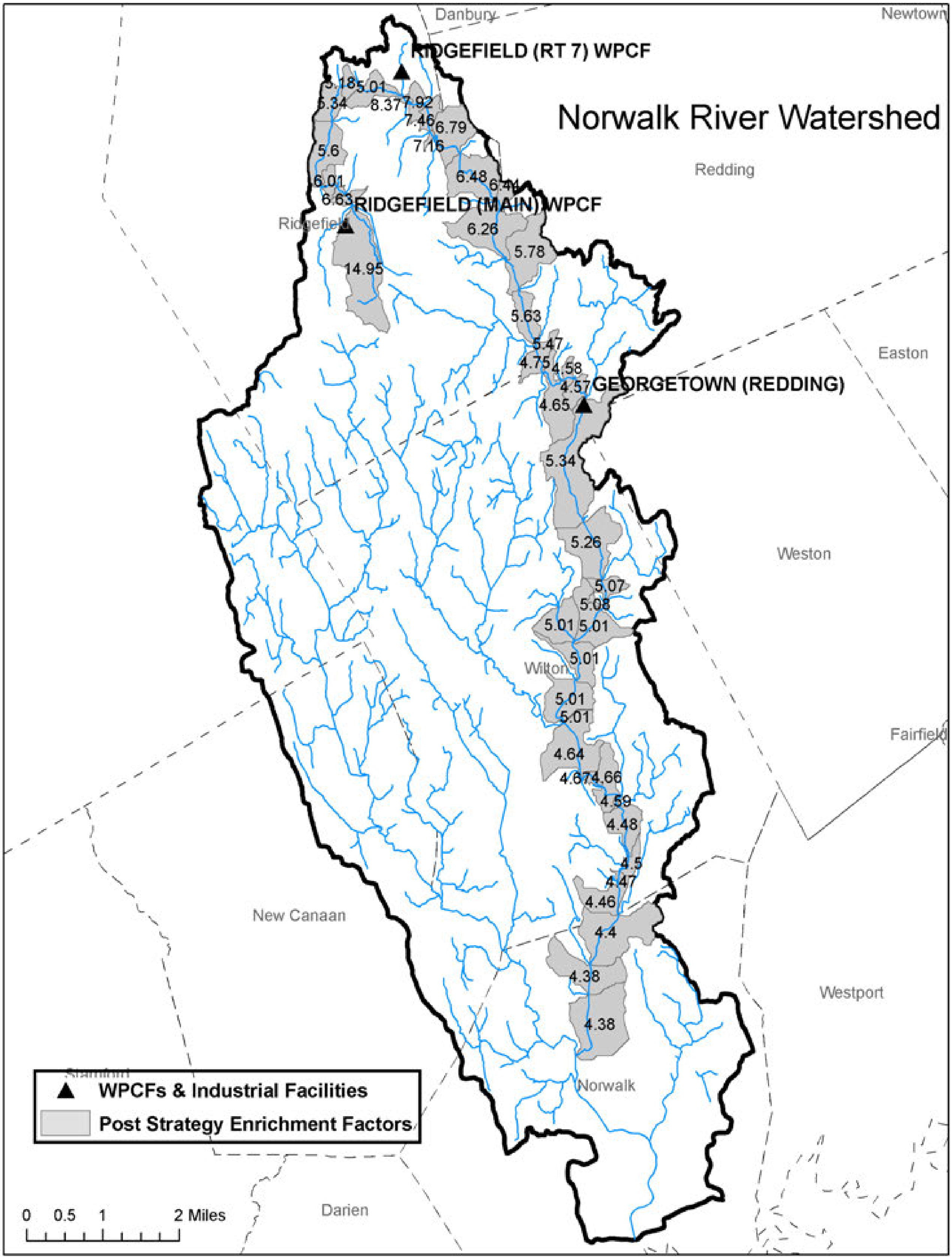
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\frac{lbs}{day}\right) + \text{Land Cover Load}\left(\frac{lbs}{day}\right)}{\text{Forested Condition Load}\left(\frac{lbs}{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
RIDGEFIELD MAIN WPCF C/O OMI	5.99	0.15	0.04	**137.90**	0.52	**15.00**
RIDGEFIELD RTE 7 C/O OMI*	5.99	0.84	0.28	**24.20**	1.52	**8.40**
REDDING WPCF	7.07	2.66	0.99	**9.90**	2.60	**5.30**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Pomperaug River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
SOUTHBURY HERITAGE VILLAGE WPCF*	CT0101133	SOUTHBURY	0.78	AS, Nitr, DNitr, PRem

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
SOUTHBURY HERITAGE VILLAGE WPCF*	0.66	0.96	10.92	**Cap**	10.92

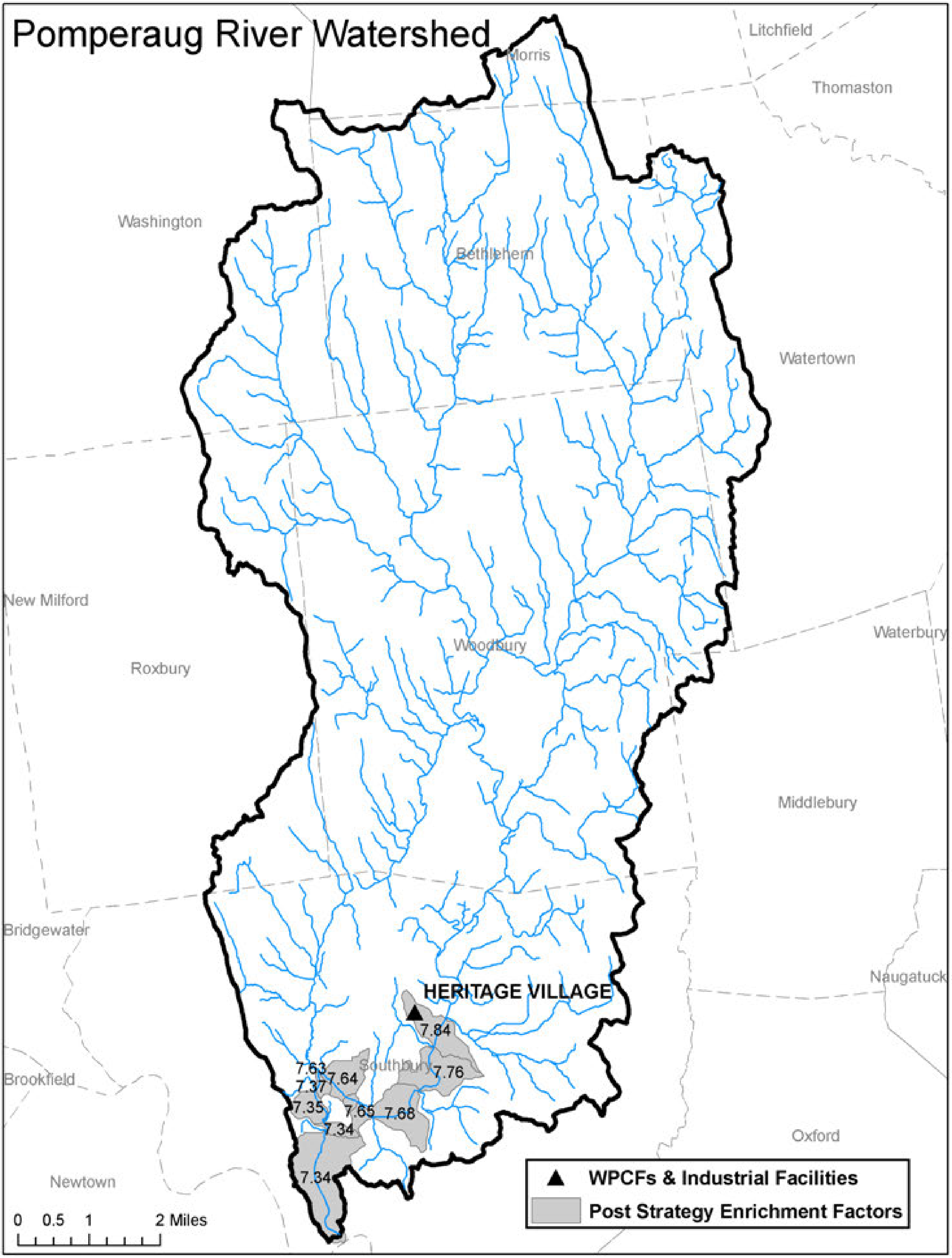
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/\text{day}\right) + \text{Land Cover Load}\left(\text{lbs}/\text{day}\right)}{\text{Forested Condition Load}\left(\text{lbs}/\text{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
SOUTHBURY HERITAGE VILLAGE WPCF*	10.92	28.47	5.03	**7.80**	10.92	**7.80**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Pootatuck River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
NEWTOWN WPCF	CT0101788	NEWTOWN	0.93	AS, OD, EA, UV,AdvTr, PRem, Nitr, DNitr

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
NEWTOWN WPCF	0.48	0.52	4.01	**Cap**	4.01

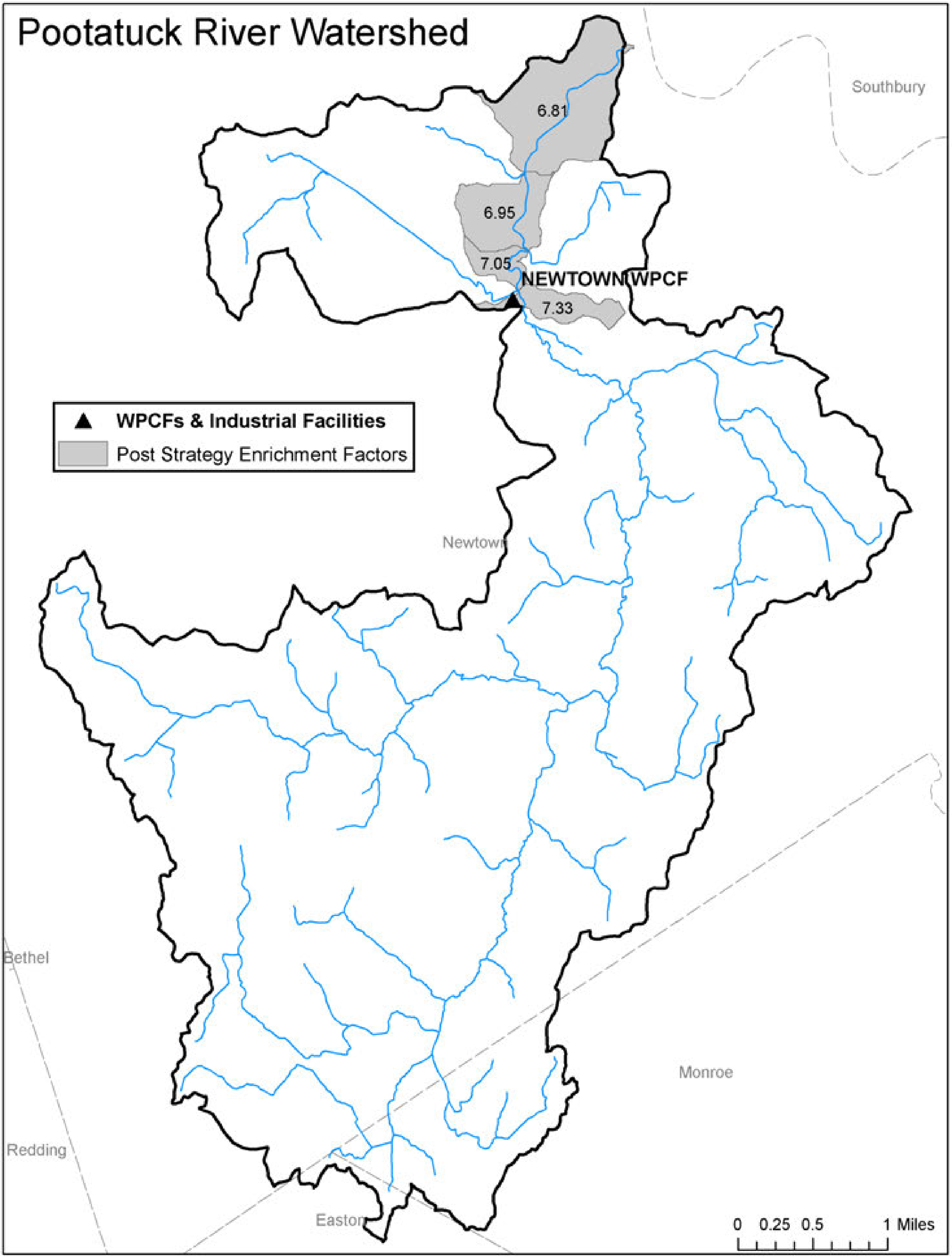
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/_{\text{day}}\right) + \text{Land Cover Load}\left(\text{lbs}/_{\text{day}}\right)}{\text{Forested Condition Load}\left(\text{lbs}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
NEWTOWN WPCF	4.01	6.86	1.48	**7.33**	4.01	**7.33**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Quinebaug River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
THOMPSON WPCF	CT0100706	THOMPSON	1.36	AS, DChlor
PUTNAM WPCF	CT0100960	PUTNAM	2.91	AS, DChlor
KILLINGLY WPCF	CT0101257	DANIELSON	8.00	AS, DChlor, TFilt
PLAINFIELD NORTH WPCF	CT0100447	PLAINFIELD	1.08	AS, DChlor
PLAINFIELD WPCF	CT0100439	PLAINFIELD	0.71	AS, EA, DChlor
GRISWOLD WPCA	CT0100269	JEWETT CITY	0.50	AS, OD,PRem, UV, (Nitr, DNitr capable)

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
THOMPSON WPCF	0.36	2.32	6.29	**0.7**	2.10
PUTNAM WPCF	1.44	1.80	19.69	**0.7**	8.41
KILLINGLY WPCF	3.12	1.58	40.64	**0.7**	18.23
PLAINFIELD NORTH WPCF	0.66	3.52	17.82	**0.7**	3.86
PLAINFIELD WPCF	0.43	3.13	10.51	**0.7**	2.51
GRISWOLD WPCA	0.50	2.11	5.52	**0.7**	2.92

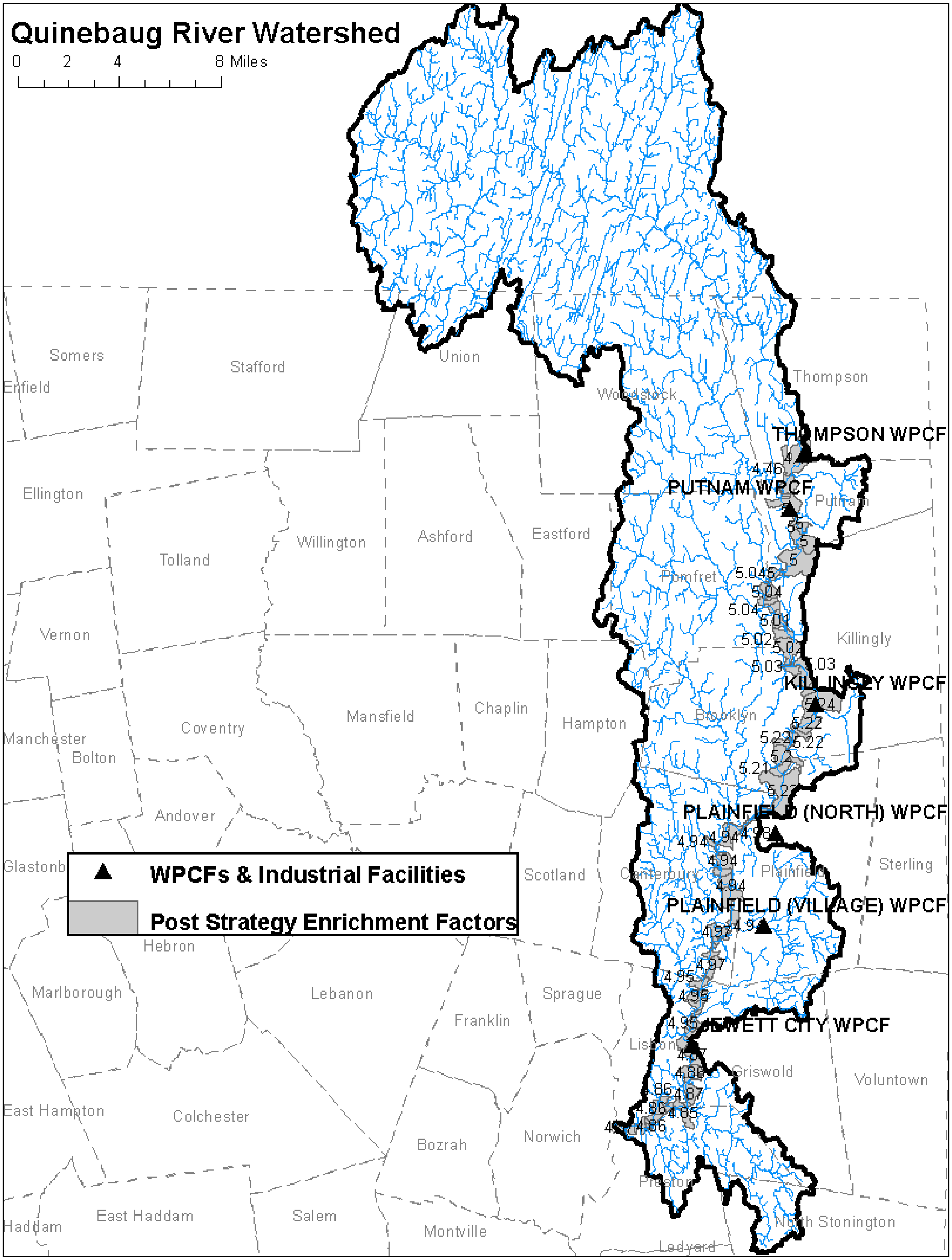
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/_{\text{day}}\right) + \text{Land Cover Load}\left(\text{lbs}/_{\text{day}}\right)}{\text{Forested Condition Load}\left(\text{lbs}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
THOMPSON WPCF	6.29	25.65	7.45	**5.80**	2.10	**5.30**
PUTNAM WPCF	25.98	78.18	21.60	**5.70**	10.52	**5.00**
KILLINGLY WPCF	66.62	111.14	30.42	**6.50**	28.75	**5.20**
PLAINFIELD NORTH WPCF	84.44	133.45	37.22	**6.40**	32.60	**5.00**
PLAINFIELD WPCF	94.95	152.67	41.70	**6.40**	35.12	**5.00**
GRISWOLD WPCA	100.47	172.44	47.25	**6.20**	38.04	**4.90**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Quinnipiac River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
SOUTHINGTON WPCF	CT0100536	SOUTHINGTON	7.40	AS, AdvTr, TFilt, UV, Nitr
CHESHIRE WPCF	CT0100081	CHESHIRE	3.50	AS, Nitr, DNitr, DChlor
MERIDEN WPCF	CT0100315	MERIDEN	11.60	AS, AdvTr, DChlor, Nitr, DNitr
WALLINGFORD WATER & SEWER	CT0100617	WALLINGFORD	8.00	RBC, UV, Nitr, DNitr, AdvTr
CYTEC INDUSTRIES INC.	CT0000086	WALLINGFORD		

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
SOUTHINGTON WPCF	4.51	2.74	100.00	**0.2**	7.53
CHESHIRE WPCF	2.43	4.61	88.20	**0.2**	4.06
MERIDEN WPCF	10.44	1.47	121.64	**0.1**	8.71
WALLINGFORD WATER & SEWER	5.36	3.46	145.16	**0.2**	8.95
CYTEC INDUSTRIES INC.	1.79	1.31	19.44	**0.1**	1.49

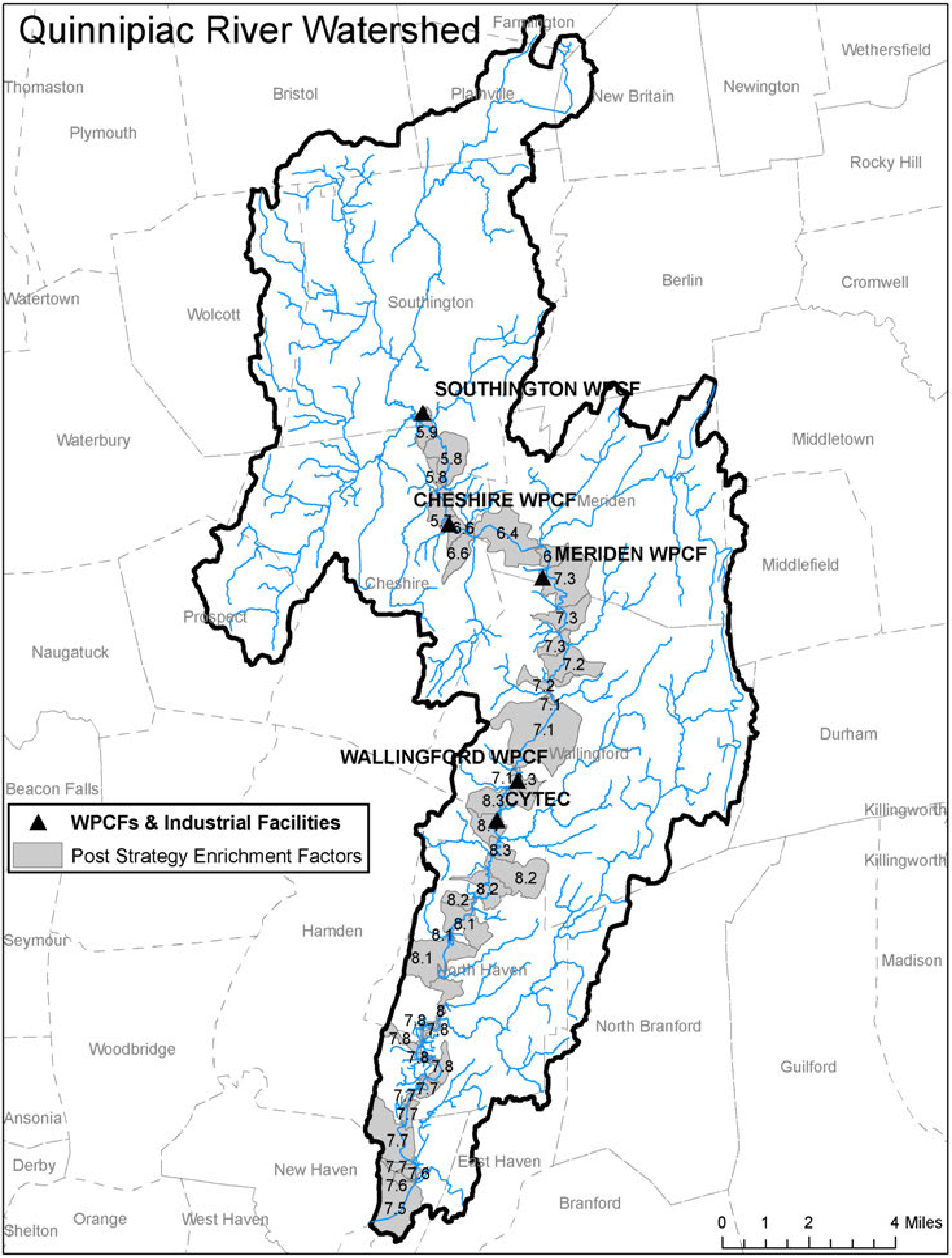
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/\text{day}\right) + \text{Land Cover Load}\left(\text{lbs}/\text{day}\right)}{\text{Forested Condition Load}\left(\text{lbs}/\text{day}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
SOUTHINGTON WPCF	100.00	14.61	3.72	**30.80**	7.53	**6.00**
CHESHIRE WPCF	188.20	18.77	4.61	**44.90**	11.59	**6.60**
MERIDEN WPCF	309.84	26.41	6.38	**52.70**	20.30	**7.30**
WALLINGFORD WATER & SEWER	455.00	31.45	7.34	**66.20**	29.25	**8.30**
CYTEC INDUSTRIES INC.	474.44	32.47	7.50	**67.60**	30.74	**8.40**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Shetucket River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
SPRAGUE WPCF	CT0100978	Baltic	0.40	AS, EA

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration,
OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification
DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
SPRAGUE WPCF	0.17	2.68	3.11	**Cap**	3.11

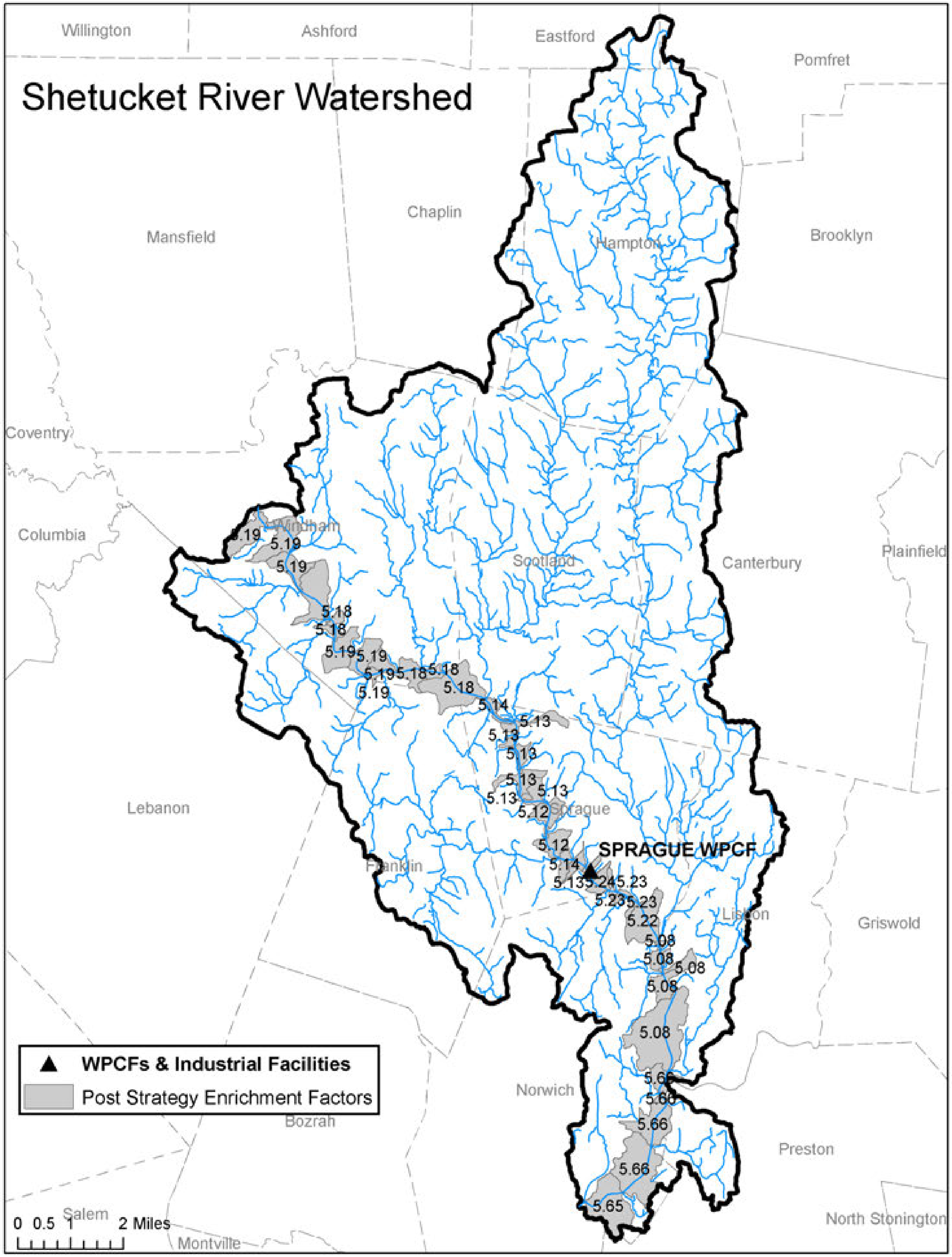
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/_{\text{day}}\right) + \text{Land Cover Load}\left(\text{lbs}/_{\text{day}}\right)}{\text{Forested Condition Load}\left(\text{lbs}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
SPRAGUE WPCF	54.11	107.31	30.83	**5.20**	54.11	**5.20**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Nutrient Enrichment Analysis Watershed Overview

Willimantic River Watershed

Facility Overview

NPDES	NPDES#	Town	Design Flow	Type of Treatment*
STAFFORD WPCA	CT0101214	STAFFORD SPRINGS	2.00	AS, UV, Anthracite Filters
UCONN WPCF	CT0101320	STORRS	3.00	AS, ADvTr, OD, Nitr, DNitr, DChlor
WILLIMANTIC WPCF	CT0101001	WILLIMANTIC	5.50	AS, DChlor

* AS = activated sludge, RBC = rotating biological contractor system, SBR = sequencing batch reactor system, EA = extended aeration, OD = oxidation ditch, DChlor = dechlorination, UV = ultraviolet disinfection, AdvTr = advanced treatment, Nitr = nitrification DNitr = denitrification, PRem = phosphorous removal, PAC = powdered activated carbon system, Sfilt = sand filter, TFilt = trickling filter

Current and Proposed Seasonal Phosphorus Treatment

NPDES	Current Average Flow (MGD) 2001 - 2007	Current Average Concentration (mg/L) 2001 - 2007	Current Average Load (lbs/day) 2001 - 2007	Proposed Performance Limit (mg/L)	Proposed Permit Load (lbs/day)
STAFFORD WPCA	1.49	0.71	8.61	**Cap**	8.61
UCONN WPCF	1.27	2.45	23.76	**Cap**	23.76
WILLIMANTIC WPCF	2.42	0.95	18.63	**Cap**	18.63

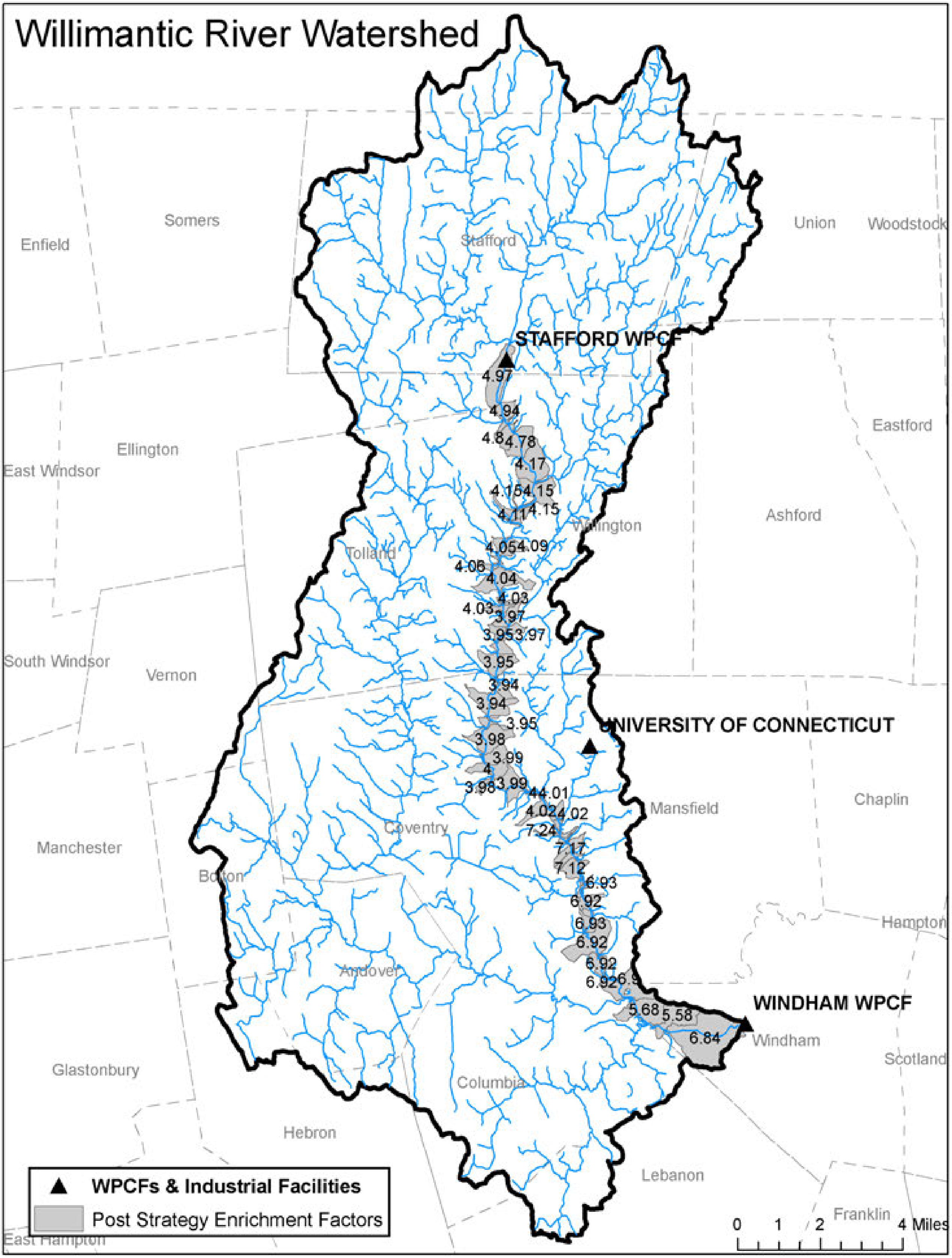
Enrichment Factor at Point of Discharge

$$\text{Enrichment Factor (EF)} = \frac{\text{Total NPDES Load}\left(\text{lbs}/_{\text{day}}\right) + \text{Land Cover Load}\left(\text{lbs}/_{\text{day}}\right)}{\text{Forested Condition Load}\left(\text{lbs}/_{\text{day}}\right)}$$

NPDES	Upstream NPDES Load (lbs/day)	Estimated Land Use Export Load (lbs/day)	Forested Condition Load (lbs/day)	Current EF	Proposed Upstream NPDES Load (lbs/day)	Proposed EF
STAFFORD WPCA	8.61	8.99	3.54	**5.00**	8.61	**5.00**
UCONN WPCF	32.37	21.06	7.36	**7.30**	32.37	**7.30**
WILLIMANTIC WPCF	51.00	50.78	14.89	**6.80**	51.00	**6.80**

Nutrient Enrichment Analysis Watershed Overview

Post Strategy Implementation Enrichment Factors



Appendix C: October 26, 2010 letter to DEEP from the USEPA approving Connecticut's Interim Strategy

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 1
5 POST OFFICE SQUARE, SUITE 100
BOSTON, MA 02109-3912

October 26, 2010

Betsey Wingfield
Bureau Chief
Water Protection and Land Reuse Bureau
Connecticut Department of Environmental Protection
79 Elm Street St
Hartford, CT 06106

Dear Ms. Wingfield:

On June 18, 2010, EPA objected to the Beacon Falls permit which was based on a prior statewide phosphorus reduction strategy for inland waters that used "Best Available Conditions." EPA met with the Connecticut Department of Environmental Protection (CT DEP) on August 4 and September 14, 2010 to discuss the issues in EPA's objection and work towards resolution. We have reviewed the CTDEP's revised Nutrient Management Strategy for Freshwater which you presented to EPA staff at the September 14th meeting as an interim strategy while work progresses on developing numeric nutrient criteria. The revised strategy, as currently developed, focuses on diatoms as the key nutrient response variable and phosphorus enrichment factor thresholds that represent significant changes to the diatom community based on statewide diatom community data. We are impressed with the quantity and quality of analyses conducted to date in order to develop the strategy and believe that the approach CTDEP is taking represents a scientifically sound method for establishing water quality based phosphorus limits for municipal wastewater treatment plants (WWTPs) and other facilities that discharge phosphorus.

We recognize that further refinements are planned, including evaluating diatom community differences between water body sizes and further evaluating appropriate enrichment factor thresholds that ensure attainment and maintenance of the biological integrity of Connecticut's rivers and streams. At the same time, we are committed to working with CTDEP to ensure that progress continues to be made towards the central task of developing and adopting numeric nutrient criteria. While we understand that there currently are not sufficient ambient phosphorus data for relating diatom changes to ambient phosphorus concentrations, this should be a priority focus going forward and, where possible, EPA will provide technical and financial support to assist DEP in collecting the necessary data. Relating response variables, such as diatoms, to numeric phosphorus targets is a critical component of nutrient criteria and essential for EPA approval of nutrient criteria.

We understand that the interim strategy will be the basis for issuing permits with water quality based phosphorus limits for Beacon Falls and other treatment plants on the Naugatuck River. As to EPA's outstanding objection to the Beacon Falls draft permit, we understand that, notwithstanding CTDEP's protective request for a hearing, CTDEP plans to address EPA's objection in the near future by (1) revising the Beacon Falls permit to meet EPA's June 18, 2010 objection to the draft permit, and then (2) submitting this revised permit to EPA pursuant to Section 402(d)(4) of the Clean Water Act and 40 CFR 123.44(h).

We also understand that CTDEP plans to broaden this approach to apply it statewide and intends to reissue all affected municipal WWTP permits in approximately a two to three year time period. For dischargers to water bodies where the current phosphorus enrichment is greater than the enrichment factor threshold, CTDEP will incorporate mass limits for total phosphorus in order to ensure that phosphorus enrichment in those water bodies stays below the enrichment factor threshold. For municipal WWTP dischargers to water bodies where the current phosphorus enrichment is lower than the enrichment factor threshold, CTDEP will derive total phosphorus effluent limits to ensure that the current phosphorus enrichment level is maintained.

Since nutrient science is evolving and your analysis is not complete, municipal WWTP dischargers should be advised when planning upgrades that the designs should accommodate further reductions in nutrient loads beyond that required in this next round of permits if determined to be necessary in the future.

If you have any questions please contact me at (617) 918-1501 or have your staff contact Ellen Weitzler at (617) 918-1582 or Dave Pincumbe at (617) 918-1695.

Sincerely,

Stephen Perkins, Director
Office of Ecosystem Protection

Appendix D: Report of the Nonpoint Source Workgroup dated 7/28/2016

Nonpoint Source Workgroup #1 Report to P.A. 12-155 Coordinating Committee

July 28, 2016

Acknowledgements

Many individuals and partner organizations provided information and input to the work and reporting of the Nonpoint Source Workgroup. The Collaborative Activities of DEEP and Connecticut stakeholders throughout the PA 12-155 process are documented at: http://www.ct.gov/deep/phosphorus

Co-Chairs: Christopher Malik, DEEP and Virgil Lloyd, Fuss & O'Neill, Inc.

Workgroup Participants

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Greg Bugbee, CT Agricultural Experiment Station
Amanda Clark, CT Dept. of Public Health
Bill Hoerle, CT Military Dept. / Air Force
Andrew Lord, Geomatrix
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Cooperating State and Federal Agencies: CT Department of Public Health, CT Department of Agriculture, UConn Cooperative Extension Service, CT Agricultural Experiment Station, USDA Natural Resources Conservation Service, US Environmental Protection Agency.

Contents

1 Executive Summary: Nonpoint Source Workgroup Report Pursuant to Public Act 12-155

Public Act 12-155 provided legislation enabling municipalities to receive additional funds from Connecticut's Clean Water Fund to remove phosphorus in sewage treatment plant discharges, regulates fertilizers use and the amount of phosphorus in fertilizers, and required DEEP to work with affected municipalities to develop a statewide response to address phosphorus in nonpoint source pollution. Nonpoint source (NPS) pollution is water pollution from sources such as stormwater, agricultural runoff, septic system leachate, and soil erosion. To develop this statewide response, an NPS Workgroup made up of municipal representatives, Federal and State environmental professionals, environmental consultants, and academicians was formed to evaluate the sources of phosphorus from NPS pollution. The NPS Workgroup reviewed existing programs that address NPS pollution, studied the status and trends of phosphorus in NPS pollution, and identified and assessed methods and strategies to reduce phosphorus in NPS runoff. The Nonpoint Source Workgroup was co-chaired by Virgil Lloyd, of Fuss and O'Neill and Christopher Malik from the Nonpoint Source and Watershed Section of DEEP's Bureau of Water Protection and Land Reuse.

The NPS Workgroup reviewed DEEP planning, outreach and education, technical assistance, financial assistance, and regulatory programs that address NPS pollution. Additionally the NPS Workgroup reviewed programs in other State, Federal, and municipal agencies that focus on NPS pollution including UConn, CT Agricultural Experiment Station, CT Department of Public Health, CT Department of Agriculture, USDA Natural Resource Conservation Service, EPA, municipal land use commissions, and local health departments. The NPS Workgroup then went on to identify and review the sources of phosphorus in NPS pollution impacting Connecticut waters. The sources identified by the NPS Work Group are: stormwater runoff, agricultural runoff, fertilizers, soil erosion, internal phosphorus loading from sediments, and septic systems. The NPS Workgroup assessed how each identified nonpoint source of phosphorus is being addressed and how programs could be implemented or augmented to further reduce phosphorus in NPS pollution.

Stormwater runoff is a known conveyer of phosphorus to waterways. The NPS Workgroup found that a number of DEEP stormwater permits were in place and that these permits were being enhanced at the time the Workgroup was gathering its information. The NPS Workgroup recommended continued development of watershed based planning by DEEP with towns and local groups, enhancing outreach to municipalities, continuing evaluation of practices and technologies to remove phosphorus, regional approaches to managing stormwater, and developing and promoting financing programs to assist municipalities with improving stormwater infrastructure and programs. The Workgroup also recommended enhancing DEEP's Stormwater Permitting program by targeting source of phosphorus.

Through information provided by UCONN, the NPS Workgroup found that Connecticut has excess phosphorus in the form of animal manure, feed, and fertilizer. Centrifugal separation of solids from manure can concentrate phosphorus in the solids, allowing liquid manure to be land applied with less impact to water quality. Anaerobic digestion, paired with solid separation, can further reduce the volume of waste and can produce energy and value added products like farm animal bedding, soil conditioners, and peat for potting. The Workgroup also discussed manure exchange/brokerage systems that coordinate manure transfers from areas of phosphorus excess to areas with phosphorus deficiencies.

To better manage phosphorus in agriculture wastes, the NPS Workgroup recommended providing funding to finance technologies, develop pilot projects, and create manure exchange programs. The goal of additional financing would be to make these technologies more available to more farmers. The NPS Workgroup also recommended expanding nutrient management plans for animal feed lot operations, and incentivizing and educating farmers to adopt soil health practices.

Public Act 12-155 restricts the amount and use of phosphorus in fertilizer for residential lawns and gives authority to the Connecticut Department of Agriculture to write regulations and enforce this provision of the act. The NPS Workgroup made recommendations for fertilizer use of lawns and gardens, croplands, container nurseries, and golf courses.

The NPS Workgroup reviewed existing state and municipal permitting programs to control soil erosion from land being developed. These programs are supported by DEEP published guidelines for erosion and sedimentation control and low impact development. The NPS Workgroup recognized that enforcement of local and state regulations for erosion and sedimentation control is an important component in controlling phosphorus from construction sites. The NPS Workgroup determined that comprehensive planning on a watershed-wide scale would be beneficial in reducing in-stream channel erosion.

The extent of water quality impacts from phosphorus releases in lake and pond sediments, known as internal loading, were considered by the Workgroup. The NPS Workgroup report includes a discussion on methods to control internal phosphorus loading including chemically binding the phosphorus by treating the water body with aluminum or calcium compounds or adding oxygen to water. Both techniques require active management and are not commonly used in Connecticut.

Onsite wastewater disposal systems, commonly called septic systems, can also be a sources of phosphorus. The NPS Workgroup worked with several experts to assess the extent of phosphorus from septic systems. While current regulatory requirements are quite effective, old systems; lack of maintenance, improper use, poor sitting, and uneven distribution of effluent in the leaching field can result in phosphorus loading to watercourses. The NPS Workgroup recommended encouraging town-wide wastewater planning, establishing a state grant or loan program to fund septic systems upgrades, and implementing a statewide septic system management program that tracks and manages data to identify areas with excessive phosphorus loading. The NPS Workgroup also recommended a point of sale inspection and repairs program for septic systems similar to other states.

The NPS workgroup found that many Federal, state, and local programs are in place that address phosphorus in NPS pollution. In some cases additional programs for agricultural waste and septic system upgrades are needed to reduce phosphorus loading to Connecticut waters. In other cases, existing programs could be expanded to further address phosphorus in NPS pollution. Some new or expanded programs will require additional funding and expansion or addition of regulatory programs will require individuals, communities, and businesses to accept a higher level of control than is currently required by existing statutes and regulations.

2 Introduction

2.1 Purpose of Workgroup Study

Public Act 12-155 required the Connecticut Department of Energy and Environmental Protection (DEEP) to collaborate with municipalities impacted by the statewide strategy to reduce phosphorus pollution affecting non-tidal surface water bodies. A provision of the act required an evaluation and recommendations for a state-wide response to address phosphorus nonpoint source pollution. A work group was formed with the following primary goals:

- Evaluate the relevant sources of phosphorus from nonpoint sources (NPS), and current status and trends.
- Identify and assess alternative methods and strategies to achieve realistic phosphorus reductions from NPS. Where possible, assess the relative associated costs.
- Make concluding recommendations to reduce phosphorus loading from NPS.

2.1.1 Nonpoint Source Pollution

Many activities associated with various land uses within Connecticut have the potential to contribute pollution to ground and surface water resources. Water pollution that is not concentrated within a drainage system, or discharged from a point, such as a pipe, is called nonpoint source pollution. Potential sources of Nonpoint Source Pollution can include agriculture, waste from domestic animals and wildlife, malfunctioning septic systems, runoff from impervious surfaces / developed areas and managed turfgrass, and soil erosion.

Pollutant levels, or loadings, from nonpoint sources can vary greatly depending on watershed conditions, land use, and weather conditions. For the purposes of this committee's report we have included regulated stormwater as an NPS source, so the terms nonpoint source runoff and stormwater are used interchangeably, and have focused on discharges to fresh waters.

2.2 Nonpoint Source Workgroup Structure

- The Nonpoint Source Workgroup is co-chaired by Virgil Lloyd, of Fuss and O'Neill and Christopher Malik from the Nonpoint Source and Watershed Section of DEEP's Bureau of Water Protection and Land Reuse.

- The Nonpoint Source Workgroup met 10 times and collaboratively discussed and shared information. The group's makeup was well balanced and represented expertise in all the potential source groups that are discussed below.

- Details of the Nonpoint Source Workgroups meetings have been recorded on the website www.ct.gov/deep/phosphorus

- The organization of the workgroup strived to assure continuity, transparency, and balance.

- The individuals who participated in the Nonpoint Source Workgroup are listed in the acknowledgements:

NPS Workgroup Meeting Schedule:

- November 20, 2014, from 10 to 11:30 a.m. Holcombe Room, 5th floor, DEEP HQ

- October 7, 2014, from 1 to 2:30 p.m. in Room 2B at DEEP Headquarters

- July 22, 2014, from 1 to 2:30 p.m. in Holcombe Room, 5th floor, DEEP HQ
- May 6, 2014, from 1 to 2:30 p.m. in Room 2B at DEEP Headquarters
- March 24, 2014, from 1 to 2:30 p.m. in Room 2B at DEEP Headquarters
- February 10, 2014, from 10 to 11:30 a.m. in Room 2B at DEEP Headquarters.
- January 6, 2014 from 1 to 2:30 p.m. in Room 2A, at DEEP Headquarters.
- November 25, 2013, from 1 to 2:30 p.m. in Room 2B, at DEEP Headquarters.
- October 25, 2013 from 1 to 2:30 p.m. in DEEP Holcombe Room.
- September 30, 2013 in DEEP Russell Room

There was one subcommittee for Onsite Wastewater Systems, the subcommittee meeting schedule was:

- June 24, 2014, at 10 a.m. in Room 2B at DEEP Headquarters
- March 10, 2014, at 1 p.m. in Room 2A at DEEP Headquarters
- January 17, 2014, at 1 p.m. in Room 2B at DEEP Headquarters

3 Connecticut Nonpoint Source Pollution Management

3.1 DEEP Nonpoint Source Pollution Program

DEEP is responsible for protecting water quality under a number of regulatory and non-regulatory programs, including the NPS Management Program. The U.S. Clean Water Act, Section 319 requires states to have NPS management plans. Connecticut's first NPS Management Plan was approved by the EPA in 1989 and since then has been updated several times to address changes to national NPS guidance and changing conditions. The most current plan was approved in 2014. Many of the existing plan elements target nonpoint sources of water quality impairments related to nutrients including phosphorus, and sediments which contribute phosphorus.

2014 CT NPS Program Plan
DEEP's 2014 Nonpoint Source Management Program Plan is posted at www.ct.gov/deep/nps Connecticut's approach to controlling NPS pollution includes

both statewide initiatives and focused watershed management planning and implementation projects. The 2014 Plan seeks to address the following Statewide:

- Protect the environment and public health from the impacts of polluted runoff
- Inform the public and partners about the causes and impacts of NPS pollution
- Set priorities for addressing pollution sources
- Identify long-term goals for protecting and restoring water resources in Connecticut that are threatened or impaired by polluted runoff.
- Establish specific short-term goals, objectives, and measurable milestones for the next 5-years that will contribute to achieving long-term NPS program goals of restoring and protecting water quality
- Evaluate NPS priority watersheds lists

DEEP Nonpoint Source Program Elements

Programatic goals include:

- Coordinate State actions and assist communities in forming partnerships
- Draft watershed based plans, and implementing environmental projects to restore and protect Connecticut's water quality on a watershed-wide scale.
- Facilitate development of a statewide NPS management tracking system or program to quantify NPS pollution reductions and credits (i.e., BMPs implemented, areas applied, pollutant load reductions achieved).
- Review pollution credit/trading programs developed by other states and their applicability.

Source specific strategies exist for major NPS categories:

Table 2-1. Connecticut NPS Pollution Categories

Major Sources	Other Sources
• **Runoff from Developed Areas** • **Transportation** • **Landscaping and Turf Management** • **Subsurface Sewage Disposal Systems** • **Agriculture** • **Domestic and Wild Animals** • **Boating and Marinas** • **Hydrologic and Habitat Modification**	• Land Disposal • Brownfields and Contaminated Sites • Forestry • Material Storage • Resource Extraction • Atmospheric Deposition

DEEP's Nonpoint Source Program

DEEP's Nonpoint Source Program consists of three Watershed Managers and a supervisor. The NPS program works with other DEEP programs and stakeholders including municipalities, Connecticut's five Conservation Districts, watershed, advocacy and other non-governmental organizations, and citizens. DEEP develops collaborative partnerships with stakeholders to develop and implement strategies to reduce pollutant loadings and restore water quality. More details of Connecticut's Nonpoint Source Program are available at www.ct.gov/deep/nps

DEEP uses a number of overall strategies to address NPS pollution, major ones include:

- Pollution Prevention
- Education and Outreach

- Enhanced Management and Regulation of Stormwater
- Agricultural Management and Assistance
- Municipal Technical Assistance
- Watershed Based Plans and Total Maximum Daily Load Analyses (TMDLs)
- Planning & Implementation Grants

Pollution Prevention is of Central Importance
Pollution prevention (P2), or source reduction, is a logical starting point to reduce nonpoint source phosphorus pollution. Pollution prevention emphasizes preventing or minimizing pollution, rather than controlling pollution after it is generated. Pollution prevention is the most effective NPS pollution control strategy and therefore plays a central role in the state's NPS Management Program and other DEEP regulatory and non-regulatory programs. Numerous pollution prevention practices are available for a variety of land uses and pollution source categories. P2 practices are emphasized in the recommendations in this report and DEEP's NPS Program Plan. DEEP has a Pollution Prevention Program that coordinates pollution prevention activities in cooperation with the NPS Program. Information can be found at www.ct.gov/deep/p2

Stormwater Runoff in Urban Areas is the Largest Single Source of Nonpoint Source Pollution in Connecticut
Urban storm runoff is the largest single source of nonpoint source phosphorus polluting Connecticut's surface waters. Much of the runoff from urban areas that is collected in storm drains, or discharges from construction, commercial, or industrial sites, is now regulated by stormwater general permits (regulated stormwater pollution). Regulated stormwater is considered nonpoint source pollution for the purposes of this report. More information on Stormwater Management and Permitting www.ct.gov/deep/stormwater

Best Management Practices (BMPs)
Adoption or application of practical and cost-effective measures known as Best Management Practices (BMPs) is a common strategy to control NPS pollution. Many necessary land use activities require BMPs to protect water quality. BMPs can be structural: infrastructure or devices, or non-structural: operational practices or behavioral modifications. Capital, operational, and maintenance funds must be provided to ensure that BMPs successfully control pollution.

3.2 DEEP's Program Partners

Regional and local partners are needed to implement effective strategies to reduce NPS pollution because NPS pollution is diffuse and comes from many different sources. DEEP cooperates with numerous partners for technical outreach in the agricultural sector including, but not limited to, the USDA Natural Resource

Conservation Service (NRCS), Connecticut Department of Agriculture, University of Connecticut Cooperative Extension System, Connecticut Agricultural Experiment Station, and Connecticut Conservation Districts. These agencies work with agricultural industry representatives and individual producers to improve operations, reduce the threat of pollution, and manage wastes in a safe and efficient manner. Similarly DEEP has many municipal program partners in urban areas addressing NPS phosphorus pollution. Connecticut's municipalities are without a doubt our most important partner in managing nonpoint source pollution.

Some of DEEP's primary NPS partners and activities are summarized in Appendix 4.

Table 2.2

NPS Program Partners in Connecticut

Federal:
- U.S. Environmental Protection Agency
- U.S. Department of Agriculture
  - Natural Resources Conservation Service
- U.S. Army Corps of Engineers
- U.S. Department of Commerce
  - National Oceanic and Atmospheric Administration Fisheries, Ocean and Coastal Resource Management, National Weather Service
- U.S. Department of Interior
  - U.S. Fish and Wildlife Service
  - U.S. Geological Survey
  - National Park Service

State:
- CT Department of Energy & Environmental Protection
- CT Department of Public Health
- CT Department of Transportation
- CT Department of Agriculture/Aquaculture
- CT Office of Policy and Management
- CT Department of Economic and Community Development
- CT Department of Emergency Services and Public Protection
- CT Department of Administrative Services
- University of Connecticut NEMO, CLEAR, Agriculture Extension Centers, CIRCA, Sea Grant
- CT Agricultural Experiment Station

Local/Regional:
- Municipalities
- Regional Councils of Government
- Conservation Districts
- Water Utilities
- Water Pollution Control Authorities
- Local Health Districts
- CT Conference of Municipalities (CCM)

CT Council of Small Towns (COST)
Neighboring State and County Governments

Other:

Private Colleges and Universities
Watershed Organizations
Advocacy Groups and other NGOs
Land Trusts
Industry Organizations
News Media Organizations

Native American Tribes

3.3 Major Pollutant Source Groups

The following primary source groups of NPS phosphorus have been categorized by the NPS Workgroup and are consistent with the 2014 CT DEEP NPS Program Plan. Each of these source groups is discussed in greater detail later in the report. There may be some overlap in these groupings: urban stormwater may contain animal waste from pets and wildlife, and soil erosion may contain animal wastes and fertilizers, etc.

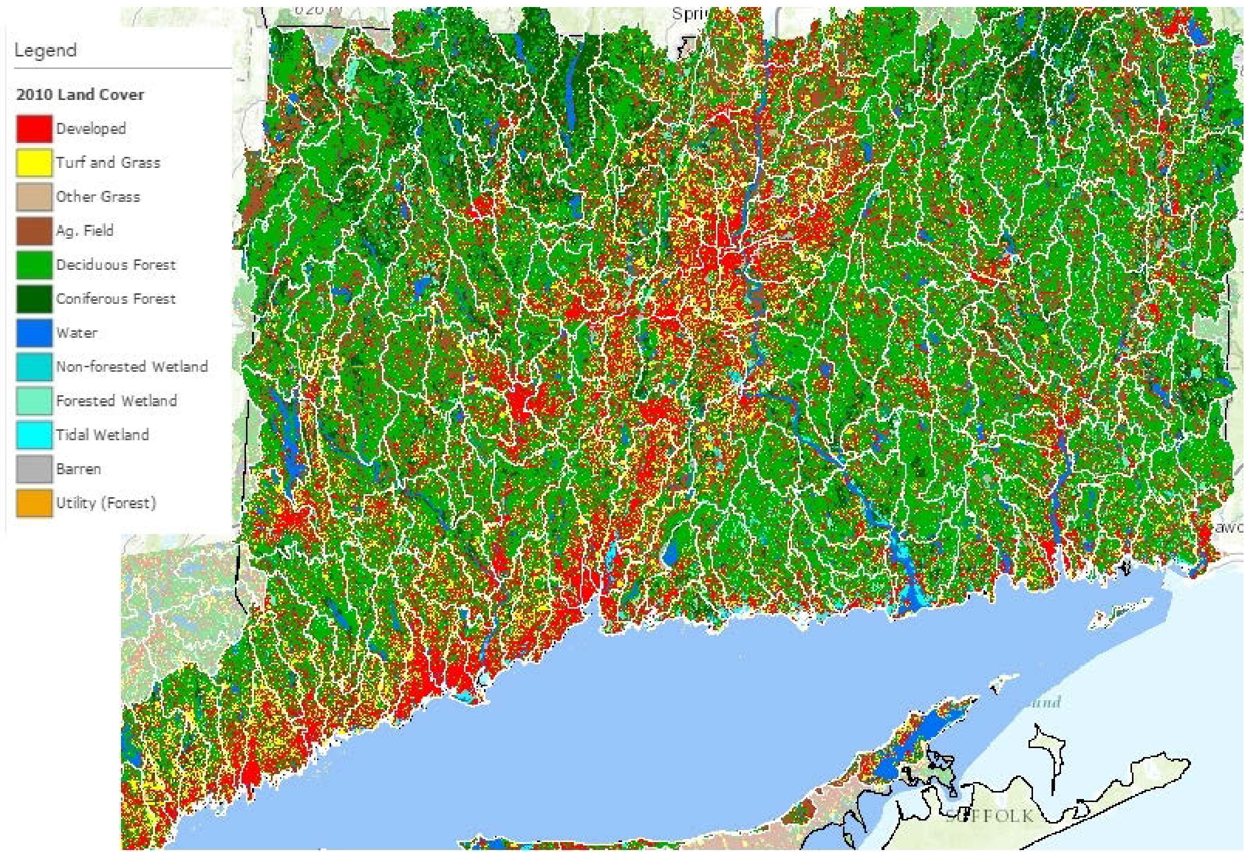
- **Urban Stormwater**
- **Agricultural Animal Waste and Manures**
- **Phosphorus Fertilizers**
- **Soil erosion**
- **Internal Loading**
- **Onsite Wastewater Disposal Systems**

3.4 Relative Assessment of NPS Loading

Differing land use/land cover types, patterns, and conditions are the most important factors to consider when estimating NPS pollutant loads. Connecticut's Land Use Land Cover types were analyzed by UConn Cooperative Extension Service Center for Land Use Education and Research (Clear) in 2010. The following values and trends were observed between 1985 and 2010 that affect efforts to reduce phosphorus input to surface waters:

Within streamside corridors, (within 300 feet of a watercourse) 39.5 square miles were converted to "turf" or "developed" from a total of 1323 square miles. That amounts to 1186 acres per year of valuable stream buffers lost to development or turf. Similarly, Connecticut lost 13.3 acres per day of its forested land, and added 10 acres per day of developed area and 4.4 acres per day of turf. All of these trends point to an increase in the rate of nonpoint source phosphorus pollution if they continue unabated.

DEEP conducted a statewide analysis of phosphorus loading from nonpoint sources as part of the Interim Phosphorus Strategy. Modeling analyzed outputs for three aggregated land cover types: Developed, Forested, and Agriculture and applied export coefficients to predict phosphorus loadings based on land cover areas. DEEP's analyses tell us that overall pollution loadings vary considerably by regional watershed, governed by land cover. Maps have been prepared of this analysis and can be found in Appendix 1. The methodology is discussed in detail in the reporting from the Scientific and Technical Workgroup #2. Additional modeling will utilize the USGS Sparrow model.



2010 Connecticut Land Use Land Cover Map (UConn Clear Changing Landscape Website)

More precise assessment and modeling of NPS pollution can be done to further quantify NPS loadings from more specific sources in regional and local watersheds. This is done in both Watershed Based Plans and TMDLs that have an NPS load. See http://www.ct.gov/deep/watershed Watershed Management Plans and Documents page and http://www.ct.gov/deep/tmdl . The modelling accomplished by DEEP indicates that conversion of agricultural land to developed land use has resulted in increased phosphorus loadings from nonpoint sources.

3.5 Review of Alternative Approaches

Each major NPS source grouping for NPS phosphorus was evaluated looking at current status, trends, and existing management efforts. Consideration was given to additional alternative methods and strategies to achieve realistic phosphorus reductions from the NPS source, looking at both regulatory and non-regulatory approaches. This involved looking at State and local authorities. Both statewide initiatives and focused watershed management approaches were considered. Where possible key responsible parties, partners and funding needs were identified. Pollution prevention and source control was emphasized as the most effective NPS pollution control strategy and therefore plays a central role in many recommendations. A common strategy to control NPS pollution is through the adoption or application of practical and cost-effective management practices known as Best Management Practices (BMPs) and is discussed below in more detail.

3.6 Best Management Practices

BMPs allow for many everyday activities to continue while preventing or reducing NPS pollution. BMPs can be:

- Structural: infrastructure or devices; or
- Non-structural: operational practices, programs, or behaviors

The use of BMPs can reduce pollution and protect water quality while allowing many necessary land use activities to continue. In many cases they require education and technical assistance, and capital, operational and maintenance costs must be allocated. Many times BMPs are implemented in a treatment train, with several types combined in sequence. (i.e., in combination or one after another)

3.6.1 BMP Efficiencies and Costs

Assigning pollutant removal efficiency values and cost effectiveness to BMPs is not a simple analysis. There have been numerous recent analyses, many with support from the US EPA, that have identified ranges of both BMP efficiencies and costs. BMP efficiencies are typically expressed by a percentage value, the percentage of a pollutant that is removed or prevented by a practice. Costs are generally expressed as a cost per pound of a pollutant removed. BMP pollutant removal values can be very important if reductions are to be formally credited in a regulatory program such as permits or TMDLs.

The types of structural BMPs that are most effective at removing phosphorus were reviewed and researched as part of this report, particularly those applicable to urban and agricultural runoff. Those most effective at removing phosphorus are essentially those which remove suspended solids efficiently, particularly those which remove the fine fraction: silt and clay particles. Structural BMPs that infiltrate or filter the first flush of runoff, including the use of natural soil and vegetation site features, have been shown to be quite effective at controlling phosphorus. This is because most well drained natural soils in Connecticut are very effective at removing and holding (adsorbing) phosphorus. Site conditions must be able to handle and infiltrate runoff volumes. Examples of structural BMPs include retention/infiltration basins, infiltration wells/trenches, bio-retention basins, vegetated swales and buffers, separation chambers, and media filters. Based on DEEP's informal observations, filtration devices which are most effective are also those which require short maintenance intervals.

In addition to capital costs, maintenance of BMPs is critical and often affects both cost and removal efficiencies significantly. As expected, many of the removal efficiencies and costs varied greatly as many factors come into play such as soil conditions, land area, land and capital costs, and operation and maintenance requirements. Maintenance costs also vary by site, particularly if there are other contaminants in the material removed from the BMPs. Urban Runoff, (Section 4.1) and Urban BMP Performance Efficiency and Costs Analysis Appendix 2, (Section 5.2) contain more information on some of the estimated ranges of BMP efficiencies and costs.

4 Summary of Priority Recommendations

The Nonpoint Source Workgroup recommends the following actions be considered priority recommendations for implementation. Considerable analysis of the source group categories has been undertaken to produce these recommendations. Additional detail for each recommendation is presented in the appropriate source group section, along with other pertinent recommendations.

Predicting load reductions, if specific recommendations are implemented, is not a simple task, as all NPS water pollution loadings are subject to considerable variation, and can be increased or reduced by climate and behavioral practices. The recommendations are not ranked by cost effectiveness or load reductions expected, as the load reductions achieved may vary considerably by location, and over time. Some of the recommendations, if implemented, will provide additional benefits, above and beyond their role in reducing phosphorus inputs to surface waters.

4.1 Urban Runoff & Soil Erosion

Watershed Based Plans: DEEP and their partners should continue the development of watershed plans in urbanized areas as the best way to holistically look at water quality conditions related to stormwater sources and propose management measures. Watersheds with phosphorus related water quality impairments due to urban runoff and high impervious cover should be targeted for development of plans. These plans should include a modeled assessment of NPS phosphorus loading, sources, management measures, and estimated load reductions. These plans could also qualify towns for NPS funding for implementation projects.

Municipal Green Infrastructure Low Impact Development Outreach and Implementation: Enhance municipal outreach and implementation of Green Infrastructure (GI) and Low Impact Development (LID). Maintain a website and listserve to share information with municipalities on the use and effectiveness of GI and LID techniques in Connecticut and nationally. Hold workshops or training to share and exchange information on GI and LID approaches and techniques. Develop municipal regulation guidance related to GI and LID. DEEP and UConn CLEAR should be key partners in this effort.

BMP Research and Guidance: Continue to research and evaluate the latest information on new or modified BMPs to more effectively address water quality impacts from urban runoff, including consideration of pollutant removal and runoff reduction effectiveness, maintenance issues, and cost. This should target the most recently available research on the performance of existing and new structural and non-structural BMPs for reduction of nutrients. Regularly update statewide Stormwater BMP manuals and guidance, including the 2004 Connecticut Storm Water Quality Manual, the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control, and associated LID Appendices. Solicit regular input from the consulting community, UConn and the academic community, state agencies, and the regulated community through a State NPS Technical Committee.

Enhance the existing DEEP Stormwater Programs and General Permits: Target stormwater impaired waters and phosphorus related sources. This should include all four types of General Permits that DEEP issues, which require steps to control stormwater pollution from urban areas and land use types. The MS4 permit in particular should target measures to reduce urban phosphorus sources and transport including: illicit discharges; fertilizer use and turf management; minimizing the effect of impervious cover (IC); road and property management measures for sweeping paved areas, catch basin cleaning and leaf management; pet waste; first flush retention; LID practices; and public education programs to raise awareness about fertilizers, lawn and leaf management, detergents, sediment and effects of IC. To assist municipalities in these efforts DEEP and UConn CLEAR should be key partners to develop an outreach and technical assistance program.

Preserve or augment staff and resources to inspect and enforce **DEEP's Stormwater General Permit program.** The Construction General Permit was recently revised with tighter restrictions affecting activities that drain to impaired water bodies. Similar restrictions will be implemented in revisions of the other stormwater general permits, including MS4, as they are revised and adopted. DEEP oversees and enforces activities which affect over 5 acres of disturbed area. Municipalities oversee and enforce projects which disturb less than 5 acres.

4.2 Animal Waste & Fertilizer

Enhance Agriculture Animal Waste Management and Technologies that concentrate phosphorus in separated solids (centrifuge technologies): Allow for reduced phosphorus concentrations in land applied liquid manure and repurposing of phosphorus in compost or other value added products. Separated portions of the manure can be stored more easily and may allow more feasible transportation of manure to become an economically viable substrate for biomass to energy facilities. A solid separator coupled with a decanter centrifuge may remove up to 40% of the phosphorus in liquid dairy manure. Includes:

- **Manure solid/liquid separation technologies on individual farms** – promote and provide funding for the purchase and installation of manure separation facilities on targeted farm locations.
- **Centralized/regional composting centers -** promote regional animal waste composting facilities in combination with food waste/leaf compost facilities.

Centralized/regional anaerobic digestion for dairy and food waste: Assist with capital costs and organize cooperative agreements to pool resources for centralized digesters. Existing models of centralized digesters demonstrate a means of reducing waste volume while capturing gas and energy from the manures. Anaerobic digesters can convert waste that can pollute surface waters to value added products that can be more easily transported and applied as fertilizers and soil conditioners, reducing problems from excess phosphorus, odors, and pathogens. Benefits include:

- Electricity from digester complex can be used to power a separator, centrifuge, and farm operations.

- Heat for drying locally grown grains, reducing import of grains containing phosphorus.
- Phosphorus extracted from manure used as soil amendment or fertilizer.
- Value-added products (containing phosphorus) transported out of watersheds of concern.
- Liquid dairy manure applied at an agronomic rate for nitrogen without over applying phosphorus.
- Reducing phosphorus in runoff because land applied liquid is absorbed better than solid or semi-solid manures.

Manure exchange/brokerage system – Incentivize or capitalize private companies to coordinate manure transfer from areas of nutrient excess to areas of soil nutrient need. This will demonstrate value of the nutrients in manures and offset the costs of chemical fertilizers needed on farms.

Nutrient Management Plans for Animal Feeding Operations (AFOs), Identify and incentivize manure management strategies on fields to discourage manure applications greater than agronomic, or crop removal levels, where agronomic levels exist, based on soil test recommendations. Improve distribution of manure on cropped lands with incentives for optimal (or less) soil test values and nutrient management plans.

Provide capital funding for pilot projects to evaluate new technologies for managing manures and agricultural waste such as:

- Pelletizing
- Gasification
- Phosphorus recovery from poultry and liquid dairy manure.

Provide incentives for farms to adopt and apply soil health practices. Soil health refers to the goal of having a diverse and functional soil through the use of land management and plants in the soil as much as possible. Incentives to apply soil health practices would help to reduce soil loss, phosphorus transport from fields, and reduce water runoff from fields by maintaining or improving water infiltration to soils and potentially reduce nutrient application need. Some incentives related to soil health may include provision of assistance to maximize the use of diverse cover crops including inter-row seeding.

Support the formation of a NRCS State Technical Committee, Nutrient Management Subcommittee: Representatives from poultry and dairy operations, NRCS, UCONN Extension, DEEP, CT Farm Bureau, CT Dept. of Agriculture, and other stake holders should organize to determine how to best implement these recommendations.

Fund continuing farmer education related to soil nutrient management, manure management and soil health to bring awareness to the existing problems and provide opportunity to learn or develop new solutions on the subject of NPS Phosphorus (and nutrient) reduction.

4.3 Onsite Wastewater Treatment

Through outreach programs at the regional and state level, encourage development of **town-wide wastewater management plans** that evaluate the potential for water pollution in areas of concern based on the preceding criteria, as they relate to onsite wastewater treatment systems that do not function properly. Such a planning document should also evaluate the range of options available to mitigate or prevent pollution impacts, and recommend one or more strategies to cost-effectively prevent or address those impacts.

Implement a Statewide Comprehensive Onsite Wastewater Treatment System (OWTS) management program through regulation or statute, with ongoing maintenance and inspection requirements. As part of a comprehensive program, the means and resources to track and manage data is critical for the administration and success of any management undertaking. A Data Tracking and Management System will allow regulators of OWTS to: identify data trends, identify, and prioritize actions in areas of concern, implement site-specific measures, and reduce phosphorus discharge from systems, as identified.

Require **Point of Sale Inspections of all Onsite Wastewater Treatment Systems** and require upgrades to systems not meeting a minimum standard through regulation or statute.

4.4 Statewide NPS Management

Convene a **Nonpoint Source Technical Committee** with other State Agencies and meet regularly to develop and implement more effective policies and procedures to minimize nonpoint Source pollution.

5 Analysis of Nonpoint Source Phosphorus Pollution by Source Group with Recommendations

5.1 Urban Stormwater

5.1.1 Analysis of Problems and Issues

5.1.1.1 Urban Runoff

In developed areas, a large portion of the natural landscape has been replaced with impervious surfaces such as roads, driveways, parking lots, buildings and other highly altered landscape conditions. Rainfall and snowmelt that once percolated slowly into the soil now quickly runs off these hardened surfaces in higher volumes, picking up and transporting various accumulated pollutants. This is commonly referred to as "urban runoff". Often, urban runoff is conveyed directly to storm sewers or drainage ways and discharged directly to water bodies, where the captured pollutants degrade surface water quality. Approximately 47% of the state's land area is considered developed land use (CLEAR, 2010) and much of that area is pre-1980s development before modern stormwater management practices and regulation were in effect. New growth and development will continue to contribute urban runoff impacts unless management practices are changed.

5.1.1.2 Urban Phosphorus Sources

Phosphorus can be a significant pollutant in urban runoff and contributor to water quality related impairments in lakes, ponds, rivers, and streams in the urban areas of Connecticut. Phosphorus in urban runoff can be roughly characterized into three forms: dissolved, adsorbed, and organic / colloidal. The fine particles that accumulate on impervious surfaces contains both adsorbed and organic forms of phosphorus, and most of the phosphorus that accumulates on impervious surfaces is contained in that fine material. For this reason the majority of phosphorus contained in urban stormwater is contained in the first flush, or initial period of discharge of stormwater from impervious surfaces. Best Management Practices (BMPs) that infiltrate or treat that first flush can therefore be effective to control phosphorus in stormwater. Phosphate ions in the soluble form, such as those found in fertilizers and wastewater are the most plant available form of phosphorus. In most well drained soils, ferric, aluminum, and other cations are very effective at removing and holding (adsorbing) phosphorus. Infiltration practices are effective at preventing P from reaching surface water bodies, provided that soil particles are not eroded by runoff.

Sources of phosphorus in urban areas can vary by urban land use type (residential, commercial, industrial), location and specific activities, however primary urban sources of phosphorus generally include:

- Lawn and landscape fertilizer
- Leaf litter and yard waste
- Animal and pet waste
- Litter and trash
- Illicit wastewater discharges
- Soil erosion and sediment.

5.1.2 Pollution Abatement Strategies for Urban Areas

Nonpoint source pollution, because it is diffuse and variable in nature requires a combination of strategies including those listed here to achieve results:

- Build **capacity for further watershed planning,** restoration, and protection.
- Reduce and **disconnect impervious cover**.
- **Identify and utilize areas where stormwater infiltration is feasible** and prudent, and prioritize preservation and protection of important groundwater recharge areas. Analyze impervious cover and effects of build-out, including teardowns where appropriate.
- **Identify potential stormwater retrofit sites**: areas with high loading such as agricultural areas, disturbed soil, parking lots, road crossings, and areas of increased road sand and salt application / hills
- Implement **Streambank stabilization** practices to reduce instances of severe erosion
- Enhance **Riparian buffer management** to more effectively remove pollutants and sediments from sheet flow
- **Pollution Source Control and Discharge prevention**, characterize pollutants, primary pollutant of concern, others including pathogens, TSS, metals, nutrients, BOD, COD, pesticides, organic pollutants, hydrocarbons,

volatiles, and PAHs. Some sources that can be abated or reduced include: dumping, trash, litter and spills by residents and drivers, lawncare, pet waste, nuisance wildlife, and illicit discharges. Citizen awareness of risks associated with improper disposal is a necessary starting point.

- **Prioritize** which of these strategies can have the most benefit and are achievable. Estimate funding sources available, quantify needs, shortcomings, and benefits.

- **Maintain** Best Management Practices to ensure optimum function.

5.1.2.1 Best Management Practices (BMPs)

Phosphorus pollution from urban areas can be reduced through a variety of non-structural and structural methods. The overall tiered approach to addressing stormwater impacts is to start with non-structural source controls/pollution prevention measures, then apply practices to reduce runoff volumes, and then apply treatment practices. Applying multiple practices in sequences, known as treatment trains, is accepted as an effective strategy where feasible.

Non-structural BMPs are source controls, operational and maintenance practices, and education/outreach programs that prevent or reduce phosphorus pollution at the source. Examples include reduced fertilizer use, low phosphorus fertilizers and detergents, leaf pickup, pet waste pickup, and road and parking lot sweeping. Rainwater harvesting and water re-use options, collecting and storing runoff for later use to water lawns, golf courses and gardens are also good source control practices.

Structural BMPs are constructed practices and manufactured devices used to reduce runoff volume or capture and treat runoff. Examples of structural BMPs include retention/infiltration basins, infiltration wells/trenches, bio-retention basins, vegetated swales, separation chambers, and media filters. Structural BMPs that infiltrate the first flush of stormwater have shown to be quite effective to control phosphorus as most natural soils are very effective at removing and holding (adsorbing) phosphorus. Site conditions must however be able to handle and infiltrate runoff volumes. More recent research from USEPA has suggested that the very first flush of runoff (as little as the first ¼ inch) may contain the most significant portion of the phosphorus load. This may be important, as it suggests that perhaps smaller volume and less expensive treatment structures/devices may help address existing highly urbanized areas where land area and soil conditions are limited.

Many urban site retrofit techniques have concentrated on reducing the effect of impervious cover (IC), by disconnecting impervious areas and infiltrating or treating

runoff in those areas. In 2014, DEEP developed a document, "Watershed Response Plan for Impervious Cover", to help reduce the negative effects of IC and restore water quality. The plan is a useful tool and guidance for local communities, municipal officials, businesses and watershed groups. The plan provides information on the local watershed conditions, impervious cover, and implementation measures, and can be used to complement existing municipal stormwater programs and practices. The document can be found at:
http://www.ct.gov/deep/cwp/view.asp?a=2719&Q=567354&deepNav_GID=1654

Low Impact Development (LID) or Green Infrastructure (GI) techniques provide cost effective pollution prevention in site planning and design, through management of both runoff volumes and stormwater quality. These techniques use natural site features (soil and vegetation) and small scale controls and practices designed to mimic the natural hydrology of a site. Many of these LID and GI techniques are effective at reducing phosphorus and can be effectively applied for new or re-development sites. Examples of LID include pervious pavement, natural drainage ways, vegetated buffers/filter strips, rain gardens, parking lot islands, and green roofs.

DEEP has produced both a Storm Water Quality Manual and Low Impact Development Appendix to provide planning, design concepts, various stormwater management techniques and practices, pollutant removal effectiveness and selection criteria. These documents are available at DEEP's Municipal Outreach for Green Infrastructure and Low Impact Development web page:
http://www.ct.gov/deep/cwp/view.asp?a=2719&q=464958&deepNav_GID=1654

5.1.2.2 Best Management Practices (BMPs) Pollutant Removal Efficiencies and Costs

DEEP's Storm Water Quality Manual and Low Impact Development Appendix are a primary resource for Connecticut stakeholders seeking to implement stormwater mitigation plans. For this report, DEEP conducted a further literature search of the latest information on stormwater BMPs, pollutant removal efficiencies, and relative costs. BMPS with phosphorus removal information were analyzed. The University of New Hampshire Stormwater Center is one of the more notable sources of stormwater management BMP testing and information. Local New England sources provide relevant information due to similarities in precipitation and soil types. DEEP's search for current BMP information also included meeting with USEPA Region 1 stormwater and water quality technical staff as well as collaboration with UConn CES/Clear and NEIWPCC. Appendix 2 (Section 5.2) includes a narrative summary of this information and a detailed table of pollutant removal efficiencies and relative costs researched. As expected, many of the removal efficiencies and costs varied greatly as many factors come into play such as soil conditions, land area, land and capital costs, and operation and maintenance requirements.

Most phosphorus in urban runoff is adsorbed onto fine sediment and also becomes suspended in the first flush of runoff from impervious surfaces. The easiest way to reduce nonpoint source phosphorus, once pollution prevention is already exhausted, is to divert that first flush of runoff to infiltrate it to the ground, or if that is not feasible, apply a treatment practice to remove that fine sediment.

It is often necessary to pretreat and remove the coarse grained solids (sand), so that the second level of stormwater treatment does not become overwhelmed with sediment. Effective phosphorus treatments must remove the fine grained sediments (silt and clay). This often requires devices that take up a significant area or volume so that those fine particles can have residence time needed to settle out, or come in contact with significant surface areas of plant material, or filtration media such as sand and gravel.

BMP removal efficiencies for phosphorus range greatly from 0-80%. However BMPs for certain infiltration systems and LID techniques have removal efficiencies as high as 60% and are generally cost effective. The values in the tables below are taken from Appendix 2 Table 5.2.1 and are estimates. All references are included there. "No treatment" values were changed to 1% to facilitate comparison.

The workgroup's prioritized recommendations for non-structural practices to reduce NPS phosphorus pollution loading to surface water bodies include:

BMP Type	**Removal Efficiency**	**Cost per lb. P removed**
Street sweeping (enhanced)	1 – 15%	<$100/lb. (spring/fall) $600/lb. (summer)
Fertilizer use education program	3 – 10%	$311/lb.
Organic waste / leaf litter collection	5%	Not Determined

The workgroup's prioritized recommendations for structural practices to reduce NPS phosphorus pollution loading to surface water bodies include:

BMP Type	**Removal Efficiency**	**Cost per lb. P removed**

Infiltration Practices	60 – 85%	$3252-$3399/lb.
Impervious Urban Surface Reduction	Not applicable	$7,354/lb.
Illicit Discharge Detection	100%	$35 - $75 / lb.
Permeable pavement (porous asphalt)	20 – 80%	$12,563 -$70,342/lb.
Bioretention Unit/ Rain Gardens	1- 85% 59% (retrofit)	$2,935-$5,544/lb. $12,501/lb. (retrofit) $2791-$4329/lb. (rain gardens)
Sub-surface gravel wetlands	58%	Not Determined
Vegetated filter strip	Not determined	Not determined
Vegetated swales	1 – 90%	$14,600/acre treated

Selection of BMPs is site dependent. Available area and accessibility for maintenance can be important concerns in urban areas. A qualified engineer or stormwater professional should be consulted, and pretreatment and maintenance schedules and costs are necessary considerations. There are many other types of practices and references included in Table 5.1.1 Appendix 2. Combining several implementation strategies is often recommended.

Low Impact Development strategies are included within the structural and non-structural recommendations. Retrofits in urban areas are often very costly compared to installing these types of features at time of construction.
Cost and benefits are evaluated relative to phosphorus removal. Many types of practices have secondary benefits that are not accounted for in this analysis. Tree filters are an example of devices that provide secondary benefits. All costs are approximate. LID approaches are most effective where water is infiltrated into the ground. Practices with underdrains are often not as effective at removing pollutants including phosphorus.

5.1.2.3 Current Stormwater Regulation

Knowledge of the impact of urban stormwater on water quality, led to the development of federal and state regulation of urban stormwater during the 1990s. There are now four types of General Permits that DEEP issues under the federal Clean Water Act, National Pollutant Discharge Elimination System (NPDES) which requires steps to control stormwater pollution from urban areas and land use types. Four Stormwater General Permit programs are administered by the DEEP:

"Industrial General Permit" regulates industrial facilities with point source stormwater discharges that are engaged in specific activities according to their Standard Industrial Classification (SIC) code.

"Construction General Permit" requires developers and builders to implement a Stormwater Pollution Control Plan to prevent the movement of sediments off construction sites into nearby water bodies and to address the impacts of stormwater discharges from a project after construction is complete.

"Commercial General Permit" found only in Connecticut, requires operators of large paved commercial sites such as malls, movie theaters, and supermarkets to undertake actions such as parking lot sweeping and catch basin cleaning to keep stormwater clean before it reaches water bodies.

"MS4 General Permit" requires each regulated municipality to take minimum measures to keep the stormwater entering its storm sewer systems clean before entering water bodies. One important element of this permit is the requirement that towns implement public education programs to make residents aware that stormwater pollutants emanate from many of their everyday living activities, and to inform them of steps they can take to reduce pollutants in stormwater runoff.

For more information on state stormwater permits, go to www.ct.gov/deep/stormwater

DEEP also recommends that municipalities use local land use authorities to implement similar stormwater control measures for activities not regulated by a state stormwater permit. DEEP has produced both a Storm Water Quality Manual and Low Impact Development Appendix to provide planning tools and technical guidance to develop local stormwater programs and regulations. These documents are available at:
http://www.ct.gov/deep/cwp/view.asp?a=2719&q=459488&deepNav_GID=1654

5.1.2.4 Recommendations: Urban Areas

The following recommendations have been developed to address the impacts from urban runoff, targeting phosphorus in particular. They are based partly on the above analysis of existing urban runoff conditions, current stormwater regulatory programs, and recommendations contained in the 2014 Connecticut NPS Program Plan.

- DEEP and their partners should continue the development of **Watershed Based Plans** in urban areas as the best way to holistically look at water quality conditions related to stormwater sources and propose management measures. Watersheds with phosphorus related water quality impairments due to urban runoff and high impervious cover should be targeted for development of plans. These plans should include a modeled assessment of NPS phosphorus loading, sources, estimate load reductions, and management measures. These plans could also qualify towns for NPS funding for implementation projects.

- **Impervious Cover (IC) Outreach and Assistance:** Develop an outreach effort for the 2014 DEEP Watershed Response Plan for Impervious Cover, targeting phosphorus related impairments and urban and suburban communities where impervious cover (IC) and stormwater runoff are responsible for water quality impairments. This should include building on the technical tools and outreach developed for the Eagleville Brook IC TMDL and responding to an Impervious Cover-Based TMDL, UConn NEMO/CLEAR Program, 2011.

- **Municipal GI/LID Outreach and Implementation**: Enhance municipal outreach and implementation of GI and LID. Maintain a Municipal Outreach for Green Infrastructure and Low Impact Development website to share information with municipalities on the use and effectiveness of GI and LID techniques in Connecticut and nationally. Hold workshops or training to share and exchange information on green infrastructure (GI) and Low Impact Development (LID) approaches and techniques. Develop municipal regulation guidance related to GI and LID. DEEP and UConn CLEAR should be key partners in this effort.

- **BMP Research and Guidance**: Continue to research and evaluate the latest information on new or modified BMPs to more effectively address water quality impacts from urban runoff, including consideration of pollutant removal and runoff reduction effectiveness, maintenance issues, and cost. This should target the most recently available research on the performance of existing and new structural and non-structural BMPs for reduction of nutrients. Regularly update statewide Stormwater BMP manuals and guidance, including the 2004 Connecticut Storm Water Quality Manual, the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control, and associated LID Appendices. Solicit regular input from the consulting community, UConn and the academic community, state agencies, and the regulated community through the State NPS Technical Committee.

- **Regional Approaches**: Promote regionalization, watershed management and municipal cooperation to address runoff-related water quality issues and implement more effective municipal stormwater programs. Support the development of regional partnerships (i.e., coalition, collaborative, etc.) to increase the capacity and cost-effectiveness of municipal compliance with the MS4 General Permit and non-regulatory NPS runoff issues, and provide capacity and tools for partners. Regional stormwater partnerships could build upon existing watershed management plans, regional planning, watershed organizations, conservation districts and others. This could be modeled after successful stormwater coalitions in other areas of New England such as the Central Massachusetts Regional Stormwater Coalition. Seek startup funding to establish a regional stormwater coalition in Connecticut. One possible source is the Regional Performance Incentive Program (RPIP) grants through the Connecticut Office of Policy and Management.

- **Stormwater Program Financing Mechanisms**: Promote the development of long-term, dedicated financing mechanisms for municipal stormwater programs, such as a stormwater utility. Funding derived from a stormwater utility can be used to address local stormwater management needs including drainage infrastructure, flooding, and polluted waterbodies, as well as support regulatory compliance such as municipal MS4 Permit responsibilities. Support the implementation of a stormwater utility in those Connecticut communities that have already performed stormwater utility feasibility studies and/or that have expressed an interest in pursuing a utility or similar funding mechanism.

- **Enhance the existing DEEP Stormwater Programs and General Permits** to target stormwater impaired waters and phosphorus related sources. This should include all four types of General Permits that DEEP issues which requires steps to control stormwater pollution from urban areas and land use types. The MS4 permit in particular should target measures to reduce urban phosphorus sources and transport including: illicit discharges; fertilizer use; minimizing the effect of IC; IC retrofit programs; road and property management measures for sweeping paved areas, catch basin cleaning and leaf management; pet waste; local requirements for new and redeveloped sites to minimize runoff volume and effect of IC, first flush retention, and LID practices; turf management for municipal properties to reduce turf area and fertilizer use; and public education programs to raise awareness about fertilizers, lawn and leaf management, detergents, sediment and effects of IC. To assist municipalities in these efforts DEEP and UConn CLEAR should be key partners to develop an outreach and technical assistance program. NPS and Stormwater Permit programs should target outreach and regulatory strategies that specifically address phosphorus pollution from the fine dust and organic matter that accumulates on impervious surfaces. Education of citizens and landscape contractors that disposing of anything onto paved streets is illegal and has adverse environmental effects. Disposal practices for yard and landscape waste onto impervious areas, streets, and wetlands have been commonplace, exacerbated by the widespread modern practice of using leaf blowers.

5.2 Animal Waste and Manures

5.2.1 Analysis of Problem and Issues

Connecticut's agricultural producers generate large tonnages of manure and animal waste that has high concentrations of phosphorus. Sources include chickens for egg production, dairy and beef cattle, horses, and other smaller farms. There can be significant costs involved with recycling and disposal of those wastes, while minimizing pollution. Some of the relevant issues include: high energy costs associated with transporting wet materials and/or processing them into marketable products, shortage of available land area for application, and seasonal climatic issues. Connecticut's soils, where well drained, typically have excellent capacity to adsorb phosphorus. Erosion of phosphorus enriched soils can result in significant phosphorus loading to surface waters. Manure management and storage practices play a role in controlling rates of phosphorus release to surface waters. Severity and impacts resulting from phosphorus pollution problems is influenced by local soils, topography, and receiving water characteristics, as well as variations in storms and seasonal attenuation.

A statewide analysis of manure nutrient production was prepared by the University of Connecticut Cooperative Extension Department (Meinert, unpublished data). The analysis by Richard Meinert showed that Connecticut's estimated animal population could produce approximately 9.1 million pounds (4,550 tons) per year of phosphorus (as P_20_5). Meinert concluded that if all available cropland received agronomic manure nutrient application that there would be a theoretical annual surplus of 3.9 million pounds (1,950 tons) of phosphorus. 43% of the phosphorus in Connecticut's manure is surplus, assuming that all cropland is "open" to manure spreading. The dairy and poultry industries together account for nearly 80% of these nutrient loads.

Up to 90% of the phosphorus transported from cropland is attached to sediment. Thus, erosion control is of prime importance in minimizing phosphorus loss from agricultural land. Because surface runoff is the main mechanism by which phosphorus and sediment are exported from most watersheds, it is clear that phosphorus export will be minimized if surface runoff does not occur. (http://pubs.cas.psu.edu/FreePubs/pdfs/uc162.pdf)

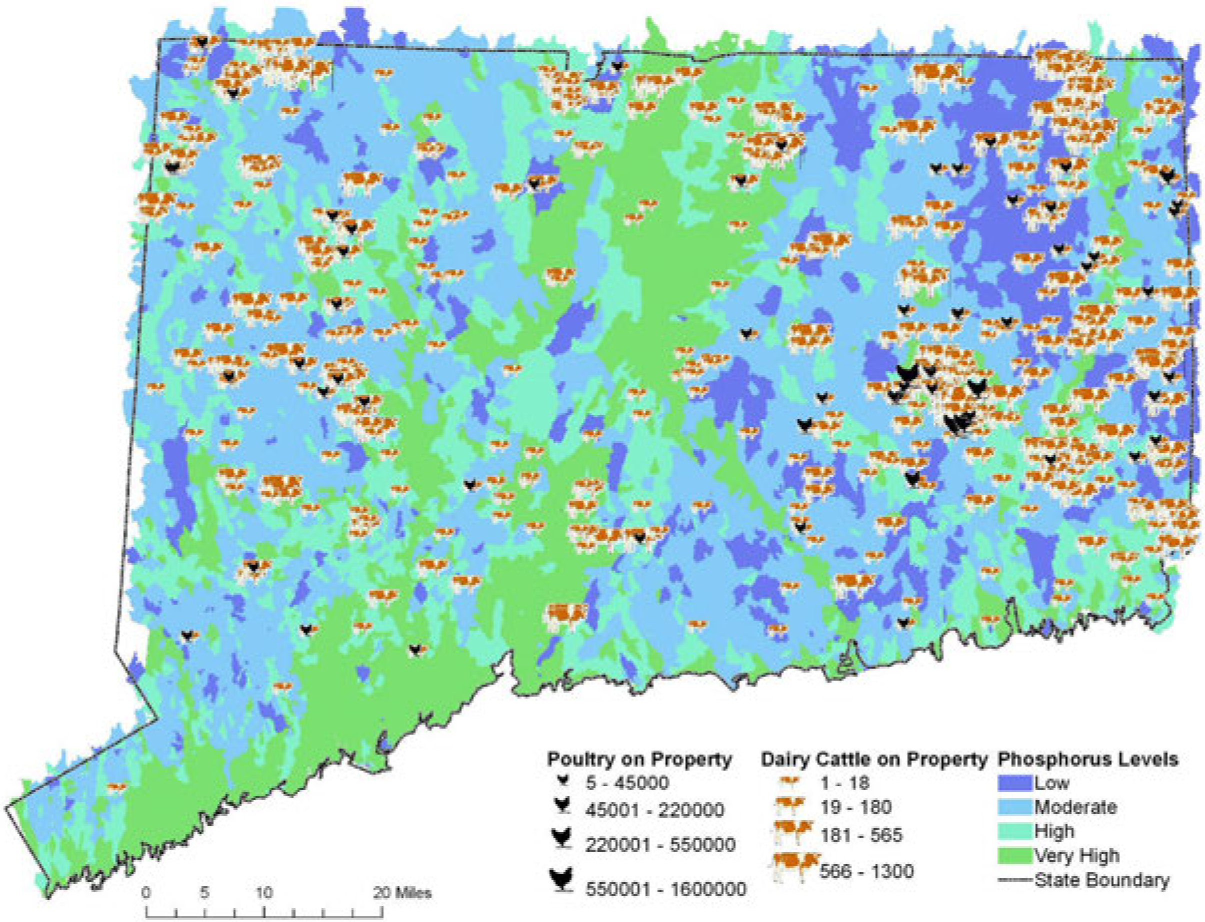


Figure 4.2.1 Poultry and Dairy Cattle Animal Feeding Operations Superimposed over Modeled Phosphorus Values in Non-tidal waters

Over application of manure sometimes occurs in farm fields that are most convenient and cost effective for farmers. Phosphorus export can increase dramatically where over-application of manure to fields occurs, resulting in concentrations of phosphorus in soils that are greater than what soils can adsorb. Leaching of soluble phosphorus can result in very high rates of export. Export of soluble phosphorus to surface waters can also occur when manure is applied to wetland soils as hydric soils do not have the capacity to adsorb much phosphorus.

Connecticut's dairy and poultry producers produce more that 1.15 million tons of manure per year. This is more than can be land applied to cultivated fields at agronomic rates. In addition, social factors, like odors, increasingly limit land application of manure as residential properties are developed adjacent to farmland.

Development of feasible and efficient manure management systems will be essential when DEEP's proposed Concentrated Animal Feeding Operation (CAFO) general permit is implemented.
It is necessary to reduce excess water pollution that results when the animal waste generated is not managed and disposed in an optimal manner. Even with thorough implementation of best management practices, some pollution to the State's waters is inevitable, particularly during large storm events.

Value added products such as compost, container growing media, organic fertilizer, and energy can and should be produced from the waste products produced. There are startup and maintenance costs associated with these recommended practices. In some cases improvements are simply lacking a funding source and local backing to be implemented. In other cases, more collaborative planning is needed to flesh out details.

Most of the recommendations in this section apply to cattle and poultry operations. Additional planning and implementation should take place to better address pollution from sources such as horse farms and smaller sources where animals are raised. Connecticut DEEP's Nonpoint Source Program partners with UConn and NRCS to assist those that are willing.

5.2.2 Anaerobic Digesters

Anaerobic digesters with secondary treatment technologies are expensive. Regional digesters can increase the economic feasibility of processing a combination of livestock manure and food waste from a region. The result is reducing waste and pollutant volumes, generating energy in the form of both methane and heat, and creating of a product that can be used as a soil conditioner.

Public Act 11-80 authorized the Clean Energy Finance and Investment Authority (CEFIA) to establish a 3 year pilot program to support the use of on-site anaerobic digestion facilities to generate electricity and heat through loans, grants or power purchase agreements. The objective was to promote renewable energy, sustainable practices and economic prosperity of CT farms and other businesses by using organic waste. CEFIA published a request for proposals (RFP) in 2012 for on-site anaerobic digestion facilities but received no proposals, despite extending the deadline for submittal.

The CEFIA's 2012 RFP intended to solicit digester projects, but was unsuccessful. The following barriers were identified in 2012 by stakeholders and listed below:

- Electrical generation was limited to only offsetting on-site demand.
- Did not recognize the potential for anaerobic digesters to reduce greenhouse gases.
- Did not include anaerobic digesters as a priority of the State plan to meet the Renewable Portfolio Standard mandate.

- Required shovel ready projects.

The following benefits of regional renewable energy digesters with secondary treatment technologies can have significant local, regional and statewide environmental importance:

- Energy production reduces the demand for electricity.
- Reducing greenhouse gases by improved nutrient management and renewable energy production. Methane, a potent greenhouse gas, is captured for beneficial uses rather than released to the atmosphere.
- Enabling dairy farms to comply with the manure and wastewater handling and management requirements of federal regulations concerning Concentrated Animal Feeding Operations (CAFOs).
- Establishing manure and food waste processing capacity in CT to address surplus manure nutrients and the Solid Waste Management Plan.
- Reducing nutrient surplus and nutrient loading to CT's waterbodies and soils resulting in improved surface and ground water quality.
- Creating alternative technology models and long-term solutions to dairy manure and food waste management.
- Protecting local and regional public health, air quality, water quality and impacts to climate.
- Investing in viable farming operations for local food production thereby reducing transportation energy consumption and emissions
- Building sustainable agriculture to maintain a working landscape and preserve open space.

If we are going to encourage the efficient generation of methane from on-farm digesters, we need to incorporate an economically viable process for farm digester operators to evaluate and use various sources of carbon to increase methane yields. One Connecticut farmer with a digester discovered that the regulatory framework to bring ice cream waste (a food grade carbon source) to a farm digester is a bit onerous and potentially costly, with no certainty that additional, more costly permits would not be required in the future.

Legislative authorization to simplify utilization of available carbon materials would streamline the permitting processes for anaerobic digesters on farms. Legislation could be proposed that redefines certain types of dairy "waste" as not waste when used as a carbon supplement in digesters at amounts necessary to maximize the yield of methane. It would need to be made clear that anaerobic digestion is not a disposal operation for dairy waste, but a use of dairy waste. Material handling and storage should be reviewed and approved under the Comprehensive Nutrient Management Plan (CNMP) developed for the farm with assistance from NRCS. DEEP's Water Permitting and Enforcement Division reviews and approves CNMPs.

5.2.3 Recommendations: Animal

Waste

Centralized poultry waste combustion/incineration – Develop the means to provide assistance with capital costs and/or incentives to install a combustion system to concentrate nutrients for more effective transport, and capture energy from the manure.

- Available poultry manure would require a clean wood waste source for incineration and land application
- Revenue produced from energy production and ash by-product which can be used as a phosphate/potash fertilizer, approx. Residual ash would be 10% weight of the litter going in. (Dagnall et al. 2000)
- Conversion of poultry manure and wood biomass into a soil fertilizer that can be managed, transported, stored and applied at an agronomic rate for phosphorus.
- Heat used at poultry facilities for heating, hot water for egg washing, and drying locally grown grains. Using locally grown grains reduces importation of phosphorus in grains from out of state.

Manure solid/liquid separation technologies on individual farms tied in with manure transport/composting – Help with capital costs to purchase and install facilities on farms. Composting of separated solids is more feasible than slurry alone

- New centralized/regional composting centers combined with food waste/leaf compost facilities.
- On-farm compost systems.
- Incorporate technologies that concentrate phosphorus in separated solids (centrifuge or other technologies) allowing for reduced phosphorus concentrations in land applied liquid manure and re-purposing of phosphorus in compost or other value added product.

Separated portion of the manure can be stored at a high dry matter (DM) content. Allows more feasible transportation of manure to be economically viable for biomass to energy facilities, high DM waste (~70% DM) can be transported 4x further than low DM wastes (<10% DM) (Dagnall et al. 2000)

Manure transportation system – Develop the means to implement a manure transport system throughout the state of CT to help distribute manure nutrients from areas of high livestock and nutrient concentrations to areas in need of nutrients.

- Deferred cost payments: Accounting for appropriate costs per mile for method of transport utilized (rail, road, barge) must be associated with soil testing and nutrient management plans (NMPs) where nutrients are needed

- Incentive payment program for optimal (or lower) soil test values ($/ac) to encourage adaptive soil nutrient management and defer costs of transport when excess nutrients need to be exported from the farm.

Centralized/regional anaerobic digestion for dairy and food waste – Provide grant funding and organize cooperative agreements to pool monies and resources for centralized digesters.

Existing models of centralized digesters demonstrate a means of centralizing nutrients to gain economic feasibility and capture gas and energy from the manures. Digesters significantly reduce manure odors, allowing for greater use and diversity of manure applications, such as application to previously unavailable land bases near populous areas. Anaerobic digesters as a stand- alone technology do not reduce phosphorus concentration or improve water quality directly. However, pre-treatment technologies can reduce phosphorus concentrations in liquid manure and potentially improve water quality. A solid separator coupled with a decanter centrifuge may remove up to 40% of the phosphorus in liquid dairy manure. The synergy of technologies and the resulting value-added products make anaerobic digesters appealing for reducing phosphorus:

- Electricity from digester complex used to power separator, centrifuge, and operation of farm.
- Heat for drying locally grown grains reducing importation of grains with more phosphorus.
- Phosphorus extracted from manure used in compost or in organic fertilizer
- Value-added products (containing phosphorus) transported out of watersheds of concern.
- Liquid dairy manure applied at an agronomic rate for nitrogen without over applying phosphorus.
- Reducing runoff from liquid application because land applied liquid is infiltrated into the soil more readily than solid or semi-solid manure, reducing NPS phosphorus in storm runoff.

Existing grants and financial incentives should be modified and developed to support regional anaerobic digesters with secondary treatment technologies for phosphorus removal.

Incentives are needed to attract private entities to develop/invest in regional facilities. To identify the type and size of incentives needed, funds are needed to evaluate feasibility for development of regional manure management facilities.

Establish a manure exchange/brokerage system – Incentivize or capitalize private companies to effectively coordinate manure transfer from areas of nutrient excess to areas of soil nutrient need to demonstrate a value of the nutrients in manures and offset the costs of chemical fertilizers needed on farms with nutrient management plans or soil test recommendations.

Financial incentives, tax credits, grant and loan program - To implement NPS phosphorus reduction practices for on farm, off farm solutions, and establish regional facilities financial incentives, tax credits, grant and loan programs need to be expanded, modified, and created.

Example: Farm tax credits for manure export/compost sales

Incentivize the implementation of Nutrient Management Plans for Animal Feeding Operations (AFOs), Encourage and identify manure management on fields to discourage P applications above crop removal levels, based on soil test recommendations. These fields are identified as those where the field specific P-Index is 'Low'.

Reduce animal feed import by:

- Maximizing crop yield with adaptive management practices incentives for farms or farm groups
- Growing more grain crops locally
- Encouraging pasture based practices with incentives to reduce imported feed need
- Provide a regional grain drying facility associated with a regional digester/incinerator/energy facility to make local grains more available and feasible

Improve current distribution of manure on cropped lands with incentives for optimal (or less) soil test values and nutrient management plans.

Provide capital funding for pilot projects such as:

- Pelletizing
- Gasification and biochar production
- Chemically precipitate or recover phosphorus and exporting phosphorus from the State
- Phosphorus recovery from poultry manure using quick wash process to produce calcium forms of phosphorus fertilizers (remove 90% phosphorus)
- Phosphorus recovery from liquid dairy manure using Struvite Crystallization to produce $MgNH_4PO_4 \cdot 6H_2O$ form of phosphorus fertilizer (slow release fertilizer
- Manure separation through mechanical means or with coagulants, flocculants, or addition of magnesium for struvite precipitation to increase phosphorus precipitation, leave higher phosphorus in solids for composting and lower phosphorus concentrations in liquid for land applications.

Evaluate potential benefits of a phosphorus trading program within watersheds by providing funding for an analysis of cost effectiveness for the installation of phosphorus reduction technologies from waste water treatment plant discharge, or to pay farmers (and/or regional projects) to install and operate a phosphorus removal system from manure. P removal on a local or regional level would allow for easier transport of the nutrients to areas where soil nutrients are needed and allow for the manure to be applied to crop fields to maintain productivity and soil health.

Provide incentives for farms to adopt and apply soil health practices and adaptive management. Soil health refers to the goal of having a highly diverse and functional soil through the use of land management and plants in the soil as much as possible. Incentives to apply soil health practices would help to reduce soil loss and phosphorus transport from fields, reduce water runoff from fields by maintaining or improving water infiltration to soils and potentially reduce nutrient application need through the synergistic effects of land management and soil health. Some incentives related to soil health may include:

- Cover crop seed on any cropped field
- Diversity of seed or plants in cropped/hayed/pastured field
- Purchase of seed equipment to plant crops and cover crops
- Cost of seeding cover crops by custom operators (inter-row seeding at mid or late crop stage, aerial seeding)
- Early seeding of cover crops (September or earlier) for nutrient recovery and soil cover
- Termination of cover crop with alternate methods to chemical only, such as rolling/crimping, harvesting, or winter kill annuals in such a way to maximize nutrient uptake and soil coverage.

Provide incentives to offset costs to production for farms adopting environmentally based management practices. The conversion to new land or crop management practices may incur a drop in product or yield during a transitional time period, which could be detrimental to the immediate economic needs of the farm. The cost offset to yield/productivity could help reduce the risk of converting management practices.

Support the work of the NRCS State Technical Committee: Nutrient Management Subcommittee with representatives from poultry and dairy operations, NRCS, UCONN Extension, DEEP, CT Farm Bureau, CT Dept. of Agriculture, and other stake holders to determine how to best implement these recommendations.

Fund continuing education related to soil nutrient management, manure management and soil health to bring awareness to the existing problems and provide opportunity to learn or develop new solutions on the subject of NPS Phosphorus (and nutrient) reduction.

Citations:

S. Dagnall, J. Hill, D. Pegg. **Resource mapping and analysis of farm livestock manures–assessing the opportunities for biomass-to-energy schemes.** Bioresour. Technol., 71 (2000), pp. 225–234

M. Asai, V. Langer, P. Frederisksen, B. H. Jacobsen. **Livestock farmer perceptions of successful collaborative arrangements for manure exchange: A study in Denmark.** Ag. Systems, 128 (2014), pp. 55-65

Brochure: "IMPACT OF NEW GENERAL PERMIT ON CONNECTICUT FARMERS" Prepared by the CAFO Advisory Committee, April 2003

Richard Meinert. Personal communications

5.3 Phosphorus Fertilizers

5.3.1 Analysis of the Problem and Issues

Public Act 12-155 established controls on fertilizer use on lawns including a formula limit of 0.67% phosphorus for use on established lawns as well as seasonal prohibition on lawn fertilizer applications from December 1 – March 15. Lawn fertilizer may not be applied within 20 feet of a watercourse or on impervious surfaces. These controls do not apply to Golf Courses or agricultural lands.

PA 12-155 also allows the Commissioner of Agriculture to approve distribution of consumer information at the point of sale for fertilizers and adopt regulations. There is no dedicated funding source available for these activities. Educating fertilizer users to choose the right fertilizers, and apply them at the right time and rate to reduce offsite movement of phosphorus can have profound effects on the amount of phosphorus exported to surface waters.

Phosphate ions are effectively bound to iron or aluminum ions in well-drained soil. Wetland soil minerals will not adsorb dissolved phosphate. Application of phosphorus fertilizers to wetlands can result in soluble phosphorus release to surface waters.

Overall reduction of phosphorus in fertilizer and application rates is a cost effective way to reduce pollution in storm runoff. Homeowners typically do not have the same concerns relative to controlling costs as commercial operators and their application rates are not as likely to be carefully measured. Homeowners are likely to continue applying until the package is used up with the idea that if a little is good a lot is better. Golf courses and commercial lawncare companies have greater cost concerns so are less likely to over apply fertilizers. Poorly timed fertilizer application before heavy rainfall, and the significant quantities of soluble nutrients applied over larger acreages can lead to high pollutant loadings. More frequent light applications are preferable to occasional heavier applications for both plants and water quality.

Timing of fertilizer applications relative to rainstorms is a critical variable in controlling soluble phosphate loadings to surface water bodies. Fertilizer applied prior to a very light rain allows the phosphate to infiltrate into the soil profile where it can be bound effectively. Applications prior to rainstorms which cause surface runoff will result in water pollution. Other factors influencing infiltration like slope, soil compaction, sparse vegetation, and soil type can all lead to increased runoff and subsequent pollutant loadings. Raising mowing heights can result in healthier turf and less fertilizer reaching surface waters.

Removing phosphorus from organic lawn fertilizers is difficult because P is present in relatively large quantities in the organic materials from which the fertilizers are derived. Because synthetic fertilizers are much higher in nitrogen than organic fertilizers the amount of phosphorus being applied per pound of nitrogen is much higher when organic fertilizers are used. Phosphorus content in fertilizer is labelled as guaranteed minimum values. Phosphorus content can sometimes be higher than the guaranteed minimum value on the label in organic fertilizers.

The New England Interstate Water Pollution Control Commission organized the Northeastern Regional Turf Fertilizer Initiative, a collaborative effort, completed in January of 2014 that sought to engage the six New England states, New York State, EPA, and industry and non-industry stakeholders in discussion on the contribution of fertilizers applied to lawns to polluted runoff and water quality problems. A final report describing the 33 guidelines developed through this process is available at: http://www.neiwpcc.org/turffertilizer.asp . The set of 33 regional guidelines presented in this report are organized around "5 R's": right formulation, right rate, right time, right place, and right supporting actions.

DEEP published guidance on Best Management Practices for Golf Course Water Use in 2006.
http://www.ct.gov/deep/lib/deep/water_inland/diversions/golfcoursewaterusebmp.pdf The document's primary focus is water conservation, however, recommendations are also made for Wetland Protection, Stormwater Management, Erosion and Sediment Control, Turf Management - Nutrient and Integrated Pest Management (IPM) Plans, and Water Quality Monitoring.

Container nurseries can present unique problems if they are not managed to minimize nutrient runoff. If water soluble fertilizer is applied via the irrigation system a considerable amount of phosphorus may miss the containers and be subject to offsite movement. Because container nursery growing media needs to drain well to prevent root diseases leaching of phosphorus is a concern. Leachate from container media can contain from 60 – 150 lbs. phosphorus/acre/year (Bugbee and Elliott, 1998). CAES has found that certain Connecticut water treatment plant residuals are high in reactive aluminum (Bugbee and Elliott, 1999).

These residuals are often a disposal problem but have the capability of being able to adsorb large quantities of phosphorus. These residuals could be incorporated into buffer zones or detention basins to enhance phosphorus removal.

5.3.2 Recommendations for Fertilizers:

5.3.2.1 Statewide: All Areas

The following general recommendations apply to all of the additional specific areas below.

- Reduce phosphorus applications.
- Apply phosphorus based on soil tests.
- Maintain unfertilized buffer strips between nurseries and water courses.
- Minimize applications of phosphorus fertilizers to nontarget areas.
- Utilize vegetated containment areas for drain discharges.
- Collect runoff and reuse.
- Consider phosphorus removal zones containing water treatment residuals.
- Educate fertilizer users on ways to reduce offsite movement of phosphorus.
- Timing of phosphorus application relative to occurrence of intense runoff events may provide decreases in phosphorus runoff. Applications of P should be applied during times when intense runoff events are less likely.
- Subsurface placement of phosphorus away from the zone of removal in runoff will reduce phosphorus loss potential. Light tilling after application or subsurface injection.
- Manure and soil analysis of phosphorus and nitrogen content determined by soil test labs before land application of manure, conducted before any manure application and used as guidelines in determining application rates.

5.3.2.2 Recommendations for Fertilizers: Lawns and Gardens

- Many newer rotary fertilizer spreaders have deflectors to limit the spread of fertilizer to the side where it is not needed. Their use should be encouraged or, alternatively, the use of drop spreaders that apply fertilizer directly to the ground below should be encouraged.
- Where soil tests indicate adequate phosphorus, an option is for home gardeners to use phosphorus free lawn fertilizers that do not contain herbicides or pesticides that will harm garden plants.
- Maintain unfertilized buffer strips between lawns and gardens and water courses. Utilize vegetated containment areas for drain discharges.

- Encourage fertilizer industry to begin marketing garden fertilizer with reduced or no phosphorus.
- Educate fertilizer users on ways to reduce offsite movement of phosphorus.

5.3.2.3 Recommendations for Fertilizers: Agricultural Croplands

- See the Agriculture Waste and Manures Section 4.2 of this report for more guidance on using manure as a fertilizer and soil conditioner.
- Utilize cover crops.
- Maintain unfertilized buffer strips between croplands and water courses.
- Utilize vegetated containment areas for drain discharges.
- Reduce excess manure and compost applications.
- Utilize no-till farming practices to reduce soil erosion and conservation of phosphorus.

5.3.2.4 Recommendations for Fertilizers: Container Nurseries

- Maintain unfertilized buffer strips between nursery and water courses.
- Minimize applications of liquid phosphorus fertilizers to non-target areas.
- Utilize vegetated containment areas for drain discharges.
- Collect runoff and reuse.
- Consider phosphorus removal zones containing water treatment residuals.
- Educate nursery industry on practices to reduce offsite movement of phosphorus.

5.3.2.5 Recommendations for Fertilizers: Golf Courses

Many issues regarding offsite movement of phosphorus from golf course turf is similar to that discussed previously under home lawns.

- Reduce phosphorus applications. Apply phosphorus based on soil tests.
- Maintain unfertilized buffer strips between fertilized turf and water courses.
- Utilize vegetated containment areas for drain discharges.

5.4 Soil Erosion

Phosphate anions in well drained soils are typically adsorbed quickly to the surfaces of silt or clay particles or to organic colloids. These fine fractions, when eroded by storm runoff, have the capacity to stay suspended and travel downstream where they can exacerbate recreational impairments to surface water bodies, by contributing nutrients which can trigger algae blooms. They can also disrupt habitat functions in wetlands and watercourses leading to further impairments in aquatic life use support. These sediments can also settle out where they adversely impact navigation and water supplies. Sediments can be remobilized by various processes, depending on the water body and its physical and chemical characteristics.

Statutory and regulatory requirements have been in place for many years to minimize the quantities of sediments and nutrients that are contributed to surface water bodies by soil erosion. CT DEEP had recently revised and strengthened its Stormwater Construction General Permit. DEEP has produced both a 2002 Erosion and Sedimentation Control Manual, and Low Impact Development Appendix to provide planning, design concepts, various stormwater management techniques and practices, pollutant removal effectiveness and selection criteria. Links to both documents are available at DEEP's Stormwater General Permits and Incorporation of Low Impact Development Evaluation web page:
http://www.ct.gov/deep/cwp/view.asp?a=2719&q=459488

Appendix 6 provides a Matrix of Laws which may require Erosion and Sediment Control from the 2002 Connecticut E&S Control Manual.

5.4.1 Agricultural Land Erosion

Up to 90% of the phosphorus transported from cropland is attached to sediment. Thus, erosion control is of prime importance in minimizing phosphorus loss from agricultural land. Because surface runoff is the main mechanism by which phosphorus and sediment are exported from most watersheds, it is clear that phosphorus export will be negligible if surface runoff does not occur.
http://pubs.cas.psu.edu/FreePubs/pdfs/uc162.pdf
This conclusion supports the use of cover crops and soil health implementation which reduces runoff and erosion by increasing infiltration and minimizing soil disturbance. NRCS and DEEP have partnered to provide education, technical and financial support to farmers aimed at minimizing pollution to surface water bodies. EPA has recently released an Agricultural BMP database
http://www.bmpdatabase.org/agBMP.html to provide a consistent and scientifically defensible set of data on Best Management Practice.

5.4.2 BMP Methods / Designs and

Related Performance

BMPs to reduce NPS phosphorus pollution rely upon infiltration to the ground, settling out of suspended sediments, and biological uptake of phosphorus. The second and third options often require substantial area to be fully effective. Vegetated buffers to interrupt sheet flow, and grass lined swales, to spread out channelized flows, are commonly recommended.

5.4.3 Erosion Associated with Developed Areas

DEEP administers four Stormwater General Permits: Construction, Industrial, Commercial and MS4 for municipal stormwater systems. DEEP has produced both a 2002 Erosion and Sedimentation Control Manual, and Low Impact Development Appendix to provide planning, design concepts, various stormwater management techniques and practices, pollutant removal effectiveness and selection criteria. Links to both documents are available at DEEP's Stormwater General Permits and Incorporation of Low Impact Development Evaluation web page: http://www.ct.gov/deep/cwp/view.asp?a=2719&q=459488

Generally speaking, DEEP oversees stormwater construction general permit registration if the disturbed area of a construction sites is over 5 acres and municipalities oversee the registration and compliance if the disturbed area is between 1 and 5 acres. Construction projects must comply with the guidelines in the 2002 Connecticut Guidelines for Erosion and Sediment Control, a manual for the design, installation and maintenance of soil erosion and sediment controls that fulfills the requirements of Connecticut's Soil Erosion and Sediment Control Act (see CGS 22a-328, Connecticut General Statutes).

DEEP's Stormwater Construction General Permit requires developers to implement a Stormwater Pollution Control Plan (SPCP) to prevent the movement of sediments off construction sites into nearby water bodies and to address the impacts of stormwater discharges from a project after construction is complete.

All Stormwater Pollution Control Plans (SPCPs) must be approved by a qualified soil erosion and sediment control specialist or a professional engineer, and follow guidelines in the 2004 Connecticut Stormwater Quality Manual. DEEP's 2002 Connecticut Guidelines for Soil Erosion and Sediment Control is recommended as guidance in designing SPCPs.

Encouraging new development to infiltrate stormwater to the same extent as natural landcover is the goal of low impact development and green infrastructure. DEEP's Low Impact Development Appendix to the Connecticut Stormwater Quality Manual and a Low Impact Development Appendix to Connecticut Guidelines for Soil

Erosion and Sediment Control provide consistent guidelines that can assist registrants for stormwater general permits.

5.4.4 Stream Channel Erosion

Erosion of streambeds and banks is an important nonpoint source of sediment and phosphorus threatening the impairment of surface waters in the Northeast. Stream corridors tend to reach a stable state that minimizes erosion and allows for sequestration of sediment and associated pollutants on the floodplain, based on characteristics of watershed and climate[1]. Changes in climate, watershed land use/land cover or disturbance to stream corridor morphology can result in stream channel instability and corresponding increases in erosion and sediment loads[2]. As P is generally adsorbed to soil particles, increases in rates of erosion tend to predict increased P-loads.

Streams responding to climate change and/or disturbance can also become entrenched and disconnected from their floodplains, which increases a stream's erosive power and limits capacity to sequester sediment and associated P along the stream corridor[3]. Streams that are connected to functioning floodplains have reduced erosive power and sediment loads, and consequently reduced P loads.

The most important causes of current and future stream instability and entrenchment in the Northeast are:

- Watershed disturbance including vegetation clearing and conversion to impervious surface resulting in a corresponding increase in peak flows.
- Stream corridor disturbance including riparian buffer degradation, stream channel modifications such channel straightening, gravel mining and bank hardening, and floodplain encroachments such as structural flood control
- More intense rain storms and a corresponding increase in peak flows.

5.4.5 Recommendations: Erosion

- DEEP's Stormwater General Permit program has been in place for many years to reduce sediment inputs to surface water bodies. The Construction General Permit was recently revised with tighter restrictions affecting activities that drain to impaired water bodies. DEEP oversees and enforces activities which affect over 5 acres of disturbed area. Municipalities oversee and enforce projects which disturb less than 5 acres. At a time when budget reductions are occurring in all segments of government, staff resources to

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[1] Rosgen, David. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

[2] Rosgen 1996.

[3] Vermont Rivers Program. 2010. Floodplains Key to the Health of Lake Champlain. White Paper/Report. Available here: http://www.watershedmanagement.vt.gov/rivers/docs/Educational%20Resources/rv_FloodplainsKeytoHealthofLakeChamp.pdf

inspect and enforce stormwater permits should be preserved or augmented where necessary.

- Including potential impacts to stream channel stability in the review of proposed development, especially in floodplains is recommended. More scrutiny should be given to the geomorphic impacts of development, especially actions that will increase peak flows such as vegetation clearing and creation of impervious surface. In some cases cumulative impacts need to be considered and total maximum daily load (tmdl) analyses or watershed based permitting can be implemented. Expanding the use of floodplain restoration, or reconnecting incised streams to their floodplains, can aid in the sequestration of phosphorus-laden sediments during large storm events when the majority of sediment is transported.

5.5 Internal Loading from Lake Sediments

5.5.1 Analysis of the Problem and Issues

In summer thermal stratification occurs in lakes due to differences in density of water as it heats up. Oxygen cannot diffuse to the bottom due to a density stratification at the boundary point known as the thermocline. Water and become anoxic below the thermocline as available oxygen is used up by respiration processes. Thermoclines typically exist at about 18 foot depth plus or minus a few feet in Connecticut lakes.

Water with low dissolved oxygen triggers a reducing environment where bacteria use oxygen from iron oxides, changing the oxidation state of iron from Fe^{3+} to Fe^{2+}. The phosphate ion: PO_4^{2-} which was previously sequestered by iron oxides now becomes soluble and available to plants. When wind mixing occurs, or the lake cools, stratification breaks down, and phosphate in bottom waters mixes with top waters, often triggering a bloom of algae.

Phosphate ion concentrations in Connecticut lakes near the surface are commonly 10-20 parts per billion (ppb). Phosphate ion concentrations in anoxic bottom water often range into the hundreds of ppb in lakes with nutrient loading.

5.5.2 Recommendations

Phosphorus released from sediments under anoxic conditions is called internal phosphorus loading. Treatment options to reduce internal phosphorus loading include introducing compounds that have greater phosphorus binding capacity than iron under anoxic conditions or adding oxygen to bottom waters.

Compounds with aluminum or calcium can be used to bind with phosphorus in the sediments under anoxic conditions. This technique is called **phosphorus inactivation** and although it is not widely used in Connecticut, it is a common lake management technique for deeper lakes with internal phosphorus loading. The cost to implement a phosphorus inactivation project is approximately $1,000 per acre treated. Costs may vary depending on the conditions and the intensity of internal phosphorus loading.

The intent of **adding oxygen to deeper waters by mixing** the thermally separated upper and lower layers of a lake is to keep oxygen concentrations high enough so that phosphorus and iron stay bound in the sediments. Mixing usually requires a compressor connected to a delivery system above the lake bottom. As bubbles of compressed air move up the water column, stratification of the thermally separated layers is broken down so oxygen can diffuse from the atmosphere to the bottom of the lake. If not done correctly, this method can exacerbate internal phosphorus loading by bring up phosphorus rich water from the bottom to the surface of the lake.

Aeration can also be accomplished by **adding oxygen rich water or pure oxygen** to the bottom of a lake. This technique requires equipment with ongoing operation and maintenance costs. The oxygen demand of the area to be aerated should be calculated prior to installing an aeration system so the system can be properly sized. Aeration systems may be more appropriate for utility companies who have staff and funds to maintain and operate the equipment and supplies needed for an aeration system. Bothe of the preceding two strategies require operation and maintenance.

Normally sediments that release phosphorus are in the deeper locations of the lake so **dredging is usually cost prohibitive**. The goal of most dredging projects is to remove sediment in shallower areas to reduce habitat for aquatic plants. Dredging sediments in deeper areas would require specialized equipment, water handling, and permitting. Dredging to reduce internal phosphorus loading has not been used in Connecticut.

Before proceeding to management efforts to control internal phosphorus loading in lakes, an **assessment of all phosphorus loading sources** is recommended. Benefits from controlling or reducing internal phosphorus loading will be short lived if the sources of phosphorus in the watershed are not controlled. DEEP usually recommends that watershed sources of phosphorus be addressed before initiating phosphorus inactivation or aeration projects.

5.6 Onsite Wastewater Disposal/Septic Systems

5.6.1 Analysis of Problems or Issues

Onsite Wastewater Treatment Systems (OWTS), generally referred to as septic systems, serve roughly 1.5 million people in Connecticut, approximately 40 percent of the state's population. These systems are effectively utilized in rural and low-density suburban areas, but can be problematic in higher density situations and lakefront and shoreline settings.

Septic system failures, where untreated sewage breaks out on the surface, can represent a significant threat to groundwater and surface water. Similarly, septic system malfunctions, where no breakout occurs, but site conditions are not conducive to effective onsite treatment of wastewater, have the potential to impact waters of the State, especially when in close proximity to sensitive environmental receptors.

Current OWTS regulations and technical guidance provide a stringent and regulated process for environmentally protective standards, separating leaching systems from groundwater, surface water, and wetland areas. However, older systems that do not meet the current mandated separating distance to groundwater or surface waters or do not provide an even distribution to a leaching system, may not provide such protections. These older OWTS can contribute to the overall phosphorus load to a waterbody. A number of factors are listed here that can contribute to an OWTS not functioning properly:

- **Age and design of system**: Department of Public Health regulations for the design and construction of OWTS became effective in 1982 and are reviewed and updated on a regular basis. Today system designers and installers are much more aware of the necessity of adequate treatment and not just dispersal. In addition, most studies indicate that the average useful life of a leaching (dispersal) system is 30-40 years, and current regulations require a reserve area but do not mandate replacement at 40 years.

- **Lack of maintenance**: OWTS require maintenance to function as designed. Regular maintenance, consisting of septic tank pumping and inspection, is needed every 3-5 years to remove solids buildup. Regular maintenance also provides an opportunity to evaluate the functionality of the system and inspect components if needed, as well as educate owners.

- **User habits**: Septic systems are designed utilizing a design flow, or estimated flow from a structure. Using water in excess of the specified design flow, such as more people in the house, a sump pump, or a water treatment backwash can result in premature failure and overloading of the leaching system. Garbage disposals, cooking and cleaning habits such as excessive grease, and excessive chemical usage can also affect the functionality of the system.

- **Improper siting**: Extensive older (pre 1982) development utilizing OWTS has occurred in areas that today would be considered unsuitable for OWTS. Examples of improper siting include installations of OWTS too close or into groundwater. This can result in inadequate phosphorus removal or treatment. A suitable unsaturated soil layer is the most important part of the septic system.

- **High loading rate or uneven effluent distribution**: Hydraulic overloading of the unsaturated natural soils can result due to many factors. The most common is putting too much sewage effluent into too small of an area. This can overwhelm the natural soils, thereby not allowing for effective phosphorus removal or treatment, or in a worst case scenario causing a surface breakout. Change in use, or intensification of use, can also be a factor in situations where the property has been expanded to accommodate additional residents or where a seasonally occupied home is now occupied on a more frequent, or year-round, basis.

5.6.2 Recommendations

- Through outreach programs at the regional and state level, encourage development of **town-wide wastewater management plans** that evaluate the potential for water pollution in areas of concern based on the five factors above in Section 4.6.1, as they relate to onsite wastewater treatment systems that do not function properly. Such a planning document should also evaluate the range of options available to mitigate or prevent pollution impacts, and recommend one or more strategies to cost-effectively prevent or address those impacts.

- **Establish a state grant or loan program to fund upgrades of OWTS** to current standards.
    - Funding should be directed to local and state agencies directly responsible for regulatory oversight of OWTS.

- **Implement a statewide comprehensive OWTS management program** with ongoing maintenance and inspection requirements.
    - As part of a comprehensive program, the means and resources to **track and manage data** is critical for the administration and ongoing

success of any management undertaking. A data tracking and management system will allow users to identify data trends, identify areas of concern, and implement site-specific measures to reduce P discharge from OWTS systems as they are identified.

- Implement a **point of sale inspection of all OWTS** and require upgrades to systems not meeting a minimum standard.

- Develop phosphorus source controls or restricted use for:
  - Garbage disposals
  - Commercial automatic dishwasher detergents containing phosphorus. Dishwasher detergents with more than 0.5% phosphorus are currently restricted in Massachusetts, Vermont and New Hampshire.

6 Appendices

6.1 Appendix 1 Phosphorus Yield Maps to Non-Tidal Surface Waters

Estimated Yield Categories for Regional Basin Total Phosphorus Maps (kg/km2/yr.)

The maps display the estimated total phosphorus (TP) yield (kg/km2/yr.) for each watershed. The TP yield was estimated using the USGS Northeastern Spatially Referenced Regressions on Watershed (SPARROW) developed by Moore et al. (2011). Where available, updated NPDES daily monitoring report TP data submitted to DEEP by municipal waste water treatment plants (WWTPs) was used. Each map displays a portion of the yield attributed to different aggregated land use activities to estimate land use loadings. These include agriculture, developed, municipal WWTPs and non-point sources (agriculture and developed combined). The estimated yield is partitioned into four categories: low, medium, high and very high. The categories are approximately based on work developed by DEEP (Becker, 2014) that associated different levels of TP yield with changes in the algal community in rivers and streams. Changes were identified at 'Enrichment Factor' (EF) points, which is a scaled measure of TP yield. Significant changes in the algal community were identified at (1) 8.01 kg/km2 (1.9 EF) above which sensitive taxa steeply declined (2) 26.12 kg/km2 (6.2 EF) above which most sensitive taxa were lost and tolerant taxa steeply increased to their maxima and (3) 35.4 kg/km2 (8.4 EF) which appeared to be a saturation threshold beyond which substantially altered community structure was sustained. The low, medium, high and very high map categories correspond as 0 – 8.01 kg/km2, > 8.01 – 26.12 kg/km2, > 26.12 – 35.4 kg/km2, and > 35.4 kg/km2, respectively.

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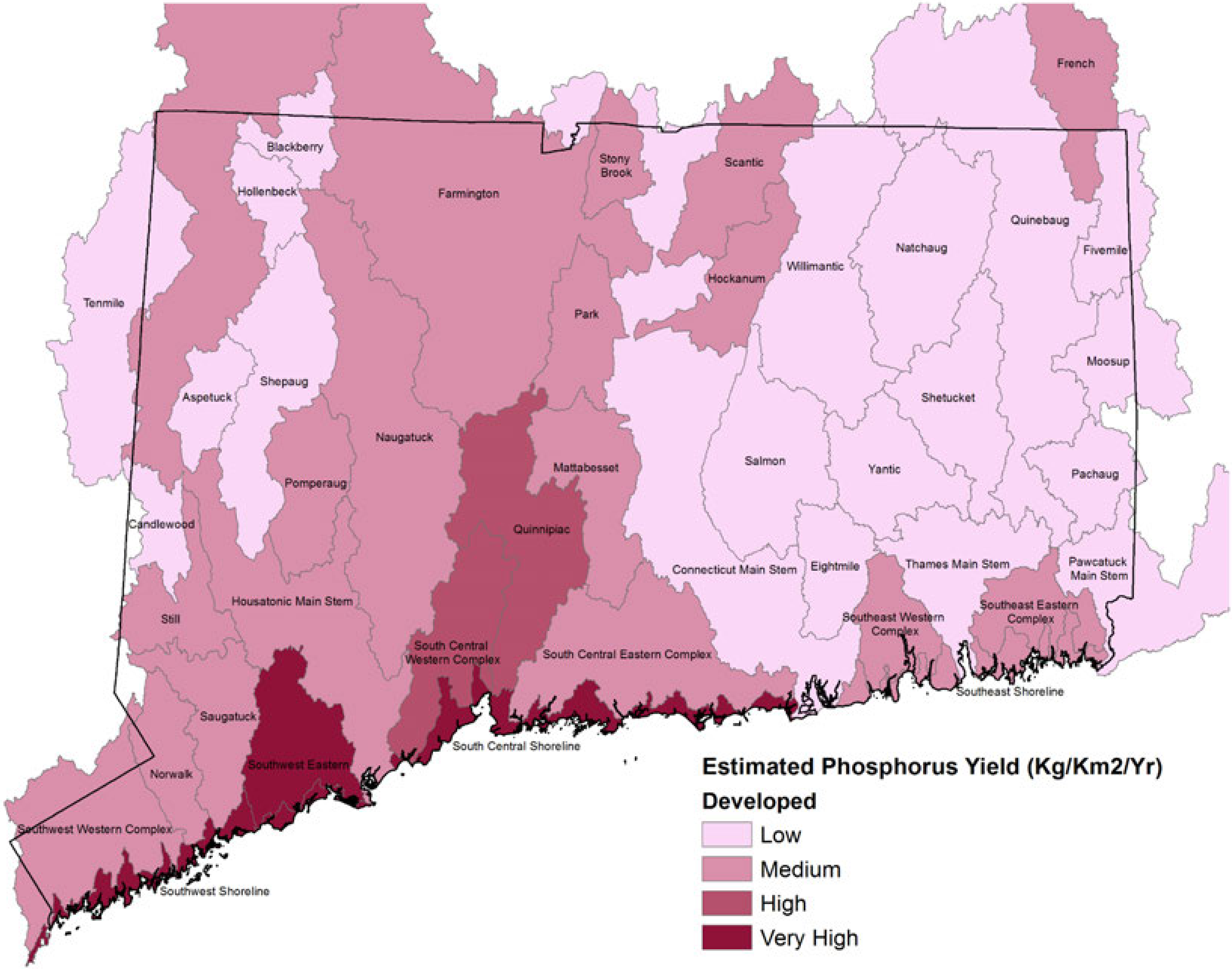
Blackberry
Hollenbeck
Farmington
Stony Brook
Scantic
French
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Connecticut Main Stem
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Southeast Eastern Complex
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Southeast Western Complex
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Southeast Shoreline
Saugatuck
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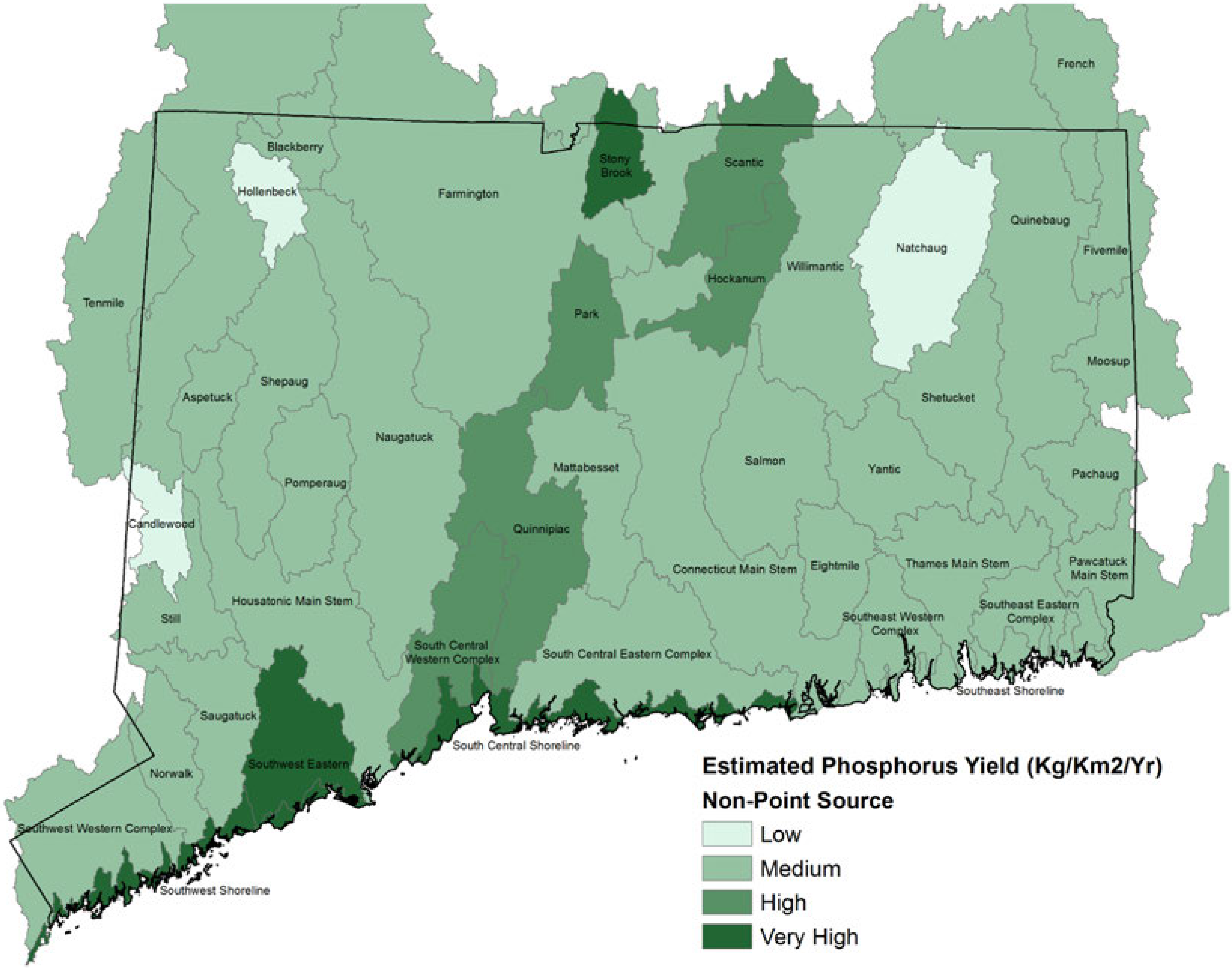
Estimated Phosphorus Yield (Kg/Km2/Yr)
Developed
Low
Medium
High
Very High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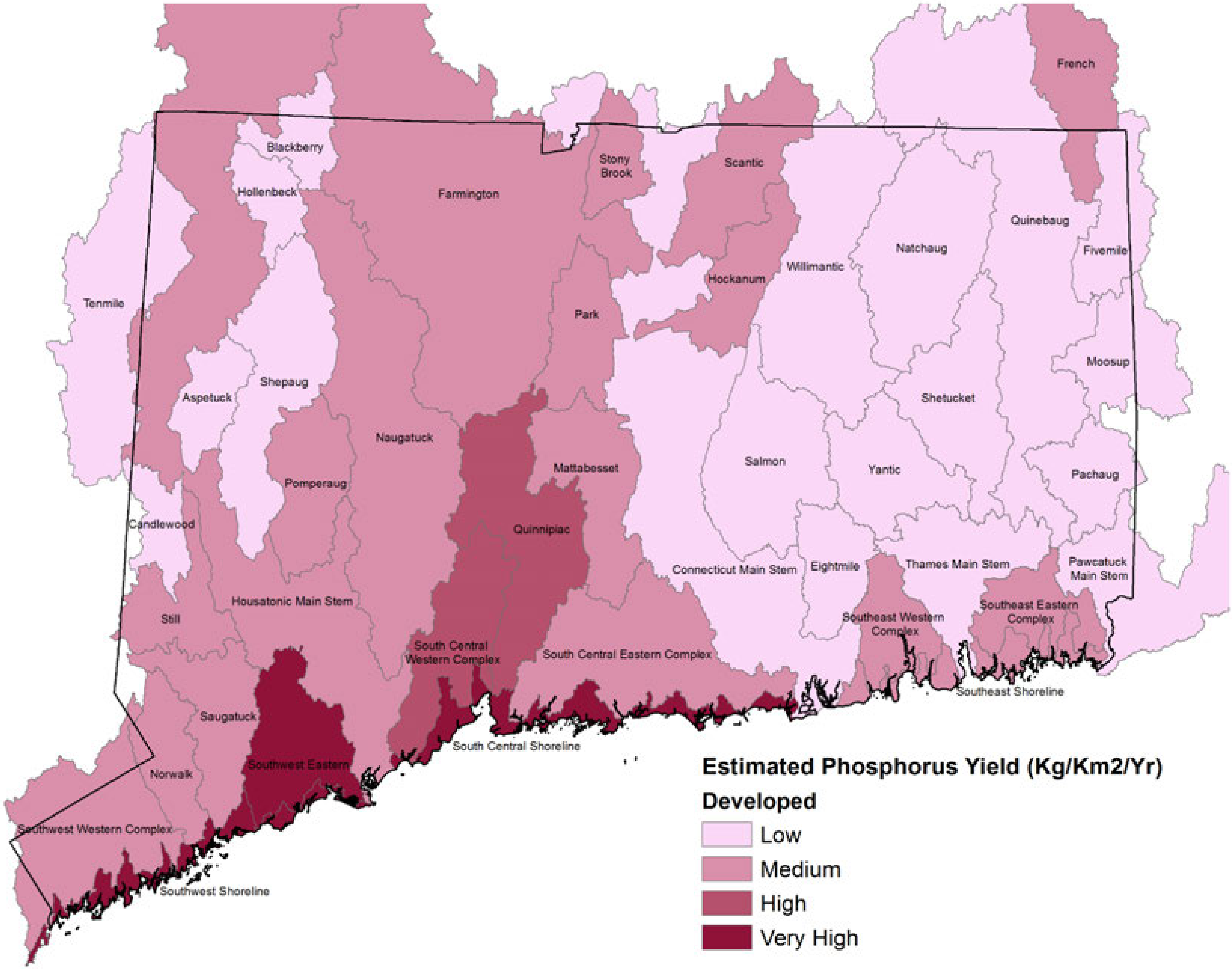
Estimated Phosphorus Yield (Kg/Km2/Yr)
Non-Point Source
Low
Medium
High
Very High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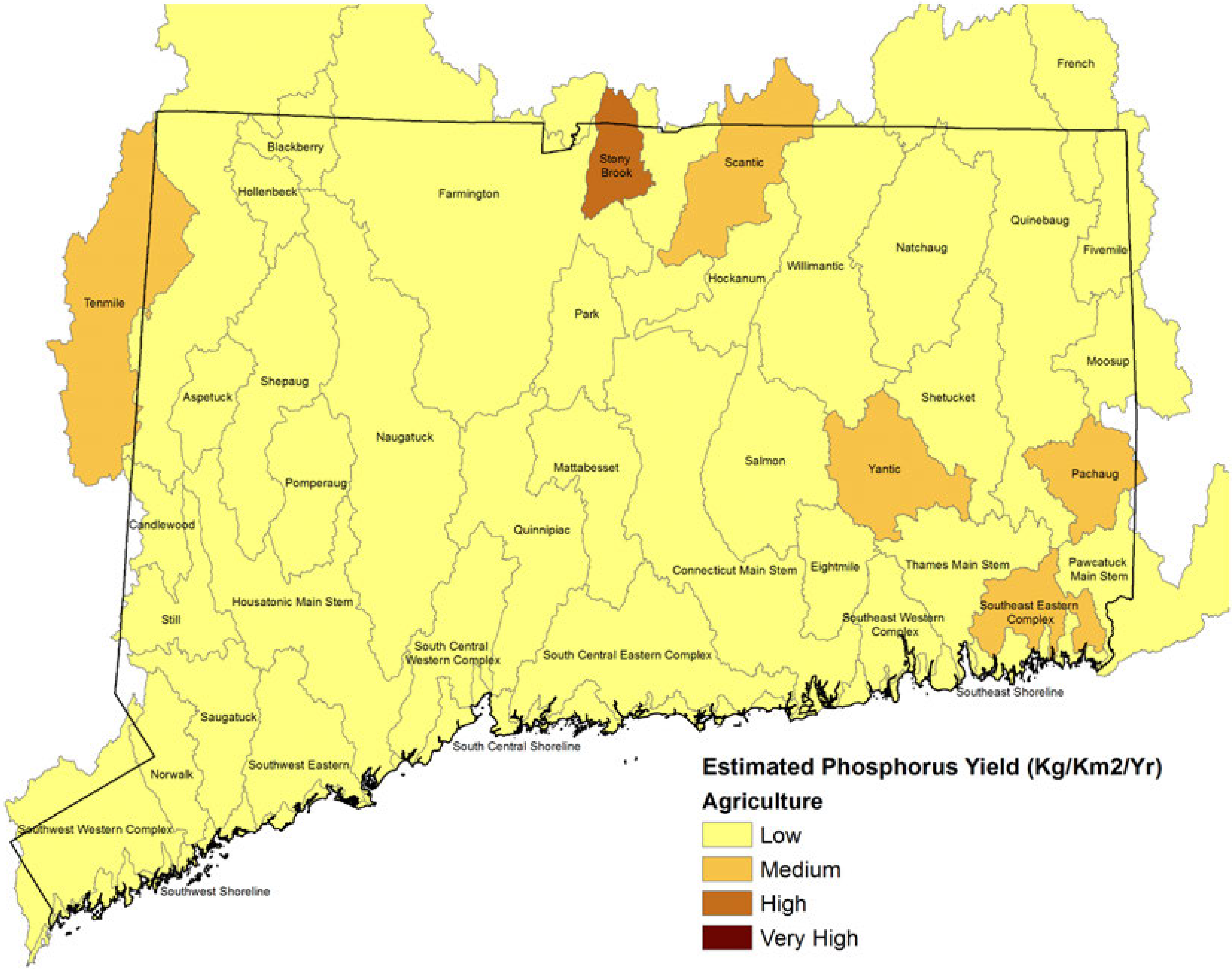
Estimated Phosphorus Yield (Kg/Km2/Yr)
Developed
Low
Medium
High
Very High


Estimated Phosphorus Yield (Kg/Km2/Yr)
Agriculture
Low
Medium
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Very High
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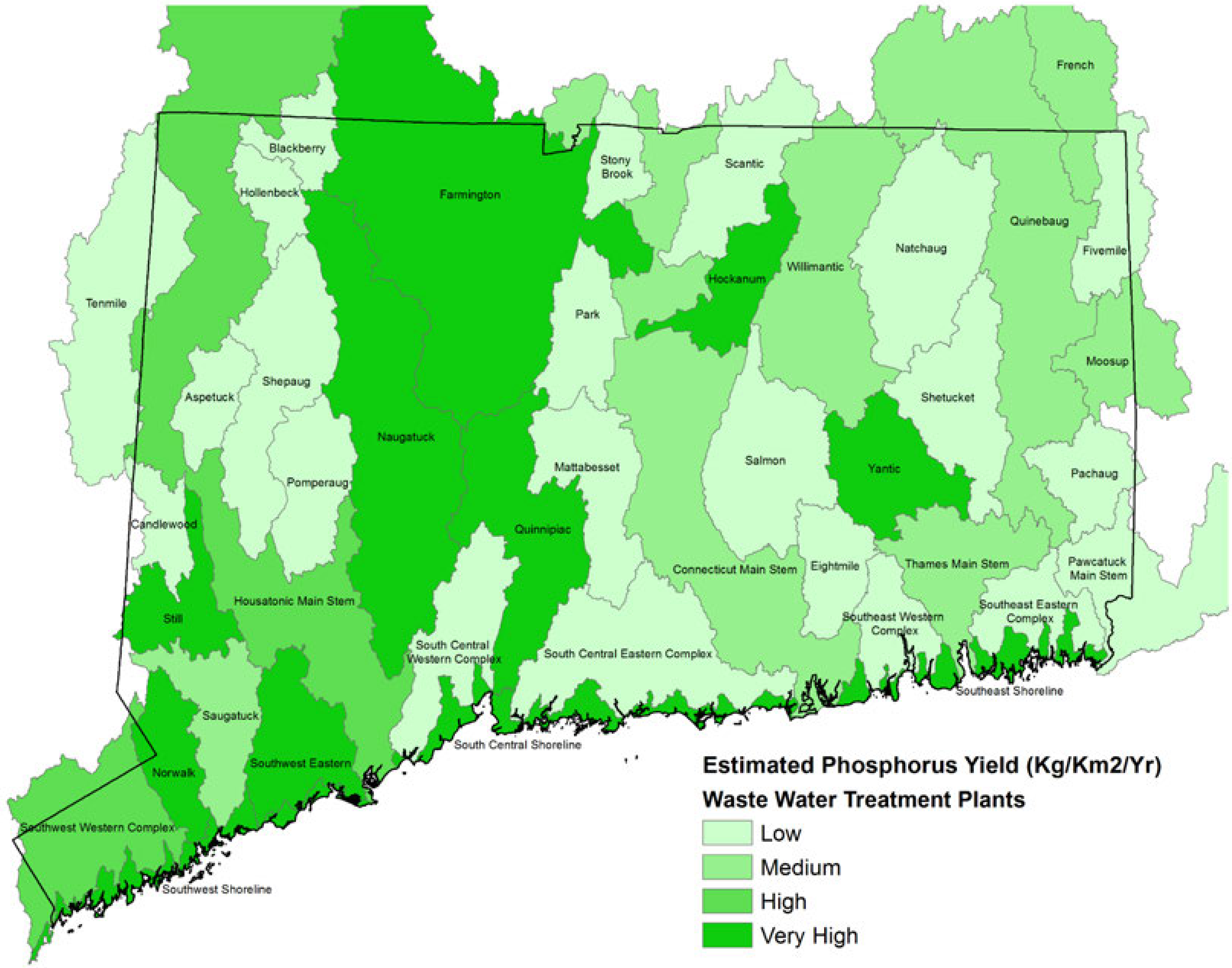
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Southeast Shoreline
Saugatuck
South Central Shoreline
Southwest Eastern
Norwalk
Southwest Western Complex
Southwest Shoreline
Estimated Phosphorus Yield (Kg/Km2/Yr)
Waste Water Treatment Plants
Low
Medium
High
Very High

6.2 Appendix 2 Urban BMP Performance Efficiency and Costs Analysis

Reducing phosphorus in runoff from urban and suburban areas includes a range of structural and non-structural treatments - best management practices (BMPs) - that vary in removal efficiencies and costs. Structural BMPs are constructed structures designed to capture and treat runoff while non-structural BMPs are programs practices and activities that decrease the amount of phosphorus entering surface waters. Although numerous studies document the costs and performance efficiencies of BMPs data is limited for some BMPs, especially non-structural treatments. Table 1 is a summary of BMP data researched recently by DEEP

6.2.1 BMP Performance Efficiencies

The performance of structural BMPs is influenced by a system's design, installation, and maintenance as well as site conditions, such as the amount of land available, the degree of land development, the form of phosphorus on a site, the phosphorus concentration of inflowing waters, soil type, local climate, and vegetation. In considering the feasibility of a structural BMP type, it is critical to consider these variables along with initial project costs (design, construction, and land costs) and operation and maintenance costs over a 20-year period. For any BMP, it is also important to consider the limitations of the BMP and any supplemental benefits the BMP may provide. For example, a community with few dog owners or few lawn owners would limit the effectiveness of BMPs designed to change behavior through outreach programs aimed at reducing pet waste and changing how lawns are fertilized. Where there are many dog owners, pet waste programs, in addition to reducing phosphorus levels in runoff, also have supplemental benefits like public education, public health and safety, neighborhood beautification, and recreation (CWP 2013).

6.2.2 BMP Costs

In comparing the costs of removing phosphorus and suspended solids (TSS) from runoff waters, phosphorus is more expensive than TSS. Reviewing cost studies for structural and non-structural BMPs is particularly difficult due to differences in the data they report. Some break down costs into three categories – capital costs, maintenance costs, and cost-effectiveness, while others report only on one category. Cost estimates for non-structural BMPs generally do not include the cost of program development.

6.2.3 Structural BMPs

The most cost-effective BMPs for removing phosphorus are infiltration and filtration systems including bioretention units, constructed wetlands, and infiltration basins and trenches (Table 1). Capital costs and cost-effectiveness of structural BMPs, however, can be very site specific. Differences in soil type, bedrock, and slope can cause significant cost variations for the same BMP as can local zoning and permitting conditions, land values, and design features. The design life for most structural BMPs is typically 20 years or greater. In general, design costs for structural BMPs, including site location, surveying, design, planning, and permitting, make up 10% to 40% of the construction budget (King and Hagen 2011).

Operation and maintenance costs, including annual routine maintenance and intermittent (every 3-5 years) maintenance costs, are a substantial portion of stormwater management costs for structural BMPs. In one study, annual maintenance costs as a percentage of capital costs ranged from 5% to 23% (UNH 2012).

Variations in capital and maintenance costs are, in part, dependent on whether a BMP was designed using conventional engineering or a low impact development (LID) approach. Conventional stormwater management focuses on reducing the effects of flooding by conveying stormwater runoff to off-site locations. LID is a method of land planning and engineering design that focuses on managing rainfall on site. The goal of LID is to reduce the impacts of development by replicating the hydrologic conditions of the pre-development landscape. Instead of piping stormwater runoff to watercourse as quickly as possible, LID designs employ techniques to reduce runoff speed and volume and improve runoff quality. The result is a developed landscape with less surface runoff and less pollution entering lakes and streams.

While the environmental and water quality benefits of LID-designed BMPs are more commonly known, there are considerable economic, infrastructure, and planning benefits as well. LID-designed BMPs may have higher capital costs, but lower annual maintenance costs compared to conventional BMPs. Amortized maintenance costs for a retention pond, a conventional BMP, can equal total capital construction costs after only 4.5 years, while amortized costs for LID-designed BMPs, like bioretention, gravel wetland, and porous pavement, equal capital costs after 11 years for bioretention and gravel wetlands and 20 years for porous pavement (UNH 2012).

The economic benefits for construction budgets and project life-cycle costs can also be substantial. For example, in 2009, a LID approach to drainage at a 14-acre New Hampshire condominium development resulted in a 6% reduction ($49,000) in site development expenses compared to the conventional design proposal. Rather than use asphalt paving and typical drainage (curbing, catch-basins, stormwater ponds, outlet structures), the LID design incorporated infiltration and filtration BMPs, roof runoff infiltration trenches, and porous pavement on driveways, sidewalks, and a road. Although porous pavement materials are more expensive than traditional materials, reductions in drainage infrastructure, erosion control, and site clearing resulted in reduced overall costs and more open space on the site. Additionally, by the end of the first winter, property owners reported using substantially less salt for winter de-icing resulting in even greater environmental and cost benefits. In 2008, several LID-designed BMPs were incorporated into a 56-acre New Hampshire retail shopping development resulting in a 26% reduction ($930,000) in stormwater management costs compared to a purely conventional design. Two porous parking lots, totaling 4.5 acres, were installed along with a below-ground reservoir and filtration system and a large gravel wetland to which the lots drained. Although porous paving costs were considerably more expensive, there were substantial savings in site clearing and stormwater infrastructure, primarily large piping. Pre- and post-construction monitoring of waters exiting the gravel wetland showed a high level of treatment for runoff from the site and significant protection for the receiving waters of an already impaired nearby stream. Concentrations of phosphorus and suspended solids were reduced by 84% and 60%, respectively (UNH 2012).

Although the cost benefit of using a LID approach in new developments has been demonstrated, the cost effectiveness of removing phosphorus decreases when BMPs are retrofit vs. new. If municipalities have public works staff, however, the cost of simple retrofits can be reduced. In New Hampshire, a bioretention system was installed in a university parking lot median strip and connected to existing drainage infrastructure. Labor and equipment for retrofitting the existing infrastructure were provided by the facilities department, limiting retrofit costs to design and materials only. Total projects costs were $14,000/impervious acre drained. With labor and equipment provided, costs dropped to $5,500/impervious acre (UNH 2012).

6.2.4 Non-Structural BMPs

Six cost-effective non-structural treatments (BMPs) for removing phosphorus include illicit discharge elimination, enhanced street sweeping, downspout disconnection, education to reduce fertilizer use, and pet waste programs. Illicit discharge elimination and enhanced street sweeping, especially, have great potential to play a significant role in urban stormwater management. Illicit discharges, including leaky sewer pipes, illegal connections, and cross-connections between sanitary sewer lines and storm drains, have been identified as a potentially large contributor to nutrient pollution and, although data on performance and cost is currently limited, correcting these discharges may be a very cost-effective way of reducing phosphorus levels (Lily, et.al. 2012). In Baltimore, for example, it was calculated that phosphorus removed by eliminating one of the identified illicit discharges would be equivalent to building 143 bioretention units, each treating a 0.5 acre of impervious area, at a conservative cost of over $1.7 million dollars

(CWP 2010). While finding and fixing illicit discharges can be costly, once fixed, the problems are permanently remedied at the source.

Street sweeping operations, typically done to maintain appearance and keep storm grates open, can be highly cost-effective at removing phosphorus from stormwater if done more than twice a year, the typical schedule for many public works departments. In Minnesota, a comprehensive 2-year study showed that sweeping frequency, season, and tree canopy coverage substantially impacted the amount of phosphorus removed (Baker, et.al. 2014). Sweeping was highly cost effective when done twice monthly in the spring and fall, especially on roads with relatively high canopy cover from deciduous trees. When compared with the cost of building and maintaining structural BMPs, enhanced street sweeping is far less expensive. In communities with nutrient-impaired waters and relatively high tree canopy cover, especially those in watersheds with specified phosphorus limits, enhanced sweeping can be a valuable tool to meet nutrient reduction goals. To aid communities in comparing the cost and effectiveness of various sweeping frequencies on routes with different canopy covers, a free Street Sweeping Planning Calculator Tool and user manual was developed and can be downloaded by clicking on "Quantifying nutrient removal by street sweeping" (Excel spreadsheet) and "User Support Manual: Estimating Nutrient Removal by Enhanced Street Sweeping" at http://bit.do/StreetSweeping (Baker, et. al. 2015).

Where infiltration of stormwater is possible, disconnecting downspouts is an easy and cost effective way for homeowners to reduce phosphorus loadings. By directing roof drainage away from foundations and onto gardens, lawns, and landscaped areas, stormwater is removed from the sewer system and slowly soaks into the ground where it is filtered. When water is infiltrated to the ground in well drained soil nearly all the phosphorus is removed, so the efficiency is governed by the infiltrative capacity. In some cases infiltration in severely compacted soil can be enhanced by using a ripping plow and incorporating organic material to enhance soil structure.

Education and outreach programs that aim to reduce fertilizer application rates on lawns, golf courses, and athletic fields can be a cost effective way to reduce phosphorus levels in runoff. Public Act 12-155 limited phosphorus application levels on established lawns and prohibited fertilizer use within 20 feet of a watercourse and on impervious surfaces. Many homeowners with waterfront lots do not understand the water quality value of maintaining naturally-vegetated, unfertilized buffer strips. Residential sources of phosphorus from established parcels could be reduced through intensive public education/outreach programs aimed at homeowners who maintain their lawns and landscapes and manage their yard waste. For new developments, which are not subject to the enacted controls, fertilizer application rates can be limited by conducting soil tests, reducing lot sizes (cluster development), restricting lawn sizes, and/or incorporating more naturally-vegetated buffer areas (Cape Cod Commission 2015). Golf courses, also not subject to the enacted limits, can reduce phosphorus levels in runoff by maintaining no-mow buffer strips around waterways, avoiding fertilizer use in rough areas and before heavy rainstorms, and adjusting application rates based on soil tests.

Pet waste programs can be a cost-effective approach to reducing phosphorus. Data summarizing pollutant loads contributed by pet waste is inconsistent. Dogs produce upwards of 62.7 million pounds per day in the U.S. (DoodyCalls 2014). Dog waste contains phosphorus and pathogens such as bacteria, viruses, and parasites. If left on the ground, these pathogens and phosphorus can make their way to lakes and streams via stormwater runoff. Nutrients can consume oxygen chemically or indirectly by promoting algae blooms which decompose and consume oxygen, and release toxic substances where cyanobacteria are present.

6.2.5 Municipal Stormwater Treatment and Incentive Programs

Municipalities are seeking to address water quality concerns and meet regulatory compliance as their program costs simultaneously climb. Utilization of Low Impact Development strategies can reduce overall project costs associated with stormwater management. The cost-effectiveness of stormwater BMPs can greatly increase if some of the costs are shifted from local government to private landowners. As municipalities develop stormwater management plans, they might consider how to shift some of the cost burden by, for example, establishing stormwater utilities or outreach and incentive programs to encourage landowners to reduce impervious cover or otherwise reduce runoff volume. Stormwater utilities, that assess user fees based on measurable impervious area, can provide a dependable source of revenue and alleviate the need to compete for general tax revenues. In New England, user fees range from approximately $2-$12 per month. Annual revenue generated from the fees ranges from approximately $400,000 in Reading, MA (2006 dollars) to $2M in Bangor, ME (2012 dollars) and $4.6M in Fall River, MA (2008 dollars) (AMEC 2014).

Since a large portion of paved area is privately owned, land owner involvement is critical to reducing stormwater runoff in a cost-effective manner. Many municipalities now require new development and redevelopment projects above a certain square footage to manage their stormwater runoff on site as a condition of permit approval. To address runoff from existing development, some stormwater utilities are offering incentives to commercial and residential property owners to retrofit their properties with LID-designed BMPs. Incentives include reduced stormwater fees and construction cost subsidies among others. In Montgomery County, MD, for example, the water department offers rebates to residential (up to $2500) and commercial (up to $10,000) property owners that install stormwater BMPs (MCDEP). In Philadelphia, the water department gives a 100% credit for monthly fees to commercial customers who invest in treatments capable of retaining one inch of rainfall on site. The city also gives grant monies to businesses and community organizations to install BMPs that reduce stormwater runoff which, in turn, generates stormwater fee credits and helps lower water bills (Arrandale 2012, NRDC 2012). In 2014, the city launched another grant program that encourages contractors and design/construction firms to develop large scale stormwater retrofit projects with multiple BMPs (City of Philadelphia).

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Table 5.2.1 Removal Efficiency, Capital Costs, Maintenance Costs, Type, and Frequency, and Cost Effectiveness for Urban Stormwater Best Management Practices (BMPs).

BMP Type	BMP Description	% Removal Efficiency		Capital Cost	Cost Effectiveness[a]		Maintenance Cost	Maintenance Type/Frequency
		TP (mg/l)	TSS (mg/l)	$	TP $/lb. removed	TSS $/lb. removed	$/acre/year	
Structural Pretreatment BMPs								
Deep Sump Catch Basin	An underground retention system that removes coarse sediment, trash, and debris from stormwater runoff and serves as a spill containment for floatables like oil and grease.	NT[9]	9[11] 25[9] (if hooded)	ND	ND	ND	ND	• Inspect four times annually and at end of foliage and snow removal seasons. • Remove sediment four times a year or when 50% of sump volume is filled.[9]
Oil/Grit Separator	An underground storage tank with three chambers designed to remove heavy particulates, floating debris, and hydrocarbons from stormwater.	ND	25[9]	ND	ND	ND	ND	• Inspect monthly and after major storms. • Clean biannually with a vacuum truck.[9]
Proprietary Separator	A flow-through structure with a settling or separation unit to remove sediment and other pollutants.	ND	ND	ND	ND	ND	ND	Inspect and remove sediment and other pollutants based on manufacturer recommendations.[9]
Sediment Forebay	A pit, bermed area, or cast structure combined with a weir, designed to slow incoming stormwater runoff and facilitate the settling of suspended solids.	ND	25[9] (if off-line)	ND	ND	ND	ND	• Inspect monthly. • Remove sediment at least four times per year. • Mow and re-seed as needed.[9]
Vegetated Filter Strip (various widths)	A uniformly graded area with low-growing, dense vegetation that treats runoff running through it as sheetflow by slowing runoff velocity, trapping sediment, and promoting infiltration.	ND	10[9] (25') 45[9] (50')	ND	ND	ND	ND	• Inspect for erosion and sediment buildup every 6 months. Remove sediment as needed. • Mow frequently and re-seed as needed.[9]
Structural BMPs								
Baffle Box	A structure containing a series of sediment settling chambers.	20[10]		ND	ND	ND	ND	ND
Bioretention Unit/Rain Garden[b] (rain gardens = residential bioretention units)	A shallow, landscaped depression filled with soil mix, topped with a thick layer of mulch, and planted with dense native vegetation. Stormwater runoff collects in the unit and filters through the soil mix, treating the runoff before it reaches groundwater or is conveyed to a discharge outlet, a municipal storm drain, or another BMP.	NT-85[5,11,13] 59[5] (retrofit)	45-97[5,9,11] 63[5] (retrofit)	$25,600/acre drained[11] (2012 dollars) Cost does not include design, permitting or construction supervision.[11]	$2,935-$5,544/lb.[5] (2011 dollars) $12,501/lb.[5] (retrofit) (2011 dollars)	$5.82-$9.53[5] (2011 dollars) $22.25[5] (retrofit) (2011 dollars)	$1900[11] (2012 dollars)	• Inspect monthly for signs of erosion. • Mow, rake, and remove trash and invasive plants monthly. • Mulch, prune and replace dead vegetation annually. • Water plants during initial establishment and drought. • Be careful with snow – do not plow or store snow in unit.[9]
				$160,000/8 rain gardens[3] (2007 dollars)	$2791-$4329/lb.[3] (2008 dollars)	$0.39-$0.46[3] (2008 dollars)	$5,803-$7544 /8 gardens[3] (2008 dollars)	
Constructed Wetland (a.k.a. shallow marsh, pocket wetland, basin/wetland, extended detention wetland)	A shallow constructed pool that temporarily stores runoff creating conditions suitable for the growth of wetland vegetation. Pollutants are removed from runoff through retention and settling and uptake by vegetation.	40-60[5,9] 40[3] (retrofit)	60-80[5,9] 51[3] (retrofit)	ND	$2,847/lb.[5] (2011 dollars) $6,670/lb.[5] (retrofit) (2011 dollars)	$4.49[5] (2011 dollars) $10.99[5] (retrofit) (2011 dollars)	ND	• Inspect twice a year. • Clean forebay annually. • Remove sediment in basin every 10 years. • Include measures to monitor and prevent invasive species in O&M plan.[9]

Detention Pond and Extended Detention Pond (a.k.a. dry pond, dry detention basin, dry extended detention basin)	A low-lying area designed to temporarily retain stormwater runoff that slowly drains to a downstream water body. Extended ponds are designed to hold stormwater for at least 24 hours to allow solids to settle.	NT-80[9,10,11,13]	NT-79[6,9,11]	$16,500/acre treated[11] (2012 dollars)	$10,572 - 21,143/lb.[5] (2011 dollars)	$7.41 - $44.43[5] (2011 dollars)	$2,380 [11] (2012 dollars)	• Inspect outlet structure twice a year for evidence of clogging. • Mow and remove trash and debris at least twice a year. • Remove sediment at least every 5 years.[9]
Drainage Channel	Vegetated open channels designed for non-erosive conveyance of stormwater rather than treatment. Pollutant removal by sedimentation, filtration, and biological activity is limited.	ND	0[9]	ND	ND	ND	ND	• Inspect twice a year for slope integrity, ponding, vegetation health, sediment accumulation and signs of erosion. • Mow and reseed as needed. • Remove sediment/debris at least once a year.[9]
Gravel Wetland (subsurface)	A series of horizontal flow-through treatment cells preceded by a sediment forebay. Stormwater runoff is treated as it passes through the microbe rich gravel substrate.	58[10]	96[10]	$27,400/acre treated[10] (2012 dollars)	ND	ND	$2140[11] (2012 dollars)	• Remove sediment from forebay/treatment cells. • Remove vegetation at least once every three growing seasons.[11]
Hydrodynamic Separators (HDS) (On-line and Off-line)	Proprietary devices that use features to remove sediment, nutrients etc. from urban runoff.	NT-10[5,11]	10-80[5,11]	$18,000-$20,000/acre runoff treated plus $3,000 upstream flow diversion materials and installation[11]	$32,866/lb.[5] (2011 dollars)	$69[5] (2011 dollars)	ND	• Inspect quarterly to assess sediment accumulation. • Remove sediment with a vacuum truck.[11]
Impervious Urban Surface Reduction	A change in land use from impervious to urban pervious.	N/A	N/A	ND	$7,354/lb.[5] (2011 dollars)	$11.96[5] (2011 dollars)	N/A	None.
Infiltration Practices (basins and trenches)	A depression where stormwater runoff is trapped and gradually drains through the bottom and/or sides into the subsoil and eventually into the groundwater.	60-85[5,9,13]	80-95[5,9]	ND	$3252-$3399/lb.[5] (2011 dollars)	$5.53-$5.78[5] (2011 dollars)	ND	• Inspect after major storms for first 3 months then twice a year and when discharges through outlet are high. • Inspect/clean pretreatment devices every other month and after major storms. • Mow grass bottoms, rake stone bottoms, and remove trash, debris, and grass clippings twice a year. [9]
Leaching Catch Basin	A pre-cast concrete barrel and riser with an open bottom that permits runoff to infiltrate into the ground.	ND	80[9] (if with pre-treatment)	ND	ND	ND	ND	• Inspect annually and remove debris. • Remove sediment when basin is 50% filled. • Rehabilitate basin if clogging causes failure.[9]
Media Filtration	Two-chambered underground concrete vaults that reduce pollutants in stormwater runoff by settling out large particles in the first chamber and filtering flow through special media in the second chamber. The type of media used depends on the pollutant targeted.	40-42[6,13]	83[6]	ND	ND	ND	ND	• Inspect filtering media for clogging. • Inspect for standing water and sediment at least twice a year. • Remove trash and debris during inspections. • Annually inspect after large storms to determine if system drains in 72 hours.[9]
Permeable Pavement: Grass Pavers (a.k.a. turf blocks)	Concrete or synthetic paving units with open cells which are filled with soil and planted with turf.	ND	ND	ND	ND	ND	ND	• Inspect annually for signs of deterioration. • Periodically reseed to fill in bare spots. • In winter, do not sand and minimize salt use. • Attach rollers to bottom of snowplows to prevent from catching on pavers.[9]

Permeable Pavement: Permeable Interlocking Concrete Pavement (PICP)	Pervious pavement system comprised of interlocking precast paving units (also called paving stones). Stormwater drains through the joints between the pavers and into a stone sub-base that supports the pavers and stores and treats runoff.	99[11]	99[11]	$4/sf[11] (2010 dollars) Cost is for mechanical installation and increases with hand installation.[11]	ND	ND	ND	• Remove surface debris by air vacuuming or use leaf blower at least twice annually. • Add joint material to replace material that has been transported. • In winter, do not sand and minimize salt use. • Attach rollers to bottom of snowplows to prevent from catching on pavers.[8,11]
Permeable Pavement: Pervious Concrete	Concrete pavement with a higher than normal percentage of pore spaces that allow stormwater to pass through and infiltrate into the ground.	NT[11]	85[11]	$4-$5/sf[11] (2012 dollars) Cost does not include site work and sub-base construction.[11]	ND	ND	ND	• Inspect annually for signs of deterioration. • Use power washer to dislodge trapped particles then vacuum sweep at least twice a year. • Regularly monitor for proper drainage. • In winter, do not sand and minimize salt use.[9,11]
Permeable Pavement: Porous Asphalt	Asphalt pavement with a higher than normal percentage of pore spaces that allow stormwater to pass through and infiltrate into the ground.	20-80[5,11]	70-99[5,6,11]	$26,600[11] (2012 dollars) $2.80-$3.17/sf[11] (2008 dollars) Costs do not include site work and sub-base construction.[11]	$12,563 - (2011 $70,342/lb.[5] dollars)	$22.47-$48.61[5] (2011 dollars)	$1080[11] (2012 dollars)	• Inspect annually for signs of deterioration. • Use power washer to dislodge trapped particles then vacuum sweep 2-4 times annually. • Regularly monitor for proper drainage after storms. • In winter, do not sand and minimize salt use.[9,10]
Retention Pond (a.k.a. wet pond, stormwater pond)	A constructed basin with a permanent pool of water that treats stormwater runoff by allowing sediment and other pollutants to settle.	NT-70[6,9,11]	68-80[6,9,11]	$16,500[11] (2012 dollars)	ND	ND	$3060[11] (2012 dollars)	• Mow and remove trash, debris, and sediment from forebay biannually. • Remove sediment from basin as needed. [9]
Sand & Organic Filter (a.k.a. filtration basin)	A bed of sand or peat (or combination of the two) underlain with perforated underdrains or designed with cells that have inlets/outlets. Stormwater runoff is filtered through the bed before being discharged or conveyed to another BMP.	10-60[5,9,11]	51-80[5,9,11]	$15,200/acre treated[11] (2012 dollars)	$4,542-$4,490/lb.[5] (sand filter) (2011 dollars)	$6.47-$7.04[5] (sand filter) (2011 dollars)	$2810[11] (2012 dollars)	Inspect filters and remove debris after major storms for first few months then every six months. [9]
Subsurface Structure (*e.g.*, infiltration pit, chamber, perforated pipe, galley)	An underground system that captures stormwater runoff and gradually infiltrates it into the groundwater through rock and gravel.	ND	80[9]	ND	ND	ND	ND	• Inspect inlets at least twice annually and remove debris. • Include mosquito controls in O&M plans.[9]
Swale (Stone-lined)	A drainage channel with an erosion-resistant rock lining designed to carry stormwater runoff to an outlet.	NT[11]	50[11]	ND	ND	ND	ND	ND
Swale (Vegetated) (a.k.a. wet swale, dry swale)	A broad, shallow, densely vegetated channel designed to capture and slow stormwater runoff by spreading it horizontally across the landscape, facilitating runoff infiltration into the soil.	NT-90[5,9,11]	50-70[5,9,11]	$14,600/acre treated[11] (2012 dollars)	ND	ND	$820[11] (2012 dollars)	• Inspect for signs of erosion. Repair/replant eroded areas. • Remove sediment and debris annually. • Re-seed swales as needed. • Mow dry swales as needed. [9]
Tree Box Filter	A mini-bioretention unit installed beneath a tree behind a curb. Units can be open-bottomed, where infiltration is desirable, or close-bottomed where infiltration is impossible or undesirable.	NT->50[11]	>80-91[11]	$4,000-$6,000/unit/0.1 acre treated (closed system)[7,11] (2015 dollars)	ND	ND	$100-$500/unit[7,8] (2015 dollars)	• Inspect 1-4 times annually to assure bypass and soils are adequately conveying water. • Remove leaves and trash regularly. • Rake media surface biannually to maintain permeability.

				$8,000-$11,000/unit/0.25-0.75 acre treated (open system)[7] (2015 dollars) Installation: $1500 and up depending on number of units[7,8] (2015 dollars)				• Replenish mulch as needed. • Water plants during initial establishment and extreme drought.[8,9,11]
Urban Stream Restoration	Projects that reduce flooding and erosion and restore, enhance, or protect the natural ecological values of streams.	0.068 lb./ft.[5]	52.5 lb./ft.[5]	ND	$769/lb.[5] (2011 dollars)	$1/lb.[5] (2011 dollars)	ND	ND
Non-Structural BMPs								
Downspout Disconnection	Redirection of downspout from impervious area or storm drain to lawn or other pervious area.	ND	ND	ND	$30/lb.[4] (2014 dollars)	<$1/lb.[4] (2014 dollars)	$0	None.
Fertilizer Use Education/Reduction Program	Program to reduce fertilizer application rates on lawns, golf courses, and athletic fields. Residential application rates are reduced through intensive public education/outreach.	3-10[2]	NT	ND	$311/lb.[2] (2015 dollars)	N/A	$0	None.
Forest Buffer[s]	Area of trees at least 35 ft. wide on either side of a stream, accompanied by other vegetation.	50[5]	50[5]	ND	$1,851/lb.[5] (2011 dollars)	$7.66[5] (2011 dollars)	ND	ND
Illicit Discharge Elimination	Program to correct cross-connections and repair leaky sewers.	100[5]	100[5]	ND	$35-$71/lb.[5] (2011 dollars)	$0.89 - (2011 - | $6.69[5] dollar s)	$0	None.
Organic Waste/Leaf Litter Collection	Municipal program to pick-up leaves and other landscape debris on a weekly basis.	5[12]	ND	ND	ND	ND	ND	ND
Pet Waste Program	Municipal program to reduce pet waste via installation of pet waste stations.	ND	NT	ND	$938/lb./pet waste station[4] (2014 dollars)[d]	N/A	ND	• Refill bags. • Empty trash baskets. • Replace damaged baskets.[4,5]
Phosphorus Ban in Fertilizers	Manufacturer requirement to remove phosphorus from lawn fertilizer.	10-33[12]	NT	ND	ND	N/A	$0	None.
Street Sweeping (enhanced) (enhanced sweeping = sweeping more than twice annually)	Pickup of street litter and dirt using a street sweeper more than twice annually.	1-15[5,10,12]	9[5]	ND	<$100/lb. - (spring/fall, high canopy) (2012 | $600/lb.[1] (summer, low canopy) dollars)[e]	$10-$11.58[5] (2011 dollars)[f]	ND	Maintain sweeper as needed.
Urban Tree Planting	Planting trees on urban pervious areas to produce a forest-like condition over time.	ND	ND	ND	$9,621/lb.[5] (2011 dollars)	$46.23/lb.[5] (2011 dollars)	ND	ND

NT = no treatment, ND = no data or insufficient data available, N/A = not applicable

Pretreatment BMPs are used to treat runoff before it reaches another BMP. Proprietary BMPs are listed by category only, not by proprietor. TP = total phosphorus, TSS = total suspended solids.

[a]Cost-effectiveness values for BMPs were generally grouped into cost-effectiveness categories - green (High), yellow (Moderate), red (Low) - for each pollutant. Cut-off values between categories are based on similar cut-offs from the Center for Watershed Protection.
[b]P-removal efficiency is enhanced by adding certain amendments to bioretention soil mixes. Research into bioretention design and soil media amendments is ongoing.
[c]Assumes land use change from urban pervious.
[d]Cost is for Year 1 and includes installation and maintenance of a single pet waste station in an area with lots of dogs (*e.g.*, dog parks, public parks, walking trails). Pet waste stations include sign, trash basket, and bags. Cost assumes a usage rate of 10 bags per station per day. Post Year 1 cost is lower and includes maintenance only.
[e]Based on 392 sweepings from snowmelt to snowfall on streets with 0-20% canopy cover of north-temperate deciduous trees. Assumes use of a regenerative air sweeper.
[f]Cost-effectiveness values dependent on method of calculation (mass loading vs. street lane).

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6.4 Appendix 4 DEEP's Primary NPS Partner Organizations

6.4.1 USDA Natural Resources Conservation Service (NRCS)

Agricultural NPS pollution in Connecticut is addressed primarily through outreach, funding and technical assistance provided by federal and state agencies including the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), USDA Farm Service Agency. NRCS offers technical and financial support to farm businesses in their farm waste efforts through the "Partnership for Assistance on Agricultural Waste Management Systems." Through this partnership, a farm business may obtain waste management planning, facility design, and qualify for financial assistance, as well as help in procuring required permits. Technical assistance is also available in selecting and implementing agricultural BMPs and soil erosion control methods and technologies.

A number of financial and technical assistance programs are implemented by the NRCS through the federal Farm Bill. The Environmental Quality Incentives Program (EQIP) in particular provides financial and technical assistance to agricultural producers to address natural resource concerns and deliver environmental benefits such as improved water quality. Eligible program participants receive financial and technical assistance to implement conservation practices that address natural resource concerns on their land. NRCS delivers conservation technical assistance through its Conservation Technical Assistance Program.

NRCS and DEEP cooperatively offer a variety of technical resources and assistance implementing agricultural BMPs including:

- Livestock exclusion fencing
- Manure collection and storage
- Comprehensive Nutrient Management Plans (CNMPs)
- Cover crops
- Vegetated buffers, filter strips
- Covered heavy use areas
- Diverting clean water
- Soil health

The National Water Quality Initiative Program (NWQI) further helps target water quality impaired watersheds with enhanced NRCS funding and assistance.

6.4.2 US Environmental Protection Agency (EPA)

US EPA provides Clean Water funding under Section 319 NPS funds help support DEEP's Nonpoint Source Program. NPDES Stormwater General Permit authority is delegated to DEEP by EPA. EPA also provides a number of research and technical assistance efforts for NPS and stormwater.

6.4.3 NEW England Interstate Water Pollution Control Authority (NEIWPCC)

NEIWPCC supports state water programs by coordinating activities and forums that encourage cooperation among the states and interstate issues, developing resources that foster progress on water and wastewater issues, representing the region in matters of federal policy, training environmental professionals, initiating and overseeing scientific research projects, educating the public, and providing overall leadership in interstate water management and protection.

6.4.4 Connecticut Department of Public Health

DEEP delegates the authority to regulate onsite wastewater systems which handle less than 5000 gallons per day to the CT Department of Public Health (DPH) who in turn delegate some of that authority to local Health Departments. DPH also administers a program to manage public drinking water supply systems, drinking water supply planning and source water protection.

6.4.5 Connecticut's Soil and Water Conservation Districts

Provide technical advice to a wide range of stakeholders including municipalities and their land use boards. Many of the Conservation District's activities involve helping assure compliance with Storm Water Manual and Erosion and Sedimentation Manual, promoting Low Impact Development and Green Infrastructure on a local level, and planning activities to assure that the important functions of soils and water conservation can be implemented consistently and efficiently statewide.

6.4.6 University of Connecticut (UConn) Cooperative Extension Service: Clear and NEMO Programs, Extension

Centers; Engineering, etc.

CLEAR and NEMO programs. DEEP has had a long relationship with UConn providing Nonpoint Source Education and outreach to Municipal Officials. The Clear program has provided extensive technical expertise and outreach to implement green infrastructure and low impact development practices, as well as analysis of Municipal land use regulations to better enable adoption of these practices. DEEP continues to work with Clear on municipal outreach for NPS and stormwater management.

6.4.7 Connecticut Agricultural Experiment Station (CAES)

CAES provides valuable technical and research science for many agricultural and water-related disciplines. Staff have long been key technical advisors in several important areas of the phosphorus pollution problem, particularly inputs to Connecticut lakes and their role in triggering harmful algal and cyanobacteria blooms, as well as devising strategies to minimize and address other impacts resulting from excess nutrients in runoff.

6.4.8 Municipalities

Connecticut's 169 municipalities are the primary partner for land use and water quality management activities statewide. They regulate land use through planning, zoning and inland wetlands and watercourses authorities. They also are responsible for implementing MS4 stormwater program.

6.4.9 Connecticut Department of Agriculture

CT Dept. of Agriculture has regulatory authority over fertilizer sales in the State and farmer assistance programs. Their Aquaculture Division also is involved with sanitary surveys and related pollution problems affecting of shellfish areas coastal waters.

6.4.10 Other Important Partners

Regional Councils of Government
Water Utilities
Rivers Alliance of Connecticut
Trout Unlimited
The Nature Conservancy
Local and Statewide Watershed and Lakes Stakeholder organizations
Others, too numerous to mention including: citizens, civic organizations, news media, business and industry, youth groups, schools and universities.

Appendix E: Science Methods Workgroup Report dated 8/2/2016 and CASE Report dated 12/12/2014

Draft Report of Subcommittee #2, for inclusion in the PA12-155 Report to the Legislature

1. <u>Background</u> – The Clean Water Act regulates and contains requirements that must be met for discharges that contain phosphorus. In October 2010, U.S. EPA approved the methods proposed by the Connecticut Department of Energy and Environmental Protection ("DEEP") to establish water quality based phosphorus limits in non-tidal freshwaters for industrial and municipal water pollution control facilities (WPCF) National Pollutant Discharge Elimination System (NPDES) permits. DEEP has proposed these approaches as an interim strategy until numeric nutrient criteria are established in Connecticut's Water Quality Standards (WQS). This Interim Strategy was the topic of numerous discussions between DEEP, stakeholders, and U.S. EPA.

In 2012, the Connecticut General Assembly passed Public Act 12-155 which requires the Commissioner of DEEP, 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 state-wide strategy to reduce phosphorus, to collaboratively evaluate and make recommendations regarding a state-wide strategy to reduce phosphorus loading in inland non-tidal waters in order to comply with standards established by the United States Environmental Protection Agency. The evaluation and recommendations are to include (1) a state-wide 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.

To implement PA 12-155, DEEP and the participating municipalities[1] established a Coordinating Committee and three Workgroups. Each workgroup was charged with evaluating one of the three elements identified in PA 12-155 and report its findings to the Coordinating Committee.

This is the report of the workgroup tasked with evaluating and making recommendations regarding 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 Science Methods Workgroup" or "the Workgroup").

2. <u>Workgroup Composition</u> - The Science Methods Workgroup consisted of a diverse group of members from state, federal and municipal government, non-governmental organizations, and private consultants (Table A, attached). The Workgroup was co-chaired by Roger Dann from the Town of Wallingford Water and Sewer Division and Mary Becker from the Monitoring and Assessment Program of DEEP's Bureau of Water Protection and Land Reuse.[2] Ten workgroup meetings were held over the course of a two year time period (Table A, attached). Minutes from

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[1] Of the municipalities listed in PA 12-155, Meriden, Danbury, Southington and Wallingford participated. Cheshire and Waterbury did not.

[2] For a time, Chris Bellucci, from the Monitoring and Assessment Program of DEEP's Bureau of Water Protection and Land Reuse served as a co-chair for Mary Becker. Also, during the course of its work, George Adair from the Town of Wallingford, assisted by Fred Andes, an attorney with Barnes and Thornburg, LLP, replaced Roger Dann as co-chair of the Workgroup.

the workgroup meeting can be found on the DEEP website at
http://www.ct.gov/deep/phosphorus.

3. Methodology - The Science Methods Workgroup's charge was to evaluate 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. Of primary concern was the method to measure phosphorus that DEEP had used and relied upon in developing the Interim Strategy. A variety of viewpoints were expressed by group members.

The Workgroup engaged the Connecticut Academy of Science and Engineering ("CASE"), a non-profit institution patterned after the National Academy of Sciences, to provide unbiased expert guidance on scientific issues of concern. The CASE Study Committee consisted of 17 members and staff (Table B, attached). The study was led by Dr. Peter Raymond from the Yale School of Forestry and Environmental Studies at Yale University who served as study manger and Richard Strauss, the Executive Director of CASE.

The Science Methods Workgroup held a number of meetings aimed at framing the tasks for CASE's consideration and came to a consensus on the following four tasks:

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?

4. The CASE Report

The CASE Study Committee conducted a comprehensive literature review, interviews and held eight meetings. At each meeting an expert made a presentation to the subcommittee. Details and presentations from those meetings can be found on the CASE website at http://www.ctcase.org/reports/phosphorus/EXTERNAL%20APPENDIX%20COMMITTEE%20MEETINGS%2002%2020%2015.pdf . The Science Methods Workgroup members were invited to attend and participate in the CASE Study Committee meetings and were provided with an opportunity to comment on drafts of the CASE reports as it was being developed. The Science Methods Workgroup members provided extensive comments throughout the entire study timeframe.

CASE issued its Report, entitled "Methods to Measure Phosphorus and Make Future Projections" in December 2014 ("the Case Report"). The Report reviews all of the tasks noted above and includes nine recommendations. The full CASE report can be found in Appendix A or on the CASE website at http://www.ctcase.org/reports/phosphorus/phosphorus.pdf.

The CASE Report begins with a recognition that "[h]uman induced additions of phosphorus to inland waters is one the leading causes of stream impairment in the United States and globally." CASE Report, p. 6. CASE recognizes that "[p]hosphorus 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." CASE Report, p. 6, citing Dodds and Welch, 2000 and Smith, 2003. CASE's Report notes that alterations to the environment from phosphorus can "threaten endangered species and impact the food production and breeding habits for a wide range of animal and plant species." CASE Report, p.6, citing Carpenter et al, 1998 and Mainstone and Parr, 2002.

With respect to measuring phosphorus levels to establish standards, the CASE Report finds that

"[t]he 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 numeric phosphorus standard inappropriate."

CASE Report, Executive Summary p. x. Accordingly, the CASE Report committee members rule out establishing a single numeric phosphorus standard applicable statewide. The Report then reviews and discusses the four approaches commonly used by the regulatory community and recommended by EPA to develop numeric criteria: reference, mechanistic models, stressor-response models and scientific literature. After reviewing the pros and cons of each method, the CASE Report recommends use of the stressor-response approach. CASE Report, p 33. The model that DEEP used in developing the Interim Strategy is a stressor-response model.

After reviewing the approach used by DEEP, the CASE Report concludes that DEEP's "Interim Strategy was a reasonable and justified approach for setting numeric criteria" that "aligns with the guidance provided by the EPA". Id., p. xiii. The CASE Report notes that:

> 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 diatoms species and phosphorus concentrations. DEEP should continue to utilize this approach and the Interim Phosphorus Reduction Strategy for Connecticut Freshwater Non-Tidal Waste-Receiving Rivers and Streams (Interim Strategy)…derived therefrom while continuing to collect data to implement this report's recommendations.

CASE Report, Executive Summary, p. x.

In making this recommendation the CASE Report pointed out that "[a] critical component of the stressor response model is the selection of proper response parameters to measure the impact of phosphorus pollution." CASE Report, p. 33. CASE recommended use of two response parameters, dissolved oxygen and diatom species, in developing numeric criteria, or future response parameter standards, for phosphorus. (CASE Report, p. 34). Since DEEP has been sampling the diatom community, CASE recommended that the State continue those efforts and that it add diurnal dissolved oxygen to its sampling regime. CASE Report, p. 36. The goal of the State, CASE recommends, "should be to move from the Interim Strategy to a decision framework that includes phosphorus concentrations and these response parameters." CASE Report, Executive Summary, p. xi.

The CASE Report also recognizes that the approach for setting numeric criteria for phosphorus is "a rapidly evolving area of scientific inquiry," that "statistical methods used to derive numeric criteria will continue to improve with time and new data" and that "the response parameters used to set criteria will also change with scientific and methodological advancements." CASE Report, Executive Summary, p. xiii. Also, "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." As such, CASE recommends that DEEP re-evaluate its approach to establishing numeric criteria for phosphorus every three 3-5 years.

The CASE Report also recommends the following for the state's consideration:

1. Continue sampling diatom community assemblage, but add diurnal dissolved oxygen.

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

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.

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.

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.

7. Consider collaborating with neighboring states that use diatoms and dissolved oxygen.

8. For impaired watersheds, continue and accelerate the process of creating stream management plans similar to those in the Connecticut Integrated Water Quality Report, incorporating these plans into a GIS, and perform response parameter measurements more frequently.

9. Begin to collect data on phosphorus import into watersheds and consider collecting additional economic/recreational use data.

The Report states that those 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.

- 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.

- 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, collect a greater percentage of the measurements 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.
- The state should consider mechanisms to facilitate the data collection necessary for recommendation #9.

Other than highlighting the importance of adding diurnal dissolved oxygen to the state's sampling regimen, the CASE Report does not prioritize these recommendations.

5. The Science Methods Workgroup Recommendations to the Coordinating Committee

The Science Methods Workgroup endorses the CASE Report. The CASE Report identifies: 1) phosphorus pollution as a problem, 2) the current water quality standards relative to phosphorus; 3) the methods to measure the impacts of phosphorus in non-tidal waters; and 4) the methodologies appropriate for use in Connecticut to measure phosphorus impacts on water quality and aquatic life and other designated uses.

The Workgroup also endorses the nine recommendations made in the CASE Report although the Workgroup recognizes that additional fiscal and staffing resources may be needed to implement certain recommendations. No other recommendations were offered by any Workgroup members and other than recognizing the importance of adding diurnal dissolved oxygen to its sampling efforts, the Workgroup did not prioritize implementation of these recommendations. Finally, the Workgroup also recommends that DEEP develop a conceptual implementation plan and that it periodically post on its website a detailed progress report on the efforts being undertaken to implement CASE's recommendations.

TABLE A: SCIENCE METHODS WORKGROUP MEMBERS AND MEETINGS

Name	Organization	9/30/13	10/31/13	11/21/13	12/19/13	3/6/14	5/22/14	9/11/14	11/6/14	7/27/15	9/18/15
Adair, George	Town of Wallingford									X	X
Andes, Fredric	Barnes & Thornburg	X	X	X (phone)	X	X	X	X	X	X	X
Applefield, Dean	CT DEEP	X	X	X	X	X	X			X	X
Becker, Mary (Co -Chair)	CT DEEP	X	X	X	X			X	X	X	X
Bellucci, Christopher	CT DEEP		X	X	X	X	X	X	X		X
Bollard, Greg	Friends of the Lake / Rivers Alliance			X							
Brumback, Garry	Town of Southington	X		X							
da Silva, Allegra	CDM Smith		X	X	X			X (phone)			
Dann, Roger (Co-Chair)	Town of Wallingford	X	X	X	X	X	X	X	X		
Fisk, Andy	CT River Watershed Council		X	X		X			X	X	X
Francucci, Mario	Black & Veatch	X	X	X						X	
Gara, Betsy	CT Lobbying Group, LLC		X	X		X					
Hust, Rob	CT DEEP						X	X	X		
Iott, Traci	CT DEEP	X		X	X	X	X	X	X		
Jastremski, Mike	Housatonic Valley Association			X							
Morrison, Jon	U.S. Geological Survey					X	X				
Miner, Margaret	Rivers Alliance	X	X		X			X	X		X

TABLE A: SCIENCE METHODS WORKGROUP MEMBERS AND MEETINGS

Name	Organization	9/30/13	10/31/13	11/21/13	12/19/13	3/6/14	5/22/14	9/11/14	11/6/14	7/27/15	9/18/15
Mueller, Fred	Tighe & Bond	X	X		X	X					
Mullaney, John	U.S. Geological Survey			X		X			X	X	X
Raymond, Peter	Yale University				X						
Reynolds, Roger	CT Fund for the Environment, Save the Sound		X	X		X (phone)		X (phone)	X (phone)	X	
Stover, Toby	US EPA Region 1		X	X	X	X	X	X	X		
Strauss, Richard	CT Academy of Science and Engineering				X						
Sullivan, Chris	CT DEEP		X	X		X					
Taylor, Bob	Loureiro Engineering Associates, Inc.	X	X	X	X	X	X	X	X	X	X
Wingfield, Betsey	CT DEEP	X			X	X			X		
Weitzler, Ellen	US EPA Region 1				X				X		

Table A. Methods to Measure Phosphorus and Make Future Projections Workgroup attendees and dates of meetings. 'X' indicated presence at the meeting.

TABLE B: CASE STUDY GROUP MEMBERS

Name	Title and Organization
Ann G. Bertini	Assistant Director for Programs, Connecticut Academy of Science and Engineering
Robert Buchkowski, Research Team	Research Associate, Yale School of Forestry & Environmental Studies, Yale University
Terri Clark	Associate Director, Connecticut Academy of Science and Engineering
Kelly Coplin, Research Team	Research Associate, Yale School of Forestry & Environmental Studies, Yale University
Ashley Helton, PhD	Assistant Professor, Department of Natural Resources and the Environment, Center for Environmental Sciences and Engineering UConn
Gale Hoffnagle, CCM, QEP Senior Vice President and Technical Director TRC Environmental Corporation	*(CASE Academy Member)* Senior Vice President and Technical Director TRC Environmental Corporation
Kimberlee Kane, PhD	Research Scientist, Watershed Protection Programs, Bureau of Water Supply NYC Department of Environmental Protection
David A. Keiser, PhD	Assistant Professor, Department of Economics Iowa State University
Jennifer L. Klug, PhD	Associate Professor of Biology, Fairfield University
Ralph Lewis	*(CASE Academy Member), Chairperson* Professor in Residence, Marine Sciences Long Island Sound Center, UConn-Avery Point; State Geologist, Connecticut Department of Environmental Protection (ret.)
Karl M. Prewo, DrEngSc	*(CASE Academy Member)* President, Innovatech
Wendy Jastremski Smith	Formerly Environmental Protection Specialist EPA
Peter A. Raymond, PhD Research Team Study Manager	Professor of Ecosystem Ecology, Yale School of Forestry & Environmental Studies, Yale University
Jane Stahl	Consultant, Deputy Commissioner, Connecticut Department of Environmental Protection (ret.)
Richard H. Strauss	Executive Director,Connecticut Academy of Science and Engineering
Craig Tobias, PhD	Associate Professor of Marine Sciences, UConn
Lisa Weber, Research Team	Research Associate, Yale School of Forestry & Environmental Studies, Yale University

APPENDIX A

The Connecticut Academy of Science and Engineering Report

Methods to Measure Phosphorus and Make Future Projections

Methods to Measure Phosphorus and Make Future Projections

December 2014

<u>A Report By</u>

The Connecticut Academy of Science and Engineering

<u>For</u>

The Connecticut Department of Energy and Environmental Protection

Methods to Measure Phosphorus and Make Future Projections

A Report By

The Connecticut Academy of Science and Engineering

Origin of Inquiry:	The Connecticut Department of Energy and Environmental Protection
Date Inquiry Established:	November 12, 2013
Date Response Released:	December 17, 2014

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.

Richard H. Strauss
Executive Director

MEMBERS OF THE STUDY COMMITTEE ON METHODS TO MEASURE PHOSPHORUS AND MAKE FUTURE PROJECTIONS

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UConn

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Senior Vice President and Technical Director
TRC Environmental Corporation

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State Geologist, Connecticut Department of Environmental Protection (ret.)

Karl M. Prewo, DrEngSc *(Academy Member)*
President, Innovatech

Wendy Jastremski Smith
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EPA

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Consultant
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Craig Tobias, PhD
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ACADEMY PROJECT STAFF

Richard H. Strauss, Executive Director
Terri Clark, Associate Director
Ann G. Bertini, Assistant Director for Programs

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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.

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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.

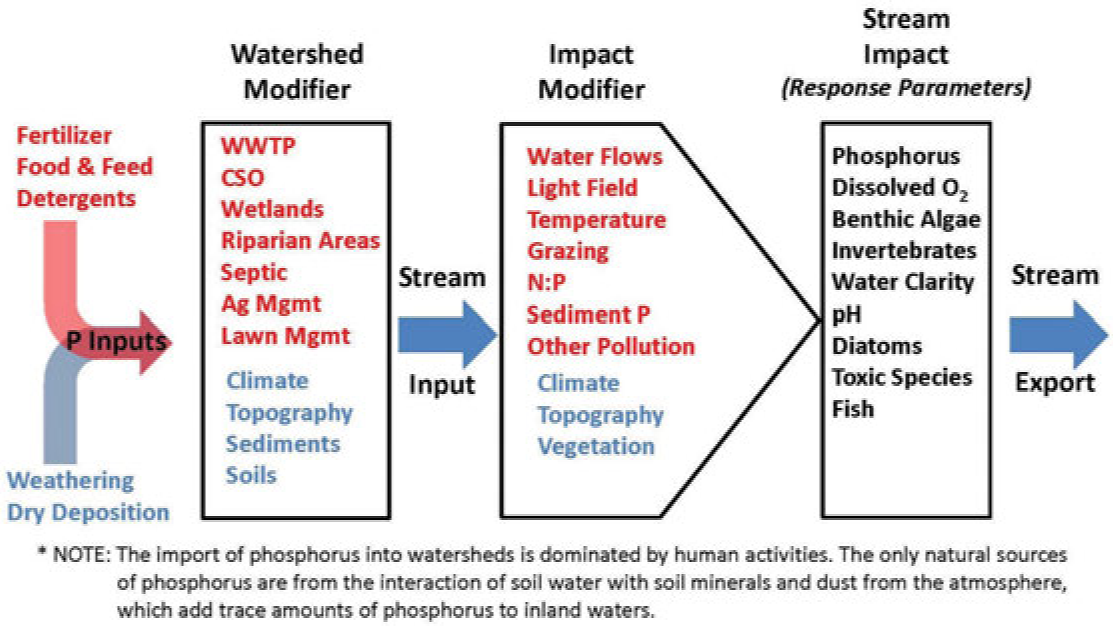

FIGURE 2-2: CONCEPTUAL MODEL DEPICTING THE RELATIONSHIP BETWEEN SOURCES OF PHOSPHORUS AND EFFECTS ON AQUATIC LIFE AND OTHER DESIGNATED USES IN CONNECTICUT

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.

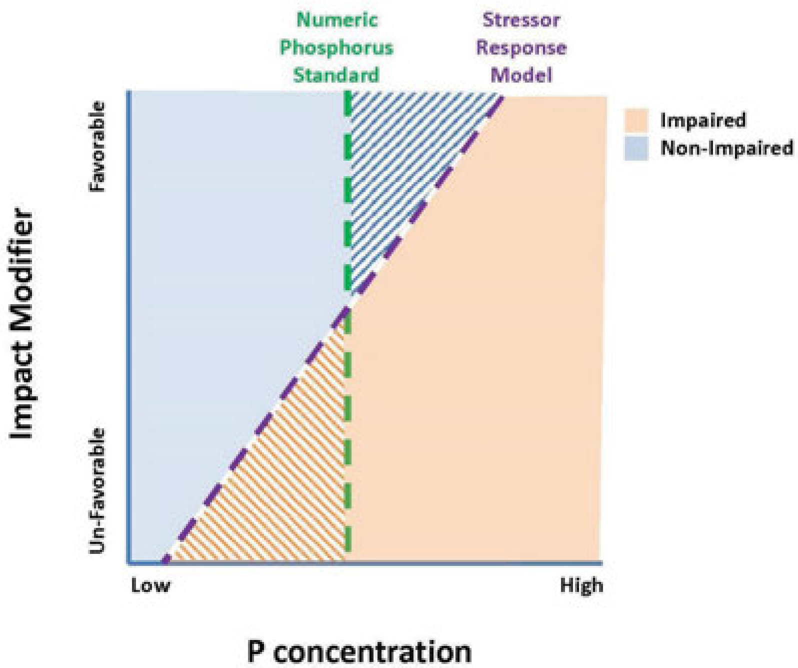

FIGURE 2-3: A CONCEPTUAL DIAGRAM ILLUSTRATING THE RELATIONSHIP BETWEEN IMPACT MODIFIERS (Y-AXIS) AND NUMERIC STANDARD (DASHED GREEN LINE) AND A STANDARD DEVELOPED USING A STRESSOR RESPONSE MODEL (PURPLE DASHED LINE). A PROBLEM WITH USING A SINGLE NUMERIC STANDARD ARISES IN SOME SYSTEMS WITH UNFAVORABLE 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 critera. 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	Biological community with ecological attributes consistent with Biological Condition Gradient Tiers 1-4 as adopted in Connecticut Water QualityStandards Section 22a-426-5 of the Regulations of Connecticut State Agencies. Benthic community: benthic MMI, value >48 (Gerritsen and Jessup, 2007) and meets narrative criteria in CT WQS*. Screening Approach data with 6 or more "Screening Taxa" RBV data submitted to DEEP listed 4 or more pollution sensitive "Most Wanted" invertebrates (see http://www.ct.gov/deep/rbv) Fish community: species composition, trophic structure, and age class distribution as expected for an unimpaired stream of similar watershed size. Conventional physical/chemical criteria are not exceeded. Measured toxicants do not exceed chronic toxicity criteria. No record of episodic events (e.g., chemical spills, fish kills) Biological communities show no evidence of impact from anthropogenic manipulations to stream flow. No evidence of chronic toxicity in ambient waters.
Not Supporting	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 Benthic community: benthic MMI < 43 (Gerritsen and Jessup, 2007), and does not meet narrative criteria in CT WQS*. Screening Approach data with 2 or less "Screening Taxa" 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. Physical/chemical or toxicant criteria exceeded in ≥ 10% of samples. Biological communities show evidence of impact from anthropogenic manipulations to stream flow. Stream completely enclosed in conduit or cleared concrete trough. Documented episodic event (*e.g.*, chemical spill, fish kill) from anthropogenic cause.
Insufficient Information	Some community data exist, but sampling was very limited and/or the results are ambiguous or conflicting, requiring follow-up monitoring.
* 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.	

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

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

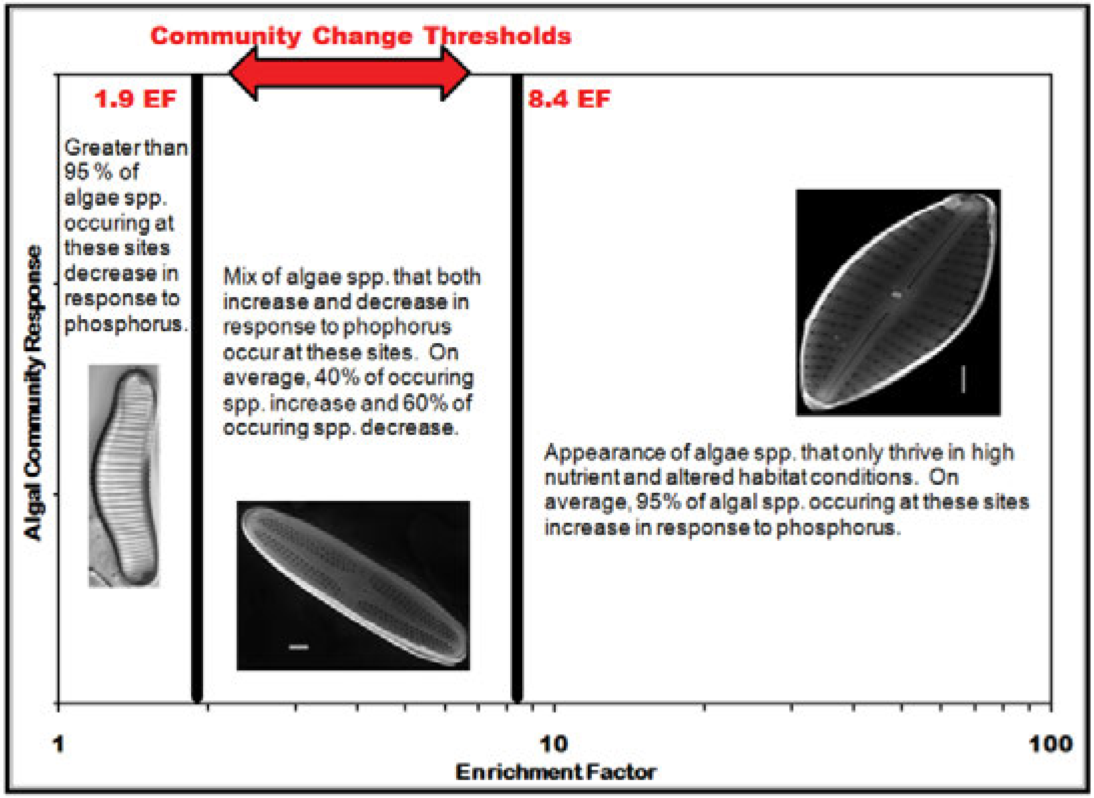

Figure 3. Upper and lower algal community thresholds in response to EF indicated in TITAN analysis

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

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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.

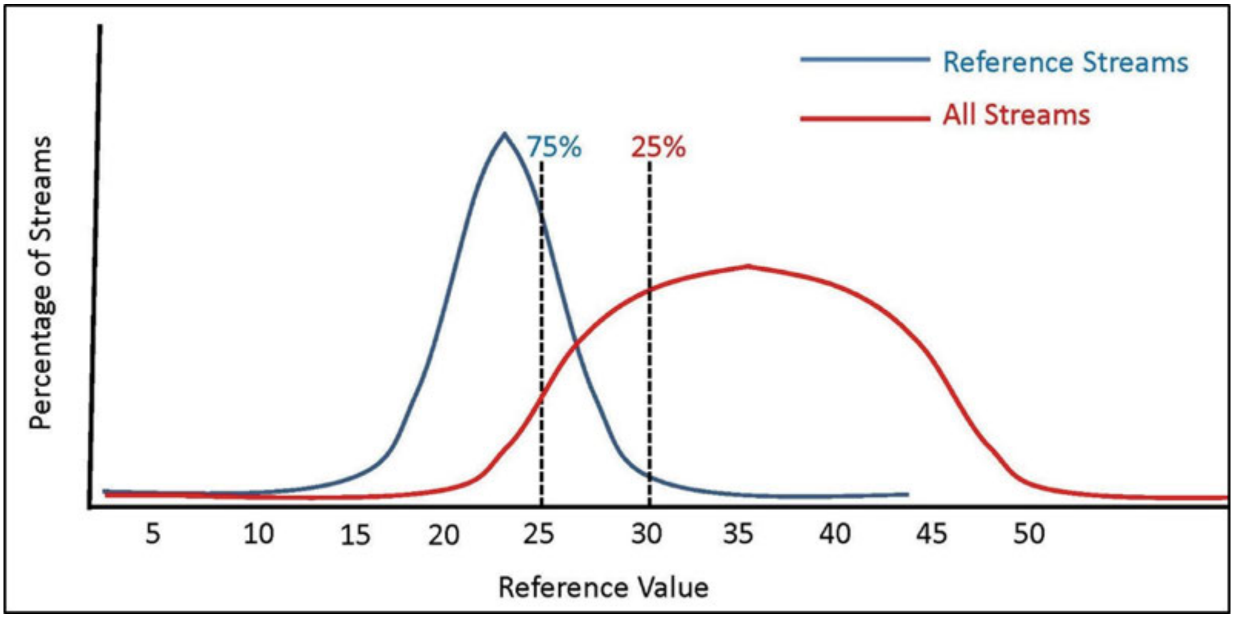

FIGURE 4-1: AN EXAMPLE AFTER (EPA 2000) FOR SELECTING REFERENCE VALUES FOR TOTAL PHOSPHORUS (TP) FROM STREAM PHOSPHORUS MEASUREMENTS. THE X-AXIS IS TP IN UG L^{-1}, WHILE THE Y-AXIS IS PERCENTAGE OF STREAMS IN THE SURVEY. IN THE FIRST FREQUENCY APPROACH, EPA SUGGESTS USING THE 75^{TH} PERCENTILE OF REFERENCE STREAMS. A SECOND FREQUENCY DISTRIBUTION USES A PERCENTILE (E.G., 25^{TH}) 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 (VanNieuwenhuyse 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).

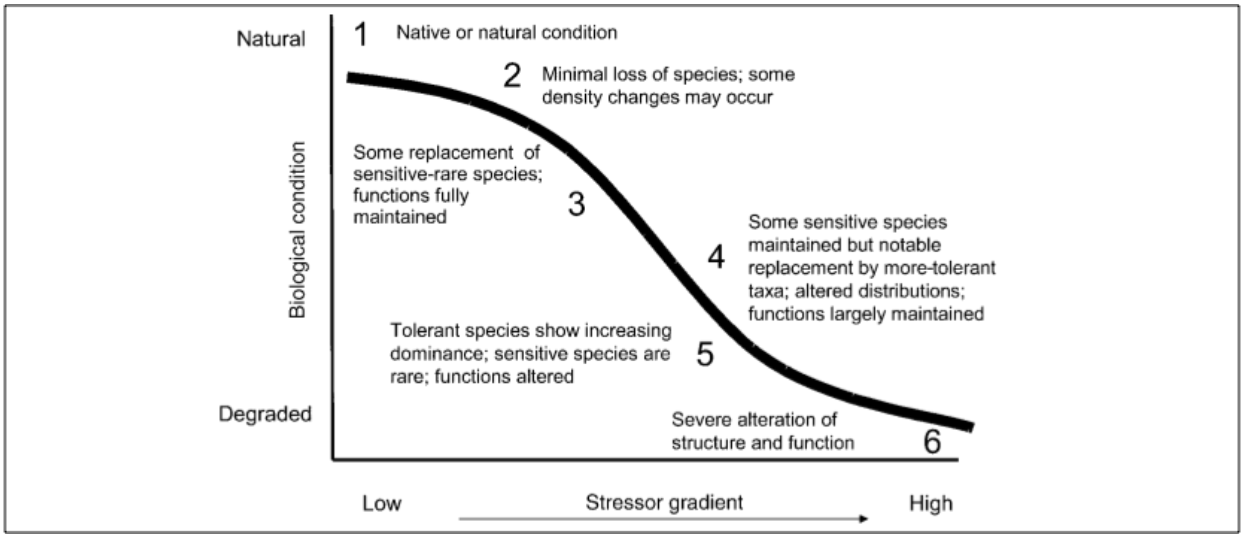

FIGURE 4-2: BIOLOGICAL CONDITION GRADIENT STRESSOR-RESPONSE MODEL

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 antidegredation 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 >500km^2. 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 CITERIA 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)

	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/interimmgntphosstrat_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 O_2 (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).

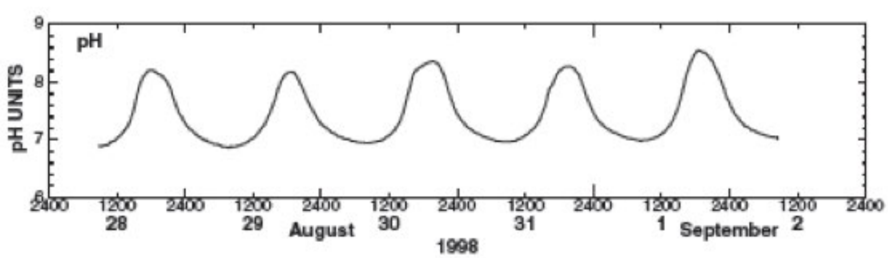

FIGURE C-1: DIURNAL FLUX IN DO IN RESPONSE TO ALGAL PHOTOSYNTHESIS AT THE QUINEBAUG RIVER (COTTON ROAD BRIDGE NEAR POMFRET LANDING, CT, USGS GAGE: 01125520) FROM 8/28/1998-9/2/1998. (SOURCE: TRENCH 2004)

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 (CO_2). Therefore similar to dissolved oxygen, pH levels are responsive to respiration and photosynthesis (Figure C-2; Trench 2004).

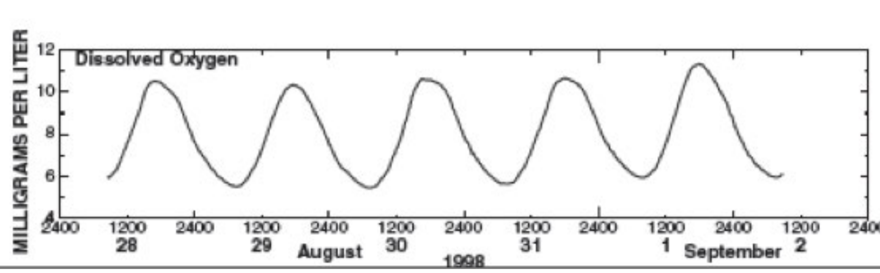

FIGURE C-2: DAILY FLUX IN PH IN RESPONSE TO ALGAL PHOTOSYNTHESIS AT THE QUINEBAUG RIVER (COTTON ROAD BRIDGE NEAR POMFRET LANDING, CT, USGS GAGE: 01125520) FROM 8/28/1998-9/2/1998. (SOURCE: TRENCH 2004)

During excess primary production fueled by nutrients (i.e., phosphorus, nitrogen), CO_2 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 thresh-old 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**

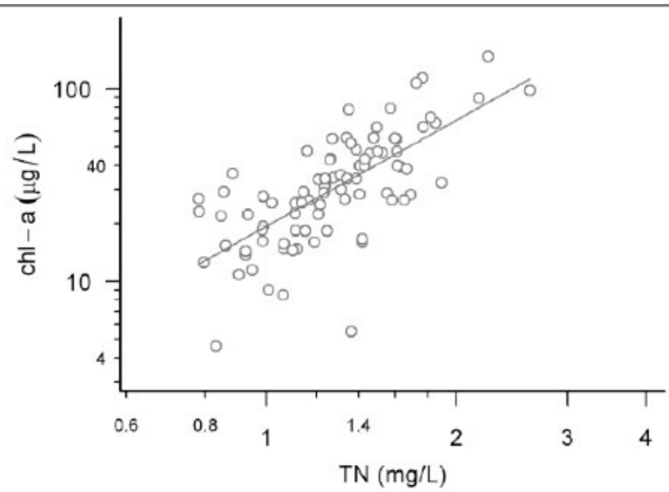

Figure 4-1. Total nitrogen (TN) versus chlorophyll a (chl *a*) in one lake collected during March-August over 10 years. Solid line: simple linear regression fit.

- **Multiple Linear Regression**

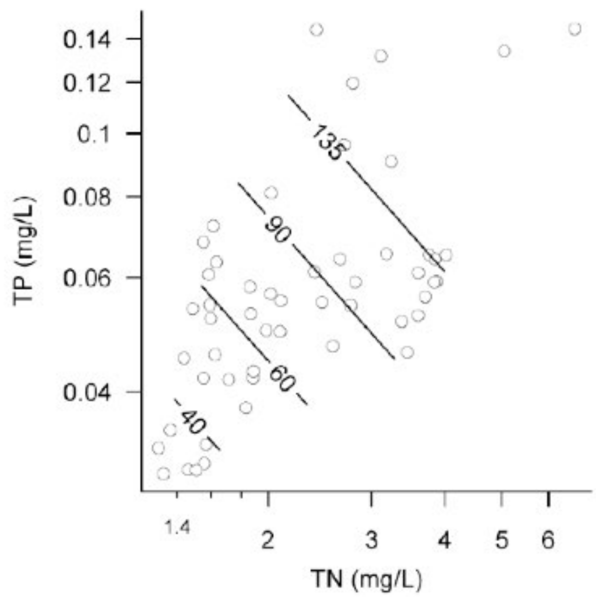

Figure 4-15. Modeled relationship between TP, TN, and chl *a*. Plotted circles indicate combinations of TN and TP values observed in the data, and contour lines indicate modeled mean chl *a* concentrations (µg/L) associated with particular combinations of TN and TP.

- **Quantile Regression**

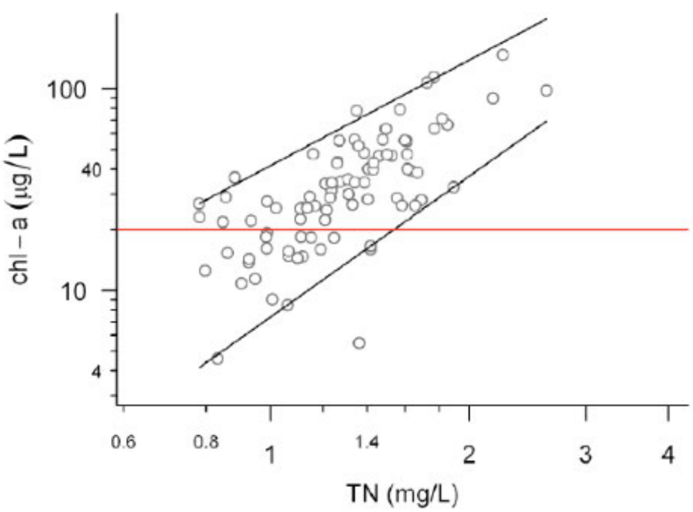

Figure 4-16. Example of quantile regression. Same data as shown in Figure 4-1. Solid black lines are the 5th and 95th percentiles. Red horizontal line shows the response threshold of chl *a* = 20 µg/L.

- **Nonparametric Regression**

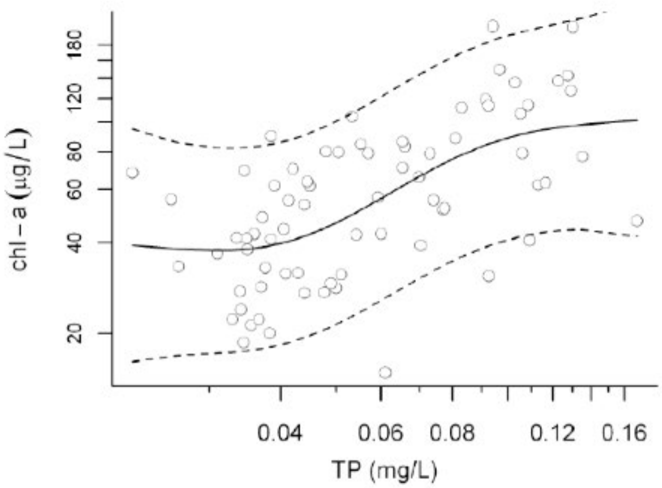

Figure 4-18. Example of nonparametric regression curve. TP versus chl *a* in one lake. Mean relationship estimated with a penalized regression spline. Solid line: estimated mean relationship. Dashed lines: 95% prediction intervals.

- **Nonparameteric Changepoint Analysis**

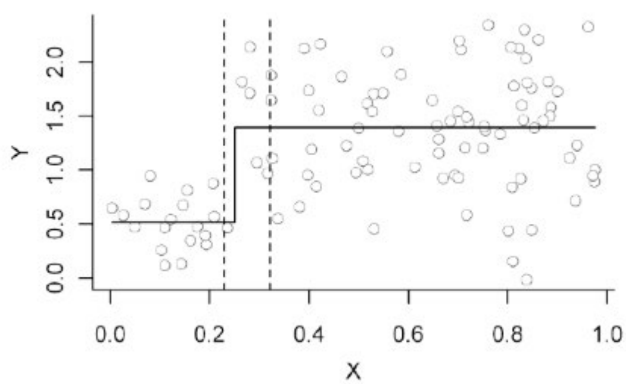

Figure 4-19. Illustrative example of changepoint analysis for a stressor (X) and a response (Y). Solid line shows modeled response, with a step increase at X = 0.25. Vertical dashed lines show the 95% confidence intervals about the changepoint calculated from bootstrap resampling.

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.mcpx

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-tsd_2-21-14.pdf

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Ohio EPA. (2013). Ohio Lake Erie Phosphorus Task Force II Final Report. Columbus, OH. http://lakeerie.ohio.gov/Portals/0/Reports/Task_Force_Report_October_2013.pdf.

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Vermont Department of Environmental Protection. (2014). Proposed Nutrient Criteria for Vermont's Inland Lakes and Wadeable Streams – Draft for Public Review. http://www.watershedmanagement.vt.gov/mapp/docs/mapp_nutrient-tsd_2-21-14.pdf.

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

2013

- Analyzing the Economic Impact of Transportation Projects
- Health Impact Assessments Study
- Connecticut Disparity Study: Phase I
- Connecticut Stem Cell Research Program Accomplishments

2012

- Strategies for Evaluating the Effectiveness of Programs and Resources for Assuring Connecticut's Skilled Workforce Meets the Needs of Business and Industry Today and in the Future
- Benchmarking Connecticut's Transportation Infrastructure Capital Program with Other States
- Alternative Methods for Safety Analysis and Intervention for Contracting Commercial Vehicles and Drivers in Connecticut

2011

- Advances in Nuclear Power Technology
- Guidelines for the Development of a Strategic Plan for Accessibility to and Adoption of Broadband Services in Connecticut

2010

- Environmental Mitigation Alternatives for Transportation Projects in Conecticut
- 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

- A Study of the Feasibility of Utilizing Fuel Cells to Generate Power for the New Haven Rail Line
- Guidelines for Developing a Strategic Plan for Connecticut's Stem Cell Research Program

2006

- Energy Alternatives and Conservation
- 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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Appendix F: Report of the Municipal Options Workgroup dated 11/23/2016

Public Act 12-155 Workgroup 3

BACKGROUND

In 2010 the United States Environmental Protection Agency (EPA) objected to two permits written by Connecticut Department of Environmental Protection (DEP) with an interim strategy of technology-based phosphorus limits.

DEP (now known as Connecticut Department of Energy and Environmental Protection or DEEP) shifted the strategy to one based on best available science with the intention that the strategy may be modified based on future findings from studies of the nutrient dynamics found in freshwater streams in Connecticut. This interim best available science based strategy was accepted by EPA.

A coalition of municipalities objected to the new strategy and entered into negotiations with DEEP concerning the new strategy and the resulting permit limits. Permits have since been issued to the coalition facilities with timetables requiring immediate treatment to at least 0.7 mg/l and implementation of final limits as defined by the interim strategy in seven and a half to nine years.

Public Act 12-155 put in place a collaborative program for the State of Connecticut Department of Energy and Environmental Protection (DEEP) and affected municipalities to evaluate and make recommendations regarding the DEEP interim nutrient management strategy for reducing phosphorus loading in inland non-tidal waters so as to meet current standards:

> *Section 1. 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 state-wide strategy to reduce phosphorus, or such chief elected officials' designees, shall collaboratively evaluate and make recommendations regarding a state-wide strategy to reduce phosphorus loading in inland nontidal waters in order to comply with standards established by the United States Environmental Protection Agency. Such evaluation and recommendations shall include (1) a state-wide 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 nontidal waters and to make future projections of phosphorous levels in such waters.*

The DEEP and affected communities assigned each of the numbered tasks to a workgroup for evaluation and recommendation. A coordinating committee was put in place to guide the workgroups.

CHARGE

The charge for Work Group 3 comes from Section 1 of PA 12-155:

> *". . .(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, . . ."*

Workgroup 3 is led by Co-Chair Dennis Waz, Director of Public Utilities for the City of Meriden and Co-Chair Rowland Denny, Senior Sanitary Engineer for the Municipal Facilities Section of the Water Bureau at DEEP. Numerous municipal officials, scientists, consulting engineers and environmental group representatives contribute to this workgroup.

Workgroup 3 developed and adopted the following scope of work:

> Review and make recommendations for use of technologies, methods, or a mix of approaches that can be applied to individual basins to reduce phosphorus to various levels. Consider technologies effective in removal of emerging contaminants. Identify tools that exist, prioritize methods and approaches to be employed, prioritize methods and approaches by cost/pound of total phosphorus removed/day.

The objective of Workgroup 3 is to provide a way of comparing the cost of various methods and approaches so municipalities can select the most cost-effective path for complying with the standards that Workgroup 2 is evaluating. The results of Workgroup 1 are to be integrated into this report as their report encompasses phosphorus non-point source controls and cost-effectiveness. This is intended to allow for a direct cost-effective comparison between point and non-point methods.

DATA COLLECTION

Two interns, Demetri Athanasiou and Judi Meunier, working for DEEP made contact with facilities in an attempt to gain information on performance capabilities, capital costs and operation and maintenance (O&M) costs of their phosphorus removal projects. They utilized a questionnaire developed by the workgroup to maximize the quality of data retrieved. Included were Ansonia, Bristol, Beacon Falls, Canton, Cheshire, Danbury, Killingly, Litchfield, Meriden, Naugatuck, Plainville, Southington, Wallingford and Windham, Connecticut, and Concord, Marlborough Easterly, Marlborough Westerly and Webster, Massachusetts.

Demetri and Judi searched for reports covering phosphorus removal project performance and costs.

Members of consulting engineering firms serving on the workgroup made information available concerning performance and costs of phosphorus removal projects that they were involved in. This included Bristol, Cheshire, Manchester and Plainville, Connecticut; Hudson, Marlborough Westerly and North Attleboro, Massachusetts; and Warwick, Rhode Island.

At least one member of the workgroup visited phosphorus removal facilities to see what information was available on the capabilities of some facilities and the associated costs.

REPORTS

Reports on nutrient removal technology were collected and reviewed for performance and cost data. This included the following reports: “Estimation of Costs of Phosphorus Removal in Wastewater Treatment Facilities: Construction *De Novo*”, F. Jiang, et. al. 2004, “Wastewater Treatment Performance and Cost Data to Support an Affordability Analysis for Water Quality Standards”, Montana DEQ in 2007, “Municipal Nutrient Removal Technologies Reference Document” EPA in 2008, “EPA Nutrient Control Design Manual” from 2010, “Evaluation of Practical Technology-Based Effluent Standards for Phosphorus and Nitrogen in Illinois” from 2011 and the 2012 supplement, “Cost Estimate of Phosphorus Removal at Wastewater Treatment Plants” Ohio EPA in 2013, “Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management” EPA in 2013, “Lake Champlain Phosphorus Removal Technologies and Cost for Point Source Phosphorus Removal” by Tetra Tech Inc. in 2014 and “Six Municipalities, One Watershed: A Collaborative approach to Remove Phosphorus in the Assabet River Watershed” by EPA in March 2015.

DATA COLLATION AND EVALUATION

Demetri and Judi spent a significant amount of time collating the data and Demitri spent additional time working with the data we collected and plotting it on graphs.

DISCUSSION

CAPITAL COSTS

Very little information on the real capital costs of phosphorus removal facilities was found. True capital costs are hard to come by as they are usually lost in a wholesale upgrade or expansion and upgrade. Most of the reports we reviewed were based on simulations. These simulations were set up using many assumptions that can lead to widely varying costs.

A review of numerous reports by EPA provided in "A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution" in May of 2015 highlights the dilemma. Figure IV-10 illustrates the capital costs ($/gallon treated per day or $/gpd) as they relate to the level of treatment required to meet a specific effluent concentration (mg/l or milligrams per liter).

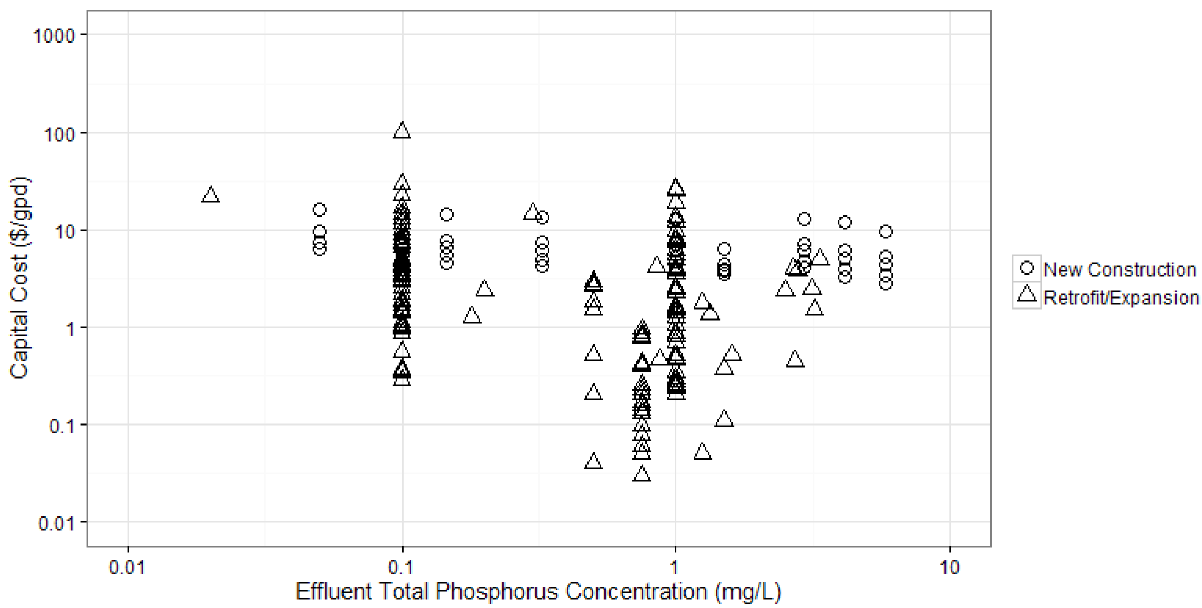


Figure IV-10. Capital cost and phosphorus effluent concentration for municipal WWTPs (2012$).

The widely varying costs encountered in their review of reports are well illustrated. For example, for an effluent total phosphorus concentration of 0.1 mg/l the costs range from $0.50 per gallon per day to $100 per gallon per day, a variation of 200 times.

As with many construction contracts at wastewater treatment facilities there are any number of local conditions that can affect the cost of a project. Some may have hydraulic limitations that require them to include pumping facilities, some may have limited area to add a new process that require them to use more expensive processes and/or construction techniques, some may be in high cost areas, some may be larger facilities that may gain an economy of scale. . . etc.

A continued review of the EPA report shows another limitation of reported data. In Table IV-3 below, there is an attempt to provide cost ranges (in $/gpd) as they relate to required treatment levels. The value of the reported data is lessened by the combining of treatment technology costs into three categories: two for treatment levels below 1 mg/l and one for those above 1 mg/l:

Effluent Quality (mg/L as P)	Removal Efficiency Range (%)	Capital Cost Range ($/gpd)[1]	Annual O&M Cost Range ($/gpd/year)[1]	Technologies
<1.0	75 – 99	0.03 – 22.17	<0.01 – 2.33	Chemical precipitation or any of a variety of BNR technologies - BNR frequently used in combination with tertiary filtration, ultrafiltration, and/or reverse osmosis.
<1.0	81 – 99	0.14 – 98.40	0.04 – 1.85	Lagoons and oxidation ditches capable of meeting this standard but at relatively higher unit costs.
>1.0	22 – 85	0.05 – 12.82	<0.01 – 1.55	Oxidation ditches, lagoons, and a variety of BNR systems.

[1] *All costs are in 2012$*

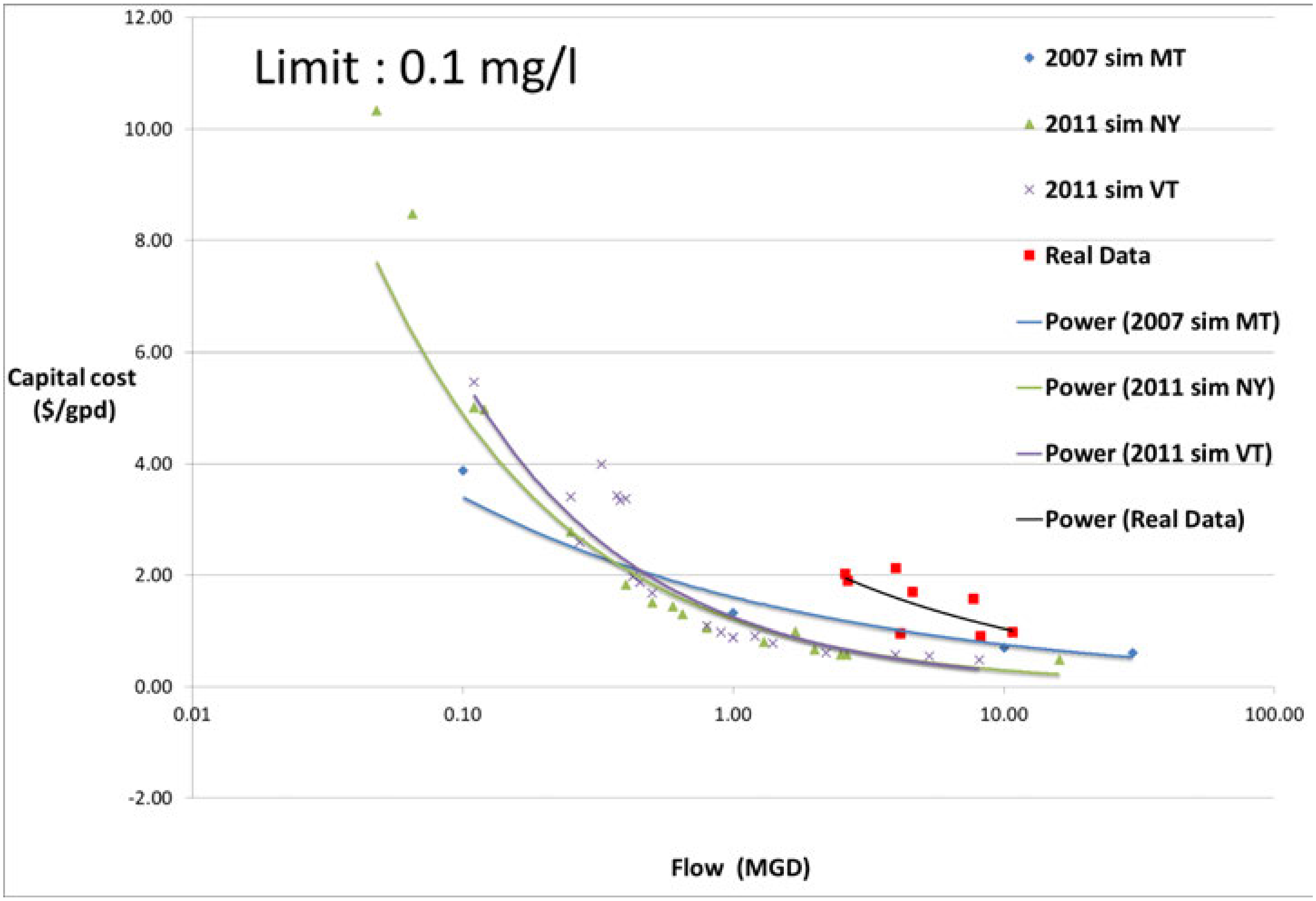
Table IV-3. Total Phosphorus Cost and Treatment Performance for Municipal WWTPs

The value of such data would be greatly enhanced if the categories were matched up with technological capabilities. Removal of total phosphorus down to 0.4 and sometimes 0.3 mg/l does not always require advanced treatment technologies and therefore does not require significant capital investment while removal below that level typically does require advanced treatment. The reporting of the costs of various technological levels of treatment in one group does not provide a realistic range for reference or comparison to ones' own facility.

Further review of the data that we compiled from reports showed some of the cost data were skewed to an unrealistically low cost per gallon treated as some of the simulations were based on facilities already removing total phosphorus to very low levels (such as 0.132 or 0.233 mg/l). Since these facilities were already using advanced phosphorus removal systems, the cost to remove total phosphorus to a slightly lower level (0.1 or 0.2 mg/l) did not entail a capital project but did end up as an artificially low cost per gallon. These were not plotted on the chart.

The members of the workgroup decided that the 2004 DeNovo data should be excluded as it appears to be less representative of current cost data. This may be due to the age of the report or the assumptions utilized.

Our search for real data provided fairly well defined capital costs for six real projects and estimated capital costs for two real projects. In the chart shown below we have capital costs for treatment technologies able to meet a 0.1 mg/l maximum limit in dollars per gallon per day ($/gpd) versus the design flow of the facility in million gallons per day (MGD).



When the eight real projects are plotted on the chart above there appears to be some correlation but variability is still an issue. Instead of having a 200 times variation in costs (as shown in Figure IV-10 on page 4) we have a 4 times differential. While this is better it is difficult to utilize such results for determining what steps an individual municipality should take to mitigate phosphorus impacts.

O&M

While it is clear that there is little real data available on the capital costs of phosphorus removal treatment facilities it is even more difficult to get data on the O&M costs of those facilities. It might be related to some facilities not having the infrastructure to be able to break out O&M costs related to phosphorus removal activities.

Whatever the case is, real data was not found and simulated data had variability issues similar to capital cost simulations. Therefore, a meaningful chart was not able to be constructed.

CONCLUSION

The objective of this workgroup was ". . . to provide a way of comparing the cost of various methods and approaches so municipalities can select the most cost-effective path for complying with the standards that Workgroup 2 is evaluating."

The intent was to provide a cost per pound of total phosphorus removed for different levels of treatment. The reports we reviewed provided simulated cost per gallon treated data with little to no data to support a cost per pound scenario.

With the lack of data and with variability of simulated data being an issue it would appear that it would be best for each municipality to engage an engineering firm to conduct a planning study to better define the range of capital and O&M costs one should expect at the level of treatment needed for each individual project. This way individual local conditions can be factored into the analysis. Those costs could then be compared to the Workgroup 1 costs for non-point remediation projects to provide some direction for municipalities.

Appendix G: Scope of Work for the NPS Phosphorus Workgroup

Scope of Work: PA 12-155 Nonpoint Source Phosphorus Workgroup

Purpose

- Identify the relevant components and sources of nonpoint source (NPS) phosphorus pollution.
- Identify reasonable reduction goals that support designated uses of aquatic life and recreation.
- Identify and assess methods and strategies to achieve those goals.

Assess Existing Information

- Organize Workgroup and ensure communications within group, and with Coordinating Committee, Scientific Methods Workgroup, and Municipal Implementation Workgroup. Organization should assure continuity, transparency, and balance.
- Interface with the CTDEEP 2014 Nonpoint Source Management Program Plan Update relative to phosphorus nonpoint source pollution issues. It is intended that much of the work of this Workgroup be integrated with the work of the NPS Plan Update. Identify and contact potential stakeholders, to participate in the NPS Plan Update process, and establish a process to communicate through website and email.
- Identify existing local and national nonpoint source phosphorus planning and implementation efforts including TMDLs, watershed plans, and other relevant information.

Identify Problem and Issues

Identify phosphorus nonpoint source pollution sources, their relative inputs, and factors influencing variability of those inputs.

Analysis of the Problem

Quantify and allocate practicable loading reductions in phosphorus loading to water bodies that can be attained by implementing various actions and strategies.

Goals and Objectives

Bring together knowledge and experience necessary to analyze and recommend strategies to better manage phosphorus nonpoint source pollution, and recommend cost effective solutions.

Identify Alternative Solutions

- List potential strategies to mitigate or prevent pollution.
- Investigate feasibility of implementation of strategies. List advantages and disadvantages and evaluate overall cost-effectiveness of actions on a macro scale.
- Identify funding needed and responsible parties or partners to implement strategies to reduce NPS loadings.
- Coordinate with DEEP MS4 permitting staff and summarize regulatory framework related to nonpoint source phosphorus pollution.
- Communicate with DEEP's TMDL staff to further assess potential reductions in phosphorus loading in individual basins through implementation of nonpoint source controls.

- Work to engage stakeholders involved with Watershed Based Planning processes to implement Best Management Practices to reduce NPS phosphorus pollution.

Evaluation of outcome and discuss of next steps

- Summarize and disseminate recommendations and findings to Coordinating Committee.
- Qualitatively describe the benefits of achieving support for designated uses of aquatic life and recreation.
- Identify the connection with other NPS issues that might benefit from widespread implementation of practices.

Appendix H: Scope of Work for the Scientific Methods Workgroup

PA 12-155 Work Group 2

Scope of Work: Workgroup 2 Project
Timeframe: ***November 2013 – September 2014***

<u>Tasks:</u>

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.

2. **What is Connecticut's current approach to addressing phosphorus to achieve Water Quality Standards?**

    a. Identify relevant CT Water Quality Standards, such as the narrative phosphorus standard and narrative biological condition standard.

    b. Explain the aquatic life assessment methodology process in CT CALM and how it relates to the narrative biological condition standard. Identify elements of methodology that may be related to phosphorus.

    c. Provide an overview of the CT Statewide Phosphorus Strategy for Non-Tidal Waste-Receiving Streams

3. **How can phosphorus impacts be measured in non-tidal waters such that relevant contributing stressors are considered in order to achieve 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 CT.

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 CT. 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 4a. above.

e. Identify what existing available CT data may be relevant and used to implement such an approach in an example water body.

Appendix I: Water Quality Standards: Regulations of Connecticut State Agencies Sections 22a-426 1 through 9

The State of Connecticut Water Quality Standards are “certified documents” and must be downloaded separately from:

https://eregulations.ct.gov/eRegsPortal/Browse/RCSA/%7B2328E62B-7982-48A7-AF52-F3F382A821FA%7D

Appendix J: Integrated Management Approaches

Integrated Management Approaches

Integrating Point and Nonpoint Pollution Sources

A significant number of the lakes, rivers, streams throughout Connecticut are impaired due to phosphorus overloading from both point and nonpoint sources (NPS). Restoring these water bodies to federally-mandated fishable and swimmable status means pollution reductions will continue to come from point sources such as wastewater treatment facilities, but also from nonpoint sources such as urban and agricultural runoff. Comprehensive watershed planning and management within the entire watershed, where an inventory and assessment of both sources and management options with participation and commitment from all municipalities in the watershed, is critical to restoring and protecting water quality. Watershed management is a theme used in many DEEP programs and management efforts further discussed below. USEPA encourages states to accelerate reduction of nutrients by prioritizing watersheds on a state-wide basis and setting load-reduction goals. The DEEP Interim Phosphorus Strategy is centered around holistic watershed assessment and management of phosphorus.

Integration is increasingly important as removing nutrients from municipal wastewater facilities via advanced treatment, and focusing only on these large point sources will not by itself achieve our end-goals. Although it can be both technically and cost-effective to reduce nonpoint source pollution through collaborative and less regulatory approaches, there must be "reasonable assurances" (see TMDL below) that reductions have a high likelihood of implementation. USEPA and CT DEEP continue to evaluate integrated and innovative approaches to address both sources in the most effective manner.

Nonpoint Sources and Permit Strategies

As permitting programs for point-source wastewater discharges from municipal and industrial sources reduce phosphorus through increased levels of phosphorus treatment and control, the environmental importance of managing nonpoint sources becomes more widely recognized. As such, traditional nonpoint source pollution sources such as urban stormwater and agricultural runoff are now being moved under federal and state permitting programs as they become more important statewide and nationally. These permitting strategies usually fall under a "general permit" type in which coverage is broad and standard requirements or best management practice are established.

Stormwater Permits- a number of general permit programs are administered by the DEEP, to deal with stormwater pollution including:

1. Industrial General Permit**-** regulates industrial facilities with point source stormwater discharges that are engaged in specific types of activities.
2. Construction General Permit**-** requires developers and builders to implement a Stormwater Pollution Control Plan to prevent the movement of sediments off construction sites and to address the impacts of stormwater discharges from a project after construction is complete.
3. Commercial General Permit**-** found only in Connecticut, requires operators of large paved commercial sites such as malls, movie theaters, and supermarkets to

undertake actions such as parking lot sweeping and catch basin cleaning to keep stormwater cleans.

4. Small Municipal Separate Storm Sewer Systems (MS4 General Permit)**-** requires urban municipalities to take steps to keep the stormwater entering its storm sewer systems clean. One important element of this permit is the requirement that towns implement public education programs to make residents aware of stormwater pollutants from everyday living activities, and to inform them of steps they can take to reduce pollutants in stormwater runoff.

DEEP regularly assesses the coverage and effectiveness of these general permits as they are reissued and makes revisions or enhancements. One important addition has been the addition of green infrastructure measures which can provide multiple benefits environmental benefits.

Emerging Effort on Agriculture, Concentrated Animal Feeding Operations (CAFO)- the importance of managing environmental risks from the agricultural sector has become more widely recognized. Reflecting on those concerns, USEPA and the United States Department of Agriculture (USDA) published the *Unified National Strategy for Animal Feeding Operations* (USDA and USEPA, 1999). The *Unified National Strategy* is based on a national performance expectation for all AFO owners and operators, and presents a series of actions to minimize public health impacts and to improve water quality, while supporting the long-term sustainability of livestock production throughout the country. The goal of the *Unified National Strategy* was to encourage the implementation of technically and economically feasible Comprehensive Nutrient Management Plans (CNMPs). Regulatory activities at a national level are applied in different ways in the states, depending upon program delegation. Connecticut is a delegated state and has the authority to implement EPA NPDES requirements. DEEP has recognizes the importance of minimizing agricultural impacts on water quality, while maintaining agriculture as sustainable contributors to economic activity in the state. DEEP intends to use its established General Permit program to address the agricultural sector. A CAFO General Permit is being drafted and is now under review.

Total Maximum Daily Load (TMDL) Program

Under the federal Clean Water Act, states may develop pollutant reduction plans called Total Maximum Daily Loads (TMDLs) to restore waters and address water quality problems. A TMDL can be thought of as a water pollution budget or diet. TMDLs provide the formal framework for restoring impaired waters by establishing the maximum amount of a pollutant that a waterbody can receive. This amount can be divided up between all potential pollutant sources, both point and nonpoint, and is expressed as:

TMDL = Point Sources + Nonpoint Sources + Background + Margin of Safety

The end result of the TMDL process is a water quality management plan with quantitative goals, pollutant allocations and requirements to reduce pollutant loadings. Under section 303(d) of the Federal Clean Water Act (CWA), states are required to develop TMDLs for waters identified and listed as impaired. Listed waterbodies are

prioritized for TMDL development by DEEP based on knowledge of the waterbody, pollutants of concern, resource availability, and programs in place to aid in TMDL implementation.
Controls for Point Sources- an NPDES permit contains numerical limits and specifies treatment and monitoring requirements to ensure that the discharge does not impact water quality. TMDL allocations must be incorporated into NPDES permits to ensure that water quality standards will be met.
Controls for Nonpoint Sources- Nonpoint sources can be reduced by implementing preventative measures and programs such as reducing the use of fertilizers, keeping septic systems in working order, managing stormwater, establishing buffers, and pet waste management. Public education and local commitment are key to reducing nonpoint sources of pollution. There must "reasonable assurances" that reductions have a high likelihood of implementation controls through programs and state and local requirements. DEEP has traditionally used Watershed Based Plans as a primary way to address nonpoint pollution.
CTDEEP has typically developed traditional TMDL plans to address impaired water quality for specific waters. Some TMDLs were developed to address issues which affect widespread areas within the state. These TMDLs include the Long Island TMDL to address the impacts of nutrients on the oxygen levels within Long Island Sound, the Regional Mercury TMDL which was done in conjunction with other New England states and New York to address elevated levels of mercury in fish tissue, and the Connecticut Statewide Bacteria TMDL to address the impacts of elevated levels of bacteria on recreational and shellfishing activities within Connecticut.

TMDL Alternatives

USEPA and states agencies are taking a new approach to TMDLs after looking at past practices and seeing some changes which could improve this effort. EPA calls this updated approach the "Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program" or the 303d Vision in short. Integrated Water Resource Management is a new CT DEEP approach to the TMDL program to work more effectively towards restoring our waters. This approach is done under existing TMDL authority and doesn't create new regulations, but enhances CT DEEP TMDL efforts by focusing state resources, building on partnerships, and looking at flexible and efficient ways to connect our environmental data with actions that restore Connecticut's waters. States, with support from EPA, are encouraged to consider the best type of alternative plans to develop in order to better restore waters.

Watershed Management Approach, Watershed Based Plans

Watershed management is a term used to describe the process of implementing land use and natural resource management practices to protect and improve water quality within a watershed in a comprehensive manner. Because watershed boundaries are natural, not political boundaries, it allows for more comprehensive assessment of the entire watershed which is critical to restoration of impaired waters. A watershed management approach is also important because the planning process results in a partnership among all affected stakeholders in the watershed. Development and implementation of these plans usually focus on addressing specific nonpoint source pollution.

USEPA requires nine elements that must be addressed in an approved Watershed Based Plan to qualify for federal funding under Section 319 of the Clean Water Act. A Watershed Based Plan, is a specific watershed management plan that has the goal of reducing or removing an impairment, so the waterbody can meet water quality standards. Watershed management plans can widen the scope of Watershed Based Plans by addressing broader water and land resource issues on a watershed scale. Watershed management plans may qualify as an alternative to traditional TMDLs.

USEPA Integrated Municipal Stormwater and Wastewater Planning Approach

USEPA, states, and municipalities have achieved real progress in implementing the Clean Water Act protecting public health and the environment. However, today there are many factors affecting the implementation of CWA programs including population growth, aging infrastructure, increasingly complex water quality issues, limited resources, and other economic challenges. Currently, EPA, states, and municipalities often focus on each CWA requirement individually which may have the unintended consequence of constraining a municipality from addressing its most serious water quality issues first. An integrated planning approach offers a voluntary opportunity for a municipality to propose to meet multiple CWA requirements by identifying efficiencies from wastewater and stormwater programs and sequencing investments so that the highest priority projects come first. This approach can also lead to more sustainable and comprehensive solutions, such as green infrastructure that improve water quality and provide multiple benefits that enhance community sustainability. The integrated planning approach is not about changing existing regulatory or permitting standards or delaying necessary improvements. Rather, it is an option to help municipalities meet their CWA obligations while optimizing their infrastructure investments through the appropriate sequencing of work. More information about EPA's Integrated Planning Approach can found at https://www.epa.gov/npdes/integrated-planning-municipal-stormwater-and-wastewater