LONG ISLAND SOUND STUDY ENHANCEMENT PROJECT FINAL REPORT

INTERSTATE NUTRIENT TRADING PROGRAM:

OPTIONS AND OBSTACLES EVALUATION

AN ALTERNATIVE, ECOSYSTEM-BASED ANALYTICAL PLATFORM

TO TEST AND FACILITATE WATER QUALITY TRADING

2 November 2021

By

Paul E. Stacey
Owner and Principal Scientist
Footprints In The Water LLC

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement (LI00A00384) to NEIWPCC in partnership with the Long Island Sound Study (LISS). The contents of this document do not necessarily reflect the views and policies of NEIWPCC, LISS or the EPA, nor does NEIWPCC, LISS or the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

Footprints In The Water LLC
PO Box 373
Moodus, CT 06469 USA
Voice/Text: (860) 978-6925
FootprintsInTheWater@outlook.com

Executive Summary

The Decision Support Framework (DSF) used for this analysis identified LIS-specific options and obstacles to trading that might promote or limit its use. The DSF offers a prospective assessment and planning resource to guide management and is a potential trading platform for concurrently assessing, facilitating, and tracking trades for both biointegrity and Total Nitrogen (TN) loading outcomes. Among the technical challenges to Water Quality Trading (WQT) that were explored with the DSF are balancing supply and demand; uncertainties of baseline conditions; effectiveness of targets, caps, or limits; and the attainability of target or benchmark conditions that might constrain WQT.

The DSF is an adaptable model for assessment, planning, and management decision support. The Combined land cover Condition Index (CCI) provides a robust assessment of biological condition (biointegrity) along the Biocondition Gradient (BCG) continuum that translates to the Connecticut Department of Energy and Environmental Protection's (CT DEEP) Tiered Aquatic Life Use Support (ALUS) protocol used for benchmarking biointegrity and TN loading and setting user-defined targets. The DSF estimates of TN yields and loads compare favorably to the Long Island Sound (LIS) Total Maximum Daily Load (TMDL) evaluation used for setting the LIS Dissolved Oxygen targets in the TMDL. The DSF proved to be a useful and viable analytical framework for assessment and planning for both biointegrity and pollutant (TN) management outcomes, and WQT, in an ecosystem context.

The viability and potential for WQT trading in the Long Island Sound (LIS) watershed was found to be limited. The potential for viable trading hinges on two factors: target or cap stringency and management or recovery potential. A lax cap provides greater trading potential but sets a lower bar for aquatic ecosystem health while increasingly restrictive caps limit trading potential but are more protective.

Although an aggressive management scenario advancing recovery potential of structural and functional integrity in the watershed and riparian buffer improves prospects for trading by increasing credit supply, it sets at a very high bar for attainability. It may exceed a plausible Best Attainable Condition. In sum, the technical analyses of a large-scale, LIS-centered trading program reveals an imbalance between credit supply and demand, creating a credit deficit that is likely too large to support viable credit trading at the state-wide scale. Thus, prospects for expanding WQT into a multi-state, LIS watershed-wide program are doubtful.

The DSF was also used to explore a distributed approach suitable for localized, intra-watershed trading of TN for four Connecticut watersheds – the Salmon River in the Connecticut River Basin; the Quinnipiac River in south-central Connecticut; the Norwalk River in southwestern Connecticut; and the Willimantic River in eastern Connecticut. The analysis showed that each watershed has its own distinctive site-specific character and would need to be evaluated on an individual basis for water-quality trading. Across a gradient of watershed types and conditions, trading potential will be variable depending on local factors.

Categorically, the Salmon River watershed with a relatively healthy landscape condition enjoys a surplus of credits but low demand; the Quinnipiac River and Norwalk River watersheds run deep TN credit deficits and have low potential for WQT because demand far exceeds supply; the Willimantic River watershed, has the best potential for trading of the four watersheds as supply is close to demand established by a proposed cap and the supply of credits generated from management actions may be adequate to meet the demand and the TN loading target. Overall potential for individual intra-watershed trading programs that could collectively contribute to improving local water quality that benefits LIS as well should be further explored to determine basin-wide benefits.

The DSF provides the capacity to easily conduct watershed evaluations to set caps and test management scenarios wherever high-resolution land cover data are available in the classifications appropriate to the DSF. However, the technical ability to trade may not overcome the lack of regulatory caps, management plans, and enforceable mechanisms to effect or incentivize management action. Successful WQT will rely on political and public support necessary to implement land conservation, recovery and mitigation management actions that are powerful enough to offset TN loads that exceed management targets and concomitantly support healthy biointegrity outcomes.

Acknowledgements:

In addition to the excellent team assembled by NEIWPCC to execute this Long Island Sound Study Enhancement Project, the work of the University of Connecticut's Center for Land Use Education and Research (CLEAR) for another LISS Enhancement Project in developing the Decision Support Framework was essential the success of this trading analysis. These include Principal Investigator Chet Arnold, and a great team of CLEAR scientists: David Dickson, Emily Wilson, Qian (Rachel) Lei-Parent, and Cary Chadwick. Also, the prior and continuing work of Christopher Bellucci and Mary Becker with the Connecticut Department of Energy and Environmental Protection credited as citations throughout the report was foundational to the development and success of the DSF. However, the importance of those contributions notwithstanding, the opinions expressed in this report are those of the author. They do not purport to reflect the opinions or views of those persons or entities acknowledged here who have yet to review this material, or the authors of materials cited or quoted in this presentation.

Table of Contents

Introduction

This report addresses the structure and mechanics of a regional water quality trading (WQT) concept. The focus is on the technical capability of trading and only generally considers the economics or market forces (addressed in a separate report) other than in a "natural capital" sense and potential outputs of Ecosystem Goods and Services (EGS) derived from structurally and functionally healthy watersheds and aquatic ecosystems. However, it unavoidably crosscuts with policies and regulatory requirements of the Clean Water Act (CWA), which shape and sometimes constrain options for technical trading applications.

To avoid an overwhelming and potentially distracting discussion on the legal – technical interactions, the WQT concept proposed here is guided by EPA WQT policies and discusses, but does not try to resolve, potential constraints, which are few. In general, EPA WQT policies provide ample flexibility and thoughtful direction that should avoid a serious conflict of WQT intent and technical contortions that might impair the construct of a scientifically sound trading platform.

The Long Island Sound Study (LISS) FY19 Enhancement Project proposal submitted by NEIWPCC, "Interstate Nutrient Trading Program: Options and Obstacles Evaluation", describes this work as "an initial scoping analysis…to identify potential applicability of a regional WQT program to the LISS watershed". However, the concept proposed here benefitted from another LISS Enhancement Project on GIS-based Watershed Metrics led by the University of Connecticut's Center for Land Use Education and Research (CLEAR). That project is completing a Decision Support Framework (DSF) based on land-cover metrics that provides an analytical framework for scoping viability and potential for WQT in the LIS watershed but also technical support for design and implementation of programs and scenario-testing at varying scales.

Although the DSF will not be finalized for several months, a beta version was recently completed and is used here for the first time. For that reason, all analyses, conclusions, and recommendations should be considered preliminary and subject to change pending a final report in preparation.

The DSF provides a platform for assessment and planning adaptable to user-defined biointegrity and water quality targets and outcomes (dependent or response variables) based on watershed condition (the independent or causal variable). It aligns pollutant loading, nitrogen in this case, with integrated or "generalized" watershed pressures or stressors that yield biointegrity outcomes. It uniquely captures in a single index the interplay of upland pressures, including pollutant loading, with mitigation benefits of riparian buffers. This is an enormous advantage for integrated watershed management planning linked to landscape condition, a major driver of aquatic ecosystem health, that helps guides nonpoint source and stormwater (NPS/SW) management towards water quality attainment goals in an ecosystem context. The DSF technical outputs also directly apprise the viability and potential for individual or collective biointegrity and pollutant trading that help meet the objectives of this WQT analysis and further the goals of the LISS.

Background

Overview of Water Quality Trading Programs and Progress

Water quality trading has proven to be a technical, economic, and logistical challenge, with few trading programs of significance implemented according to a 2017 US Government Accountability Office (GAO) report (GAO, 2017). Only three programs of significance are identified in the report, including Connecticut's Nitrogen Credit Exchange (NCE). The CT NCE is a point-to-point source nitrogen trading program that has successfully attained its aggregate 2014 reduction goal for 80 Publicly Owned Sewage Treatment Works (POTW) distributed throughout the State (Figure 1; Stacey, 2015). Although called an "Exchange" its market structure is technically a clearinghouse with an appointed Advisory Board that governs the trades and serves as the "bank" that constitutes the central clearinghouse.[1]

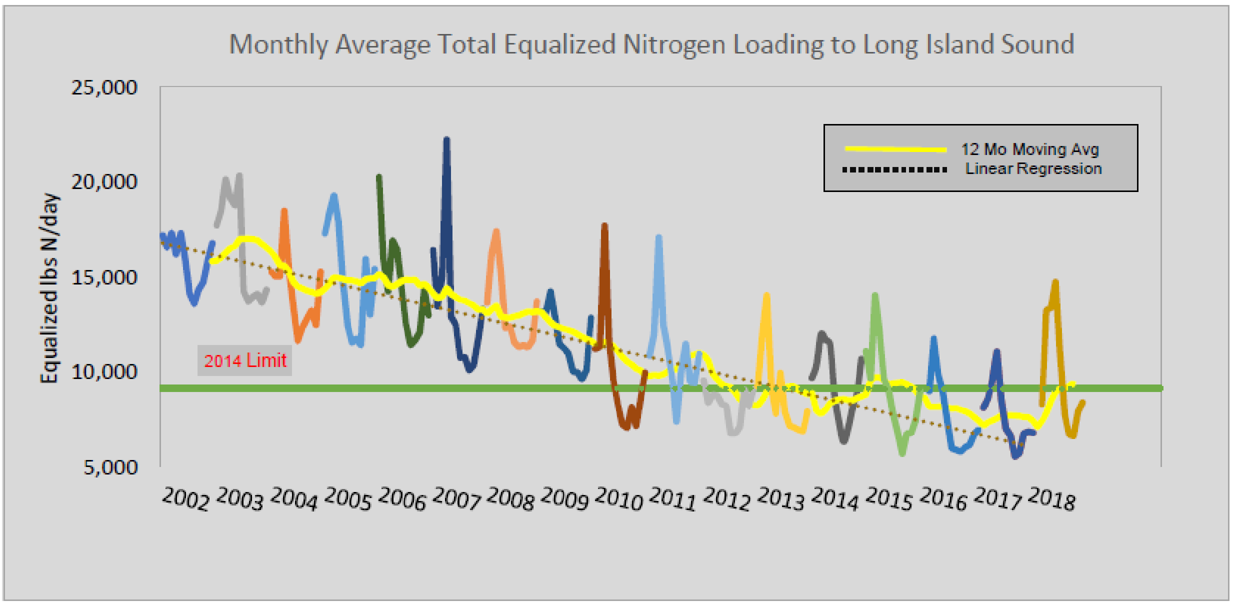


Figure 1. Progress and attainment of the 2014 nitrogen wasteload allocation to Long Island Sound in Connecticut's Nitrogen Credit Exchange. (Source: Dykes, 2019)

Given the success of the CT NCE, the LISS Management Conference Implementation Action WW-3 in the "Clean and Healthy Watersheds" theme proposed to "Explore expansion of point source and nonpoint source nutrient trading programs for the entire Long Island Sound watershed". The rationale and intent for this action is: *Nutrient trading programs can assist in attaining water quality objectives by providing economic market-based incentives to support cost effective nutrient reduction strategies. State agencies will continue to expand and support existing point source nutrient trading programs (such as Connecticut's Nitrogen General Permit and Nitrogen Credit Exchange Program) and evaluate establishing nonpoint source trading programs implemented at the municipal level throughout the Long Island Sound watershed as well.*[2]

As a management option, the introduction of WQT generated a lot of interest and enthusiasm for the purported water quality and economic benefits that could include: early pollutant reductions; reduced

[1] https://portal.ct.gov/DEEP/Municipal-Wastewater/Nitrogen-Control-Program-for-Long-Island-Sound
[2] https://longislandsoundstudy.net/wp-content/uploads/2015/09/WW-CCMP-Supp-Doc-1.pdf

costs; economic incentives; offsets for new or increased pollutant loads; long-term, sustainable improvements; and multiple ecological benefits derived from healthier aquatic ecosystems, now commonly described and used in this report as Ecosystem Goods and Services (EGS). Yet, despite a considerable investment in studies, pilot programs and evaluations of trading programs under development or underway, few have flourished according to GAO (2017).

The Decision Support Framework (DSF) central to this analysis is used to identify some of the LIS-specific options and obstacles to trading that might promote or limit its use. The DSF offers a prospective assessment and planning resource to guide management and a potential trading platform for concurrently facilitating and tracking trades. Among the technical challenges to WQT that can be explored in the DSF are: balancing supply and demand[3]; uncertainties of baseline conditions; effectiveness of targets, caps, or limits; and the attainability of target or benchmark conditions that might constrain WQT.

Management and trading in LIS have been guided by the Total Maximum Daily Load (TMDL) (NYSDEC and CTDEP, 2000) and the prescribed nitrogen reductions necessary to attain CT and NY water quality standards (WQS) for dissolved oxygen (DO). The TMDL created a "centralized" management strategy with DO assessment endpoints in offshore LIS that tend to disregard local water quality impacts throughout the LIS watershed and its embayments. Thus, centralized trading may be inconsistent with CWA requirements and state and federal policies (discussed below) to protect and restore chemical, physical, and biological integrity for *all* connected waters in the watershed or trading domain.

A "distributed" management approach, which places assessment endpoints in each individual stream segment (or defined sub-watershed unit) and embayment, provides protection for all connected and contributing segments and sub-watersheds down to a very local scale and into the coastal embayments, consistent with the CWA. Further, the TMDL only addresses a single pollutant (nitrogen) and its link to a single water quality response attribute (DO), a management and trading approach that narrows the potential for more holistic and far-reaching beneficial outcomes at the ecosystem level as described in more detail below.

As discussed in Stacey's (2015) report on the CT NCE, the distribution of the 80 POTWs and the power of trading ratios were essential to both economic viability and to a successful outcome for nitrogen load reductions to LIS. Despite the notable progress with nitrogen control from POTWs fostered by the CT NCE, the centralized program did not preclude local water quality impairments in streams and embayments and also traded "over the cap", i.e., the wasteload allocation (WLA) specified in the TMDL was inadequate to meet CT and NY WQS in LIS, a primary requirement of a TMDL.

Managers and researchers have looked at new WQT approaches in an ecosystem health context to not only help resolve some of these policy and regulatory issues but also deliver broader, "multiple ecological benefits" of ecosystem goods and services (GAO, 2017). A more holistic, ecosystem-based

[3] Throughout this report "supply", "demand" and "credit" are not used in an economic or market sense to represent the physical state (inventory) or changes in land condition (e.g., an acre impervious or natural land cover) and pollutant loads (e.g., a pound of total nitrogen) and the balance of condition or loading state ("surplus" and "deficit") with respect to a cap or target that may be used for offsets or trading. "Demand" represents a credit deficit in excess of a cap or desired state that needs to be offset to achieve the target; "Supply" are credits that exist in inventory (i.e., "natural capital") or can be gained through recovery or management action and used to offset demand. As a non-economist, I do not delve into market forces and pricing driven by supply and demand, which is covered in another product of this Enhancement Project and in the final report.

context engenders options and flexibilities that make conventional, single-pollutant WQT targets more viable and successful in that context along with the lure of added management efficiency and compounded benefits of multi-market trading, sometimes called "credit stacking" in a market setting (Carroll, Fox and Bayon, 2008). The Water Environment Federation (WEF), for example, produced an authoritative volume on "Advances in Water Quality Trading as a Flexible Compliance Tool", highlighting successful endeavors and the key interactions of economy, science and management that might support WQT (WEF, 2015). In the WEF publication, the chapter by Weimar, Brown and Vatter (2015) on the future of WQT concluded with two key thoughts that have helped guide this analysis:

> *Great strides have been made in water quality improvement across the US by focusing on individual pollutants and individual sources, sometimes [often][4] without an eye on the overall integrity and health of the watershed and its water quality goals,* and:
>
> *The future of WQT will focus on the goal of the CWA – to protect and restore the chemical, physical, and biological integrity of the waters of the United States.*

With these concerns in mind, this analysis aims to:

> ***Develop an alternative, ecosystem-based analytical platform to test and facilitate trading that is more inclusive than the regulated sources and single pollutant program currently implemented in Connecticut as "The Connecticut Nitrogen Credit Exchange"***

The primary goal is to:

> ***Extend the reach of Water Quality Trading to achieve broader, integrated benefits demonstrated by ecosystem-based concepts and the multiple advantages of more ecosystem-relevant solutions that an integrated approach with ecosystem health outcomes may provide in the social-ecological context.***

In sum, extending water quality management outcomes to the full range of ecosystem goods and services derived from healthy, functional watershed and aquatic ecosystems adds social, economic and ecological benefit and value to management efforts over single-pollutant, centralized management objectives common to requirements of a TMDL and typical of WQT to date. Further, it is likely to yield broader benefits that extend beyond clean water outcomes, as managers grapple with integrated air-land-water connections and pervasive effects of climate change in an increasingly disturbed landscape that should be managed collectively for optimal benefit. Importantly, local attainment of environmental health conditions that a distributed system promotes will also reduce social inequities caused by the uneven access to ecosystem goods and services that provide clean air and water in the neighborhood.[5]

---

[4] Author's opinion interjected in brackets

[5] This issues of social injustice and equities should be incorporated as a matter of policy at the state or local level where management takes place. EPA's Recovery Potential Screening Tool (https://www.epa.gov/rps/overview-recovery-potential-screening-rps#recovery), introduced below in Footnote 22, assesses the likelihood of successful restoration, protection or management in a complex socio-ecological context using indicator index values for ecological, stressor and social categories to assess management potential and implications for social equity.

Water Quality Trading Policy

Like many EPA policies, the original *Water Quality Trading Policy*[6] sets the tone in the opening sentence: "The Clean Water Act (CWA) was enacted in 1972 to restore and maintain the chemical, physical and biological integrity of the nation's waters." Further, "The CWA also established a national policy for development and implementation of programs so the goals of the Act could be met through controls of *point and nonpoint sources*[7] of pollution." With that underpinning, EPA's WQT policy thought market-based approaches would "…provide greater flexibility and have potential to achieve water quality and environmental benefits greater than would otherwise be achieved under more traditional regulatory approaches."

EPA identified several elements and provisions to guide "credible" WQT programs including trading areas within a watershed basis "…resulting in trades that affect the same water body or stream segment…" to "…ensure that water quality standards are maintained or achieved *throughout the trading area and contiguous waters*.[8]" This became a difficult challenge for large waterbodies with large watersheds like the Chesapeake Bay (NRC, 2011) and LIS. In implementing the CT NCE, WQS in the local watersheds were considered irrelevant to nitrogen control since it was not believed to be the "limiting nutrient" in freshwaters. Since that time, EPA has advanced requirements for adopting nutrient criteria in all waterbody types for both nitrogen and phosphorus and response indicators like chlorophyll-*a* (EPA, 1998), though progress has been slow with few LIS watershed states adopting numeric nutrient criteria and none for all required waterbody types.[9]

The LISS recognizes that estuarine subsystems must be managed for nutrients in concert with offshore LIS and has been working on a Nutrient Reduction Strategy[10] to "…continue progress on nitrogen reductions, in parallel with the States' continued implementation of the 2000 Total Maximum Daily Load (TMDL) and achieve water quality standards [or nutrient targets] throughout Long Island Sound and its embayments and nearshore coastal waters." Although the Strategy is still in its early phases, no mention is made of the need to harmonize embayment management targets with contributing watershed targets for local waterbodies or how the individual embayment targets or nutrient standards will be rectified with the offshore LIS TMDL and management needs. Individual embayment management will likely upset the centralized LIS TMDL and management programs, including the potential for trading as used in the CT NCE.

The current centralized WQT structure with attenuation factors identified in the TMDL would not likely protect Eastern LIS embayments where seagrass meadows are extant but are threatened from nutrient loading and other stressors. The low trading ratios for Eastern LIS in the CT NCE have allowed eastern POTWs the option of purchasing nitrogen reductions from other facilities located anywhere in the state at a very favorable exchange rate (trading ratio), which would not provide necessary reductions to protect eelgrass in Eastern LIS embayments. Clearly, the local watershed must be managed apart from the greater LIS hypoxia effort.

---

[6] US EPA Office of Water (2003). https://archive.epa.gov/ncer/events/calendar/archive/web/pdf/finalpolicy2003.pdf
[7] Emphasis added.
[8] Emphasis added.
[9] https://www.epa.gov/nutrient-policy-data/state-progress-toward-developing-numeric-nutrient-water-quality-criteria
[10] https://longislandsoundstudy.net/our-vision-and-plan/clean-waters-and-healthy-watersheds/nitrogen-strategy/

Without a revised direction that the LISS Nutrient Reduction Strategy might provide, WQT for LIS would likely continue to rely on the LIS TMDL with its nitrogen point source WLA and combined NPS/SW load allocation (LA) to alleviate hypoxia (NYSDEC and CTDEP, 2000). This would continue the centralized management and WQT structure that links only nitrogen delivery to LIS towards attainment of the DO WQS for CT and NY, and not the multiple benefits of a distributed, holistic, and interconnected ecosystem approach that the 2003 Trading Policy[11] seeks to promote.

The EPA 2003 WQT Policy identifies other concerns and interests that may have not been fully addressed at the time the LIS TMDL was adopted and the CT NCE instituted. Some aspects and consequences of WQT may extend beyond the points raised above, especially the need for a "cap" that might be addressed in an updated TMDL or the LISS Nutrient Reduction Strategy. Among the challenges and obstacles that WQT in the LIS watershed should consider and address are:

- New or increased discharge offsets
- Combined ecological services to achieve multiple water quality and habitat benefits
- Baseline consistency with a WQS or cap
- Associating a redefined NPS/SW baseline with land uses and management practices that comply with applicable state and local regulations to facilitate management implementation
- Trading activity that causes the PT/NPS/SW TN loads to exceed the cap established in the TMDL or other water quality targets or requirements
- Standardized protocols to quantify pollutant loads, load reductions and credits that estimate load delivery to the individual stream segment, waterbody, or watershed where trading occurs that are consistent with regulatory and CWA requirements

In the last few years, EPA has released some updated and ancillary policies and guidance in memoranda that reinforce and elaborate on the potential and policy requirements for WQT under the CWA. With interest in WQT trading flagging, EPA issued a 2019 Memorandum[12] intended to incentivize market-based programs that would promote "…implementation of technologies and land use practices that reduce nonpoint pollution…" and provided additional guidance that would achieve water pollution load reductions at a lower overall cost. Six "market-based principles" were proffered:

- States, tribes, and stakeholders should consider implementing water quality trading and other market-based programs on a watershed scale.
- The EPA encourages the use of adaptive management strategies for implementing market-based programs.
- Water quality credits and offsets may be banked for future use.
- The EPA encourages simplicity and flexibility in implementing baseline concepts.
- A single project may generate credits for multiple markets.
- Financing opportunities exist to assist with deployment of nonpoint land use practices.

[11] US EPA Office of Water (2003). https://archive.epa.gov/ncer/events/calendar/archive/web/pdf/finalpolicy2003.pdf

[12] David P. Ross, Assistant Administrator, US EPA Office of Water. February 6, 2019. Updating the Environmental Protection Agency's (EPA) Water Quality Trading Policy to Promote Market-Based Mechanisms for Improving Water Quality. US EPA, Washington DC. 5 p. https://www.epa.gov/sites/default/files/2020-11/documents/transmittal_memorandum_-_water_quality_trading_on_a_watershed_scale_november_5_2020_0.pdf

Also in 2019, relative to the 2019 Memorandum, EPA requested comment on new policies proposed for WQT under the National Pollutant Discharge Elimination System (NPDES) program for watersheds with TMDLs. They received substantial and substantive comments that are still under review.[13]

A related EPA Memorandum followed in November 2020[14] with an attached white paper, "Water Quality Trading on a Watershed Scale." Of relevance to this analysis were three defining points on WQT trading for evaluating the appropriate scale listed below. The white paper seems to promote a more integrated link to the contributing watershed ecosystem, especially in Point 1:

1. Water Quality Goals, Connectivity and Pollutant Processing.
    a. Necessary to provide a viable trading market and to ensure that targeted water quality concerns are addressed throughout the trading area
    b. Informed by the hydrology and ecology of the watershed in conjunction with the effects and extent of the pollutants of concern
    c. The degree of connectivity within a potential trading area may also be considered in evaluating the goals for water quality improvements in the targeted waterbodies and how upstream and downstream actions to improve water quality, including the purchase and sale of credits or offsets upstream and downstream of particular discharges, can help achieve those goals.
        i. Variation and degree of connectivity is critical to the integrity and sustainability of downstream waters.
        ii. Connectivity is determined by the characteristics of both the physical landscape and the biota of the specific system.
2. Relevant Clean Water Act Provisions, Regulations and Policies
3. Availability of Data and Modeling

According to the World Resources Institute (Selman, et al., 2009), "The primary policy driver for all water quality trading programs has been the implementation or forthcoming implementation of nutrient caps that limit pollutant discharges." In the United States, the CWA provides the foundation for point-source nutrient caps, as reinforced in the 2003 WQT Policy. However, it is unclear if the LIS TMDL provides a cap that is consistent with policy and regulations for WQT. Given that point source nitrogen loading to LIS has leveled with attainment of the point source WLA in the TMDL, additional reductions under a new cap seem unlikely, however necessary they might be to attaining water quality goals for LIS.

Finally, Selman et al. (2009) identify five key factors of successful trading programs that the LISS should keep in mind for an expanded trading option for LIS:

- Strong regulatory and/or non-regulatory drivers, which help create a demand for water quality credits

---

[13] https://www.federalregister.gov/documents/2019/09/19/2019-20324/water-quality-trading-under-the-national-pollutant-discharge-elimination-system-program

[14] David P. Ross, US EPA Office of Water. November 5, 2020. Water Quality Trading on a Watershed Scale. Attached 8 p. white paper, "Water Quality Trading on a Watershed Scale". US EPA, Washington DC. https://www.epa.gov/sites/default/files/2020-11/documents/transmittal_memorandum_-_water_quality_trading_on_a_watershed_scale_november_5_2020_0.pdf and white paper attachment: https://www.epa.gov/sites/default/files/2020-11/documents/trading_white_paper_watershed_scale.pdf

- Minimal potential liability risks to the regulated community from meeting regulations through trades
- Robust, consistent, and standardized estimation methodologies for nonpoint source actions
- Standardized tools, transparent processes, and online registries to minimize transaction costs
- Buy-in from local and state stakeholders.

In sum, this analysis, technically supported by the DSF as described in detail below, provides a technical perspective on WQT design and viability that may also help satisfy WQT Policy and guidance requirements for WQT programs. In particular, as listed in the EPA Watershed Scale memorandum[15], the DSF will help LIS planners, managers and regulators to:

- Identify and set water quality goals, including pollutants of concerns and their sources, and waters targeted for improvement;
- Determine how upstream and downstream waters are connected using the best available maps and tools for the watersheds of interest;
- Determine the upstream and downstream extent of impact for the pollutant [and integrated landscape pressures] of concern; and
- Identify watershed features [and conditions] that may inform the trading area [and the potential and viability of trading to improve management and aquatic ecosystem outcomes].

[15] See Footnote 14.

The Decision Support Framework

As introduced above, a LISS Enhancement Project awarded to UConn's CLEAR, is completing a Decision Support Framework (DSF) based on land-cover metrics to help guide watershed managers towards attaining user-defined water quality goals and targets. The DSF also provides an analytical framework for scoping viability and potential for WQT and technical support for scenario-testing at varying scales to guide design and implementation of programs.

The DSF is formulated as a steady-state platform of relative change to avoid pervasive complications caused by spatial and temporal variation. The use of very precise and accurate 1-meter resolution land cover data aggregated into just three general classes minimizes error due to excessive parameterization. Further, all spatial trading unit and credit estimates and outcomes are normalized relative to time and space to not only provide a consistent basis for analysis, but to facilitate trading in a more realistic portrayal of land cover change and management recovery times that are often on the scale of decades.

Since the DSF will not be finalized for several months, the technical documentation is not yet available as a reference; hence, this overview describes the features of the DSF, its technical basis, and its assessment and planning capabilities as applied to WQT. Therefore, the qualification stated in the Introduction is repeated here, that ***all analyses, conclusions, and recommendations should be considered preliminary and subject to change***.

Study Area

The geographic domain for this analysis is the entire state of Connecticut, an area that is more than adequate to test out the skill of the methodology and evaluate potential trading options and scenarios. It includes nearly 2800 geographic units, termed "local basins", most less than 5000 acres, that might be considered individual trading units (Figure 2). The local basins can be aggregated to evaluate any user-defined basin, watershed, or sub-watershed of interest and test suitability of trading domain program scenarios that meet local needs and EPA WQT policies. The DSF could also be expanded to the entire LIS watershed with a comparable land cover layer if trading at that scale is deemed practicable.

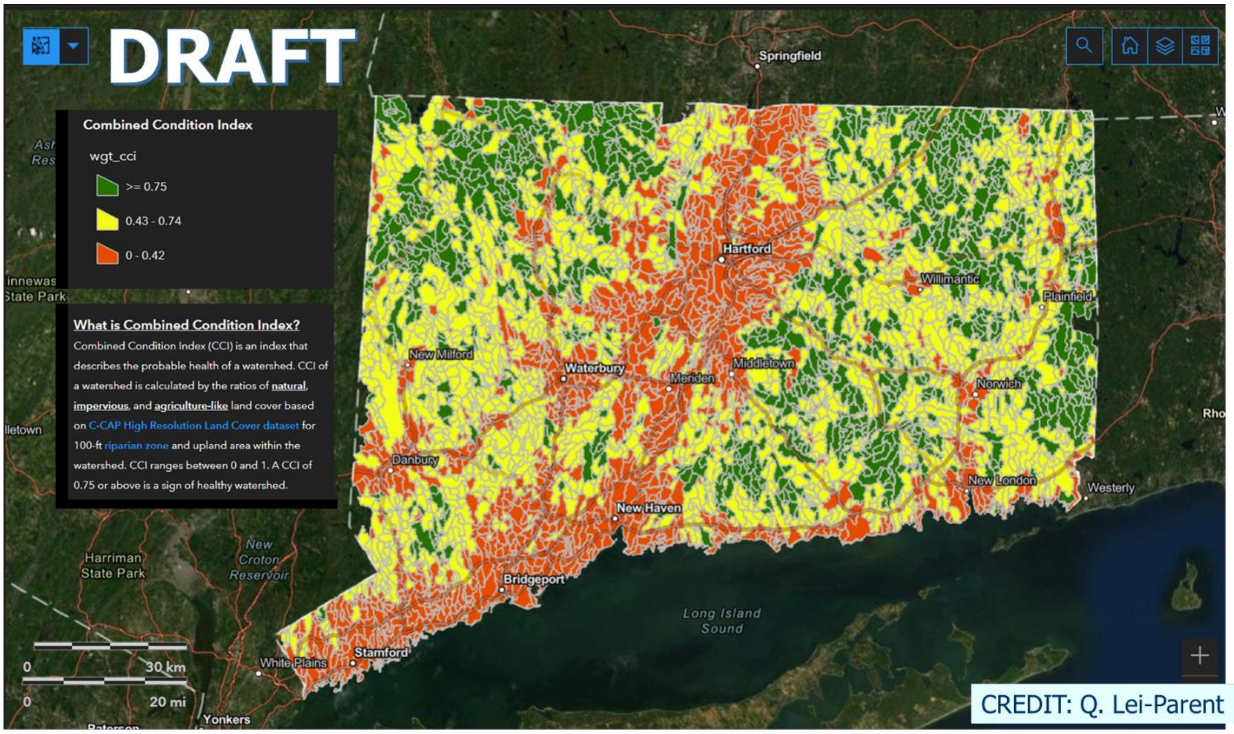


Figure 2. Distribution of local basins in Connecticut used in the Decision Support Framework (DSF) for assessing watershed condition and related stream biointegrity using three Combined Condition Index (CCI) levels representing high (green), mid (yellow) and low (red) bioconditon. (CLEAR LISS Enhancement Study on Watershed Metrics and Decision Support, in preparation)

Analytical Foundation

The objective of the CLEAR LISS Enhancement project is to use land cover metrics to assess aquatic biological condition relative to watershed condition and develop a DSF to guide planning and management. The DSF is based on simplified equations drawn from empirical land cover and biological stream response data that relate land cover character to stream biointegrity, a measure of stream health. DSF scenarios identify landscape management actions necessary meet stream biointegrity outcomes consistent and harmonized with water quality goals and objectives and nitrogen loading in that ecosystem context.

The relationship between land cover and aquatic ecosystem health is well-studied and fundamental to empirical watershed models that define collective chemical, physical, and biological stress that impact aquatic life health. Land cover is the dominant driver of overall aquatic ecosystem health (Allan, 2004; Allan and Castillo, 2007) as defined and assessed in the USEPA (2016) *Practitioner's Guide* and a primary determinant of nonpoint source/stormwater (NPS/SW) nitrogen loading to Long Island Sound (LIS), a management focus of the Long Island Sound Study (LISS).

The decision support framework (DSF) described in this report pairs a land-cover condition index with ecosystem indices used by EPA and the State of Connecticut to link land cover data to overall aquatic ecosystem health assessments. These indices include:

- Biocondition Gradient (BCG), an assessment of stream health based on aquatic plant and animal assemblage indicators.

- Macroinvertebrate Multimetric Index (MMI), which scores stream site water quality based on the stream's populations of aquatic macroinvertebrates.
- Watershed Condition Index (WCI), which scores watersheds based on their developed, cultured, and natural land cover.
- Buffer Condition Index (BCI), a companion to the WCI which provides a land cover score for the riparian buffer area.
- Combined Condition Index (CCI) comprising both the WCI and BCI, which incorporates the mitigation potential of the riparian buffer, to produce a holistic watershed health score or index of stream biointegrity.

The *Biocondition Gradient* (BCG) of aquatic plant or animal assemblage indicators has been used by EPA and state regulators for decades to assess stream health and guide designated-use status and management for Aquatic Life Use Support (ALUS) under the CWA (Gerritsen and Jessup, 2007; Stamp and Gerritsen, 2009; USEPA, 2013). The DSF assesses aquatic life state and nitrogen loads in that context to assure that nitrogen loads are consistent and harmonized with healthy water quality objectives and biointegrity outcomes.

The literature on the *impact* of watershed disturbance and its management, especially development and agriculture, on aquatic ecosystem health reflected in the BCG is extensive (e.g., NRCS, 2009; 2010; Schueler *et al.,* 2009; USEPA, 2016). There is also a growing body of knowledge on the relationship between natural landscape features, including in the LIS region, such as forest and riparian vegetative cover extent (e.g., Becker and Bellucci, 2021; Bellucci, Becker and Beauchene, 2011; Bellucci, et al., 2013; Goetz *et al.* 2003; USEPA, 2012) and aquatic life use condition along the BCG as well as the role of stream connectivity (USEPA, 2015). Riparian buffers as a landscape management practice that mitigates the pressures from upland disturbance is also extensively studied, including the positive response of aquatic communities and the reductions of pollutant loadings (Buffer Options for the Bay, Undated; Flanagan et al., Undated; Goetz et al., 2003; Smith et al., 2008; Stacey, 2018).

The Macroinvertebrate Multimetric Index (MMI) used by CTDEEP in their BCG protocol was selected as the response indicator for this analysis and translated to a decimal range of 0.00 to 1.00 from the reported percentages. The MMI has a long history of use in CT and the Northeast region for assessing ALUS under the CWA and guiding Tiered Aquatic Life Use (TALU) towards stepwise improvements at six levels along the BCG. Details on the CTDEEP protocols for sampling and calculating the MMI and TALU are available at: https://portal.ct.gov/DEEP/Water/Inland-Water-Monitoring/Ambient-Benthic-Macroinvertebrate-Monitoring.

MMI data from the 2020 Biological Condition Gradient (BCG) assessment report were used to develop the relationship between land cover condition and biointegrity. Samples collected primarily in 2018 from the CTDEEP dataset yielded 200 samples distributed throughout the state that were suitable for the analysis. A subset of 139 samples from 1^{st} – 4^{th} order streams representing 121 unique sites (18 stations were sampled on two occasions) were used to finalize the relationship. The character of lower order streams reduces potential complications associated with higher order streams that might have pockets of concentrated discharge or complex landscape disturbance patterns.

Initial land cover statistics for each contributing watershed were from UConn's Center for Land Use Education and Research (CLEAR) buffers compilation in 100' and 300' fixed widths at 30-m resolution (Wilson and Arnold, 2008; Wilson, Barrett and Arnold, 2011). Those datasets were updated with 1-m and 10-m resolution land-cover data generated for the CLEAR LISS Enhancement Project. Ultimately, the 1-m resolution data and a 100-ft buffer width proved to be most useful to the analysis and are used here.

Three land cover types representing developed (Impervious Cover (IC)), cultured (Agriculture-Like (AL)), and Natural Cover (NC) were used to formulate a Watershed Condition Index (WCI) for watershed areas upland of the riparian buffer and a companion Buffer Condition Index (BCI) within the riparian buffer (Table 1). Together, as shown below, they comprised a Combined Condition Index, or CCI, that combines the effects of upland land cover and the modifying effects of the buffer.

The CLEAR Enhancement study developed an independent (causal) variable (the CCI) that is aligned to the dependent (response) variable (the MMI), that would reliably assess aquatic health based on landscape condition. There are many complex mechanistic and deterministic models that can accomplish this, but a secondary study objective was to keep the model reasonably simple and salient to a broad segment of managers and the public. As described below, the DSF met those objectives and can effectively guide assessment and management towards desired and tractable biointegrity and TN loading outcomes and also provides a scoping and assessment of WQT program viability and potential, the primary objective of this analysis.

Table 1. Aggregation of land cover classifications into three categories for data sets used in developing the CCI. The 1-meter CCAP – 2016 layer was used for the final CCI.

Aggregated Class	30-meter NLCD - 2011 WikiWatershed.org	30-meter CCAP - 2016 CLEAR	10-meter CCAP - 2016 CLEAR	1-meter CCAP - 2016 CLEAR
Natural	Deciduous Forest Evergreen Forest Mixed Forest Shrub/Scrub Woody Wetlands Emergent Herbaceous Wetlands Open Water	Grassland Deciduous Evergreen Mixed Forest Scrub/Shrub Bare Land <u>Palustrine</u> Forested Wetland Scrub/Shrub Wetland Emergent Wetland Aquatic Bed <u>Estuarine</u> Scrub/Shrub Wetland Emergent Wetland Aquatic Bed Unconsolidated Shore Bare Land Open Water	Upland Forest Scrub/Shrub Bare Land <u>Palustrine</u> Forested Wetland Scrub/Shrub Wetland Emergent Wetland Aquatic Bed <u>Estuarine</u> Scrub/Shrub Wetland Emergent Wetland Aquatic Bed Unconsolidated Shore Bare Land Open Water	Grassland Deciduous Evergreen Mixed Forest Scrub/Shrub Bare Land <u>Palustrine</u> Forested Wetland Scrub/Shrub Wetland Emergent Wetland Aquatic Bed <u>Estuarine</u> Scrub/Shrub Wetland Emergent Wetland Aquatic Bed Unconsolidated Shore Bare Land Open Water
Agriculture-Like*	Barren Land (Rock/Sand/Clay) Grassland/Herbaceous Pasture/Hay Cultivated Crops	Developed Open Space Cultivated Land Pasture/Hay	Upland Herbaceous	Developed Open Space Cultivated Land Pasture/Hay
Developed*	Developed Open Space Low Intensity Medium Intensity High Intensity	High Intensity Medium Intensity Low Intensity	Impervious Cover	Impervious Cover
*Originally comprised the "Non-Natural" category.				

The Combined Condition Index

The Combined Condition Index (CCI) was developed to assess the effects of land cover condition on stream biointegrity. It integrates a Watershed Condition Index (WCI) and a Buffer Condition Index (BCI) according to the following formulation:

<u>Combined Condition Index (CCI):</u>

CCI = WCI x (1 + (BCI - WCI))

Where:

WCI = Watershed Condition Index = Natural Cover (NC_{ws}) area in the watershed upland from the buffer divided by the sum of the NC_{ws} area plus Agriculture-like Land Cover (AL_{ws}) area times a weight of 2 plus Impervious Cover (IC_{ws}) area times a weight of 7

WCI = $NC_{ws}/(NC_{ws} + (AL_{ws} \times 2) + (IC_{ws} \times 7))$

And:

BCI = Buffer Condition Index = Natural Cover (NC_b) area in the buffer divided by the sum NC_b area plus Agriculture-like (AL_b) area times a weight of 2 plus Impervious Cover (IC_b) area times a weight of 7

BCI = $NC_b/(NC_b + (AL_b \times 2) + (IC_b \times 7))$

The “weighting” shown above has the dual purpose of identifying the relative pressure intensity from the three land cover classes and of centering the index with respect to the MMI response variable paired with the CCI. Although other land cover scales were evaluated (10-m and 30-m), the CCI provided the best fit to the sample population of 121 MMI watersheds (139 samples) at a fine-scale resolution (1-m) with a 100’ buffer (Figure 3). The slope is centered at the midpoint of the x and y axes (0.5) with a y-intercept of 0.2 and a predicted maximum MMI of y_{max} = 0.8. Although the MMI theoretically ranges from 0 – 1, neither extreme has been observed in the field as there are no watersheds that are either 100% (all NC) or 0% (all IC) structurally and functionally natural or impervious, respectively.

The CCI application was on a site-specific basis over the entire CCI range (0-1). While not aligned to the full MMI range, the CCI describes a relative, normalized biocondition response to watershed condition reflected in the CCI as y = x. This form of “scoring”, supported by the CCI – MMI analysis, provides reasonable assurance that high condition watersheds would yield a concomitant biointegrity response; it will not equate to or predict the MMI since all watersheds are inherently variable naturally and may be subject to pressures extraneous to the CCI in addition to the effect of the scoring process, which correlates the BCG and CCI ranges from 0 to 1.

Hence, the CCI is appropriate in a site-specific, local context for predicting a relative biointegrity response for assessment and decision support for management. The scoring or normalization also facilitates intercomparisons among watersheds, helpful for strategic planning and assigning priorities to projects and management efforts, and to facilitate trading as used in this analysis.

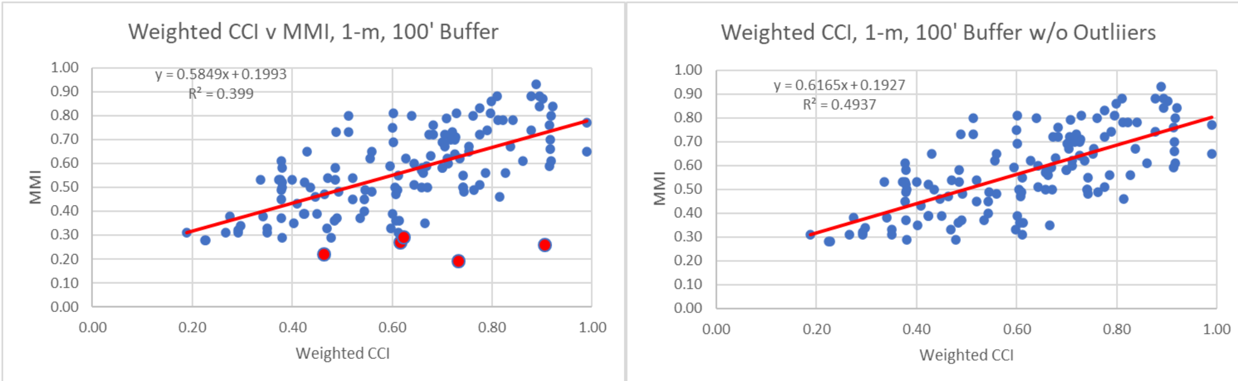


Figure 3. The Weighted Combined Condition Index (CCI_w) relationship to the Macroinvertebrate Multimetric Index (MMI) for 121 1^{st}-4^{th} order Connecticut streams (139 samples) using 1-m resolution land cover data and a 100' buffer with potential outliers identified in red (left) removed from the relationship (right).

Total Nitrogen Loading

The DSF uses standard total nitrogen (TN) export coefficients typical of the Northeastern US region to link three land cover types used in the CCI to TN yields (Table 1): Impervious Cover (IC) for Developed Lands; Agricultural-Like Cover (AL) representing a cultivated landscape, including crops and residential lawns and landscapes; and Natural Cover (NC) vegetation types. Generalized export coefficients typical of CT's geography of 14, 4 and 0.6[16] lbs/acre-yr for IC, AL and NC land classes, respectively, were used as a starting point to determine Total Nitrogen (TN) yields relative to the CCI watershed condition index. The initial export coefficients were aligned with the CCI producing a final exponential relationship (Figure 4):

TN yield = Total Nitrogen export in lbs/acre-yr = $16.63e^{-2.82x}$

Where:

e = the natural exponential e = 2.71828

And:

x = the CCI

[16] These values were approximations taken from a current NEIWPCC LISS Enhancement Project developing a tracking system for nutrients and management.

Nitrogen yields predicted by the CCI reflect both the extent of land cover types in the watershed and buffer, and the mitigative effects of the buffer. A CCI = 0 depicts TN yield of 16.63 lbs/acre-yr for a 100% IC condition; a CCI = 1, reflective of a 100% NC condition produces a TN of about 1 lb/acre-yr. Figure 4 shows the TN load yields in lbs/acre-yr generated by the equation above, and the effect of decreasing IC connectivity (Sutherland, 2000) as the CCIs increase leading to reduced TN yields. Conversely, the TN yields increase with increasing fragmentation of NC caused by disturbance or conversion to AL or IC land covers (Becker and Bellucci, 2021; Holdt, Civco and Hurd, 2004; Hurd, Wilson and Civco, 2002).[17]

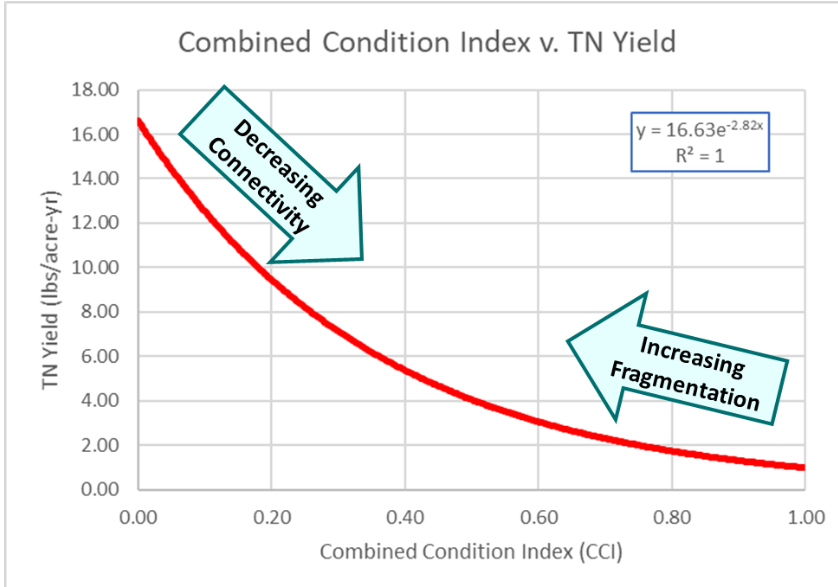


Figure 4. The Combined Condition Index (CCI) and Total Nitrogen (TN) yields for CT watersheds and effects of reducing impervious cover and connectivity (increased CCI – reduced TN yield) and increasing natural cover and fragmentation (decreased CCI – increased TN yield).

The accuracy of the TN yield estimates was checked by comparing them to flow-normalized TN loads (Mullaney, 2016) from 13 USGS monitoring stations in Connecticut and the Spatially Referenced Regression On Watershed (SPARROW) statistical model outputs[18] (Ator, 2019a; 2019b), POTW loads removed (Table 2). The comparison showed a good correlation between the CCI equation TN load estimates from the DSF for both the empirical Mullaney data analysis and the model loads from SPARROW (Figure 5).

The relationships between DSF TN loading and the USGS and SPARROW loads were strongly correlated for both 13 watersheds of all sizes and for 10 watersheds less than 300,000 acres in size (Table 2 and Figure 5). The correlation may have been strengthened by including the much larger Housatonic River at Stevenson site. For the 10 smaller watersheds, the correlation did weaken from the Housatonic River removal, but also due to outliers and perhaps the kinetics of nitrogen in highly enriched systems. Two watersheds stand out as outliers – the Quinnipiac River at Wallingford for both USGS and SPARROW estimates and the Hockanum River near East Hartford for SPARROW (Table 2). This is likely a function of point source, POTW-dominated TN loading.

[17] NB, it is important to use consistent land cover data interpretation, including classifications and resolution, especially for detecting spatial variation and changes over time effectively and accurately.
[18] SPARROW Mapper: 2012 SPARROW Models for the Northeast: Total Phosphorus, Total Nitrogen, Suspended Sediment, and Streamflow. https://sparrow.wim.usgs.gov/sparrow-northeast-2012/

Table 2. Total Nitrogen (TN) load comparison for 13 USGS Stations (CT River eliminated) using USGS, SPARROW and CCI estimates with POTW load estimates removed. The three stations highlighted in tan were removed for the smaller watershed comparison.

USGS Station Number	USGS Station Name	Watershed Area (acres)	Acre in CT (acres)	Pct in CT	USGS (Mullaney) 2004-2013 (tons/yr)	USGS SPARROW (tons/yr)	CCI Estimate (tons/yr)
01122610	Shetucket River at South Windham CT	262467	258118	98	392.0	445.5	297.4
01124000	Quinebaug River at Quinebaug CT	96654	10326	11	93.1	97.7	64.2
01127000	Quinebaug River at Jewett City	453149	260303	57	909.2	762.2	562.6
01184000	Connecticut River at Thompsonville CT	6189857	15547	0.25	N/A	N/A	N/A
01188000	Bunnell Brook near Burlington CT	2554	2554	100	4.3	6.4	3.5
01188090	Farmington River at Unionville CT	241661	146214	61	210.4	312.3	269.8
01189995	Farmington River at Tariffville CT	368748	269090	73	673.1	533.7	570.5
01192500	Hockanum River near East Hartford CT	46957	46957	100	154.2	23.1	154.8
01193500	Salmon River Basin near East Hampton	65050	65050	100	98.5	147.1	75.9
01196500	Quinnipiac River at Wallingford CT	70984	70984	100	86.8	49.5	259.0
01205500	Housatonic River at Stevenson CT	988074	527530	53	1363.6	1388.7	1490.9
01208500	Naugatuck River at Beacon Falls	166455	166455	100	339.9	461.0	368.6
01208990	Saugatuck River	13287	13287	100	19.1	24.9	18.0
01209710	Norwalk River at Winnipauk	20860	20860	100	52.9	60.4	56.0

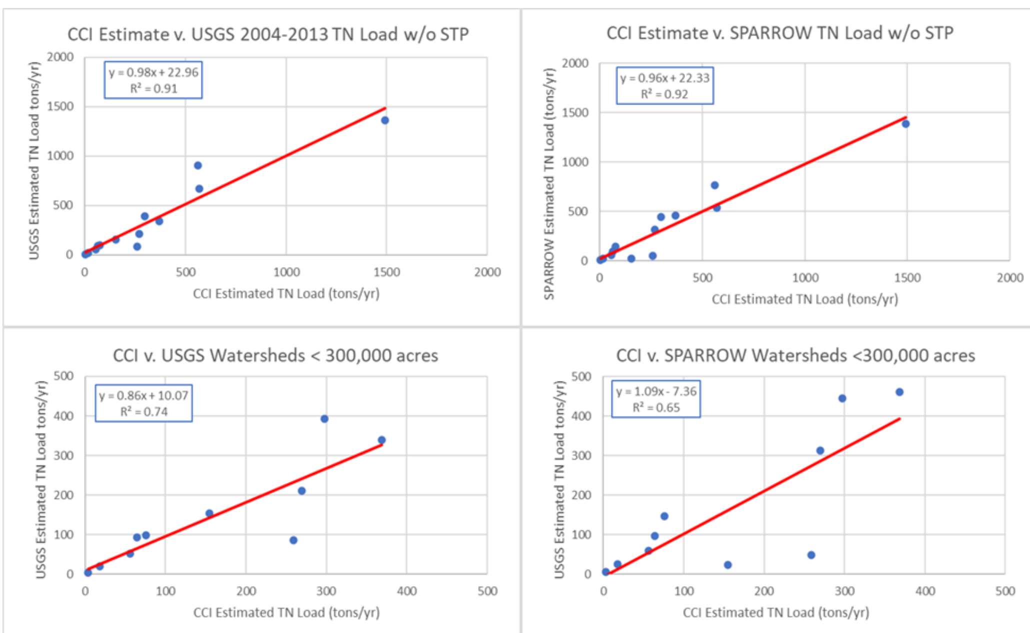


Figure 5. CCI Total Nitrogen (TN) load estimates compared to USGS and SPARROW estimates for 12 watersheds (top) and 10 watersheds less than 300,000 acres in size (bottom). (See Table 2).

Time-variable, accurate TN load contributions from major dischargers such as POTWs (Figure 1) are difficult to isolate from landscape loads that are meteorologically variable at a monitoring point. If sewage TN loads are overestimated, the NPS/SW loads will be erroneously low, as may be the case here. A second cause may be increased rates of denitrification often observed in enriched situations where water or sediment anoxia promotes denitrification (Galloway, et al., 2003). This is sometimes referred to as "the nitrogen paradox" because more nitrogen may be removed from the system under these enriched conditions than after management reduces the pollutant load and denitrification capacity diminishes (Billen, 1990).

Benchmarking Biocondition and Total Nitrogen Loading

As discussed in earlier sections, successful trading requires a governing target, standard, or TMDL to act as a "cap" to establish contextual credit inventories and supply and demand under current, planning, and managed scenarios. Lack of a cap and uncertain targets have been identified as an obstacle to effective trading (Selman, et al., 2009). The DSF offers an alternative benchmarking approach to establish several breakpoints along the continuum of the BCG. Benchmarks can be used to guide policy and the public process for target-setting, developing TMDLs, and facilitating and tracking WQT using both the CCI and TN indicators independently, or in concert, as the basis for credits and WQT.

The CCI represents a gradient or continuum of effect established by the BCG concept. Setting standards along a continuum is challenging because the associated criterion, target, endpoint, changepoint, or benchmark used for assessment and to set a final standard is often subject to interpretation and variable in time (e.g., season) and space (e.g., site-specific). Often, there is not provide a sharp dividing line between healthy and impaired conditions of an ecosystem unlike the case for toxic pollutants; thus, predictions of ecosystem health along a continuum may engender a range of acceptable outcomes. Further, legal standards and criteria are presumptively "one size-fits-all", often covering broad jurisdictional, geographic, and time scales. Consequently, natural variability ranges may bracket a standard and contribute to Type I and Type II assessment error.

Inaccurate standards combined with imprecise environmental health assessments and predictions caused by natural circumstances or erroneous interpretation of health metrics can create a dilemma for management and policy. This "continuum conundrum"[19] is not only a major obstacle in setting standards that appropriately define desired health and management outcomes of aquatic ecosystems but are a potential constraint on effective WQT and credit definition. As established in EPA policies, the goal of WQT is to attain healthy conditions more efficiently without compromising water quality targets. However, with or without WQT, confidence in water quality assessments and often costly management actions may be diminished if anticipated ecosystem benefits are not realized even when the standard is met. Setting appropriate caps and targets with reliably predictable outcomes that avoid the continuum conundrum is key to successful management and trading that sustains public and political support.

While landscape degradation and deforestation are increasingly linked to biodiversity decline at all scales, from local to global, effective management should combat collective drivers of land degradation, climate change, and agriculture that provide for healthy human conditions as well (NAS, 2021; Stiglitz,

[19] Used as a novel but apropos application of the term here. The term is widely recognized as the academic grading scheme, ranging from 0 to 100 percent and translated into grades, usually from A to F. Since passing grades are in the A to D range, there is a continuum that may represent a conundrum as to what an acceptable passing grade is. It is also a conundrum for a Pass/Fail system that a cap or water quality criterion might represent, especially since management is often forced to the "brink" of the standard that represents an impairment just below the brink, and triggers management and regulatory authorities to act. Above the standard, pressures such as development may be allowed, resulting in a game of brinksmanship that may come close to the standard, and create an impairment under certain conditions within the range of variation or uncertainty. The term was recently used, and perhaps coined by Isaacson (2021) regarding the ethics and application of DNA editing technology in humans, pp. 337-338.

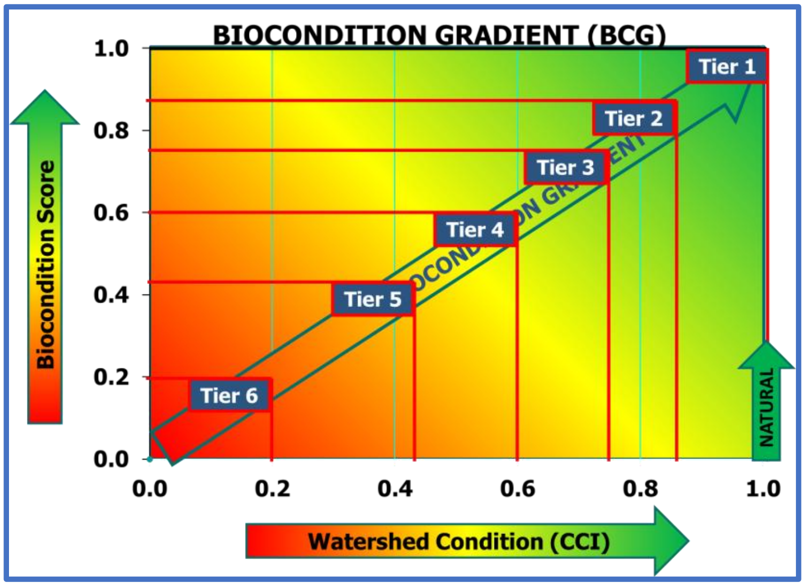
Fen and Fitoussi, 2009; Wilson, 2016). Recovery or rehabilitation of the watershed and buffer are the most powerful management actions to improve biointegrity and resiliency in both terrestrial and aquatic ecosystems by ensuring a balance of “operating space” that sustainably supports Nature and humanity (Stevenson, 2011; Cardinale et al., 2012; Liu et al., 2015; Diaz et al., 2019) and the ecosystem services that healthy aquatic ecosystems provide, especially water supply (Zipper et al., 2020). For resilient conditions to co-exist in both natural and human domains, a sustainable balance of fundamentally incompatible social and environmental functional outcomes must be achieved. In a sense, the CCI speaks to that balance, and a mechanism for balancing operating space as best we can though there will undoubtedly be compromises for both if a sustainable outcome is to be realized. Trading can be part of the solution.

EPA’s Biocondition Gradient (BCG) and the Tiered Aquatic Life Use (TALU) were devised to promote better management along a continuum as applied here for biointegrity and TN in the DSF and can provide an opportunity for WQT at both the individual pollutant and the ecosystem levels. BCG and TALU approaches help alleviate the “continuum conundrum” effect that has limited progress in setting caps and standards necessary to guide effective management planning and WQT. TALU distributes biological response along 6 tiers of effect that could serve as benchmarks for guiding management (Gerritsen and Jessup, 2007; Stamp and Gerritsen, 2009; USEPA, 2013; 2016) and as caps for trading.

CCI benchmarks were applied to CTDEEP’s TALU application of the BCG by pairing CCI values with breakpoints for each of the 6 tiers (Figure 6). Connecticut’s combined MMI score for Tiers 1 and 2 was greater than 0.75, which was split into two here to provide a Tier 1 range from 0.88 – 1.00 and 0.75 – 0.87 for Tier 2. On this basis, the benchmarking concept used for biointegrity (Figure 6) was then converted to TN yields that provide yield estimates harmonized with biocondition outcomes based on landscape condition, i.e., CCI values (Figure 7). Benchmarks provide managers, policymakers and the public with options for setting targets and interpreting impacts consistent with local goals and objectives that are also essential as a cap for WQT.

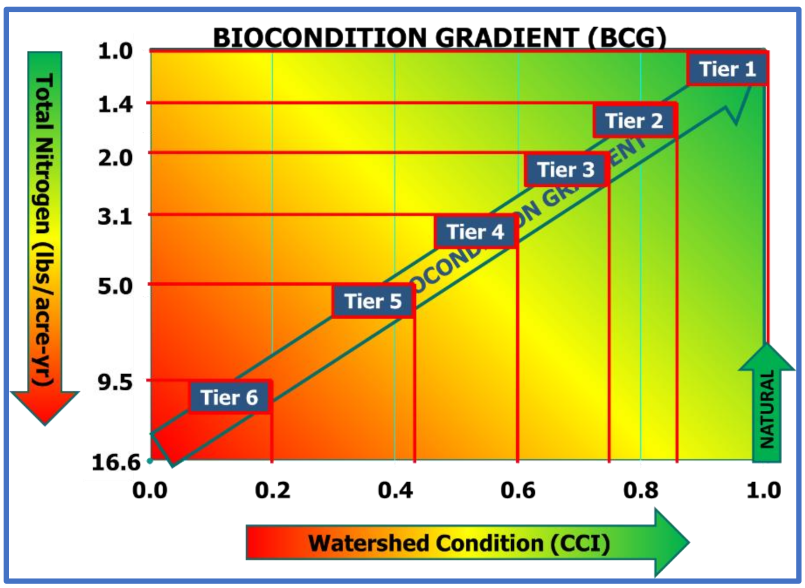
Often the tiers in the middle range of the BCG continuum, e.g., Tiers 3 and 4 in TALU, are referred to as the “threshold” range. Although the CCI reveals no apparent threshold where the conditions appear to deteriorate more rapidly, the Tier 3-4 range may be used to describe the range where a management target or cap may be appropriately set consistent with water quality goals and objectives. The 0.75 CCI (2.01 lbs/acre-yr for TN) at the upper end of the range may serve as a point where decline is of concern and will at some point along the continuum be considered to represent an impairment under the CWA. At the lower end of the range, a CCI equal to 0.43 (TN = 4.95 lbs/acre-yr), impairment may be considered certain.

Setting the caps or a criterion point to set a standard is a public and legal decision and process. For trading assessment and discussion purposes, the midpoint (CCI = 0.60; TN = 3.06 lbs/acre-yr) of the Tier 3 to 4 range will be used as an example cap. The final decision on CCI or TN targets requires that public and legal process and may result in a standard and criterion or set of criteria, and a related TMDL or other enforceable plan, perhaps established under the LISS Nutrient Management Strategy, that will establish a cap to guide WQT.



Tier	CCI
1	0.88-1.00
2	0.75-0.88
3	0.60-0.75
4	0.43-0.60
5	0.20-0.43
6	0.00-0.20

Figure 6. Application of benchmarks or breakpoints for Connecticut's Tiered Aquatic Life Use (TALU) (Gerritsen and Jessup, 2007) and related CCI.



Tier	CCI	TN Yield
1	0.88-1.00	1.39-1.00
2	0.75-0.88	2.01-1.39
3	0.60-0.75	3.06-2.01
4	0.43-0.60	4.95-3.06
5	0.20-0.43	9.46-4.95
6	0.00-0.20	16.63-9.46

Figure 7. Application of CCI benchmarks or breakpoints for Connecticut's Tiered Aquatic Life Use (TALU) (Gerritsen and Jessup, 2007) to TN yields.

The TALU tiers and CCI and TN benchmarks are also color-coded into three categories, representing the CT DEEP proposed management strategies for mitigation, recovery, or conservation based on each tier's state and management potential (Bellucci, Beauchene and Becker, 2008). A gradient of color is correlated to TALU benchmarks (Figures 6 and 7) representing the actual continuum effect in the graphic background and the three TALU categories in the accompanying tables for CCI and TN. A conservation management focus is coded green, a recovery focus is yellow, and a mitigation focus is red. These color codes are used in subsequent assessment scenario graphics to visually highlight tier assessment and management focus with respect to the benchmarks and potential for recovery and lend texture to the local watershed maps that may be generated to describe trading potential within and among watersheds (Figure 2).

The TN yield rates are also formulated as Enrichment Factors (EF), i.e., the proportional dose of TN relative to a natural state. The natural state indicated in Figures 6 and 7 is represented by a CCI = 1, which coincidentally translates to a TN yield of 1 lb/acre-yr. An EF is simply the current TN yield divided by the estimated natural TN yield (Becker, 2014), which is equal to about 1 lb/acre-yr. This coincidence of a natural TN yield value of 1 means TN export rates and EFs are numerical equivalents since any number divided by 1 is the number itself. For example, with a CCI = 0, the TN yield is 16.63 lbs/acre-yr (Figures 4 and 7), which is also the EF representing a proportional dose of 16.63 times the expected TN yield under 100% NC land cover.

EFs can also be calculated by dividing the estimated natural TN load (e.g., tons TN/yr) based on a TN yield multiplied by the watershed or basin size (e.g., acres) into the current load or other loading scenario of interest, providing a salient way to compare normalized condition and TN enrichment for any size watershed or basin. In sum, the EF's unitless translation of relative impact assessment (proportional dose) is useful for comparing watersheds of varying size and pollutant-load magnitude and normalizing credit exchanges among trading units that meet local and collective targets in a watershed.

Decision Support Framework Outputs and the Long Island Sound TMDL

The DSF TN outputs for the six management zones in Connecticut (Appendix 2) were compared to the LIS TMDL for dissolved oxygen (NYSDEC and CTDEP, 2000) and used to update the TN loads to 2016 land cover layer status. The DSF TN loading estimates compared very favorably with both the 2000 TMDL and the 2009 TMDL Update[20] estimates for NPS/SW (Table 3). This adds credibility to the DSF as an assessment and potential tracking platform for TN WQT programs and provides a connection to the TMDL for both management and trading.

Most of the difference between the DSF and TMDL estimates was attributable to reductions in the Point Source Wasteload Allocation (WLA), which reflects the good progress made managing POTWs in Connecticut under the CT NCE. The DSF POTW loading is taken from the 2018 report of the CT NCE (Dykes, 2019), representing attainment of the CT WLA in 2014. Differences in the NPS/SW[21] Load Allocation (LA) are likely due to the difference in estimation methodologies between the TMDL and the DSF, and the changes in land cover since the TMDL was adopted in 2000 and has not been updated until now using the 2016 1-m resolution land cover data (Table 1).

[20] K. Streich Draft Memorandum, DRAFT Long Island Sound TMDL Nitrogen Loading Estimates, December 14, 2010, February 10, 2011 revision. CT DEEP, Hartford, CT.

[21] Since the TMDL was written, stormwater in Municipal Separate Storm Sewer System (MS4) has moved into the point source category in the National Pollutant Discharge Elimination System (NPDES). Since the DSF does not differentiate between MS4 and "nonpoint" (non-MS4) areas, MS4 and NPS were kept combined. The 2009 CT DEEP loading estimates (Table 3) show how the separation NPS/SW look in the TMDL.

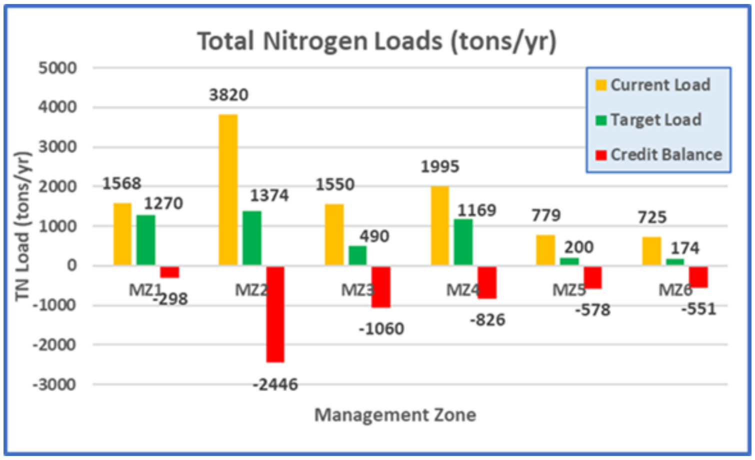


Figure 8. Current and target Total Nitrogen loads and credit balances in tons TN/yr for six Long Island Sound Management Zones.

On the downside, the TN yields and EFs show that TN loading rates still exceed a potential EF cap of 3, representative of a TN yield cap of 3 lbs/acre-yr, the midpoint benchmark between Tiers 3 and 4 (Figure 7). Only Management Zone 1 remains under the midpoint cap for NPS/SW TN loading but rises over the cap when a combined target with POTW loads are added in (Table 3; Figure 8). The bottom line for attaining a potential cap TN yield of 3 lbs/acre-yr with POTW TN loads added in is an additional reduction of 5,759 tons TN/yr, equivalent to about 75% of the 7,435 tons TN/yr reduction already achieved by 2018 from POTW upgrades. Since the DSF TN load estimates for NPS/SW tend to be lower than the TDML and its 2009 update, the need for additional TN reductions from NPS/SW could be higher if the TMDL estimates are used.

In sum, the DSF appears to be a viable model for assessment, planning, and management decision support. The CCI land cover condition index provides a robust assessment of biological condition along the BCG and translates well to CT DEEP's Tiered ALUS for benchmarking and user-defined target-setting. It also provides estimates of TN yields and loads, and EFs that compare favorably to TMDL numbers used for the LIS DO targets derived from CCI values to provide an ecosystem context that supports ecosystem-based management approaches. The detailed evaluation for WQT viability and potential follows, but the potential for the CT TMDL analysis (Table 3) seems constrained by a large demand for credits, nearly 6000 tons TN/yr, that cannot likely be met by managing NPS/SW. Given that most of the POTW reductions have already been attained, prospects for further TN reductions and for successful WQT that meets the mid-range target used in the DSF example are poor.

Table 3. Comparison of the 2000 and 2009 Update TMDLs with the Decision Support Framework (DSF) analysis for TN loading (tons TN/yr) from Connecticut's portion of 6 Management Zones. Negative Credits indicate the tons TN/yr loading over a potential cap of 3 lbs/acre-yr yield, i.e., a credit deficit. *2018 point source end of pipe (EOP) TN loads (tons/yr) are from Dykes' (2019) report of the CT NCE for 2018.

Source	LIS Management Zone 1	LIS Management Zone 2	LIS Management Zone 3	LIS Management Zone 4	LIS Management Zone 5	LIS Management Zone 6	CT TOTAL
2000 TMDL							
Nonpoint/Stormwater	1852	2473	999	1652	475	545	7996
Point Sources (Delivered)	1243	2805	2103	1669	948	1108	9876
TOTAL	**3095**	**5278**	**3102**	**3321**	**1423**	**1653**	**17872**
2009 TMDL Update							
Nonpoint	1664	1567	453	1550	175	213	5622
Stormwater	222	925	689	492	307	377	3012
Nonpoint/Stormwater	1886	2492	1142	2042	482	590	8634
Point Sources (Delivered)	1243	2805	2103	1669	948	1108	9876
TOTAL	**3129**	**5297**	**3245**	**3711**	**1430**	**1698**	**18510**
DSF Estimates							
Nonpoint/Stormwater	1198	2077	957	1483	441	434	6590
Pt Sources EOP (2018)*	370	1743	593	512	338	291	3847
TOTAL	**1568**	**3820**	**1550**	**1995**	**779**	**725**	**10437**
Natural Load	423	458	163	390	67	58	1559
Enrichment Factor (EF)	2.83	4.53	5.86	3.81	6.60	7.50	4.21
EF w/Point Sources	3.70	8.34	9.48	5.12	11.66	12.52	6.69
2000 TMDL - 2018 DSF	-1527	-1458	-1552	-1326	-644	-928	**-7435**
Credits - 3.0 TN Yield Cap							
Target Load (tons/yr)	1270	1374	490	1169	200	174	4677
Current Load (tons/yr)	1198	2077	957	1483	441	434	6590
Credit Balance	72	-703	-467	-314	-240	-260	-1912
Pt Sources EOP (2018)*	370	1743	593	512	338	291	3847
Credits w/ Pt Sources	-298	-2446	-1060	-826	-578	-551	-5759

Trading Feasibility and Potential Assessment

The Decision Support Framework (DSF) was applied to various scenarios to test skill and to evaluate the technical feasibility and potential of WQT for both biointegrity indicated by the combined condition index (CCI) and total nitrogen (TN) loading. The DSF has several attributes suitable for biocondition and TN assessment that translates to surplus or deficit credits with respect to management target-setting (or caps). These outputs or diagnostics of the technical feasibility and an assessment of potential for trading based on credit supply and demand[22] address the scoping objectives of this project (see Appendix 1A for the structure of the DSF and its attributes and Appendix 1B for a preview of the user-friendly output dashboard under development at CLEAR).

The DSF was used to run biocondition and TN loading trading scenarios in a centralized, statewide application. The centralized approach used in the LIS TMDL was compared earlier to the DSF analytics to evaluate the biointegrity and TN potential for centralized, statewide-scale WQT using Connecticut's six Management Zones from the TMDL (Appendix 2; Table 3). This state-wide assessment will be examined in more detail for both biointegrity and TN WQT potential.

Four smaller watershed scenarios were also analyzed to evaluate distributed watershed TN trading approaches at the individual watershed scale.[23] Smaller scale, distributed approaches can apply assessment endpoints in each individual segment or sub-unit, which reduces concerns over cross-watershed trading effects that occur in a centralized approach. The individual watershed examples elucidate some of the the policy and technical risks and opportunities associated with distributed WQT at the individual watershed scale, and the potential contributions to local and LIS water quality improvements that smaller-scale WQT in the LIS basin may afford.

The DSF scenarios assess conditions and test potential outcomes for a number of attributes used to evaluate WQT potential: the current condition based on existing land use; the cumulative credit surplus or deficit from each of the individual local basins within the trading domain for biointegrity and TN with respect to user defined benchmarks (Figures 6 and 7), which are measures of unused/exceeded capacity from landscape sources that might offset point source or NPS/SW loads; and an estimate of recovery potential[24] using a scenario of converting half of the agricultural-like (AL) acreage to natural cover (NC) upland of the riparian buffer, and converting all impervious cover (IC) and AL acreage to NC in the buffer. These scenarios are easily calculated in the DSF, which also has input fields for increases and reductions from point source and NPS/SW loads resulting from POTW expansions or upgrades and landscape change or management using best management practices (BMP), respectively (Appendix 1A and 1B).

In sum, the DSF was used to assess trading potential for ecosystem-based trading guided by prospective biointegrity targets benchmarked along the biocondition gradient, and single-pollutant trading based on

---

[22] See Footnote 3 for usage of "Supply", "Demand" and "Credits" in this analysis.

[23] See the final and companion reports completed as part of this study for more information on the importance of appropriate water quality trading market size for successful trading.

[24] In this report "Recovery Potential" is used in the narrow sense of recovery or rehabilitation of degraded land cover (IC and AL classes defined herein) to a natural (NC) state. EPA's Recovery Potential Screening Tool (https://www.epa.gov/rps/overview-recovery-potential-screening-rps#recovery) assesses the likelihood of successful restoration, protection or management in a complex socio-ecological context using indicator index values for ecological, stressor and social categories to assess management potential.

TN yields estimated from the CCI. These will be explored using both centralized and distributed approaches for a statewide and four individual watershed scenarios in the next sections.

State-Wide Assessment

Biointegrity

Assessments using closely aligned covariates for biointegrity and TN generally yield the same conclusions for WQT assessment as demonstrated in this state-wide exercise. The coarse-scale, centralized trading program comprising the six Connecticut management zones used in the TMDL (Appendix 2) was presented earlier to check the relationship between DSF TN loads and TMDL loads (Table 3). Since river delivery factors for TN are generally high (low attenuation), they are not applied in the statewide analysis and would be insignificant or undetectable at the local basin level in any case.

The DSF cannot make the decision on targets or caps, which is a public and regulatory process, so three biocondition-based trading cap scenarios were assessed using the management target or cap range of CCI benchmarks for Tiers 3 and 4 described earlier, i.e., a low-end 0.43, a mid-range 0.60 (see Table 3), and a 0.75 CCI for a high-end scenario (Figures 6 and 7). The Tier 3-4 range is within the apparent target response area of the CCI where biocondition brackets a healthy state at the high end, and a likely "impaired" state at the low end. The analysis shows that with a low-end target or cap (CCI = 0.43), 4 of the 6 Zones meet the cap, as well as the entire state total (Table 4). Under a more stringent cap scenario using the mid-level CCI of 0.60, all zones except MZ1 and the Pawcatuck River[25] and the state-wide total did not attain the cap, and for the most stringent CCI of 0.75, all zones and the state total exceed the cap (Table 4).

Although the DSF user can devise any number of recovery management scenarios appropriate to their local needs and management potential, the aggressive recovery management program example was used here to illustrate the effect of perhaps a Best Attainable Condition (BAC). Half the AL land in the watershed upstream of the buffer was converted to NC and all the IC and AL acreage in the buffer was converted to NC. Under this aggressive recovery scenario, and a low-end CCI cap of 0.43, all zones and the state would fall below the cap (Table 4).

For a highly protective condition (CCI = 0.75), none of the zones nor the entire state meet the cap. Under the aggressive management scenario, 4 of the 6 zones still would not attain the target. For the mid-range cap (CCI = 0.60), probably the most realistic target or cap scenario, 5 of the 6 Zones and the state exceed the cap under current conditions and, with the potential recovery management scenario, only two Zones would exceed the cap (Table 4).[26] This indicates some limited potential for biointegrity trading provided an aggressive management program can be implemented to generate credits to satisfy demand.

Table 4. Current state and managed state for biocondition with a recovery potential scenario applied that converts half of the Agriculture-Like land in the watershed upland of the buffer to Natural Cover, and all the Impervious Cover and Agriculture-Like land in the 100-ft buffer to Natural Cover. The shaded negative credit balances (a

[25] The Pawcatuck River watershed was not included in the LIS TMDL but is incorporated here for completeness.

[26] Since the CCI tends to represent a parabolic relationship with biocondition, it presently works best when BCI > WCI>0. An adjustment has been made to the CCI to eliminate this effect, but not in time to redo this analysis. Since, for the vast majority of the local basins, BCI>WCI, or only slightly lower, the revision only changes the number slightly and will not significantly alter the conclusions of this analysis.

"credit" is an acre of land) indicate the cap is exceeded and approximate the number of acres in need of management; positive credits indicate the surplus of acres below the cap, i.e., credits available for offsets.

				Current State				Recovery Potential Management				
Manage-ment Zone	Basin	Segments	Acres	CCI	Credits with 0.43 CCI Cap	Credits with 0.60 CCI Cap	Credits with 0.75 CCI Cap	Ave CCI	Credit Gain	Credits with 0.43 CCI Cap	Credits with 0.60 CCI Cap	Credits with 0.75 CCI Cap
Zone 1	Eastern/Thames	779	846878	0.65	202375	58406	-68626	0.86	157264	359639	215670	88638
Zone 2	Connecticut River	793	915957	0.48	101847	-53866	-191260	0.71	178571	280417	124704	-12689
Zone 3	Central CT/Quinnipiac	281	326988	0.38	2520	-53068	-102117	0.59	61482	64002	8414	-40635
Zone 4	Housatonic River	651	779270	0.54	115874	-16602	-133492	0.79	171312	287186	154710	37820
Zone 5	East Southwest Coastal	132	133610	0.32	-5007	-27721	-47762	0.53	26812	21805	-908	-20950
Zone 6	West Southwest Coastal	131	115841	0.27	-13716	-33409	-50785	0.48	23943	10228	-9465	-26842
Pawcatuck	Pawcatuck	25	30069	0.71	8960	3849	-662	0.89	4847	13807	8695	4185
Total		2792	3148614	0.51	412853	-122411	-594703	0.73	624231	1037084	501820	29528

In sum, as shown in this analysis, the potential for viable trading is dependent on two factors: target or cap stringency and landscape management or recovery potential. A lax cap, e.g., the 0.43 CCI, provides greater trading potential on a Zone basis – increasingly restrictive caps limit trading potential. Although the recovery potential management scenario shows improved prospects for trading under all three caps (Table 4), BAC is set at a very high bar of uncertain attainability.

Total Nitrogen

The assessment of TN trading potential parallels the centralized biointegrity analysis and places TN management in the same ecosystem context as biointegrity. The three TN yield cap scenarios were assessed using the CCI biointegrity benchmarks translated to a TN yield range from 2 to 5 lbs/acre-yr for Tiers 3 to 4 (Figures 6 and 7). As with the state-wide biointegrity trading assessment, this range represents the apparent target response area for TN yield and loading, bracketing a good eutrophic state at the high end, and a likely "impaired" state at the low end.

Because biointegrity and TN are harmonized within the CCI and share benchmarks, the trading potential results closely correspond (cf. Tables 4 and 5). The DSF predicts that with a low-end cap (TN yield = 5 lbs/acre-yr), 3 of the 6 zones meet the cap and all 6 and the entire state are close to the target as was the case for the biointegrity assessment. With the aggressive recovery management scenario used in the biointegrity assessment applied, all zones and the state would fall below the low-end cap (Table 5).

For a highly protective scenario (TN yield = 2 lbs/acre-yr, an EF of 2), neither the zones nor the state meets the cap and, with the recovery potential management scenario applied, 5 of the 6 zones and the entire state would not attain the target. The mid-range cap (TN yield = 3 lbs/acre-yr, 3 times the estimated natural TN load) is exceeded in 5 of the 6 zones and the entire state under current conditions; with the aggressive management scenario applied, half the zones and the entire state would still exceed the cap (Table 5).

A brief look at enrichment factors, which are by construct consistent with the TN mass loading analysis and conclusions on technical trading potential and viability. The "DSF Estimates" panel in Table 3 show EFs, which are an estimate of proportional TN loading relative to a natural load (100% Natural Cover). Landscape loading EFs ranged from 2.83 (MZ1) up to 7.50 (MZ6), correlated to increasing levels of development. With respect to the mid-level cap scenario (TN yield = 3 lbs/acre-yr), EFs > 3.0 represent three times the natural TN load. Only MZ1 fell below that benchmark (Table 3). With the 2018 point source loads added, some EFs exceed 9 times the estimated natural TN load (MZ3, MZ5 and MZ6) and ranged to over 12 (MZ6).

This analysis suggests limited potential for both biointegrity and TN credit trading, even within a broad-scale, centralized program for landscape NPS/SW management, depending on cap stringency and landscape recoverability. However, if point source TN loads are included as in the bottom panel of Table 3, all six Management Zones would have a substantial TN deficit to offset under a mid-range cap (3 lbs/acre-yr) scenario (Figure 8), and the entire state would need to offset nearly 6000 tons TN/yr to support a viable, centralized trading program under the mid-range cap.

Table 5. Current state and managed state for TN loading with a recovery potential scenario applied that converts half of the Agriculture-Like land in the watershed upland of the buffer to Natural Cover, and all the Impervious Cover and Agriculture-Like land in the 100-ft buffer to Natural Cover. The shaded negative credit balances (a "credit" is a lb of TN/yr; loads are in units of tons TN/yr) indicate the TN yield cap (lbs of TN/acre-yr) is exceeded and the approximate tons TN/yr in need of management; positive credit balances indicate the surplus load of TN in tons/yr below the cap, i.e., credits available for offsets.

				Current State				Recovery Potential Management				
Manage-ment Zone	Basin	Segments	Acres	CCI	Credits with 5 TN Cap	Credits with 3 TN Cap	Credits with 2 TN Cap	Ave CCI	Credit Gain	Credits with 5 TN Cap	Credits with 3 TN Cap	Credits with 2 TN Cap
Zone 1	Eastern/Thames	779	846878	0.65	919	72	-351	0.85	-521	1440	594	170
Zone 2	Connecticut River	793	915957	0.48	213	-703	-1161	0.71	-892	1105	189	-269
Zone 3	Central CT/Quinnipiac	281	326988	0.38	-140	-467	-630	0.59	-394	254	-73	-236
Zone 4	Housatonic River	651	779270	0.54	465	-314	-704	0.79	-703	1168	389	-1
Zone 5	East Southwest Coastal	132	133610	0.32	-107	-240	-307	0.53	-177	71	-63	-130
Zone 6	West Southwest Coastal	131	115841	0.27	-145	-260	-318	0.48	-183	39	-77	-135
Pawcatuck	Pawcatuck	25	30069	0.71	38	8	-7	0.89	-15	53	23	8
Total		2792	3148614	0.51	1244	-1904	-3479	0.73	-2887	4131	982	-592

The management options for generating offsetting credits from landscape recovery or from point source (POTW) upgrades and SW/NPS BMP applications seem insufficient, especially since most POTWs have attained their WLA and are unlikely to make significant, additional TN reductions. In fact, an analysis by CLEAR also shows that IC continues to increase at the expense of natural, mostly forested, lands, which would add to both biointegrity pressures and TN loads. From 1985 – 2010, forest loss was estimated to be about 13.3 acres/day[27], a rate that would be difficult to offset with recovery or landscape BMPs.

In sum, the technical analyses of a centralized trading program using the DSF identify an imbalance and deficit between credit supply and demand that is too large to support viable credit trading at both the Management Zone and state-wide scales. Prospects for expanding WQT into a multi-state, LIS watershed-wide program are not good.

Individual Watershed Biointegrity and Total Nitrogen Assessment

Given the limited potential for centralized trading on a broad geographic scale for the entire State of Connecticut or individual Management Zones, the DSF was used to explore a few individual watersheds of varying sizes and landscape condition for distributed trading potential. Smaller watershed, distributed WQT programs have the advantages of preventing or minimizing local water quality degradation; avoiding concerns over inter-basin WQT between disconnected watersheds; providingfull attention to the smallest trading units, e.g., the local basins used in the DSF; applying a more proximate assessment endpoint, e.g., at the mouth or confluence point of a river for a more distributed approach among upstream trading units; and affording a more manageable and transparent accountability system. These attributes may improve WQT programs' consistency with Selman et al.'s (2009) key factors for successful

[27] https://clear3.uconn.edu/viewers/ctstory/

trading program introduced above in the Trading Policy Section and provide benefits of WQT and water quality outcomes for amenable watersheds.

Four river basins of varying size and character were assessed for current condition using the mid-range cap scenario. Selected watersheds are the Salmon River watershed in Management Zone 2 (Connecticut River Basin); the Quinnipiac River watershed in Management Zone 3 (New Haven Harbor); the Norwalk River watershed in Management Zone 6 (Southwestern CT); and the Willimantic River watershed in Management Zone 1 (Eastern Connecticut) (Figure 9 and Appendix 2). Recognizing the parallel water quality outcome relationship between biocondition and Total Nitrogen (TN), the biointegrity outcomes are included in the output tables, but the discussion will focus on TN.

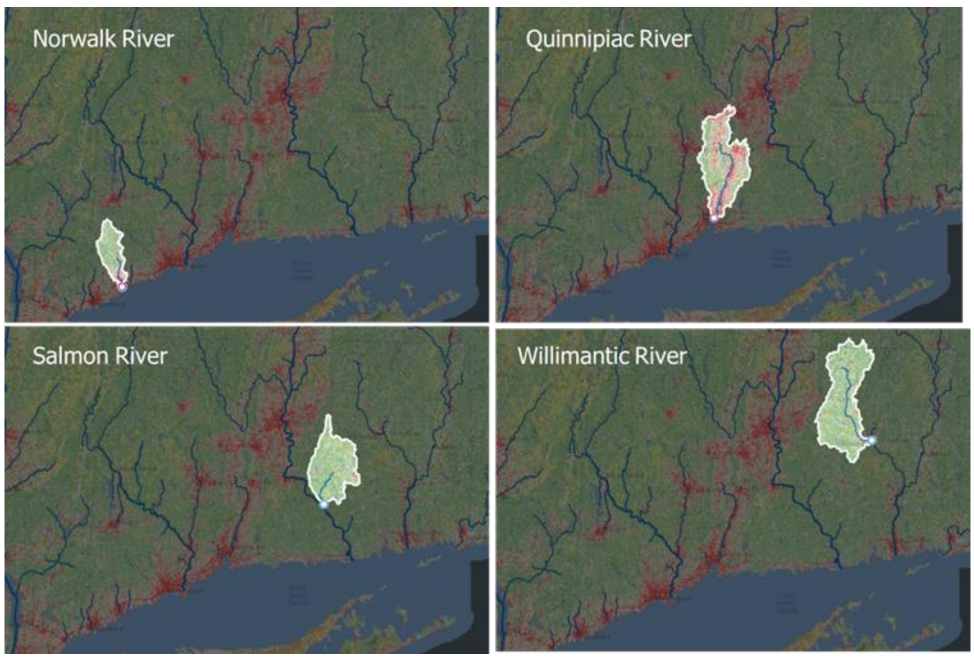


Figure 9. Four watersheds in Connecticut selected to explore Total Nitrogen Water Quality Trading using the Decision Support Framework.

The schematics and summary tables for each of the four watersheds describe characteristics and the potential for TN WQT within each watershed. The evaluation of just four watershed examples demonstrates that WQT potential will be variable depending on local factors, current landscape condition, and TN loading dynamics. The DSF allows for assessing those potentials as demonstrated for the centralized, state-wide analysis above; however, the importance of a viable cap, target or standard for successful WQT is not diminished in a distributed, individual watershed analysis.

The analysis employs the same three benchmarks used for the centralized analysis representing the Tier 3 and 4 range where a cap is likely to be set, but only the mid-range cap scenario (CCI = 0.6 and TN Yield = 3 lbs/acre-yr) is reported here. As emphasized above, standard setting will ultimately be the decision of state and local regulators, managers, and the public, especially with the need to set management targets that will serve as a cap to more effectively direct WQT towards positive outcomes.

Salmon River Watershed: The Salmon River Watershed (SRW) comprises 95,349 acres, 84.4% of which is NC land cover and only 5.2% IC. It is composed of 82 local basins (segments) in 11 sub-watersheds (Figure 10). The SRW CCI is 0.70 with no sub-watersheds falling below the Tier 4 CCI of 0.43 (Table 6). Only one sub-watershed, Meadow Brook, has a negative credit balance and an EF above the mid-range 3.0 cap. In sum, the ample supply of credits with little demand within the SRW is unlikely to stimulate much intra-watershed trading activity (Figure 11). Inter-watershed trading with proximate watersheds may be a possibility for offsetting the high level of enrichment in the Connecticut River Management Zone 2 (EF = 8.34) from proximate upstream sources (Table 3 and Figure 2) but would not move those degraded watersheds towards goal attainment, which may be deemed contrary to existing EPA Trading Policies and Guidelines.

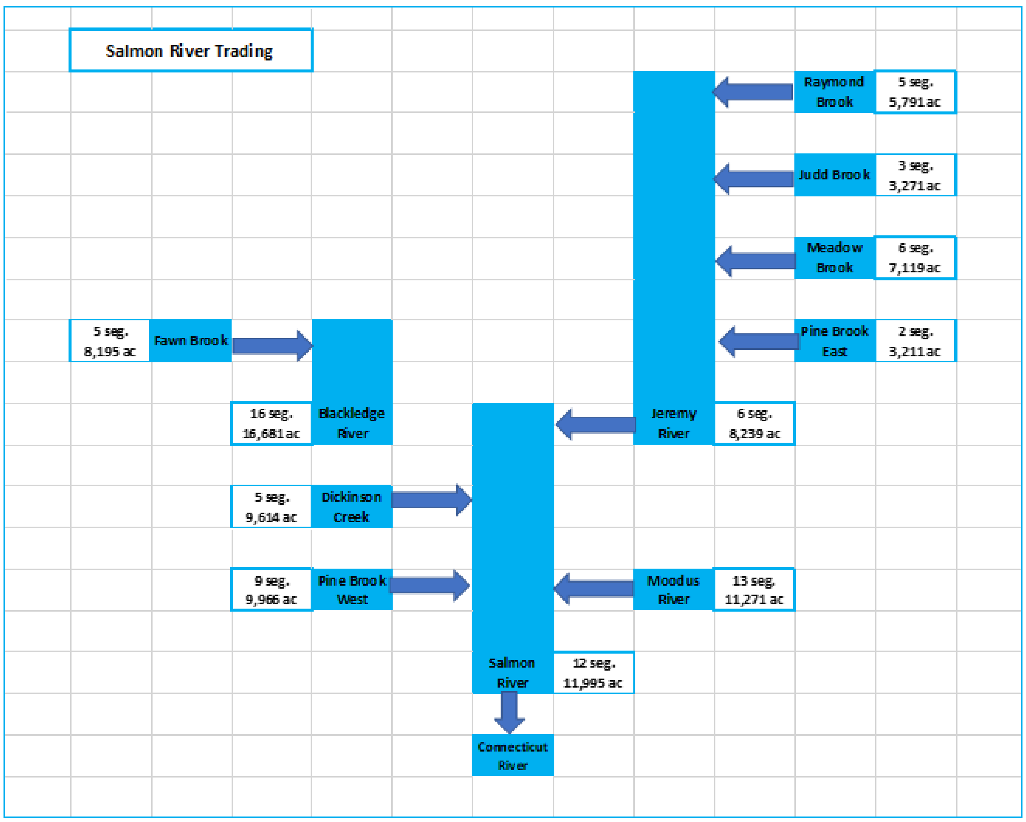


Figure 10. Salmon River Watershed trading schematic identifying 11 sub-watersheds with individual segment (local basin) distribution.

Table 6. Salmon River Watershed assessment statistics and credit distribution for TN in tons/yr. Current CCI is color coded green for Tier 1-2 attainment, orange for Tiers 3-4, and red for Tiers 5-6. Tan shaded sub-watershed credit balances and Enrichment Factors (EF) identify watersheds with a credit balance deficit from exceeding the mid-range cap scenario (3.0 lbs TN/yr).

Sub-Basin	Area (acres)	Segments	Current CCI	Current TN Load	TN Target w/3.0 cap	TN Credit Bal. w/3.0	Point Source TN	TN Credit Bal. w/Pt	Current Enr. Factor (EF)
Raymond	5,791	5	0.62	8.18	8.69	0.50	0	0.50	2.88
Judd	3,271	3	0.70	3.88	4.91	1.03	0	1.03	2.29
Meadow	7,119	6	0.54	12.97	10.68	-2.29	0	-2.29	3.58
Pine East	3,211	2	0.82	2.62	4.82	2.20	0	2.20	1.64
Jeremy	8,239	6	0.73	8.81	12.36	3.55	0	3.55	2.13
Fawn	8,195	5	0.76	8.08	12.29	4.22	0	4.22	1.97
Blackledge	16,681	16	0.69	21.20	25.02	3.82	0	3.82	2.41
Dickinson	9,614	5	0.74	10.12	14.42	4.30	0	4.30	2.07
Pine West	9,966	9	0.64	14.00	14.95	0.95	0	0.95	2.72
Moodus	11,271	13	0.66	14.92	16.91	1.98	0	1.98	2.57
Salmon	11,995	12	0.81	10.17	17.99	7.82	0	7.82	1.67
Total	95,353	82	0.70	114.95	143.03	28.07	0	28.07	2.33

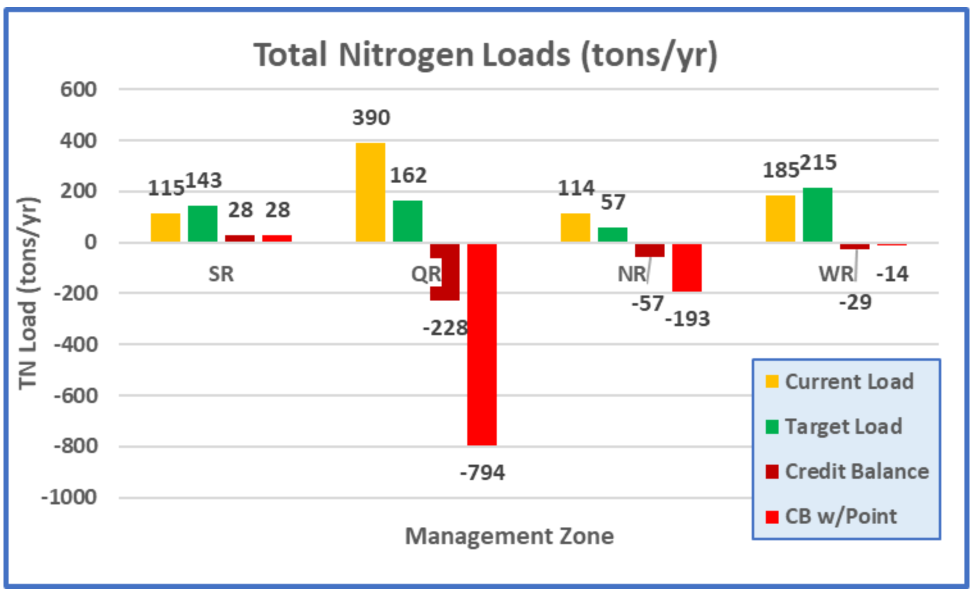


Figure 11. Comparison of current TN loads (tons/yr) with target loads and credit balances based on a 3.0 lbs/acre-yr cap scenario for the Salmon River (SR), Quinnipiac River (QR), Norwalk River (NR) and Willimantic River (WR) evaluations (see Tables 6-9).

Quinnipiac River Watershed: The 106,955-acre Quinnipiac River Watershed (QRW) has 19.6% IC land cover and another 22.2% cultured land area. Only 58.2% of the land cover is classified as Natural, yielding a CCI of only 0.29 (Table 7). Seventy-three local basin segments are distributed among 9 sub-watersheds (Figure 12). All but one sub-watershed, Broad Brook, have negative credit balances using the 3.0 lbs/acre-yr TN-yield cap, and the QRW EF including point sources exceeds 18, representing a proportional dose of TN loading more than 18 times higher than the estimated natural load. With an appropriate regulatory driver, the QRW is clearly a potential buyer, with a need for many times the credits than could be realistically produced within the watershed (Figure 11). There would be few proximate watersheds that could supply credits given the 9.5 EF for the entire management Zone 3 (Table 3 and Figure 2). The potential for trading in a distributed program is very low and unlikely to support a viable TN WQT market.

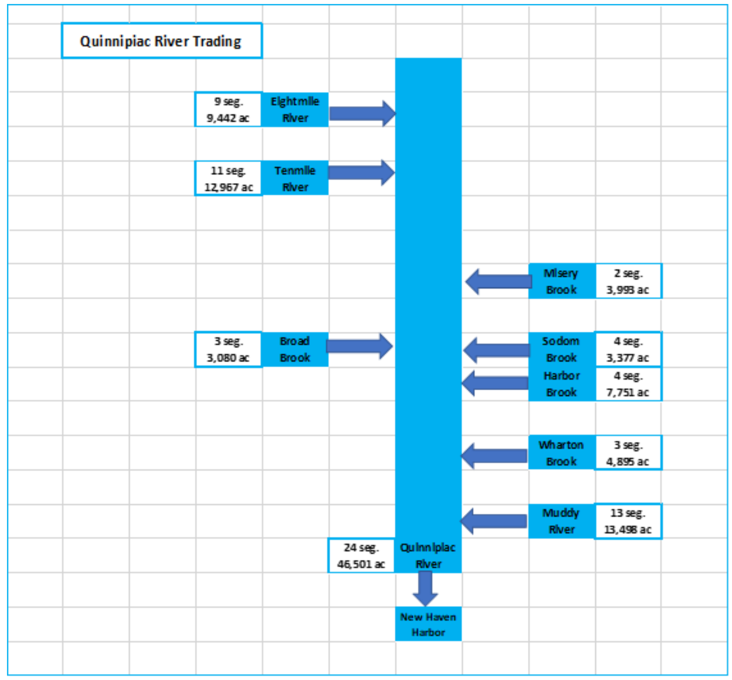


Figure 12. Quinnipiac River Watershed trading schematic identifying 9 sub-watersheds with individual segment distribution.

Table 7. Quinnipiac River Watershed assessment statistics and credit distribution for TN in tons/yr. Current CCI is color coded green for Tier 1-2 attainment, orange for Tiers 3-4, and red for Tiers 5-6. Tan shaded sub-watershed credit balances and Enrichment Factors (EF) identify watersheds with a credit balance deficit from exceeding the mid-range cap scenario (3.0 lbs TN/yr).

Sub-Basin	Area (acres)	Segments	Current CCI	Current TN Load	TN Target w/3.0 cap	TN Credit Bal. w/3.0	Point Source TN	TN Credit Bal. w/Pt	Current Enr. Factor (EF)
Eightmile	9,442	9	0.45	23.65	14.45	-9.20	0	-9.20	4.71
Tenmile	12,967	11	0.44	31.78	19.84	-11.94	0	-11.94	4.88
Misery	3,993	2	0.32	13.42	6.11	-7.31	0	-7.31	6.70
Broad	3,080	3	0.71	3.54	4.71	1.17	0	1.17	2.27
Sodom	3,377	4	0.25	14.25	5.17	-9.08	0	-9.08	8.28
Harbor	7,752	4	0.19	36.91	11.86	-25.05	0	-25.05	9.77
Wharton	4,895	3	0.21	22.29	7.49	-14.80	0	-14.80	9.16
Muddy	13,948	13	0.39	39.15	21.34	-17.81	0	-17.81	5.55
Quinnipiac	46,501	24	0.22	205.18	71.15	-134.03	-566	-700.03	33.29
Total	105,955	73	0.29	390.15	162.11	-228.04	-566	-794.04	18.11

Norwalk River Watershed: The Norwalk River Watershed (NRW) has 40 local basin segments distributed among only 3 sub-watersheds (Table 8 and Figure 13). Developed land (IC) comprises 16.8% of the NRW, with 15.5% in AL cover and 67.7% classified as Natural. Like other urbanized coastal watersheds in Southwestern Coastal Connecticut Management Zones 5 and 6, the NRW has a low CCI of 0.35 and a TN EF over 20 in the Norwalk River sub-watershed. Overall, the NRW's EF is 13.5 (Table 8). All sub-watersheds exceed the benchmark TN yield cap of 3.0 lbs/acre-yr resulting in an overall credit deficit of more than 200 tons TN/yr (Figure 1). A viable market-based TN WQT program in either Management Zone 5 and 6 for an individual watershed is very unlikely and, like the QRW, proximate watersheds are unlikely to offer a viable inter-watershed program (Table 3 and Figure 2). Demand for credits far exceeds any plausible supply by recovery, additional POTW upgrades, or NPS/SW BMP implementation.

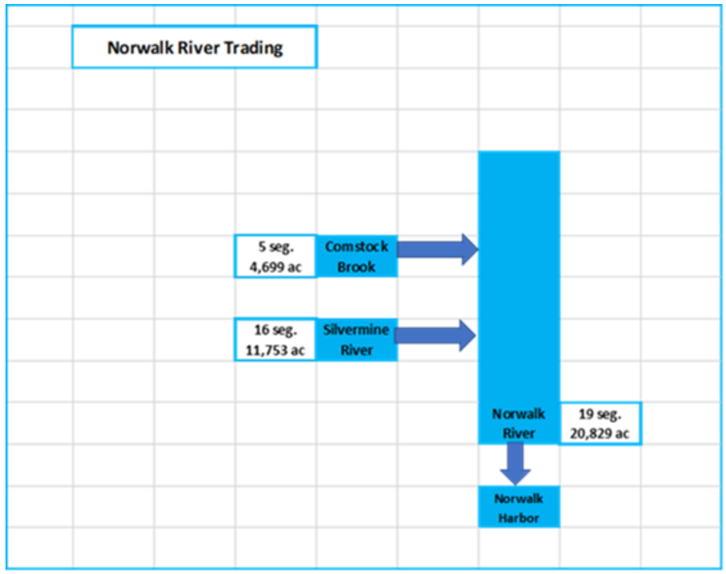


Figure 13. Norwalk River Watershed trading schematic identifying three sub-watersheds with individual segment distribution.

Table 8. Norwalk River Watershed assessment statistics and credit distribution for TN in tons/yr. Current CCI is color coded green for Tier 1-2 attainment, orange for Tiers 3-4, and red for Tiers 5-6. Tan shaded sub-watershed credit balances and Enrichment Factors (EF) identify watersheds with a credit balance deficit from exceeding the mid-range cap scenario (3.0 lbs TN/yr).

Sub-Basin	Area (acres)	Segments	Current CCI	Current TN Load	TN Target w/3.0 cap	TN Credit Bal. w/3.0	Point Source TN	TN Credit Bal. w/Pt	Current Enr. Factor (EF)
Comstock	4,699	5	0.54	8.62	7.19	-1.44	0	-1.44	3.66
Silvermine	11,753	16	0.43	28.70	17.98	-10.72	0	-10.72	4.90
Norwalk	20,829	19	0.28	76.48	31.87	-44.61	-136	-180.61	20.55
Total	37,281	40	0.35	113.80	57.04	-56.76	-136	-192.76	13.51

Willimantic River Watershed: The Willimantic River Watershed (WRW) has 121 local basin segments distributed among 11 watersheds, offering some potential for a diverse WQT program (Figures 11 and 14). Although only two sub-watersheds exceed the proposed cap, the addition of a substantial point source load to the mainstem Willimantic River sub-watershed boosts the entire WRW just above the 3.0 EF benchmark (Table 9). This could allow for some upstream-to-downstream trades of unused upstream assimilative capacity credits sold offset the downstream sources, especially the POTWs in a point-NPS/SW WQT trading program. However, although technically feasible, WQT potential may be weak due to low credit volume that may not provide much of a financial incentive to trade, combined with the lack of enforceable mechanisms to manage NPS/SW towards watershed recovery.

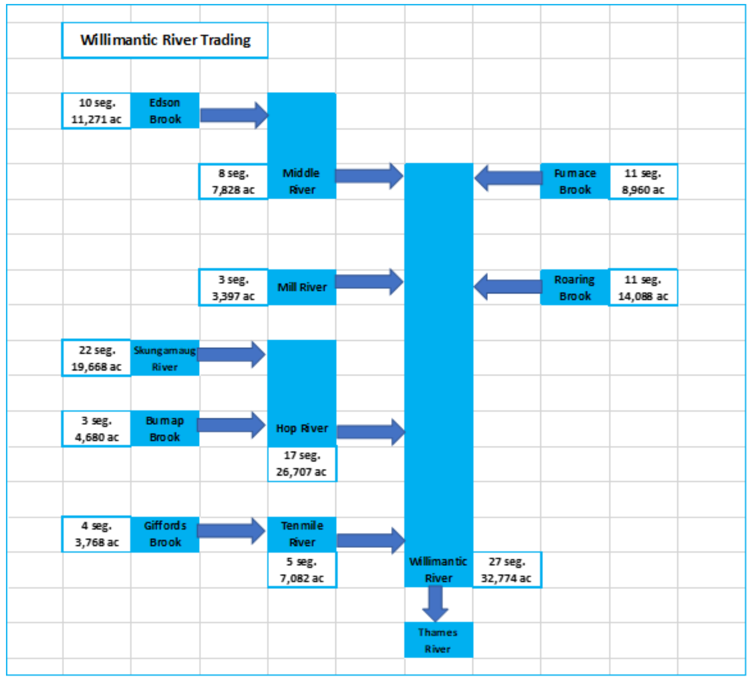


Figure 14. Willimantic River Watershed trading schematic identifying 11 sub-watersheds with individual segment distribution.

Table 8. Willimantic River Watershed assessment statistics and credit distribution for TN in tons/yr. Current CCI is color coded green for Tier 1-2 attainment, orange for Tiers 3-4, and red for Tiers 5-6. Tan shaded sub-watershed credit balances and Enrichment Factors (EF) identify watersheds with a credit balance deficit from exceeding the mid-range cap scenario (3.0 lbs TN/yr).

Sub-Basin	Area (acres)	Segments	Current CCI	Current TN Load	TN Target w/3.0 cap	TN Credit Bal. w/3.0	Point Source TN	TN Credit Bal. w/Pt	Current Enr. Factor (EF)
Edson	11,271	10	0.77	11.06	17.24	6.18	0	6.18	1.92
Middle	7,828	8	0.67	9.89	11.98	2.09	0	2.09	2.49
Furnace	8,960	11	0.66	11.63	13.71	2.07	0	2.07	2.58
Roaring	14,088	11	0.79	12.77	21.55	8.78	0	8.78	1.80
Mill	3,397	3	0.48	7.20	5.20	-2.00	0	-2.00	4.25
Skungamaug	19,668	22	0.65	26.51	30.09	3.58	0	3.58	2.67
Burnap	4,680	3	0.69	5.83	7.16	1.33	0	1.33	2.37
Hop	26,707	17	0.66	35.89	40.86	4.98	0	4.98	2.60
Giffords	3,786	4	0.70	4.31	5.79	1.48	0	1.48	2.28
Tenmile	7,082	5	0.72	7.89	10.83	2.95	0	2.95	2.21
Willimantic	32,774	27	0.59	52.21	50.14	-2.06	-43	-45.06	5.75
Total	140,240	121	0.66	185.20	214.57	29.37	-43	-13.63	3.16

Management Discussion

The ability to implement effective management relative to the state-wide and individual watershed scenarios presented above has been identified as an obstacle to trading in passing but without much detail or analysis provided. Although beyond the project objective of technical scoping for WQT potential, management connects to the Management Recovery Potential scenarios, for example, which sets a high bar for attainment within the cap scenarios. This clearly defines a potential obstacle for WQT that warrants attention because the success of WQT depends on the success of management. This short review provides the LISS with some considerations for technical management and WQT viability at the topical level, but it is not intended to be an exhaustive review.

Successful WQT depends on a governing standard or cap to set targets for management. This analysis would be somewhat directionless without incorporating a cap in each scenario, as is trading without a target or a TMDL. There also must be relevant caps throughout the watershed to ensure local water quality goals and objectives are met, a problem that was described for the current, centralized management approach adopted in the LIS TMDL, which also guides the CT NCE. Little attention is paid to TN conditions in the contributing watershed, and how biointegrity and TN enrichment may be creating local problems that a distributed approach would detect.

As a matter of policy and consistency with the CWA, prevailing standards or targets must be met for each individual local basin and stream reach, a logistic and management challenge for effective WQT. In the case of meeting multiple designated uses, including ALUS and TN eutrophication endpoints emphasize here, it is necessary to harmonize correlative goals to ensure attainment of the most sensitive designated use.

The DSF captures that relationship and uses watershed landscape condition as the driving force for both biointegrity and TN offering recovery of structural and functional landscape attributes. Recovery to a more natural state is the best solution for an integrated and holistic approach that would meet collective water quality goals and standards that produce ecosystem outcomes that yield a multiplicity of ecosystem goods and services. The integrated approach could also support multi-media trading to simultaneously resolve interrelated problems. For example, watershed recovery would also mitigate climate change pressures and open the door for producing and trading credits that achieve both landscape and climate-driven impact reduction, which is encouraged by EPA WQT policies.

Actions like mitigation banking, biodiversity offsetting and banking, reforestation credits, and stream and riparian management credits are not uncommon, and may provide a potential foundation for credit trading at a higher, ecosystem level (Bledsoe, et al., 2016; Carroll, Fox and Bayon, 2008; Clements et al., 2018; Houle et al., 2019; Keller and Fox, 2019; Liu and Swallow, 2016; Moilanen and Kotiaho, 2020) perhaps facilitated by employing Natural Capital as the common currency as in the Natural Capital Coalition Protocol[28]. However beneficial from an ecosystem perspective, they may not have the impact necessary to attain biointegrity targets or caps that overcome the complex interaction of multiple drivers of degradation and support effective and productive trading.

[28] Capital Coalition Protocol: https://capitalscoalition.org/capitals-approach/natural-capital-protocol/?fwp_filter_tabs=training_material

Even in situations where conventional credit trading on a watershed scale may be unfeasible, there may still be opportunities for "upstream to downstream" trading of unused assimilative capacity credits[29]. Upstream providers would be more likely to be "sellers" of unused capacity, and downstream users would be "buyers" of credits to offset their excess loads when the local caps are exceeded, an approach that might warrant further evaluation for WQT potential at any watershed scale. Upstream-downstream trading could be facilitated by placing assessment endpoints at the most downstream trading unit in a defined WQT domain, affording flexibility that could enable broader trading opportunities among closely connected local basins in an upstream-to-downstream direction. This is a policy and legal decision that would have to be addressed if trading is to be both legally and technically viable, with necessary rules or protocols to ensure water quality in individual units is not unduly compromised by trading and contrary to the CWA, WQT policy, or state and local regulations.

Land management is usually governed at the local level, engendering a mix of local regulations and enforceable authorities that may be an obstacle to trading, which requires a more uniform accountability platform. Current state and local regulatory authorities (WestCOG, 2021) and enforceable mechanisms do not always provide a level of oversight and control that helps establish caps, and a legal mechanism for management that could incentivize trading. Since landscape impacts are only minimally mitigated by stormwater BMPs, which do come under regulatory authority and may address some individual pollutant loading issues, they do not achieve a management level that would offset the pervasive landscape condition impacts depicted by the CCI. As a physical and cultural challenge, the likelihood of rehabilitating thousands to tens of thousands of acres land to more natural condition by recovery, even in the buffer area where offsetting new development pressures may be lower, is extremely low.

Without broader regulatory authority at the state and local level, or adoption of standards and criteria for ALUS that can be translated into effective landscape management enforceable mechanisms, biointegrity is likely to continue to decline with increased development and fragmentation of NC (Figure 4). A productive role for biointegrity trading is not apparent under most prevailing watershed land cover/CCI conditions even if very favorable land cover trading ratios as discussed above could be enacted.

An additional obstacle, perhaps the biggest one as discussed above, is the sufficiency of legal authorities and enforceable mechanisms for implementation, also one of the Selman et al. (2009) key success factors. EPA's 2019 memorandum on the six market-based principles for WQT presented in the Trading Policy Section afford flexibility but will warrant legal and technical in a LIS WQT program application, even at the individual watershed scale. However, the physical setting and structural and functional attributes of a watershed and the current state of health or degradation are primary determinants of the technical feasibility to generate and trade credits in a viable technical and market setting and will remain challenges that may foil policy and management goals and strategies.

Controlling TN has been a focus of the LISS for the more than 35 years the LISS has been in existence, and progress has been made primarily by upgrading POTWs, including the CT NCE one of the few successful programs in the country (GAO, 2017). But, considering that the POTW point source TN load estimates from 2018 used in this analysis represent WLA attainment, plans for substantial additional TN

[29] See Policy section and Footnote 14.

reductions are rare. And with landscape recovery gains as discussed above unlikely, only NPS/SW BMP engineering solutions would potentially add TN credits to a trading program, actions that would not greatly contribute to overall biointegrity.

Currently, stormwater management under the MS4 general permit is not governed by performance-based practices that meet a target or a TMDL, though states do have the option of regulating stormwater discharge consistent with a TDML under NPDES authorities. Pollutant loading limits and WLAs can be set and permits for MS4 areas issued that meet water quality standards and criteria[30] as required by a TMDL. In some cases, Residual Designation Authority may be invoked to extend the reach of stormwater management that may also include NPS[31], but it is not widely applied, if at all, at this time in Connecticut.

As a final note, the LISS asked specifically about the potential for trading bioextraction credits. In their thorough evaluation of bioextraction and potential for incorporating bivalve extraction into WQT, Rose et al. (2021) made a good case for inclusion. However, the trading rules would have to be specialized towards the remediation provided by bioextraction and associated denitrification since WQT is generally based on intervention of loads before entering the receiving water.

Given the magnitude of the landscape and POTW sources, the administrative burden of a bioextraction program could outweigh the benefits of a relatively small TN reduction of uncertain relationship to source loading. Establishing trading ratios for TN bioextraction credits to equate to external loading impacts may be a considerable challenge. While it is unlikely that bioextraction could bring TN loading under a cap in the highly enriched system of LIS, there could be a place for funding bioextraction activities from WQT credit sales and purchases.

The LISS also asked how interstate movement of sludge would be incorporated into a trading program. Interstate sludge transfer would only require administrative tracking of TN loads, to determine the effect on TN loading and its location in a WQT domain, for incorporation into a traditional WQT program.

[30] https://www.epa.gov/tmdl/impaired-waters-and-stormwater

[31] https://www.epa.gov/npdes/epas-residual-designation-authority

Summary and Conclusions

The Decision Support Framework (DSF) is an adaptable model for assessment, planning, and management decision support. The Combined land cover Condition Index (CCI) provides a robust assessment of biological condition (biointegrity) along the Biocondition Gradient (BCG) continuum comprising a Watershed Condition Index (WCI) paired with a Buffer Condition Index (BCI) that mitigates upland pressures and pollutant loads in the riparian zone. The CCI translates to the Connecticut Department of Energy and Environmental Protection's (CT DEEP) Tiered Aquatic Life Use Support (ALUS) protocol used for benchmarking biointegrity and user-defined target-setting in the DSF. The CCI also produces estimates of TN yields and loads that compare favorably to the Long Island Sound (LIS) Total Maximum Daily Load (TMDL) evaluation used for setting the LIS Dissolved Oxygen targets in the TMDL.

The DSF proved to be a useful and viable analytical framework for assessment and planning for both biointegrity and pollutant (TN) management outcomes, and WQT, in an ecosystem context. The DSF demonstrated good skill in assessing WQT potential for biointegrity and Total Nitrogen (TN); however, the feasibility of trading in the LIS watershed was limited.

On a Connecticut state-wide scale using a centralized approach, which allows inter-zone trading, it appears that demand for credits would far outweigh supply for that trading domain. All but one of the LISS TMDL Management Zones, Management Zone 1 in eastern CT, had TN loading estimates above a mid-range cap scenario for nonpoint sources and stormwater (NPS/SW) alone. When point sources from Connecticut's 80 Publicly Owned Treatment Works (POTW) involved in the CT NCE were added in, all six Management Zones exceeded the cap, and most were well-beyond reductions that might be gained from even an aggressive land cover management scenario in watersheds and riparian buffers.

Reviewing the excess TN loadings in terms of proportional doses, or Enrichment Factors (EF), Management Zones were contributing anthropogenically-derived TN loads as high as 12.5 times the natural loading level, well beyond any realistic management potential. While POTW loads based on 2018 NCE data reveal good TN management progress and attain the TMDL WLA target, they still exceed available assimilative capacity in LIS and require offsetting sources from land conservation or management to meet the mid-range cap used in the evaluation. Since most of the gains for CT POTW management have already been realized, there is little expectation that they will supply credits in the future. In sum, prospects for state-wide trading are low, and expansion of trading to the entire Long Island Sound watershed scale appears untenable.

Viable WQT trading in the LIS watershed hinges on two factors: target or cap stringency and management or recovery potential. A lax cap provides greater trading potential but sets a lower bar for aquatic ecosystem health; increasingly restrictive caps limit trading potential but are more protective. Although an aggressive management scenario advancing recovery potential of structural and functional integrity in the watershed and riparian buffer improves prospects for trading by increasing credit supply, it sets at a very high bar for attainability. It may exceed a plausible Best Attainable Condition. In sum, the technical analyses of a large-scale, LIS-centered trading program reveals an imbalance between credit supply and demand, creating a credit deficit that is likely too large to support viable credit trading at the state-wide scale. Thus, prospects for expanding WQT into a multi-state, LIS watershed-wide program are doubtful.

The DSF was also used to explore a distributed approach suitable for localized, intra-watershed trading of TN for four Connecticut watersheds – the Salmon River in the Connecticut River Basin; the Quinnipiac River in south-central Connecticut; the Norwalk River in southwestern Connecticut; and the Willimantic River in eastern Connecticut. The analysis showed that each watershed has its own distinctive, site-specific character and would need to be evaluated on an individual basis for water-quality trading suitability. Across a gradient of watershed types and conditions, trading potential will be variable depending on local factors.

Categorically, the Salmon River watershed with a relatively healthy landscape condition enjoys a surplus of credits but low demand; the Quinnipiac River and Norwalk River watersheds run deep TN credit deficits and have low potential for WQT because demand far exceeds supply; the Willimantic River watershed, has the best potential for trading of the four watersheds as supply is close to demand established by a proposed cap and the supply of credits generated from management actions may be adequate to meet the demand and the TN loading target. Overall potential for individual intra-watershed trading programs that could collectively contribute to improving local water quality that benefits LIS as well should be further explored to determine basin-wide benefits.

In sum, the DSF provides the capacity to easily conduct watershed evaluations, set caps, and test management scenarios where high-resolution land cover data are available in the classifications appropriate to the DSF. However, the technical ability to trade hinges on establishing regulatory caps, management plans, and enforceable mechanisms and the public will necessary to implement the land recovery management actions that are powerful enough to resolve TN-loading problems and support healthy biointegrity outcomes.

Literature Cited

Allan, J.D. 2004. The influence of land use on stream ecosystems. Ann. Review Ecol., Evolution Systematics. 35(2004):257-284.

Allan, J.D. and M.M. Castillo. 2007. Stream ecology. Structure and function of running waters. Springer, Dordrecht, The Netherlands. 436 p.

Ator, S.W. 2019a. Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Northeastern United States: U.S. Geological Survey Scientific Investigations Report 2019–5118. 57 p. https://doi.org/10.3133/sir20195118

Ator, S.W. 2019b. SPARROW model inputs and simulated streamflow, nutrient and suspended-sediment loads in streams of the Northeastern United States, 2012 base year: U.S. Geological Survey data release. https://doi.org/10.5066/P9NKNVQO

Becker, M.E. 2014. Interim phosphorus reduction strategy for Connecticut freshwater non-tidal waste-receiving rivers and streams technical support document. Connecticut Dept. of Energy and Environmental Protection, Hartford, CT. 70 p. https://www.ct.gov/deep/lib/deep/water/water_quality_standards/p/interimmgntphosstrat_042614.pdf

Becker, M. and C. Bellucci. 2021. Informing high quality stream assessment by exploring temporal variability in macroinvertebrate assemblages across the biological condition gradient in Connecticut. Presentation at the 2021 Northeast Aquatic Biologists Conference. Abstract http://neiwpcc.org/wp-content/uploads/2021/02/Becker.pdf

Bellucci, C.J., M. Beauchene and M. Becker. 2008. Streams of hope: characterizing the biological potential of moderately urbanized Connecticut streams. CT Dept. Env. Protection, Hartford, CT. 37 p.

Bellucci, C.J., M. Becker and M. Beauchene. 2011.Characteristics of macroinvertebrate and fish communities from 30 least disturbed small streams in Connecticut. Northeast Naturalist 18(4):411–444.

Bellucci, C.J., M.E. Becker, M. Beauchene and L. Dunbar. 2013. Classifying the health of Connecticut streams using benthic macroinvertebrates with implications for water management. Environmental Management 51:1274–1283. https://doi.org/10.1007/s00267-013-0033-9.

Billen G. 1990. N-budget of the major rivers discharging into the continental coastal zone of the North Sea: The nitrogen paradox. Pages 153–172 in Lancelot C, Billen G, Barth H, eds. Eutrophication and Algal Bloom in North Sea Zones, the Baltic and Adjacent Areas: Prediction and Assessment of Prevention Actions. Brussels (Belgium): Commission of the European Communities. Water Pollution Research Report 12.

Bledsoe, B. et al. 2016. Stream restoration as a BMP: Crediting guidance. Water Environment Research Foundation (WERF), Report WERF1T13. WERF, Alexandria, VA. 120 p.

Buffer Options for the Bay. Undated. Executive Summary. 5 p. https://www.bufferoptionsnh.org/wp-content/uploads/2018/02/Executive-Summary.pdf

Cardinale, B.J. et al. 2012. Biodiversity loss and its impact on humanity. Nature 486:59-57.

Carroll, N., J. Fox and R. Bayon (eds). 2008. Conservation & biodiversity banking. A guide to setting up and running biodiversity credit trading systems. Earthscan, London and Sterling, VA. 298 p.

Clements, J. et al. 2018. Incentives for green infrastructure implementation on private property: lessons learned. Water Research Foundation (WRF), Project No. 4684. WRF, Alexandria, VA. 154 p.

Diaz, S. et al. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergov.l Science-Policy Platform on Biodiversity and Ecosys. Services. https://www.ipbes.net/sites/default/files/downloads/spm_unedited_advance_for_posting_htn.pdf

Dykes, K.S. 2019. Report of the Nitrogen Credit Advisory Board for calendar year 2018. Report to the Joint Standing Environment Committee of the General Assembly concerning the Nitrogen Credit Exchange Program. CT Dept. Energy Env. Prot., Hartford, CT. 42 p. https://portal.ct.gov/-/media/DEEP/water/municipal_wastewater/NitrogenReport2018Final.pdf

Flanagan, S.E., D.A. Patrick, D.J. Leonard and P. Stacey. Undated. Buffer options for the bay: exploring the trends, the science, and the options of buffer management in the Great Bay watershed. Key findings from available literature. 51 p. https://www.bufferoptionsnh.org/wp-content/uploads/2017/12/BOB-Coastal-buffer-literature-review_11.28.17-FINAL-3.pdf

Foster, D. *et al.* 2017. Wildlands and woodlands – farmlands and communities. Broadening the Vision for New England. Harvard Forest, Harvard University. Petersham, MA. 44 p. http://www.wildlandsandwoodlands.org/sites/default/files/W%26W%20report%202017.pdf

Galloway, J.N., J.D. Aber, J.W. Erisman, S.P. Seitzinger, R.W. Howarth, E.B. Cowling and B.J. Cosby. 2003. The nitrogen cascade. BioScience 53(4):341-356.

GAO (United States Government Accountability Office). 2017. Water pollution: Some states have trading programs to help address nutrient pollution, but use has been limited. Report to the Hon. Sheldon Whitehouse, U.S. Senate, Washington, DC. GAO-18-84. 38 p.

Gerritsen, J. and B. Jessup. 2007. Calibration of the biological condition gradient for high gradient streams of Connecticut. Prepared by TetraTech, Inc., for U.S. EPA Office of Science and Technology and the CT Dept. of Env. Protection. TetraTech, Inc., Owings Mills, MD. 86 p.

Goetz, S.J., R.K. Wright, A.J. Smith, E. Zinecker, and Erika Schaub. 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing of Environment 88 (2003) 195–208.

Holdt, B.M., D.L. Civco and J.D. Hurd. 2004. Forest fragmentation due to land parcelization and subdivision: a remote sensing and GIS analysis. Proc. 2004 ASPRS Annual Convention, Denver, CO 8 p. http://clear.uconn.edu/publications/research/tech_papers/Holdt_et_al_ASPRS2004.pdf.

Houle, et al. 2019. Pollutant removal credits for buffer restoration in MS4 permits. Final Panel Report. Roca Communications. 32 p. https://nerrssciencecollaborative.org/media/files/CGG/Green_Credit_%20Report_June2019.pdf and website: https://www.greatbay.org/credit-for-going-green/

Hurd, J.D., E.H. Wilson and D.L. Civco. 2002. Development of a forest fragmentation index to quantify the rate of forest change. Proc. 2002 ASPRS-ACSM Ann. Conf., Washington, DC. 10 p. http://clear.uconn.edu/publications/research/tech_papers/Hurd_et_al_ASPRS2002.pdf.

Isaacons, W. 2021. The code breaker. Jennifer Doudna, gene editing, and the future of the human race. Simon & Schuster, NY. 536 p.

Keller, A.A. and J. Fox. 2019. Giving credit to reforestation for water quality benefits. Plos One. https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0217756

Liu, J. et al. 2015. Systems integration for global sustainability. Science 347(6225):1258832-1 – 9. DOI: 10.1126/science.1258832.

Liu, P. and S.K. Swallow. 2016. Integrating cobenefits produced with water quality BMPs into credits markets: Conceptualization and experimental illustration for EPRI's Ohio River Basin Trading. Water Resources Research, 52:3387-3407.

Moilanen, A. and J.S. Kotiaho. 2020. Three ways to deliver a net positive impact with biodiversity offsets. Conservation Biology, 35(1):197-205.

Mullaney, J.R. 2016. Nutrient, organic carbon, and chloride concentrations and loads in selected Long Island Sound tributaries: Four decades of change following passage of the Federal Clean Water Act. U.S. Geological Survey Scientific Investigations. Report 2015-5189. 47 p. https://pubs.usgs.gov/sir/2015/5189/sir20155189.pdf

NAS. 2021. Our planet, our future. An urgent call for action. Statement of the National Academies of Sciences, Engineering and Medicine. April 29,2021. https://www.nationalacademies.org/news/2021/04/nobel-prize-laureates-and-other-experts-issue-urgent-call-for-action-after-our-planet-our-future-summit

NRC. 2011. National Research Council 2011. Achieving nutrient and sediment reduction goals in the Chesapeake Bay: An evaluation of program strategies and implementation. Report of the Committee on the Evaluation of Chesapeake Bay Program Implementation for Nutrient Reduction to Improve Water Quality. National Research Council, Water Science and Technology Board, Division on Earth and Life Studies. The National Academies Press, Washington, DC. 258 p. https://doi.org/10.17226/13131

NRCS. 2009. National Watershed Program Manual. Report M - 390 – NWPM, Third Edition. USDA, National Resource Conservation Service, Washington, DC. 179 p.

NRCS. 2010. National Watershed Program Handbook. Report H - 390 – NWPH, First Edition. USDA, National Resource Conservation Service, Washington, DC. 197 p.

New York State Department of Environmental Conservation (NYSDEC) and Connecticut Department of Environmental Protection (CTDEP). 2000. A total maximum daily load analysis to achieve water quality standards for dissolved oxygen in Long Island Sound. NYSDEC Albany, NY and CTDEP, Hartford, CT. 73 p. https://longislandsoundstudy.net/wp-content/uploads/2010/03/Tmdl.pdf

Rose, J.M. et al. 2021. Opportunities and challenges for including oyster-mediated denitrification in nitrogen management plans. Estuaries & Coasts, 15 p. Published online: https://doi.org/10.1007/s12237-021-00936-z.

Schueler, T. R., Fraley-McNeal, L. Cappiella, K. 2009. Is Impervious Cover Still Important? Review of Recent Research. Journal of Hydrologic Engineering Vol. 14, Issue 4 (April 2009).

Selman, M., S. Greenhalgh, E. Branosky, C. Jones and J. Guiling. 2009. Water quality trading programs: an international overview. WRI Issue Brief No. 1, Water quality trading. World Resources Institute, Washington, DC. 16 p. www.wri.org

Smith, M.P., R. Schiff, A. Olivero and J.G. MacBroom. 2008. The active river area: A conservation framework for protecting rivers and streams. The Nature Conservancy, Boston, MA. 59 p.

Stacey, P.E. 2015. Connecticut's Long Island Sound Nitrogen Credit Exchange. Chapter 12 *in* Advances in water quality trading as a flexible compliance tool. A special publication of the Water Environment Federation, Alexandria, VA. 342 p.

Stacey, P.E. 2018. Watersheds and buffers. Letting Nature do the work. Interstate Waters, 2(1):8-14.

Stamp, J. and J. Gerritsen 2009. Methods and Assessment Comparability Among State and Federal Biological Monitoring Protocols. Prepared for New England Interstate Water Pollution Control Commission (NEIWPCC), Lowell, MA. 102 p. https://www.neiwpcc.org/monitoringold/docs/Final%20NEIWPCC%20rpt_20090929.pdf

Stevenson, R.J. 2011. A revised framework for coupled human and natural systems, propagating thresholds, and managing environmental problems. Physics Chem. Earth. 36(2011):342-351.

Stiglitz, J., A. Sen and J.-P. Fitoussi. 2009. Report of the Commission on the Measurement of Economic Performance and Social Progress. Paris. Available online from the Commission on the Measurement of Economic Performance and Social Progress: http://www.stiglitz-sen-fitoussi.fr/en/index.htm

Sutherland, R.C. 2000. Methods for estimating the effective impervious area of urban watersheds. Article 32, pp. 193-195 *in* T.R. Schueler and H.K. Holland. The practice of watershed protection. Center for Watershed protection, Ellicott City, MD. 742 p.

USEPA. 1998. National strategy for the development of regional nutrient criteria. EPA 822-R-98-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. 53 p. https://www.epa.gov/sites/production/files/2018-10/documents/nutrient-strategy-1998.pdf

USEPA. 2003. Water quality trading policy. U.S. Environmental Protection Agency, Office of Water, Washington, DC. 12 p.

USEPA. 2012. Identifying and protecting healthy watersheds. Concepts, assessments, and management approaches. EPA 841-B-11-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. 296 p.

USEPA. 2013. Biological assessment program review: assessing level of technical rigor to support water quality management. EPA 820-R-13-001. Office of Science and Technology, Washington, DC. 158 p.

U.S. EPA. 2015. Connectivity of streams and wetlands to downstream waters: A review and synthesis of the scientific evidence. EPA/600/R-14/475F. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. 408 p.

USEPA. 2016. A Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems. EPA-842-R-16-001. U.S. Environmental Protection Agency, Washington, DC.

Water Environment Federation (WEF). 2015. Advances in water quality trading as a flexible compliance tool. A special publication of WEF, Alexandria, VA. 342 p.

Weimar, R.A., S. Brown and B.C. Vatter. 2015. Chapter 6. The future of water quality trading. Pages 133 – 159 in Advances in water quality trading as a flexible compliance tool. Water Environment Federation, Alexandria, VA. 342 p.

WestCOG. 2021. The case for riparian corridor protection. Zoning strategies to reduce pollution of inland waters and resultant hypoxia of Long Island Sound. Western Connecticut Council of Government. Sandy Hook, CT. 91 p. https://westcog.org/wp-content/uploads/2021/08/WestCOG-Riparian-Protections-and-Zoning-Strategies.pdf

Wilson, E.H. and C.L. Arnold, 2008. The status of Connecticut's coastal riparian corridors. Research report of the UConn Center for Land Use Education and Research. Publication #080215.1.

Wilson, E. H., J. Barrett and C. L. Arnold. 2011. Land cover change in the riparian corridors of Connecticut. Watershed Science Bulletin Fall 2(1): 27-33.

Wilson, E.O. 2016. Half-Earth. Our planet's fight for life. Liveright Publishing, New York, NY. 258 p.

Zipper, S.C. et al. 2020. Integrating the water planetary boundary with water management from local to global scales. Accepted, Peer-Reviewed Article in Earth's Future. https://doi.org/10.1029/2019EF001377

Appendices

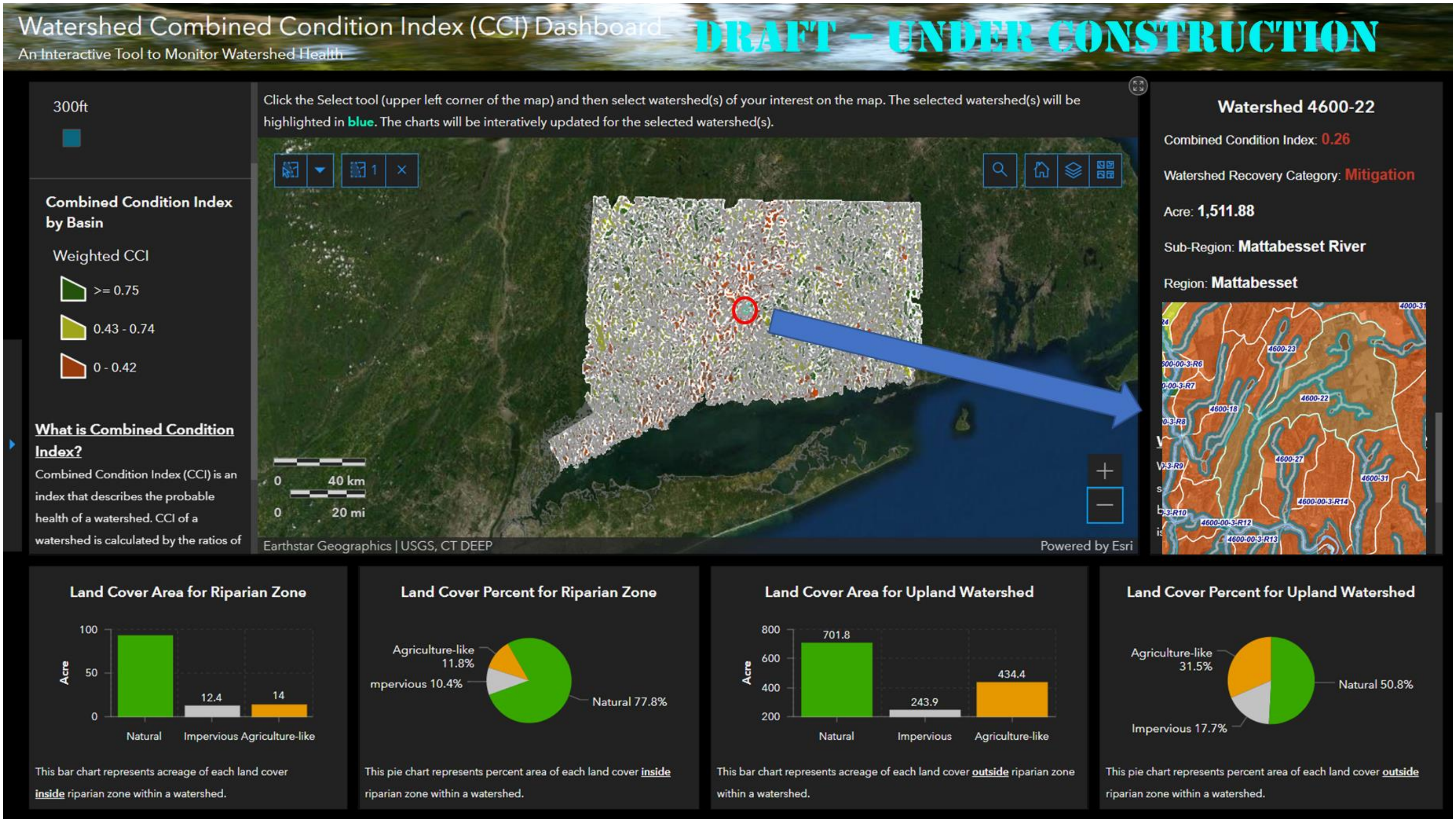
Appendix 1A. The Decision Support Framework (DSF) with 5 local basin examples.

Section 1 - Land Cover input and Current Biointegrity				Watershed Condition Index					Buffer Condition Index							CCI Target =	0.6	1 Credit = 1 Acre	
BASIN or PROJECT	Name or Scenario	Sum WCI and BCI Area (acres within CT)	CCI>	WCI Area Sum (acres)	WCI Developed (acres)	WCI Ag-like (acres)	WCI Natural (acres)	Weighted WCI (N=1; AL=2; IC=7)	BCI Area Sum (acres)	BCI Developed (acres)	BCI Ag-like (acres)	BCI Natural (acres)	Weighted BCI (N=1; AL=2; IC=7)	Weighted CCI (N=1; AL=2; IC=7)	Current Bio-integrity >	CCI Target	CCI Surplus(+)/ Deficit(-)	Credit(+)/ Deficit(-) (BI acres)	Percent Credit(+)/ Deficit(-)
Pawcatuck River Basin																			
Leave this line blank																			
1000-00	Pawcatuck River	3197		3018	429	709	1879	0.30	179	17	20	142	0.47	0.35		0.60	-0.25	-800	-42
1000-01	Pawcatuck River	1051		979	52	202	724	0.48	72	4	8	61	0.60	0.54		0.60	-0.06	-62	-10
1001-02	Wyassup Brook	2089		1925	58	188	1679	0.68	164	3	5	156	0.84	0.79		0.60	0.19	400	32
1004-01	Shunock River	1109		980	13	39	929	0.85	128	0	0	128	0.98	0.96		0.60	0.36	401	60
2000-26	Southeast Shoreline	587		517	217	111	189	0.10	71	16	13	41	0.23	0.11		0.60	-0.49	-288	-82

Section 2 - Management and Biointegrity Outcomes				Management												CCI Target =	0.6	1 Credit = 1 Acre	
BASIN or PROJECT	Name or Scenario	Sum WCI and BCI Area (acres within CT)	CCI>	Gain(+)/ Loss(-) WCI Developed (acres)	Gain(+)/ Loss(-) WCI Ag-like (acres)	Gain(+)/ Loss(-) WCI Natural (acres)	Change Must = 0	Managed Weighted WCI (N=1; AL=2; IC=7)	Gain(+)/ Loss(-) BCI Developed (acres)	Gain(+)/ Loss(-) BCI Ag-like (acres)	Gain(+)/ Loss(-) WCI Natural (acres)	Change Must = 0	Managed Weighted WCI (N=1; AL=2; IC=7)	Managed Weighted CCI (N=1; AL=2; IC=7)	Managed Bio-integrity >	CCI Target	CCI Surplus(+)/ Deficit(-)	Managed Credit(+)/ Deficit(-) (BI acres)	Managed Net Gain(+)/ Loss(-) (BI acres)
Pawcatuck River Basin																			
Leave this line blank																			
1000-00	Pawcatuck River	3197		0	0	0	0	0.30	0	0	0	0	0.47	0.35		0.60	-0.25	-800	0
1000-01	Pawcatuck River	1051		0	0	0	0	0.48	0	0	0	0	0.60	0.54		0.60	-0.06	-62	0
1001-02	Wyassup Brook	2089		0	0	0	0	0.68	0	0	0	0	0.84	0.79		0.60	0.19	400	0
1004-01	Shunock River	1109		0	0	0	0	0.85	0	0	0	0	0.98	0.96		0.60	0.36	401	0
2000-26	Southeast Shoreline	587		0	0	0	0	0.10	0	0	0	0	0.23	0.11		0.60	-0.49	-288	0

Section 3 - Management and Nitrogen Outcomes						NYield Target	3.06	1 Credit = 1 lb TN/yr											
BASIN or PROJECT	Name or Scenario	Sum WCI and BCI Area (acres within CT)	Current TN Load/ Status >	Total N Yield w/100' Buffer (lbs/acre-yr)	Current Total N Load w/100' Buffer (tons/yr)	N-Yield Target	N-YIeld Surplus(+)/ Deficit(-) (lbs/acre-yr)	Credit(+)/ Deficit(-) (tons/yr)	TN Load Mgmt Tool>	Managed Total N Yield w/100' Buffer (lbs/acre-yr)	Managed N Yield Change (lbs/acre-yr)	Managed TN Load (tons/yr)	Managed Net Gain(+)/ Loss(-) (tons/yr)	Options for other Reductions>	Optional - Added non-Stormwater Point Sources (tons/yr)	Current Combined TN Load (tons/yr)	Optional - Calculated Reductions from Landscape BMPs (tons/yr)	Calculated non-Stormwater Point Source Reductions (tons/yr)	Managed Total N Load (tons/yr)
Pawcatuck River Basin																			
Leave this line blank																			
1000-00	Pawcatuck River	3197		6.20	9.91	3.06	-3.14	-5.02		6.20	0.00	9.91	0.00			9.91			9.91
1000-01	Pawcatuck River	1051		3.61	1.90	3.06	-0.55	-0.29		3.61	0.00	1.90	0.00			1.90			1.90
1001-02	Wyassup Brook	2089		1.78	1.86	3.06	1.28	1.33		1.78	0.00	1.86	0.00			1.86			1.86
1004-01	Shunock River	1109		1.10	0.61	3.06	1.96	1.08		1.10	0.00	0.61	0.00			0.61			0.61
2000-26	Southeast Shoreline	587		12.18	3.58	3.06	-9.12	-2.68		12.18	0.00	3.58	0.00			3.58			3.58

Appendix 1B. Screenshot of Watershed Combined Condition Index Dashboard being developed, Mattabesset River example. (Source: CLEAR, Q. Lei-Parent)



Appendix 2. LIS Management Zones (Figure 3 from NYSDEC and CTDEP, 2000) and delivery and equivalency factors used in the LIS TMDL (Table 7 from NYSDEC and CTDEP, 2000).

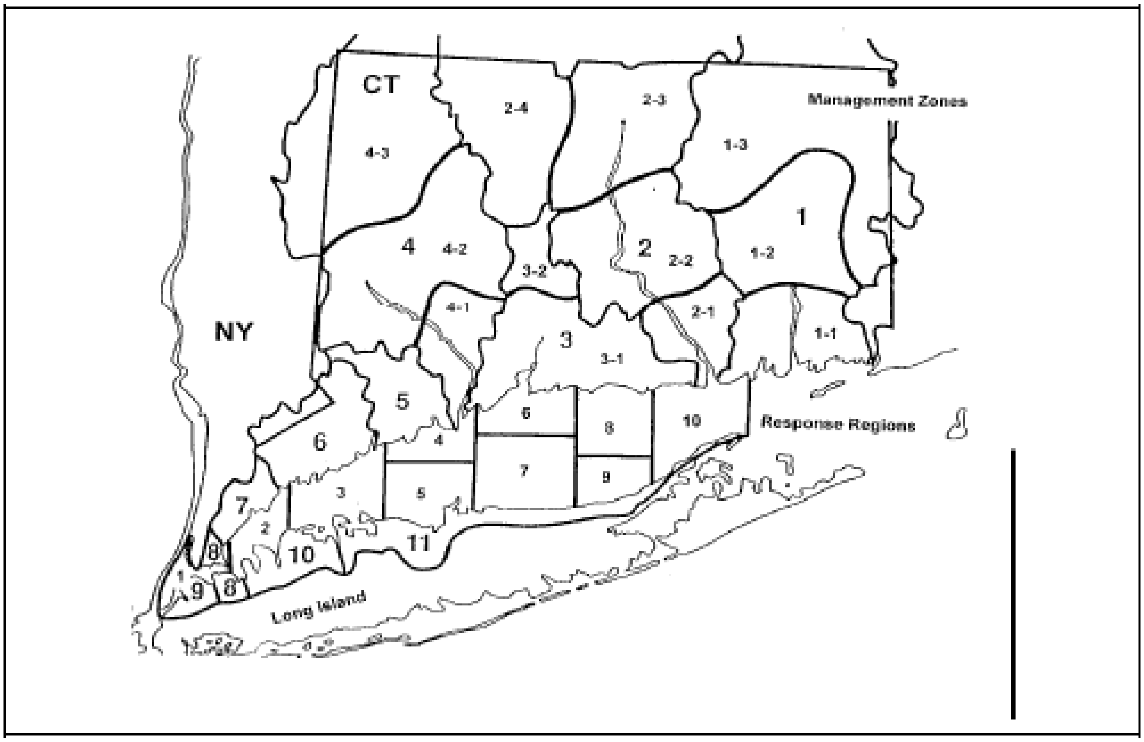


Figure 3. Geographic segments (zones and tiers) and response regions for Long Island Sound.

Table 7. River delivery factors, Long Island Sound transport factors, and calculated equivalency factors that combine river and Long Island Sound effects for in-basin management zones and tiers.			
Zone-Tier1	River Delivery Factor	LIS Transport Efficiency	Combined Equivalency Factor
1-1	1.00	0.17	0.17
1-2	0.91	0.17	0.15
1-3 Quinebaug	0.75	0.17	0.13
1-3 Shetucket	0.83	0.17	0.14
2-1	1.00	0.20	0.20
2-2	0.93	0.20	0.19
2-3	0.87	0.20	0.17
2-4	0.81	0.20	0.16
3-1	1.00	0.55	0.55
3-2	0.83	0.55	0.46
4-1	1.00	0.62	0.62
4-2 Housatonic	0.69	0.62	0.43
4-2 Naugatuck	0.90	0.62	0.56
4-3 Housatonic	0.52	0.62	0.32
4-3 Naugatuck	0.90	0.62	0.56
5-1	1.00	0.79	0.79
6-1	1.00	0.93	0.93
7-1	1.00	0.83	0.83
8-1	1.00	0.21	0.21
9-1	1.00	0.11	0.11
10-1	1.00	1.00	1.00
11-1 West	1.00	0.94	0.94
11-1 East	1.00	0.55	0.55
See Figure 3 for location of zones and tiers. Factors are expressed as the decimal fraction of the nitrogen load delivered			