Subtask E. Summary of Hydrodynamic Analysis

Introduction

As stated in the Performance Work Statement, the purpose of this task was to "relate tributary loads to areas of influence using both SWEM[1] outputs and other work." To accomplish this, Tetra Tech calculated (1) the area of influence of the Connecticut River and its contribution to nitrogen concentrations in primary tier embayments and (2) the relative mixing between LIS open water and individual primary tier embayments. The results will allow Tetra Tech to estimate the contribution of nitrogen loads from the Connecticut River and the open waters of LIS to each embayment, and consequently, the amount of mixing between LIS and embayments. Subtask E supports Subtask F, which will develop estimated total nitrogen levels for each primary tier embayment that are protective of seagrass and that do not show adverse effects related to macroalgae and dissolved oxygen, by defining the area of Connecticut River influence which needs to be protected. These estimated levels and estimated contributions can then be used by states to estimate nitrogen reductions needed by various sources in the watershed. This subtask also supports Subtask G, calculating reductions, because it provides estimates of mixing or dilution of embayment water with LIS water, explained in detail below. There are several options available to simulate estimate mixing that range from simple estimates of dilution and endpoint nutrient contributions (less resource intensive) to developing more complex, individual hydrodynamic models for each embayment (more resource intensive).

Relative mixing estimates for embayments provide an indication of the extent to which local nutrient loads are diluted by tidal and dispersive processes. Dilution of salinity within estuaries can be used as a proxy for nitrogen dilution under an assumption that nitrogen within embayments is conservative. There are several assumptions for this analysis, which are detailed in this memo and in the NYHOPS documentation, including validation information. There will be some settling and volatilization losses, but total nitrogen is likely to be nearly conservative or enough so on the spatial and temporal scales being considered to merit comparison. Larger losses are likely expected within the watershed, which should be considered in allocation. With this assumption, the following equation[2] can be used to estimate reductions based on seasonal average nitrogen concentrations:

$$Percent\ Reduction = \frac{(C_t - C_w)}{\left\{C_w - \left[C_{LIS} \times \left(\frac{S_e}{S_{LIS}}\right)\right]\right\}} \times 100 \qquad \text{(equation 1)}$$

Where,

C_t = target total nitrogen (TN) threshold concentration

C_w = receiving waterbody TN concentration

C_{LIS} = TN concentration in LIS boundary outside the embayment mouth

S_e = embayment salinity

S_{LIS} =LIS boundary salinity

This equation uses existing concentrations of an embayment, the boundary (LIS), and the target threshold concentration to calculate reductions. The S_e/S_{LIS} component of the equation is the relative

[1] Note, as discussed later in the memo, NYHOPS was chosen as the most appropriate model (not SWEM).

[2] Equation provided by Joe Costa, Executive Director of the Buzzards Bay National Estuary Program.

mixing between the open sound and individual embayments and is available from an LIS hydrodynamic model (selection of model detailed below).

A hydrodynamic model of LIS is also appropriate to address the area of influence of the Connecticut River, which is the major source of freshwater to LIS. Its area of influence is that region within which Connecticut River water exerts a predominant effect on water quality conditions and, consequently, designated use attainment. For this subtask, we identified this area of influence for the purposes of setting TN thresholds for those waters. Moreover, the Connecticut River contributes TN load to embayments influenced by its flow. If TN reductions from sound side TN loads are needed for those embayments, then it is necessary to know the contribution from the Connecticut River in order to allocate reductions to that source.

Given the resources available and the timeline of the project, Tetra Tech and EPA decided to use existing hydrodynamic models of LIS, preferably with salinity models already completed on an appropriate timescale (ideally hourly or daily during the summer critical season) rather than developing such models de novo. Local universities and groups continue to model LIS and individual embayments. In the future, such models might be more appropriate once more site-specific data have been gathered and more analyses have been conducted. Additionally, these models might potentially improve model estimated areas of influence. More information about the research Tetra Tech conducted and used to select a final model is provided in the section *Hydrodynamic Model Selection*, specifically Table E-1 and Table E-2.

The first part of the Subtask E analysis involved selecting an appropriate hydrodynamic model and extracting the salinity modeling component to estimate mixing between LIS and the embayments. As mentioned above, Tetra Tech used salinity to measure dilution by LIS and then dispersion of that salinity as a reasonable surrogate for nitrogen dilution and nitrogen dispersion from freshwater streams into the embayments. The second part consisted of applying a particle tracking model to the hydrodynamic model output to calculate Connecticut River area of influence and percent contribution. The particle dispersion model analysis estimates the extent of the contribution of Connecticut River water in LIS and, in turn, can be used to estimate how much of the nitrogen load from the Connecticut River flows into any of the primary tier embayments.

Hydrodynamic Model Selection

Tetra Tech and EPA identified several candidate existing hydrodynamic models for potential use for Subtask E, including the New York Harbor Observing and Prediction System (NYHOPS), the Regional Ocean Modeling System (ROMS), and the Estuarine, Coastal, and Ocean Model (ECOM) and Finite Volume Community Ocean Model (FVCOM) (Table E-1).

Table E-1. Hydrodynamic Models Considered

Model	Source
New York Harbor Observing and Prediction System (NYHOPS)	Nikitas Georgas, Stevens Institute of Technology
Regional Ocean Modeling System (ROMS)	Michael Whitney, University of Connecticut
Estuarine, Coastal, and Ocean Model (ECOM)	Originally developed by Hydroqual with updates and management by James O’Donnell and Grant McCardell, University of Connecticut
Finite Volume Community Ocean Model (FVCOM)	James O’Donnell and Grant McCardell, University of Connecticut

Tetra Tech and EPA organized a series of meetings with each of these model teams to discuss the characteristics, advantages, and disadvantages of each. Model summaries resulting from those meetings are compiled in Table E-2.

Table E-2. Hydrodynamic Model Meeting Summaries

Model	Summary
New York Harbor Observing and Prediction System (NYHOPS)	• Model built to predict hydrodynamics and any conservative pollutant transport primarily for NY Harbor, but extends to LIS and beyond. • While primary focus is on operational modeling for NY Harbor, Georgas recently completed a successful effort to validate model performance for flow, temperature, and salinity in LIS. • Immediately available are hindcast hydrodynamics for 1979–2013 on a daily timestep for a standard grid (500x500m; 11 sigma levels) from Delaware Bay to Cape Cod, including LIS. More recent output is also available on the server. • Available output includes daily and monthly average: wave height, currents, water level, temperature, salinity, and wind. • All data are freely available via a THREDDS data server from Stevens Institute of Technology. Access can be automated. • Finer temporal resolution output could be obtained through use of finer scale, nested models for embayments. However, they are not currently available and implementing them would be resource intensive. • Small embayments may not be fully resolved on a 500m grid. • Freshwater inputs to LIS are represented directly in NYHOPS for all gaged rivers and multiple ungaged areas between them (the exact methods for the ungaged areas do not appear to be thoroughly documented at this time, however). • Model is run every 6 hours in near-real time.
Regional Ocean Modeling System (ROMS)	• Model framework calibrated and validated for LIS by Michael Whitney. • Similar spatial resolution to NYHOPS model. • Small embayments may not be well resolved by the grids. • Have explicitly modeled large freshwater tributaries, as well as many small river inputs along the estuary with the intent of looking at nutrient transport. • Temporal extent (years modeled) is unknown, but, unlike NYHOPS, ROMS is not run in near-real time. • Model output data are very limited in public availability and what has been compiled is not at a daily time scale. • Norwalk Harbor fine-scale nested model output could be shared easily; other data would take more time and presumably resources to make available. • The output could not be provided in ready fashion by Dr. Whitney, and he recommended the NYHOPS model under these constraints.
Estuarine, Coastal, and Ocean Model (ECOM)	• Model developed by Hydroqual for original LIS TMDL, model output managed for LIS by Jim O'Donnell and Grant McCardell. • ECOM is the hydrodynamic model for SWEM for which the UCONN researchers possess the output (also available on disks provided by Hydroqual to EPA). UCONN reviewed and updated the SWEM (eutrophication) model code in 2010. • This model is comparable to ROMS and NYHOPS. • Small embayments may not be well resolved in the coarse grids of ECOM. • Freshwater inputs from major tributaries are represented in models. • Temporal scales: ECOM output: 1988/1989, 1994/1995, and 1998–2002 (only output; no forcing files). • ECOM output available in older binary format; • Output is not hosted on a public server at this time.

Model	Summary
Finite Volume Community Ocean Model (FVCOM)	• Model calibrated and validated for LIS by Jim O'Donnell and Grant McCardell. • FVCOM is a newer updated hydrodynamic model that has been calibrated and validated for LIS. FVCOM is a finite element model (as opposed to a gridded model) that has triangular grids that are more easily adapted to provide finer resolution in near shore areas and embayments. • This model is comparable to ROMS and NYHOPS. • FVCOM has a more flexible grid structure but is still principally an open water model; some nested models could be used for smaller embayments, but only a few have currently been developed. • Freshwater inputs from major tributaries are represented in models. • Temporal scales: FVCOM output: 2014. • FVCOM output is in easier to use NetCDF format and could likely be made available. • Output is not hosted on a public server at this time. • In recapping the characteristics of available models, McCardell suggested that model skills were similar, but if there were need to move on a quick schedule, NYHOPS would be the model of choice due to its hosting model output on a THREDDS server.

After meeting with each model team and discussing the pros and cons of each model, as well as the availability of data, Tetra Tech and EPA selected NYHOPS as the best modeling framework currently available to accomplish Subtask E within the project schedule and budget. The models produce comparable output, but the NYHOPS output is readily available for the project schedule; covers a longer temporal scale than any other model (so one can account for temporal variability), including resolution during critical summer conditions; and provides sufficient spatial resolution comparable to other model output datasets. The NYHOPS archive provides flow vectors and salinity predictions. The salinity model output can be used to calculate dilution/exchange for each embayment and the flow vector output can be used to run particle tracking models for the Connecticut River to identify the area of influence and to trace its contribution to primary tier embayments. Detailed NYHOPS model information, including construction and calibration/validation, can be found on their website: http://hudson.dl.stevens-tech.edu/maritimeforecast/.

Methods

Methods used to conduct the hydrodynamic analysis are described below. Note that Tetra Tech's quality assurance process is described in our approved Quality Assurance Project Plan, which is available at http://longislandsoundstudy.net/wp-content/uploads/2016/02/January-11-2017_TO-23-QAPP_LIS-N-Thresholds-and-Allowable-Loads.pdf.

NYHOPS Model Download and Processing

Tetra Tech downloaded the NYHOPS hydrodynamic modeling output from the OPenDAP Server,[3] including flow velocity vectors and salinity for all vertical layers for each NYHOPS grid cell (Figure E-1) for the period 2004–2013. The model uses a sigma grid, so each lateral cell has the same number of vertical layers (11), regardless of depth. More detail on the grid structure can be found in the NYHOPS model

[3] http://colossus.dl.stevens-tech.edu/thredds/dodsC/LISS/Hindcast/all_nb_mon_81.nc.html

documentation at http://hudson.dl.stevens-tech.edu/maritimeforecast/. Grid sizes were not adjusted. Data were later clipped to just the LIS region.

The NYHOPS model provides varied lateral grid cell densities across embayments, largely as a function of the size and shape of each embayment. As a result, some embayments contained more model grid cells than others (e.g., more cells in the Northport Centerport Harbor Complex than in Niantic Bay, CT) (Figure E-2). The density of grid cells within each embayment will influence the resolution of salinity estimates for each and, thus, estimates of mixing. Without embayment specific hydrodynamic modeling, these are the constraints imposed by the available models and the best estimates of mixing will be made using these data.

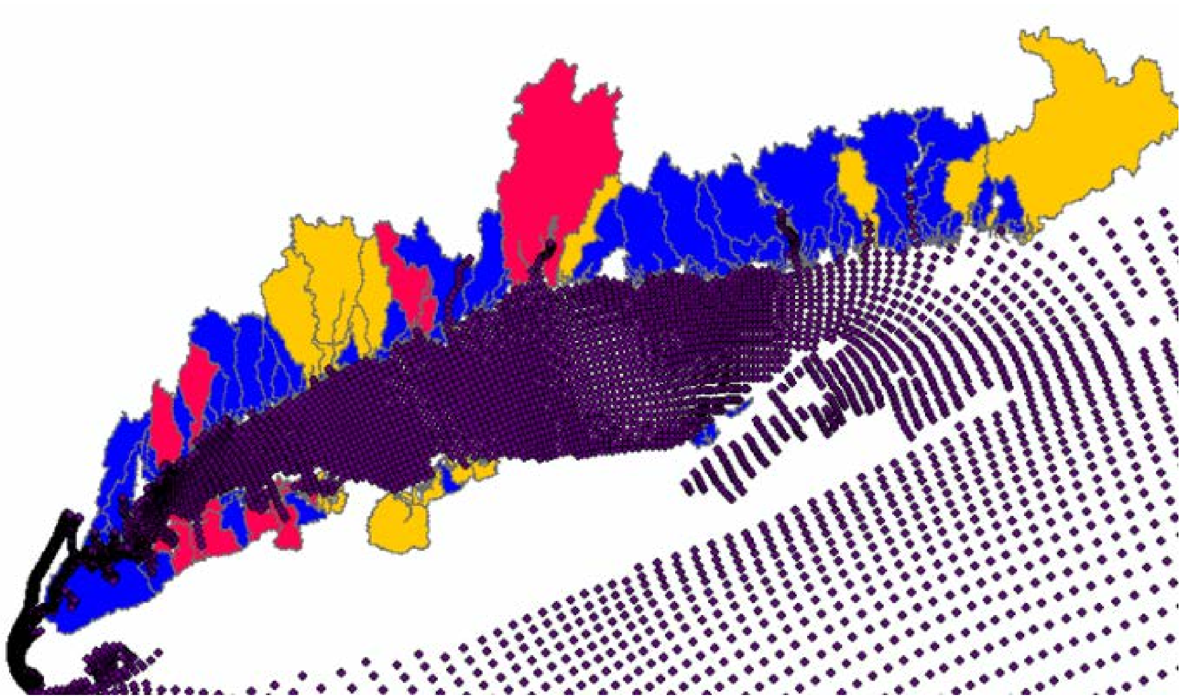
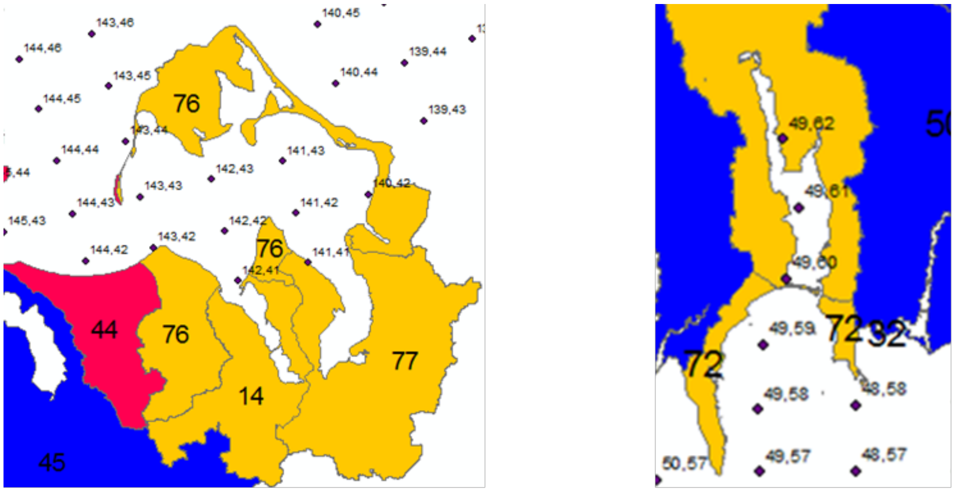


Figure E-1. NYHOPS Grid Domain Along with LIS Embayments (Points Represent the Center of Grid Cells; Primary Tier Watersheds are In Yellow, Secondary in Red, and Others in Blue)



Northport Centerport Harbor Complex, NY

Niantic Bay, CT

Figure E-2. Close-up Images of Two LIS Primary Tier Embayments

Salinity Modeling

The archived NYHOPS output provided daily average salinity data for each vertical layer for each grid cell (although the model itself runs on a shorter time step), and thus does not resolve sub-daily tidal excursions which would require hourly archived output. Model salinity prediction output (run sub-daily, but summarized daily) provided a simple and direct route to resolve calculations of embayment dilution. In essence, the predicted average salinity within an embayment at a weekly or monthly scale is a mixture of the salinity within the adjacent part of LIS and a freshwater concentration that is near zero on the land side. This observation enabled a direct estimate of the average degree of dilution of landside nutrient inputs:

In general, concentration of a constituent in an embayment, C_e, can be represented as

$$C_e = \frac{(C_0 Q_0 + C_{LIS} Q_{LIS})}{(Q_0 + Q_{LIS})} \qquad \text{(equation 2)}$$

where C is concentration and Q is net volumetric contribution and the subscripts 0 and LIS represent conditions from the freshwater inflow to the embayment and tidal mixing from LIS, respectively. For salinity we can assume that C_0 is insignificant relative to C_{LIS} (at the daily step, $C_0 \sim 0$ is appropriate because it represents net inflow from the land).[4] With that assumption,

$$Ce \approx \frac{(C_{LIS} Q_{LIS})}{(Q_0 + Q_{LIS})} = C_{LIS} \times D \qquad \text{(equation 3)}$$

where

[4] Refer to Appendix 1 in Anning, D.W, and M.E. Flynn. 2014. Dissolved-Solids Sources, Loads, Yields, and Concentrations in Streams of the Conterminous United States. U. S. Geological Survey Scientific Investigations Report 2014-5012, 101 p. http://dx.doi.org/10.3133/sir20145012

$$D = \frac{(Q_{LIS})}{(Q_0 + Q_{LIS})} \qquad \text{(equation 4)}$$

and is a dilution factor relative to water in the Sound. D is also by definition equal to C_e/C_{LIS}, which may be obtained from the salinity results (S_e/S_{LIS}). Q_0 and Q_{LIS} are then related by

$$Q_0 = Q_{LIS}\left(\frac{1}{D} - 1\right) \qquad \text{(equation 5)}$$

One can then estimate the concentration of any other conservative constituent for which C_0 is non-zero using the mixing and dilution information deduced from salinity by substituting the definition of Q_0 (equation 5) into the general equation for C (equation 2), such that

$$C_e = \frac{\left(C_0\left(\frac{1}{D}-1\right)+C_{LIS}\right)}{\left(\frac{1}{D}\right)}, \qquad \text{(equation 6)}$$

or

$$\frac{C_e}{C_0} = \left(\frac{C_{LIS}}{C_0} - 1\right)D + 1 \qquad \text{(equation 7)}$$

NYHOPS daily average salinity data were averaged over the summer growing season (July–September) to estimate average dilution rates in each primary tier embayment using the approach above. Average dilution over this critical summer growing season was considered of greatest relevance to the eutrophication response because nutrient retention is likely the greatest during this time. Tetra Tech considered a longer growing season per concerns, however, extending the growing season from April to September for hydrodynamics would decrease residence time (increase flushing) and reduce nutrient conditions and there was a desire to model to a theoretically most stressful condition. The 10-year average (2004–2013) of the median annual July–September salinity concentrations in the top six vertical layers was used to calculate the dilution ratio ($D = S_e/S_{LIS}$) for each embayment. The median was used to dampen the influence of storm events on the results.

Particle Tracking

To estimate the area of influence of the Connecticut River and its contribution to loads from LIS to particular embayments, Tetra Tech conducted a particle tracking routine using the NYHOPS flow vector output and releasing "particles" into the model grid at the mouth of the Connecticut River.

Tetra Tech used the daily flow vector output from the NYHOPS model and released particles every 4 hours from the top six sigma layers of grid cells at the mouth of the Connecticut River during the growing season (July–September) for each year of simulation. The selection of 4 hours allows for more resolution of particle movement estimates (against only a single daily release) and the model was limited to using the NYHOPS average daily flow vectors; finer resolution would not, therefore, resolve more of the sub-daily movement but would increase the computational burden. These particles moved according to the deterministic NYHOPS flow vectors, and each particle's motion was tracked. Particles leaving the sound were no longer tracked. The average percent of released particles across sigma layers within a grid cell gave the percent contribution of Connecticut River water to each grid cell and each depth. These were averaged across grid cells and depths to estimate the contribution of Connecticut River water to each grid cell. The deterministic tracking algorithm ignores the effects of dispersion and sub-daily tidal and wind mixing and is thus likely to produce an estimated zone of influence that is more compact, particularly at the edges, than actually occurs. More specifically, tracking is done on daily average net movement, thus it does not fully represent sub-daily mixing. The resulting zone of influence is more concentrated than it should be, which is more conservative near the source and less conservative further away. Future efforts could resolve more of the sub-daily hydrology, but this effort is a defensible approximation of average daily movement, the time scale of interest. Note that the vertical (Z) flow components were not available from the model output, meaning the exchange of particles between depths could not be calculated. This was addressed by releasing particles equally in all vertical layers at the Connecticut River mouth. This model is on a sigma grid, with equal number of layers everywhere, so this correction should not largely affect the estimated long-term average concentrations for the entire water column. Only the top six vertical layers were averaged for the analysis because they had particle movement once released in the model. Again, the NYHOPS model lacked advection and mixing between layers; the bottom five layers dispersed only minimally and would have underestimated mixing if included. The modeling team recognizes these limitations and encourages improvement in the future; but these limitations are the result of the constraints of using the available hydrodynamic model and represent a reasonable and defensible approximation under these conditions.

To display the area of influence of the Connecticut River, Tetra Tech used the particle tracking algorithm output on the percent contribution of Connecticut River particles to each grid cell to construct contour maps based on relative contributions. Tetra Tech used these maps to identify the downstream extent of Connecticut River area of influence (areas where the concentration contribution from the Connecticut River is > 40% of the concentration present at the Connecticut River mouth). Areas upstream of the release point were assumed to represent > 40% Connecticut River contribution. More information about the rationale for selecting 40% can be found in the results section below. Note that Tetra Tech defined the average boundary of Connecticut River water at the mouth. Particles were not tracked upstream.

Results

Salinity Model

The output from the salinity model consisted of long-term (10 year) average salinities inside and outside of the primary tier embayments, as well as the ratio of these salinities to estimate dilution (D) of loads from the watershed contributing flows and loads to the embayment (Table E-3). In general, these embayments have high dilution and are dominated by tidal flushing and mixing with LIS, at least at the scale resolved by NYHOPS. Note that these are daily average results and are most applicable to slack flood (high tide) conditions. Contributions from freshwater tributaries would likely be of greater importance on the ebb slack and with greater information on embayment salinity. Combined, these would lower the dilution ratios and increase the contribution of landward sources to each embayment and decrease the dilution from the LIS. These dilution ratios will be included in the calculation of reductions using the equations described above.

Table E-3. Salinity Dilution Analysis for Critical July–September Period, 2004–2013 for the Primary Tier Embayments (See Map in Figure E-3 for Primary Tier Embayments)

Primary Tier Watersheds (Component Embayments)		Salinity Inside (ppt)	Salinity Outside (ppt)	D
Pawcatuck River, RI		30.14	30.26	0.9961
Stonington Harbor, CT		28.92	29.98	0.9646
Saugatuck Estuary, CT	(Saugatuck River, CT)	25.56	26.88	0.9507
	(Saugatuck River, North, CT)	26.39	27.04	0.9759
Norwalk Harbor, CT		25.84	27.03	0.9561
Mystic Harbor, CT		29.90	29.93	0.9987
Niantic Bay, CT	(Niantic River, CT)	27.50	29.23	0.9408
	(Niantic Bay, CT)	28.50	29.23	0.9750
Farm River, CT		27.10	27.59	0.9823
Southport Harbor/Sasco Brook, CT		26.57	27.04	0.9824
Northport/Centerport Harbor Complex, NY	(Centerport Harbor, NY)	26.41	26.92	0.9811
	(Northport Bay, NY)	26.62	26.92	0.9890
	(Northport Harbor, NY)	26.27	26.92	0.9760
Port Jefferson Harbor, NY		26.93	27.30	0.9865
Nissequogue River, NY		26.66	26.98	0.9883
Stony Brook Harbor, NY		26.83	27.09	0.9902
Mount Sinai Harbor, NY		27.05	27.30	0.9909

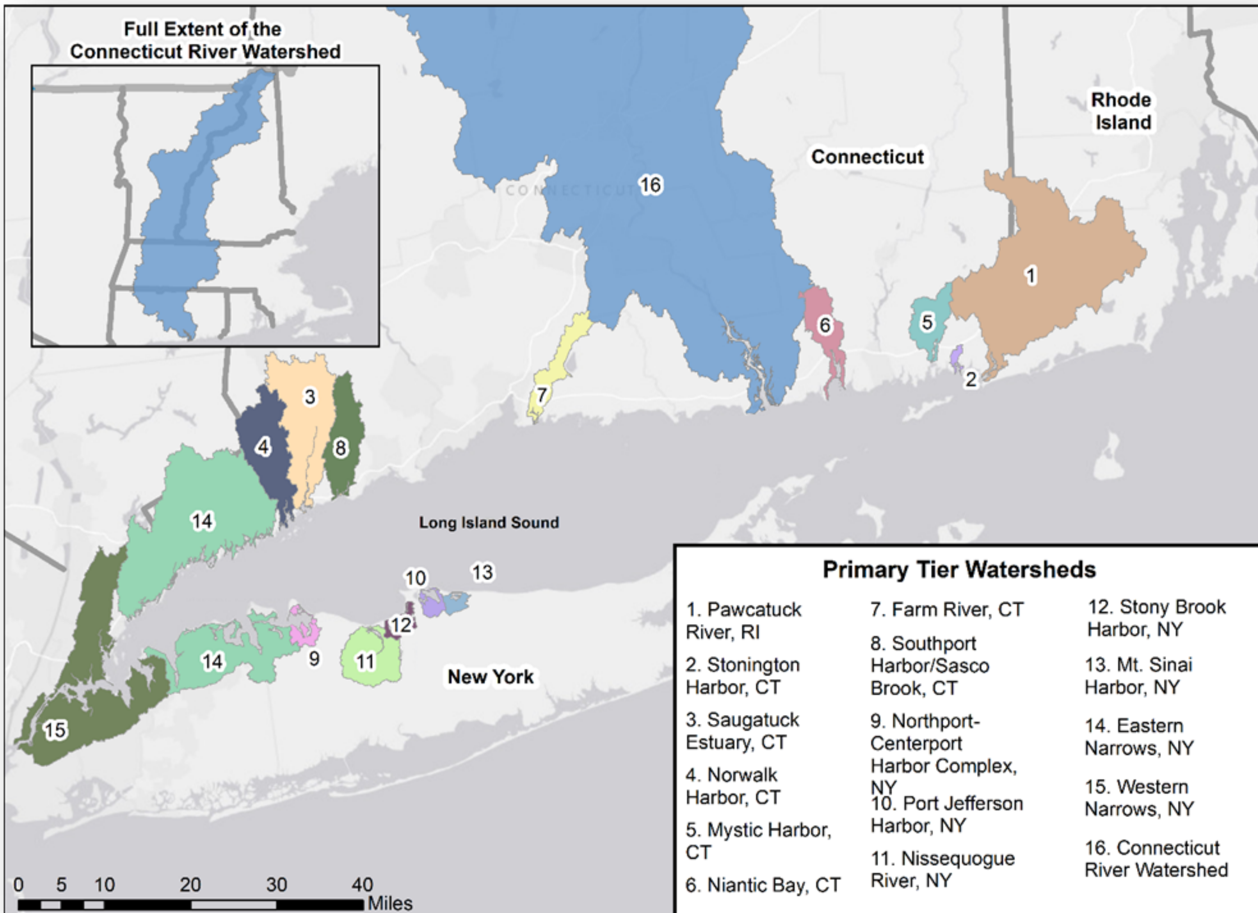


Figure E-3. Map of Primary Tier Watersheds in LIS. Eastern And Western Narrow and Connecticut River Watershed are Not Embayments

Particle Tracking Model—Identification of Area of Influence

For the first part of the particle tracking results, the area of influence was identified. This consisted of isopleths of the percent contribution of Connecticut River water to coastal water (Figure E-4). The results of this analysis delineate a space from 90% to less than 10% contribution. A value of > 40% contribution was used to define the area of influence for the Connecticut River, because there is error around this value as a function of changes in flow. As such, 40% would encompass an area more likely to include > 50% flow during higher flow periods (e.g., during spring runoff). The area with > 40% contribution of the Connecticut River is concentrated around the mouth of the Connecticut River and is more easily viewed with a close-up map (Figure E-5). Tetra Tech constructed a polygon from this > 40% isopleth and the resulting area was used in setting nitrogen (N) thresholds for the area of influence.

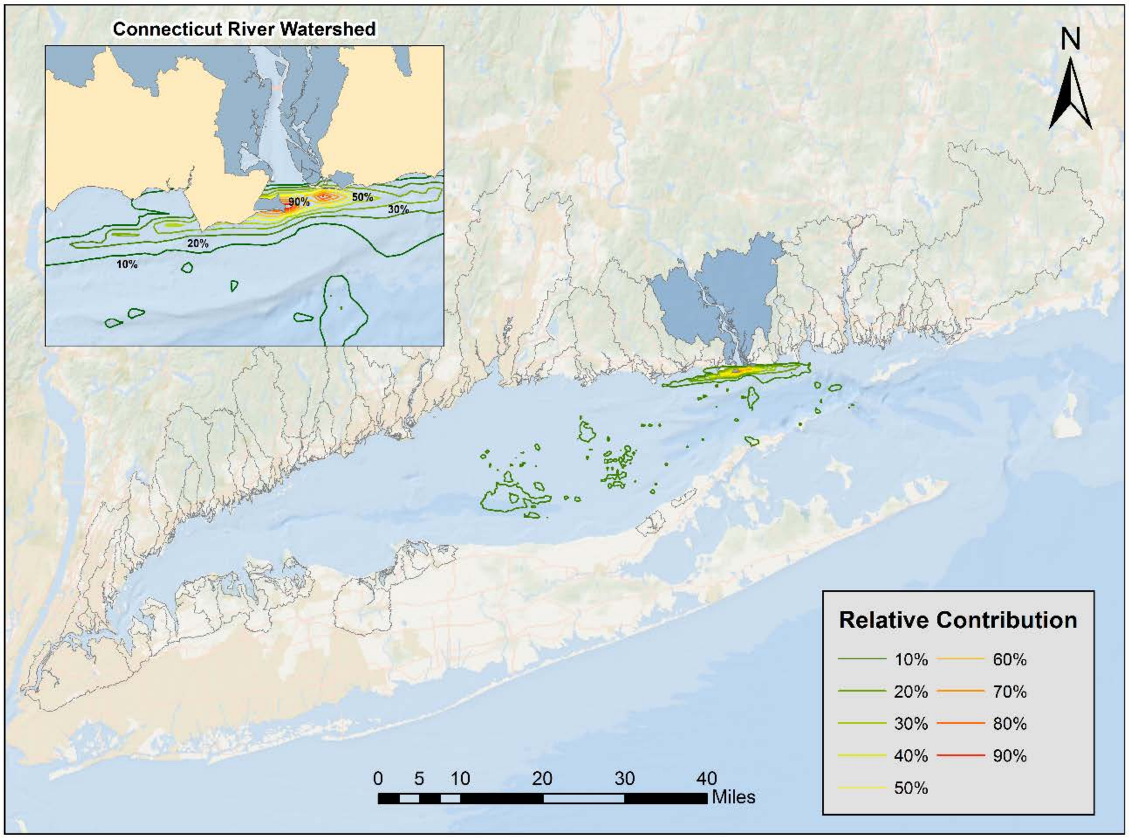


Figure E-4. Relative Contribution of Connecticut River Concentrations to Total Water Concentrations around LIS

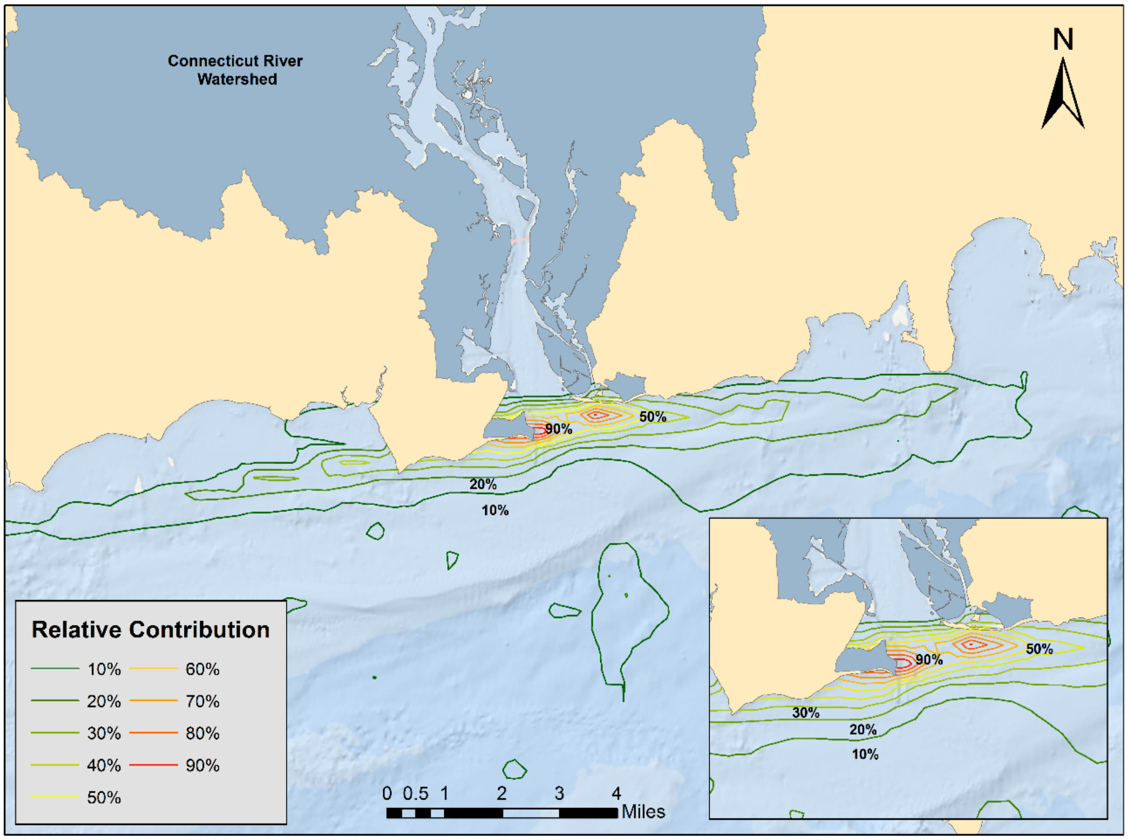


Figure E-5. A Closer View of the Relative Contribution of Connecticut River Concentration to Total Water Concentration around LIS Shown in Figure E-4

Particle Tracking Model—Contribution of Connecticut River Water to Each Embayment

The purpose of the second analytical output from particle tracking was to calculate the contribution of Connecticut River water to each primary tier embayment for purposes of eventual allocation, as needed. A certain portion of Connecticut River N loads will contribute to N loads and concentrations in some embayments. Tetra Tech calculated the contribution of Connecticut River water using the particle tracking model. The output consists of a multiplicative factor of Connecticut River N concentration generated as an average contribution of particles from the Connecticut River to each embayment (Table E-4). The multiplicative factor depends on both locations and distance in Euclidean space, as well as the relative rate of exchange with the Connecticut River plume in LIS.

Table E-4. Contribution of Connecticut River to Concentrations in Primary Tier Embayments

Primary Tier Watersheds (Component Embayments)	Multiplicative Factor on Connecticut River Concentration Average All Years, All Layers—Summer Critical Period
Connecticut River	1.00000
Pawcatuck River, RI	0.00021
Stonington Harbor, CT	0.00466

Saugatuck Estuary, CT	Saugatuck River, CT	0.00209
	Saugatuck River, North, CT	0.01071
Norwalk Harbor, CT		0.03155
Mystic River, CT		0.01235
Niantic Bay, CT	Niantic River, CT	0.07269
	Niantic Bay, CT	0.10942
Farm River, CT		0.00555
Sasco Brook, CT		0.01071
Northport/Centerport Harbor Complex, NY	Centerport Harbor, NY	<0.00001
	Northport Bay, NY	<0.00001
	Northport Harbor, NY	<0.00001
Port Jefferson Harbor, NY		0.02093
Nissequogue River, NY		0.00001
Stony Brook Harbor, NY		0.00208
Mount Sinai Harbor, NY		0.06438

The multiplicative factors are relative concentration multipliers on the Connecticut River discharge for each embayment. For example, if the TN concentration in the Connecticut River discharge is 3.5 mg/L, then the additive contribution of the Connecticut River to concentrations in Saugatuck River North, CT would be 0.01071 x 3.5 = 0.0375 mg/L based on assumptions that concentrations are conserved and superimposable. The analysis is based on particle transport with NYHOPS daily flow vectors for the 2004–2013 period. The results are averages for all NYHOPS grid cells that intersect a defined embayment of interest. Although the NYHOPS grid resolution is too coarse to resolve details within embayments, NYHOPS remains the best model based on available data, resources, and deadlines. Should resources become available to develop individual temporal and spatial hydrodynamic models, this would resolve more detail within embayments.

Conclusion

The goal of this work was to calculate (1) the area of influence of the Connecticut River and its contribution of nitrogen to primary tier embayments and throughout LIS (specifically Western LIS) and (2) the relative mixing between LIS open water and individual primary tier embayments. Both analyses provide preliminary information on the linkage between nitrogen loading sources and ambient concentrations in the embayments. Resources were insufficient to develop *de novo* highly resolved, temporally extensive hydrodynamic models for LIS including for every embayment. Therefore, the project team identified available defensible hydrodynamic model output, which it did with the expert input of three existing LIS hydrodynamic modeling teams from Stevens Institute and the University of Connecticut. After consultation with and input from these experts, it was determined that the NYHOPS models provided the best combination of readily available output at the spatial and temporal resolution needed given the constraints of the project schedule and resources. The modeling team recognized that the readily available output of the model had constraints (e.g., did not provide sub-daily flow vectors, did not provide mixing between sigma layers), but that it still provided defensible and comparable approximations of flow and salinity across the widest area of LIS for the purposes of this project.

The NYHOPS model data were used to estimate dilution (D) of LIS water with the priority tier embayments to be applied in calculating reductions in Subtask G. The model data were also used to track water movement in LIS to evaluate the contribution of Connecticut River water during the summer to each grid cell in LIS, allowing the team to estimate both an area of influence of the Connecticut River for purpose of informing N targets for that waterbody as well as for calculating the contribution of Connecticut River nitrogen during the summer to priority tier embayments.

The limited resolution of the NYHOPS grid did not include the entirety of each embayment and likely overestimated dilution of the landward, freshwater ends of embayment waters. This could be improved in the future by constructing more resolved hydrodynamic models or greater empirical estimates of dilution for each embayment. Since the temporal scale of interest is average dilution, the lack of sub-daily hydrodynamics was likely not as influential on dilution estimates.

The available NYHOPS data did provide vertical flow vectors, although the salinity predictions incorporated those flows. The lack of vertical mixing and diffusive exchange among grid cells affected the estimates of Connecticut River water movement through LIS. Because the deterministic tracking algorithm ignored the effects of dispersion and sub-daily tidal and wind mixing, it is thus likely to produce an estimated zone of influence that is more compact, particularly at the edges, than actually occurs in LIS. Future efforts, again, could help resolve this limitation.

The temporal scale of modeling (July – September) was intentionally focused on a critical time period most stressful in terms of nutrient effects on responses in LIS embayments. Flow and material contributions from all tributaries, including the Connecticut River, are greater at other times, especially the spring and during storms, and mixing and exchange likely varies. Because of significant tidal flushing of water, nutrient loads from earlier in the season (i.e., winter) are likely only retained into the late summer primarily through storage in sediment and biota (dissolved nutrients will be flushed out). However, without the resources to model the fate of such temporal inputs in each embayment, their influence on critical period exposure concentrations is unknown. Future efforts should certainly consider how to improve on these estimates.