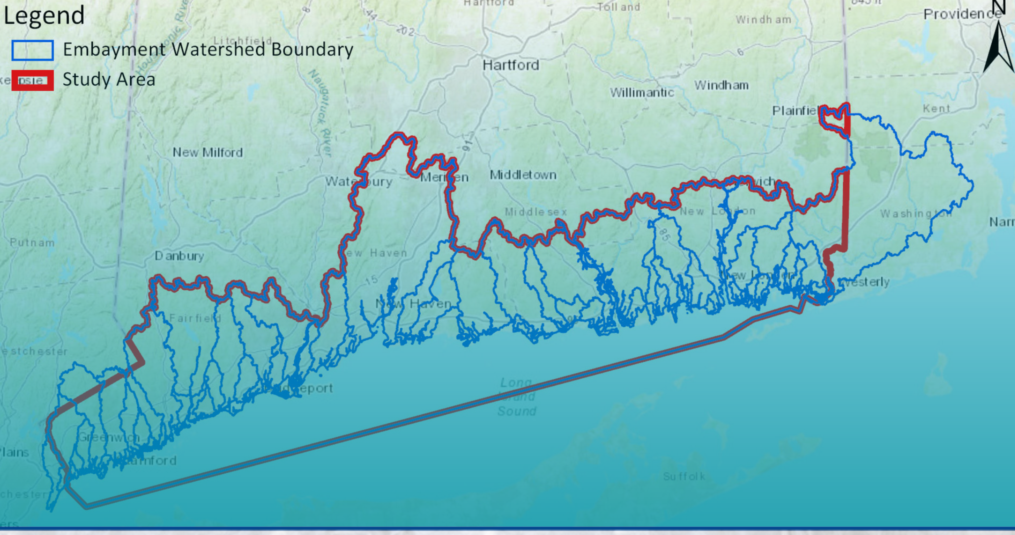
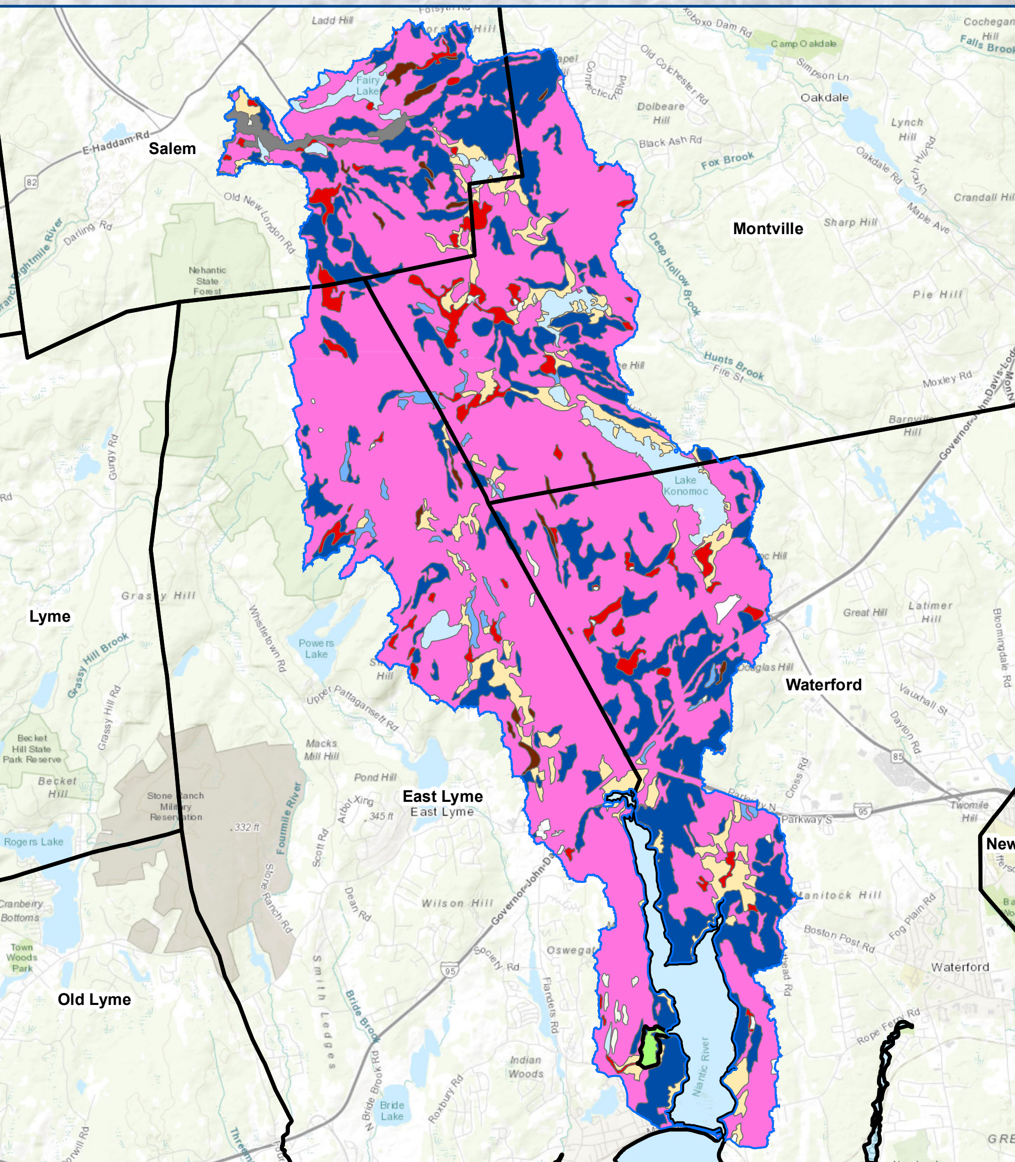



# EXECUTIVE SUMMARY

Connecticut Department of Energy and Environmental Protection

## Phase II Onsite Wastewater Treatment Systems Project (DEEP-WPLR-2019LISN)




October 2020

CDM Smith

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CDM Smith

# Executive Summary

The Long Island Sound Study (LISS) was initiated in 1985 to address low levels of dissolved oxygen attributed to nitrogen pollution. The states of Connecticut and New York and the Environmental Protection Agency (EPA) developed and approved the 1994 Comprehensive Conservation and Management Plan (CCMP) to address priority problems, including low dissolved oxygen. The CCMP included development of a Total Maximum Daily Load (TMDL) to reduce nitrogen loading by 58.5 percent and in 2001, EPA approved the TMDL.

Upgrades to wastewater treatment plants over the past decades have successfully achieved nitrogen reductions from point sources, which contributed the largest nitrogen loads to the Sound. However, despite the significant nitrogen reductions, dissolved oxygen impairments remain in Long Island Sound. The 2015 CCMP identifies that control of nitrogen remains a top priority. In 2015, EPA initiated the Long Island Sound Nitrogen Reduction Strategy with the primary focus of reducing nutrient pollution from stormwater, fertilizer, and coastal on-site wastewater treatment systems (OWTS).

In 2016, DEEP developed its Second Generation Nitrogen Strategy which enhances efforts to address nonpoint sources of nitrogen. These sources include stormwater, atmospheric deposition, fertilizer use and onsite wastewater treatment systems. The strategy also directly addresses embayments and called for an assessment of nitrogen loading from OWTS located in coastal areas.

To estimate the magnitude and impacts of nitrogen loads from OWTS, DEEP retained Lombardo Associates, Inc. (LAI) to complete an ***Inventory and Assessment of Onsite Wastewater Treatment Systems and their Impact on Nitrogen Loading to Connecticut's Coastal Areas***. This study, referred to as the Phase I study, included an OWTS inventory, estimation of the nitrogen loads from the OWTSs and the attenuation of the nitrogen loads as they travel from OWTSs through the groundwater to discharge to downstream surface waters.

## Project Objectives and Phase II Watersheds

The objectives of the Phase II study, ***Evaluation and Visualization of the Findings from the Onsite Wastewater Treatment System Study Phase I Report*** were to:

- Review the OWTS inventory, nitrogen load estimates and attenuation factors described in the Phase I study documents and recommend improvements where appropriate;
- Implement the recommended improvements to inventory OWTS, calculate unattenuated and attenuated nitrogen loads from OWTS for ten selected watersheds and prepare watershed-specific maps to display the results;
- Identify potential approaches to ground-truth the nitrogen loading estimates, and
- Incorporate DEEP and stakeholder comments into a final report documenting the Phase II evaluations and work products.

Based on the Phase I estimated loads and watershed characteristics, CT DEEP selected the ten watersheds listed in **Table ES-1** for more detailed OWTS inventory and nitrogen load estimation and mapping.

**Table ES-1 Phase II Study Area Watersheds**

| Embayment | Location |
|---|---|
| Clinton Harbor | Madison, Clinton |
| Direct Drain to Long Island Sound | Madison |
| Farm River | East Haven |
| Fence Creek | Madison |
| Mill River | Fairfield |
| Niantic River | East Lyme |
| Pawcatuck River | Stonington, Westerly |
| Sasco Brook | Westport, Fairfield |
| Toms Creek | Madison |
| Williams Cove | Stonington |

# Evaluation of Phase I Study Approach and Recommendations

The Phase I study considered the watersheds of 82 embayments within the study area, shown in **Figure ES-1.** A reliable inventory of OWTS is important because it is the foundation for the estimated nitrogen loading to each watershed and because it guides the framework for consideration of wastewater management alternatives.

The Phase I study used U.S. Census data to estimate OWTS inventory and nitrogen loads for each of the watersheds. In addition, three watersheds were studied in more detail, evaluating OWTS inventory and nitrogen loads on a lot-by-lot basis.

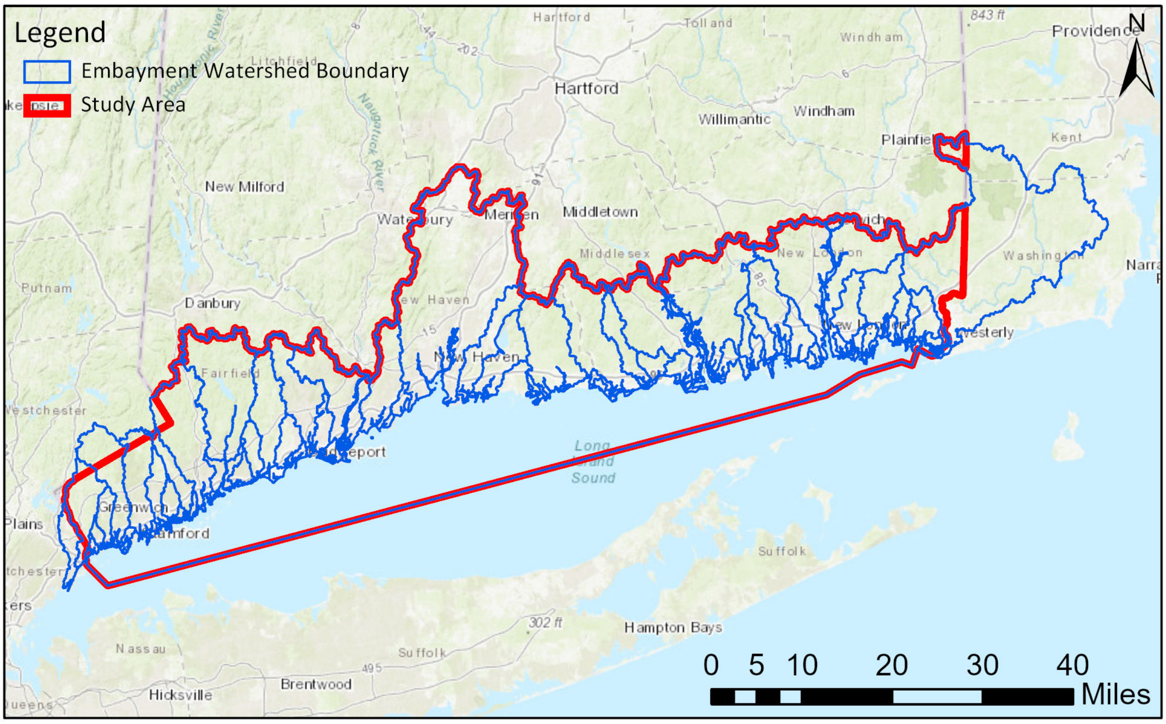



**Figure ES-1 Phase I Study Area and Embayment Watershed Boundaries**

# On-site Wastewater Treatment System (OWTS) Inventory

## Description of Phase I Approach

The Phase I OWTS inventory of residential systems was developed using three approaches:

- A census block level analysis was performed for 82 watersheds;
- A revised census block level approach was implemented after the initial census block level analysis yielded counterintuitive results; and
- A more detailed lot-by-lot analysis was performed for three watersheds

GIS coverages of U.S. Census blocks, 2015 CLEAR land use, the 2015 Statewide Sewer Service Area (SSA) coverage, and watershed boundaries were used to estimate the OWTS inventory in each watershed by allocating census housing units to developed unsewered areas using an area-weighted approach shown on **Figure ES-2**. However, a spreadsheet error prompted LAI to conclude that the population density in unsewered areas was misrepresented in the census data. An alternative methodology, shown by **Figure ES-3**, was then developed which aggregated the estimated unsewered population for each community (e.g., town or city) comprised of multiple U.S. census blocks.

The non-residential OWTS inventory was based on groundwater subsurface system (GSS) and underground injection control (UIC) permit data collected from CT DEEP and internal work logs for non-residential SSDS systems with design flows greater than 2,000 gallons per day (gpd) from CT DPH for both approaches.

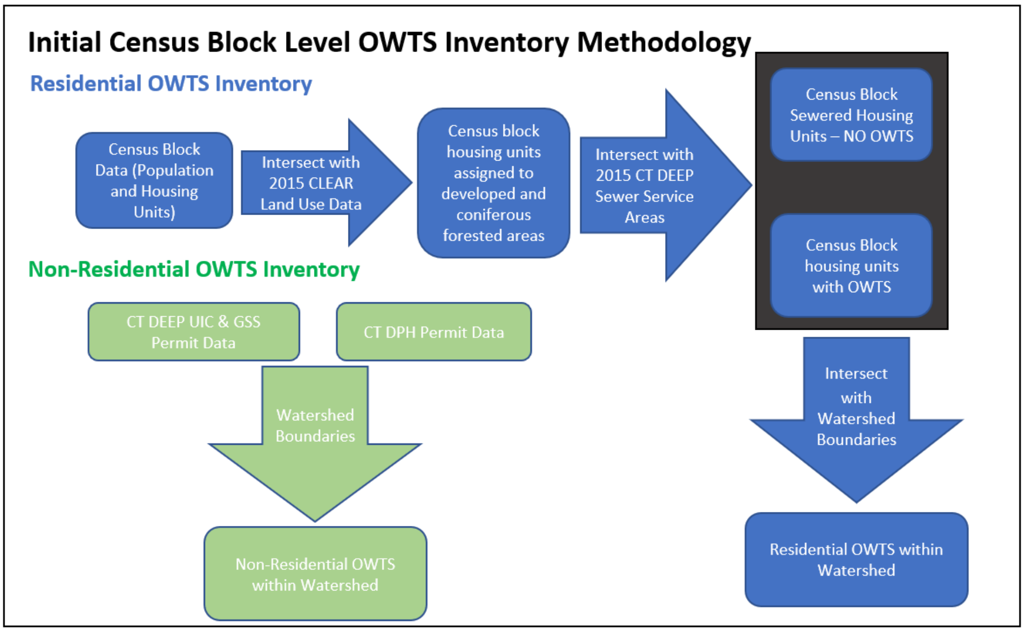



**Figure ES-2 Overview of Census Block OWTS Inventory Analysis**

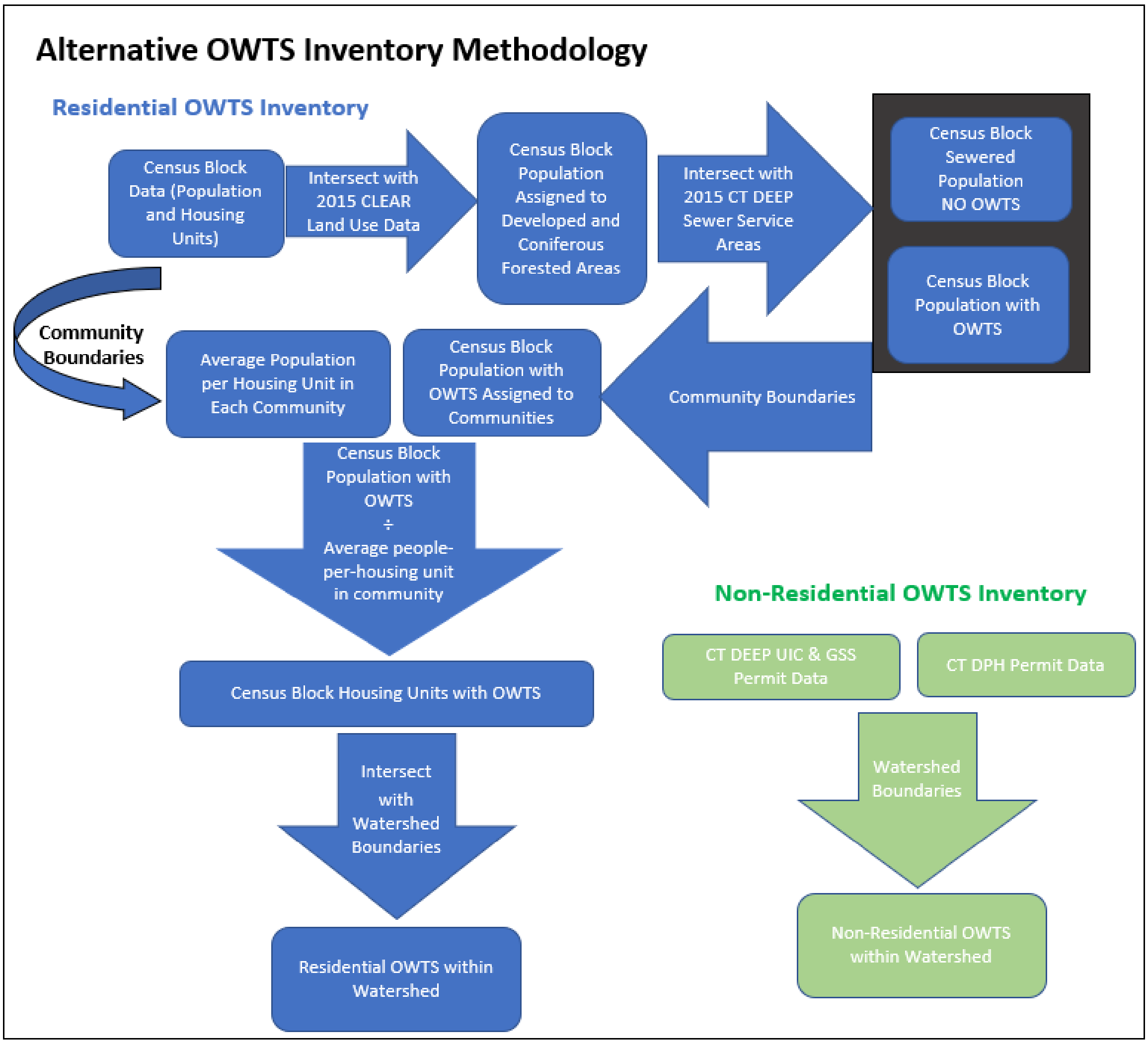



**Figure ES-3 Alternative OWTS Inventory Methodology**

A lot-by-lot OWTS inventory was also developed for the Mill River, Sasco Brook, and Williams Cove watersheds based on tax parcel data and parcel shapes from the GIS departments of the communities located within each watershed. The lot-by-lot analysis also incorporated the same commercial and industrial permit and work log data from CT DEEP and CT DPH that was used for the census-level analysis.

## Evaluation of the Phase I Approach and Data Gaps

The Phase I approach to inventory OWTS was evaluated and assumptions, errors, inconsistencies and potential data gaps were identified. **Table ES-2** summarizes the assumptions and approaches used in the Phase I study. Aspects of the Phase I study that could be improved are shaded in blue.

**Table ES-2 Summary of Phase I OWTS Inventory Approach & Assumptions Assessment**

| Assumption | Assessment |
|---|---|
| Developed areas are defined as the developed and coniferous forest coverages of the 2015 UCONN CLEAR land use dataset, and all housing units exist within developed areas. | Reasonable |
| An OWTS is associated with every housing unit outside of the 2015 version SSA coverage area provided by CT DEEP | Reasonable, assuming the sewer system coverage is up-to-date.<br><br>This assumption may underestimate the number of OWTS in a watershed, as housing units with functioning OWTS may choose to remain unsewered rather than connect to the sewer system. |
| Population and housing density within each census block are uniformly distributed across sewered and unsewered areas | Reasonable when estimating total OWTS in study area.<br><br>May overestimate OWTS density in some areas, as densely developed areas are more likely to be sewered than areas with large parcel sizes.<br><br>May overestimate or under-estimate OWTS inventories because the developed land use coverage includes areas that should not contain any housing units (e.g. highways) |
| The number of people-per-housing unit is uniform for each community | Reasonable when estimating total OWTS in study area.<br><br>May overestimate or under-estimate OWTS inventories because towns can span multiple watersheds and the number of people-per-housing unit varies at the census block level. |
| Non-residential OWTS are identified in CT DEEP permit databases or CT DPH work logs | Underestimates the number of non-residential OWTS – newer (e.g., post-2013 GSS permits) and larger non-residential OWTS are included in the State permit and work log databases. OWTS less than 2,000 gpd are most often regulated by local health departments. |
| Parcels with a residential or commercial land use code have residential or commercial developments | Reasonable, but should include some level of QA/QC. Tax parcel data may not be up to date, and may include errors that result in over or underestimating the OWTS inventory |
| Parcels within the statewide sewer service area coverage, version 2015, do not have OWTS | May underestimate the OWTS inventory if housing units with functional OWTS do not connect to the sewer system.<br><br>Parcels along the edge of the sewer service coverage may appear to intersect the sewer service area but still have OWTS. |

## Recommended Phase II OWTS Inventory Approach

The existing census block level and lot-by-lot analyses should both provide reasonable estimates of OWTS inventory but additional quality control efforts could improve the accuracy of and confidence in the results, especially with respect to the non-residential component of the inventory. The recommended OWTS inventory approach implemented during Phase II is summarized by **Figure ES-4** and by the steps below:

1. Collect parcel data (land use and if available, utility data) for each community.
2. Cross-check parcel land use against building footprint data (i.e. confirm that buildings exist on residential and commercial parcels).

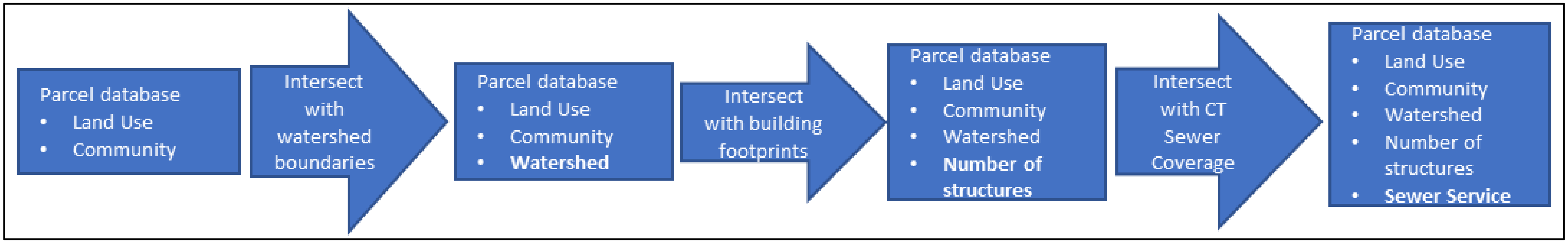



**Figure ES-4 GIS Process Used to Identify Parcels with an OWTS**

3. Assign population to residential parcels based on the average number of people-per-housing unit based on census block population.

4. Identify parcels that are located within the updated SSA (version 2018) coverage and compare against utility information from tax assessor data[1].

5. Investigate parcels for which sewer service coverage and tax assessor data conflict, and document such investigation, or make the conservative assumptions that any parcel outside of the sewer service area has an OWTS and any parcel marked as having septic utilities has an OWTS.

6. Remove parcels that were identified as sewered.

7. Aggregate OWTS inventory by watershed, then visualize and analyze the results.

The foundation of the updated OWTS inventory was the collection of parcel-specific tax assessor GIS data from the 22 communities that have land within the ten study area watersheds. Most parcels in the parcel database included a land use description that indicates whether wastewater is generated at that parcel; remote sensed GIS data was leveraged to fill in missing data where necessary.

Using the consolidated land use data, the parcel database was intersected with three additional GIS datasets to identify the watershed within which the parcel was located, whether a building was located on the parcel and whether the parcel was within the DEEP sewer service area.

Starting from the parcel database with fields for land use and community, GIS intersections were performed with the following datasets:

- The study area watershed boundaries from UCONN watershed delineations (Vaudrey, 2016) to identify the watershed within which each parcel is located;
- Remote sensed US building footprints (Microsoft, 2019) to identify the number of structures within each parcel boundary, and
- The Statewide SSA 2018 version (6/15/2018) to identify whether a parcel lies within a sewered area.

Following the GIS intersections, each parcel in the database had enough information to assess whether an OWTS should be present. Quality control measures reviewed the presence or absence of buildings using google street view for parcels with missing land uses.

In addition to the parcel database driven OWTS inventory, non-residential OWTSs permitted by CT DEEP and identified in CT DPH work logs that were catalogued in the Phase I study were also included.

[1] Local communities and delegated Water Pollution Control Authorities have the responsibility of maintaining sewer service maps for their jurisdictions. In 2018, CTDEEP received the most recent version of sewer service maps from local municipalities and referenced those maps to update the existing statewide sewer service area map; identified as the Statewide Sewer Service Area (SSA) 2018 version.

## Phase II OWTS Inventory Results

A comparison of the Phase I and Phase II OWTS inventories for the ten study area watersheds is provided by **Table ES-3**.

**Table ES-3 Comparison of Phase I and Phase II OWTS Inventories**

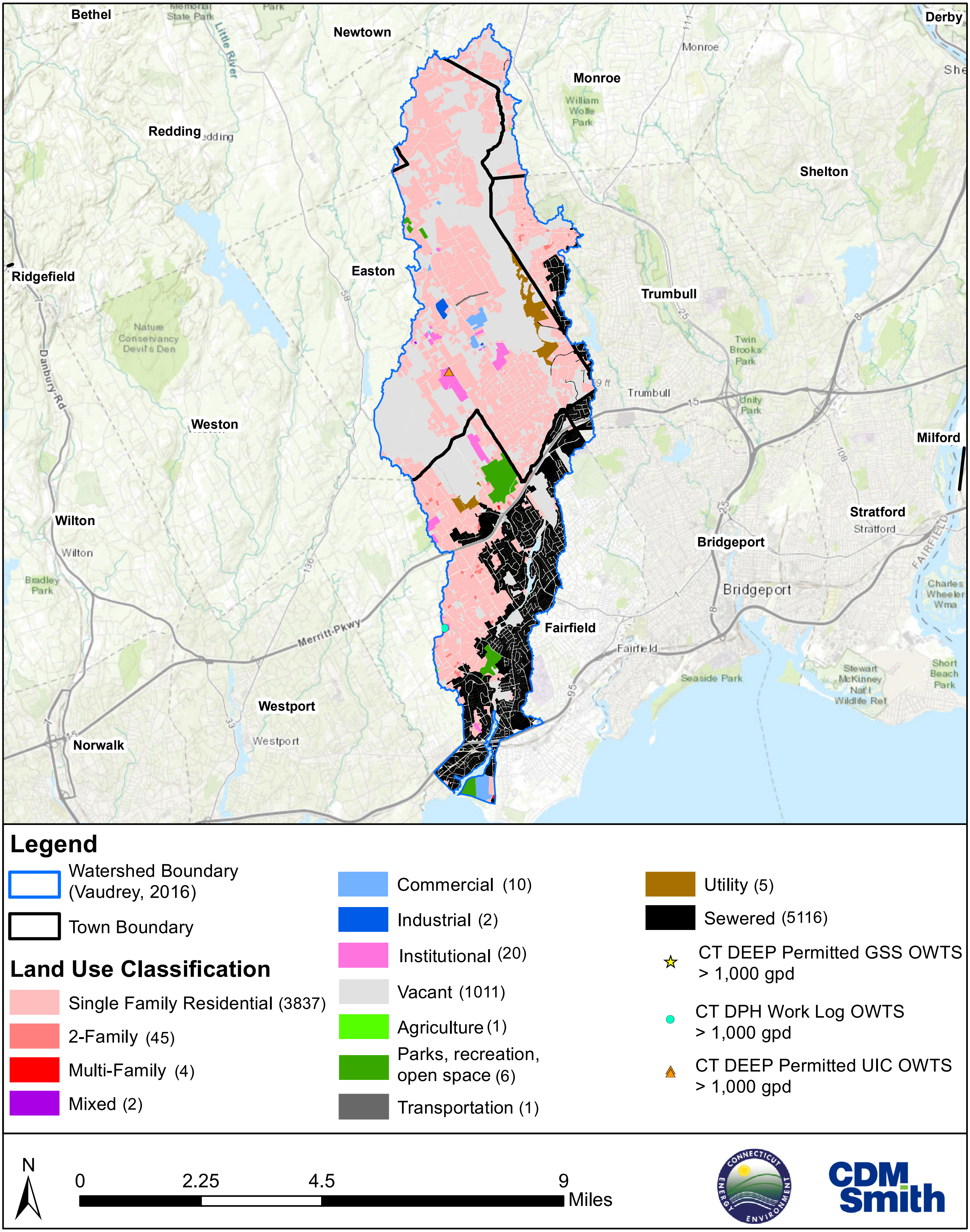
| Watershed | Phase II Residential OWTS | Phase II Non-Residential OWTS | Phase I Residential OWTS (Census Block Approach) | Phase I Residential OWTS (Lot-by-lot Approach) |
|---|---|---|---|---|
| Clinton Harbor, CT | 9,432 | 325 | 13,151 | N/A |
| Farm River, CT | 1,287 | 20 | 2,411 | N/A |
| Fence Creek, CT | 654 | 29 | 1,947 | N/A |
| Madison LIS | 1,167 | 101 | N/A | N/A |
| Mill River, CT | 3,888 | 32 | 6,146 | 4,445 |
| Niantic River, CT | 1,147 | 46 | 3,258 | N/A |
| Pawcatuck River, RI | 2,194 | 97 | 3,362 | N/A |
| Sasco Brook, CT | 1,509 | 8 | 3,106 | 1,901 |
| Toms Creek, CT | 446 | 8 | 854 | N/A |
| Williams Cove, CT | 189 | 8 | 801 | 208 |

The Phase II OWTS inventories are significantly lower than those from the census-based Phase I study. The reduced Phase II inventory is attributed to the following:

- The updated Statewide SSA 2018 version coverage used in the Phase II study includes a significantly larger area in three watersheds**;**
- The census block approach of the Phase I study assumed that housing density was uniform across the developed area of each census block. However, densely developed areas are more likely to be served by a sanitary sewer system than rural areas, and not all developed areas defined by the Phase I study contained structures (e.g. highways);
- The census block approach of the Phase I study used "housing-units" from the U.S. Census as a proxy for OWTSs. This over-estimated the number of OWTS because multiple census housing units associated with a multi-family dwelling were assigned multiple OWTSs, instead of a single OWTS, and
- Differences between the Phase I lot-by-lot and Phase II inventories also appear to result from the additional quality controls implemented in the Phase II study.

The land use of each parcel in each watershed was mapped to illustrate the distribution of potential OWTS across the study area. These maps may be found in Appendix C of this report, but an example map of land use in the Mill River watershed is shown in **Figure ES-5**.

# Figure ES-5: Example Land Use Classification Map for the Mill River Watershed



# Nitrogen Loads

## Description of Phase I Approach

Understanding the magnitude of nitrogen loads from OWTSs helps to establish the overall nitrogen loading to downgradient groundwater and coastal embayments and to establish priorities for wastewater management.

Like the OWTS inventory, the Phase I nitrogen load estimation followed two approaches: a census block level analysis for 82 watersheds  and a more detailed lot-by-lot analysis for three watersheds.

The Phase I census block level analysis used different approaches to derive residential and non-residential nitrogen loads.  Phase I residential nitrogen loads were calculated for both the year-round and seasonal populations, assuming that each person generates 4.8 kg N/year (or 10.58 pounds N/year) based on the value used in the Nitrogen Loading Model (NLM) documented in Valiela et al. (1997). Residential OWTS nitrogen loads due to seasonal population fluctuations assumed that the area south of I-95 has a seasonal population increase of 100 percent to 200 percent during 2.5 summer season months.  For simplicity, the Phase I analysis assumed a 30 percent seasonal increase in nitrogen loads from residential OWTS located south of I-95.

Non-residential nitrogen loads were developed based on the GSS and UIC permits collected from CT DEEP, and work logs for additional non-residential SSDS systems from CT DPH. The nitrogen load for each permitted system was calculated assuming that the flow was 50 percent of the system design flow, the effluent nitrogen concentration for CT DEEP-permitted UIC systems and CT DPH-logged SSDS systems were assumed to be 60 mg-N/L and CT DEEP-permitted GSS systems were assumed to provide advanced treatment that reduces effluent nitrogen to 10 mg-N/L.

The lot-by-lot analysis combined population data from the U.S. Census with land use, building, and utilities information from tax assessor parcels to estimate the nitrogen load from OWTSs in the Mill River and  Sasco Brook watersheds.  Nitrogen loads for each OWTS parcel were calculated based on assumed flows and assumed nitrogen concentrations for residential and non-residential land uses. Average wastewater flow rates from residential OWTS systems were back-calculated based on the average number of people-per-housing unit within each watershed (from U.S. Census block data), an annual nitrogen load of 4.8 kg/person and an assumed OWTS discharge nitrogen concentration of 60 mg/L. Unlike the census-based approach, the impact of seasonal population fluctuations was not considered in the lot-by-lot analysis.

Average flow rates from non-residential systems were developed for individual land use categories, but no basis for the wastewater flow assumptions was provided. On-residential OWTS were assumed to discharge 120 mg-N/L (no reference was cited).

The Williams Cove watershed is located entirely in a single community, Stonington. A slightly different methodology considering additional building size and bedroom count data provided by Stonington, (the only town within the Williams Cove watershed) was used to estimate nitrogen loads from OWTS Parcels with one to four bedrooms were assumed to discharge 150 gpd. For each additional bedroom above four, 50 gpd was added to the residential wastewater flow. For example, a 6-bedroom home was estimated to discharge 250 gpd of wastewater. The

Williams Cove non-residential nitrogen load calculations were based on parcel-specific wastewater flow data calculated from *usable area* data from tax assessor parcels.

## Evaluation of the Phase I Approach and Data Gaps

The reported differences between the nitrogen loads from residential OWTS estimated using the census-based and parcel-specific residential methods are consistent with the differences between the OWTS inventories. The most significant difference between the two approaches observed for Williams Cove resulted from the sewered parcels located outside of the 2015 version of the SSA coverage area.

The estimated non-residential loads are significantly higher in the parcel-based analysis compared to the census-based analysis because the parcel analysis considered all parcels with a non-residential land use, while the census approach only included large permitted systems; only five permitted non-residential system were found in the lot-by-lot analysis, all within the Mill River watershed.

**Table ES-4** summarizes the assumptions. Aspects of the Phase I study that could be improved are shaded in blue. The census block level method and lot-by-lot analysis are considered separately.

**Table ES-4 Evaluation of the Nitrogen Load Estimation Approach and Assumptions**

| Assumption | Assessment |
|---|---|
| 4.8 kg N/capita/year<br>(10.58 lbs. N/capita/year) | Reasonable. Consistent with:<br>▪ 10.58 lb. N/capita/year used in the Nitrogen Loading Model (NLM), by TNC, Vaudrey and Stinnette<br>▪ 10 lb./capita/year used in the New Jersey Nitrate Dilution Model and Suffolk County Subwatersheds Wastewater Plan<br>▪ 11 lb./capita/year identified by the Chesapeake Bay Partnership's Expert Panel |
| Seasonal Loads | Reasonable. Incorporation of seasonal loads is appropriate, although the calculation method may over-estimate or underestimate watershed-specific loads as no references to support assumptions were provided. |
| Seasonal loads only apply to land south of I-95 | Reasonable. Beach communities are found along the coast. |
| Seasonal population increases of 100-200% | Uncertain. May over or underestimate actual seasonal population.<br>ACTION: Census data may be able to inform upon seasonal occupancy. Valiela was able to obtain 1990 census data on the duration of occupancy of individual houses within the Waquoit Bay watershed. (Valiela, 1997) The availability of this data in the 2010 census should be investigated. |
| Seasonal loads occur for 2.5 months/year | Reasonable. Matches school vacation/summer recreational season. |
| CT DEEP permit files and CT DPH work logs as the data source of non-residential OTWS | Not conservative. A total of 83 DEEP permits were identified since 1989 and 430 DHS facilities > 2,000 gpd since 1970 logged (note there are some duplicates in the DPH work logs).<br>Older and smaller non-residential OWTS are not included. |
| Wastewater flow is 50% of permitted design flow | Not conservative. Connecticut public health code section 19-13-B103 requires a minimum 1.5 safety factor be used for non-residential OWTS design flows. Consequently, non-residential flow rates may be as high as 66% of the design flow rather than 50%. |

| Assumption | Assessment |
|---|---|
| Does not consider increased loads from seasonal population | Not conservative. Census data may be able to inform upon seasonal occupancy. Valiela was able to obtain 1990 census data on the duration of occupancy of individual houses within the Waquoit Bay watershed. (Valiela, 1997) The availability of this data in the 2010 census should be investigated. |
| Residential flow rates are based on total population including sewered and unsewered areas | Reasonable. Although the average people-per-housing unit may differ between sewered and unsewered areas, it is not expected to significantly impact the flow-per-SFR, from which loads are calculated. |
| Residential OWTS discharges 60 mg-N/L | Reasonable. Consistent with EPA (EPA, 2002) and USGS (Rosen, Kropf and Karen, 2006) publications |
| Williams Cove Residential Parcels discharge 150 gpd for a 4-bedroom residence and 50 gpd for each additional bedroom. | May overestimate year-round loads. Given the population and housing units in the Williams Cove watershed, following the methodology performed for Mill River and Sasco Brook yield an average flow-per-housing unit of 125.7 gpd. |
| Non-residential OWTS discharges 120 mg-N/L | May overestimate non-residential loads. Although commercial and industrial OWTS nitrogen concentrations have been shown to vary considerably (EPA, 2002); Suffolk County's Subwatershed Wastewater Plan recommends non-residential OWTS effluent concentrations closer to 60 mg-N/L. |
| Non-residential OWTS flow rates derived from fire codes regulating maximum allowable occupant density | Reasonable, since the fire codes dictate the maximum allowable document density, they facilitate a conservative estimation of daily wastewater flow. |

The approach for estimating census-based year-round nitrogen loads is reasonable, grounded largely by 2010 U.S. Census population data and a reasonable per capita nitrogen loading rate. However, the analysis should be updated to account for the most up-to-date Connecticut statewide sewer service area coverage, which was the most significant source of error in the census-based residential load estimates when compared to the lot-by-lot estimates. Seasonal residential nitrogen loads may be significantly over or underestimated as there is no data supporting the estimates and underlying assumptions used to develop them.

The non-residential census-based nitrogen loads may be underestimated since they are only based upon CT DEEP permit data and CT DPH work logs, which do not appear to include older non-residential systems and do not include most SSDS with design flows less than 2,000 gpd.

The lot-by-lot residential loads for the Mill River and Sasco Brook watersheds provide reasonable estimates of year-round nitrogen loads that match the census-based estimations well. However, the impacts of seasonal population fluctuations are not considered in the lot-by-lot analysis, which may be significant in watersheds that have large amounts of coastal developed land. The lot-by-lot residential load for the Williams Cove watershed provides a better estimate of OWTS nitrogen load than the census-based approach because it incorporates a more accurate representation of the sewered area. The loads may still be slightly overestimated due to uncertainty in the assigned residential wastewater flowrates.

## Recommended Phase II OWTS Nitrogen Load Estimate Approach

Based on the assessment of the Phase I approaches and results, the following recommendations (summarized on **Figure ES-6**) were identified to improve the estimated watershed nitrogen loads from OWTS:

- Combining the 2010 U.S. Census data and local community tax parcel data can help to provide an estimate of people-per-OWTS from which the nitrogen load can be developed. A parcel database including individual tax parcels from the 22 communities in the ten study watershed areas, the Statewide SSA 2018 version (6/15/2018) and U.S. Census Population and Housing Vacancy Status (2010) and remote sensed US building footprints (Microsoft, 2019) was developed. Nitrogen loads from residential OWTS were estimated based on the updated OWTS inventory and a per capita nitrogen load of 4.8 kg/N/year (10.58 lbs/N/year) (Valiela et al., 1997)
- A consistent approach should be used to estimate nitrogen loads for each watershed.
- Census data on seasonal population or other sources of information including Town Halls, utilities and real estate agents should be explored to improve seasonal population/seasonal load estimates. The seasonal population in each census block was estimated from seasonal housing-unit data provided in the 2010 census database, assuming that seasonal units have twice the number of people per seasonal-housing-unit as the year-round housing units, or at least 4 people per seasonal-housing-unit.
- Non-residential loads should be estimated based on land use, building footprints, flow assumptions derived from the CT DPH Subsurface Sewage Technical Standards 2018, and occupant loads derived from the International Fire Code 2015 and assumed nitrogen concentrations of 60 mg/L or 10 mg/L based on OWTS-type. Data from CTDEEP GSS and UIC permits as well as CTDPH worklogs should also be considered when calculating non-residential nitrogen loads using 10 mg/L for UIC systems and 60 mg/L for conventional and GSS systems.

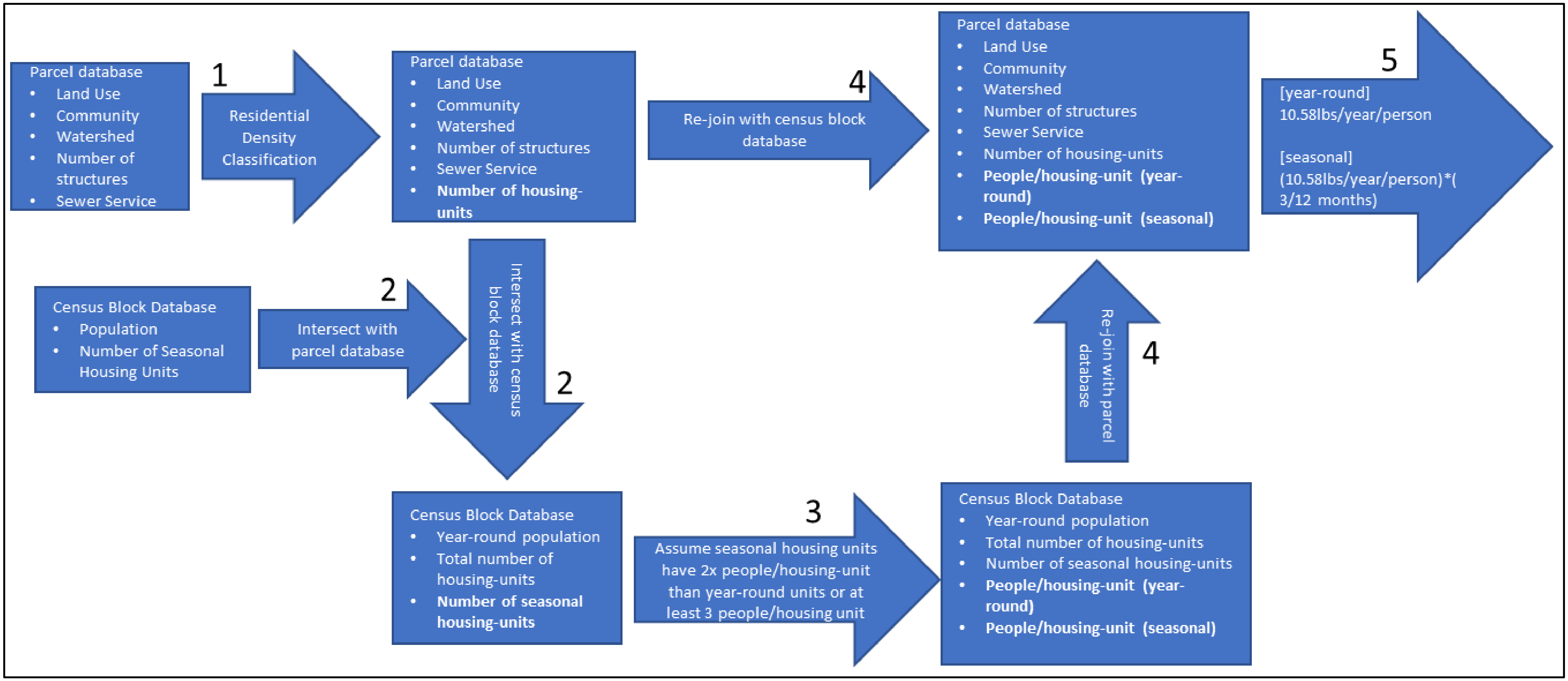



**Figure ES-6 Overview of Approach Used to Estimate Nitrogen Loads from Residential Parcels**

## Phase II Unattenuated Nitrogen Load Results

**Table ES-5** and **Figures ES-7a** and **7b** summarize the unattenuated nitrogen loads for each watershed and the unattenuated nitrogen loads for each watershed normalized to unsewered watershed area. **Figure ES-8** compares the Phase I and Phase II unattenuated nitrogen loads from OWTS for the ten study area watersheds.

**Table ES-5 Phase II Total and Normalized OWTS Nitrogen Load Estimates**

| Embayment | Total Watershed Area (ac) | Unsewered Watershed Area (ac) | Total Nitrogen Load (Pounds/Year) | Nitrogen Load per Acre per Year (Pounds) |
|---|---|---|---|---|
| Clinton Harbor | 37,736 | 36,766 | 36,766 | 286,956 |
| Direct Drainage in Madison | 1,274 | 1,139 | 1,139 | 28,550 |
| Farm River | 16,653 | 15,846 | 8,932 | 37,803 |
| Fence Creek | 925 | 755 | 755 | 18,808 |
| Mill River | 21,513 | 20,721 | 17,134 | 126,392 |
| Niantic River | 18,064 | 17,188 | 14,093 | 37,427 |
| Pawcatuck River (Connecticut Only) | 35,188 | 26,037 | 24,957 | 69,971 |
| Sasco Brook | 6,059 | 5,705 | 4,714 | 45,107 |
| Toms Creek | 763 | 495 | 495 | 11,443 |
| Williams Cove | 1,546 | 1,416 | 932 | 5,333 |

The Phase II study identified lower residential nitrogen loads for each watershed compared to the Phase I study. Much of the reduction may be explained by the increased sewer service area incorporated into the Phase II study (Niantic River, Sasco Brook, and Williams Cove). In watersheds where there was no significant change to the sewer service area, the reduced load in the Phase II study may be attributed to a more spatially resolved population distribution.

Phase II non-residential loads are significantly higher than the Phase I study estimates because the Phase I study only considered non-residential loads from CT DEEP permitted

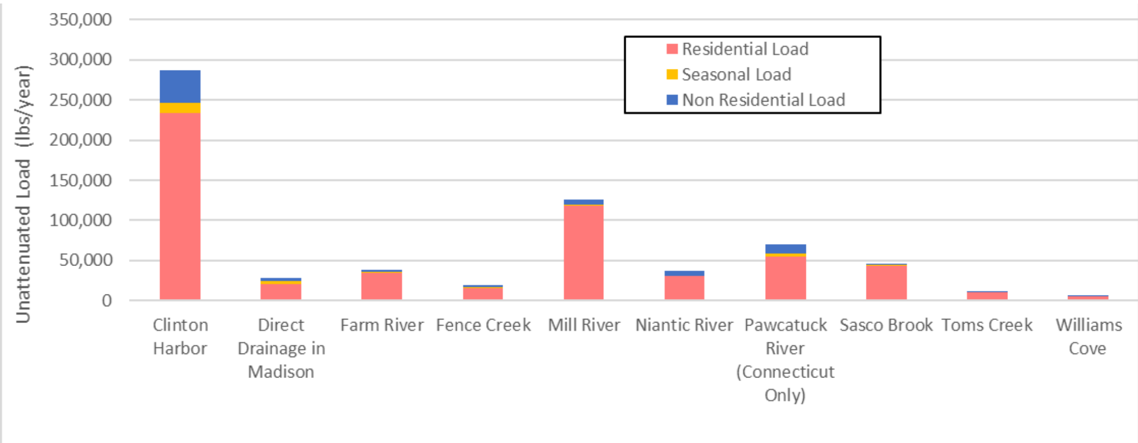



**Figure ES-7a Unattenuated Nitrogen Loads to Each Watershed**

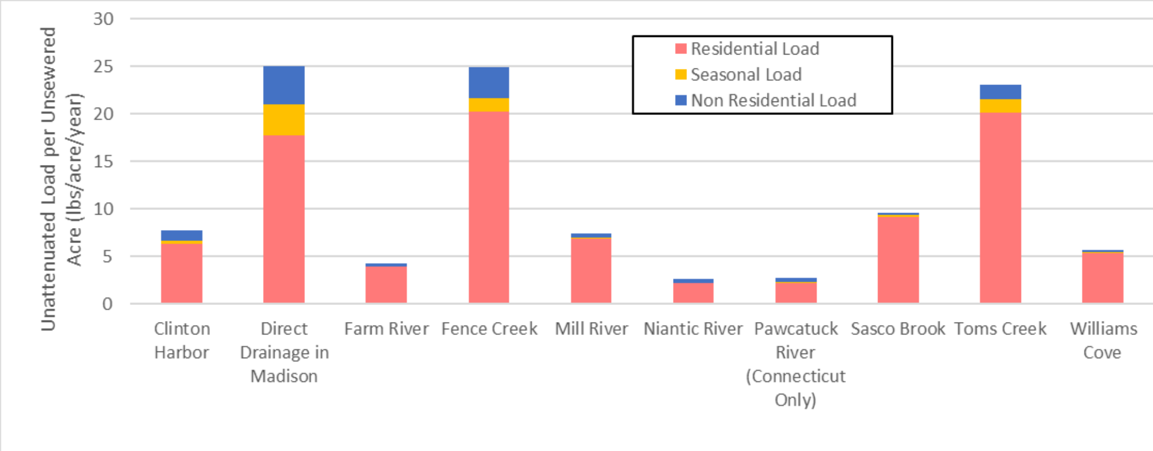



**Figure ES-7b Unattenuated Loads Normalized to Unsewered Area in Each Watershed**

systems and CT DPH work logs of systems with flows >1,000 gpd. The permits and work log records do not include smaller non-residential systems permitted by local community health departments. (Tom's Creek is an exception where the higher Phase I non-residential loads resulted from a misplaced CT DEEP permitted UIC system.) Town land use data and building footprints were used to identify non-residential buildings with OWTS. In addition, CT DEEP provided site-specific information and guidance to estimate nitrogen loads for several large non-residential facilities including seasonal camp grounds and Hammonasset State Park.

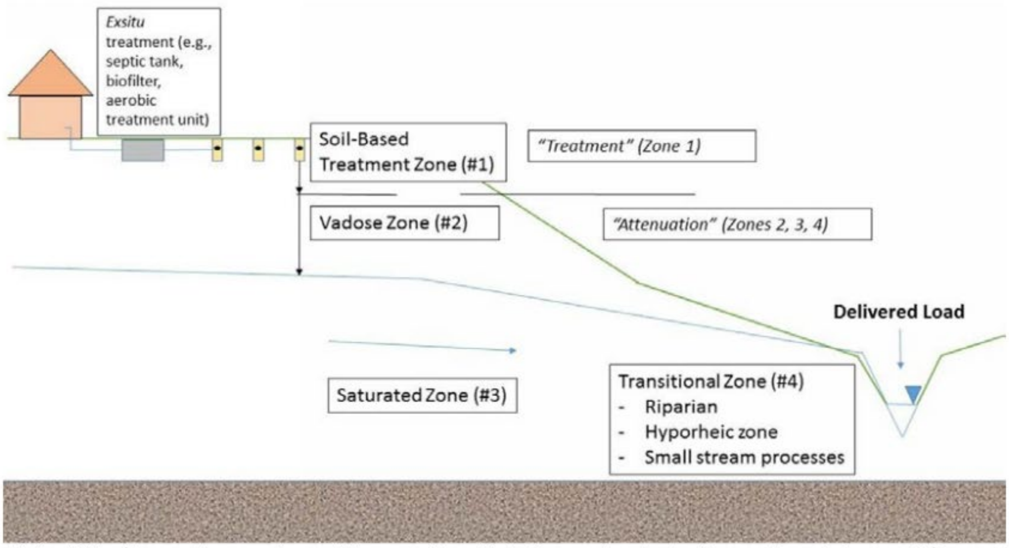
Seasonal loads in the Phase I and Phase II studies are very different because they were developed from different data and assumptions. The seasonal loads in the Phase II study were estimated from 2010 U.S. Census block housing vacancy data, which provided a more focused assessment of the locations of seasonal loads.

# Nitrogen Attenuation

## Phase I Approach

The Phase I study developed spatially variable attenuation factors based on a conceptual model described by an expert panel convened by U.S. EPA to develop recommendations on nutrient attenuation rates from OWTS as part of the Chesapeake Bay Total Maximum Daily Load program. Attenuation was assumed to occur in four distinct zones, as shown in **Figure ES-9.**


**Figure ES-8 Comparison of Phase II and Phase I Census Block Based Unattenuated Loads**




***Note: This figure does not consider ponds within the watershed. Zones 3 and 4 repeat for each pond in the system prior to reaching the embayment.***

**Figure ES-9 Attenuation Zones Applied in the Phase I OWTS Study (Reproduced from Figure 2-1 in the Lombardo Associates Task 3 Report and Figure 3 of D'Amato 2016).**

The attenuation factors for Zones 1-3 were largely taken from the Chesapeake Bay studies, while attenuation factors for Zone 4 followed the methodology of the Massachusetts Estuaries Program (MEP) as described below. The individual zone attenuations were aggregated into a **bulk composite attenuation factor** to represent an overall attenuation factor including the soil-based, vadose, saturated and transitional zones.

## Soil-based Treatment Zone (Soil Texture) Attenuation (Zone 1)

The Zone 1 attenuation factors applied in the Phase I study were taken directly from the Chesapeake Bay Program expert panel report (D'Amato et al., 2016) and conceptually represent the edge of the drainfield.

## Vadose Zone Attenuation (Zone 2)

The conceptual model applied in the Phase I study considers the vadose zone to be the area between the edge of the drainfield and the water table. The Phase I study assumed that any attenuation in the vadose zone is negligible, consistent with the recommendations of the Chesapeake Bay Program expert panel report.

## Saturated Zone (Surficial Geology) Attenuation (Zone 3)

The saturated zone extends from the vadose zone (Zone 2) through the aquifer to the surface water (river, pond, or embayment). Attenuation in the saturated zone was assumed to be spatially variable based on surficial geology. While the Phase I report references the Chesapeake Bay Program expert report for the derivation of the saturated zone attenuation rates, the rates adopted in the Phase I study did not match those in the Chesapeake Bay Program report. No other reference on the source of the attenuation rates was provided.

## Transitional Zone Attenuation (Zone 4)

Additional nitrogen attenuation can occur at the interface between the receiving water body and the groundwater due to denitrification at the sediment-water interface. The Phase I study adopted transitional zone attenuation rates from the Massachusetts Estuaries Project (MEP), a Massachusetts Department of Environmental Protection-funded project that estimated nitrogen loads to Cape Cod and Buzzards Bay embayments in southeastern Massachusetts.

Each subwatershed was assigned a transitional zone attenuation rate based on the receiving water of the subwatershed as follows :

- Subwatersheds that discharge directly to Long Island Sound were assigned a nitrogen attenuation rate of 0 percent. (No Phase I study subwatersheds were in this category).
- Subwatersheds that discharge directly into the receiving embayment were assigned a nitrogen attenuation rate of five percent. This accounts for attenuation within very small streams and/or ponds discharging to these embayments.
- Subwatersheds that represent discharge to a major river were assigned a nitrogen attenuation rate of 30 percent.
- Basins with large ponds were assigned a nitrogen attenuation rate of 50 percent.

Each census block in the subwatershed was then assigned the subwatershed's attenuation factor. When census blocks crossed subwatershed boundaries, the census block was assigned an area-weighted attenuation factor.

The Phase I report did not describe the methodology used to assign transitional zone attenuation rates to each subarea, and the methodology was not clear based on a detailed review of the Phase I backup calculations.

The attenuation rates were applied to each subwatershed and where there are downgradient subwatersheds prior to reaching an embayment, the initial attenuation rate was compounded, so if one subwatershed drains into a downstream subwatershed the attenuation rate of the upstream subwatershed was the product of the two or more attenuation rates yielding a range of attenuation factors between 0 and 98 percent. **Figure ES-10** presents a histogram of compounded transitional zone attenuation rates assigned in the Phase I study.

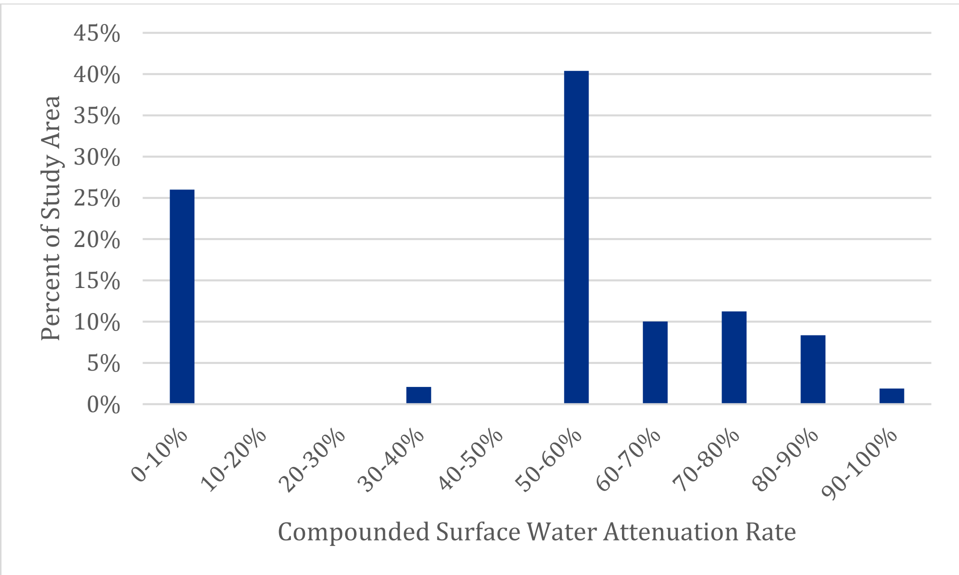



**Figure ES-10 Histogram of Compounded Transitional Zone Attenuation Rates in the Phase I Study**

The final step in the Phase I attenuation rate assignment was to calculate a bulk composite attenuation factor for each subwatershed based on the product of the soil texture attenuation (Zone 1), saturated zone attenuation (Zone 3), and transitional zone attenuation (Zone 4). As noted above, the vadose zone attenuation (Zone 2) rate was assumed to be negligible.

The bulk composite attenuation factor was calculated differently for the census block level analysis than for the lot-by-lot analysis. In both cases, the composite attenuation was calculated as the product of the composite soil texture, saturated zone, and transitional zone attenuation:

$$[\text{Bulk Composite Attenuation}] = 1 - (1 - [\text{Zone } 1]) * (1 - [\text{Zone } 3]) * (1 - [\text{Zone } 4])$$

The Phase I census block level analysis composite nitrogen attenuation rate was calculated by applying the calculated average nitrogen attenuation for each census block in each attenuation zone (1, 3, and 4) to all nitrogen loads from OWTS located in the census block. The attenuated nitrogen loads were compared across each watershed in the study area (e.g., Stonington Harbor, Niantic River, etc.) by calculating a watershed-scale attenuation factor. This was calculated by comparing the attenuated and unattenuated load from each watershed:

$$[\text{Watershed-scale Attenuation Factor}] = 100 * \frac{[\text{Unattenuated Load}] - [\text{Attenuated Load}]}{[\text{Unattenuated Load}]}$$

The composite watershed-scale attenuation factors ranged between 35 and 85 percent.

The lot-by-lot bulk composite attenuation rates use the same Zone 1 through 3 attenuation zone factors as were used for the census block level analysis, but a refined attenuation factor for Zone 4. The lot-by-lot bulk composite attenuation factors differed by less than 3 percent from slightly different from the census block level analysis. .The similarity is attributed to the relatively homogeneous soil texture, saturated zone, and transitional zone attenuation rates assigned across the study area.

## Evaluation of the Phase I Approach and Data Gaps

The factors used to develop the attenuation factors are summarized below in **Table ES-6**.

**Table ES-6 Evaluation of Attenuation Factor Approach and Assumptions**

| Assumptions | Assessment |
|---|---|
| Conceptual Model of Attenuation Assignment | Reasonable. Based on approach developed by expert panel assembled for Chesapeake Bay Program, which separates the attenuation into four zones, and compounds the attenuation rate for each watershed:<br>▪ Soil-based treatment zone<br>▪ Vadose zone<br>▪ Saturated zone<br>▪ Transition zone |
| Soil-based Treatment Zone Attenuation<br>Zone 1 | Generally reasonable, with caveats. Based on approach and model results developed by the expert panel assembled for Chesapeake Bay Program.<br>Caveats:<br>▪ Attenuation rates derived directly from Chesapeake Bay Program values. Requires additional investigation to confirm that the underlying assumptions used to develop the attenuation rates match conditions in Connecticut, including depth to groundwater and regulations related to minimum separation above the groundwater table. |

| Assumptions | Assessment |
|---|---|
| | ▪ Assignment of some soil textures to a low attenuation rate may not be appropriate and should be revisited. |
| Vadose Zone Attenuation<br>Zone 2 | Reasonable – Based on approach developed by expert panel assembled for Chesapeake Bay Program |
| Saturated Zone Attenuation<br>Zone 3 | Factors generally match literature values, but sources are not cited, and values are not consistent with local (Connecticut and New York) studies. Attenuation factors should be revised to align with local studies. |
| Transition Zone (Surface Water) Attenuation<br>Zone 4 | Revisit attenuation factors. Transition zone factors are derived from the Massachusetts Estuaries Program and represent Zone 3 + Zone 4 attenuation rates developed based on data collected from embayments in southeastern Massachusetts. The attenuation factors used in the Phase I study likely overestimate Zone 4 attenuation. Attenuation factors should be revised to align with local studies. |
| Compounded Transition Zone Attenuation<br>Zone 4 | Revisit approach and calculations. The compounding of attenuation, with additional attenuation occurring at each subwatershed boundary, potentially overestimates composite watershed attenuation. |
| Bulk Composite Nitrogen Attenuation | Reasonable – This approach, which composites the attenuation factors from the four zones is widely used in the literature. |

## Phase II Attenuation Approach and Results

Attenuation of nitrogen loads from OWTS was calculated using the conceptual model shown in **Figure ES-11** and summarized below:

- **Removal in OWTS**: A nitrogen removal of 6 percent was included (Suffolk County, 2020);
- **Vadose Zone Attenuation:** This zone represents the area between the leach field and the saturated zone (combining the soil treatment zone and the vadose zone referenced in the Chesapeake Bay Project study and the Phase I study);
- **Saturated Zone Attenuation**: This zone represents the area below the unsaturated zone (consistent with the eponymous zone referenced in the Chesapeake Bay Program study and the Phase I study);
- **Transitional Zone Attenuation:** This zone represents denitrification that occurs at the groundwater-surface water interface, where groundwater flows through the sediment/soil matrix and includes the hyporheic zone.

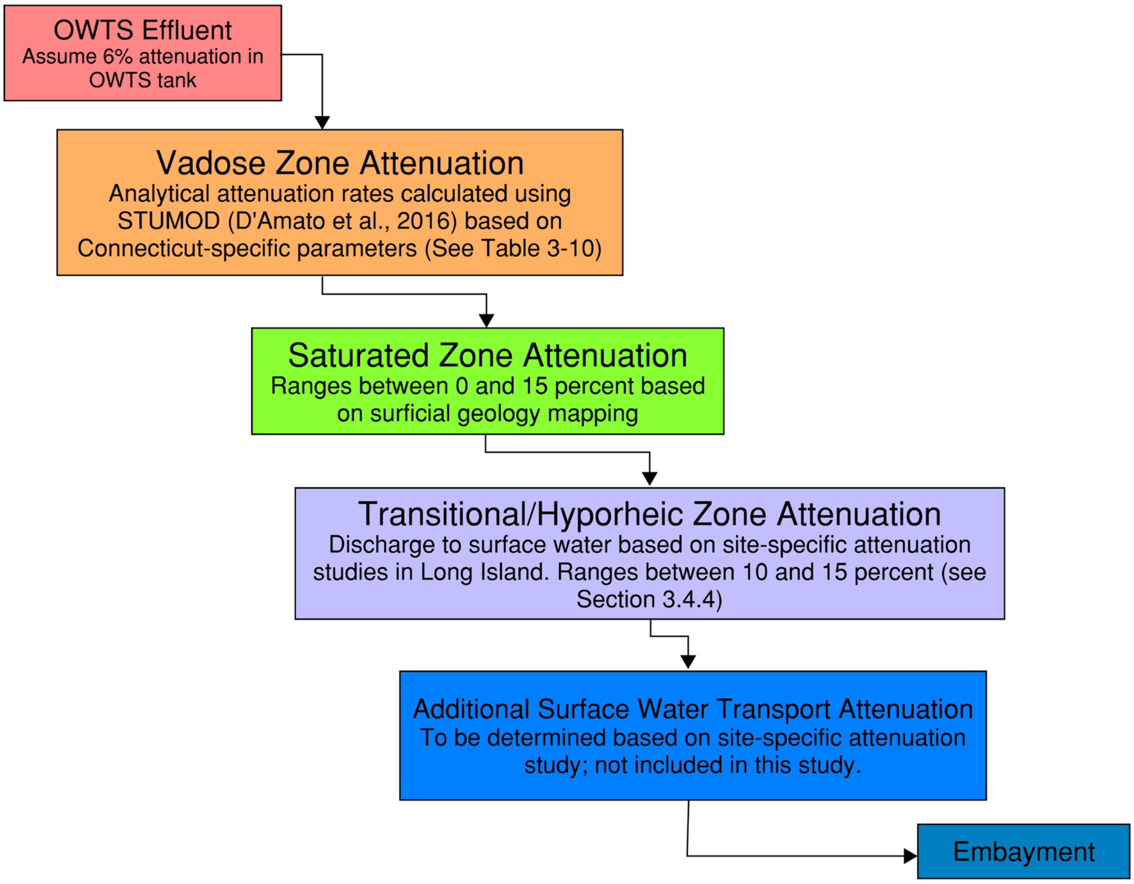



**Figure ES-11 Flow Chart of Recommended Conceptual Model for Nitrogen Attenuation**

## Vadose Zone Attenuation

Attenuation in the vadose zone was estimated using the soil-texture-based analytical model STUMOD describing the denitrification potential between the bottom of the leaching field and the water table based on Connecticut data. STUMOD was run using input parameters for soil texture and depth-to-groundwater data from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic Database (gSSURGO, USDA 2019), soil temperature based on data for coastal Connecticut and hydraulic loading rate based on Connecticut information.

Based on the gSSURGO database, nearly 95 percent of the study area is covered by sandy loam, loamy sand, sand, silty loam, or loam soil textures. Attenuation rates for each soil texture were applied for each parcel within each watershed by assigning the dominant soil texture for parcel. The gSSURGO database also showed that depth to groundwater data across the ten watersheds is at least 23 inches, validating the 60 cm (23.6 inches) assumption applied in the Phase I study. The annual average soil temperature in the mesic zone of 11.5°C was applied and fifty percent of the theoretical hydraulic loading rate was assigned as the wastewater discharge rate based on the Chesapeake Bay Project expert panel conclusions and the Connecticut State Water Plan (CDM Smith 2018) which showed declining water use due to conservation.

The Phase II estimated nitrogen attenuation rates in the vadose zone ranged from 17 percent in the Fence Creek watershed to 31 percent in the Williams Cove watershed.

## Saturated Zone Attenuation

The saturated zone attenuation rate was estimated based on surficial geology mapping from the CT DEEP surficial geology layer, based on 1:24000 scale geologic mapping completed by Connecticut (Radway Stone et al., 1992). The dominant surficial geology across the 10 study area watersheds is till and thick till, comprising 76 percent of the overall surficial geology. An attenuation rate of 15 percent was applied for the glacial ice-laid deposits, with no attenuation in other geologic formations. This assumption is consistent with studies in Long Island and Connecticut (e.g., Vaudrey, 2016; Suffolk County, 2019; Young et al., 2013; McMahon et al., 2008, Mullaney, 2015), which suggest that saturated zone attenuation in southern Connecticut and on Long Island may be lower than rates reported elsewhere in the country due to lower concentrations of dissolved organic carbon and oxic conditions that are not conducive to denitrification.

## Transitional Zone Attenuation

Transitional zone attenuation represents nitrogen loss that can occur as water passes through /anoxic sediments at the groundwater-surface water interface. For this study, the transitional zone attenuation rates were aligned with the attenuation rates approved by the Nitrogen Load Model Focus Area Work Group convened by Suffolk County during development of the County's nitrogen load model (https://suffolkcountyny.gov/Portals/0/formsdocs/planning/CEQ/2020/SWP%20Revised%20Appendices%20A-F%20August%2015%20update%20Feb%202020.pdf?ver=2020-02-27-155835-400). The transitional zone attenuation rate will be 10 percent for groundwater transport to surface water (e.g., into rivers, ponds, lakes, embayments, and Long Island Sound), and 15 percent through marshes, shoals, bars, and mudflats. The higher attenuation rate for the latter category accounts for additional denitrification that occurs in these environments.

The locations of marshes, shoals, bars, and mudflats were inferred from the National Hydrography Dataset (NHD) (USGS, 2020). An OWTS present in a Local Basin was assigned the higher attenuation rate of 15 percent if a significant portion of the Local Basin area is located within the Swamp/Marsh category (FType 466 in the NHD). The transitional zone attenuation rate in all other Local Basins was assumed to be 10 percent to represent denitrification as the groundwater discharges through low oxygen sediments into surface water.

Nitrogen losses through this zone are highly variable, site-specific, and are difficult to generalize without detailed field investigation. Therefore, the transitional zone attenuation rates applied in this study are conservative estimates of the potential for denitrification across the groundwater-surface water interface. The average transitional zone attenuation rate for each watershed ranges between 10 and 15 percent.

## Watershed Attenuation

Attenuation rates from the four zones (Septic Tank, Vadose Zone, Saturated Zone, and Transitional Zone) were combined to derive composite attenuation rates, following the approach taken in Valiela et al. (1997), the Chesapeake Bay Project (D'Amato et al., 2016), Vaudrey et al. (2020), and the Phase I study (Lombardo Associates, 2018). The basic unit of the load calculation methodology used in this study is the parcel, where the attenuated nitrogen load assigned to each parcel represents the load delivered to Long Island Sound. The composite attenuation rate is calculated for each parcel based on the following equation, where the attenuation rate represents the fraction of the unattenuated nitrogen load removed:

$$R = 1 - [(1 - R_{VADOSE}) * (1 - R_{SATURATED}) * (1 - R_{TRANSITIONAL}) * (1 - R_{SEPTIC\ TANK})]$$

where:

| | | |
|---|---|---|
| $R$ | = | Attenuation rate for each parcel |
| $R_{VADOSE}$ | = | Soil texture-based vadose zone attenuation rate (see Section 3.4.2) |
| $R_{SATURATED}$ | = | Surficial geology-based saturated zone attenuation rate (see Section 3.4.3) |
| $R_{TRANSITIONAL}$ | = | Attenuation rate for groundwater to surface water transport (see Section 3.4.4). |
| $R_{SEPTIC\ TANK}$ | = | 6% attenuation that occurs within the septic tank of any OWTS |

The average composite attenuation rate for the unsewered area in each of the ten watersheds is presented in **Table ES-7**.

**Table ES-7 Composite Attenuation Rate Average and Range for the Ten Study Watersheds**

| Watershed | Watershed Average Composite Attenuation Rate | Composite Attenuation Rate Range |
|---|---|---|
| Clinton Harbor | 44% | 24% - 70% |
| Farm River | 49% | 24% - 70% |
| Fence Creek | 37% | 24% - 65% |
| Madison Direct Drainage | 35% | 24% - 68% |
| Mill River | 49% | 24% - 68% |
| Niantic River | 47% | 24% - 70% |
| Pawcatuck River | 44% | 15% - 70% |
| Sasco Brook | 49% | 24% - 68% |
| Toms Creek | 43% | 28% - 70% |
| Williams Cove | 49% | 41% - 68% |

The watershed attenuated nitrogen load is calculated for each parcel by multiplying the unattenuated load by (1 -$R$).

A high-level summary of the attenuated nitrogen loads for each watershed is shown in **Figure ES-12**, which compares the attenuated nitrogen loads and the average composite attenuation rates from the Phase I census-based analysis with those of the Phase II study. Average composite attenuation is significantly lower for the larger watersheds in the Phase II study than the Phase I study while the smaller watersheds (Fence Creek, Toms Creek, and Williams Cove) have more comparable attenuations. These differences in nitrogen attenuation between the Phase I and II studies can largely be attributed to the Phase I study's use of compounded attenuation, which applied the transitional zone attenuation rate each time the flow path crossed through a Local Basin watershed boundary, resulting in the attenuation applied multiple times to each load for parcels far from the Sound.

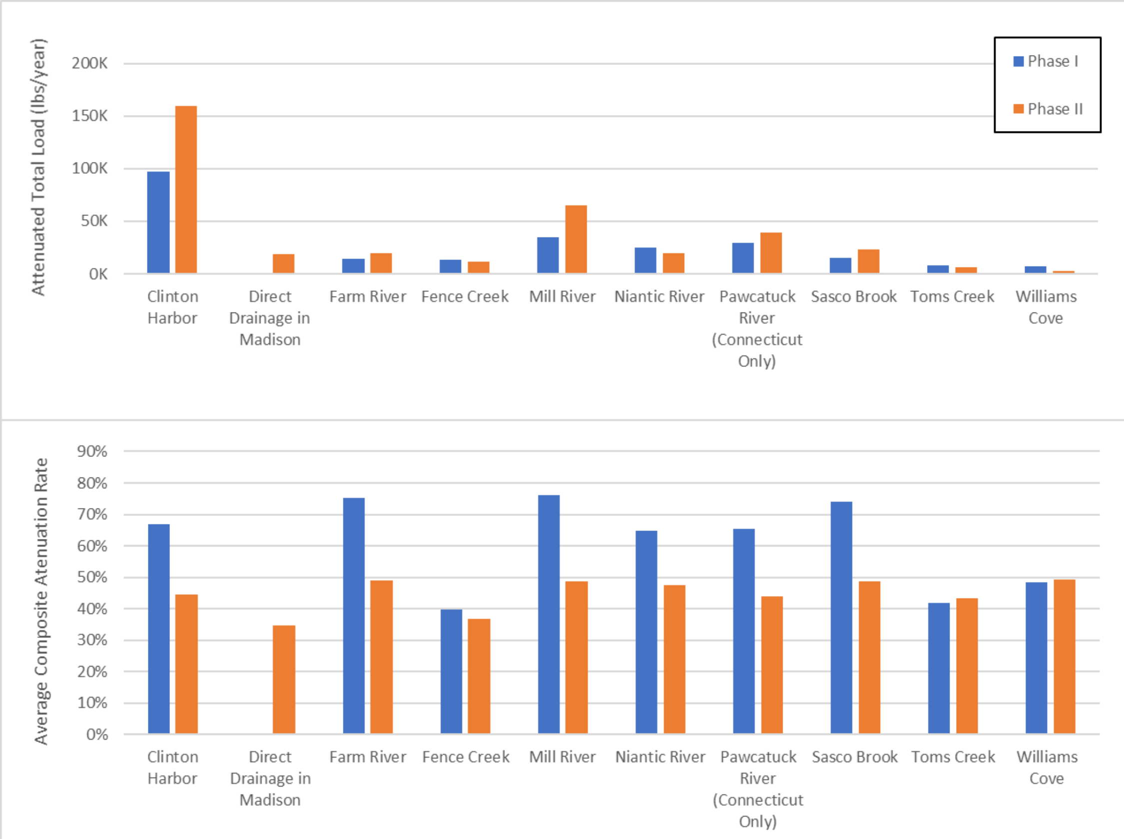



**Figure ES-12 Watershed Average Composite Attenuation Rates and Attenuated Nitrogen Loads**

In addition to calculating the total attenuated nitrogen loads for each watershed, as shown in **Figure ES-12** and **Table ES-8**, loads were aggregated from each parcel onto a 0.25-mile resolution grid to show areas of high nitrogen loading across the study area. The attenuated loads in each 0.25-mile grid cell in each watershed are presented in Appendix C of this report, but an example map for the Mill River watershed is shown in **Figure ES-13.**

**Table ES-8 Summary of Unattenuated and Attenuated Nitrogen Loads to Selected Embayments**

| Embayment | Total Watershed Area (ac) | Unsewered Watershed Area (ac) | Total Load Weighted Average Attenuation Rate | Unattenuated Nitrogen Load (lbs/year) | | Attenuated Nitrogen Load (lbs/year) | |
|---|---|---|---|---|---|---|---|
| | | | | Year Round | Seasonal | Year Round | Seasonal |
| Clinton Harbor | 36,766 | 36,766 | 44% | 274,856 | 11,895 | 152,238 | 6,986 |
| Direct Drainage in Madison | 1,139 | 1,139 | 35% | 24,867 | 3,683 | 16,213 | 2,435 |
| Farm River | 15,846 | 8,932 | 49% | 37,683 | 120 | 19,250 | 62 |
| Fence Creek | 755 | 755 | 37% | 17,805 | 1,004 | 11,216 | 686 |
| Mill River | 20,721 | 17,134 | 49% | 125,177 | 1,215 | 64,222 | 621 |
| Niantic River | 17,188 | 14,093 | 47% | 37,288 | 139 | 19,597 | 77 |
| Pawcatuck River (Connecticut Only) | 26,037 | 24,957 | 44% | 66,123 | 3,847 | 37,135 | 2,150 |
| Sasco Brook | 5,705 | 4,714 | 49% | 44,205 | 902 | 22,718 | 467 |

| Embayment | Total Watershed Area (ac) | Unsewered Watershed Area (ac) | Total Load Weighted Average Attenuation Rate | Unattenuated Nitrogen Load (lbs/year) | | Attenuated Nitrogen Load (lbs/year) | |
|---|---|---|---|---|---|---|---|
| | | | | Year Round | Seasonal | Year Round | Seasonal |
| Toms Creek | 495 | 495 | 43% | 10,786 | 657 | 6,088 | 405 |
| Williams Cove | 1,416 | 932 | 49% | 5,252 | 80 | 2,657 | 44 |

## Recommendations to Ground Truth Nitrogen Estimates

The nitrogen load estimates described above for the ten watersheds were developed using data describing zoning, land use, population density, and attenuation based on underlying soil texture, surficial geology, and rates from literature studies. While the attenuation estimates were based on best available information and data, there is considerable uncertainty associated with each aspect of the nitrogen attenuation estimates. Furthermore, the total nitrogen load to each embayment includes additional sources of nitrogen, including fertilizer and atmospheric deposition that are conveyed to the embayment via groundwater baseflow and stormwater runoff, atmospheric deposition to the surface water, and permitted point source discharges that discharge directly to surface waters. Because nitrogen attenuation is a complex biogeochemical process, the attenuation of nitrogen from wastewater is highly variable in time and space and is difficult to generalize from literature values alone. For these reasons, site-specific field data may be helpful to validate the assumptions underlying the load estimates.

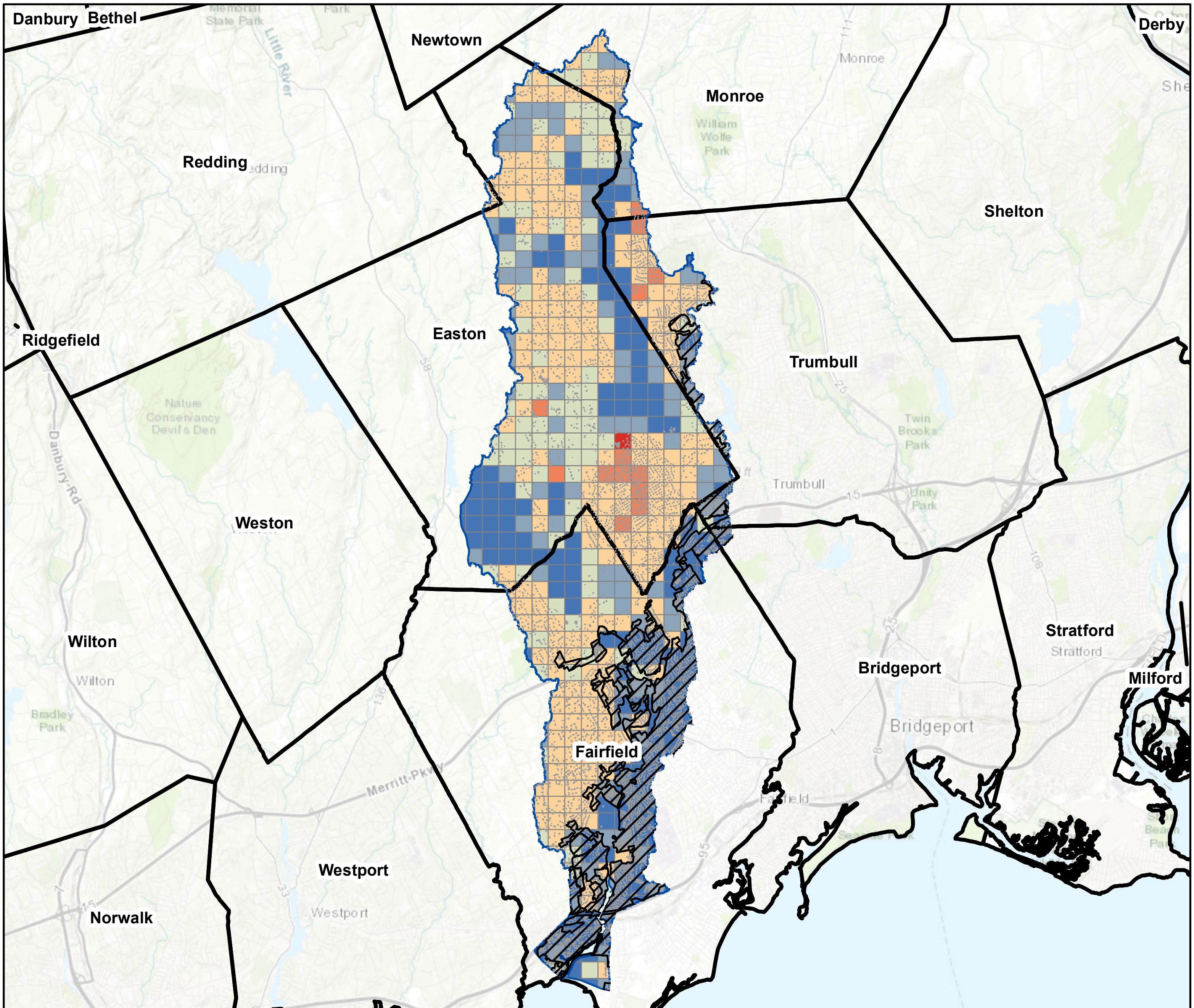
Because limited field data is available to characterize nitrogen concentrations in coastal Connecticut ground and surface waters, additional nutrient data collection is required to ground truth the estimates of nitrogen attenuation from OWTS to surface water discharge. Two potential approaches to ground truth the OWTS nitrogen loading estimates were developed.

The first approach was developed to characterize the magnitude of each individual nitrogen attenuation component (e.g., loss in septic tank, attenuation in the unsaturated zone, attenuation in the saturated zone, and attenuation in the transitional zone). The transitional zone component is the most uncertain because it is dependent on site-specific factors that are difficult to generalize from watershed-scale data.

The second approach is a watershed-scale load evaluation that would include a comprehensive surface water quality monitoring program incorporating nitrogen from OWTS along with nitrogen contributed by other sources including fertilizer, atmospheric deposition conveyed to the surface water via groundwater baseflow and stormwater, and mixing and dilution in the embayment. This approach would provide an overall nitrogen attenuation rate encompassing all of the nitrogen attenuation mechanisms described above.

A framework to develop both approaches was developed, building upon existing information and monitoring programs wherever possible.

# Figure ES-13 Example Mapping of the Mill River Watershed Annual Attenuated Nitrogen Load (Including Seasonal Loads, lbs/year)




## Legend

- Statewide Sewer Service
- Microsoft Remote Sensed Building Footprint
- Watershed Boundary (Vaudrey, 2016)
- Town Boundary

**Annual Attenuated Load (lbs/year)**

- 0
- 0 - 50
- 50 - 100
- 100 - 500
- 500 - 1000
- 1000 - 2132

| Watershed Total Values | |
|---|---|
| Annual Attenuated Load (lbs/year) | 64842.25 |
| Sewered Acres | 3587 |
| Unsewered Acres | 17134 |

N

0 2.25 4.5 9 Miles

# Ground Truthing of Nitrogen Attenuation Components

The nitrogen attenuation component evaluation is designed to collect local data confirming each of the attenuation components . This evaluation would consist of four parallel evaluations that would ideally all be implemented within a single watershed so that the total nitrogen attenuation within that watershed could be assessed.

## Nitrogen Attenuation in Septic Tanks

Recent studies evaluating the impacts of nitrogen from unsewered areas have concluded that cesspools or septic tanks are not designed to remove nitrogen and provide limited attenuation. The Water Research Foundation (WERF, 2008) reported less than five percent removal of total nitrogen in a septic tank. The anoxic conditions that exist within a septic tank preclude nitrification of the ammonia present in raw wastewater and nitrification must occur prior to denitrification. Nitrogen attenuation in septic tanks would be measured as the difference between the nitrogen concentrations in septic tank influent and septic tank effluent.

There are two potential approaches that could be implemented to estimate nitrogen attenuation within the septic tank.

The preferred approach would be to install sampling ports on both the influent line of residential septic tanks and the effluent line leading to the leaching field. Characteristics of existing contributing parcels (e.g., number of residents, age of septic system, etc.) should be documented in the data base along with the day of the week and time that the sample is collected. This information would more fully characterize the range of nitrogen reduction achieved by septic systems, including their performance based on age, load, etc. It is possible that existing permitted sites with monitoring wells be included in the study; these locations could be used to evaluate attenuation in the septic tank, attenuation in the vadose zone and could begin to estimate attenuation in the saturated zone.

The second approach would be to work with an established research partner, such as the Massachusetts Alternative Septic System Test Center in Sandwich, MA or Stony Brook University's Center for Clean Water Technology (CCWT) in Stony Brook, New York to measure influent and effluent concentrations over time at a test septic tank that could be readily sampled.

## Vadose Zone

Nitrogen attenuation within the vadose zone should be studied using water level sensors, tensiometers and suction lysimeters using the approach documented in Bradshaw and Radcliff (2012) to monitor nitrogen attenuation in a variety of soil types, focusing on the dominant soil textures identified within the 10 watersheds: sandy loam (68 percent by area), loamy sand (13.1 percent by area), and sand (6 percent by area). The location of the data collection is subject to available land or a partnership with an outside agency with an experimental testing site. For example, a partnership with a testing site such as Massachusetts Alternative Septic System Test Center in Sandwich, MA or the Center for Clean Water Technology in Stony Brook, New York would enable CT DEEP to potentially examine multiple soil textures more cost effectively using existing equipment. An initial in situ approach should be coordinated with the saturated zone component evaluation to be sited in the Clinton Harbor, Mill River, Pawcatuck River, or Sasco Brook watersheds, focusing on sites in the watersheds where the Paxton-Montauk Series, Canton-Charlton Series and a sand and gravel series (e.g., Agawam, Ninigret, etc.) exist, if this can be coordinated with available sites.

## Saturated Zone

Saturated zone attenuation rates applied in this study were based on limited data collected in Long Island and Connecticut  that suggest that aquifer sediments have little carbon and that groundwater in the saturated zone is typically well oxygenated which prevents significant denitrification from occurring.

Adequate field work has been completed in glacial outwash and post-glacial deposits to support the assumption of zero attenuation applied in this study, however, little field work has been completed in the morainal deposits that dominate the study area. Supplemental field work should be completed in morainal (glacial ice-laid) deposits.

Direct measurement of denitrification in morainal deposits could begin in collaboration with USGS using existing monitoring wells to reduce the sampling program cost. After an evaluation of upgradient land use and groundwater flow direction, candidate active groundwater wells within the Phase II study area watersheds are:

- USGS 411832072325501 (contingent upon accessibility) and 411826072322401 in Clinton, completed in thick till located in the Clinton Harbor watershed.
- USGS 411124073172201, 411118073175801, 411103073181301, and 411058073182001 in Fairfield, completed in the top of the bedrock aquifer, beneath till. USGS 411124073172201 is located in the Mill River watershed, and the remaining three are in the Sasco Brook watershed.

It is acknowledged that obtaining water quality samples from wells screened in till can be difficult given the slow recovery times after purging.

Groundwater samples should be collected for nitrogen gas analysis following the sampling design in Young et al. (Young et al. and Mullaney both used dissolved nitrogen gas sampling to empirically determine the in situ denitrification rate. In Young's study, sampling was completed using a submersible pump and the dissolved $N_2$/Ar data were used to determine the denitrification rate after correcting for atmospheric nitrogen gas.  As the nitrogen gas samples are easily contaminated during sampling and/or storage, this approach would need to be very carefully implemented.), with one sample round collected in spring, summer, and fall to discern whether there is seasonal variation in the denitrification rate. Groundwater samples should be analyzed for ammonia, nitrate, nitrite, TKN, and field parameters (dissolved oxygen, temperature, conductivity, pH).  In addition, measurement of dissolved organic carbon and sulfide would provide further insight into the availability of electron donors required for denitrification.

If the data suggest significant differences or substantial geographic variation, consider adding additional monitoring wells, either through additional USGS wells outside of the Phase II study area, municipal supply wells, or developing new wells in areas of highest uncertainty.

## Transition Zone

Nitrogen attenuation in the transition zone is anticipated to be the most variable of the four components of nitrogen attenuation considered in this study. Denitrification potential across the groundwater-surface water boundary has been shown to be site-specific and potentially time-variable and is complicated to measure given the myriad of factors that need to be considered.

Measurement of nitrogen attenuation in the transition zone is a complicated and intensive task that must address groundwater flow paths and gradients, and the complex biogeochemical environment in the area(s) of groundwater/surface water mixing in the sediments beneath the surface water. It is assumed that the field program would be conducted in a localized area of a watershed that has been well-characterized, such that:

- The groundwater flow field, including groundwater flow direction and horizontal and vertical gradients has been defined,
- The study site is located downgradient of an unsewered area where an inventory of OWTS based upon parcel-specific land use indicates nitrogen from sanitary wastewater is being discharged to the groundwater and
- Available shallow groundwater quality data suggests nitrogen enrichment.

The approach presented in this document is based on the program implemented in Suffolk County and assumes groundwater discharge to a brackish or saline water body.

- Based on water quality data obtained from a transect of geoprobes, piezometers or nested monitoring wells on land, confirm that nitrogen concentrations in the shallow aquifer adjacent to the water body are elevated.
- Evaluate the groundwater flow path to confirm that the shallow nitrogen-laden groundwater is discharging to the surface water (and not travelling vertically downward into the aquifer and flowing downgradient beneath the surface water).
- After the existence of impacted groundwater is confirmed, the spatial extent of SGD should be mapped to identify the area of focus. This can be accomplished using a screening probe, such as the Trident, a SuperSting, thermal infrared cameras or other equivalent instrumentation.
- Sampling points must be installed in the surface water in the areas where SGD is occurring. These sampling points can be a combination of temporary and permanent monitoring points.
- Characterize bathymetry and sediments across the transects.
- The SGD should be quantified using a site-specific approach, including for example, an ultrasonic seepage meter.
- Collect samples from the groundwater monitoring points, SGD monitoring points, and the surface water and analyze for field parameters (salinity, temperature, DO, pH and ORP) and laboratory parameters (nitrogen species).
- Evaluate the data, correcting for tidal impacts as appropriate. In addition to the absolute values of the nitrogen concentrations in the land-side samples and the SGD and surface water samples, the evaluation of nitrogen attenuation must consider the changing biochemical environment (e.g., presence of dissolved oxygen, nitrogen species), mixing

(e.g., of fresh and saline water), gradients (e.g., both hydraulic and concentrations), and porosity.

## Watershed-scale Nitrogen Attenuation Evaluation

The watershed-scale nitrogen attenuation evaluation is designed to evaluate the nitrogen load delivered to the embayment based on model-based estimates of the watershed load and monitored nitrogen loads from upstream sources. This approach provides a composite nitrogen attenuation rate based on the nitrogen load calculated from land use and OWTS characteristics and the measured nitrogen flux at monitoring locations. There are two potential approaches for this type of evaluation:

- Simplified monitoring approach where flow monitoring and water quality sampling are conducted at a distinct freshwater node, such as a weir or other structure that marks the freshwater/saltwater interface (e.g., the dam on the Mill River in Fairfield). The monitoring program is used to calculate the net nutrient flux from the watershed, which can be compared against model-predicted estimates of the unattenuated nutrient load. The difference between the model predicted unattenuated load and the measured mass flux is attributed to the composite attenuation.

- Complex monitoring approach where water quality is measured at multiple locations within the embayment. Linked hydrodynamic and water quality models are developed to describe the embayment. This approach may be implemented by CT DEEP in the future but will not be discussed further here.

Implementation of a watershed-scale loading evaluation within several watersheds that include a variety of land uses and OWTS densities and that have a distinct freshwater node (weir or other structure that separates the freshwater/saltwater interface) to calculate the nutrient flux measurements is recommended.

The watershed-scale load evaluation program should consist of the following elements:

- An estimate of the unattenuated OWTS nitrogen load as described above (one caveat is that only the portion of the watershed load upgradient of the monitoring location should be considered) ;

- Estimation of the other nitrogen loads: stormwater, atmospheric deposition, sediment flux, fertilizer, and permitted point sources, and

- An estimate of the nutrient load in the surface water, based on flow and nitrogen concentrations measured as part of a field monitoring program.

### Watershed Nitrogen Loading

The next component of the watershed-scale load evaluation is an estimate of the nitrogen load from stormwater, atmospheric deposition, sediment flux, fertilizer, and permitted point sources. This load can be developed using several methods.

- Use a spreadsheet model based on the parcel-level land use classification from the Phase II OWTS survey. For this method, a land-use based nitrogen load is estimated for each parcel based on its land use classification, including OWTS loading, stormwater runoff (including fertilizer loads), and atmospheric deposition. If this approach is used, the spreadsheet model from the MEP study, which has literature-based export coefficients for nitrogen loading could be applied. While this method assumes typical conditions for the watershed loading which may not necessarily align with the timeframe used for water quality monitoring. The impacts of this can be mitigated by conducting a multi-year watershed monitoring program to determine a typical annual load.

- Develop a watershed hydrologic and water quality model or use the current Connecticut Watershed Model, a dynamic rainfall-runoff model developed in EPA's Hydrological Simulation Program – Fortran (HSPF). The benefit of this method is that the modeled load will be site-specific and will vary temporally. However, this method relies on the strength of the hydrologic and water quality calibration and requires substantially more data.

If adequate data exist to develop, calibrate, and validate a watershed hydrologic and water quality model (e.g., HSPF), this would be the recommended approach. In addition to the watershed load, permitted point sources should be accounted for based on the monthly reporting in each facility's Discharge Monitoring Report to EPA and CT DEEP.

The watershed load should be evaluated for the same period as the water quality and flow monitoring component so that the measured load and modeled-predicted load can be compared.

## Water Quality and Flow Monitoring

A routine water quality monitoring program would be developed at a freshwater node. One potential location for this study is at the dam marking the change between the upstream fresh class A water and the downstream saltwater class SA on the Mill River in Fairfield For this program, a minimum of one year of regular (monthly or bi-weekly) water quality and flow measurements would be collected at the freshwater node. Monitored parameters should include ammonia, nitrate, nitrite, TKN, total phosphorus, orthophosphate, chlorophyll *a,* and field parameters (temperature, dissolved oxygen, conductivity, and pH). Ideally, data should be collected over multiple years so that typical conditions can be established that are not biased by interannual hydrologic variation.

Water quality sampling and flow metering at this location will allow for the nitrogen load from the upper watershed to be estimated without consideration of potential tidal mixing and dilution from Long Island Sound.

The USGS has cautioned that monitoring at this location must consider basin withdrawals for public water supply and advised that an additional gage could be located downstream of the withdrawals.  Additional water quality samples would be collected at the gage downstream of the water supply withdrawals; the nitrogen load removed by the public water supply could then be incorporated into the nitrogen load estimation.

The composite attenuation rate would be calculated from the water quality monitoring program by comparing the modeled upstream nitrogen load to the measured upstream nitrogen load. Since the modeled nitrogen load is estimated without attenuation, the composite attenuation rate is the difference between the two nitrogen loads:

$$R = 1 - \frac{\text{Measured Nitrogen Load}}{\text{Modeled Nitrogen Load}}$$

This can be compared with the calculated watershed composite attenuation rate. The composite attenuation rate calculated using this methodology encompasses all processes that result in nitrogen loss, including the OWTS septic tank, the vadose zone, the saturated zone, the transition zone, as well as losses in the surface water. While this approach does not provide estimates for the individual nitrogen attenuation components, it represents the actual nitrogen load delivered to the receiving water, providing a valuable point of comparison.