Establishing Nitrogen Target Concentrations for Three Long Island Sound Watershed Groupings:

Embayments, Large Riverine Systems, and Western Long Island Sound Open Water

Subtask C. Summary of Tributary Loadings

Submitted to:

U.S. Environmental Protection Agency
Region 1 and Long Island Sound Office

Submitted by:

Tetra Tech, Inc.

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This Tetra Tech technical study was commissioned by the United States Environmental Protection Agency (EPA) to synthesize and analyze water quality data to assess nitrogen-related water quality conditions in Long Island Sound and its embayments, based on the best scientific information reasonably available. This study is neither a proposed Total Maximum Daily Load (TMDL), nor proposed water quality criteria, nor recommended criteria. The study is not a regulation, is not guidance, and cannot impose legally binding requirements on EPA, States, Tribes, or the regulated community. The technical study might not apply to a particular situation or circumstance, but it is intended as a source of relevant information to be used by water quality managers, at their discretion, in developing nitrogen reduction strategies.

Subtask C. Summary of Tributary Loadings (Connecticut, Housatonic, and Thames Rivers)

Contents

Introduction and Methods Overview

The purpose of this Subtask was to estimate annual nitrogen loadings from the Connecticut, Housatonic, and Thames rivers. These loads are to be potentially used for calculating and allocating load reductions (Subtasks H and I) as required to meet emergent nitrogen target concentrations.

Connecticut River

The Connecticut River is New England's longest river, at approximately 410 miles in length; is the largest tributary to Long Island Sound (LIS); and drains areas of Québec, Connecticut, Massachusetts, New Hampshire, and Vermont and (Figure C-1) (Garvine 1974; CRC 2017). Summary statistics of the hydraulic and physical factors of the Connecticut River and its watershed are summarized in Table C-1.

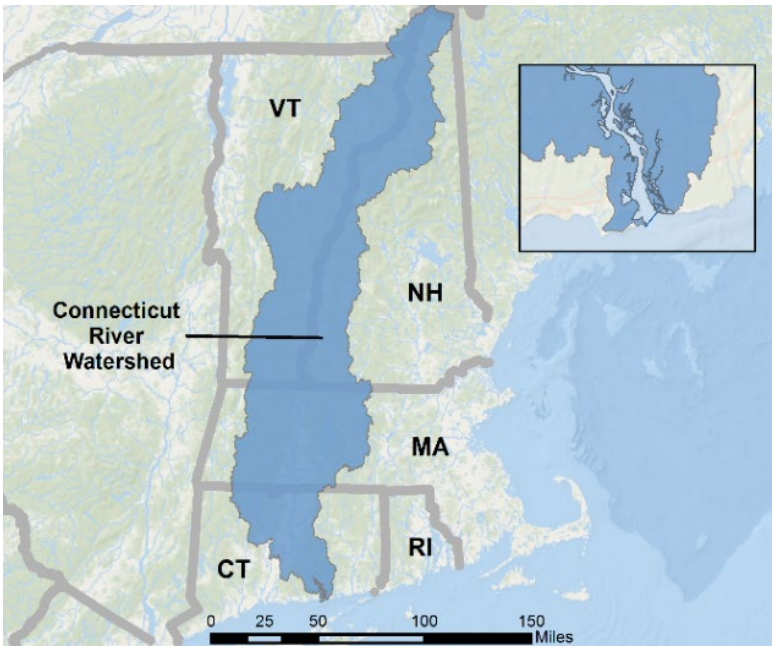

Figure C-1. Connecticut River Watershed

Table C-1. Hydraulic and Physical Factors of the Connecticut River and its Watershed

Geographic Watershed Characteristics	
Total Drainage Area[a]	29,166 km^2
Land Use (Percent Coverage)[b]	
Forested	77%
Agricultural	9%
Developed	5%
Wetlands	5%
Water or Other	4%
Connecticut River—Average Annual Discharge	
Mouth of the Connecticut River[c]	544 m^3/s
U.S. Geological Survey (USGS) Gauge 01193050 at Middle Haddam, CT (about 25 miles from the Connecticut River mouth)[d]	618 m^3/s (Range: 553 m^3/s to 804 m^3/s)
Percent of Total Freshwater Discharge to LIS[e]	70%
Dischargers within the Watershed	
Number of Municipal Separate Storm Sewer Systems (MS4s)	128

Portion Defined as MS4	9%
Number of Point Sources	132
Range of Discharge from Point Sources	0.01 to 80 MGD

[a] Moore et al. 2011.
[b] Clay et al. 2006.
[c] Data from 1992 to 1995; Garabedian et al. 1998.
[d] Data from 2010 to 2014; USGS 2017.
[e] CRC 2017.

Housatonic River

The Housatonic River is approximately 149 miles in length and drains areas of Connecticut, western Massachusetts, and eastern New York (Figure C-2). Summary statistics of the hydraulic and physical factors of the Housatonic River and its watershed are summarized in Table C-2.

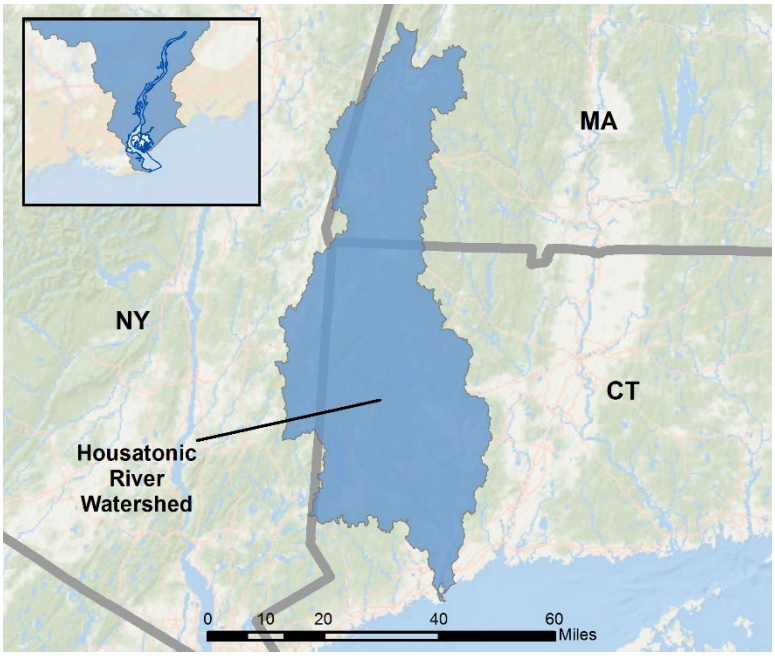

Figure C-2. Housatonic River Watershed

Table C-2. Hydraulic and Physical Factors of the Housatonic River and its Watershed

Geographic Watershed Characteristics	
Total Drainage Area[a]	5,054 km^2
Land Use (Percent Coverage)[b]	
Forested	62%
Agricultural	11%
Developed	15%
Wetlands	7%
Water or Other	5%
Housatonic River—Average Annual Discharge	
Mouth of the Housatonic River[c]	96 m^3/s
USGS Gauge 01205500 on Housatonic River at Stevenson, CT (about 17 miles upstream from the Housatonic River mouth)[d]	88 m^3/s (Range: 74 m^3/s to 125 m^3/s)
Percent of Total Freshwater Discharge to LIS[e]	11%

Dischargers within the Watershed	
Number of MS4s	53
Portion Defined as MS4	24%
Number of Point Sources	33
Range of Discharge from Point Sources	0.01 to 27 MGD

[a] CT DEEP 2017.
[b] MRLC 2015.
[c] Moore et al. 2011.
[d] Data from 2010 to 2014; USGS 2017.
[e] Calculated from data from http://longislandsoundstudy.net/.

Thames River

The Thames River is approximately 15 miles in length and begins at the confluence of the Yantic and Shetucket rivers at Norwich, CT. The Thames River watershed drains areas of eastern Connecticut, southern Massachusetts, and western Rhode Island (Figure C-3). Summary statistics of the hydraulic and physical factors of the Thames River and its watershed are summarized in Table C-3.

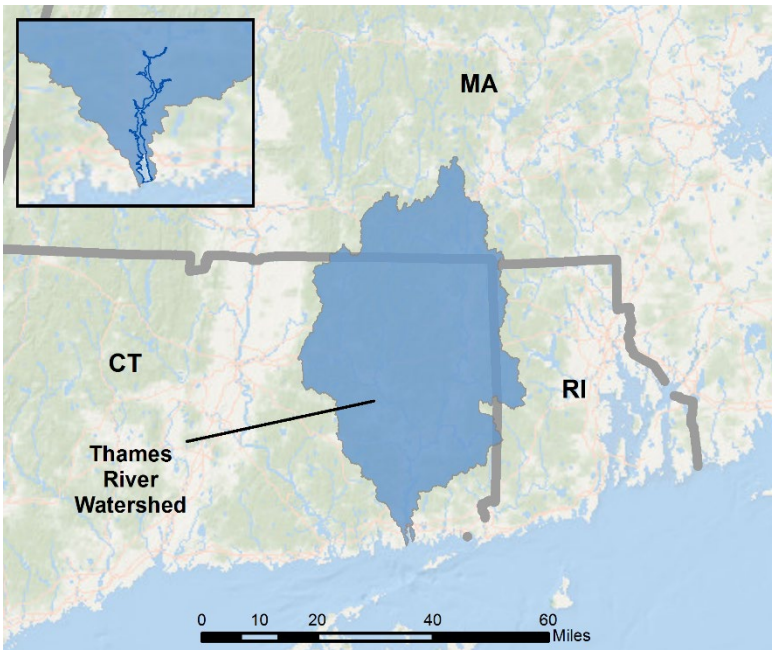

Figure C-3. Thames River Watershed

Table C-3. Hydraulic and Physical Factors of the Thames River and its Watershed

Geographic Watershed Characteristics	
Total Drainage Area[a]	3,808 km^2
Land Use (Percent Coverage)[b]	
Forested	61%
Agricultural	8%
Developed	12%
Wetlands	14%
Water or Other	5%

Thames River—Average Annual Discharge	
Mouth of the Thames River[c]	74 m^3/s
USGS Gauge 01127500 on Yantic River at Yantic, CT (about 18 miles upstream from the Thames River mouth)[d]	5 m^3/s (Range: 4 m^3/s to 7 m^3/s)
USGS Gauge 011230695 on Shetucket River at Taftville, CT (about 18 miles upstream from the Thames River mouth)[d]	28 m^3/s (Range: 23 m^3/s to 36 m^3/s)
Percent of Total Freshwater Discharge to LIS[e]	9%
Dischargers within the Watershed	
Number of MS4s	49
Portion Defined as MS4	18%
Number of Point Sources	20
Range of Discharge from Point Sources	0.01 to 10 MGD

[a] CT DEEP 2017.
[b] MRLC 2015.
[c] Moore et al. 2011.
[d] Data from 2010 to 2014; USGS 2017.
[e] Calculated from data from http://longislandsoundstudy.net/.

To determine tributary nitrogen loadings delivered to LIS from the Connecticut, Housatonic, and Thames rivers, Tetra Tech used data from the U.S. Geological Survey- (USGS-) provided SPAtially Referenced Regressions on Watershed attributes (SPARROW) modeling results and additional sources found during a literature review for the project. Values were extracted from those studies and are reported here. Any processing beyond simple literature extraction is described below to enable replication as needed. In addition to providing the summary information in this memo, Tetra Tech has provided all data in an associated Excel file (*Appendix C: Tributary Load Summary*).

Connecticut River

Summary Load Sources: Connecticut River

Load estimates from the Connecticut River were available at three different spatial scales: the entire Connecticut River watershed, specific USGS gauges throughout the Connecticut River watershed, and subwatersheds within the greater LIS watershed according to two regional SPARROW models. Note that some sources of data include data at multiple spatial scales, so the sources are named in multiple sections below. Each load estimate was based on nitrogen load standardized to kg N/yr using conditions representative of one period of time (as indicated). Load estimates were extracted directly from the sources indicated with minimal processing except to standardize units or report average conditions.

Entire Connecticut River Watershed

Nitrogen load estimates for the entire Connecticut River watershed were available from the following sources (most recent data are listed first):

- 2002 Northeastern and Mid-Atlantic regional SPARROW model (Moore et al. 2011)
- USGS annual nitrogen load estimates from 1999 to 2009 for nitrogen management zones that correspond closely to the Connecticut River watershed (Mullaney and Schwarz 2013)
- ArcView GIS Generalized Watershed Loading Function (AVGWLF) model data representing 1999–2005 (Evans 2008)
- National Oceanic and Atmospheric Administration National Estuarine Eutrophication Assessment (NEEA) representing 1994–2004 (Bricker et al. 2007)
- Load estimates from USGS reports, including data from 1988 to 1998 (Mullaney et al. 2002)

- A Hydrological Simulation Program–Fortran (HSPF) deterministic model for Connecticut representing 1991–1995 (AQUA TERRA and HydroQual 2001)
- 1992–1993 New England SPARROW model (Moore et al. 2004)
- LIS total maximum daily load (TMDL) nitrogen load estimates using input data from 1988 to 1990 (NYSDEC/CT DEP 2000)

Specific USGS Gauges throughout the Connecticut River Watershed

Nitrogen loading data were also available from specific gauge sites within the watershed. Tetra Tech summarized annual nitrogen load (kg N/yr) and yield (kg N/yr-km^2) calculated at specific USGS gauges using the most recent USGS report on a gauge-specific basis (see *Appendix C: Tributary Load Summary*) (Mullaney and Schwarz 2013; Mullaney 2016a, 2016b). Data were available from 1974 to 2013, but for uniformity with the other datasets and because of data availability, gauge load estimates were limited to data ranging from 1999 to 2013. No further processing was necessary. A map of the 19 gauges within the Connecticut River watershed is provided in Figure C-4.

- The Mullaney USGS report (2016a) included annual nitrogen loads and yields from 1974 to 2013 using weighted regressions on time, discharge, and season for six gauges within the Connecticut River watershed.
- A second Mullaney USGS report (2016b) included annual nitrogen loads and yields from 2006 to 2013 for one gauge using the USGS load estimator, LOADEST, within the Connecticut River watershed.
- Mullaney and Schwarz (2013) included annual nitrogen loads and yields from 1999 to 2009 for 12 gauges, also using LOADEST within the Connecticut River watershed.

Subwatersheds Based on SPARROW Models

Tetra Tech also summarized nitrogen loads, yields, and concentrations by subwatershed within the greater LIS watershed from the 2002 Northeastern and Mid-Atlantic regional SPARROW model[1] and the 1992–1993 New England regional SPARROW model.[2] Tetra Tech selected data from the 2002 model within the Connecticut River watershed using a geographic information system (GIS) and linked the statistics of interest by catchment ID (Com_ID) as compiled in *Appendix C: Tributary Load Summary*. No further processing was necessary. An example of the 2002 delivered nitrogen loads aggregated by 8-digit hydrologic unit code (HUC8) watersheds is provided in Figure C-5.

[1] Downloaded from the SPARROW Decision Support System https://cida.usgs.gov/sparrow/#modelid=51.
[2] Downloaded from the USGS New England SPARROW Data Viewer https://nh.water.usgs.gov/projects/sparrow/data.htm.

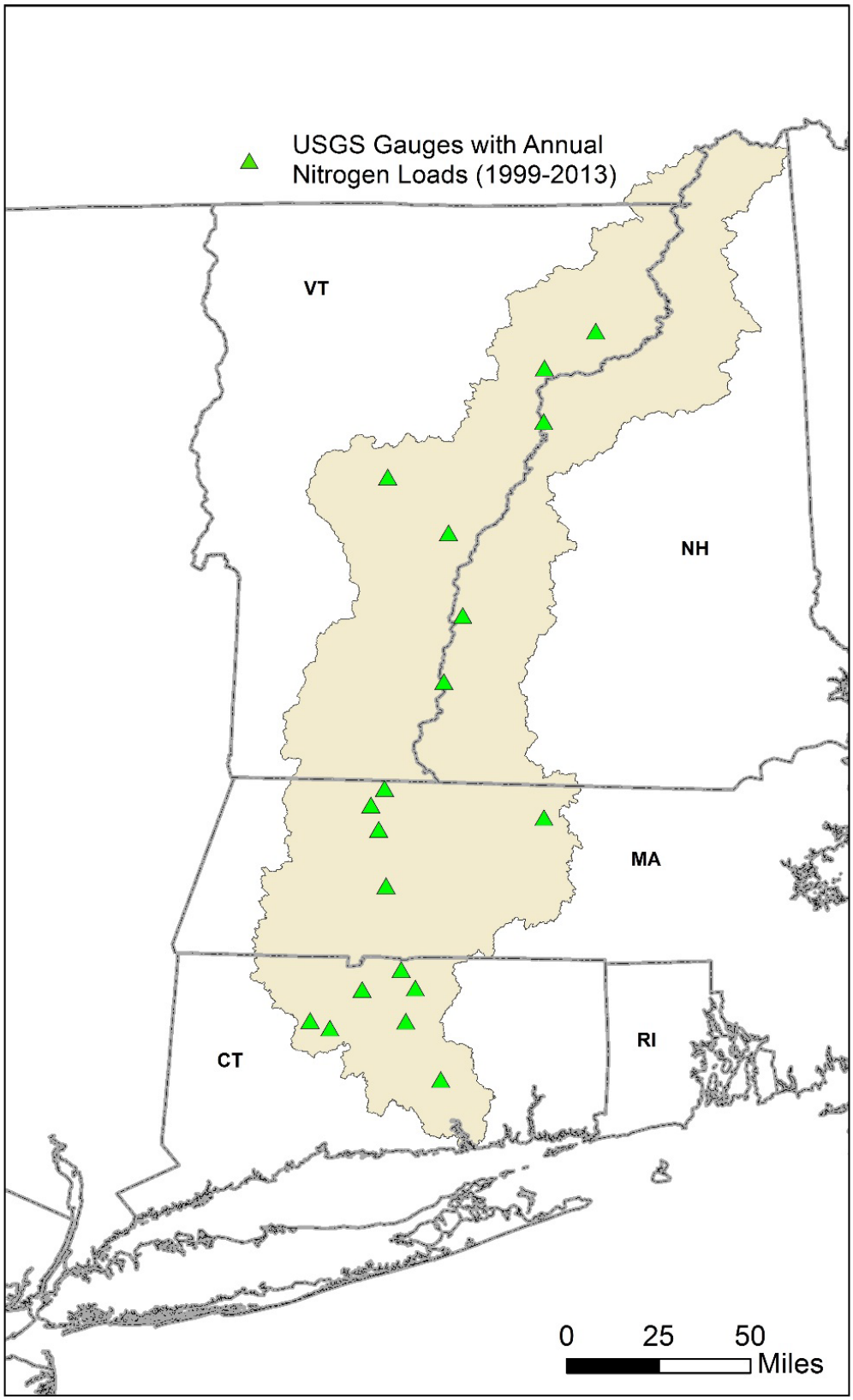

Figure C-4. USGS Gauges with Annual Nitrogen Loads (1999–2013) in the Connecticut River Watershed

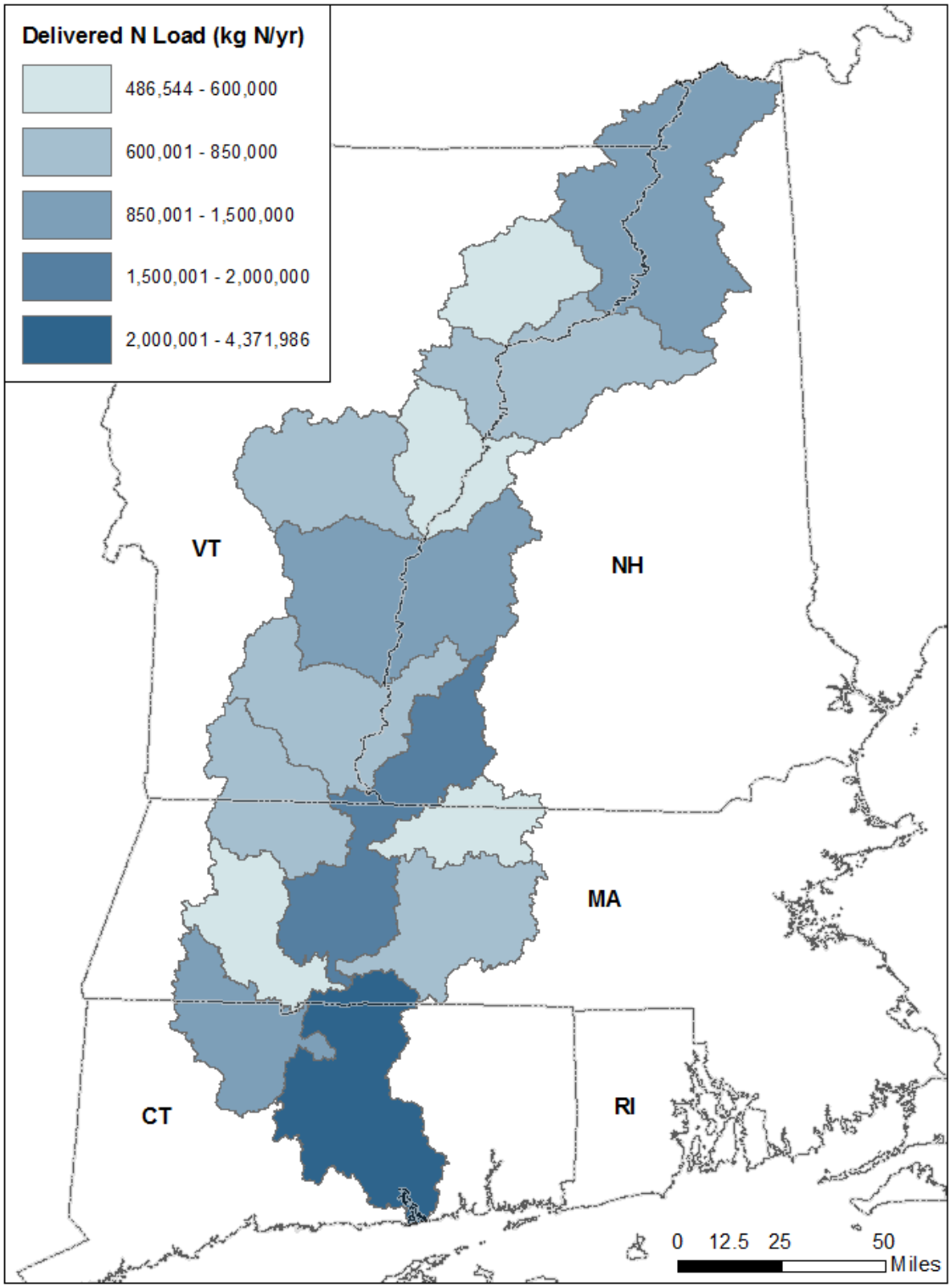

Figure C-5. LIS Delivered Nitrogen Load Estimates by HUC8 Watershed from the 2002 Northeastern and Mid-Atlantic Regional SPARROW Model in the Connecticut River Watershed

Results: Connecticut River

Estimates of watershed-wide nitrogen loads to LIS from the Connecticut River watershed were available from the literature over the time period 1988–2009 and ranged between 11,051,000 and 17,821,200 kg N/yr, as shown in Table C-4. Differences in estimates can be attributed to differences in watershed delineation, time periods (reflecting flow variability), and methodology. Tetra Tech found Connecticut River watershed nitrogen load estimates to be relatively consistent among datasets. Available data from 1999 forward was used to characterize the most recent watershed loading conditions available. Including a range of recent data rather than data for only the most recent year helps account for significant interannual variability during especially wet or dry years. Loading estimates prior to 1999 are provided for comparison. Note that Table C-4 does not include gauge- or subwatershed-specific loads. Results by monitoring gauge and subwatershed are included in Appendix C: *Tributary Load Summary* and summarized visually in Figure C-4 and Figure C-5, respectively.

Table C-4 Connecticut River Watershed Data Sources and Corresponding Nitrogen Load Estimates

Source Description	Estimated Nitrogen Load [kg N/yr]	Detailed Source
Northeastern and Mid-Atlantic Regional SPARROW 2002[a]	15,604,101	Moore et al. 2011, Table 4
USGS Report 1999–2009 Average	14,662,000	Mullaney and Schwarz 2013; annual loads and yields from Water Years 1999–2009 (1999–2009 average load reported here)
AVGWLF 1999–2005	13,021,000	Evans 2008, Table 4
NOAA NEEA 1994–2004	15,560,000	Bricker et al. 2007
Mullaney 1988–1998[b]	11,051,000	Mullaney et al. 2002
Connecticut HSPF 1991–1995	13,307,000	AQUA TERRA and HydroQual 2001
New England SPARROW Model 1992–1993	16,215,000	Moore et al. 2004, Table 7
NYSDEC and CT DEP 2000 TMDL 1988–1990[c]	17,821,200	NYSDEC/CT DEP 2000

[a] Recommended estimate.
[b] This is an estimate of nonpoint source nitrogen loads only and should, therefore, not be compared to the other estimates, which are total load estimates of both point and nonpoint sources.
[c] Includes "in-basin" and "tributary" loads as defined in the source.

Estimates reported since 1999 ranged from 13,021,000 to 15,604,101 kg N/yr. The most recent regional SPARROW model, the 2002 Northeastern and Mid-Atlantic regional model, estimated annual Connecticut River nitrogen loads to LIS as 15,604,101 kg N/yr. An average streamflow hydrograph was used for the SPARROW model to account for year-to-year fluctuations in streamflow, so the model is representative of water quality conditions specific to 2002 but combined with longer term average annual streamflow conditions. The regional model improves accuracy of previous models with the addition of updated stream networks, monitoring data, and more detailed estimates of sources and delivery factors (e.g., agriculture, wet deposition) (Moore et al. 2011). The Moore et al. (2011) average load estimate of 15,604,101 kg N/yr is recommended because the results were summarized with a bottom-up method. It provides detailed model results for every specific subwatershed, allowing derivation of the nitrogen load delivered from each subwatershed to LIS and the calculation of specific subwatershed load allocation.

One source of recent load estimates provided annual loads for each year from 1999 to 2009 (Mullaney and Schwarz 2013). Average watershed loads were calculated using the LOADEST program, while unmonitored sites and area loads were calculated via regression analysis. The annual loads reported by Mullaney and Schwarz (2013) range from a low of 10,995,192 kg N/yr in 2002 to a high of 19,150,866 kg N/yr in 2006.

Other recent estimates since 1999 are comparable to the recommended annual load estimate. Evans (2008) estimated Connecticut River nitrogen loads using in-stream water quality data and flow data from a USGS station just below the Massachusetts state line (Thompsonville gauge 1184000) along with a GIS-based watershed model (AVGWLF) (Evans 2008). Evans (2008) estimated an average annual load of 13,021,000 kg N/yr from the Connecticut River to LIS over the period 1999–2005. The NOAA NEEA program provided average annual nitrogen load estimates for nine coastal rivers, including the Connecticut River (15,560,000 kg N/yr), over the period 1994–2004 using monitoring data and other local data sources (Bricker et al. 2007).

Estimates prior to 1999 are included in Table C-4 for comparison. These estimates include a USGS report with a load estimate from 1988 to 1998 (Mullaney et al. 2002), an HSPF model estimate from 1991 to 1995 (AQUA TERRA and HydroQual 2001), a New England SPARROW model from 1992 to 1993 (Moore et al. 2004), and the 2000 LIS dissolved oxygen TMDL load estimate based on 1988–1990 data (NYSDEC/CT DEP 2000).

The recommended estimated nitrogen load is broken out by state or Canadian province in Table C-5.

Table C-5. Connecticut River Watershed Delivered Nitrogen Loads Estimates by State or Canadian Province

Source Description	Estimated Nitrogen Load [kg N/yr]	Source	Nitrogen Load by State or Canadian Province				
			Québec	NH	VT	MA	CT
Northeastern and Mid-Atlantic Regional SPARROW 2002	15,604,101	Moore et al. 2011	77,512	2,774,436	3,751,882	4,575,021	4,425,250

Nitrogen Loading Summary: Connecticut River

A visual summary of delivered nitrogen loads by HUC8 subwatershed using the 2002 Northeastern and Mid-Atlantic regional SPARROW model is provided in Figure C-5. *Delivered nitrogen load* refers to the mean annual nitrogen load delivered to LIS from a particular subwatershed and accounts for attenuation along the flow path from the source watershed to the receiving water. As shown in the legend, different colors distinguish delivered nitrogen loads at each HUC8 pour point. Within the greater Connecticut River watershed, delivered nitrogen load ranged from 486,544 kg N/yr for the Miller watershed (01080202) to 4,371,986 kg N/yr for the Lower Connecticut River watershed (01080205).

The number and location of point sources and municipal separate storm sewer systems (MS4s) along the Connecticut River are shown in Figure C-6 and Figure C-7, respectively. There were 132 point source dischargers identified across the Connecticut River watershed. In total, 128 MS4 communities were identified in the Connecticut River watershed, with the majority located in the developed areas between the greater Hartford area (Connecticut) and the greater Springfield area (Massachusetts) in the southern portions of the watershed. No regulated MS4s were identified in the New Hampshire and Vermont portions of the LIS watershed.

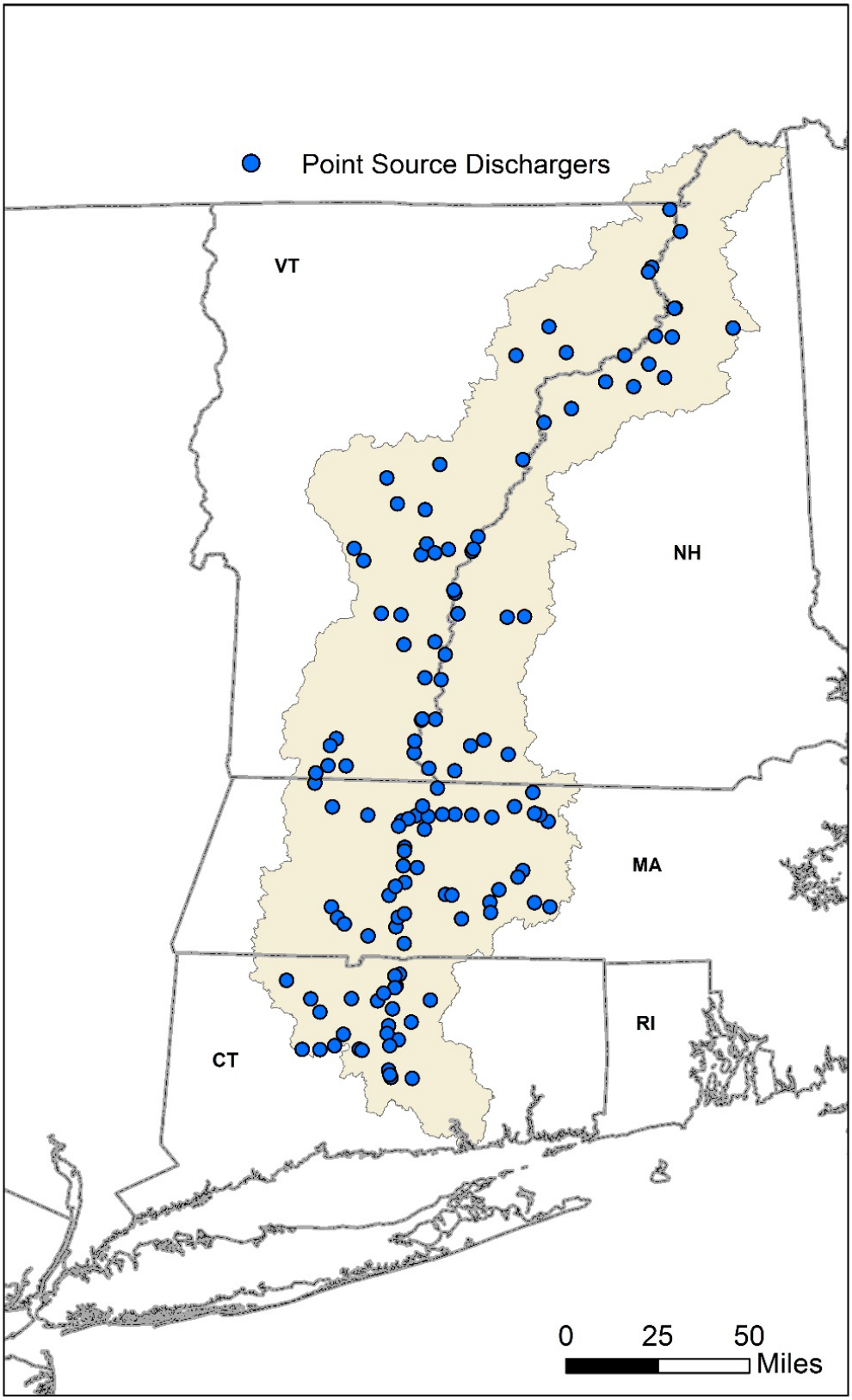

Figure C-6. LIS Watershed Point Source Dischargers in the Connecticut River Watershed

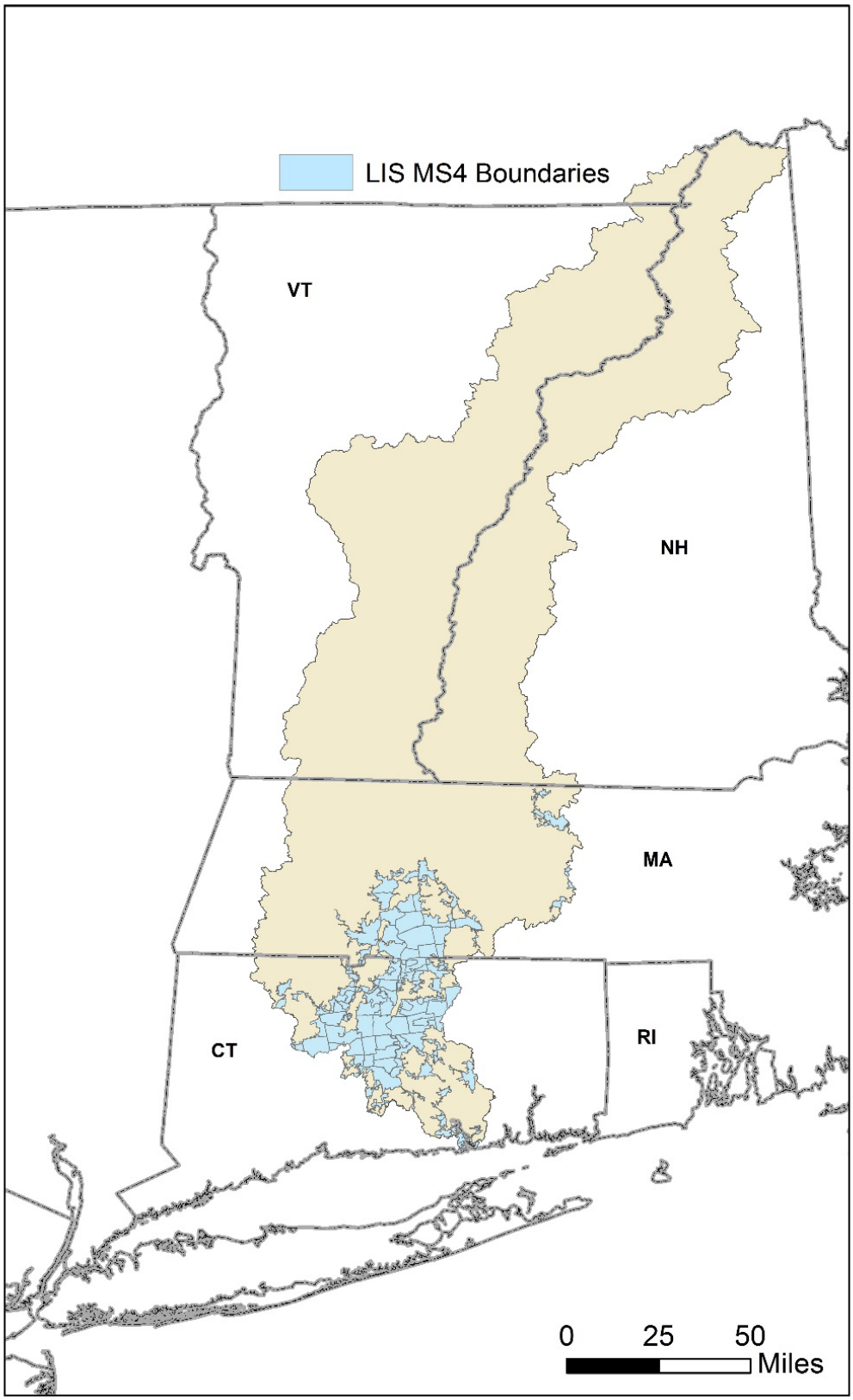

Figure C-7. LIS Watershed Point Sources by MS4 Boundaries in the Connecticut River Watershed

Housatonic River

Summary Load Sources: Housatonic River

Load estimates from the Housatonic River were available at three different spatial scales: the entire Housatonic River watershed, specific USGS gauges throughout the Housatonic River watershed, and subwatersheds within the greater LIS watershed according to two regional SPARROW models. Note that some sources include data at multiple spatial scales, so data sources are referenced in multiple sections below. Each load estimate was based on nitrogen load standardized to kg N/yr using conditions representative of one period of time (as indicated). Load estimates were extracted directly from the sources indicated with minimal processing except to standardize units or report average conditions.

Entire Housatonic River Watershed

Nitrogen load estimates for the entire Housatonic River watershed were available from the following sources (most recent data are listed first):

- 2002 Northeastern and Mid-Atlantic regional SPARROW model (Moore et al. 2011)
- USGS annual nitrogen load estimates from 1999 to 2009 for nitrogen management zones that correspond closely to the Housatonic River watershed (Mullaney and Schwarz 2013)
- Load estimates from USGS reports, including data from 1988 to 1998 (Mullaney et al. 2002)
- 1992–1993 New England SPARROW model (Moore et al. 2004)
- LIS TMDL nitrogen load estimates using input data from 1988 to 1990 (NYSDEC/CT DEP 2000)

Specific USGS Gauges throughout the Housatonic River Watershed

Nitrogen loading data were also available from specific gauge sites within the watershed. Tetra Tech summarized annual nitrogen load (kg N/yr) and yield (kg N/yr-km^2) calculated at specific USGS gauges using the most recent USGS report on a gauge-specific basis (see *Appendix C: Tributary Load Summary*) (Mullaney and Schwarz 2013; Mullaney 2016a, 2016b). Data were available from 1974 to 2013, but for uniformity with the other datasets and because of data availability, gauge load estimates were limited to data ranging from 1999 to 2013. No further processing was necessary. A map of the four gauges within the Housatonic River watershed is provided in Figure C-8.

- The Mullaney USGS report (2016a) included annual nitrogen loads and yields from 1974 to 2013 using weighted regressions on time, discharge, and season for two gauges within the Housatonic River watershed.
- A second Mullaney USGS report (2016b) included annual nitrogen loads and yields from 2006 to 2013 for two gauges using the USGS LOADEST within the Housatonic River watershed.

Subwatersheds Based on SPARROW Models

Tetra Tech also summarized nitrogen loads, yields, and concentrations by subwatershed within the greater LIS watershed from the 2002 Northeastern and Mid-Atlantic regional SPARROW model and the 1992–1993 New England regional SPARROW model. Tetra Tech selected data from the 2002 model within the Housatonic River watershed using GIS and linked the statistics of interest by catchment ID (Com_ID) as compiled in *Appendix C: Tributary Load Summary*. No further processing was necessary. An example of the 2002 incremental nitrogen loads aggregated by HUC8 watershed is provided in Figure C-9.

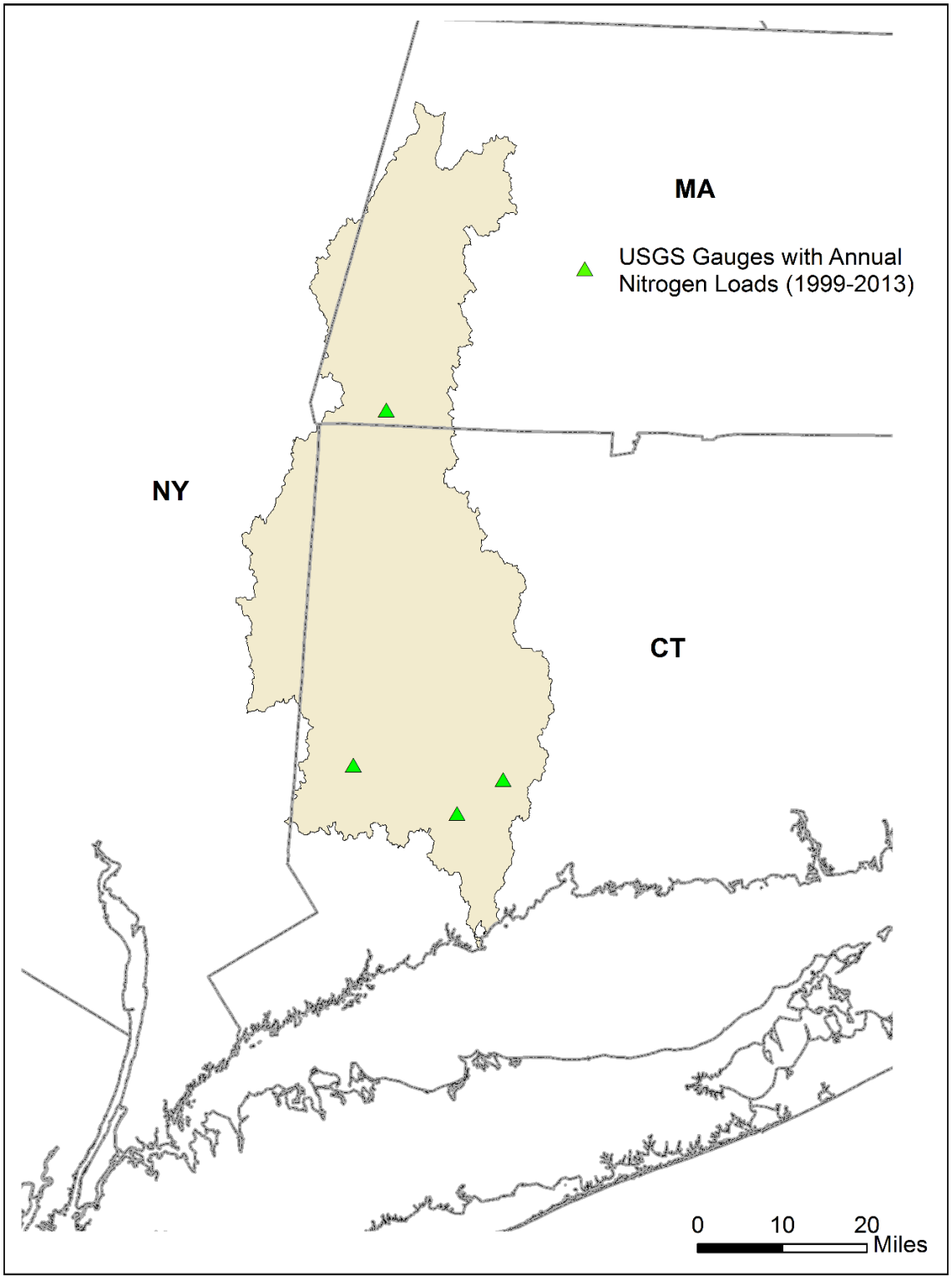

Figure C-8. USGS Gauges with Annual Nitrogen Loads (1999–2013) in the Housatonic River Watershed

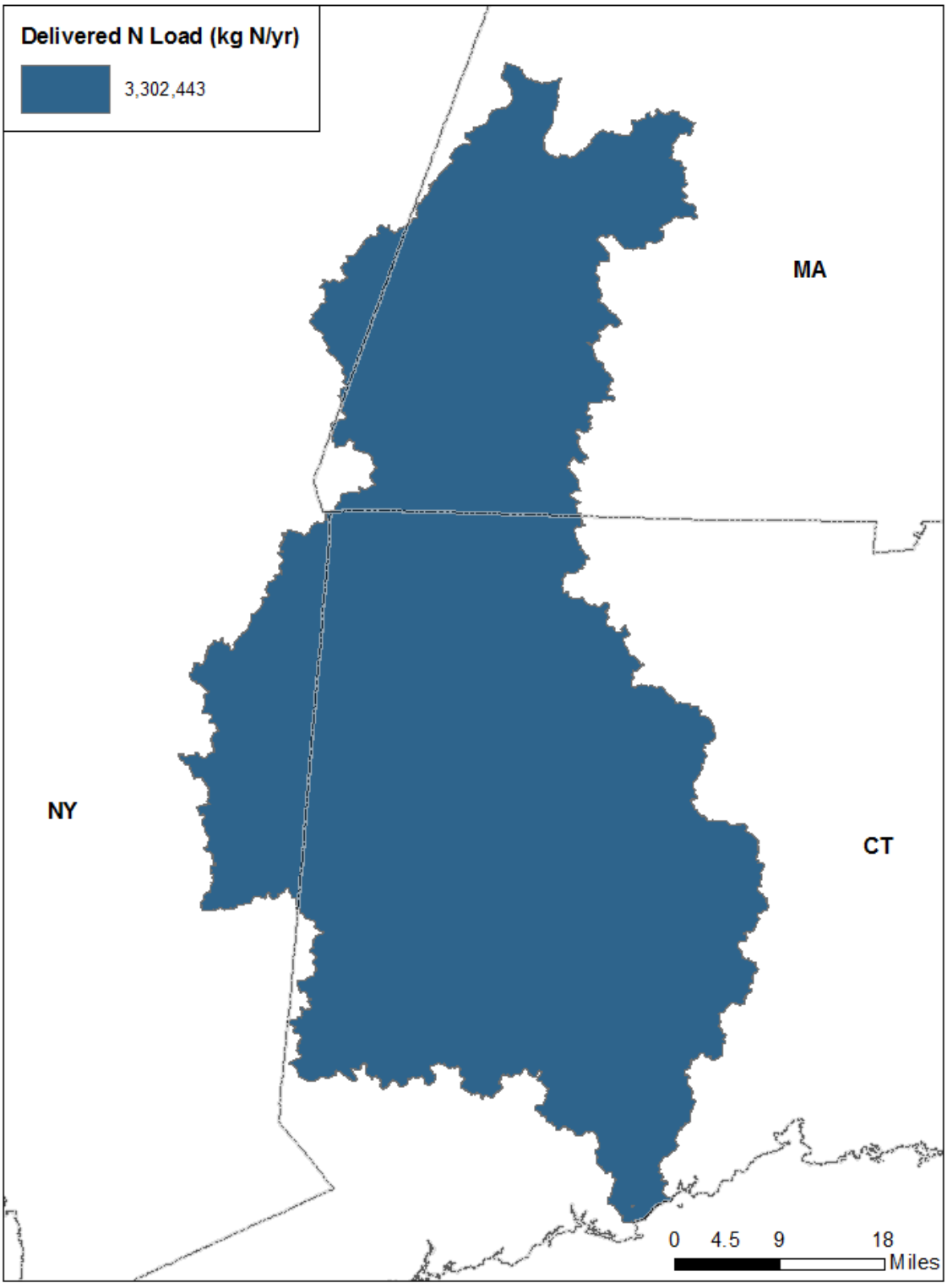

Figure C-9. LIS Delivered Nitrogen Load Estimates by HUC8 Watershed from the 2002 Northeastern and Mid-Atlantic Regional SPARROW Model in the Housatonic River Watershed

Results: Housatonic River

Estimates of watershed-wide nitrogen loads to LIS from the Housatonic River watershed were available from the literature over the time period 1988–2009 and ranged between 1,996,000 and 3,920,000 kg N/yr, as shown in Table C-6. Differences in estimates can be attributed to differences in watershed delineation, time periods (reflecting flow variability), and methodology. Tetra Tech found Housatonic River watershed nitrogen load estimates to be relatively consistent among datasets. Available data from 1999 forward was used to characterize the most recent watershed loading conditions available. Including a range of recent data rather than data for only the most recent year helps account for significant interannual variability during especially wet or dry years. Loading estimates prior to 1999 are provided for comparison. Note that Table C-6 does not include gauge- or subwatershed-specific loads. Results by monitoring gauge and subwatershed are included in *Appendix C: Tributary Load Summary* and summarized visually in Figure C-8 and Figure C-9, respectively.

Table C-6. Housatonic River Watershed Data Sources and Corresponding Nitrogen Load Estimates

Source Description	Estimated Nitrogen Load [kg N/yr]	Detailed Source
Northeastern and Mid-Atlantic Regional SPARROW 2002[a]	3,302,443	Moore et al. 2011
USGS Report 1999–2009 Average	3,063,000	Mullaney and Schwarz 2013
Mullaney 1988–1998[b]	1,996,000	Mullaney et al. 2002
New England SPARROW 1992–1993	3,386,000	Moore et al. 2004
NYSDEC and CT DEP 2000 TMDL 1988–1990[c]	3,920,000	NYSDEC/CT DEP 2000

[a] Recommended estimate.
[b] This is an estimate of nonpoint source nitrogen loads only and should, therefore, not be compared to the other estimates, which are total load estimates of both point and nonpoint sources.
[c] Includes “in-basin” and “tributary” loads as defined in the source.

Estimates reported since 1999 ranged from 3,063,000 to 3,302,443 kg N/yr. The most recent regional SPARROW model, the 2002 Northeastern and Mid-Atlantic regional model, estimated annual Housatonic River nitrogen loads to LIS as 3,302,443 kg N/yr. An average streamflow hydrograph was used for the SPARROW model to account for year-to-year fluctuations in streamflow, so the model is representative of water quality conditions specific to 2002 but combined with longer term average annual streamflow conditions. The regional model improves accuracy of previous models with the addition of updated stream networks, monitoring data, and more detailed estimates of sources and delivery factors (e.g., agriculture, wet deposition) (Moore et al. 2011). The Moore et al. (2011) average load estimate of 3,302,443 kg N/yr is recommended because the results were summarized with a bottom-up method. It provides detailed model results for every specific subwatershed, allowing derivation of the nitrogen load delivered from each subwatershed to LIS and the calculation of specific subwatershed load allocation.

One source of recent load estimates provided annual loads for each year from 1999 to 2009 (Mullaney and Schwarz 2013). Average watershed loads were calculated using the LOADEST program, while unmonitored sites and area loads were calculated via regression analysis. The annual loads reported by Mullaney and Schwarz (2013) range from a low of 1,727,751 kg N/yr in 2002 to a high of 4,095,981 kg N/yr in 2006.

Estimates prior to 1999 are included in Table C-6 for comparison. These estimates include a USGS report with a load estimate from 1988 to 1998 (Mullaney et al. 2002), a New England SPARROW model from 1992 to 1993 (Moore et al. 2004), and the 2000 LIS dissolved oxygen TMDL load estimate based on 1988–1990 data (NYSDEC/CT DEP 2000).

The recommended estimated nitrogen load is broken out by state in Table C-7.

Table C-7. Housatonic River Watershed Delivered Nitrogen Loads by State

Source Description	Estimated Nitrogen Load [kg N/yr]	Source	Nitrogen Load by State		
			MA	CT	NY
Northeastern and Mid-Atlantic SPARROW 2002	3,302,443	Moore et al. 2011	619,462	2,422,615	260,366

Nitrogen Loading Summary: Housatonic River

A visual summary of nitrogen loads by HUC8 subwatershed using the 2002 Northeastern and Mid-Atlantic regional SPARROW model is provided in Figure C-9. *Delivered nitrogen load* refers to the mean annual nitrogen load delivered to LIS from a particular subwatershed and accounts for attenuation along the flow path from the source watershed to the receiving water. The nitrogen load was 3,302,443 kg N/yr for the Housatonic River watershed (01100005).

The number and location of point sources and MS4s along the Housatonic River are shown in Figure C-10 and Figure C-11, respectively. There were 33 identified point source dischargers located across the Housatonic River watershed. In total, 53 MS4 communities were identified in the Housatonic River watershed, with the majority located in the southern portion. The point sources and MS4s were identified in Connecticut and Massachusetts; none were identified in New York.

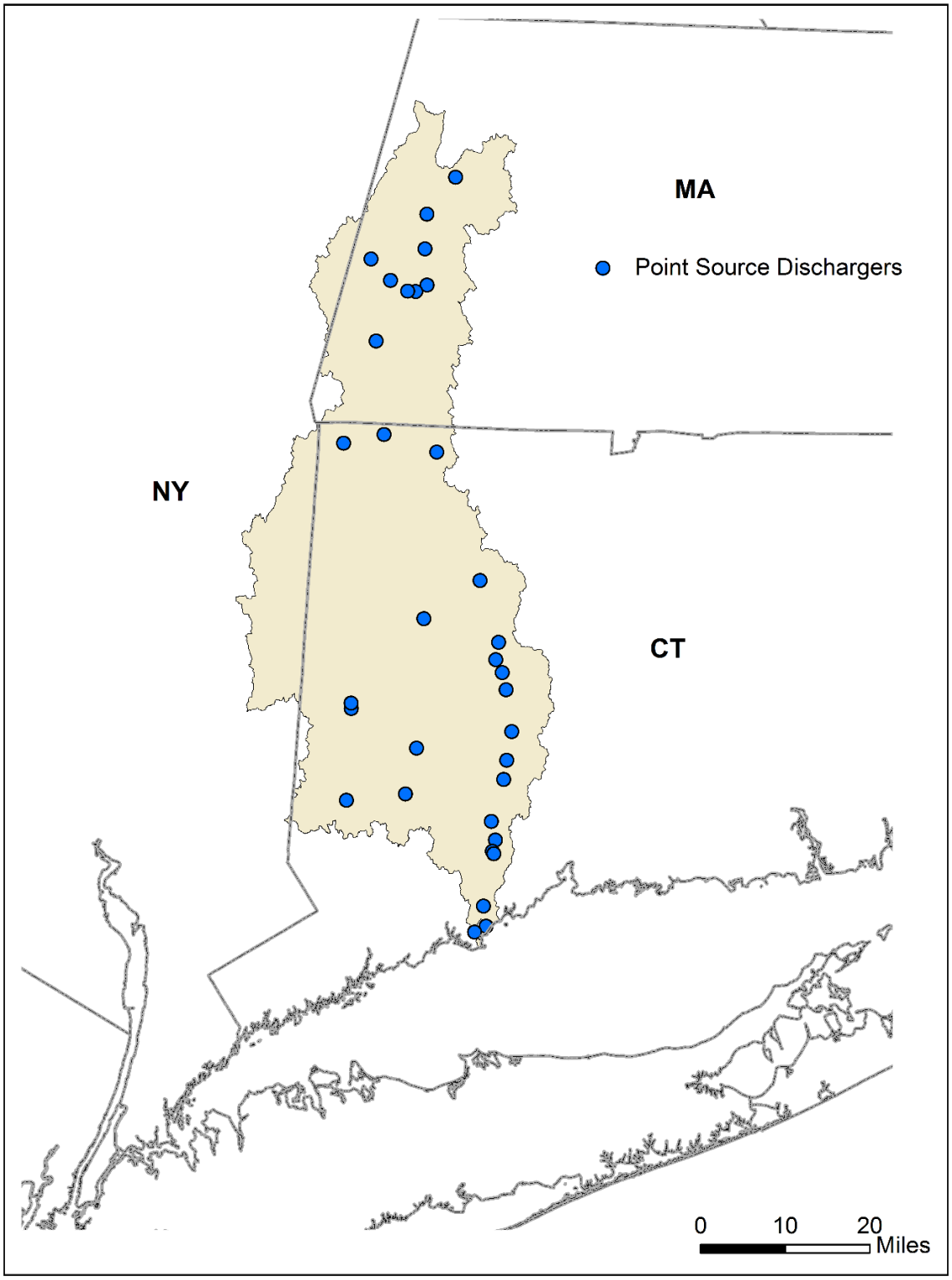

Figure C-10. LIS Watershed Point Source Dischargers in the Housatonic River Watershed

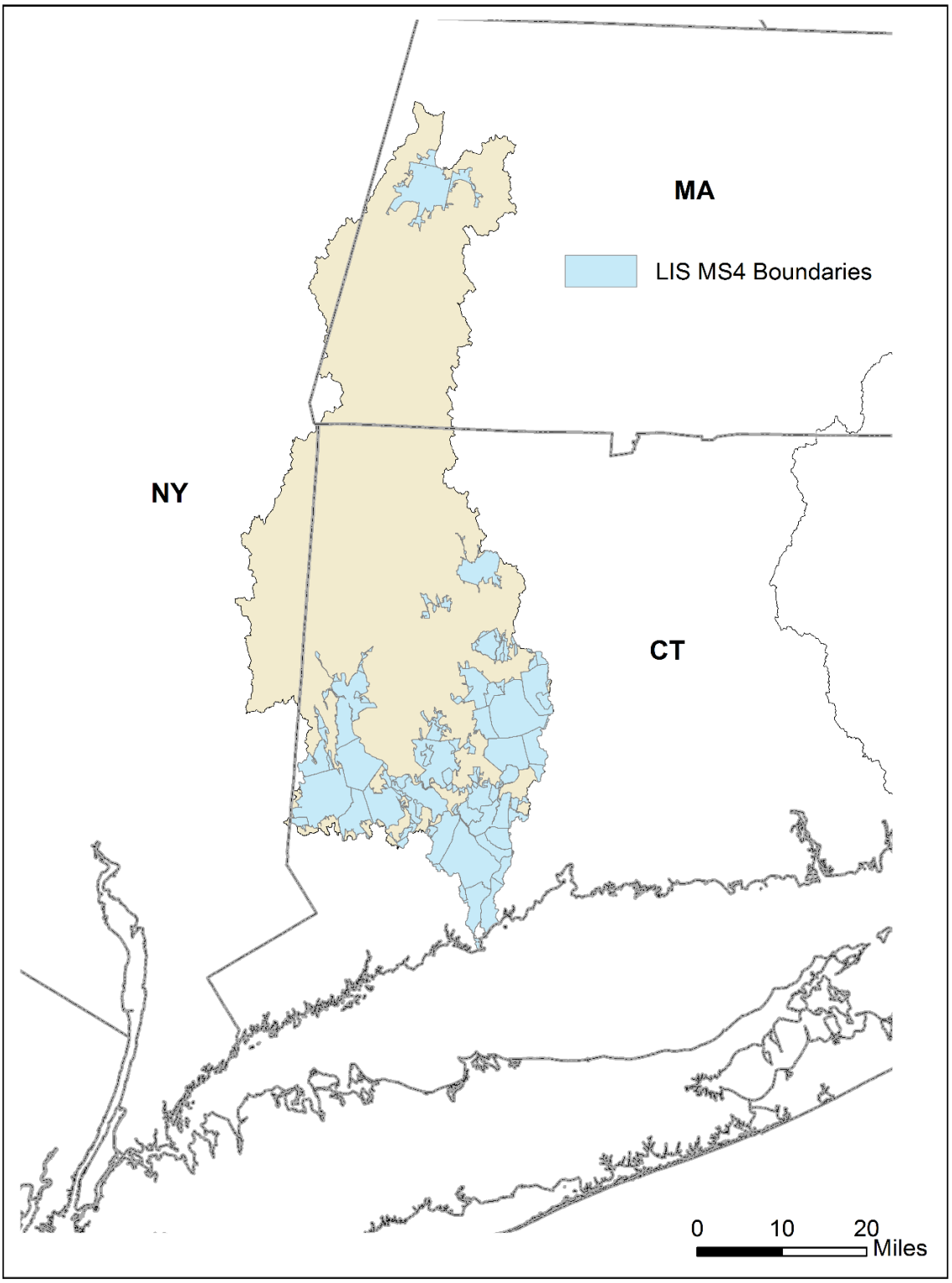

Figure C-11. LIS Watershed Point Sources by MS4 Boundaries in the Housatonic River Watershed

Thames River

Summary Load Sources: Thames River

Load estimates from the Thames River were available at three different spatial scales: the entire Thames River watershed, specific USGS gauges throughout the Thames River watershed, and subwatersheds within the greater LIS watershed according to two regional SPARROW models. Note that some sources of data include data at multiple spatial scales, so the sources are named in multiple sections below. Each load estimate was based on nitrogen load standardized to kg N/yr using conditions representative of one period of time (as indicated). Load estimates were extracted directly from the sources indicated with minimal processing except to standardize units or report average conditions.

Entire Thames River Watershed

Nitrogen load estimates for the entire Thames River watershed were available from the following sources (most recent data are listed first):

- USGS annual nitrogen load estimates from 1999 to 2009 for nitrogen management zones that correspond closely to the Thames River watershed (Mullaney and Schwarz 2013)
- 2002 Northeastern and Mid-Atlantic regional SPARROW model (Moore et al. 2011)
- 1992–1993 New England SPARROW model (Moore et al. 2004)
- LIS TMDL nitrogen load estimates using input data from 1988 to 1990 (NYSDEC/CT DEP 2000)

Specific USGS Gauges throughout the Thames River Watershed

Nitrogen loading data were also available from specific gauge sites within the watershed. Tetra Tech summarized annual nitrogen load (kg N/yr) and yield (kg N/yr-km^2) calculated at specific USGS gauges using the most recent USGS report on a gauge-specific basis (see *Appendix C: Tributary Load Summary*) (Mullaney and Schwarz 2013; Mullaney 2016a, 2016b). Data were available from 1974 to 2013, but for uniformity with the other datasets and because of data availability, gauge load estimates were limited to data ranging from 1999 to 2013. No further processing was necessary. A map of the nine gauges within the Thames River watershed is provided in Figure C-12.

- The Mullaney USGS report (2016a) included annual nitrogen loads and yields from 1974 to 2013 using weighted regressions on time, discharge, and season for three gauges within the Thames River watershed.
- A second Mullaney USGS report (2016b) included annual nitrogen loads and yields from 2006 to 2013 for five gauges using the USGS LOADEST within the Thames River watershed.
- Mullaney and Schwarz (2013) included annual nitrogen loads and yields from 1999 to 2009 for one gauge, also using LOADEST within the Thames River watershed.

Subwatersheds Based on SPARROW Models

Tetra Tech also summarized nitrogen loads, yields, and concentrations by subwatershed within the greater LIS watershed from the 2002 Northeastern and Mid-Atlantic regional SPARROW model and the 1992–1993 New England regional SPARROW model. Tetra Tech selected data from the 2002 model within the Thames River watershed using GIS and linked the statistics of interest by catchment ID (Com_ID) as compiled in *Appendix C: Tributary Load Summary*. No further processing was necessary. An example of the 2002 incremental nitrogen loads aggregated by HUC8 watershed is provided in Figure C-13.

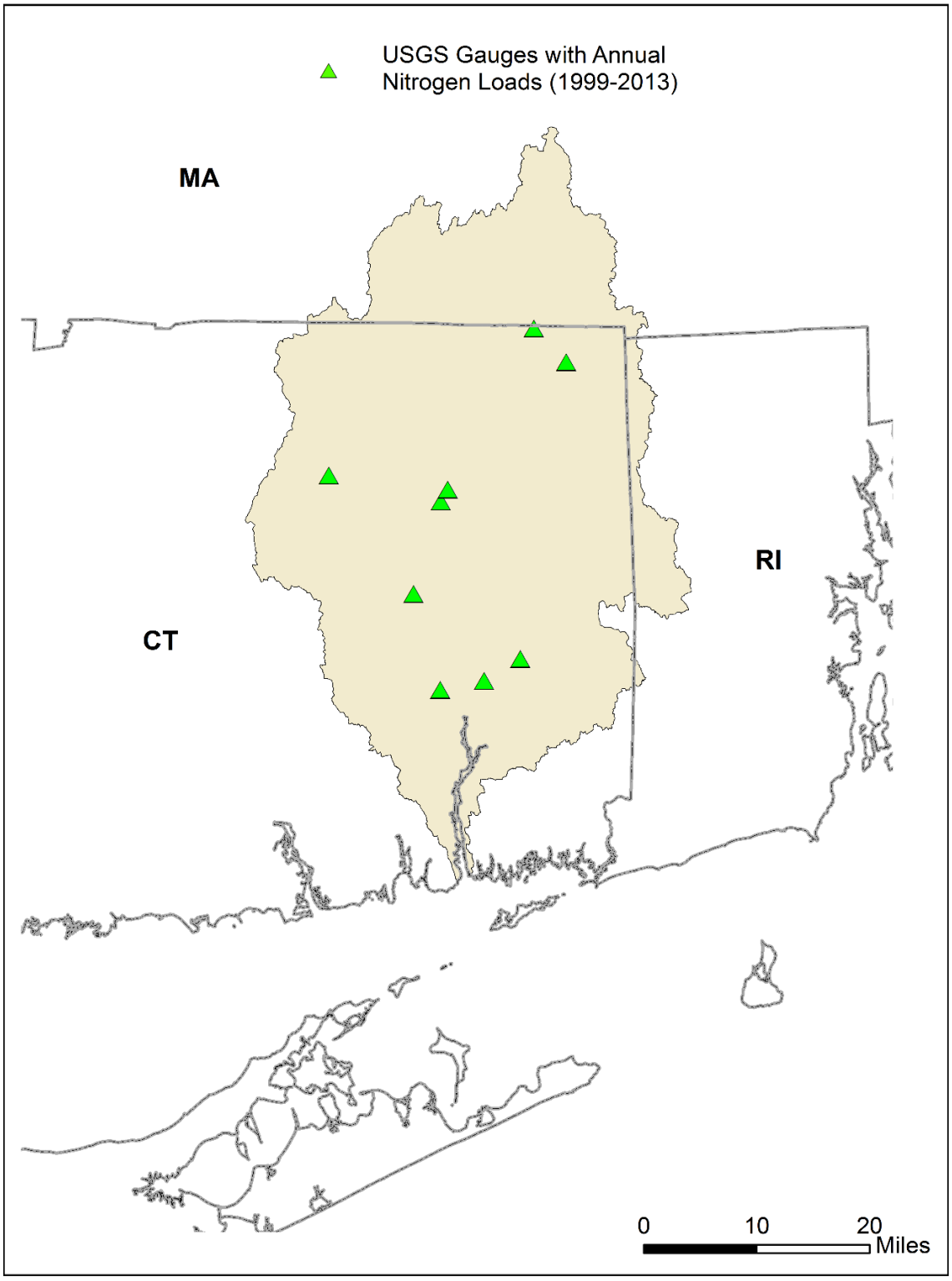

Figure C-12. USGS Gauges with Annual Nitrogen Loads (1999–2013) in the Thames River Watershed

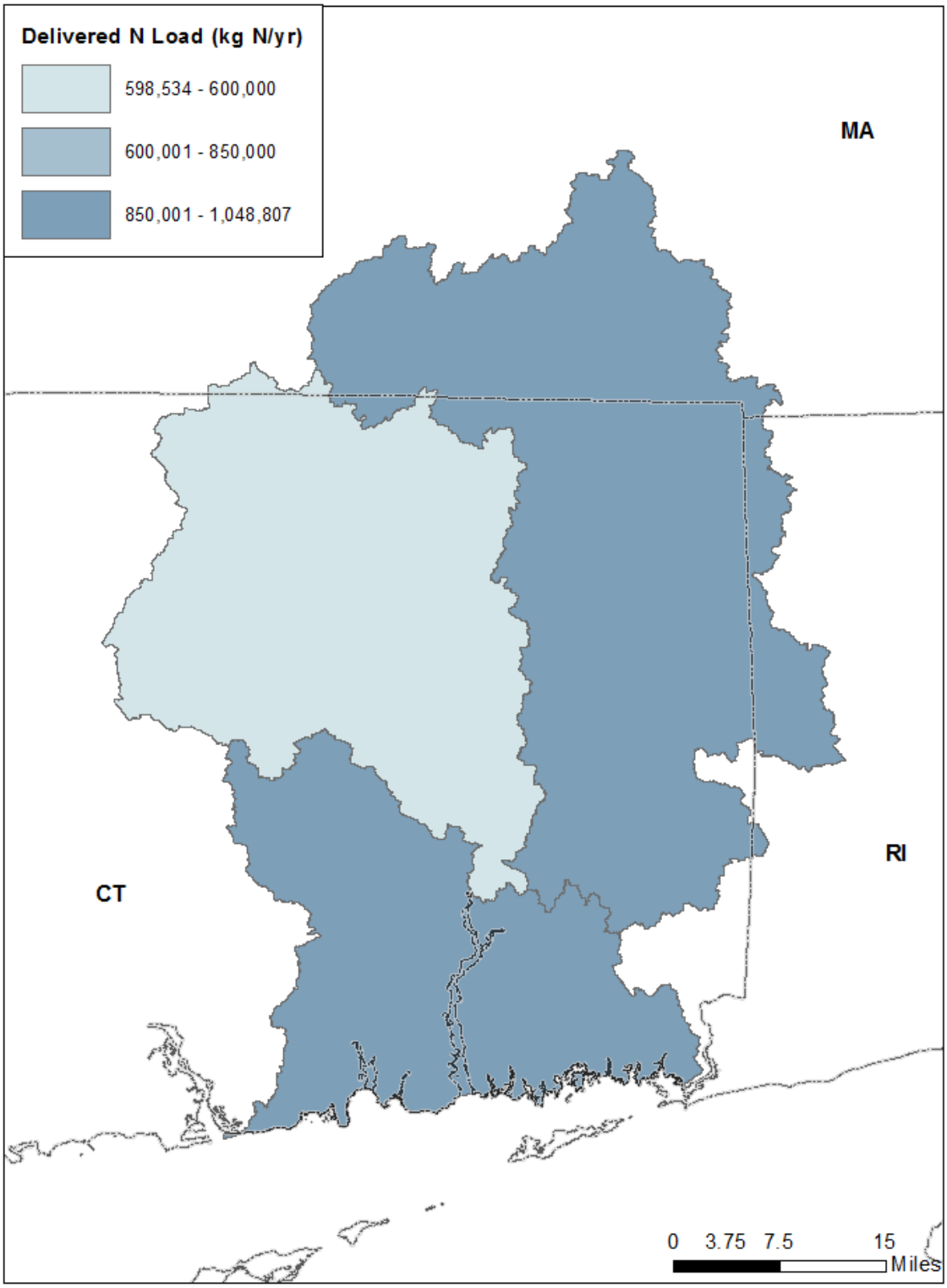

Figure C-13. LIS Delivered Nitrogen Load Estimates by HUC8 Watershed from the 2002 Northeastern and Mid-Atlantic Regional SPARROW Model in the Thames River Watershed

Results: Thames River

Estimates of watershed-wide nitrogen loads to LIS from the Thames River watershed were available from the literature over the time period 1988–2009 and ranged between 2,278,000 and 3,430,300 kg N/yr, as shown in Table C-8. Differences in estimates can be attributed to differences in watershed delineation, time periods (reflecting flow variability), and methodology. Tetra Tech found Thames River watershed nitrogen load estimates since 1999 to be relatively consistent among datasets. Available data from 1999 forward was used to characterize the most recent watershed loading conditions available. Including a range of recent data rather than data for only the most recent year helps account for significant interannual variability during especially wet or dry years. Loading estimates prior to 1999 are provided for comparison. Note that Table C-8 does not include gauge- or subwatershed-specific loads. Results by monitoring gauge and subwatershed are included in *Appendix C: Tributary Load Summary* and summarized visually in Figure C-12 and Figure C-13, respectively.

Table C-8. Thames River Watershed Data Sources and Corresponding Nitrogen Load Estimates

Source Description	Estimated Nitrogen Load [kg N/yr]	Detailed Source
Northeastern and Mid-Atlantic SPARROW 2002[a]	2,601,608	Moore et al. 2011
USGS Report 1999–2009 Average	2,501,000	Mullaney and Schwarz 2013
New England SPARROW 1992–1993	2,278,000	Moore et al. 2004
NYSDEC and CT DEP 2000 TMDL 1988–1990[b]	3,430,300	NYSDEC/CT DEP 2000

[a] Recommended estimate.
[b] Includes "in-basin" and "tributary" loads as defined in the source.

Estimates reported since 1999 ranged from 2,501,000 to 2,601,608 kg N/yr. The most recent regional SPARROW model, the 2002 Northeastern and Mid-Atlantic regional model, estimated annual Thames River nitrogen loads to LIS as 2,601,608 kg N/yr. An average streamflow hydrograph was used for the SPARROW model to account for year-to-year fluctuations in streamflow, so the model is representative of water quality conditions specific to 2002 but combined with longer term average annual streamflow conditions. The regional model improves accuracy of previous models with the addition of updated stream networks, monitoring data, and more detailed estimates of sources and delivery factors (e.g., agriculture, wet deposition) (Moore et al. 2011). The Moore et al. (2011) average load estimate of 2,601,608 kg N/yr is recommended because the results were summarized with a bottom-up method. It provides detailed model results for every specific subwatershed, allowing derivation of the nitrogen load delivered from each subwatershed to LIS and the calculation of specific subwatershed load allocation.

One source of recent load estimates provided annual loads for each year from 1999 to 2009 (Mullaney and Schwarz 2013). Average watershed loads were calculated using the LOADEST program, while unmonitored sites and area loads were calculated via regression analysis. The annual loads reported by Mullaney and Schwarz (2013) range from a low of 1,424,000 kg N/yr in 2002 to a high of 3,044,000 kg N/yr in 2006.

Estimates prior to 1999 are included in Table C-8 for comparison. These estimates include a New England SPARROW model from 1992 to 1993 (Moore et al. 2004) and the 2000 LIS dissolved oxygen TMDL load estimate based on 1988–1990 data (NYSDEC/CT DEP 2000).

The recommended estimated nitrogen load is broken out by state in Table C-9.

Table C-9. Thames River Watershed Delivered Nitrogen Loads by State

Source Description	Estimated Nitrogen Load [kg N/yr]	Source	Nitrogen Load by State		
			MA	CT	RI
Northeastern and Mid-Atlantic SPARROW 2002	2,601,608	Moore et al. 2011	377,625	2,193,469	30,514

Nitrogen Loading Summary: Thames River

A visual summary of delivered nitrogen loads by HUC8 subwatershed using the 2002 Northeastern and Mid-Atlantic regional SPARROW model is provided in Figure C-13. *Delivered nitrogen load* refers to the mean annual nitrogen load delivered to LIS from a particular subwatershed and accounts for attenuation along the flow path from the source watershed to the receiving water. As shown in the legend, different colors distinguish delivered nitrogen loads at each HUC8 pour point. Within the greater Thames River watershed, delivered nitrogen load ranged from 598,534 kg N/yr for the Shetucket watershed (01100002) to 1,048,807 kg N/yr for the Quinebaug watershed (01100001).

The number and location of point sources and MS4s along the Thames River are shown in Figure C-14 and Figure C-15, respectively. There were 20 identified point source dischargers located across the Thames River watershed. In total, 49 MS4 communities were identified in the Thames River watershed, with the majority located along the Thames and Quinebaug rivers. The point sources and MS4s were identified in Connecticut and Massachusetts; none were identified in Rhode Island.

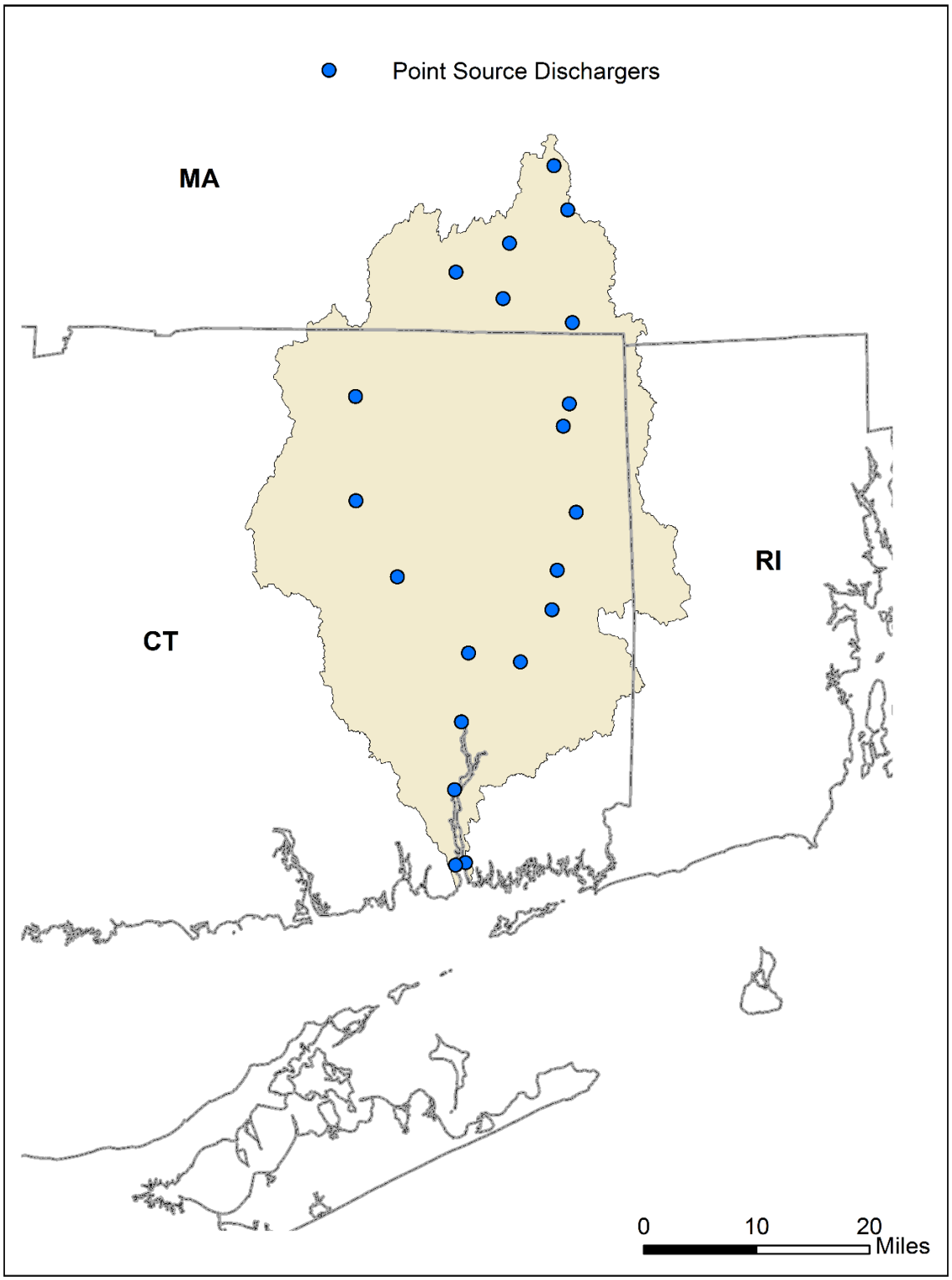

Figure C-14. LIS Watershed Point Source Dischargers in the Thames River Watershed

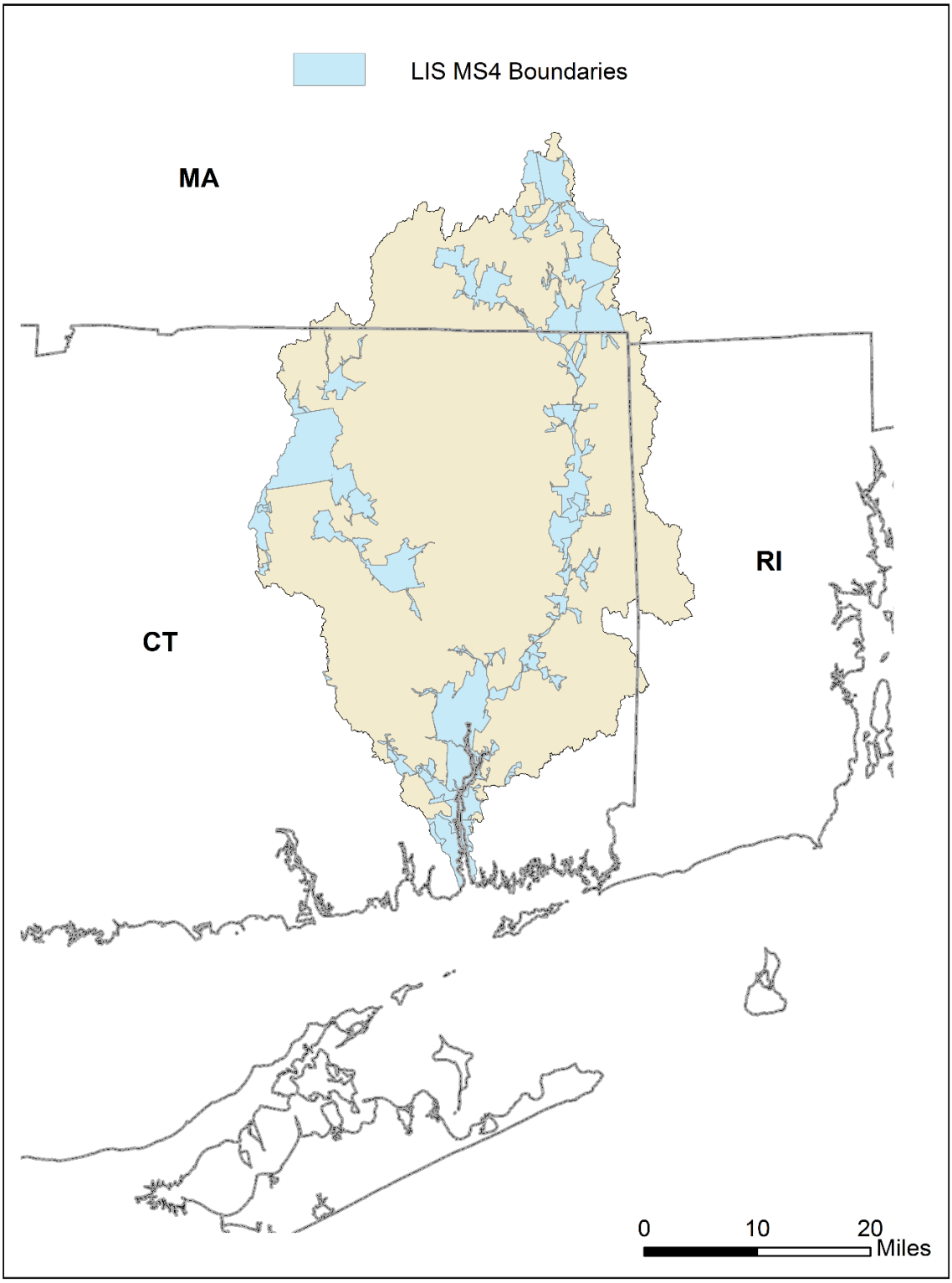

Figure C-15. LIS Watershed Point Sources by MS4 Boundaries in the Thames River Watershed

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Appendix C: Tributary Load Summary

See Excel file.