Evaluating Nutrient Loadings to the Pawcatuck River Estuary and Little Narragansett Bay

Supporting Development of a New Watershed-based Approach to Analyzing and Managing Nutrient Impacts to Coast Estuaries

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Project Partners:

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The Mission of SNEP is to foster collaboration among regional partners across Southeast New England's coastal watershed to protect and restore water quality, ecological health and diverse habitats by sharing knowledge and resources, promoting innovative approaches, and leveraging economic and environmental investments to meet the needs of current and future generations. More information about SNEP is available at: Southeast New England Program | US EPA

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Executive Summary

Water quality in the many coastal estuaries of Southeast New England is affected by excess nutrients, including nitrogen and phosphorus, from human-based sources and activities. Studies have shown impacts on fish, shellfish and other aquatic life, and their habitat. This is true for the coastal waters of Connecticut and Rhode Island, including the Pawcatuck River Estuary and Little Narragansett Bay. In the interest of developing a new approach to evaluating nutrient impacts on these waters to support development of water quality plans to restore water quality, the Connecticut Department of Energy and Environmental Protection (CTDEEP) submitted a grant request to the Southeastern New England Program (SNEP) of the United States Environmental Protection Agency (EPA) in 2018. CTDEEP was awarded a grant for the development of a water quality dataset and water quality model that would support a new approach to developing plans under the Clean Water Act to address the impacts of nutrients on coastal estuaries. This project focused on the watersheds that flow into the Pawcatuck River Estuary and Little Narragansett Bay, important shared resources for the States of Connecticut and Rhode Island.

CTDEEP partnered with the Rhode Island Department of Environmental Management (RIDEM) and Save The Bay. RIDEM provided support with continuous data collection and project development and implementation, and Save The Bay provided logistical support for project-related monitoring activities in the Pawcatuck River Estuary. Coordination with Long Island Sound Study was initiated with 2019 funds to extend the approach developed in this project to other areas in Connecticut.

Both Connecticut and Rhode Island have documented nutrient and oxygen-related impairments to the Pawcatuck River Estuary. Rhode Island and Connecticut include the upper waters of the estuarine Pawcatuck River on their Lists of Impaired Waters for dissolved oxygen. Connecticut also lists problems with excess algae in the lower waters of the Pawcatuck River Estuary and Little Narragansett Bay. This SNEP-funded project provides a tool to identify and analyze sources of nutrients and associated water quality conditions in the freshwater portion of watersheds that contribute to these coastal estuaries. Understanding contributions of nutrients from the upland areas is needed to pair with other on-going in-estuary work to link that information to water quality in the estuaries, and eventually support development of water quality-based plans. These plans will be developed under Clean Water Act-based programs to restore and protect water quality in both the upland and coastal portions of these watersheds.

This current project has two main tasks: water quality monitoring within the freshwater portion of the Pawcatuck River watershed and development of a water quality model for the freshwater portion of the Pawcatuck River and Little Narragansett Bay watersheds. A water quality model uses mathematical simulations to represent the response of a waterbody to a pollutant. It incorporates mathematical formulas and inputs of observations from the waterbody of interest to evaluate the movement of pollutants to or within a waterbody.

Under this project, the United States Geological Survey (USGS) was contracted to conduct a year-long monitoring program at 14 locations within the watershed. Monitoring was focused on nutrients, including nitrogen, phosphorus, and related compounds; chlorophyll which provides a measure of aquatic algae and plant growth, and common water quality measurements such as temperature, dissolved oxygen and stream flow. This data was used to improve the data set for development of the water quality model for this watershed.

For the water quality modeling portion of the project, RESPEC, a consulting firm, was hired to develop an HSPF model (Hydrological Simulation Program – Fortran) for the upland watersheds that contribute to the Pawcatuck River Estuary and Little Narragansett Bay. The HPSF Model was selected because it has on-going support from EPA and USGS and has been used by several states to analyze water quality conditions in support of water quality planning. Both Connecticut and Rhode Island had previous experience with HSPF models which also contributed to the selection.

Through the model development process, information was gathered for these upland waters and added to the model. Information on stream flow, water quality, land uses and land cover, meteorology, discharges from industries and sewage treatment plants, septic systems and other sources was needed for model development. After the data was added to the model, the model was calibrated and validated to make sure that the predicted values from the model accurately represented the observed environmental conditions.

The HSPF model for this project has been completed. However, a complete analysis of modeling results and implications for the Pawcatuck River Estuary and Little Narragansett Bay has not yet been conducted. Additional work to develop water quality and hydrodynamic models for these coastal areas needs to be completed before the detailed water quality analysis can be done. However, to provide some indication about the amount of nutrients coming from the upland watersheds modeled for this project, the HSPF model was run, and the amount of nutrients contributed by the various source types identified. For both Total Nitrogen and Total Phosphorus coming from the upland watersheds, the HSPF model shows that nutrients from point sources (discharges from sewage treatment plants and industries), septic systems and developed land cover account for more than 50% of the nutrients coming into the downstream embayments. This analysis indicates that there should be opportunities within the watershed to make changes to reduce the amount of nutrients coming into the coastal embayments.

CTDEEP and RIDEM have continued to build on this SNEP-funded project by seeking to link water quality and sources in these upland areas to coastal water quality. The goal is to develop a plan to restore water quality in the Pawcatuck River Estuary and Little Narragansett Bay. The partnership formed under the SNEP grant has been extended beyond the grant-supported activities to include monitoring and modeling of estuarine waters within the project areas. Staff at EPA Region 1 have provided monitoring support. Water quality and hydrodynamic models for the Pawcatuck River Estuary and Little Narragansett Bay are currently in development by scientists at the EPA Atlantic Coastal Environmental Sciences Division Laboratory at Narragansett, Rhode Island. CTDEEP is applying this new approach to coastal estuaries and embayments along the Connecticut shoreline through the Long Island Sound Study partnership and as part of the State’s Second-Generation Nitrogen Strategy.

Introduction

Across Southeast New England, coastal estuaries show the effects of excessive nutrients. Eelgrass, a common type of submerged aquatic vegetation, was commonly found in beds within Long Island Sound that are now are gone or reduced (Vaudrey et al 2013). Large amounts of macroalgae have been observed and oxygen in the bottom waters is reduced or depleted (Vaudrey et al 2016). These effects on estuaries impact the habitat for fish, shellfish, and other aquatic species, including many recreationally and commercially important species (Heck Jr. et al 2003) (Vaudrey et al 2013).

Under these conditions, habitat for fish (at all life stages) and other aquatic organisms suffers, as do recreational uses and even values of waterfront properties. State and federal regulators have responded to these nutrient-caused impairments by requiring more stringent permit limits for National Pollutant Discharge Elimination System (NPDES) discharges, but additional watershed specific analyses are needed to better address water quality issues.

The Pawcatuck River Estuary and Little Narragansett Bay, which form the border between Connecticut and Rhode Island, are showing the signs of nutrient stress as described above. A United States Geological Survey (USGS) study (Savoie et al 2017) documented the decrease in nutrient loading to the estuary from upland areas between 1979-2015. However, at the same time, researchers documented the reduction of eelgrass from the estuary, extensive growth of algae (*Cladophora* spp.), and mucky, oxygen poor sediment (Vaudrey et al 2016). A study was conducted to determine the potential for excess nutrients from human-caused sources to affect Long Island Sound embayments through a process called eutrophication. This study found that of all the embayments studied, the Pawcatuck River Estuary has the highest total load of nitrogen inputs to its waters based on the area of the embayment when compared with all embayments studied throughout LIS (Vaudrey et al 2016).

Figure 1 A mix of two hair-like or wiry green seaweeds often called collectively "Cladophora", Little Narragansett Bay. (Vaudrey Lab, Dept. of Marine Sciences, University of Connecticut (CC BY-NC-SA 4.0))

Project Overview

Project Area: Pawcatuck River and Little Narragansett Bay Watersheds

The Pawcatuck River begins in South Kingstown, Rhode Island and flows southwest through Richmond, Charlestown, Hopkinton, and Westerly, RI, before forming the border between Westerly, RI, and North Stonington, CT. The main stem of the river is approximately 36 miles long with approximately 318 square miles of the watershed covering fresh waters that drain to the coastal portion of the Pawcatuck River Estuary and Little Narragansett Bay. Most of the watershed is in Rhode Island. The estuary of the Pawcatuck River flows into Little Narragansett Bay which is bordered in Rhode Island by Watch Hill to Napatree Point and extends into Connecticut along the Stonington shoreline to just past Wequetequock Cove and is separated from Long Island Sound by Sandy Point.

The major tributaries to the Pawcatuck River include the Shunock and Green Fall Rivers and Wyassup and Pendleton Hill Brooks in Connecticut. In Rhode Island, the major tributaries include Tomaquag Brook, Wood River, Meadow Brook, Mastuxet Brook and the Beaver, Usquepaug, Queen and Chipuxet Rivers. The Pawcatuck River Watershed makes up approximately one third of the area of Rhode Island. In Connecticut, the major tributary to Little Narragansett Bay is Anguilla Brook which enters through Wequetequock Cove.

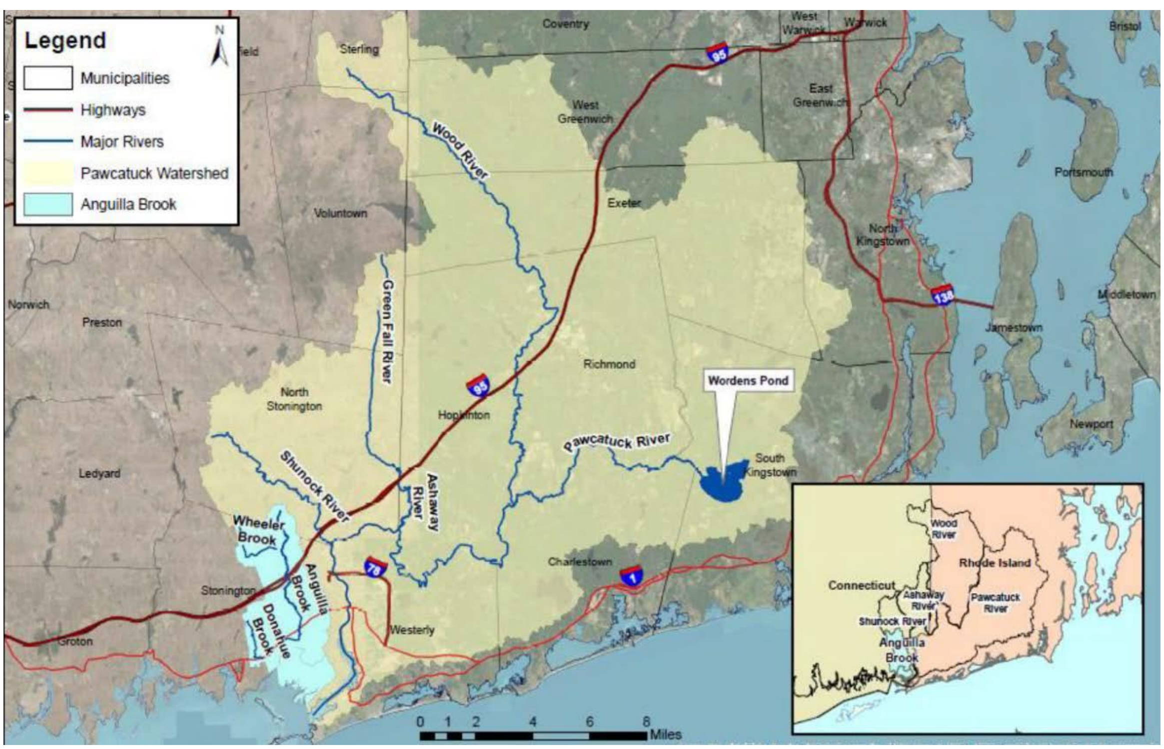

Figure 2: Project Area

Project Description

In 2018, CTDEEP was awarded a grant from the Southeast New England Estuary Program to conduct a study, in collaboration with RIDEM to develop a new watershed-focused approach for identifying and managing nutrient inputs into coastal estuaries to restore and protect water quality. The approach consists of developing a paired set of water quality models for individual coastal estuaries. The first water quality model focuses on the environmental conditions and pollution sources in the freshwater watersheds that flow into coastal estuaries. The second water quality model focuses on the coastal estuary (saltwater) to understand the connection between the amount of nutrients entering the estuary and achieving water quality goals based on indicators of good water quality. The intent is to use the approach developed in part through this grant, to provide a way to study the impact of nutrients on key water quality indicators for coastal estuaries. This study would inform the development of a water quality-based plan to restore estuarine water quality. Indicators of good water quality in embayments include the amount of dissolved oxygen in the water or how much light can penetrate the water column in areas where eelgrass could potentially grow (CTDEEP 2019, EPA 2020, CBF 2022).

This SNEP-funded project addresses the upland watershed portion of this new approach. Two major tasks were included in this SNEP-funded project: 1) Collection of the watershed specific data needed to develop the water quality model and 2) the enhancement and development of an HSPF (Hydrological Simulation Program-FORTRAN) model of water quality and flow in the upland Pawcatuck watershed.

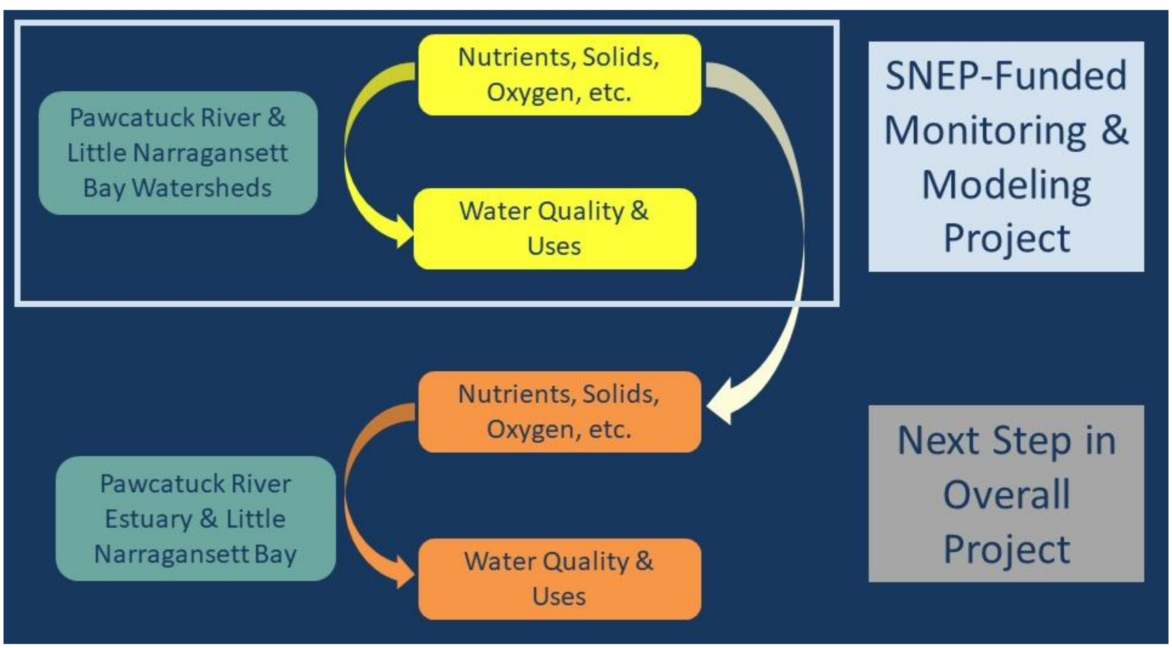

Figure 3: Approach to Addressing Nutrient Impacts in Coastal Waters

Task 1: Water Quality Monitoring

The USGS was hired to conduct water quality monitoring within the upland watershed of the Pawcatuck River and its tributaries to supplement currently available data. While there was some water quality data available for the watershed, additional data were needed to improve the development of a water quality-based model. Water samples were collected from 14 monitoring stations throughout the watershed (Table 1, Figure 9). Samples were collected from March 2019 to June 2020. Sampling was designed to gather data over the course of a year, including monthly sample collection at each sampling location and biweekly sampling from April through September.   USGS, in partnership with RIDEM, also maintains a long-term monitoring station on the Pawcatuck River at Westerly (Station 01118500), which is located at the downstream portion of the upland watershed, representing the contribution from this area into the tidal portion of the Pawcatuck River Estuary. Sampling was expanded at that station as part of the monitoring program for this project.

Figure 4: USGS Monitoring Station, Pawcatuck River at Westerly RI (USGS Photo)

Figure 5: Water Quality Monitoring location on the Shunock River (USGS Photo)

Figure 6: Water Quality Monitoring Location on Chipuxet River (USGS Photo)

Both wet and dry conditions were captured as part of this sampling protocol. The objective of the monitoring task was to generate water quality data that characterizes a range of flow conditions, weather, and seasons. This watershed specific data is critical to understanding the connected systems and processes within the Pawcatuck watershed and is central to the completion and calibration of a watershed model. While some modifications to this schedule were made to accommodate changes caused by the Covid-19 pandemic, an updated data set was completed for this project.

Table 1: USGS Water Quality Monitoring Locations

Station number	Station Name and Location
01118055	Tomaquag Brook at Rt. 216 at Bradford, RI
01118360	Ashaway River at Ashaway, RI
01117455	Pawcatuck River at Sherman Ave. at Kenyon, RI
412647071373701	Kenyon Industries Effluent to Pawcatuck River at Kenyon, RI
01118030	Pawcatuck River at Alton-Bradford Road at Bradford, RI
01118100	Pawcatuck River near South Hopkinton, RI
01117350	Chipuxet River at West Kingston, RI
01117420	Usquepaug River near Usquepaug RI
01117471	Beaver River Shannock Hill RD, near Shannock, RI
01118009	Wood River near Alton, RI
01118500	Pawcatuck River at Westerly, RI
01118400	Shunock River near North Stonington, , CT
01117351	White Horn Brook at Ministerial Rd near West Kingston, RI
01118356	Ashway River at Extension 184 near Ashway, RI

Figure 7: Pawcatuck River at Sherman Ave (USGS Photo)

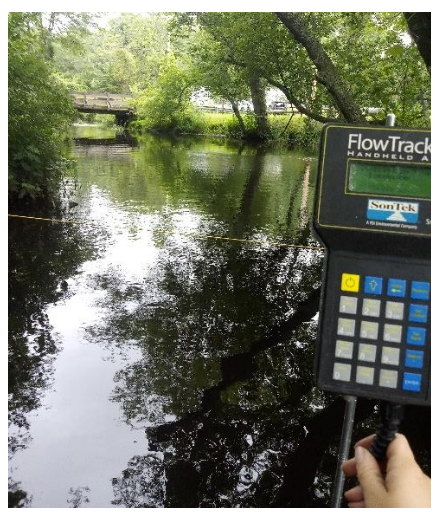

Figure 8: Water Quality Monitoring in Tomaquag Brook (USGS Photo)

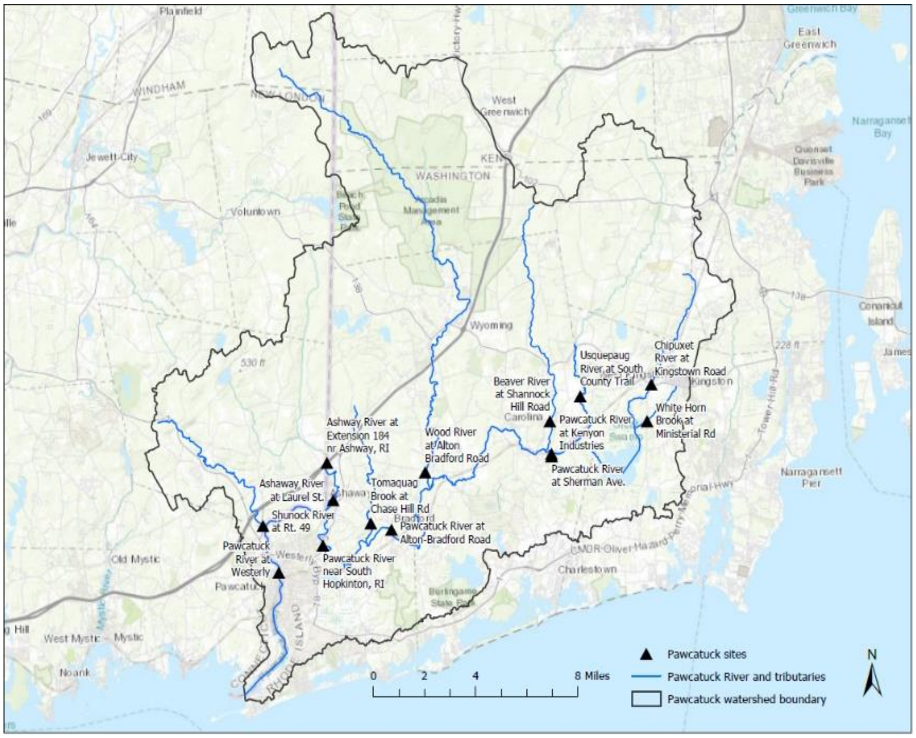

Figure 9: Water Quality Monitoring Locations

Water quality sampling focused on nutrients and related indicators including:

- Nitrogen Compounds: Ammonia, Ammonia & Organic Nitrogen (whole and filtered), Nitrite, Nitrate & Nitrogen, Total Nitrogen, Total Particulate Nitrogen

- Phosphorus Compounds: Phosphorus (Whole & Filtered), Orthophosphate

- Chlorophyll: Chlorophyll-a phytoplankton, Pheophytin A phytoplankton, Solids (Residue on Evaporation)

- Field Parameters: Chlorophyll-a, Dissolved Oxygen (mg/l & % saturation), Specific conductance, pH, Water Temperature, Turbidity

These parameters were selected to gain an understanding of the inputs from the watershed to the estuary and to help identify the source loads into the waterways. Monitoring was conducted under a Quality Assurance Project Plan that was reviewed and approved by EPA (USGS 2019). The data are available on the USGS National Water Information System (NWIS) with a link to the data and a data summary also provided on the CTDEEP project website.

Monitoring Results

Nutrients (nitrogen and phosphorus) were present in all water samples at each location, which is expected in a riverine system. Nitrogen was present in higher amounts than phosphorus. The concentration of nutrients in the data collected by USGS at each station is shown in the boxplot graphs below. These data were used to help develop the water quality model for the freshwater portion of the Pawcatuck and Little Narragansett Bay watersheds.

In these box plot graphs, the amount of nutrients measured is shown on the vertical axis. Higher amounts are towards the top and lower amounts towards the bottom. Each individual monitoring station is shown across the bottom of the graph. The light blue box shows the range of the middle 50% or half of the data. The line in the middle of the blue box is the median or middle value in the data set. The top and bottom 25% or quarter of data is shown by the lines extending from the blue box. Values that don't fit well are called outliers and are shown as red dots on the graphs.

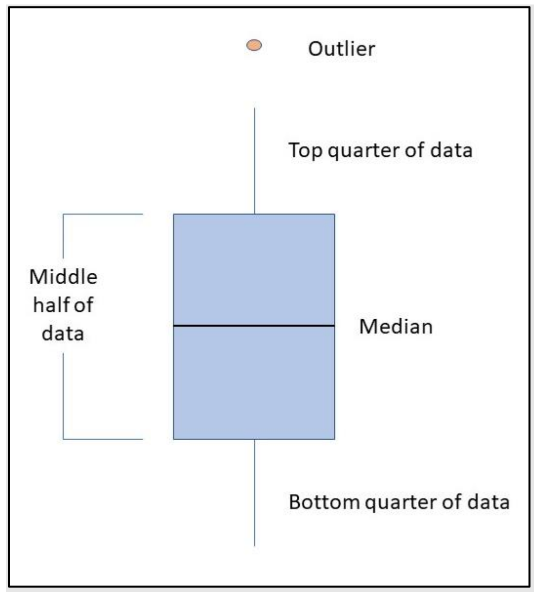

Figure 10: Explanation of box plot diagrams

The median values for nitrogen are around 1 mg/l for all stations while the median values for phosphorus are around 0.05 mg/l. There was some variation in the amount of nutrients measured at each station as shown by the height of the blue boxes, the lines extending from the boxes and the presence of outliers (red dots). The monitoring station located on the Pawcatuck River at Westerly, which is the station that shows the quality of the water that leaves the freshwater portion of the Pawcatuck River watershed and enters the Pawcatuck River Estuary is shown with an orange box around the graph.

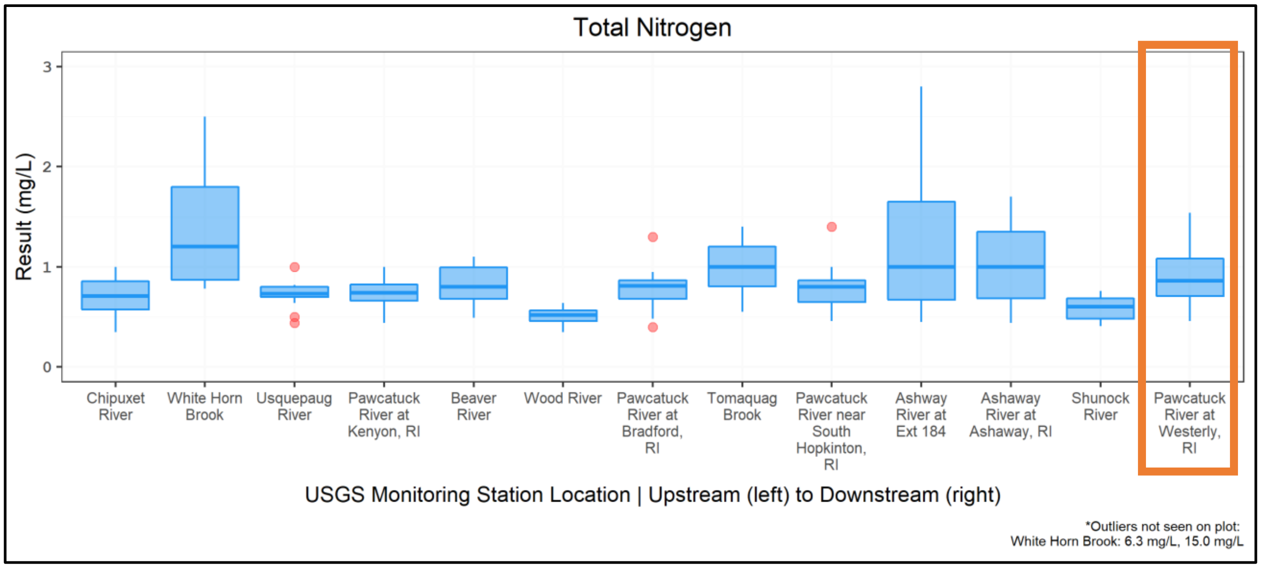

Figure 11: Total Nitrogen Water Quality Results from USGS Project Monitoring

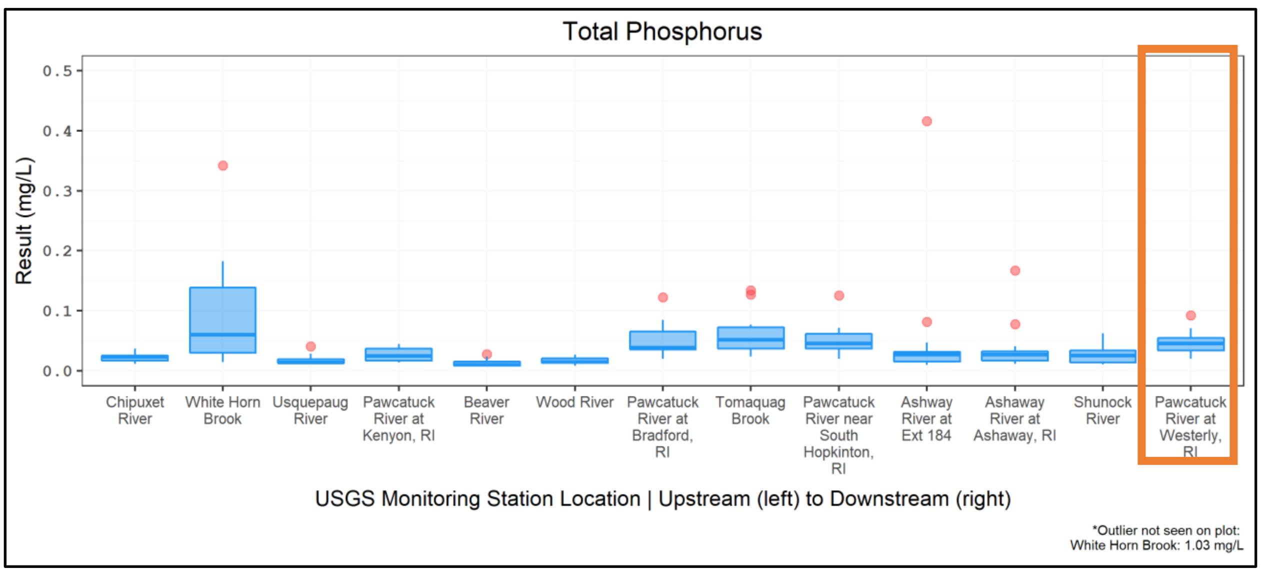

Figure 12: Total Phosphorus Water Quality Results from USGS Project Monitoring

The data for the Pawcatuck River monitoring station at Westerly is shown in another way in the following graphs. Each individual nutrient measurement is shown on the graphs. Nutrient concentrations generally are higher in the summer and fall months and are lower in the winter.

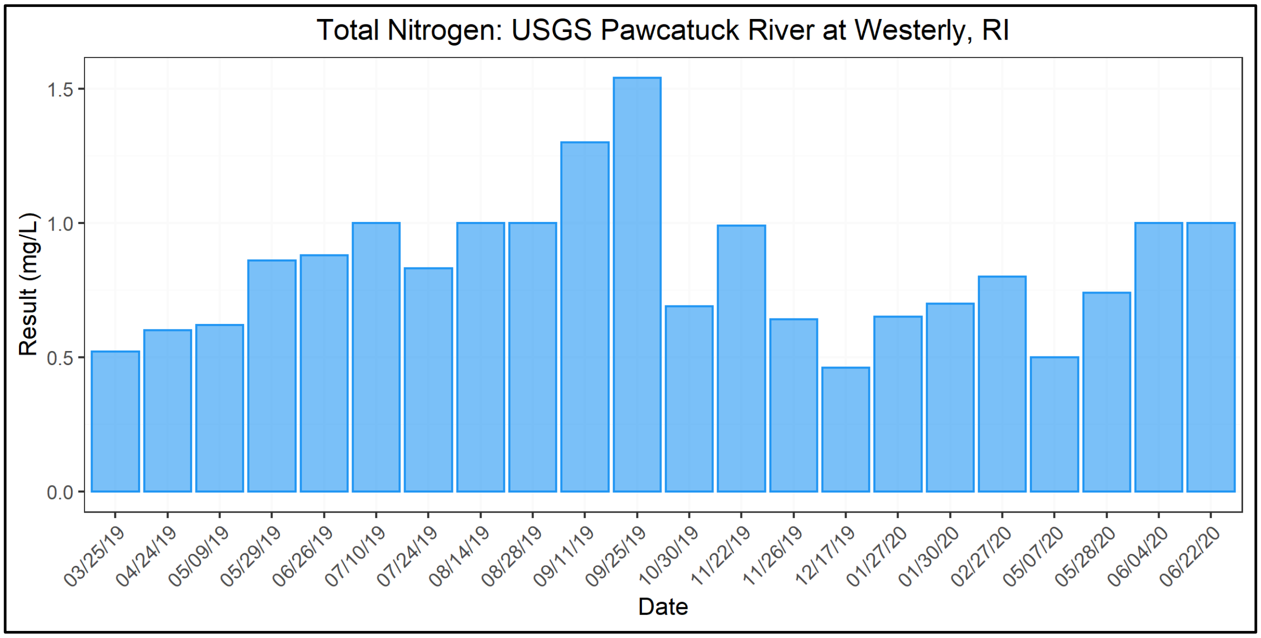

Figure 13: Total Nitrogen Results for the Pawcatuck River at Westerly, RI

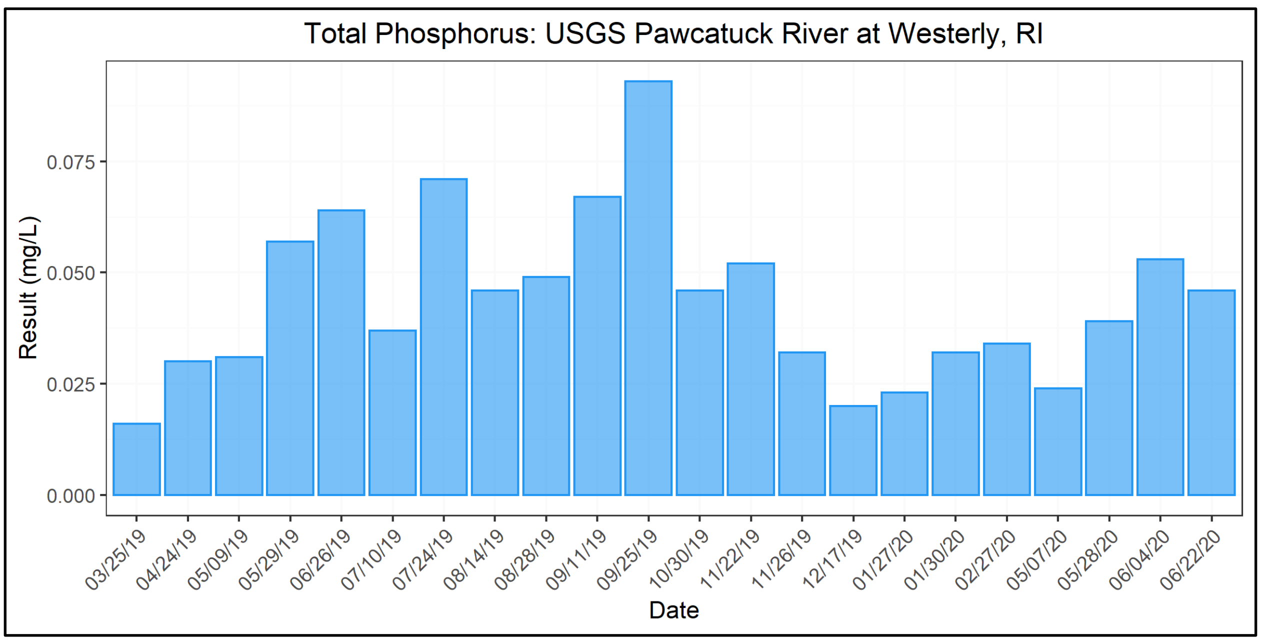

Figure 14: Total Phosphorus Results for the Pawcatuck River at Westerly RI

Figure 15: Pawcatuck River at Route 1, Westerly RI (bottom) and Stonington CT (top) (2003 Oblique CT Coastal Imagery, CTDEEP)

Task 2: Water Quality Modeling

Water-quality modeling forms the basis of the proposed approach to evaluating and managing nutrient impacts on coastal embayments developed within this project. A water quality model uses mathematical simulations to represent the response of a waterbody to a pollutant. It incorporates mathematical formulas and inputs of observations from the waterbody of interest to evaluate the movement of pollutants to or within a waterbody.

A model-based approach was selected because models allow for analysis of water quality conditions associated with current and future scenarios within the watershed. Models can also be utilized to extend analyses and predictive capacity to areas where direct measurements are not available. More importantly, models provide a proven platform for evaluating different conditions and scenarios that are needed to support improvements to water quality. These evaluations will become the basis for a water-quality based plan to identify the amount of nutrients and contributions from various sources in the watershed to meet water quality goals in the Pawcatuck River Estuary and Little Narragansett Bay.

The HSPF model was selected for this project since it can simulate both water flow and water quality. It is a dynamic watershed model that both CTDEEP and Rhode Island have previously used. In Connecticut, an HSPF model, the Connecticut Watershed Model (CTWM) (Love & Donigian, 2002), was developed to support the Long Island Sound TMDL (NYDEC and CTDEP 2000). In Rhode Island, an HSPF model previously developed for the Pawcatuck watershed (Gardner et al 2011) for the Water Resources Board, focused on water flow to analyze the effects of water withdrawals on stream flow, pond levels and groundwater levels in the Rhode Island portion of the watershed. HSPF has been widely used throughout the United States to analyze water hydrology and quality to aid in developing implementation plans based on attaining environmental goals (AQUA TERRA Consultants, 2001). The complex and dynamic HSPF model can address soil, groundwater and surface-water processes, and storm events as well as impacts from point and nonpoint pollution sources. This model has been, and continues to be, supported by the EPA and the USGS.

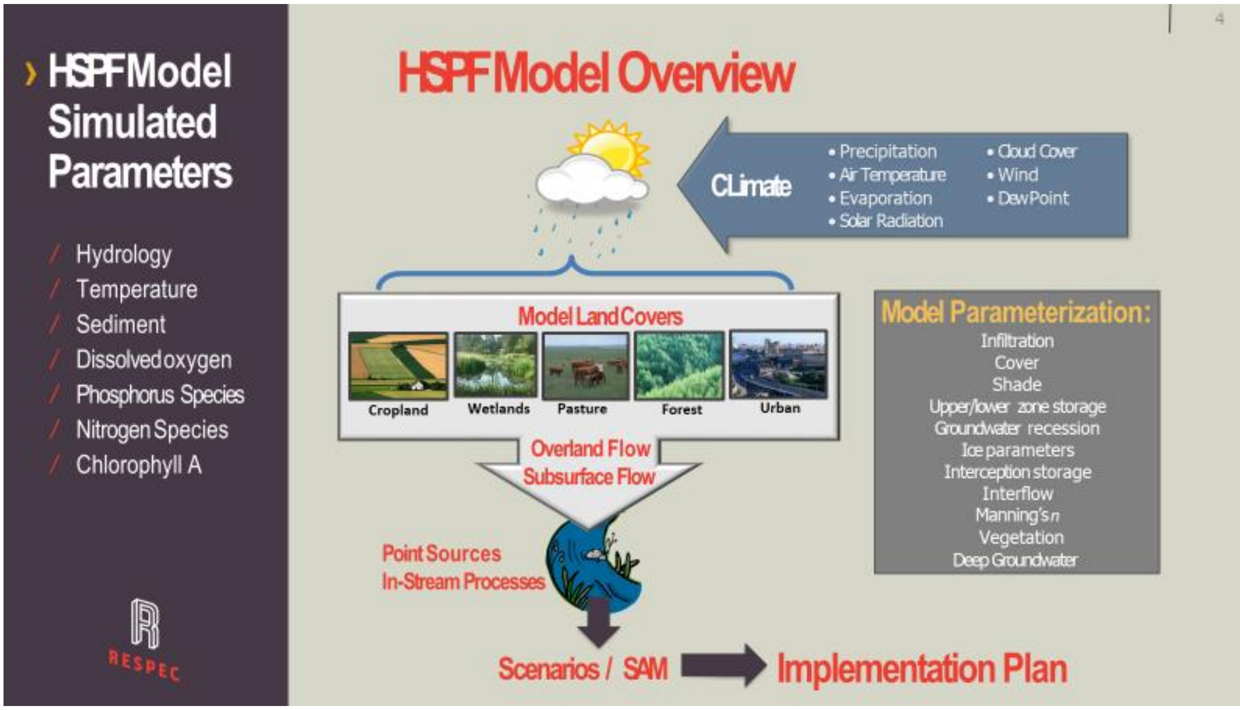

Figure 16: Overview of HSPF Model

Planning for Model Development

Before model development could begin, a modeling contractor had to be selected. CTDEEP developed a contract for modeling services and went out to bid to identify consulting firms with the appropriate expertise. From that list of contractors, RESPEC, was selected to develop the model for this project.

Three planning tasks needed to be completed to prepare for model development: 1) a review of the monitoring conducted for this project, 2) development of a modeling quality assurance plan and 3) a model simulation and analysis plan. These tasks are described below in more detail.

RESPEC was tasked with reviewing the water quality sampling plan developed for this project to learn whether changes should be considered for future projects that would replicate this current project in other watersheds and coastal embayments. The review documented that the sampling plan developed for this project was well-structured, had a good distribution of stations across the watershed and appropriate parameters were monitored. For future model development studies, recommendations were made to include targeted storm sampling, evaluate the relationship between nutrients and solids with other common water quality measurements such as turbidity and specific conductance as well as expanding some of water quality parameters to be measured or sites to be monitored. The review concluded that Pawcatuck Watershed sampling plan provides a good set-of-data to represent recent conditions and identify significant water quality responses within the watershed. (RESPEC 2020a)

The second planning task was the development of the Pawcatuck River Watershed Modeling Quality Assurance Plan (RESPEC 2020b). A quality assurance project plan for modeling describes the objectives for the model and identified the performance and acceptability criteria needed to meet project objectives. The plan makes sure that 1) the modeling input data are valid and defensible, 2) protocols to set up the model, add data and validate model output are followed and documented, 3) model components and output data are reviewed and evaluated in a consistent manner, and 4) the model can accurately predict water flow and water quality conditions over time. The plan provides a framework for identifying the data sources to be used and evaluating the quality of the data to make sure that only good quality information is added to the model. A process to evaluate the quality of project activities throughout the model building process was set up in addition to establishing processes to check the final quality of the model. CTDEEP and RIDEM project managers and technical staff reviewed and commented on the model quality assurance plan before submitting the plan to EPA for their review and approval. Model development only started after approval from EPA was received.

The approved modeling quality assurance project plan formed the basis for the Simulation Plan for the Pawcatuck River Watershed (RESPEC 2021a). This report provides a planned approach for constructing the model and ensuring the accuracy of model outputs. It adds detail to the information included in the quality assurance plan. The Simulation Plan focuses on 1) collecting and developing data that covers a broad time period, 2) identifying the characteristics of the watershed and dividing the watershed into smaller segments for improved simulations and use in future analyses, and 3) ensuring the accuracy of the model through processes called calibration and validation.

Figure 17: Looking Across Elihu Island (Stonington, CT) and Little Narragansett Bay towards Rhode Island (2003 Oblique CT Coastal Imagery, CTDEEP)

Gathering Data to Develop the Model

Information on water flow, water quality and environmental conditions within the watershed are needed to develop the model. The major types of information needed are:

- Precipitation
- Evapotranspiration and meteorological data such as air temperature, wind, solar radiation, dewpoint and cloud cover
- Stream flow
- Water Quality observations
- Information on point source (permitted) discharges within the watershed
- Atmospheric Deposition
- Other data, such as information on irrigation, water withdrawals and diversions
  This data is gathered from published national data sources, gathered from monitoring data required by permits for point sources in the watershed or environmental monitoring conducted under a quality assurance plan, typically by agencies such as RIDEM, CTDEEP, USGS or partner organizations.

  Each data set was documented, evaluated for completeness and appropriate quality. More detail on the data sources used for development of the HSPF model is provided in Appendix A.

Characterizing the Watershed

The large watersheds used in this project are divided into smaller watersheds based on the land and water flow characteristics in the area, considering certain sources or areas of interest. Having smaller watersheds allows for evaluations to be done in the future on a more local scale, which is helpful when developing plans to restore or protect water quality. Connecticut watershed delineations and the National Hydrography Data Set (Version 2) were the starting points for this analysis. The focus was on the river channel network because it is the major pathway for moving solids, nutrients and other water quality parameters throughout the watershed. CTDEEP and RIDEM provided guidance on how best to divide up the watershed for the model. As part of this effort, a subset of ponds within Rhode Island were also identified as areas to be specifically included in the model. These ponds are Barber, Chapman, Deep (Exeter), Hundred Acre, Locustville, Pasquiset, Tucker, Watchaug, White Brook, Wincheck, Worden, Yawgoo, and Yawgoog Ponds.

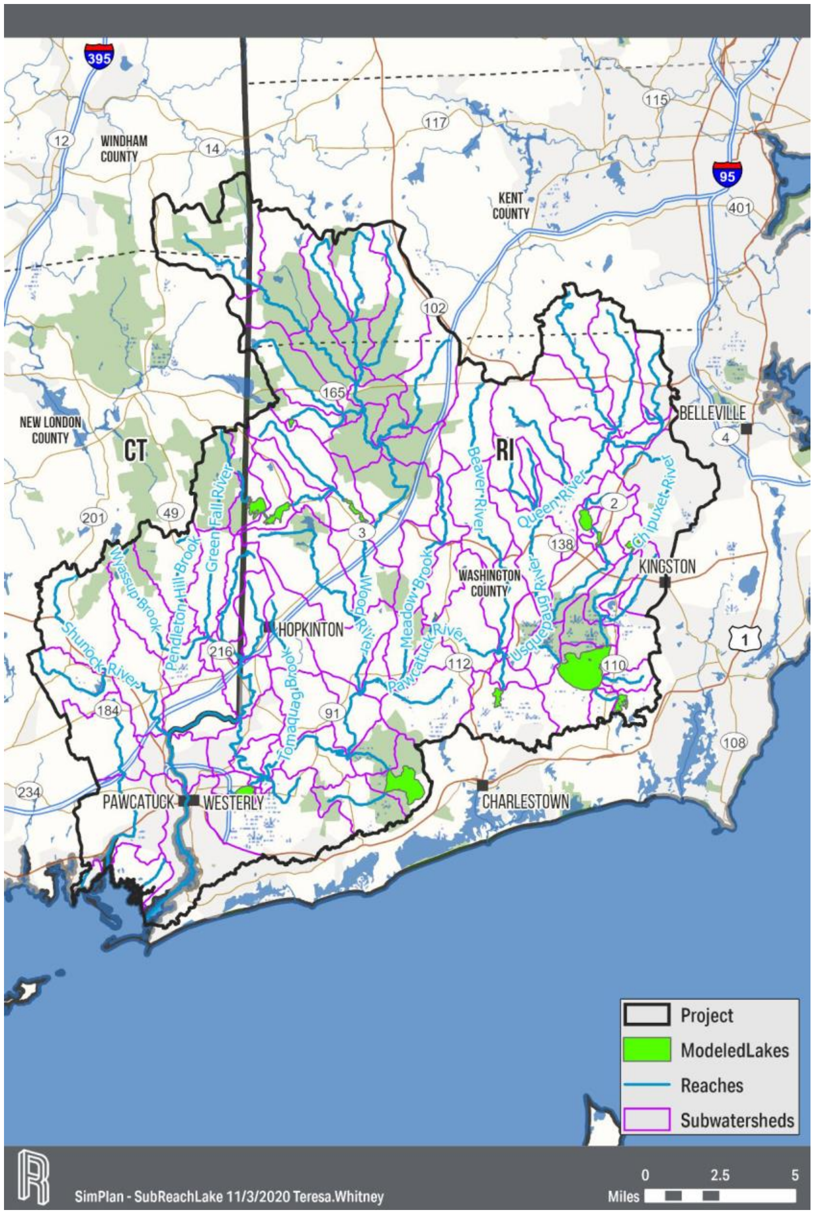

Figure 18: Watershed divisions created for HSPF Model

Information on other characteristics of the watershed, such as land cover, information on the slope and elevation of the land (topology), the location of areas covered by MS4 stormwater permits as well as areas served by either local sewage treatment plants or septic systems, was gathered for the watershed. Land cover and these other sources can contribute nutrients to the surface and ground waters in the watershed, so their location and characteristics need to be understood and included in the model.

The major types of land cover included in the model are:

- Developed land over, divided into low, medium, and high density
- Forested land cover, divided into deciduous (trees that lose their leaves in the winter) or coniferous forests and taking soil types into account

- Barren lands
- Areas covered by pastures, hay, or grassland
- Areas covered by crops
- Turf and grass areas
- Wetlands

Land cover in the modeled Pawcatuck River project area is made up of approximately 58 percent forest, 16 percent wetlands, 14 percent developed land, 7 percent crops (e.g., other hay/non-alfalfa, corn, and sod), 3 percent open water, and 2 percent classified as grassland, shrubland, or barren land. The average slope in the Pawcatuck River Watershed is approximately 6.5 percent, with the minimum at zero and the maximum at 121 percent (RESPEC 2021a).

Making Sure the Model is Accurate

To make sure that the HSPF model is accurate, processes called calibration and validation are used. The data used to develop the model is divided into two time periods. The calibration time period for this model is 2006-2020. To calibrate the draft model, the model is run using data from this time period. Adjustments are made and the model is fine-tuned so that the simulated results from the model are a good match with the observed data from this time period.

To provide a double check on the model, data from a second time period, 1991-2005 for this model, are used to run the model and the results are checked to make sure they are also good match for this second time period. This process is call validation.

Figure 19: Pawcatuck River at South Hopkinton (USGS Photo)

In order to determine that the modeled values are a good match for the observed conditions, several analyses are done, including looking at paired modeled and observed data in graphs and mathematically evaluating the difference between the modeled and observed data. All the various ways of evaluating model performance are considered together in a weight-of-evidence approach to determine how well the model is performing.

Several types of graphs are used to evaluate data including graphs that show data over the modeling time period, others that show the relationships between different varirables or others that show the frequency that the different conditions are observed. These graphs were used to evaluate the Pawcatuck HSPF model. For example, in the graphs below, modeled and observed concentrations of total nitrogen or total phosphorus over time are shown. The blue lines in the small graphs show the measured stream flows and the blue circles show the measured concentration of either nitrogen or phosphorus. The red lines show the stream flows and nutrient concentrations predicted by the model. The observed conditions (blue) and the predicted conditions (red) are very similar, with very good overlap between the modeled and observed values, indicating that the model provides a very good simulation of observed data. These graphs are for the USGS monitoring station located on the Pawcatuck River at Westerly, RI.

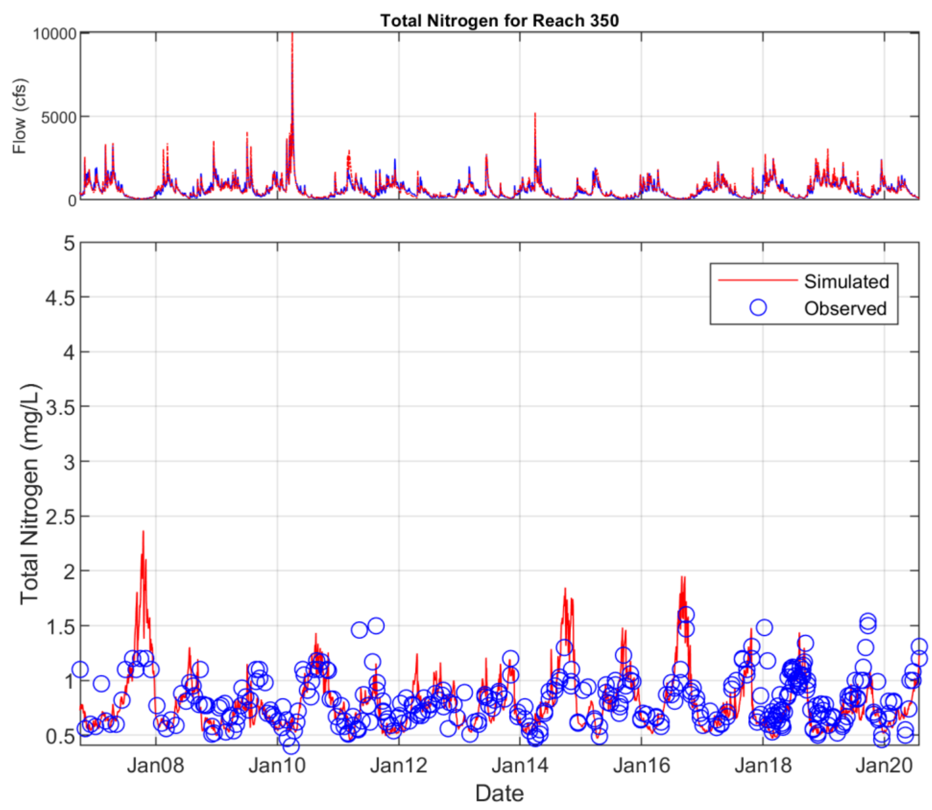

Figure 20: Simulated vs Observed Values for Total Nitrogen, Pawcatuck River at Westerly, during model calibration period

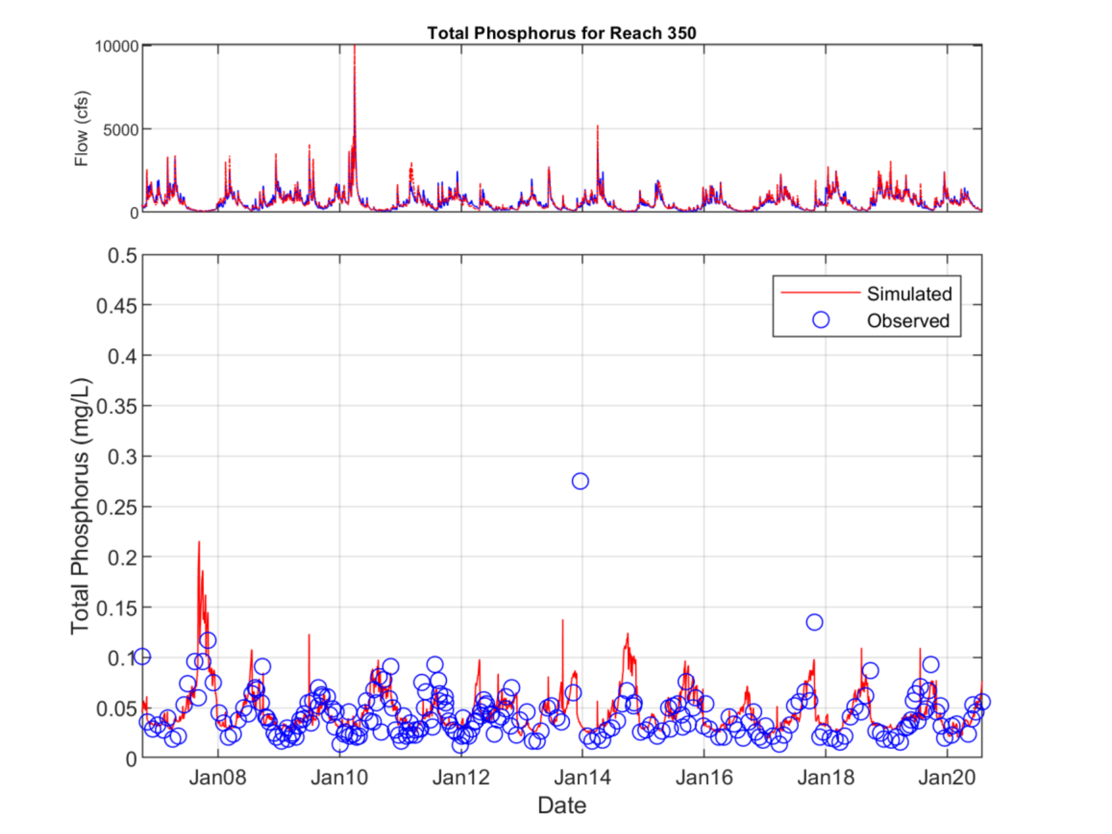

Figure 21: Simulated vs Observed Values for Total Phosphorus, Pawcatuck River at Westerly, during model calibration period

In addition to evaluating model performance using graphs, mathematical calculations are made to compare the model results to observed data. Multiple different statistics are used to evaluate model performance. One important calculation to evaluate the difference between observed conditions in the watershed and the conditions that the model predicts is called the Percent Error. Targets for acceptable Percent Error values for the Pawcatuck Watershed HSPF Model (Table 2) were taken from an HSPF training module developed for the United States Environmental Protection Agency (Donigian 2000) and subsequently published in a scientific journal (Donigian 2002). Using these values, a determination can be made for how well the final model simulates observed data. These calculations are made for multiple different flow and water quality parameters at multiple points within the modeled watershed. In the majority of cases, the model shows very good to good calibration throughout the watershed. The quality assurance data for selected water quality and flow parameters at the monitoring location on the Pawcatuck River at Westerly is provided in Tables 3 and 4. This station provides information on water quality as it leaves the freshwater watershed and enters the Pawcatuck River Estuary. The model is providing very good simulations for flow and water quality at this location.

Table 2: General Percent Error Calibration/Validation Targets for Watershed Models (RESPEC 2020b, Table 1-5)

	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Hydrology / Flow	<10	10-15	15-25
Sediment	<20	20-30	30-45
Water Temperature	<7	8-12	13-18
Water Quality / Nutrients	<15	15-25	25-35

Table 3: Average Annual Simulated and Observed Concentrations for the Simulation Period for Select Parameters. Excerpted from Table 4-10, RESPEC 2021b

Constituent	Pawcatuck at Westerly (HSPF Reach 350)			
	Obs	Sim	Diff	# Samples
	(mg/L)	(mg/L)	%	
Total Suspended Sediment	8.1	8.7	7.5	19
Temperature	54.7	52.2	−4.6	322
Dissolved Oxygen	10.5	9.5	−8.9	321
Total Nitrogen	0.81	0.79	−2.3	330
Total Phosphorus	0.042	0.045	8.3	282
Chlorophyll A	5.2	6.4	23	36
Very Good	Good			

Table 4: Average Annual Simulated and Observed Values for Selected Flow Parameters during the Calibration Period. Data excerpted from Tables 4-2 and 4-3, RESPEC 2021b

Pawcatuck at Westerly (HSPF Reach 350)	
Constituent	Diff
	%
Average Annual Flow (CFS)	5.38
Storm Volume (inches)	7.09
Storm Peak Flow (cfs)	8.38
Very Good	

Completion of the HSPF Model

The HSPF Model for this project is complete. The Pawcatuck River Watershed Final HSPF Modeling Report provides additional detail on the development and completion of the model (RESPEC 2021b)

Figure 22: View of Pawcatuck River Estuary (upper right) and Little Narragansett Bay (upper left) from Napatree Point Conservation Area, Watch Hill, RI (2003 Oblique CT Coastal Imagery, CTDEEP)

Preparing to Use the Model

Creating an Analysis Tool

In addition to the development of the HSPF model, this project also included the development of a Scenario Analysis Manager (SAM) that works directly with the HSPF model. SAM provides a tool for creating scenarios to analyze the relationships between sources of nutrients in the watershed and water quality in the surface waters. This information is needed for development of plans to improve water quality. In addition to the various types of data from the HSPF model, SAM also has information on Best Management Practices and their ability to reduce pollutant concentrations and costs for installation and upkeep. Once nutrient targets are set for the Pawcatuck River Estuary and Little Narragansett Bay, which is in progress under a separate project, SAM will be used to identify reductions in nutrient loadings from sources in the upland watersheds necessary to restore water quality goals in the coastal areas.

Table 5: Examples of Best Management Practices included in SAM

Grass Buffer	Bio Retention with an Underdrain (w/ ISR)	Infiltration Basin
Forested Buffer	Porous/ Permeable Pavement	Wetland Creation
Conservation (Nutrient Management Plans)	Urban Forest Buffer	Wetland Restoration
Manure Incorporation or Injection	Urban Stream Restoration	Illicit Discharge Detection and Elimination (IDDE)
Cover Crop	Grass Swale	Street Sweeping
Residue and Tillage Management	Rain Garden/Bio Retention (no underdrain)	Catch Basin Cleaning
Denitrifying Ditch Bioreactor	Retention Ponds/Wet Basins/Wet Ponds	Dry Detention Basins
Filters/Sand Filters	Subsurface Gravel Wetland	
Soil Amendments	Infiltration Trench	

SAM also includes information on expected environmental conditions predicted for 2050. These conditions were developed through climate change modeling for the northeast United States (Wang et al, 2020). By putting this information into the HSPF model, we can evaluate the potential future changes in water quality and water flow conditions due to the increased quantity of rain projected with changing climate conditions. This information can help with long term planning necessary to address the impacts of nutrients on the Pawcatuck River Estuary and Little Narragansett Bay. Additional improvements to these estimates are currently being developed to form the bounds of the daily variability of the anticipated precipitation increases.

Training

As part of the SNEP grant, RESPEC provided training to EPA, CTDEEP and RIDEM on the development and use of the Pawcatuck River Watershed HSPF model and SAM.

Preliminary Review of Modeling Results

The HSPF model developed for this project provides a reliable modeling platform that can be used during the next steps in the larger project to link information on nutrients in the freshwater portions of the Pawcatuck River and Little Narragansett Bay watershed with water quality conditions in the coastal areas.

A detailed analysis of the nutrient sources and contributions from the upland watersheds and their impacts on the Pawcatuck River Estuary and Little Narragansett Bay has not yet been conducted. That evaluation will be done once water quality and hydrodynamic models are completed for the coastal areas and coastal water quality targets set. The coastal models will be used to identify the amount of nutrients that can come from the upland watersheds into the Pawcatuck River Estuary and Little Narragansett Bay while supporting good water quality. That will allow us to identify the necessary reduction in nutrients from the upland areas. SAM will then be run to provide a detailed analysis of nutrient sources and the reductions needed from each source to restore water quality in the coastal areas. That analysis and information will be used to develop a water quality plan for the Pawcatuck River Estuary and Little Narragansett Bay. There will be opportunities for the public to review that analysis in the future and provide comments prior to finalizing the water quality plan.

At this point, to provide some perspective in this report on the types of information that the HSPF model developed for this project can provide, the model was run to look at the amount of nutrients and their sources coming from the upland areas included in this model. Figures 23 and 24 show the amount of Total Nitrogen and Total Phosphorus from the various sources in the model project area. For both Total Nitrogen and Total Phosphorus, point sources (discharges from sewage treatment plants and industries), septic systems and developed land cover account for more than 50% of the nutrients coming into the downstream embayments. This analysis indicates that there should be opportunities within the watershed to make changes to reduce the amount of nutrients coming into the coastal embayments.

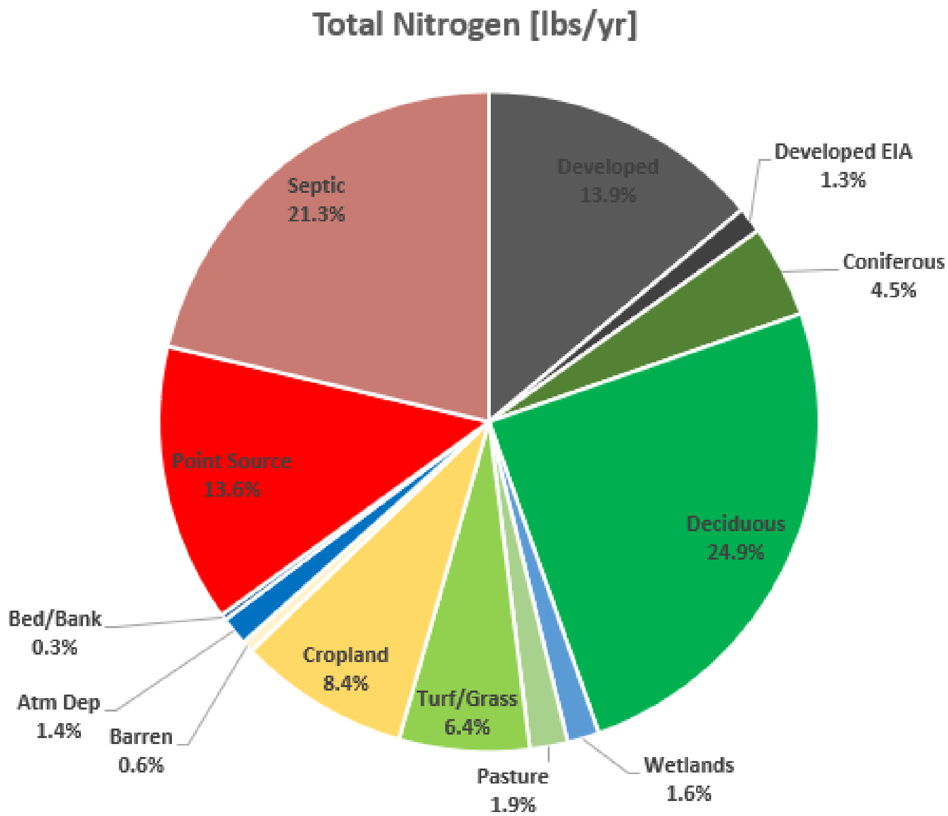

Figure 23: Total Nitrogen loads from sources within modeled watershed

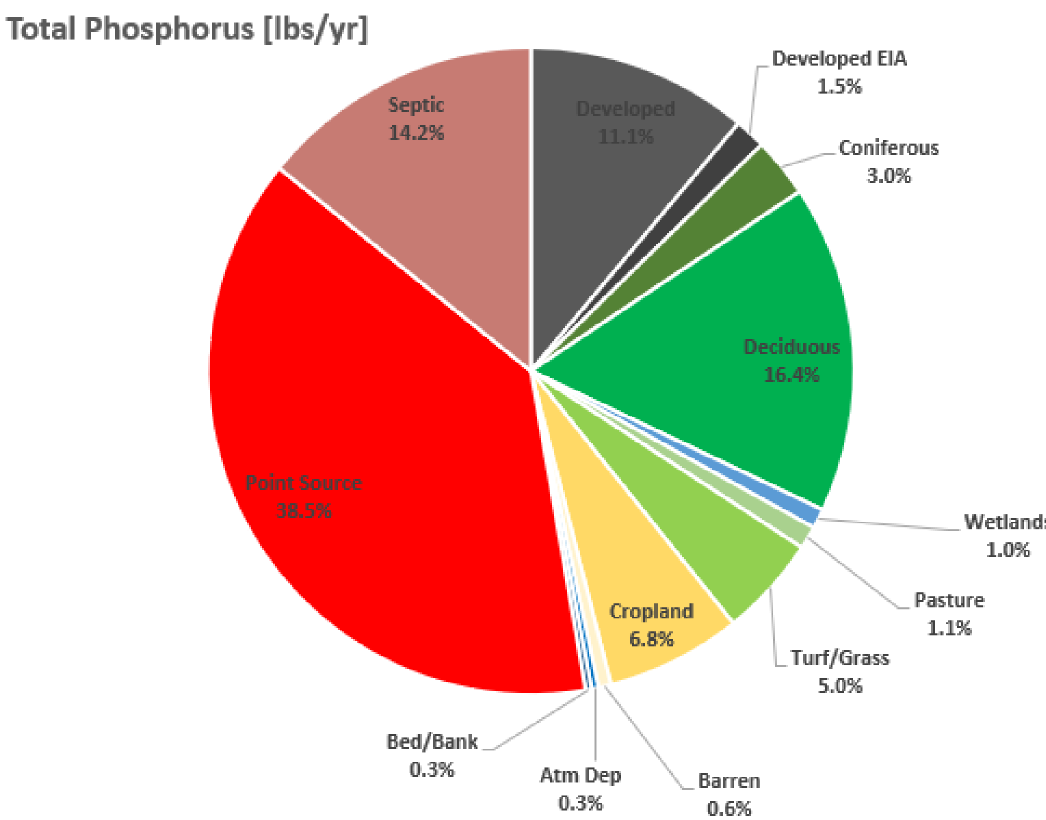

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Figure 24: Total Phosphorus loads from sources within modeled watershed

Next Steps

In the future, the results of this HSPF model will be used to provide water quality and water flow data for the Pawcatuck River Estuary and Little Narragansett Bay models. By sharing data between these models, it will be possible to take information on the nutrient loads from the upland areas and predict the effect on water quality in the estuaries and determine the amount of nutrients that will support attainment of water quality goals for aquatic life, eelgrass restoration, and recreation within the estuaries. General steps to be taken in this process are shown in Figure 25.

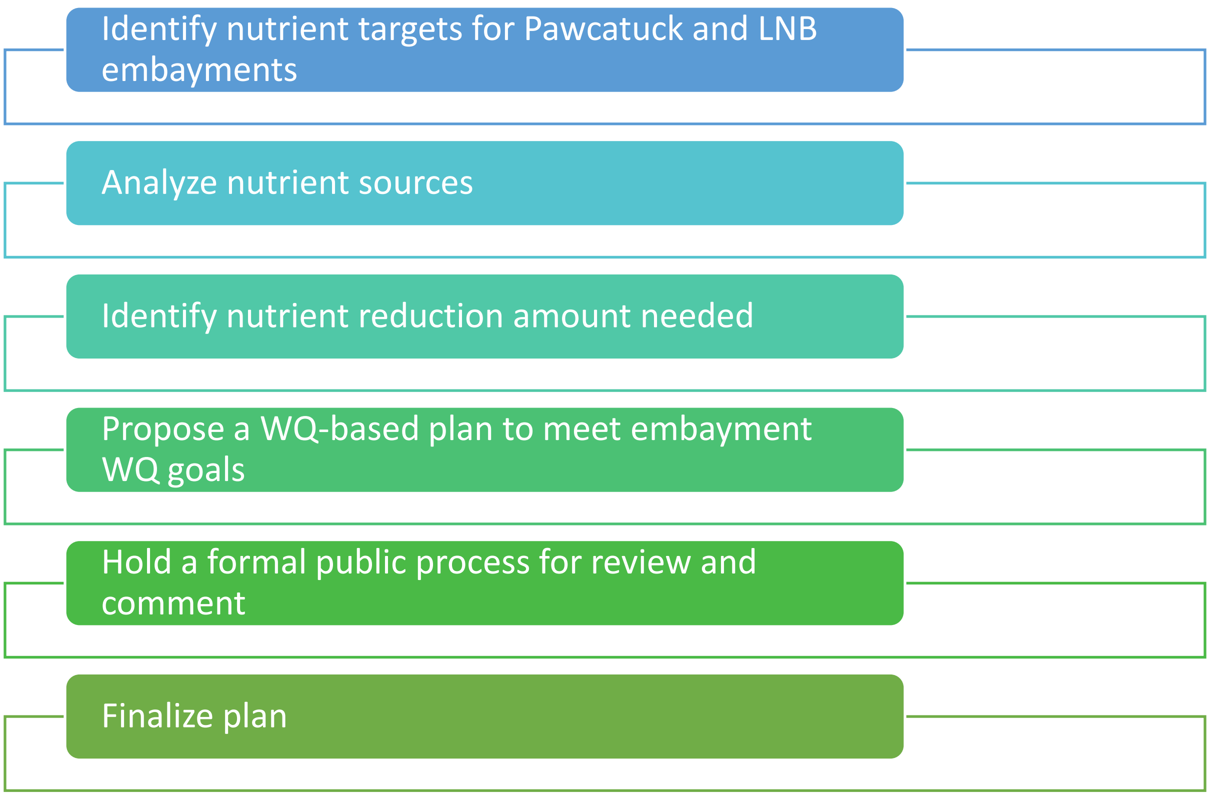

Figure 25: General process for moving forward with development of a water quality plan for the Pawcatuck River Estuary and Little Narragansett Bay

CTDEEP and RIDEM collected water quality data within the Pawcatuck River Estuary and Little Narragansett Bay over several years with support from USGS and EPA. Currently, the states are working with researchers from the EPA Atlantic Coastal Environmental Sciences Division Laboratory who are developing water quality and water flow models for the Pawcatuck River Estuary and Little Narragansett Bay. Water Quality Analysis Simulation Program (WASP) is being used for the water quality model in the estuaries. Environmental Fluid Dynamics Code (EFDC) is being evaluated for the water flow model. When these models are done, they will be run along with the HSPF model from this project to develop a water quality plan that will set nutrient related water quality targets in the estuaries and identify any needed nutrient reductions. Planning is also underway to allow for the eventual use of these models with an updated model for Long Island Sound as appropriate. The relationships between the various modeling components of the larger project is shown in Figure 26.

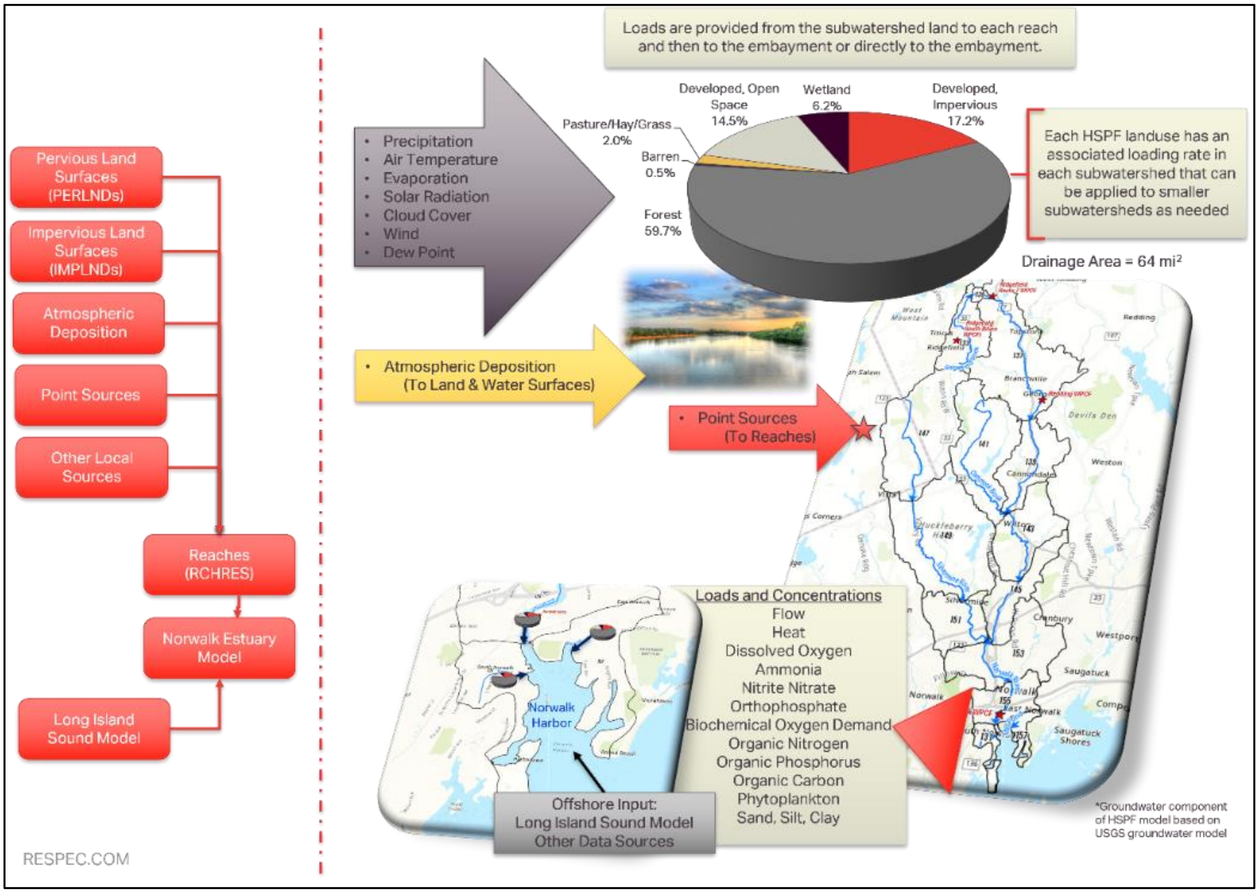

Figure 26: Connecting the HSPF Model to models for the coastal embayments and Long Island Sound

Additionally, the approaches developed through this SNEP-supported project are being applied to other coastal embayments in Connecticut. An embayment modeling framework has been developed to provide guidance on embayment complexity, appropriate water quality and hydrodynamic models, and embayment data collection needs for application in Connecticut. This framework as well as the water quality modeling and planning approach developed through this Pawcatuck-focused project is being extended to other embayments in Connecticut, including the Mystic, Farm, Southport, Saugatuck, and Norwalk estuaries. Biological, chemical, and physical data is being gathered statewide in Connecticut in upland areas and target embayments, to support development of an updated HSPF model for the rest of Connecticut for use with embayment models (Figure 27).

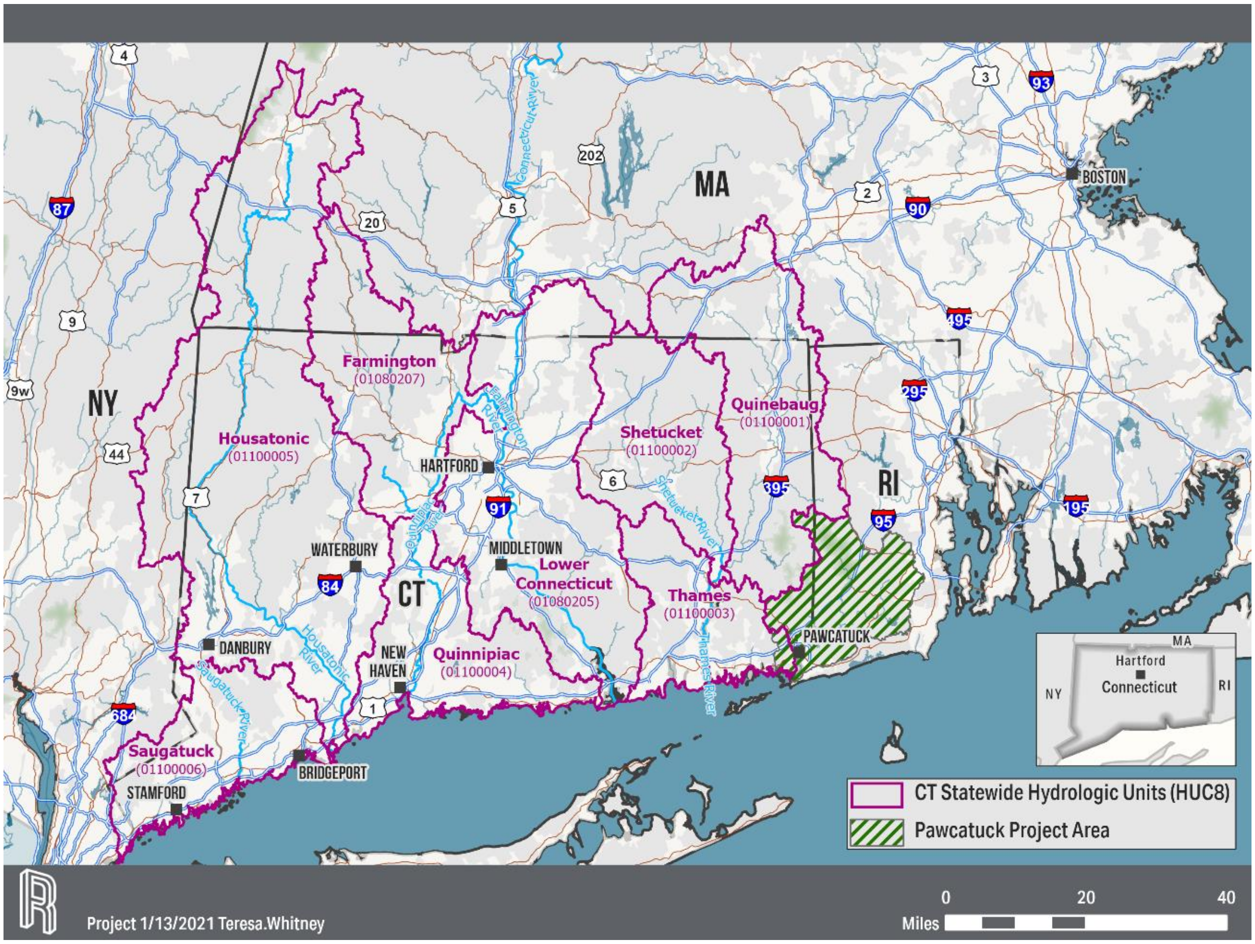

Figure 27: Watersheds to be included in update to the CT Statewide HSPF Model

Additional Project Information

Additional information on this project is available on the project website

On the website, there is a project story map to provide background information on this project and links to project related documents.

Acknowledgement

CTDEEP and RIDEM appreciate the funding support from the Southeast New England Estuary Program and project support from Save the Bay which made this current project possible. Already, lessons learned, and approaches developed through this project are being used to develop the next phase of the project for the Pawcatuck River Estuary and Little Narragansett Bay and extend this water quality modeling and planning approach to other estuaries and embayments within Connecticut. We appreciate the additional support from staff at EPA Region 1 and EPA Atlantic Coastal Environmental Sciences Division Laboratory.

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Appendix A: Data Sources for the HSPF Model

Stream Flow Data

Flow data were needed to ensure that the flow of water and the transport of sediment and nutrients within Pawcatuck River Watershed could be accurately represented. Continuous, observed stream-flow data were available at 18 USGS gages (Table 6) (Figure 28) in the Pawcatuck River Watershed.

Table 6: USGS Stream Flow Project Stations

Station Name	Station I.D.
CHIPUXET RIVER AT WEST KINGSTON, RI	01117350
QUEEN R 1400 FT UPSTR WM REYNOLDS RD AT EXETER, RI	011173545
QUEEN R AT LIBERTY RD AT LIBERTY, RI	01117370
USQUEPAUG RIVER AT RT 138 AT USQUEPAUG, RI	01117410
USQUEPAUG RIVER NEAR USQUEPAUG, RI	01117420
CHICKASHEEN BROOK AT WEST KINGSTON, RI	01117424
PAWCATUCK RIVER AT KENYON, RI	01117430
BEAVER RIVER NEAR USQUEPAUG, RI	01117468
BEAVER RIVER SHANNOCK HILL RD, NEAR SHANNOCK, RI	01117471
PAWCATUCK RIVER AT WOOD RIVER JUNCTION, RI	01117500
MEADOW BROOK NEAR CAROLINA, RI	01117600
WOOD RIVER NEAR ARCADIA, RI	01117800
WOOD RIVER AT HOPE VALLEY, RI	01118000
PAWCATUCK RIVER AT BURDICKVILLE, RI	01118010
PENDLETON HILL BROOK NEAR CLARKS FALLS, CT	01118300
ASHAWAY RIVER AT ASHAWAY, RI	01118360
SHUNOCK RIVER NEAR NORTH STONINGTON, CT	01118400
PAWCATUCK RIVER AT WESTERLY, RI	01118500

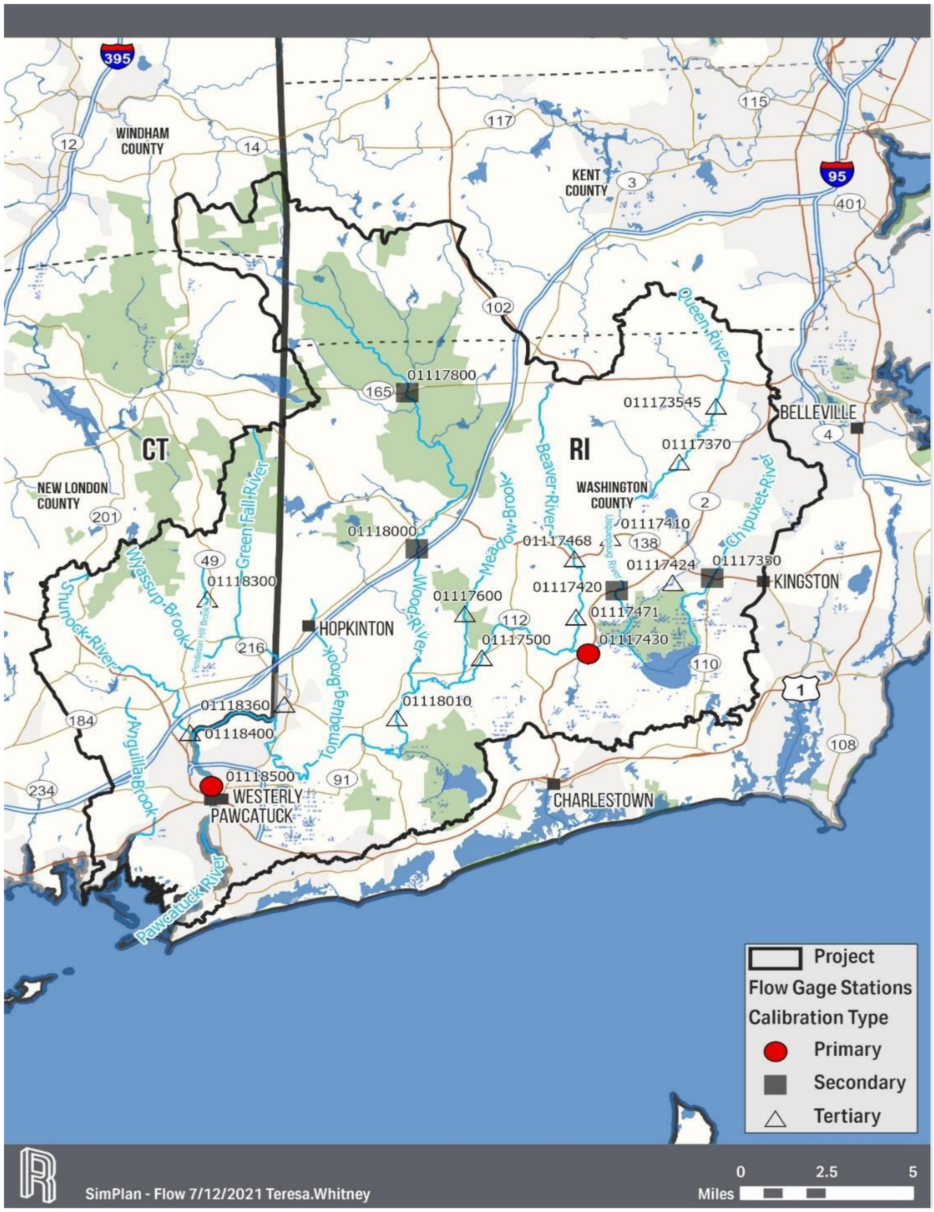

Figure 28: Project Flow Gage Station Locations:

Precipitation and Other Meteorological Data

A complete record of precipitation on an hourly basis for the watershed area to be modeled was needed. Precipitation, including rain and snow, is important because it drives the movement of water and pollutants from the land to the waterbody. The primary sources of long-term precipitation and other meteorological inputs for this watershed model the North American Land Data Assimilation

System (NLDAS) (https://ldas.gsfc.nasa.gov/nldas/nldas-get-data) and Parameter-elevation Regressions on Independent Slopes Model (PRISM) (https://prism.oregonstate.edu/).

Meteorological data collected included information on air temp, wind, solar radiation, dewpoint and cloud cover.

Atmospheric Deposition

Nutrients carried within the air can be deposited into surface waters. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP) (http://nadp.slh.wisc.edu/) and dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNet) (https://www.epa.gov/castnet/) from the stations listed in Table 7 and shown in Figure 29.

Table 7: Atmospheric Deposition Monitoring Sites

Site I.D.	Name	State	Type
CT15	Abington	CT	Wet
MA08	Quabbin Reservoir	MA	Wet
NY96	Cedar Beach-Southold	NY	Wet
ABT147	Abington	CT	Dry

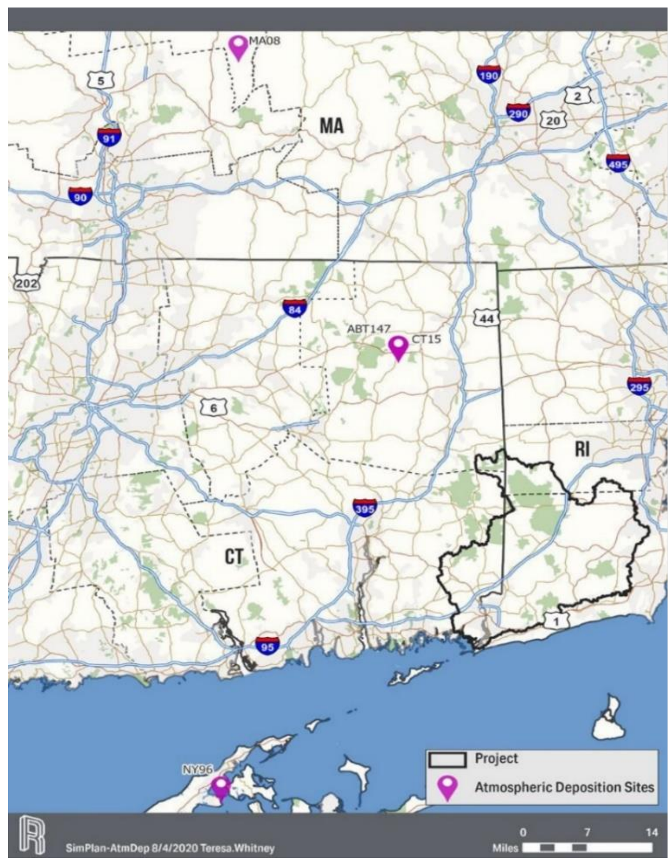

Figure 29: Atmospheric Deposition Monitoring Site Locations

Water Quality

Water quality data were primarily used to set up the model and make sure it was performing correctly. Data for the model included the data from the USGS study conducted as part of this project, but also included other data from USGS, EPA, RIDEM and CTDEEP. Water quality data was collected for:

- TSS
- Water temperature
- DO
- Carbonaceous Biochemical Oxygen Demand ultimate ($CBOD_u$) (i.e., total CBOD)
- Nitrite-Nitrate (NO_2/NO_3)
- Total ammonia (NH_3/NH_4)
- Total nitrogen (TN)
- Orthophosphate (PO_4)
- Total phosphorus (TP)
- Phytoplankton as chlorophyll *a*
- Benthic chlorophyll *a*.

Most of the data were available from the National Water Quality Monitoring Council Water Quality Portal (https://www.waterqualitydata.us/), which includes data from the USGS and EPA, and. RIDEM and CTDEEP provided additional information. Monitoring locations used to support the HSPF model are shown in Figure 30.

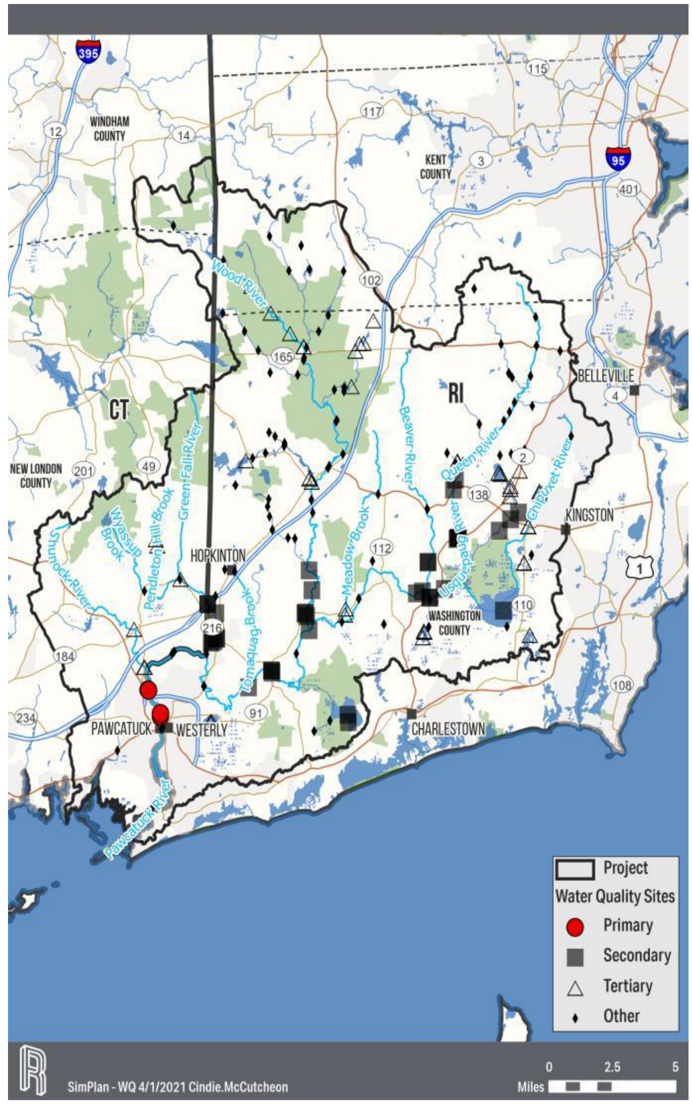

Figure 30: Water Quality Monitoring Locations

Land Cover and Non Point Sources

Land cover data are a critical factor in modeling watersheds because these data provide the detailed characterization of the potential pollutant sources entering the reaches as nonpoint-source contributions. The land cover also affects the movement of water and pollutants within the watershed. The major land cover in the Pawcatuck River Watershed is forest, which makes up more than half of the total area. For land cover data, information from each state was used. Rhode Island has a 2011 land-cover layer (https://www.rigis.org/datasets/land-use-and-land-cover-2011), and Connecticut has a 2015 land-cover layer (https://clear.uconn.edu/projects/landscape/index.htm). As part of this analysis, the amount of hard or impervious surfaces are considered since water doesn't infiltrate into the ground in these areas but instead runs off more directly to surface water bodies and can affect water quality.

Topography provides the elevation and slope values for a project area, which are also important for understanding the movement of water and pollutants within the watershed. The 3D Elevation Program from the USGS was used for this data. ((https://www.usgs.gov/core-science-systems/ngp/3dep).

Point Source Data

Point sources are permitted activities that generally release chemicals to the surface waters through a pipe. These activities have a permit to make sure that their discharges are not causing problems in the rivers and streams. Point source data for the Pawcatuck River Watershed were provided by CTDEEP and RIDEM and were also downloaded from the EPA ECHO website. Point source discharges from the Pawcatuck Watershed included in the HSPF model are listed in Table 8 and show in Figure 31.

Table 8: Permitted Facilities

Facility I.D.	Facility Name
RI0100081	Ladd School Wastewater Treatment Facilities
RI0000191	Kenyon Industries
RI0001007	RIDEM/Carolina Trout Hatchery
RI0022080	Coastal Plastics, Inc.
RI0000043	Bradford Dyeing Association
RI0020508	The Imperial Home Décor Group
RI0021814	Ashaway Line and Twine Manufacturing Company
RI0100064	Westerly Wastewater Treatment Facilities
CT0101290	Stonington Pawcatuck Water Pollution Control Facility

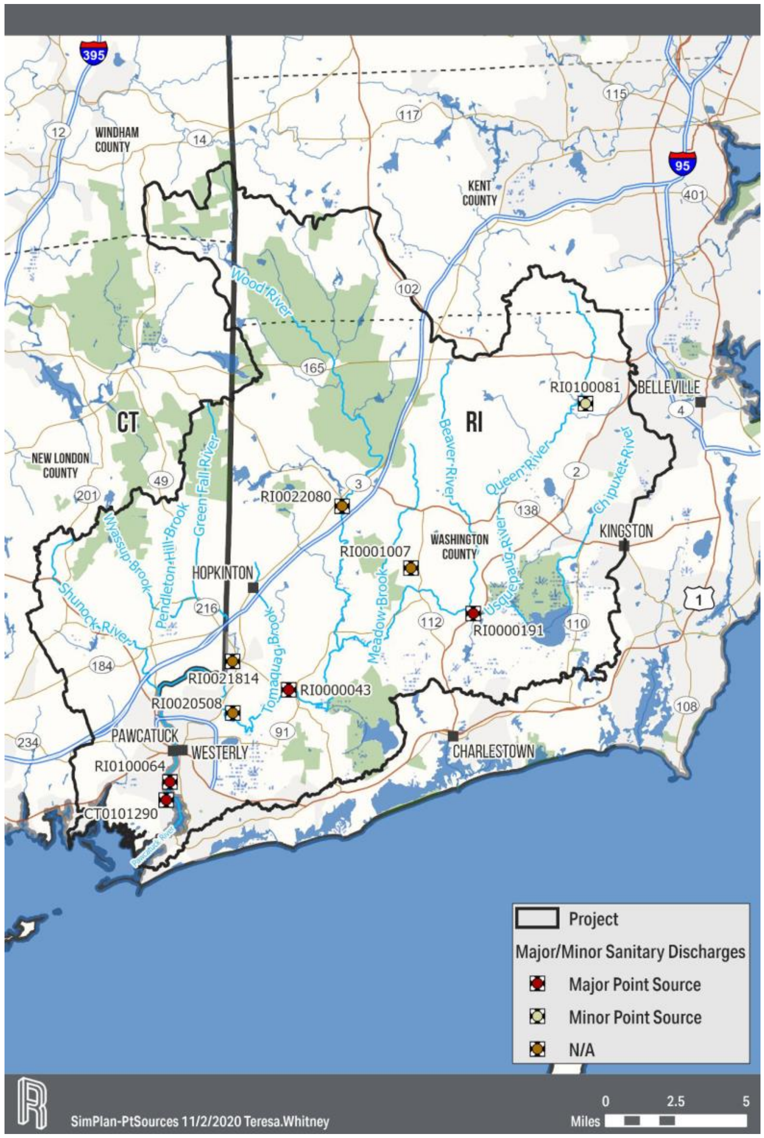

Figure 31: Permitted Facilities Locations

Other Data

Information on water diversion and withdrawals, and irrigation was also added to the model. Information on water diversions and withdrawals was available for Connecticut from CTDEEP. Irrigation rates were based on information from published literature and the HSPF model developed for water flows within Rhode Island (Gardner 2011).