SIMULATION PLAN FOR THE PAWCATUCK RIVER WATERSHED

REVISION 1 TOPICAL REPORT RSI-3074

PREPARED FOR
Connecticut Department of
Energy and Environmental Protection
79 Elm Street
Hartford, Connecticut 06106-5127

FEBRUARY 2021

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1.0 INTRODUCTION

The Connecticut Department of Energy and Environmental Protection (CTDEEP) is seeking to develop a new, watershed-focused approach to identifying and managing nutrient inputs into the coastal embayments to support healthy aquatic communities, restoration of eelgrass and recreational uses, and nutrient management in the upland watersheds. This approach will employ dynamic watershed models calibrated for hydrology and water quality characteristics. These models were chosen to facilitate the analysis of the water quality impacts associated with the current and future conditions within watersheds across the State of Connecticut. Models provide a proven platform for analyzing various implementation scenarios to achieve water quality goals that can then be translated into implementation plans.

CTDEEP has selected the Hydrologic Simulation Program-Fortran (HSPF) dynamic watershed model. This model was used to develop the Connecticut Watershed Model (CTWM) in 2002 and has been widely used throughout the United States to analyze water hydrology and quality in support of 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 sources of pollution. This model continues to be supported by both the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS).

In 2020, CTDEEP contracted with RESPEC to the develop multiple HSPF models: one model for the Pawcatuck River Watershed, as shown in Figure 1-1, and a set of models for the remaining watersheds in Connecticut. This report addresses the development of the Pawcatuck River Watershed HSPF model application. The primary water quality parameters to be predicted by the model are nitrogen, phosphorus, suspended sediments, and stream flow. The results of the dynamic watershed models will be used to link with site-specific models of lakes, reservoirs, and tidal waters to conduct assessments of these waterbodies. The models are expected to provide nutrient loads, suspended sediment loads, and freshwater inputs to other site-specific models.

Across southeastern New England, coastal embayments, lakes, and impoundments exhibit the effects of excessive nutrients: loss of or significantly diminished eelgrass beds, excessive growth of macroalgae, oxygen depleted waters, and deteriorated substrates. Eelgrass was once commonly found in many bays and harbors throughout Long Island Sound but are now largely confined to the eastern portion. Harmful algae blooms occur regularly in lakes and reservoirs across the State of Connecticut. Under these conditions, habitats for fish (at all life stages) and other aquatic organisms, as well as recreational uses and waterfront property values, suffer.

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; however, nonpoint sources and stormwater are becoming the largest sources of nutrients in Connecticut. To target these sources effectively, detailed information is needed about the nutrients in watersheds at fine spatial and temporal scales to identify where and when the bulk of nutrient

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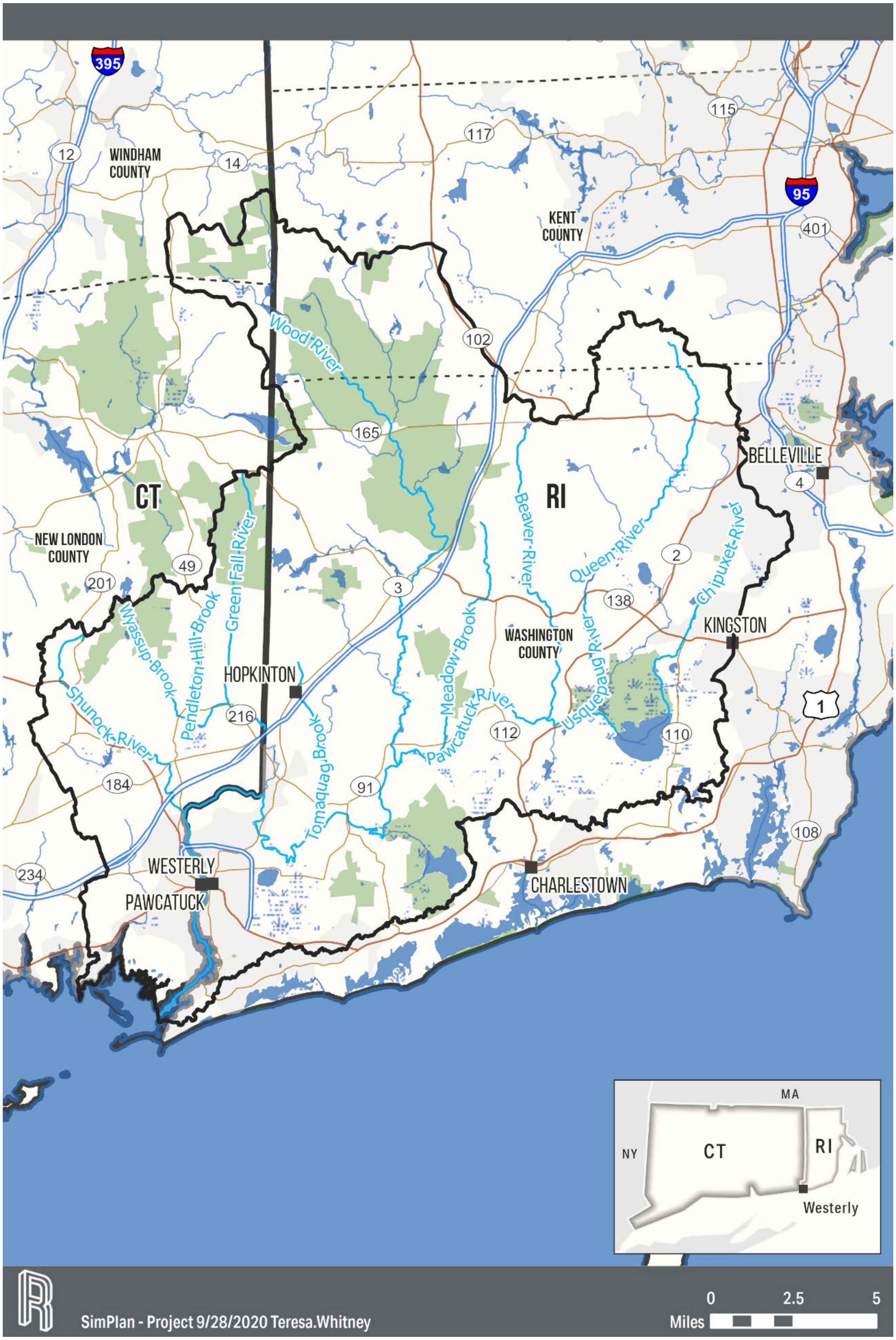

Figure 1-1. Pawcatuck River Project Area.

nonpoint- and stormwater-source nutrient loads are being released to nearby waters. This information is also needed for inputs to drive site-specific models of lakes, reservoirs, and embayments to determine total maximum daily loads.

The Pawcatuck River, Pawcatuck River Estuary (PRE), and Little Narragansett Bay form part of the boundary between the States of Connecticut and Rhode Island. The states have identified water quality impairments within these waters related to insufficient oxygen and bacteria. Connecticut has also identified impairments associated with nutrient loading and eutrophic conditions.

A dynamic watershed modeling approach is the most efficient means to obtain detailed information on nonpoint- and stormwater-source nutrient loads across the states of Connecticut and Rhode Island, as directly measuring nutrient loads at the spatial and temporal scales is not possible. While simplified watershed yield models provide annual nutrient loads, the models lack the temporal variability of loads that is important for understanding episodic events or predicting loads under different climatic conditions. The last dynamic watershed model for Connecticut was completed in 2002, which is an additional limitation to obtaining detailed nonpoint- and stormwater-nutrient information. Note that since the model was calibrated nearly 20 years ago, conditions in the watersheds draining to Long Island Sound have changed and capabilities of modeling tools have increased. The 2002 model did not include the Pawcatuck River Watershed. An HSPF model was developed for the Pawcatuck River Watershed as a collaboration between the State of Rhode Island and the USGS; however, the model only focused on stream flow and did not address nutrients and other related parameters.

To better understand the water quality within the freshwater portion of the Pawcatuck River Watershed, the States of Connecticut and Rhode Island require information on the nutrient dynamics and stream flow in locations throughout the watershed. The additional, focused data collection, completed in 2019 and 2020, has enhanced the development of an HSPF watershed model that is calibrated for nutrients, total suspended solids (TSS), stream flow, and related parameters to assist in the assessing and managing nutrients in the Pawcatuck River Watershed while considering the water quality data collection protocols established by the EPA and USGS. Information on diurnal dissolved oxygen (DO) and data on nitrogen and phosphorus concentrations are critical components of these new approaches and were collected in a joint effort by the EPA Region 1 Laboratory and Rhode Island Department of Environmental Management (RIDEM) as input datasets for a planned, watershed-scale hydrology and water quality model.

The HSPF model is a comprehensive watershed model of hydrology and water quality that includes land-surface and subsurface hydrologic and water quality processes that are linked and closely integrated with corresponding stream and reservoir processes [Donigian et al., 2018]. HSPF is considered a premier, high-level model among those currently available for comprehensive watershed assessments and has experienced widespread usage and acceptance since its initial release in 1980, as demonstrated through hundreds of applications across the United States and abroad. HSPF is jointly supported and maintained by the EPA and USGS. HSPF is also the primary watershed model in the EPA BASINS modeling system and has been incorporated into the U.S. Army Corps of Engineers (USACE) Watershed Modeling System (WMS). This widespread usage and support has helped to ensure the continued code availability and maintenance for more than two decades despite varying federal priorities and budget restrictions.

The main stem of the Pawcatuck River is approximately 36 miles long, and the Hydrologic Unit Code (HUC) 8 watershed (Pawcatuck-Wood, 01090005) drains approximately 383 square miles including a 10-square-mile area off of the coast of Rhode Island, around the independent, terrestrial area of Block Island. Only the areas that drain to the Pawcatuck River and to Little Narragansett Bay directly west of the watershed are being modeled, rather than the entire HUC 8 watershed. The project area for the Pawcatuck River Watershed model is approximately 318 square miles.

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.

This report presents the simulation plan for developing the Pawcatuck River Watershed hydrology and water quality model using HSPF. This simulation plan presents the initial planned approach for constructing and calibrating the model with an emphasis on identifying and describing data requirements, sources, and availability. Revisions to this plan are expected as the data details are further analyzed and investigated.

The major steps in the model application development process consist of:

1. Collecting and developing time-series data
2. Characterizing and segmenting the watershed
3. Calibrating and validating the model.

These three steps are discussed in detail in the following sections of this simulation plan. Chapter 2.0 describes the collection and development of the hydrologic, meteorological, and other data needed for the simulation; Chapter 3.0 discusses other types of spatial data needed for segmentation and characterization of the watershed, and Chapter 4.0 describes the calibration and validation process as well as the analysis of the simulation period for the Pawcatuck River Watershed model.

After the model has been developed, calibrated, and validated, the HSPF outputs can be used as inputs to receiving water quality models and implementation scenarios can be run. Chapter 5.0 discusses the linkage process for HSPF outputs to be used as inputs to WASP and BATHTUB, and Chapter 6.0 describes several proposed management scenarios. Because of the large amount of data required for watershed modeling, Chapter 7.0 presents methods for efficient data management, organization, and transfer.

This plan will be revised after review comments are received, ongoing discussions with the participating agencies are completed, and the additional data needed to support the modeling effort are reviewed. This study plan will therefore be revised on an ongoing basis and will ultimately become part of the final report.

RESPEC

2.0 DATA COLLECTION AND DEVELOPMENT

Hydrology and water quality simulation within the Pawcatuck River Watershed requires the following types of time-series data:

1. Precipitation
2. Potential evapotranspiration
3. Other meteorological data (e.g., air temperature, wind, solar radiation, dewpoint, and cloud cover)
4. Stream flow
5. Water quality observations
6. Point sources
7. Atmospheric deposition
8. Other data (e.g., irrigation, diversions, and withdrawals).

This section discusses the availability, selection, and processing methods of these time-series data for use in the watershed modeling. The detailed quality assurance/quality control (QA/QC) and data management procedures are provided in Chapter 7.0. Only meteorological data are required to run the HSPF model; however, stream-flow measurements and water quality observations are used to calibrate and validate the model. Other data types (e.g., point sources, atmospheric deposition, and diversions) help to define the inflow, outflow, and water quality in the watershed. All of the time-series data for the model will be placed into a Watershed Data Management (WDM) file, which is a binary database format that was originally developed to efficiently store large datasets to be used by HSPF and other models.

2.1 PRECIPITATION

The Pawcatuck River Watershed HSPF model requires complete (i.e., no missing records) precipitation time-series data at an hourly timestep and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models because it drives the hydrologic cycle and provides the foundation for transport mechanisms that move pollutants from the land to the waterbody, where the pollutant impacts are imposed.

The primary sources of long-term precipitation and other meteorological inputs for this watershed model include North American Land Data Assimilation System- (NLDAS-) and Parameter-elevation Regressions on Independent Slopes Model (PRISM)-gridded data. These data products are complete and available from 1979 up to the current year (within the last few weeks of the download date). Because these data are gridded, they allow for easy extraction and aerial averaging over each hydrozone (an aggregation of subwatersheds that receive the same meteorological inputs) using scripted processes while also providing efficient and consistent time-series extension.

The NLDAS is a 12-kilometer (km) by 12-km dataset that provides hourly meteorological data. PRISM is a 4-km by 4-km dataset that provides daily precipitation totals that are computed by combining a dense network of station data with radar measurement estimates that are interpolated based on a climate-elevation regression for each digital elevation model (DEM). Daily PRISM data will be used for the modeling, as these data provide a finer spatial resolution and generally have a better fit to point-precipitation data. The daily values will be disaggregated to an hourly timestep using the NLDAS data. The hourly NLDAS precipitation will also be loaded into the WDM to provide another option to test during calibration. Specific stations are not associated with the gridded meteorological data. The time period needed for modeling (January 1990 through July 2020) will be downloaded online (https://ldas.gsfc.nasa.gov/nldas/nldas-get-data).

Snow depth (i.e., snow on ground) data are used to calibrate the snow accumulation and melt processes when the snow section of the model is active. These data are also used in conjunction with mean and maximum winter-air temperatures to assess whether to activate the snow simulation capability within the watershed model. For the Pawcatuck River Watershed and the surrounding areas, the snow depth (in inches) and snowfall (in inches) data are available through National Climatic Data Center (NCDC) Global Historical Climatology Network stations [Menne et al., 2012] (ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/). The snow depth data will be used during the hydrology calibration in multiple locations throughout the project area to ensure that snow processes are being accurately represented. Graphs similar to that shown in Figure 2-1 will be developed plotting snowfall, snow depth, and air temperature.

Precipitation data sources include the following:

- NLDAS (https://ldas.gsfc.nasa.gov/nldas/nldas-get-data)
- PRISM (https://prism.oregonstate.edu/).

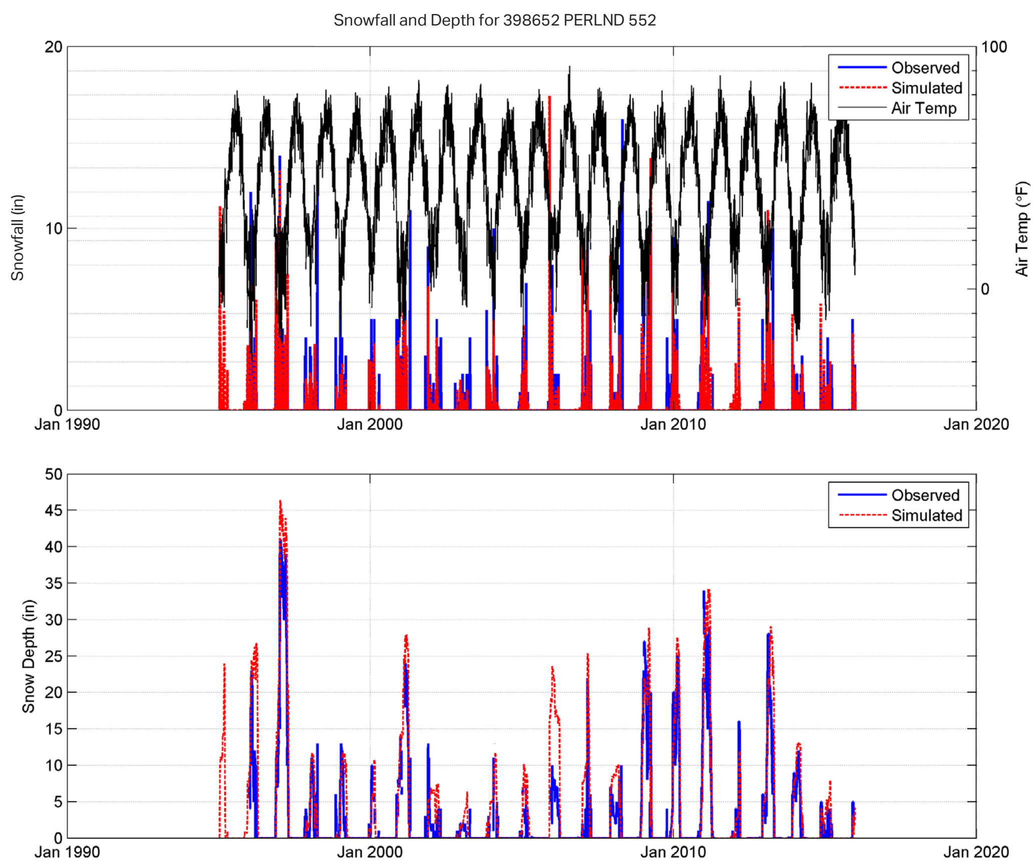

Figure 2-1. Calibration Figure to Evaluate the Snowfall and Snow Depth Simulation.

2.2 EVAPOTRANSPIRATION AND OTHER METEOROLOGICAL DATA

In addition to precipitation, evaporation data are needed to drive the water-balance calculations in HSPF. Other meteorological time series are often required in temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These time series, such as air temperature (ATEM), solar radiation (SOLR), dewpoint temperature (DEWP), wind speed (WIND), and cloud cover (CLOU) are often required if soil and/or water temperatures are simulated. Water temperature is subsequently used to adjust rate coefficients in most water quality processes, and other time series are used in selected calculations (e.g., solar radiation affecting algal growth).

The NLDAS dataset provides hourly ATEM, SOLR, and WIND parameters that will be directly applied to the meteorological time series with a conversion to the units needed for HSPF. The remaining meteorological constituents (CLOU, DEWP, and potential evapotranspiration (PEVT) are not directly available from the NLDAS dataset and require additional computations for this model.

CLOU will be estimated by SOLR data for this model provided from the NLDAS database by using a parabolic equation [Thompson, 1976]. Two options for DEWP will be computed from a series of calculations that stem from the NLDAS specific humidity. The first option uses the specific humidity and ATEM to calculate the relative humidity [World Meteorological Organization, 2014]. Relative humidity will then be applied with ATEM to the August-Roche-Magnus approximation of the Clausius-Clapeyron equation [Stull, 2017] to calculate DEWP. The second option calculates a mixing ratio using specific humidity and that mixing ratio is used with atmospheric pressure to estimate vapor pressure. DEWP is then calculated using the Clausius-Clapeyron equation [Stull, 2017]. Both of the options for DEWP will be assessed during calibration.

Hourly potential evapotranspiration (PEVT) estimates are included in the NLDAS dataset generated using a modified Penman energy-balance method; however, the NLDAS estimates of PEVT are included only for legacy compatibility with input requirements of the Sacramento Soil Moisture Accounting Model (http://hydromad.catchment.org/man/sacramento.html), do not incorporate subsequent corrections to NLDAS estimates of energy forcing, and have been found to overestimate evapotranspiration (ET) in other modeling efforts. Hourly PEVT will be represented by a computed Penman pan evaporation based on the Penman [1948] formula and the method of Kohler et al. [1955]. The necessary variables to compute the Penman pan evaporation are daily SOLR, DEWP, ATEM, and wind travel. Because two options for DEWP will be calculated, two options for PEVT will be calculated and assessed during calibration.

Evaporation and other meteorological data sources include the following:

- NLDAS (https://ldas.gsfc.nasa.gov/nldas/).

2.3 STREAM FLOW

Flow data are needed for calibrating and validating of the watershed model to ensure that the hydrologic behavior of the Pawcatuck River Watershed along with the transport of sediment and water quality constituents are reproduced. Continuous, observed stream-flow data are available at 18 gages in the Pawcatuck River Watershed. The stream-flow gages and corresponding record periods to support the model calibration are listed in Table 2-1, along with the percentage of data that were missing during the modeling time period (January 1990 through July 2020). The locations of the flow-monitoring sites are illustrated in Figure 2-2. Flow data were downloaded from the USGS National Water Information System (NWIS) (https://waterdata.usgs.gov/nwis). All continuous, stream-flow data in the watershed will be included in the calibration; however, non-continuous, stream-flow data are not as valuable for calibration purposes. As a part of the model calibration, the data will be plotted with a simulated flow.

Stream-flow data sources include the following:

- USGS NWIS (https://nwis.waterdata.usgs.gov/nwis).

Table 2-1 List of the U.S. Geological Survey Stations and Data Availability During the Modeling Time Period in the Pawcatuck River Watershed

Station Name	Station I.D.	Start Date	End Date	Missing (%)
CHIPUXET RIVER AT WEST KINGSTON, RI	01117350[b]	01/01/1991	05/04/2020	0.0
QUEEN R 1400 FT UPSTR WM REYNOLDS RD AT EXETER, RI	011173545	10/01/1999	12/14/2004	84.5
QUEEN R AT LIBERTY RD AT LIBERTY, RI	01117370	10/01/1998	05/04/2020	26.2
USQUEPAUG RIVER AT RT 138 AT USQUEPAUG, RI	01117410	07/13/1999	12/15/2004	83.7
USQUEPAUG RIVER NEAR USQUEPAUG, RI	01117420	01/01/1991	05/04/2020	0.0
CHICKASHEEN BROOK AT WEST KINGSTON, RI	01117424	09/26/2002	12/14/2004	92.5
PAWCATUCK RIVER AT KENYON, RI	01117430[b]	01/01/1991	05/04/2020	46.7
BEAVER RIVER NEAR USQUEPAUG, RI	01117468[b]	01/01/1991	05/04/2020	0.0
BEAVER RIVER SHANNOCK HILL RD, NEAR SHANNOCK, RI	01117471	10/01/2002	12/08/2004	92.6
PAWCATUCK RIVER AT WOOD RIVER JUNCTION, RI	01117500[a]	01/01/1991	05/04/2020	0.0
MEADOW BROOK NEAR CAROLINA, RI	01117600	01/01/1991	12/15/2004	92.0
WOOD RIVER NEAR ARCADIA, RI	01117800[b]	01/01/1991	05/04/2020	0.0
WOOD RIVER AT HOPE VALLEY, RI	01118000[b]	01/01/1991	05/04/2020	0.0
PAWCATUCK RIVER AT BURDICKVILLE, RI	01118010	08/06/2002	12/15/2004	92.0
PENDLETON HILL BROOK NEAR CLARKS FALLS, CT	01118300[b]	01/01/1991	05/04/2020	0.0
ASHAWAY RIVER AT ASHAWAY, RI	01118360	08/16/2002	12/15/2004	92.1
SHUNOCK RIVER NEAR NORTH STONINGTON, CT	01118400	10/01/2002	12/15/2004	92.5
PAWCATUCK RIVER AT WESTERLY, RI	01118500[a]	01/01/1991	05/04/2020	0.0

(a) Primary Calibration/Validation
(b) Secondary Calibration/Validation.

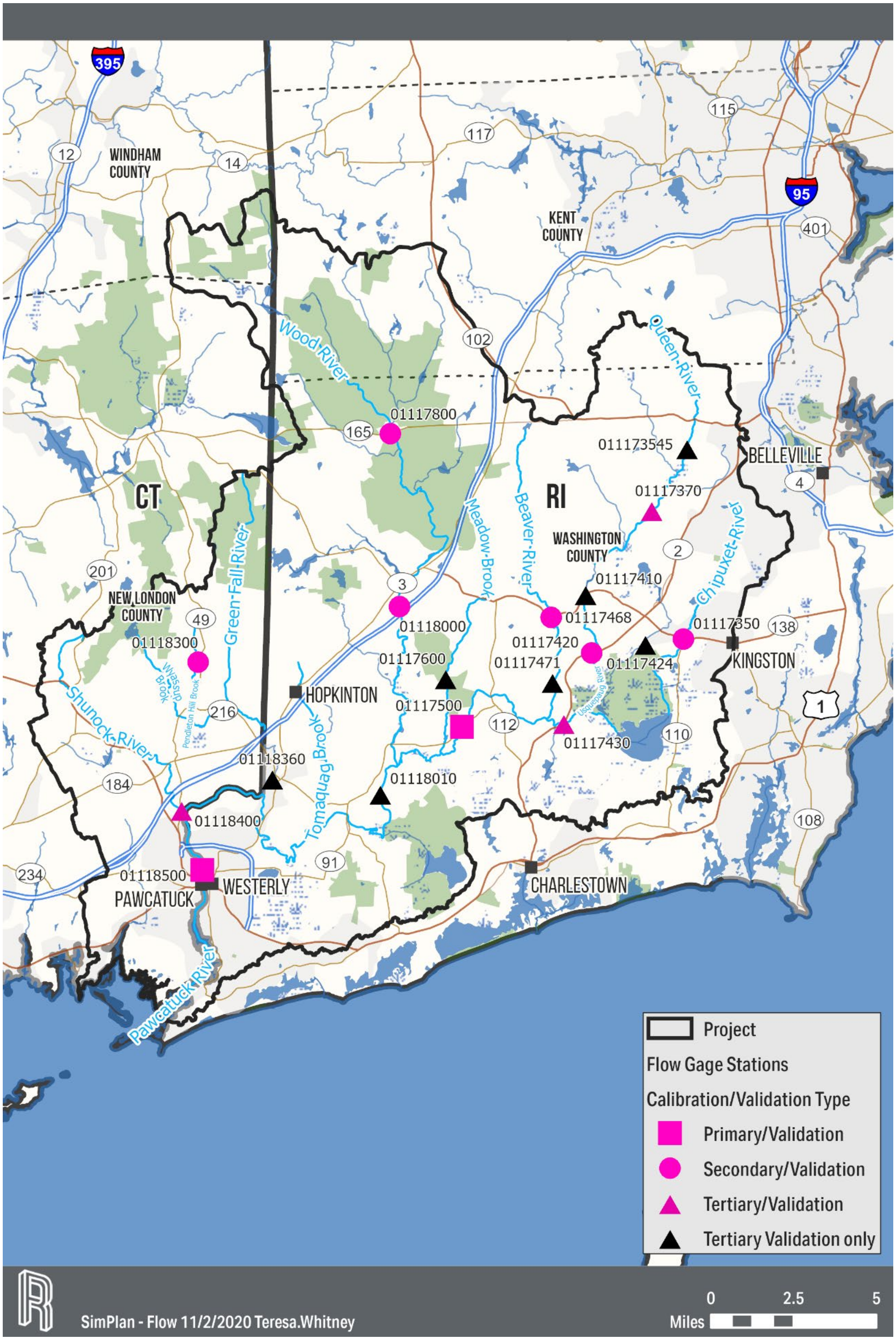

Figure 2-2. Flow Calibration Gages.

2.4 WATER QUALITY DATA

Water quality data are used primarily for model calibration and validation, but also to help quantify source contributions and boundary conditions. The specific constituents to be modeled in this study include all of the constituents needed for modeling nutrients with a specific focus on nitrogen species. The following list shows the conventional constituents that are modeled whenever nutrients are the purpose of a modeling effort:

- TSS
- Water temperature
- Dissolved Oxygen (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*.

Water quality data were collected from the National Water Quality Monitoring Council Water Quality Portal (https://www.waterqualitydata.us/), which includes data from the USGS, EPA, and National Water Quality Monitoring Council (NWQMC). This portal serves data collected by more than 400 state, federal, tribal, and local agencies. Water quality data were also provided by CTDEEP and RIDEM. Ambient surface-water quality data will be used for the water quality calibration. Applicable parameters from all sources (RIDEM, CTDEEP, and the Water Quality Data Portal) will be combined into a single dataset. A table of the water quality sites and number of applicable samples during the modeling period is included in the appendices. Data gaps were identified as a part of the development of the USGS monitoring plan [USGS, 2019]. A sampling plan review was completed that summarized the existing water quality data and data gaps in the sampling plan. The sampling plan was determined to be overall well-structured with a good distribution of stations across the watershed and appropriate parameters being monitored. The sampling plan provides an adequate dataset to represent the recent conditions and identify significant water quality responses within the watershed. The primary data gap identified was the lack of targeted storm sampling that can be critical to effectively estimating the nutrient and sediment loadings during runoff events. This recent sampling effort, in addition to previous sampling efforts, should provide a reasonable range of flow conditions and corresponding water quality data to estimate the nutrient and sediment loads and effectively support the watershed-focused approach for managing nutrient load in the Pawcatuck River Watershed.

The CTDEEP and RIDEM also supplied data from the Municipal Separate Storm Sewer System (MS4) storm drains. These data will be compared to the concentrations of developed land as a part of the calibration process. Storm drains are not explicitly represented and will not be calibrated.

For tracer modeling, an option is available in HSPF called CONS, which simulates constituents which do not decay with time or leave the Stream Reach or Reservoir (RCHRES) by any mechanism other than advection. Parameter inflows are applied and CONS calls the subroutine ADVECT to perform longitudinal advection of this material and the material already contained in the RCHRES. Finally, CONS calculates the mass of material remaining in the RCHRES after advection; this value, RCON, is necessary for the mass balance checks on conservatives. If CONS is not used, a constant load of a general water quality constituent will be applied to the headwater reaches through the GQUAL section in HSPF instead. The general constituent can remain conservative by not applying any decay processes (e.g., hydrolysis, oxidation, biodegradation) in the code and only simulating advection.

Water quality data sources include the following:

- Water Quality Data Portal (https://www.waterqualitydata.us/)
- RIDEM and CTDEEP Uploaded Water Quality Data to Shared Project Folder.

2.5 POINT SOURCES

Point-source data for the Pawcatuck River Watershed were provided by CTDEEP and RIDEM. Additionally, point-source data were downloaded from the EPA ECHO website (https://echo.epa.gov/). Discharging point sources in the Pawcatuck River Watershed are summarized in Table 2-2 and their locations are shown in Figure 2-3. Applicable parameters available at the facilities include flow, 5-day biochemical oxygen demand (BOD_5), ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen. Facilities that are not represented include the Chariho Regional Middle School, Greene Plastics, the Rhode Island Department of Transportation (RIDOT), Westerly and Richmond Mobil Service Stations, Armetta LLC, the Avondale Boat Yard, Washington County Turf Farm, and other facilities with very low flow and/or no data available. If data are provided for the excluded facilities, then they can be represented using monthly averages during their operational periods. Facilities that closed during the model time period include the Ladd School (1993) and Bradford Dying Association (2011).

Table 2-2. Discharging Point Sources

Site I.D.	Site Name	Major/Minor Sanitary Discharges	Reach
RI0100081	Ladd School Wastewater Treatment Facilities	Minor	43
RI0000191	Kenyon Industries	Major	90
RI0001007	RIDEM/Carolina Trout Hatchery	NA	111
RI0022080	Coastal Plastics, Inc.	NA	215
RI0000043	Bradford Dyeing Association	Major	250
RI0020508	The Imperial Home Décor Group	NA	290
RI0021814	Ashaway Line and Twine Manufacturing Company	NA	329
RI0100064	Westerly Wastewater Treatment Facilities	Major	370
CT0101290	Stonington Pawcatuck Water Pollution Control Facility	Major	370

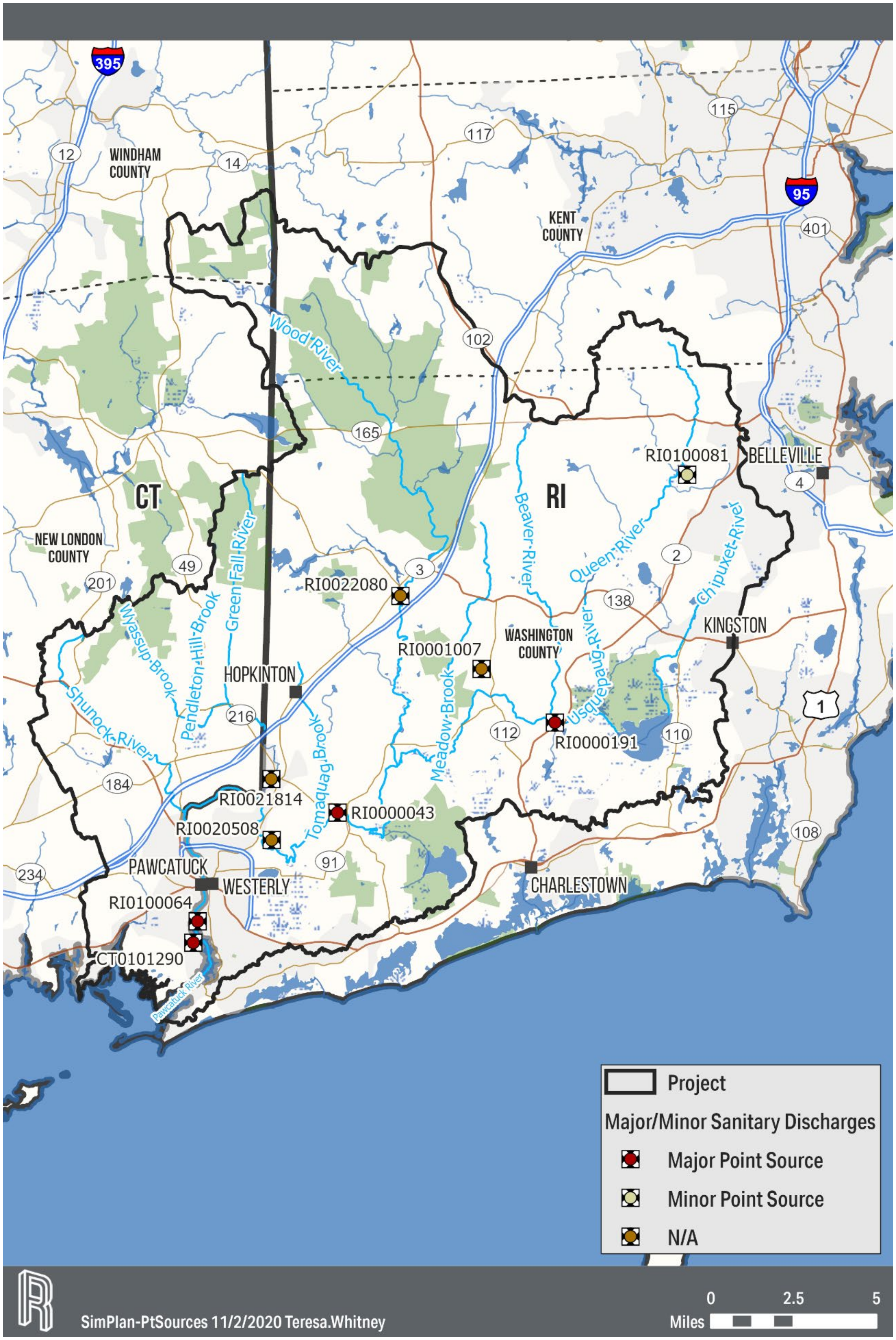

Figure 2-3. Point-Source Locations.

The provided data, which were at a monthly timestep, will be transformed into a daily time series following a set of rules and assumptions that are based on the facility type (i.e., mechanical versus controlled), which can often be determined with permits or by evaluating the dataset.

Mechanical point sources have continuous flow and are generally industrial facilities or larger municipal wastewater treatment facilities (WWTFs). These sites will be assumed to discharge every day of every month, unless otherwise noted. Months with missing data can be filled in using the average of similar months (e.g., if January 2015 is missing data, the average of all of the other January data will be used to fill the month). If data are missing before or after the full range of values, the assumption will be that the site was not operating at the time and discharge will not be represented.

Controlled ponds are lagoons and are usually small facilities that discharge intermittently for variable lengths of time. If a facility has missing monthly data, the assumption will be that the pond did not release effluent during that month. Note that some of the facilities on the Rhode Island side of the watershed are ponds.

Applicable parameters for the discharging facilities generally include carbonaceous 5-day biological oxygen demand ($CBOD_5$), ammonia nitrogen, Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, TP, TSS, and temperature. HSPF requires more input parameters than what are provided in Table 2-3.

Table 2-3. List of Pollutants That Will Be Calculated From the Point Sources

Pollutant Name	Pollutant Description	Daily Model-Input Units
Flow	Effluent Flow	Acre-Foot
Heat	Heat Energy of the Effluent	BTU
TSS	Total Suspended Solids	Tons
DO	Dissolved Oxygen	Pounds
NO_3-N	Nitrate as Nitrogen	Pounds
NO_2-N	Nitrite as Nitrogen	Pounds
NH_4-N	Total Ammonia as Nitrogen	Pounds
ORN	Refractory Organic Nitrogen	Pounds
PO_4-P	Orthophosphorus as Phosphorus	Pounds
ORP	Refractory Organic Phosphorus	Pounds
$CBOD_u$	Ultimate Carbonaceous Organic Demand	Pounds
ORC	Organic Carbon	Pounds

BTU = British thermal unit.

Some facilities also may not sample or report all of the parameters listed. In these cases, a dataset could be derived using a surrogate facility estimated with nutrient speciation factors or by setting a constant concentration, depending on the missing constituent.

Besides temperature, concentrations of all of the available constituents, including BOD as $CBOD_u$ that will be converted from $CBOD_5$ by using Equation 2-1 [Chapra, 1997] will be converted from milligrams per liter (mg/L) to loads in pounds per day (lb/day) (i.e., concentration × flow × conversion factor; conversion factor = 8.34). Temperature will be converted from degrees Fahrenheit (°F) to a heat load in BTUs per day (i.e., temperature × flow × conversion factor; conversion factor = 8,339,145).

$$L_o = \frac{y_5}{1-e^{-k_1(5)}} \qquad (0\text{-}1)$$

where:

$L_o = \text{CBOD}_u$
$y_5 = \text{CBOD}_5$
$k_1 = 0.10$ (minimum value after primary treatment).

Estimated daily time series will be imported into a WDM file and loads will be applied to the corresponding stream in the external sources block of the user control input (UCI) file.

Point-source data sources include the following:

- EPA Echo (https://echo.epa.gov/)
- RIDEM and CTDEEP Uploaded Point-Source Data to Shared Project Folder.

2.6 ATMOSPHERIC DEPOSITION

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts that focus on eutrophication issues. Nitrate and ammonium atmospheric depositions will be explicitly represented as a daily time series in the Pawcatuck River Watershed HSPF model. Wet atmospheric deposition data will be downloaded from the NADP (http://nadp.slh.wisc.edu/), and dry atmospheric deposition data will be downloaded from the EPA's Clean Air Status and Trends Network (CASTNet) (https://www.epa.gov/castnet/). The sites, corresponding record periods, and distances to the center of the Pawcatuck River Watershed are summarized in Table 2-4, with the locations are shown in Figure 2-4. The ABT147 site is the closest dry deposition site (less than 30 miles from the project area) and has a nearly complete dataset; therefore, this site will be the primary dry deposition site. Although the MA08 site has a longer record period and a more complete dataset relative to the CT15 site, the CT15 site is closest to the watershed (less than 30 miles) and will be the primary wet deposition site. Wet and dry atmospheric depositions will be applied directly to the waterbodies and land throughout the watershed.

Table 2-4. Atmospheric Deposition Site Summary

Site I.D.	Name	State	Type	Start Date	End Date	Missing (%)
CT15	Abington	CT	Wet	01/26/1999	10/21/2019	22
MA08	Quabbin Reservoir	MA	Wet	03/05/1982	10/21/2019	19
NY96	Cedar Beach-Southold	NY	Wet	11/25/2003	10/21/2019	22
ABT147	Abington	CT	Dry	12/28/1993	12/30/2019	1

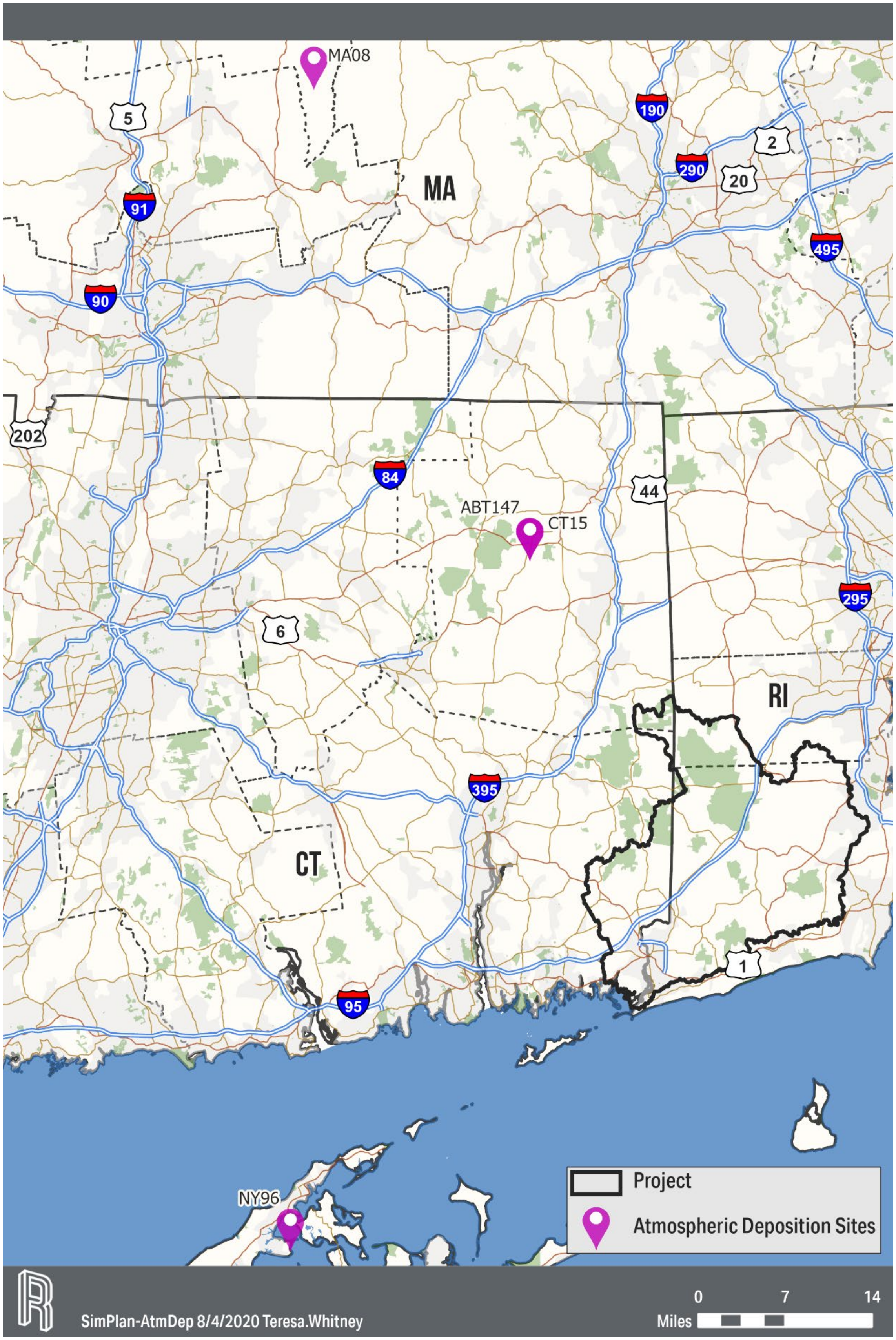

Figure 2-4. Atmospheric Deposition Locations.

The original dry deposition data are supplied at a weekly time step as a particulate flux kilogram per hectare (kg/ha). To transform the data into a daily time series, the weekly data will be divided by 7. The wet deposition is also supplied at a weekly time step but, in rare cases, sampling periods ranged from 1 to 8 days. Because wet deposition is in units of concentration (i.e., mg/L), wet deposition data will not need to be divided by the number of days in the sampling period because wet deposition is in units of concentration (mg/L). The concentration will instead be assigned to each day of the sampling period. In the model, the wet deposition data are multiplied by the precipitation amount to calculate the nutrient load. After being transformed to daily time-series data, the missing dry and wet deposition data will be filled in using interpolation when less than 14 missing days have occurred between samples and by using monthly mean values when more than 14 missing days have occurred between values. The data will be converted to elemental concentrations and fluxes using multiplication factors from the UCI (i.e., data are still NO_3 and NH_4, not NO_3-N and NH_4-N). A summary of the missing data that will be filled is shown in Table 2-4. The multiplication factors are used to convert the filled data into the units required by HSPF. The nitrogen deposition is applied as a time series to each segment and the wash-off rates are mainly driven by precipitation intensity and calibration parameters.

Continuous wet and dry atmospheric, phosphorus deposition data are not monitored through the NADP or CASTNet. Because of the lack of temporal data, an annual average value of total phosphorus deposition obtained from regional studies will be dispersed using the MONTH-DATA block in HSPF. Values of total phosphorus atmospheric, deposition fluxes range from 0.037 kilogram per hectare per year (kg/ha/yr) to 0.082 kg/ha/yr [Yang et al., 1996; Hu et al., 1998; Koelliker et al., 2004]. A midpoint value of 0.060 kg/ha/yr will be set initially with higher values occurring in the summer and lower values occurring in the winter [Yang et al., 1996]. The total flux and monthly distribution may be adjusted as part of the calibration process.

2.7 OTHER DATA

Additional, ideal items to represent in the model application include ground and surface-water withdrawals, irrigation, and diversions information and would be represented using time-series data. If available, time-series data and/or estimates will be provided by CTDEEP and RIDEM and processed to be included in the model. If time-series data are not available on a subwatershed or smaller level, estimations can be derived as described in the following sections.

2.7.1 DIVERSIONS AND WITHDRAWALS

Wild and Nimiroski [2004] estimated that self-supply withdrawals for domestic, commercial, industrial, and agricultural use averaged at approximately 2.3, 0.2, 0.5, and 1.4 million gallons per day (mgd) from 1995 to 1999 in the Pawcatuck River Watershed. According to the Gardner et al. [2011] Pawcatuck modeling report, municipal groundwater withdrawals averaged 7.18 mgd during their study period (2000 to 2004). The report stated that five major municipal water suppliers in the basin operated 16 wells and totaled 7.18 mgd between 2000 and 2004 with 13 minor, nonmunicipal suppliers withdrawing approximately 0.1 mgd each. Time-series data for the surface and groundwater withdrawals were provided by CTDEEP for the Connecticut portion of the watershed; however, RIDEM did not have surface and groundwater withdrawal time-series data to provide. Data used in the USGS

Pawcatuck River HSPF model application were evaluated and noted to be very consistent in nature. The day-of-the-year averages were used to generate the withdrawal time series for the Rhode Island portion of the watershed.

Data sources for diversions and withdrawals include the following:

- Diversions and withdrawals USGS Pawcatuck River HSPF Model.
- CTDEEP Uploaded Withdrawals to Shared Project Folder by Subwatershed.

2.7.2 IRRIGATION

Irrigation in the basin is mainly used for turf farms (4.4 square mile [mi^2]), golf courses (0.76 mi^2), vegetable farms (0.41 mi^2), and tree nurseries (0.005 sq mi^2). Because vegetable farms and tree nurseries make up a small portion of the watershed, they were grouped with cropland. The Gardner et al. [2011] Pawcatuck model report developed an equation using a logistic-regression analysis to estimate the probability of turf-farm irrigation on any given day from May 1 to October 31 based on the total PET during the previous 5 days and total precipitation during the previous 2 and 20 days. When the probability was greater than 0.40, the assumption was that irrigation had occurred. For the updated model application, the developed equation for turf/sod, shown in Equation 2-2, will be used to represent turf and golf courses because golf courses make up a very small fraction of the total land cover. The report stated that turf farms applied approximately 3,399 gallons per day per acre (gal/d/acre) and golf courses applied about 1,756 gal/d/acre [Gardner et al., 2011]. The ratio of turf farms to golf courses across the watershed will therefore be used to determine the irrigation application rate to these areas. The report also states that 40 to 50 percent of turf farms are kept fallow during each year; therefore, the calculated application rate will be reduced by 45 percent. On days determined to be irrigation days, the calculated application rate will be applied to the model land cover that represents turf farms and golf courses. If time series are available for irrigation wells and surface-water withdrawals, those time series will be used in the model application; otherwise, the report estimates of 9.32 mgd that occur on the irrigated land on irrigation days will be used to estimate the remaining withdrawals from local surface water [Gardner et al., 2011].

$$P = \frac{\left(\exp(-2.1149+51.917[PET5]-0.7777[PREC2]-0.5877[PREC20])\right)}{1+\left(\exp(-2.1149+51.917[PET5]-0.7777[PREC2]-0.5877[PREC20])\right)} \qquad (0\text{-}2)$$

where:

P = Probability of turf-farm irrigation on any day from May 1 to October 31

PET5 = Evapotranspiration during the previous 5 days (inches)

PREC2 = Precipitation during the previous 2 days (inches)

PREC20 = Precipitation during the previous 20 days (inches).

Data sources for irrigation include the following:

- Irrigation Application Estimate on Turf and Agricultural Land
- USGS Pawcatuck Model Application Turf Equation With NLDAS data.

3.0 SEGMENTATION AND CHARACTERIZATION

This section describes the methods proposed for the development of subwatershed, reach, and land-cover segments for the Pawcatuck River Watershed HSPF model application. The segmentation and characterization define water travel from the various land uses within each subwatershed to each reach segment.

3.1 DRAINAGE AREAS

Appropriate resolution for subwatershed areas will be defined by the needs of CTDEEP and RIDEM. Subwatersheds will ideally be small enough to represent impaired reaches and lakes, as well as monitoring points for calibration. The Connecticut Environmental Conditions Online (CTECO) local sub-basins in Connecticut will be used as the starting point for all of the subwatersheds in the Connecticut portion of the watershed. In addition to the Connecticut subwatersheds, The National Hydrography Dataset Plus (NHDPlus) Version 2 will be used. NHDPlus Version 2 is a national, geospatial, surface-water framework that includes elevation, flow accumulation, and flow-direction grids. To delineate areas of the Pawcatuck River Watershed that do not have detailed subwatersheds, batch points will be created in GIS at desired breakpoints and the Arc Hydro platform will be used with the NHDPlus Version 2. The two subwatersheds sets (Connecticut local and Arc Hydro generated) will be integrated into the final subwatersheds. Subwatersheds are shown in Figure 3-1.

Data used to develop subwatersheds include the following:

- Connecticut Local Subwatersheds (https://cteco.uconn.edu)
- NHDPlus Version 2 (https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data).

3.2 CHANNEL SEGMENTATION AND CHARACTERIZATION

The river channel network is the major pathway by which sediment and contaminants are transported from the watershed to the Pawcatuck River. Accurate representation or characterization of the channel system in the watershed for the model application is, therefore, important. The river-reach segmentation considers river travel time, riverbed slope continuity, cross-section and morphologic changes, entry points of major tributaries, sampling locations, and impairment status.

The channel characteristics are needed to define routing and stage-discharge behavior, bed composition for sediment, carbon, and nutrients, as well as bed/water-column interactions related to temperature, benthic oxygen demand, nutrient fluxes, and benthic algal mass. Because channel characteristics need to be defined spatially throughout the stream system, information from as many sites as possible will be used to define channel characteristics. Some benthic chlorophyll *a* data are available in the Pawcatuck River Watershed and will be used during the calibration process.

3.2.1 REACH PROPERTIES AND LAKE SELECTION

The NHDPlus high-resolution flowline layer will be used to create the primary reach network. The primary reaches layer will be edited as needed by using the DEM and an imagery basemap. The three

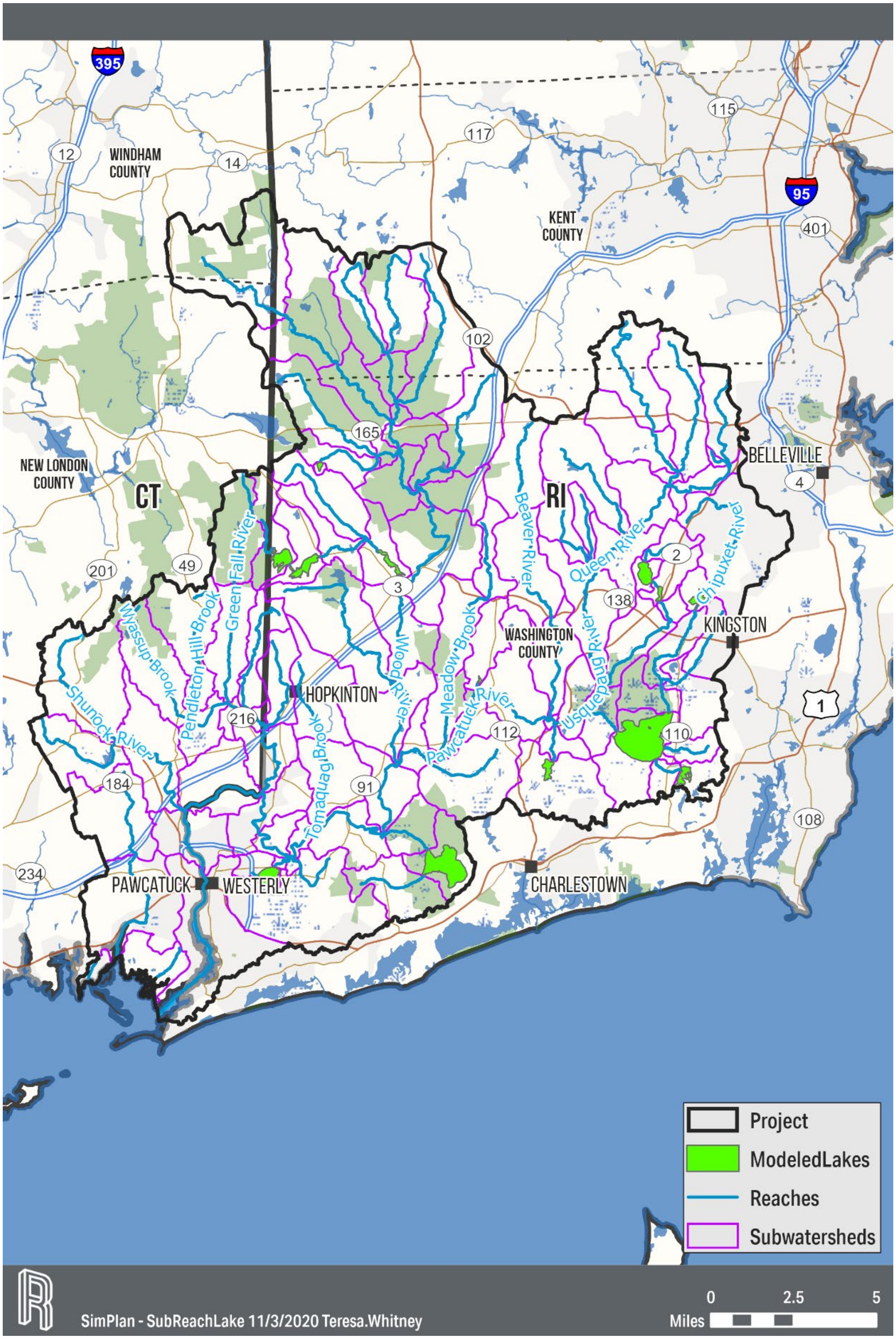

Figure 3-1. Pawcatuck Subwatersheds.

lakes that are listed in the Request for Proposal (RFP) as needing to be explicitly modeled are Watchaug, Worden, and Hundred Acre Lakes. Additional lakes selected to be explicitly modeled will be chosen based on the impairment status, lake size, data availability, and location in the watershed. If a lake is impaired for a modeled parameter is greater than 100 acres, is greater than 50 acres with a substantial dataset (1,000 or more measurements), or is not a headwaters lake and is greater than 50 acres, that lake will generally be explicitly modeled. One lake or stream segment will be modeled per subwatershed. The significant lakes for the explicit lake analysis were from the assessed lakes and ponds layers from Rhode Island and Connecticut. The final list of ponds to be explicitly model include: Barber, Chapman, Deep (Exeter), Hundred Acre, Locustville, Pasquiset, Tucker, Watchaug, White Brook, Wincheck, Worden, Yawgoo, and Yawgoog Ponds.

Reach length and slope are required to determine physically based parameters in the model application and to develop function tables (F-tables). These values will be calculated using ArcGIS for all nonlake reaches. Lakes that are modeled explicitly will be assumed to have an outflow; however, this assumption can be easily changed during calibration if any of the modeled lakes are determined as landlocked. Slope will be derived from the USGS 10-meter (m) by 10-m three-dimensional (3D) Elevation Program grid.

Data used to develop the reaches include the following:

- NHDPlus Version 2 High-Resolution Flowlines (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution)
- RIDEM and CTDEEP Assessed Streams and Lakes (https://www.rigis.org/ and https://portal.ct.gov/).

3.2.2 NUMBERING SCHEME

This section describes the numbering scheme that will be used for the watershed drainage network. Reach I.D.s consist of one to three numerical digits. Main-stem reaches occur along the Pawcatuck River and will be given I.D.s that end in zero (i.e., 0) and will be assigned an odd-tens digit (i.e., middle number) if they represent a stream segment (e.g., 110, 130, 150, and 190 in the schematic), and an even-tens digit if they represent a lake (e.g., 120 and 160 in the schematic). Tributaries will be assigned an odd reach I.D. for the ones digit (i.e., end number) if they represent a reach (e.g., 141, 143, and 153 in the schematic) and an even number if they represent a reservoir (e.g., 142 in the schematic). The tens-digit of the tributary reach I.D.s will correspond with the downstream, main-stem reach I.D. (e.g., 111 and 113 flow into 120). Reach I.D.s for subwatersheds and reaches will be numbered in order beginning with lower numbers upstream and ending with higher numbers downstream. If the next logical downstream, main-stem reach I.D. is not used, the downstream reach will be given the next largest main-stem reach I.D. For example, if a reach downstream of a main-stem reach with a reach I.D. of 170 and five tributary reaches (i.e., 171, 173, 175, 179, and 181) flow into the next downstream, main-stem reach, then that next main-stem reach would need to haven a reach I.D. of 190. Each subwatershed will typically only contain one waterbody (i.e., reach or lake) and will be given the corresponding reach I.D.

3.2.3 F-TABLE DEVELOPMENT

This section describes the development of F-tables, which are required by the HSPF model to route water through each modeled reach (i.e., lake or stream). An F-table summarizes the hydraulic and geometric properties of a reach and is used to specify functional relationships among surface area, volume, and discharge at a given depth.

3.2.3.1 LAKE F-TABLES

Data for lake F-table calculations include surface area and volume at various water elevations (depths) and overflow information. When available, surface-area, volume, depth, spillway length, height above sill, and lake runout elevation data will be used for F-table development. Because these data are often unavailable, the F-tables will be based on the average values where data are missing, which is sufficient for the purposes of this model. If additional data become available, the data will be incorporated into the existing model application. The equations that will be used to calculate flows from lakes at different water elevations, as well as any assumptions made, are discussed in this section. For simplicity and because of the lack of overflow data, the equation of discharge for overflow spillways will be used to calculate discharge from lakes (Equation 3-1). Because of the project scale, coefficient correction factors for overflow calculations will not be used and side contractions of the overflow and approach velocity have been disregarded, which allows for using the equation in its simplest form.

$$Q = C \times L_e \times H^{1.5} \tag{0-3}$$

where:

Q = Discharge (cubic feet per second[cfs])

H = Water depth above weir (head, feet [ft])

L_e = Effective length of crest (ft)

C = Variable coefficient of discharge.

The total head (H) used in the equation will be calculated at variable water levels as the difference between the water-surface and outlet elevations. The outlet will be assumed to be at the maximum recorded depth (if available) or the maximum contour depth. An effective length of the crest (L_e) can be derived from a spillway length. When a spillway length is not available the mean length of all of the available sites will be assumed. At lake depths below the outlet, L_e will be set equal to the spillway length. At lake depths above the outlet, L_e varies as a function of depth and will be increased assuming a 0.02 floodplain slope at each end of the crest. The variable coefficient of discharge (C) will be calculated using an empirical relationship derived by plotting *x-y* points along a basic-discharge coefficient curve for a vertical-faced section with atmospheric pressure on the crest from the U.S. Bureau of Reclamation [1987] (Equation 3-2):

$$C = 0.1528 \times ln\left(\frac{P}{H_d}\right) + 3.8327 \tag{0-4}$$

where:

P = Crest height (ft)

H = Head (ft).

The crest height (P) will be assumed as the height above the sill (if available). The head (H) will vary with the water surface and will be calculated as described in the previous paragraph. When the height above the sill is unavailable, the mean value from all of the available sites will be assumed.

After the available data are collected and combined, an F-table will be developed for each lake by calculating the surface area, volume, and discharge over a range of depths. F-tables for lakes with contour data will be created using the depths, surface areas, and volumes calculated with the Bathymetry Volume and Surface Area ArcGIS ModelBuilder tool. This tool creates a separate, triangulated irregular network (TIN) for each lake. The surface volume portion of the tool will be used to calculate the area and volume below specified depths. F-tables for lakes without contour data will be developed using the calculated surface area, volume, and depth relations. For these lakes, the volume and surface area at incremental depths will be estimated using conical geometry and assuming a flat bottom for an inner circle with half of the radius of the maximum surface area. The highest contour (if available) or maximum depth will be assumed as the outlet. Depths will be added incrementally above the outlet until the F-table discharge exceeds the maximum observed discharge levels. The surface area and volume above the outlet will be calculated using conical geometry with an initial floodplain slope of 0.01. The discharge at each height above the outlet will be calculated using Equations 3-1 and 3-2. The discharge values of depths at or below the outlet will be zero. The initial value of the floodplain slope is arbitrary and can easily be adjusted during the calibration process. A similar data compilation process will be completed for reach-intersecting lakes that are not modeled explicitly or represented as wetlands, which is explained in the following stream F-tables discussion.

Data sources used to develop the lake F-tables include the following:

- CTDEEP (https://portal.ct.gov/DEEP/GIS-and-Maps/Data/GIS-DATA)
- RIDEM (http://www.dem.ri.gov/maps/mapfile/pondbath.pdf)
- National Inventory of Dams (https://nid.sec.usace.army.mil/ords/f?p=105:1)
- CTDEEP Dam Information Uploaded to Shared Folder
- RIDEM Environmental Resource Map (Regulated Facilities – Dam) (https://ridemgis.maps.arcgis.com/apps/webappviewer/index.html?id=87e104c8adb449eb9f905e5f18020de5).

3.2.3.2 STREAM F-TABLES

Data requirements for stream F-table development include cross-section and discharge measurements. Cross-section measurements will be obtained from the width, depth, and area measurements provided by CTDEEP and RIDEM; HEC-RAS models, where available; USGS measurements; and Light Detection and Ranging (LiDAR) data, where available. When more than one cross section is available within the same reach, the cross section from the furthest downstream site will be assigned to the entire reach. Main-stem reaches for which cross-section data are unavailable will be assigned a representative cross section using best engineering judgment. Representative main-stem cross sections will be assigned based on the nearest available downstream, main-stem cross section because a cross-section area generally increases from upstream to downstream. Tributary reaches for which cross-section data are unavailable will be assigned a representative tributary cross section based the proximity to an available cross section and similar drainage area. After each reach is assigned the most appropriate cross section based on the location and drainage area, discharge will be calculated for each reach by using length, slope, and cross-section data with the Manning's equation shown in Equation 3-3. The channel slope (S) for each reach will be calculated by dividing the difference between the maximum and minimum elevations by the reach length.

$$Q = \frac{1.486}{n} \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \qquad (0\text{-}5)$$

where:

Q = Discharge (cfs)

n = Manning's roughness coefficient

A = Cross-section area (ft^2)

R = Hydraulic radius (ft)

S = Channel slope.

Manning's roughness coefficients (n) of 0.04 and 0.10 will be used for the channel and floodplain, respectively. The values for the floodplain slope, channel slope, Manning's roughness coefficient, and horizontal bank extension length will be set based on local topography and by using best engineering judgment, and the values can easily be adjusted during the calibration process. After the required data are collected and compiled, an F-table will be developed for each reach by calculating the surface area, volume, and discharge over a range of depths. To allow the F-table to handle large storm flows, the cross section can be extended 1,000 ft horizontally beyond each bank. The floodplain slope will be assumed as 0.05. The volume and surface area will be calculated with the cross sections and stream segment lengths. HEC-RAS models, where available, provide great detail and can be used to obtain F-tables by running models at different steady flows. The depth, surface area, and volume at each flow and cross section can then be multiplied by the distance from the upstream to the downstream cross sections, and the length-weighted parameters can then be summed for each reach. Final F-table parameters for each reach can be obtained by dividing the sum by the total reach length. The data used to calculate the elevation and slope for the model includes the USGS 3D Elevation Program (https://www.usgs.gov/core-science-systems/ngp/3dep).

Data used to develop the stream F-tables include the following:

- USGS Stream-Gaging Notes Uploaded to Shared Folder
- USGS Stream Measurements (https://waterservices.usgs.gov/nwis/)
- USGS Flood Inundation Maps (https://pubs.er.usgs.gov/publication/sir20185112)
- HEC-HMS Models Provided by Connecticut Department of Transportation (CTDOT) via CTDEEP
- USGS 3D Elevation Program (https://www.usgs.gov/core-science-systems/ngp/3dep).

3.3 LAND SEGMENTATION

Land-use, or land-cover, data are a critical factor in modeling watersheds, as these data provide the detailed characterization of the potential pollutant sources entering the reaches as nonpoint-source contributions. The land-use distribution also has a major determining impact on the hydrologic response of the watershed. The major land use in the Pawcatuck River Watershed is forest, which makes up more than 70 percent of the total area.

This section describes how the Pervious Land Segment (PERLND) and Impervious Land Segment (IMPLND) module-use categories were selected for explicit representation in the model application. The PERLND and IMPLND blocks of the UCI file contain most of the parameters that describe the way that water flows over and through the watershed. The objective of this task will, therefore, be to separate the watershed into unique land segments by using physical watershed characteristics to effectively represent the variability of hydrologic and water quality responses in the watershed. The primary watershed characteristics selected for the PERLND and IMPLND categorization include drainage patterns, meteorological variability, land-cover, and soil properties. MS4 areas will also be represented because of their link to permitting and water management. MS4 areas in Connecticut have been provided by CTDEEP and RIDEM. These characteristics will be selected based on the significance of their influence on hydrologic processes and water quality constituents of interest, as well as the quality and availability of spatial data associated with the characteristics.

3.3.1 ELEVATION

Topography provides elevation and slope values for the project area that are important to setting up HSPF as these values are needed for characterizing the landscape and land areas of the watershed. The flow accumulation and direction derived from elevation raster data are used to delineate subwatersheds. Average elevations and slopes are also calculated for each model subwatershed.

The delineated subwatershed models are linked to the pervious or impervious lands that drain to the subwatersheds in the schematic block of the UCI file. Aggregating the subwatersheds into hydrozones based on meteorological variability will provide initial boundaries for the pervious and impervious land segments and allow for accurately representing the hydrologic processes while reducing computational demands. The procedures for determining the PERLND and IMPLND categories within each hydrozone are described in the following paragraphs. The 3D Elevation Program from the USGS has 10-m by 10-m elevation data available for download across the United States at (https://www.usgs.gov/core-science-systems/ngp/3dep). These 3D Elevation data will be used to calculate the slope information for this model application.

3.3.2 LAND USE

The State of Rhode Island has a 2011 land-cover layer available through (https://www.rigis.org/datasets/land-use-and-land-cover-2011), and the State of Connecticut has a 2015 land-cover layer available through (https://clear.uconn.edu/projects/landscape/index.htm). Land covers for the two states will be aggregated/reclassified into a set of model land covers that will be used to develop the PERLND and IMPLND classifications within each hydrozone in the Pawcatuck River Watershed. These data will be used to define the movement of water through the system (i.e., infiltration, surface runoff, and water losses from evaporation or transpiration) that is significantly affected by the land cover and its associated characteristics. A hydrologic soil group will also be represented on forest land, which makes up a very large portion of the total land cover. The Connecticut land-cover layer does not divide the developed land classification into different density categories; therefore, the distribution of National Land Cover Database (NLCD) 2016 developed density categories will be applied to the Connecticut developed land-cover class. The Rhode Island land-cover layer does not include a turf and grass category; therefore, the distribution of the National Agricultural Statistics Service Cropland Data Layer 2019 (https://clear.uconn.edu/projects/landscape/download/Landcover2015_v2-03_ctstp83.zip) (Sod/Grass Seed versus all of the other cropland categories) will be applied to the Rhode Island cropland land-cover class.

3.3.2.1 PERVIOUS AND IMPERVIOUS LAND CLASSIFICATION

The number of operations (e.g., PERLND, IMPLND, RCHRES, PLTGEN, and COPY) allowed in one HSPF model application is limited; therefore, the categories represented in each state land-cover layer will be aggregated into relatively homogeneous model categories. Forest is the predominant land-cover class and, therefore, will be segmented to represent distinct forest types (e.g., deciduous and coniferous) and Hydrologic Soil Groups (HSGs). The Soil Survey Geographic Database (SSURGO) from the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) [2020] will be used to determine the HSG (AB versus CD). Figures 3-2 and 3-3 show the general reclassification schemes for converting the Connecticut and Rhode Island land-cover classes to the model land-cover classes. Tables that show more detailed land-cover reclassifications are provided in Appendix A. The HSG distributions by subwatershed can also be used as a basis for model parameterization related to infiltration and soil-moisture capacity values in the model, and the erodibility factor for each PERLND can be used to parameterize the erodibility factor of soils in the watershed. The percent of each HSG in the Pawcatuck River Watershed is shown in Table 3-1.

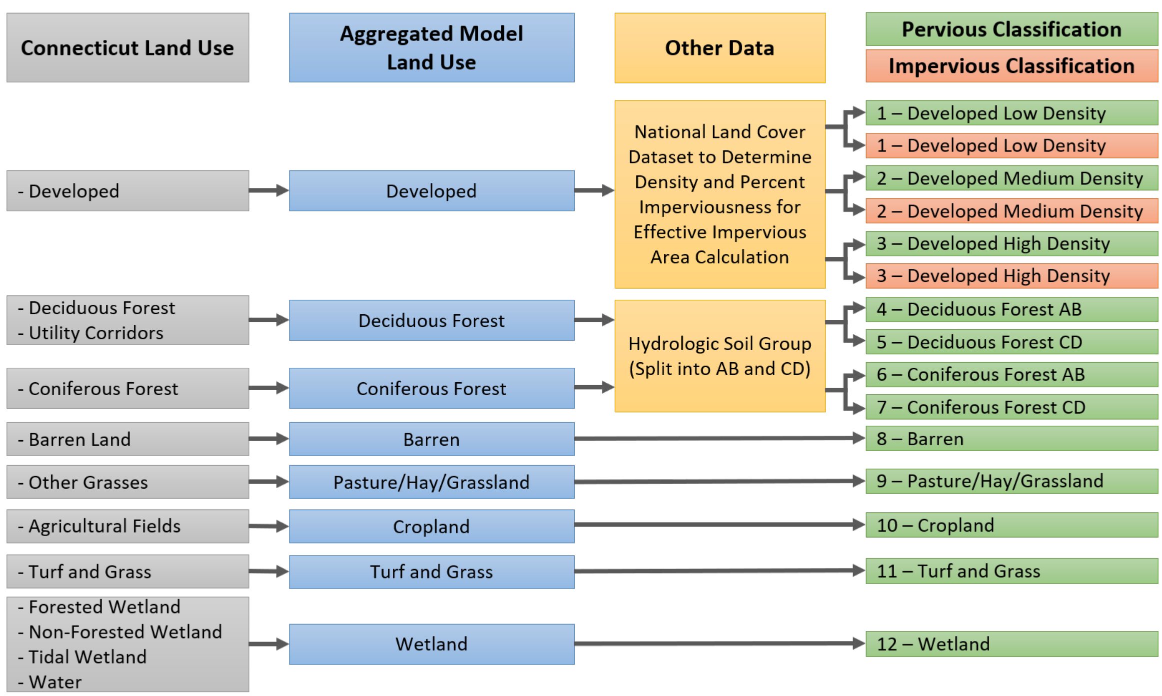

Figure 3-2. Connecticut Land-Use Category Aggregation.

Lakes and reservoirs that will not be explicitly modeled or connected to reach geometry will be modeled with the wetland category. The implications of modeling these waterbodies as wetlands are not significant. Slight differences do exist between lakes and wetlands, but lakes modeled as wetlands are generally very small and likely have similar pan evaporation as wetlands. The main differences between wetlands and small ponds/open water include different amounts of vegetation and different groundwater interaction. Lakes and reservoirs that will be explicitly modeled will be represented with an F-table rather than a modeled land cover.

The Pawcatuck River Watershed has several feedlots. Data have been provided by CTDEEP and RIDEM that include the number of dairy cattle in each subwatershed. Feedlot data provided will be used estimate fertilizer application to inform the calibration process throughout the watershed. Manure from the feedlots will be assumed to have spread into the subwatersheds that the feedlots are located in.

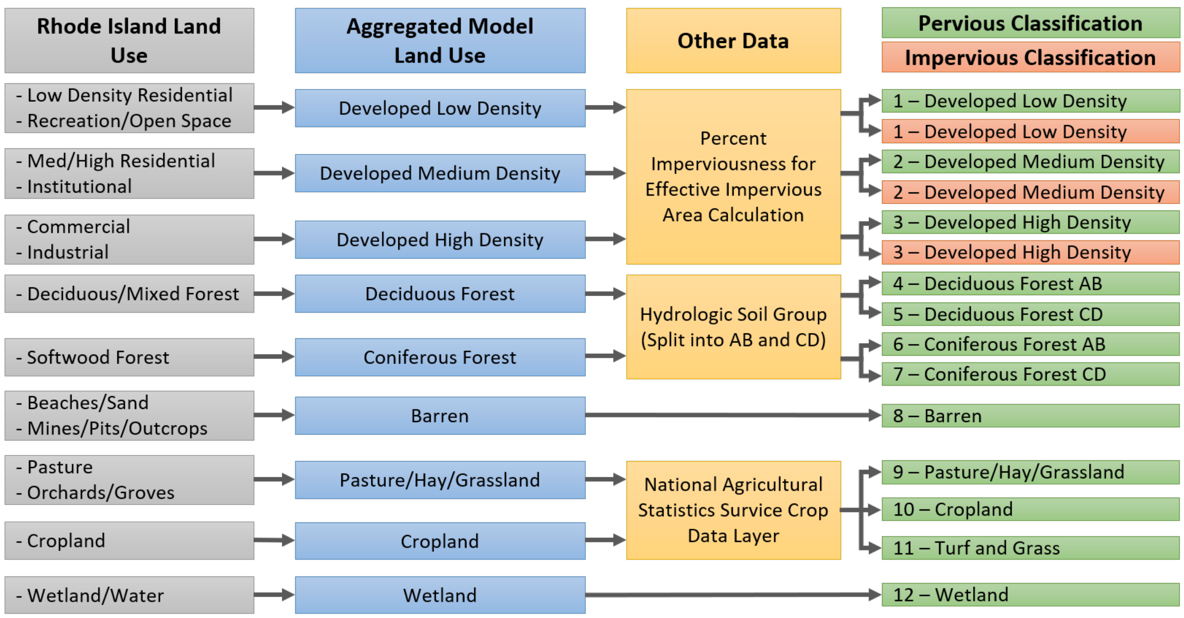

Figure 3-3. Rhode Island Land-Use Category Aggregation.

Table 3-1. General Description of Hydrologic Soil Groups

Hydrologic Soil Group	Abbreviated Description	Project Area (%)
A	Sand; sandy loams with high-infiltration rates. Well-drained soils with high transmission.	14
AD	A-group soil, if drained.	2
B	Silt loam or loam soils, moderate infiltration, moderately drained.	47
BD	B-group soil, if drained.	13
C	Sandy, clay loams. Low-infiltration rates; impedes water transmission.	6
CD	C-group soil, if drained.	6
D	Heavy soils, clay loams, silty, clay. Low-infiltration rates that impede water transmission.	11
Unclassified	No classification determined.	4

The Effective Impervious Area (EIA) is important to accurately represent in watershed models because of the EIA's impact on the hydrologic processes that occur in urban environments. The term "effective" implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river) and the resulting overland flow will not run onto pervious areas and, therefore, will not have the opportunity to infiltrate along the respective overland flow path before reaching a stream or waterbody. The average impervious area for each developed model category (low, medium, and high) in each Rhode Island subwatershed will be derived from the Rhode Island's impervious layers using the mean impervious area. The Connecticut developed model categories assigned based on the NLCD 2016 distribution will be given the average imperviousness for each category from the Rhode Island data. The data represent the percent impervious area (TIA), which will be used to determine the percent EIA by using Equation 3-4 from Sutherland [2000]. This equation is also referenced as the default equation in Appendix 3 (*Impervious Cover in Connecticut Municipalities*) of the *Connecticut Watershed Response Plan for Impervious Cover* [Connecticut Department of Energy & Environmental Protection, 2015] for areas that are mostly stormsewered, with curb and gutter, and with residential rooftops connected to the MS4.

$$EIA = 0.1(TIA)^{1.5}, TIA \geq 1 \tag{0-6}$$

Data sources used to develop the model land cover include the following:

- Connecticut
  - Connecticut Land Cover 2015, (https://cteco.uconn.edu)
  - Soils, State Soil Geographic (STATSGO) Dataset, (https://www.nrcs.usda.gov)
  - Percent Impervious, NLCD 2016, (https://www.mrlc.gov) and CLEAR IC (https://clear.uconn.edu/)
- Rhode Island
  - Rhode Island Land Cover 2011 (http://www.rigis.org)
  - Soils, STATSGO (https://www.nrcs.usda.gov)
  - Percent Impervious, NLCD 2016 (https://www.mrlc.gov) and RIDEM Impervious (http://www.rigis.org).

Data sources that will be used to develop an understanding of the manure application on agricultural land include animal unit information from RIDEM and CTDEEP uploaded to shared project folder; the data will be summarized by Subwatershed for Each State.

3.3.2.2 MUNICIPAL SEPARATE STORM SEWER SYSTEMS

Polluted stormwater runoff is commonly transported through MS4s before being discharged into local waterbodies. Certain MS4s are required to obtain NPDES permits and develop stormwater management programs that describe stormwater-control practices that will be implemented following permit requirements to minimize the discharge of pollutants from the storm sewer system [National Pollutant Discharge Elimination System, 2020]. Representing regulated MS4s in the watershed in the HSPF model applications is important. GIS layers of the MS4 areas (i.e., polygons) were provided by CTDEEP and RIDEM for Connecticut and for Rhode Island, respectively. MS4 areas will be represented in the model application schematic by using a separate mass link so that flow from those areas can be identified as separate from flow that originates in non-MS4 areas.

Data sources used to develop the modeled MS4 areas include the following:

- Connecticut MS4s, CTDEEP Staff Uploaded MS4 spatial data to Shared Project Folder
- Rhode Island MS4s, RIDEM Phase II MS4s (www.dem.ri.gov/maps).

3.3.2.3 SEPTIC SYSTEMS

A septic system falls under the category of onsite wastewater treatment systems (OWTS). OWTS are used by many households in the Pawcatuck River Watershed. Connecticut and Rhode Island have polygons that represent areas that are sewered. Blockpop points, which provide the populations from the 2010 United States Census, that fall outside of the sewered areas will be assumed to be on septic systems. OWTS are generally responsible for some pollutant loads to either the groundwater or tributaries. OWTS will be represented in the model application as a constant load and assumed to discharge at 50 gallons per person, per day. Results from the Connecticut Phase II OWTS study and the modeling efforts from the nitrogen loading to Long Island Sound embayments study by Vaudrey et al. [2016] will be used to inform and compare the OWTS simulation in HSPF. Attenuation estimates/ factors will be set in the model and may be calibrated but will stay within the range of the two studies (0.44–0.51). This information, along with nonpoint-source export estimates and point-source data, will be used to achieve the best possible representation of the source allocation while maintaining a good calibration of instream pollutant concentrations. The BOD_5 loads will be converted to CBOD by using a factor of 1.2 for untreated waste [Thomann and Mueller, 1987].

Data sources used to develop the modeled septic systems include the following:

- Individuals on Septic Systems
  - CTDEEP Staff Uploaded Connecticut Sewered Area Spatial Data to Shared Project Folder
  - Rhode Island Sewered Areas (http://www.rigis.org)
  - 2010 United States Census Blockpop (https://www.census.gov/programs-surveys/decennial-census/data.html)
- Septic Failure Rates and Loading Estimates
  - CTDEEP Will Upload Septic Study to Shared Project Folder. Data From Study to Be Extrapolated to Rhode Island.

4.0 CALIBRATION AND VALIDATION

4.1 CALIBRATION AND VALIDATION TIME PERIODS

Time-period selection for model calibration and validation depends on numerous factors, including the availability of data for model operations, land-use data for model setup, climate variability, and observed data for model-data comparisons. The principal time-series data that are needed for hydrologic and water quality calibration (i.e., meteorological, point-source, atmospheric deposition, observed flow, and water quality observations) indicate that long-term simulations (> 20 years) are possible at several of the stream-flow gages within the Pawcatuck River Watershed. Partial record periods, while not ideal, can still be used for consistency checks as part of the calibration and validation process.

The continuous meteorological and hydrological data are available for the past 40 years, and discrete water quality sampling data are available for the past 70 years; however, more-intensive water quality sampling occurs after 2006. Based on these considerations, the preliminary selection of the hydrology calibration is for 2006 to 2020 and the validation period is from 1991 to 2005. The date ranges for the calibration and validation periods include mixed wet and dry periods, as shown in Figure 4-1. For water quality calibration and validation, the same time periods will be selected; however, these periods may be adjusted based on data availability. The long-term simulation greater than20 years) is also a form of validation as well.

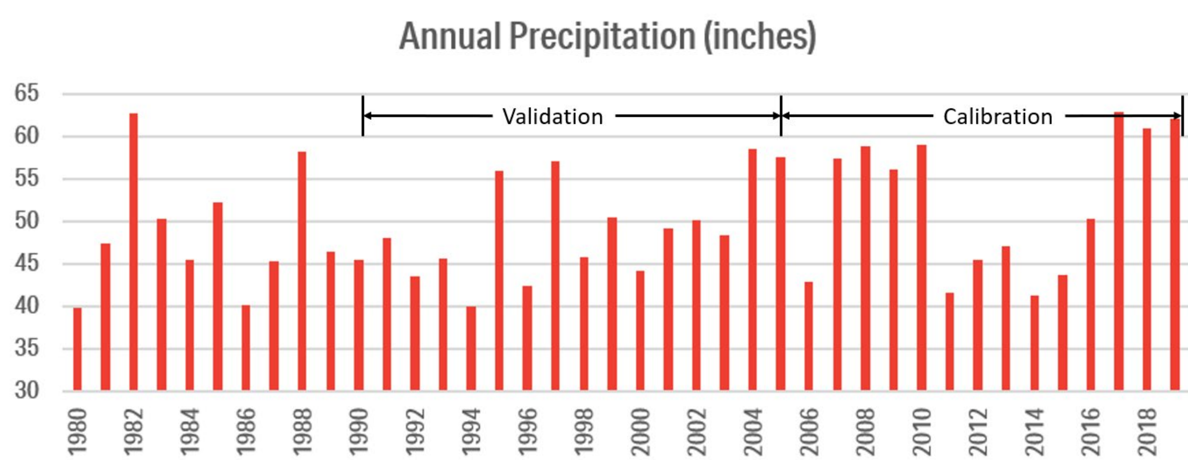

Figure 4-1. Average Annual Precipitation for Modeled Watershed Areas (Connecticut and Rhode Island) From PRISM for Years 1980 to 2019.

4.2 HYDROLOGY CALIBRATION AND VALIDATION PROCEDURES AND COMPARISONS

The Pawcatuck River Watershed model will be calibrated through an iterative process of making parameter changes, running the model, producing comparisons of simulated and observed values, and interpreting the results. This process will first occur for the hydrology portions of the model, followed by the water quality portions. The procedures have been well established over the past 35 years, as described in the Application Guide for HSPF [Donigian et al., 1984] and summarized by Donigian [2002]. The hydrology calibration process is greatly facilitated by using scripted processes in MATLAB.

Calibrating HSPF to represent the hydrology of the Pawcatuck River Watershed is an iterative trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including wet and dry conditions, to observe how well the simulation represents the hydrologic response under various climatic conditions. By iteratively adjusting specific calibration-parameter values within accepted and physically based ranges, the simulation results are changed until an acceptable comparison of simulation and recorded data is achieved.

The standard HSPF hydrologic calibration is divided into four phases:

- **Establish an annual water balance.** This phase consists of comparing the total annual simulated and observed flows (in inches) and is governed primarily by the input of rainfall and evaporation and the parameters for the lower zone nominal storage (LZSN), lower-zone ET parameter (LZETP), and infiltration index (INFILT).
- **Adjust low-flow/high-flow distribution.** This step is generally performed by adjusting the groundwater or baseflow because the distribution between high and low flow is the easiest to identify in low flow periods. Mean daily flow conditions are used and the primary parameters involved are the INFILT, groundwater recession (AGWRC), and baseflow ET index (BASETP).
- **Adjust storm flow/hydrograph shape.** The storm flow, which is compared in the form of short, timestep (1-hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the upper-zone storage (UZSN), interflow parameter (INTFW), interflow recession (IRC), and overland flow parameters (length of the overland flow plane [LSUR], Manning's N [NSUR], and slope of the overland flow plane [SLSUR]). INFILT can also be used for minor adjustments.
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over each month and season are compared to see if runoff needs to be shifted from one month or season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters vegetal interception (CEPSC), LZETP, and UZSN. Adjustments to variable groundwater recession (KVARY) and BASETP are also used.

The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and the HSPF hydrologic calibration expert system (HSPEXP) [Lumb et al., 1994; Duda et al., 2019]. The same model-data comparisons will be performed for the calibration and validation periods. The specific comparisons of simulated and observed values include:

- Annual and monthly runoff volumes (inches)
- Daily flow time series of flow (cfs)
- Storm-event periods (e.g., hourly values) (cfs)
- Flow frequency (flow-duration) curves (cfs).

In addition to the preceding comparisons, the water-balance components (input and simulated) are reviewed. This effort involves displaying model results for individual land uses, as well as the entire watershed, for the following water-balance components:

- Precipitation
- Total Runoff (sum of the following components):
  - Overland flow

    » Interflow
    » Baseflow
- PET
- Total Actual ET (sum of following components):
    » Interception ET
    » Upper-zone ET
    » Lower-zone ET
    » Baseflow ET
    » Active-groundwater ET
- Deep-Groundwater Recharge/Losses.

Although observed values are not available for every water-balance component listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land-use categories. This consistency (or reality) check is separate with data independent of the modeling (except for precipitation) to ensure that land-use categories and the overall water balance reflect the local conditions.

Figure 4-2 provides value ranges for the correlation coefficients (R) and coefficient of determination (R^2) for assessing the model performance for daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows given the uncertainties in the timing of model inputs, mainly precipitation. Table 4-1 lists the general calibration and validation tolerances or targets that have been provided to model users as a part of HSPF training workshops over the past 20 years (e.g., Donigian [2000]). The values in the table attempt to provide general guidance in terms of the percent mean errors, or differences between simulated and observed values, so that users can gage what level of agreement or accuracy (i.e., very good, good, fair) can be expected from the model application. The target level of accuracy for this project will correspond in Table 4-1 to "Good" or "Very Good" results at more-downstream, main-stem calibration sites, and "Fair" at more-upstream tributary sites. Accuracy targets are highly dependent on the amount and quality of available data and, consequently, the targets will be finalized after the data gaps are analyzed.

Figure 4-2. R and R^2 Value Ranges for Model Performance.

Table 4-1. General Calibration and Validation Targets or Tolerances for HSPF Applications [Donigian, 2000]

Calibration Parameter	Difference Between Simulated and Recorded Values (%)		
	Very Good	Good	Fair
Hydrology/Flow	< 10	10–15	15–25

Stipulations:
Relevant to monthly and annual values; storm peaks may differ more than monthly and annual values.
Quality detail of input and calibration data.
Purpose of model application.
Availability of alternative assessment procedures.
Resource availability (i.e., time, money, personnel).

The caveats at the bottom of the table indicate that the tolerance ranges should be applied to mean values and that individual events or observations may show larger differences and still be acceptable. The level of agreement to be expected also depends on numerous site- and application-specific conditions, including the data quality, purpose of the study, available resources, and available alternative assessment procedures that could meet the study objectives.

Given the uncertain state of the art in model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, absolute criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals. However, most decision-makers want a definitive answer to the question, "Is the model good enough for this evaluation?" Consequently, for the Pawcatuck River Watershed modeling effort, the targets and tolerance ranges for daily flows are proposed to correspond, at a minimum, to a fair to good agreement, and the ranges for monthly flows should correspond to good to very good agreement for calibration and validation at the primary calibration flow gages. Ideally, secondary calibration flow gages should correspond to a fair agreement. Poor to fair ranges will be allowed for the tertiary sites because these sites are on smaller tributaries and usually have a much shorter representative dataset to work with.

For any watershed modeling effort, the level of expected agreement is tempered by the complexities of the hydrologic system, the quality of the available precipitation and flow data, and the available information to characterize the watershed and quantify the human impacts on water-related activities. These tolerances are applied to comparisons of simulated and observed mean flows, annual runoff volumes, mean monthly and seasonal runoff volumes, and daily flow-duration curves. Larger deviations would be expected for individual storm events and flood peaks in both space and time. The values shown in Figure 4-2 were primarily derived from HSPF experience and past efforts on model performance criteria; however, the values do reflect common tolerances accepted by many modeling professionals.

4.3 WATER QUALITY CALIBRATION

Water quality calibration is also completed through an iterative process of parameter adjustments and comparisons of simulated and observed values and is facilitated by using scripted processes in

MATLAB and HSPEXP+. The model predictions are the integrated result of all of the assumptions used in developing the model input and representing the modeled sources and processes. Differences in model predictions and observations require the model user to reevaluate these assumptions for the estimated model input and parameters and consider the accuracy and uncertainty in the observations.

Water quality monitoring sites are shown in Figure 4-3 and summarized in Appendix C. Sites with more than 1,000 total applicable samples during the modeling period are considered primary calibration sites, sites with more than 500 total applicable samples during the modeling period are considered secondary calibration sites, and sites with less than 500 samples are tertiary, or considered the third priority. A calibration goal is to keep the parameterization consistent throughout the project area to avoid curve fitting. This is attained by prioritizing the calibration at the primary calibration sites. The following steps will be performed at each of the calibration stations after the hydrologic calibration and validation, as well as completing the input development for the point-source, atmospheric, and other contributions:

1. Estimate all of the model parameters, including land-use-specific accumulation and depletion/removal rates, wash-off rates, and subsurface concentrations.
2. Tabulate, analyze, and compare the simulated, annual, nonpoint loading rates with the expected range of nonpoint loadings from each land use (and each constituent) and adjust the loading parameters, when necessary.
3. Calibrate instream water temperature, sediment, DO, and nutrients to the observed data.

The primary calibration parameters involved in characterizing landscape-erosion processes are the coefficients and exponents from three equations that represent different soil detachment and removal processes. Nonpoint sources of total ammonia and nitrate-nitrite will be simulated through accumulation and depletion/removal and a first-order, wash-off rate from overland flow. Because of the affinity of orthophosphate to bind to sediments, orthophosphate will be simulated using a linear relationship with sediment washing off of the land. BOD will also be simulated using sediment associated wash-off. Subsurface flow concentrations will be estimated on a monthly basis. Atmospheric depositions of nitrogen and ammonia will be applied to all of the land areas and contribute to the nonpoint-source load through the buildup/wash-off process.

The nonpoint loading rates, which are sometimes referred to as export coefficients, are highly variable with value ranges up to an order of magnitude depending on management practices and the local conditions of soils, slopes, topography, and climate. The simulated, nonpoint-source loading rates from different land uses will be compared against the nonpoint-source loading rates summarized in previous studies (e.g., AQUA TERRA Consultants [2001, 2002, 2015]).

The model simulates the instream and lake processes that contribute to sediment transport, algal growth, nutrient consumption, and DO dynamics. The sediment behavior for each size class will be investigated to ensure that the sediment dynamics reflect field observations. Although HSPF does not explicitly simulate stream-bank contribution dynamics, these processes will be implicitly included by allowing the streambed to contribute those loads. All of the required instream parameters will be specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. The processes in the

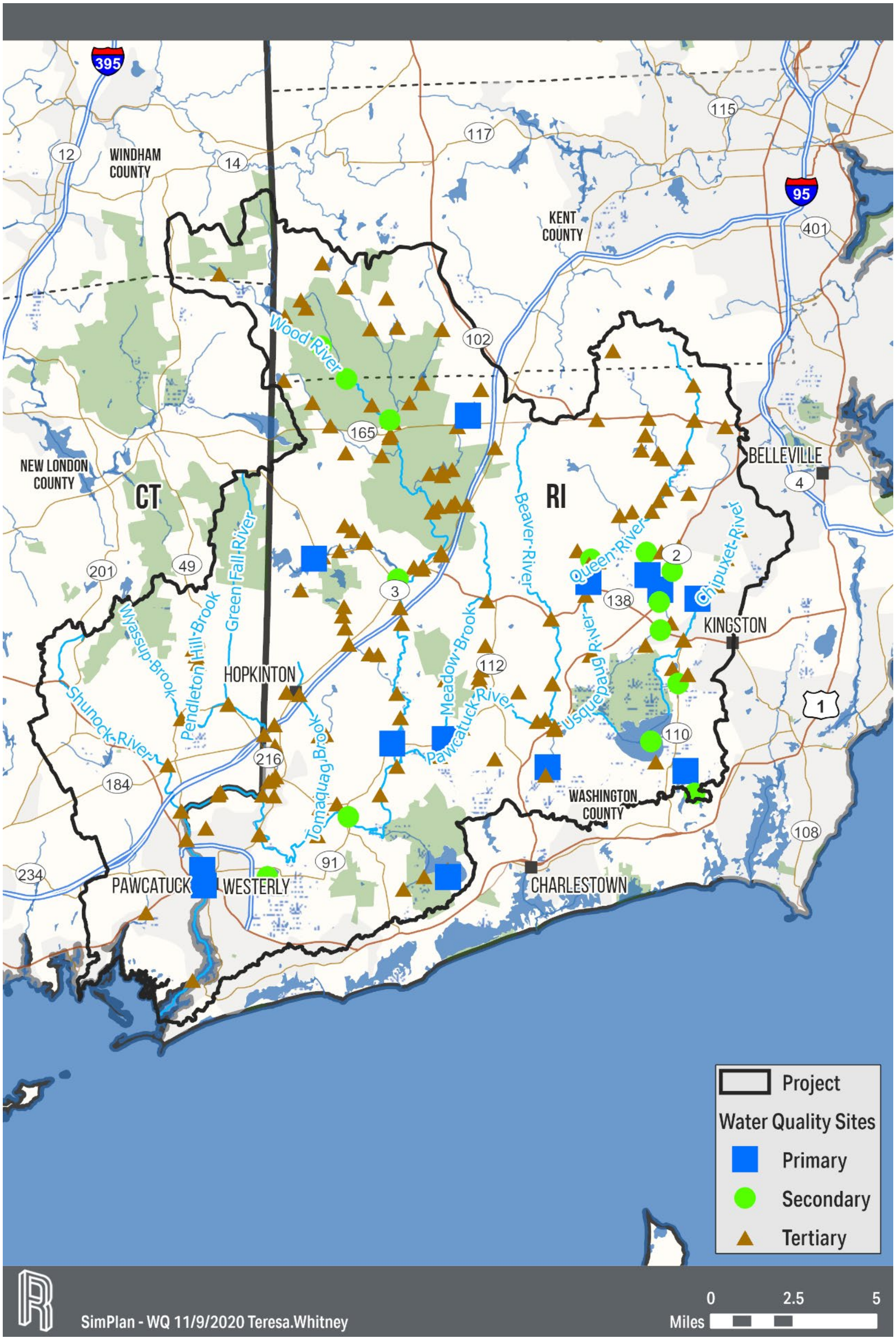

Figure 4-3. Pawcatuck River Water Quality Monitoring Locations.

instream portion of the model include BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and reaeration rates. Atmospheric deposition onto water surfaces will be represented in the model as a direct input to the lakes and river systems. Biochemical reactions that affect DO will be represented in the model application. The overall sources considered for BOD and DO include point sources such as WWTFs, nonpoint sources from the watershed, interflow, and active-groundwater flow.

The instream calibration will begin with the temperature and sediment and then to DO and nutrients. The DO and nutrient calibration will be conducted in tandem because these components depend on one another. The calibration requires developing time-series graphs to compare the simulated and observed water quality data. Instream water quality calibration will also include generating monthly boxplots, concentration-duration curves, and scatterplots of concentrations and corresponding flows. To assess the diurnal variability, hourly boxplots will be generated for temperature and DO. Sediment scour and deposition in the streambed for each reach over the period of simulation and nutrient budget will also be evaluated. An expanded calibration discussion with example plots is provided in Appendix B.

The essence of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets) while keeping the instream water quality parameters within physically realistic bounds and the nonpoint loading rates within the expected ranges from the literature. Table 4-2 shows the general water quality calibration targets or tolerances for HSPF applications. This calibration should be accomplished while maintaining consistent parameters in each land-use category throughout the Pawcatuck River Watershed.

Table 4-2. General Calibration Targets or Tolerances for HSPF Applications [Donigian, 2000]

Calibration Parameter	Difference Between Simulated and Recorded Values (%)		
	Very Good	Good	Fair
Sediment	< 20	20–30	30–45
Water Temperature	< 7	8–12	13–18
Water Quality/Nutrients	< 15	15–25	25–35
Pesticides/Toxics	< 20	20–30	30–40

Stipulations:
Relevant to monthly and annual values; storm peaks may differ more than monthly and annual values.
Quality detail of input and calibration data.
Purpose of model application.
Availability of alternative assessment procedures.
Resource availability (i.e., time, money, personnel).

5.0 HSPF LINKAGE TO RECEIVING MODELS

The HSPF model is expected to provide nutrient loads, suspended sediment loads, and freshwater inputs to other site-specific models, including BATHTUB, WASP, and EcoGEM, as well as the 3D linked hydrodynamic water quality model that is being developed for Long Island Sound. The HSPF output is planned to be used with a future WASP model for the associated estuarine embayment as well as BATHTUB models of 100 Acre, Worden, and Watchaug Ponds in Rhode Island. Because the HSPF model is being developed at an hourly time step from 1991 through 2020, as long as receiving model time periods fall within this time period, the models should be able to be used together. The Pawcatuck River HSPF model application will be extended through 2022 when the Connecticut statewide models are extended. The reach calibration ends at USGS gage 0118500, but all of the land segments will be modeled to provide further boundaries for the WASP model.

Three main components must be considered when linking watershed models to receiving water quality models: spatial resolution, temporal resolution, and state variable mapping. RESPEC will work closely with the receiving model developers during the watershed delineation to ensure that the HSPF model provides results at the correct spatial resolutions. HSPF provides results at an hourly timestep but can be aggregated or averaged to any timestep, so the temporal resolution can easily be adjusted to fit the receiving model's requirements. Each receiving model will have state variables that are slightly different than HSPF and will have to be mapped using assumptions (e.g., factors for partitioning dissolved and particulate organic matter).

Some lakes are represented explicitly in HSPF as discussed in Section 3.2.1. HSPF represents in-lake water quality well, especially for lakes that do not stratify. The primary reason for representing these larger, more data intensive lakes in HSPF is because in-lake processes can lead to substantial changes in water quality such as settling of sediment. When these are represented in the model and data area available in the lakes, the next downstream reach is more accurately represented in HSPF. BATHTUB models are often used for TMDLs because they are widely accepted by the EPA. RESPEC has a method scripted in MATLAB to develop inputs for BATHTUB from HSPF outputs.

An example of HSPF to WASP linkage is shown in Table 5-1. After the map has been defined, a linkage process will be scripted in MATLAB to ensure consistency and repeatability in the method.

Table 5-1. Linkage Between HSPF Model Outflow Constituents and WASP System Constituents

HSPF Outflow Constituent	Constituents Included in the WASP Eutrophication Model	WASP System Type	Notes
ROVOL	Flow	NA	—
TAM-OUTTOT	Total Ammonia	NH-34	—
NO3-OUTTOT	Nitrate-Nitrite	NO3O2	Add HSPF NO3 and NO2 for WASP System NO3O2
NO2-OUTTOT			
PO4-OUTTOT	Dissolved Inorganic Phosphorus	D-DIP	—
N-REFORG-OUT	Dissolved Organic Nitrogen	ORG-N	Assumed factor to disperse dissolved and detrital nitrogen
	Detrital Nitrogen	DET-N	
P-REFORG-OUT	Dissolved Organic Phosphorus	ORG-P	Assumed factor to disperse dissolved and detrital phosphorus
	Detrital Phosphorus	DET-P	
C-REFORG-OUT	Detrital Carbon	DET-C	—
NA	Total Detritus	TOTDE	Calculated by WASP
BODOUTTOT	$CBOD_u$ – Watershed	CBODU	—
NA	$CBOD_u$ – Point Source	CBODU	Obtained from WDM
NA	$CBOD_u$ – Biological	CBODU	Calculated by WASP
DOXOUTTOT	DO	DISOX	—
ROSED-SAND	Sand	SOLID	—
ROSED-SILT	Silt	SOLID	—
ROSED-CLAY	Clay	SOLID	—
PHYTO-OUT	Phytoplankton	PHYTO	—
NA	Benthic Algae	MALGA	Calculated by WASP
NA	Benthic Algae Nitrogen	MALGN	
NA	Benthic Algae Phosphorus	MALGP	
ROHEAT	Water Temperature	WTEMP	—

NA = Not Applicable

6.0 PROPOSED MANAGEMENT SCENARIOS

The Pawcatuck River Watershed HSPF RFP states that the model simulations must be able to represent predicted future precipitation and various management scenarios involving discharge limits and land-use change. The development of the HSPF model described in this report allows for flexibility in creating management scenarios such as land-use conversion, development, meteorological variations and climate change, and best management practices (BMPs). CTDEEP and RIDEM have accounted for a minimum of five management scenarios and included climate change and population projections for 2050 as a part of these scenarios.

7.0 DATA MANAGEMENT

Two data types will be used to support the Pawcatuck HSPF modeling project: GIS and time-series data. The data types must change format as they are integrated into an HSPF model and are thus subject to possible errors. As is the case with electronic data acquisition, RESPEC will adhere to protocols that we have developed while performing abundant previous HSPF applications to ensure that we properly address quality assurance considerations related to preventing, detecting, and correcting electronic data manipulation errors. RESPEC will also adhere to protocols for data acceptance criteria described in the Pawcatuck River Watershed Modeling Quality Assurance Project Plan (QAPP) [Imhoff and McCutcheon, 2020]. RESPEC will maintain a copy of the project files on the network for a minimum of 5 years following completion of the project.

Consistent data management procedures will be used during the preprocessing, model calibration, and postprocessing stages of the project. All of the data and information collected and generated during this project will be stored in a project folder on RESPEC's network. Data processing will be completed using a combination of ArcGIS, MATLAB, Python, and the San Antonio River Authority (SARA) Timeseries Utility. RESPEC modelers will be responsible for adhering to and documenting data management practices that ensure the quality of data that are downloaded and/or manipulated. Original data sources will be documented to identify the website or contact person that provided the data, data query parameters, and data request correspondence. Original (unaltered) copies of all data sources used in the project will be retained in the project folder on RESPEC's network. Metadata will be included with spatial datasets. The SARA Timeseries Utility will be used to access WDM files which will be used to store model-input data such as meteorological, point-source, atmospheric deposition, and other time-series data.

GIS data will be used in a geodatabase feature-class format. The projection of all GIS data will be consistent. When new GIS data are added to a feature class, ArcPro automatically projects the data to match the projection of the feature class. Rhode Island has developed metadata standards that are summarized for any data submissions to the Rhode Island Geographic Information System (RIGIS) (https://info.rigis.org/data-resources/metadata-resources/). A sample metadataset at (https://portal.ct.gov/DOT/Engineering-Applications/Sample-Metadata) is provided by Connecticut.

Model inputs, including meteorological data, point-source data, and surface-water withdrawals, will be stored in a watershed data management (.wdm) file during the calibration process. The size of the .wdm files for the Pawcatuck River Watershed model is approximately 140 megabytes (mb). Model outputs at calibration gages will be stored in a set of binary (.hbn) files. The size of the .hbn files for the Pawcatuck River Watershed model will vary depending on the number of parameters and reaches that are included. During calibration, the observed water quality and hydrology data will be stored in Excel files with associated calibration reach numbers. The size of these files for the Pawcatuck River Watershed model is approximately 6 mb. Both .hbn files and .wdm files can be accessed using the SARA Timeseries Utility, which can be downloaded at https://www.respec.com/product/modeling-optimization/sara-timeseries-utility. Additionally, SAM files will be used as storage, and the SAM program will have the capability to allow the user to extract any model data.

Static SAM model files are currently downloaded to the user's local drive, and responsibility for downloading new versions is placed on the end user. RESPEC's IT and Water divisions have proposed working together as a part of the Connecticut statewide modeling to move the SAM program into the cloud and enhance the existing SAM functionality to bring data distribution and versioning to model files. The plan being considered would potentially leverage cloud data services, such as Kaggle, Qri, or an implementation of Data Version Control (DVC). A version-controlled repository could be programmed into SAM that would allow the application to verify input data for a model, inform the user if updated model datasets or new versions of scenarios exist, and ensure that decisions are based on the best available data.

8.0 DATA SOURCES

The following outline shows the data sources that will be used for each modeling component. All of the data were collected for the entire modeling period (i.e., January 1991 through July 2020), when available. QA/QC documents were not collected for federal or state data, since these datasets were assumed to have robust QA/QC:

- Meteorological
  - Precipitation, NLDAS (https://ldas.gsfc.nasa.gov/nldas/nldas-get-data), and PRISM (https://prism.oregonstate.edu/)
  - Evaporation, Temperature, Wind, Solar Radiation, Dewpoint, Cloud Cover, and Humidity, NLDAS (https://ldas.gsfc.nasa.gov/nldas/)
  - Snowfall and Snow Depth, NOAA Global Historical Climatology Network (GHCN) (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn)
- Discharge for Calibration
  - USGS NWIS (https://nwis.waterdata.usgs.gov/nwis)
- Water Quality for Calibration
  - Water Quality Data Portal (https://www.waterqualitydata.us/)
  - RIDEM and CTDEEP Uploaded Water Quality Data to Shared Project Folder
- Point-Source Data
  - EPA Echo (https://echo.epa.gov/)
  - RIDEM and CTDEEP Uploaded Point-Source Data to Shared Project Folder
- Atmospheric Deposition
  - Dry Nitrogen, CASTNet (https://www.epa.gov/castnet/)
  - Wet Nitrogen, NADP (http://nadp.slh.wisc.edu/)
  - TP, Regional Studies Cited in the Atmospheric Deposition Section 2.6
    - (https://link.springer.com/article/10.1023/A:1004954923033)
    - (https://www.sciencedirect.com/science/article/abs/pii/1352231096000945?via%3Dihub)
    - (https://link.springer.com/article/10.1023%2FB%3AWATE.0000022952.12577.c5)
- Subwatersheds
  - Connecticut Local Subwatersheds (https://cteco.uconn.edu)
  - NHDPlus Version 2 (https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data)
  - ArcPro Arc Hydro and Editing Tools
- Reaches and Lakes
  - NHDPlus Version 2 High-Resolution Flowlines (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution)
  - RIDEM and CTDEEP Assessed Streams and Lakes (https://www.rigis.org/ and https://portal.ct.gov/)
- Cross Sections for F-tables
  - USGS Stream-Gaging Notes Uploaded to Shared Folder

- USGS Stream Measurements (https://waterservices.usgs.gov/nwis/)
- USGS Flood Inundation Maps (https://pubs.er.usgs.gov/publication/sir20185112)
- HEC-HMS Models Provided by Connecticut Department of Transportation (CTDOT) via CTDEEP
- USGS 3D Elevation Program (https://www.usgs.gov/core-science-systems/ngp/3dep)

/ Bathymetry for F-Tables
- CTDEEP (https://portal.ct.gov/DEEP/GIS-and-Maps/Data/GIS-DATA)
- RIDEM (http://www.dem.ri.gov/maps/mapfile/pondbath.pdf)

/ Dam Information for F-Tables
- National Inventory of Dams (https://nid.sec.usace.army.mil/ords/f?p=105:1)
- CTDEEP Uploaded Dam Information to Shared Folder
- RIDEM Environmental Resource Map (Regulated Facilities – Dam) (https://ridemgis.maps.arcgis.com/apps/webappviewer/index.html?id=87e104c8adb449eb9f905e5f18020de5)

/ Elevation and Slope
- USGS 3D Elevation Program (https://www.usgs.gov/core-science-systems/ngp/3dep)

/ Model Land Cover
- Connecticut
  - Connecticut Land Cover 2015 (https://cteco.uconn.edu)
  - MS4, CTDEEP Staff Uploaded to Shared Project Folder
  - Soils, State Soil Geographic (STATSGO) Dataset (https://www.nrcs.usda.gov)
  - Percent Impervious, NLCD 2016 (https://www.mrlc.gov), and CLEAR IC (http://cteco.uconn.edu/)
- Rhode Island
  - Rhode Island Land Cover 2011 (http://www.rigis.org)
  - MS4, RIDEM Phase II MS4s (www.dem.ri.gov/maps)
  - Soils, STATSGO (https://www.nrcs.usda.gov)
  - Percent Impervious, NLCD 2016 (https://www.mrlc.gov), and RIDEM IC (https://www.rigis.org/)

/ Individuals on Septic Systems
- Connecticut Sewered Areas, CTDEEP Staff Uploaded to Shared Project Folder
- Rhode Island Sewered Areas (http://www.rigis.org)
- 2010 United States Census Blockpop (https://www.census.gov/programs-surveys/decennial-census/data.html)

/ Septic Failure Rates and Loading Estimates
- CTDEEP Will Upload to A Report on Septic Failure Rates and Loading Estimates to Shared Project Folder. Data From Study to Be Extrapolated to Rhode Island.

/ Groundwater Transfers/Losses
- LIS Groundwater Model Results and Inputs Provided by USGS When Approved to Share

/ Irrigation Application Estimate on Turf and Agricultural Land
- USGS Pawcatuck Model Application Turf Equation with NLDAS Data

/ Diversions and Withdrawals From Surface Water

- CTDEEP uploaded withdrawals to shared project folder by subwatershed. Animal Units
  - RIDEM and CTDEEP Uploaded to Shared Project Folder; Data Summarized by Subwatershed for Each State.

9.0 OUTSTANDING DATA NEEDS

As identified in previous sections of this simulation plan, some data needs are still pending and will be needed to complete the final model.

The following list presents pending data needs:

- RIDEM estimates of diversions and withdrawals by subwatershed.
- Septic system failure and loading rates from CTDEEP.

RESPEC

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APPENDIX A

LAND-COVER RECLASSIFICATION SCHEME FOR THE PAWCATUCK RIVER WATERSHED HSPF MODEL

Table A-1. Rhode Island Land-Use Classification (Page 1 of 2)

Rhode Island Versus NLCD Land-Use Classes – Pawcatuck	Model Class
High-Density Residential (<⅛-acre lots)	Developed Medium Density
Medium-High-Density Residential (¼- to ⅛- acre lots)	Developed Medium Density
Medium-Density Residential (1- to ¼- acre lots)	Developed Medium Density
Medium-Low-Density Residential (1- to 2- acre lots)	Developed Medium Density
Low-Density Residential (>2- acre lots)	Developed Low Density
Commercial (sale of products and services)	Developed High Density
Industrial (e.g., manufacturing, design, assembly)	Developed High Density
Roads (divided highways > 200 feet plus related facilities)	Developed High Density
Airports (and associated facilities)	Developed Low Density
Railroads (and associated facilities)	Developed High Density
Water and Sewage Treatment	Developed Low Density
Waste Disposal (e.g., landfills, junkyards)	Developed Low Density
Power Lines (100 feet or more width)	Deciduous Forest
Other Transportation (e.g., terminals, docks)	Developed High Density
Commercial/Residential Mixed	Developed High Density
Commercial/Industrial Mixed	Developed High Density
Developed Recreation (all recreation)	Turf and Grass
Vacant Land	Deciduous Forest
Cemeteries	Developed Low Density
Institutional (e.g., schools, hospitals, churches)	Developed Medium Density

Table A-1. Rhode Island Land-Use Classification (Page 2 of 2)

Rhode Island Versus NLCD Land-Use Classes – Pawcatuck	Model Class
Pasture (agricultural not suitable for tillage)	Pasture/Hay/Grassland
Cropland (tillable)	Rhode Island Cropland to Split With Cropland Data-Layer Sod/Grass Seed Percentages
Orchards, Groves, Nurseries	Pasture/Hay/Grassland
Confined Feeding Operations	Pasture/Hay/Grassland
Idle Agriculture (abandoned fields and orchards)	Deciduous Forest
Brushland (shrub and brush areas, reforestation)	Deciduous Forest
Deciduous Forest (> 80% hardwood)	Deciduous Forest
Softwood Forest (> 80% softwood)	Coniferous Forest
Mixed Forest	Deciduous Forest
Water	Wetlands
Wetland	Wetlands
Beaches	Barren
Sandy Areas (not beaches)	Barren
Rock Outcrops	Barren
Mines, Quarries, and Gravel Pits	Barren
Transitional Areas (urban open)	Developed Low Density
Mixed Barren Areas	Barren

NLCD = National Land Cover Database

Table A-2. Connecticut Land-Use Classification

Connecticut Versus NLCD Land-Use Classes – Pawcatuck	Model Class
Developed	Connecticut Developed to Split With NLCD Developed Percentages
Turf and Grass	Turf and Grass
Other Grasses	Pasture/Hay/Grassland
Agricultural Fields	Cropland
Deciduous Forest	Deciduous Forest
Coniferous Forest	Coniferous Forest
Water	Wetlands
Non-Forested Wetland	Wetlands
Forested Wetland	Wetlands
Tidal Wetland	Wetlands
Barren Land	Barren
Utility Corridors	Deciduous Forest

APPENDIX B

EXPANDED DISCUSSION WITH EXAMPLE PLOTS FOR THE HYDROLOGY AND WATER QUALITY CALIBRATION

APPENDIX B: EXPANDED DISCUSSION WITH EXAMPLE PLOTS FOR THE HYDROLOGY AND WATER QUALITY CALIBRATION

B.1 HYDROLOGY CALIBRATION

Calibrating Hydrologic Simulation Program-Fortran (HSPF) to represent the hydrology is an iterative, trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions. The weight-of-evidence approach uses both qualitative (graphical comparisons) and quantitative (statistical test) methods during calibration and is summarized in the following sections.

B.1.1 QUALITATIVE

The qualitative approach involves comparing graphical outputs of flow-duration frequency curves, annual/monthly bar charts, time-series plots, and water-balance outputs by model land use. Each output is assessed at each long-term calibration flow gage. Examples of the graphs are provided in Figures B-1 through B-5, and an example of a water balance is shown in Table B-1.

The water balance can be plotted several ways to visually assess runoff and evaporation pathways by model land use. The water balance can also be compared to similar studies in the region but is most often used to assess relative runoff/ evapotranspiration (ET) rates (e.g., surface runoff from developed Effective Impervious Area [EIA] is much greater than developed, which is greater than cropland, which is greater than wetland and forest). Similar to the overall water balance, a reach balance is also generated to ensure that annual runoff rates (feet/acre) by subbasin are consistent and that any discrepancies can be explained through differences in climate, soils, and land-use management practices.

Additional graphs of lake levels and snow depth/snowfall are also assessed if data are available. Lake-level/depth time series and monthly boxplots are reviewed to ensure that the model is capturing the overall trend and seasonal variability of lake-elevation fluctuations, as shown in Figures B-6 and B-7. Snow plots are used to ensure the timing/quantity of snowfall and snowmelt processes, as illustrated in Figure B-8.

B.1.2 QUANTITATIVE

The quantitative approach uses statistical tests to determine how well the model fits when compared to the observed values. This approach involves evaluating errors, percent differences, regression analysis (correlation coefficients), and indexes of agreement (Nash-Sutcliffe efficiency). Statistics aid in discovering bias and allow for analyzing central tendencies but should only be used along with a qualitative approach.

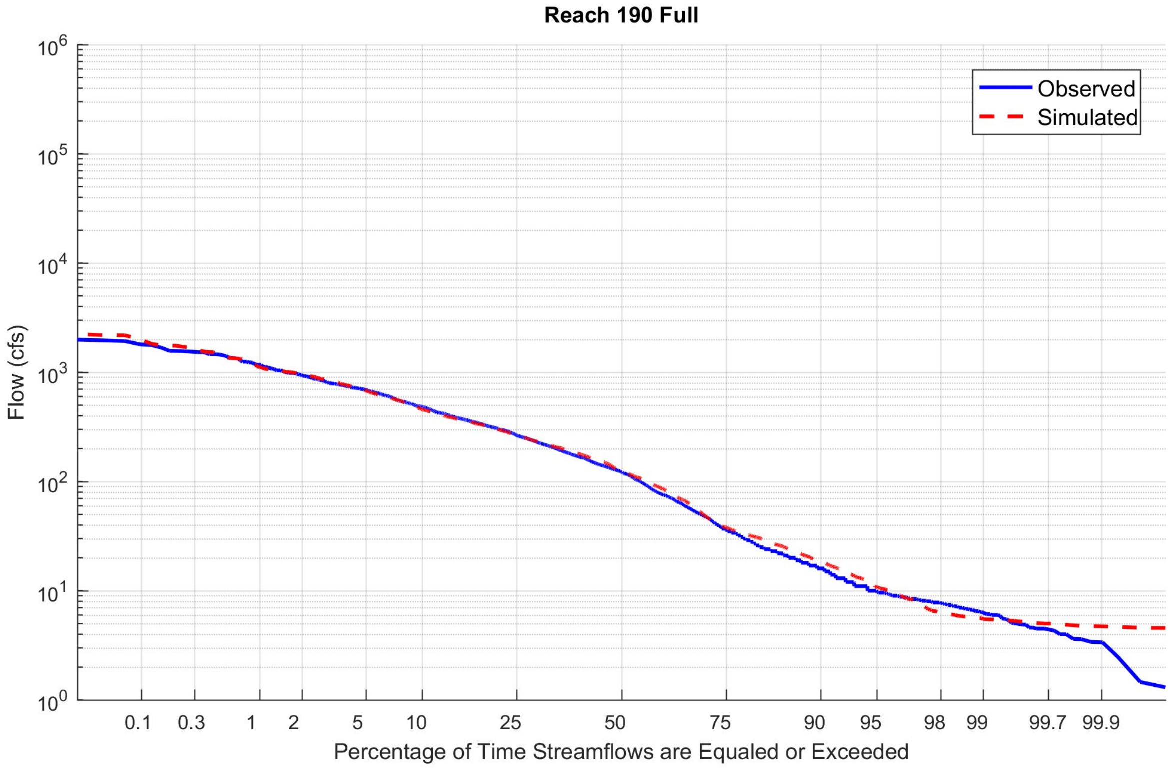

Figure B-1. Flow Frequency Duration Curve (Example).

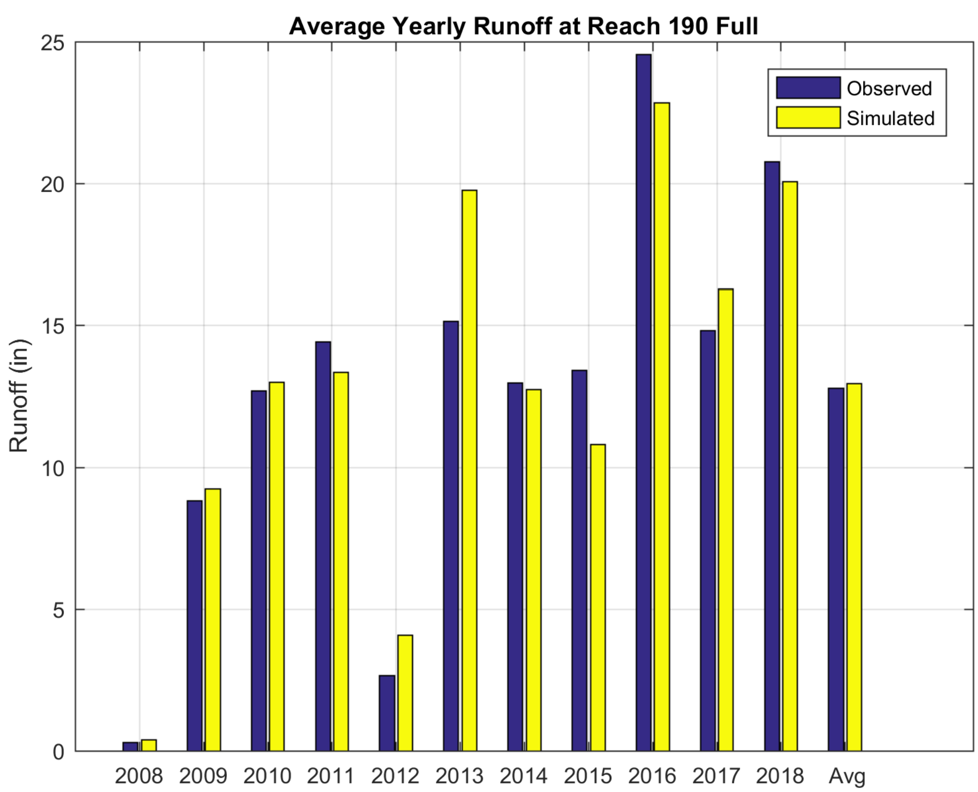

Figure B-2. Average Annual Runoff Comparison (Example).

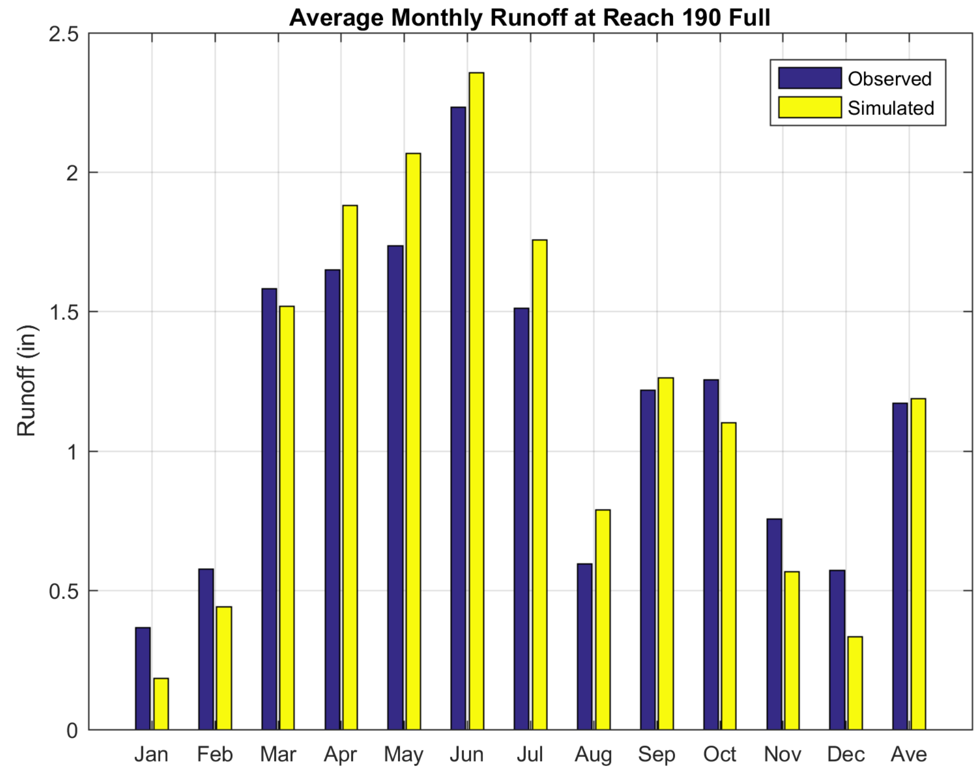

Figure B-3. Average Monthly Runoff Comparison (Example).

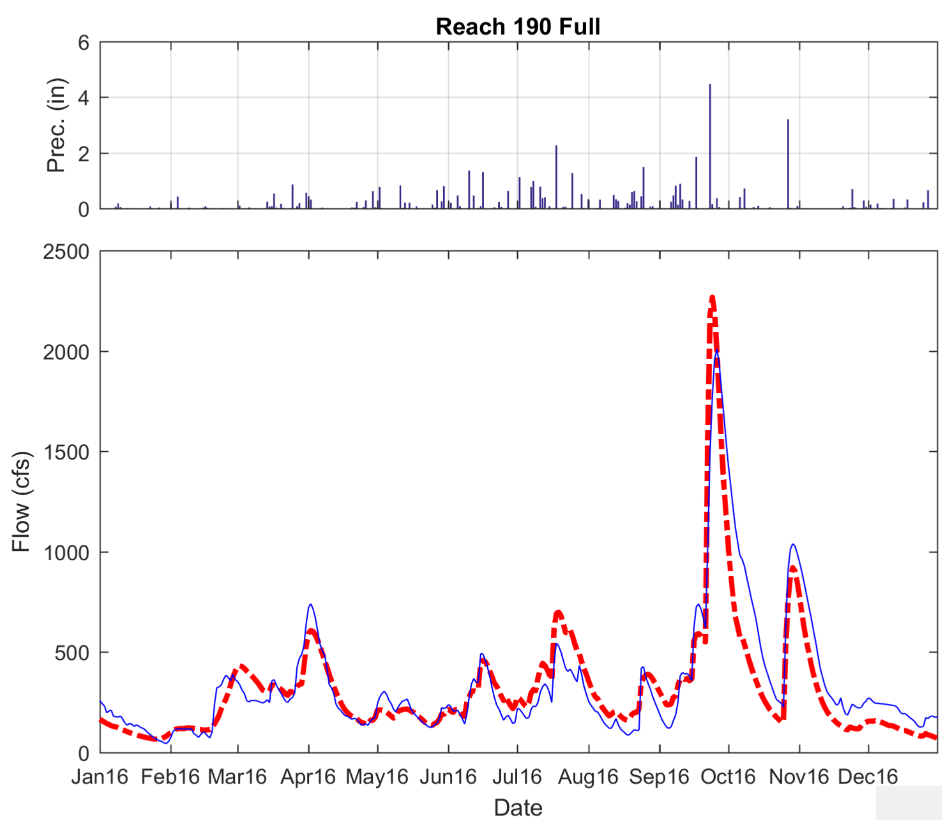

Figure B-4. Time-Series Plot for 2016 (Example).

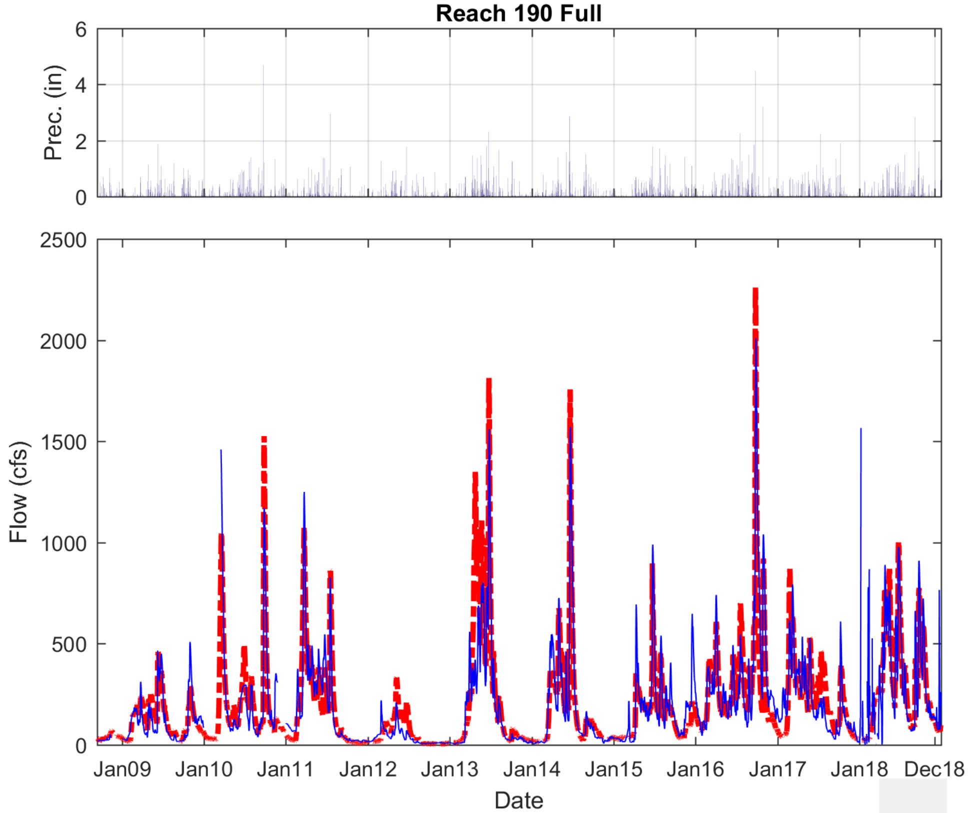

Figure B-5. Time-Series Plot for Entire Calibration Period (2009–2018) (Example).

Table B-1. Water Balance in Inches per Year for Each Model Land Class (Example)

Water-Balance Component	Developed	Developed EIA	Cropland	Other	Weighted Mean
Rainfall	36.9	36.0	37.0	36.9	36.9
Surface Runoff	0.158	30.4	0.150	0.136	0.662
Interflow Runoff	3.73	0	3.37	1.68	3.12
Groundwater Runoff	10.7	0	9.63	10.7	9.73
Total Runoff	14.5	0	13.2	12.5	13.0
Active-Groundwater Inflow	10.8	0	9.70	11.1	9.85
Potential ET	31.0	31.1	31.0	31.0	31.0
Interception ET	5.88	0	7.50	7.26	7.15
Upper-Zone ET	6.65	0	6.58	6.10	6.41
Lower-Zone ET	9.60	0	9.53	10.6	9.52
Active-Groundwater ET	0	0	0	0.140	0.0190
Baseflow ET	0.0930	0	0.0620	0.211	0.0850
Total Actual ET	22.2	5.55	23.7	24.3	23.2
% Area	11.6	1.70	72.8	13.9	100

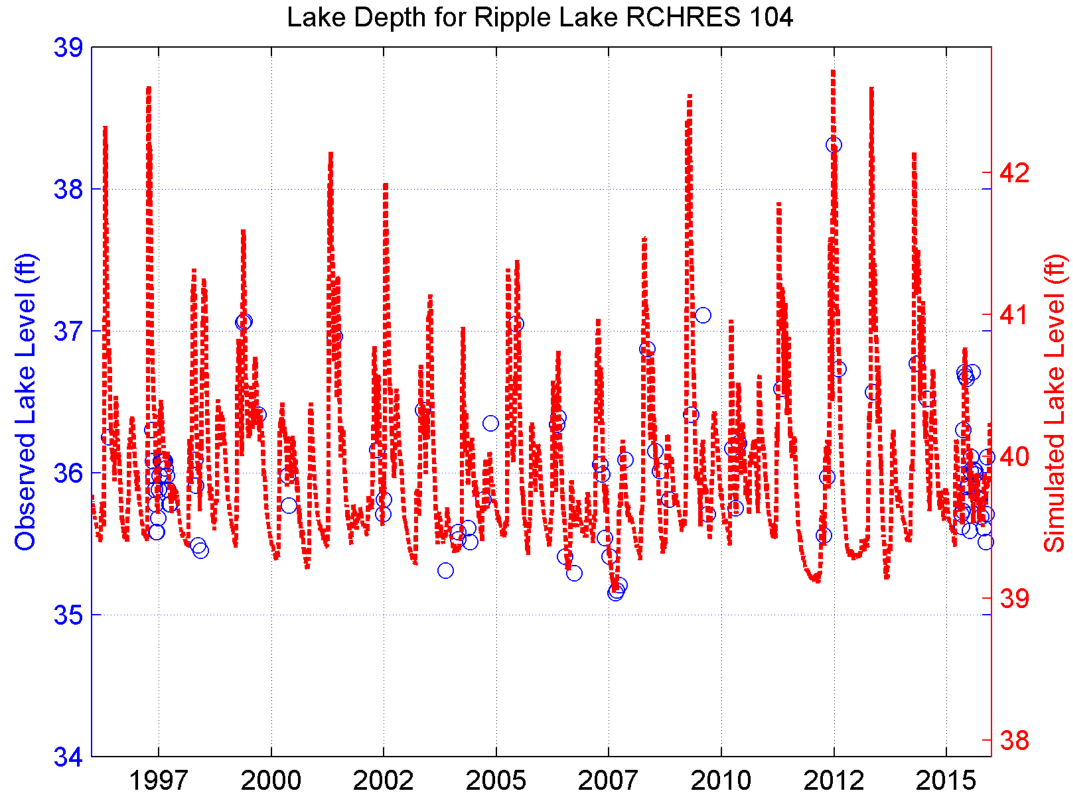

Figure B-6. Lake-Level, Time-Series Plot (Example).

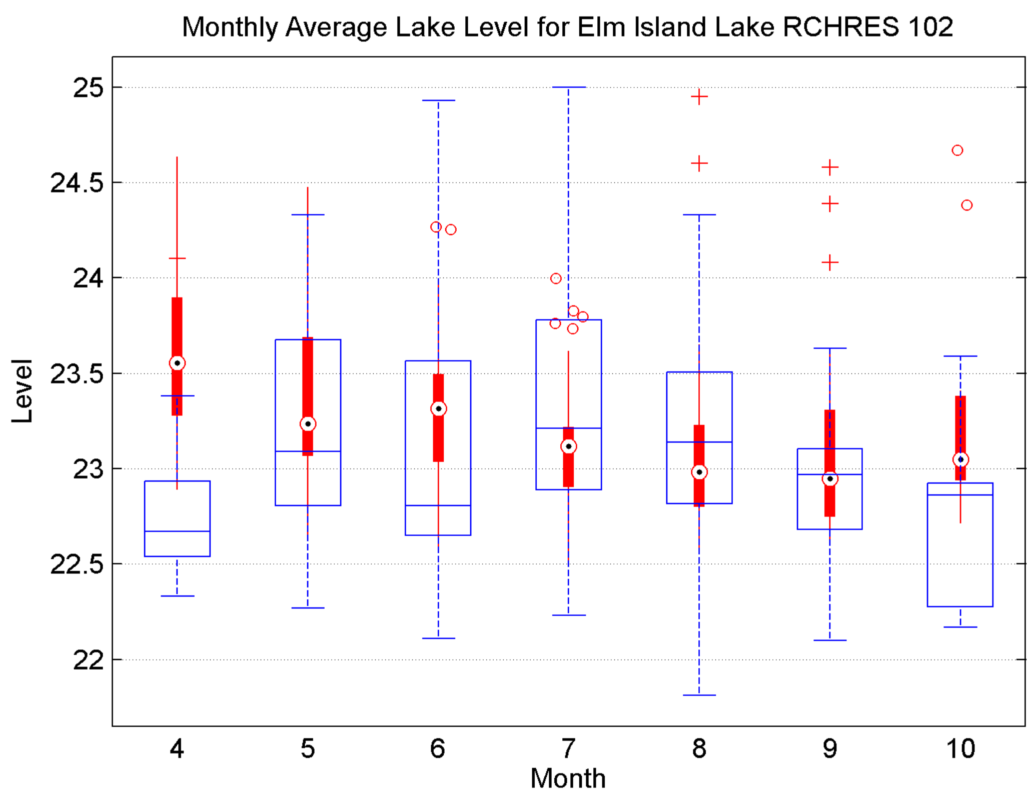

Figure B-7. Lake-Level Monthly Boxplot (Example).

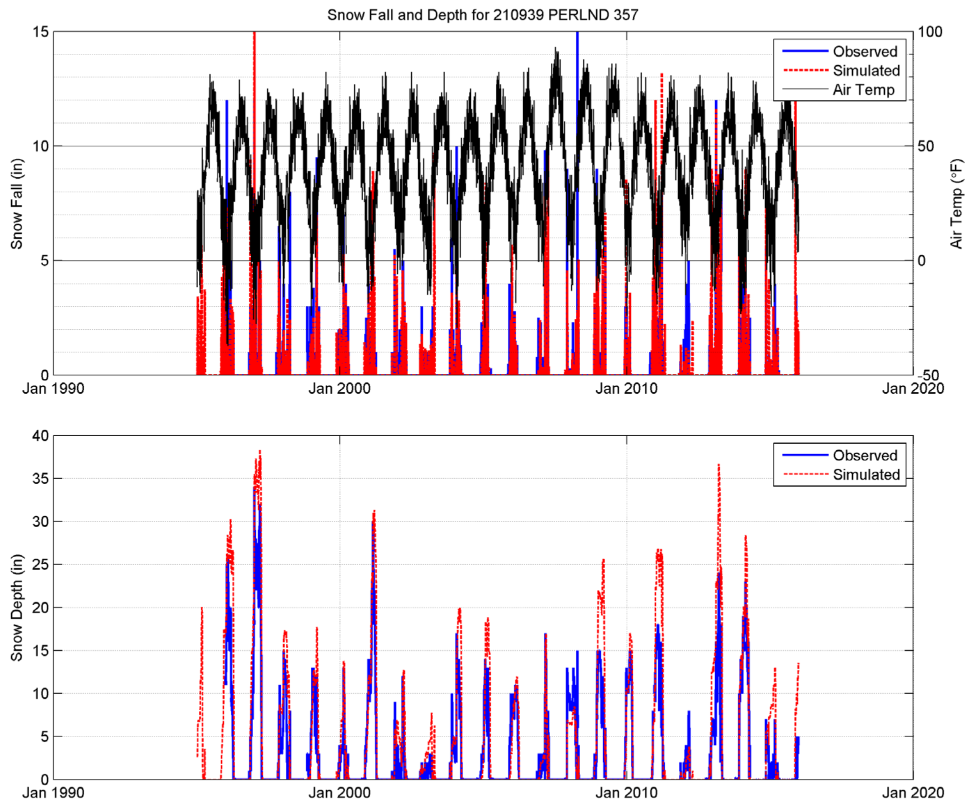

Figure B-8. Snowfall and Snow Depth Plot (Example).

An example output of hydrology model-fit statistics is shown in Table B-2. Statistics are evaluated on a daily and monthly basis, and Figure B-9 shows the criteria for assessing model performance for both of the averaging periods. The values for the correlation coefficients (R) and coefficient of determination (R^2) have been derived primarily from HSPF experience and selected past efforts on model performance criteria; however, the values reflect common tolerances accepted by many modeling professionals.

The other main statistical output that is evaluated is the average annual Expert System (ExpSys) statistics, and an example is provided in Table B-3. The ExpSys shows percent differences of simulated versus observed values at different percentiles, seasons, and average storm volumes/peaks. Similar to the criteria for R and R^2 for model performance, calibration targets or tolerances have been established for the ExpSys. Percent differences less than 10 are considered very good, from 10 to 15 are good, 15 to 25 are fair, and greater than 25 are poor.

B.2 WATER QUALITY CALIBRATION

Similar to the hydrologic calibration, calibrating water quality in HSPF is an iterative, trial-and-error process that can be divided into two main components: nonpoint-source loading/delivery and instream concentrations/processes. The water quality calibration is mainly done through a qualitative approach by visually comparing simulated versus observed instream concentrations using various calibration graphs and plots. Additional plots, tables, and maps are generated to assess the nonpoint-source (NPS) loadings and loading rates, bed/bank scour, and nutrient cycling dynamics.

Table B-2. Daily and Monthly Model-Fit Statistics (Example)

Model-Fit Statistic	Daily	Monthly
Number of Years, Months, or Days	3,568	120
Correlation Coefficient (R)	0.90	0.93
Coefficient of Determination (R^2)	0.80	0.86
Coefficient of Model-Fit Efficiency (mfe)	0.79	0.84
Predictability Score (1 - RMSE/obsStDev)	0.54	0.60
Mean Error (me)	2.9	0.8384
Percent Mean Error (% me)	1.4	0.42
Mean Absolute Error (mae)	61.2	46.8
Percent Mean Absolute Error (% mae)	30.8	23.29
Percent Time Error < 5%	8.7	16.67
Percent Time Error < 10%	18.2	25
Percent Time Error < 15%	26.8	30.83
Percent Time Error < 20%	35.0	44.17
Percent Time Error < 25%	41.8	50.83
Mean of All Percent Errors	27.0	9.24
Median of All Percent Errors	5.9	2.84
Minimum of All Percent Errors	–98.6	–84.29
Maximum of All Percent Errors	10,521.3	199.72
Overall Model Efficiency		
Weighted R^2	0.8	0.81
Modified Efficiency (E)	0.6	0.68
Modified Index (D)	0.8	0.84
Low-Flow Sensitivity		
E Using ln(obs) and ln(sim)	0.8	0.86
Relative Efficiency (E)	–2.5	0.74
Relative Index (D)	0.1	0.94
Peak Flow Sensitivity		
Coefficient of Determination R^2	0.80	0.86
Nash-Sutcliffe Efficiency (E)	0.79	0.84
Index of Agreement (D)	0.95	0.96

RMSE = root-mean-square error

Figure B-9. R and R^2 Value Ranges of Model Performance (Example).

Table B-3. Expert System Statistics (Example)

Flow Component	Observed (inches)	Simulated (inches)	Residual (inches)	Difference (%)	Quality
Overall	12.78	12.97	0.18	1.4	very good
5 Percent High	3.10	3.17	0.07	2.2	very good
10 Percent High	4.94	4.97	0.03	0.6	very good
25 Percent High	8.36	8.30	–0.05	–0.6	very good
50 Percent Low	1.49	1.61	0.12	7.9	very good
25 Percent Low	0.31	0.35	0.03	10.9	good
15 Percent Low	0.14	0.14	0.01	4.4	very good
10 Percent Low	0.07	0.07	0.00	4.2	very good
5 Percent Low	0.02	0.02	0.00	–1.8	very good
Storm Volume	9.23	9.13	–0.10	–1.1	very good
Average Storm Peak	489.10	446.21	–42.92	–8.8	very good
Spring Volume	4.45	4.89	0.44	10.0	very good
Summer Volume	3.95	4.46	0.51	13.0	good
Fall Volume	2.94	2.66	–0.27	–9.3	very good
Winter Volume	1.45	0.95	–0.50	–34.3	poor
Spring Storms	3.30	3.51	0.21	6.4	very good
Summer Storms	2.94	3.09	0.16	5.3	very good
Fall Storms	2.18	1.90	–0.28	–12.7	good
Winter Storms	0.57	0.35	–0.22	–38.7	poor

B.2.1 INSTREAM SIMULATED VERSUS OBSERVED

The main outputs assessed during the water quality calibration include concentration frequency duration curves, monthly average boxplots, flow-concentration scatter plots, and time-series graphs. Examples for total phosphorus are shown in Figures B-10 through B-13.

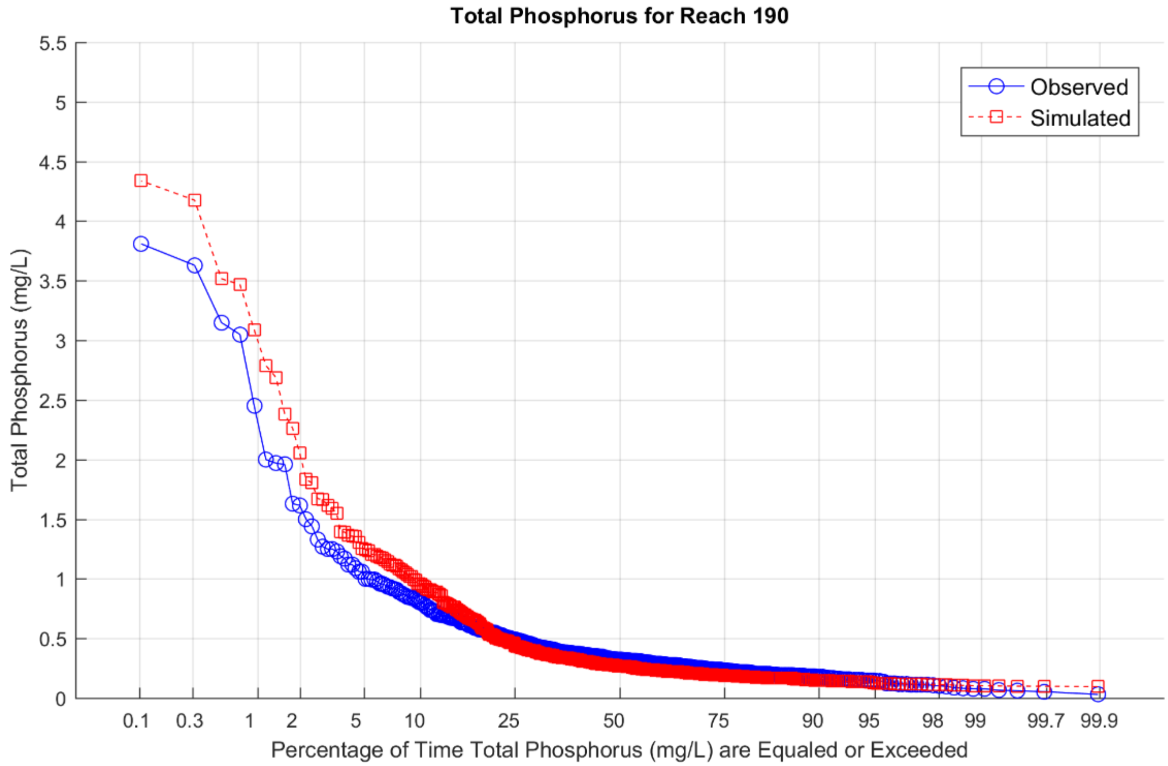

Figure B-10. Frequency Duration Curve for Total Phosphorus (Example).

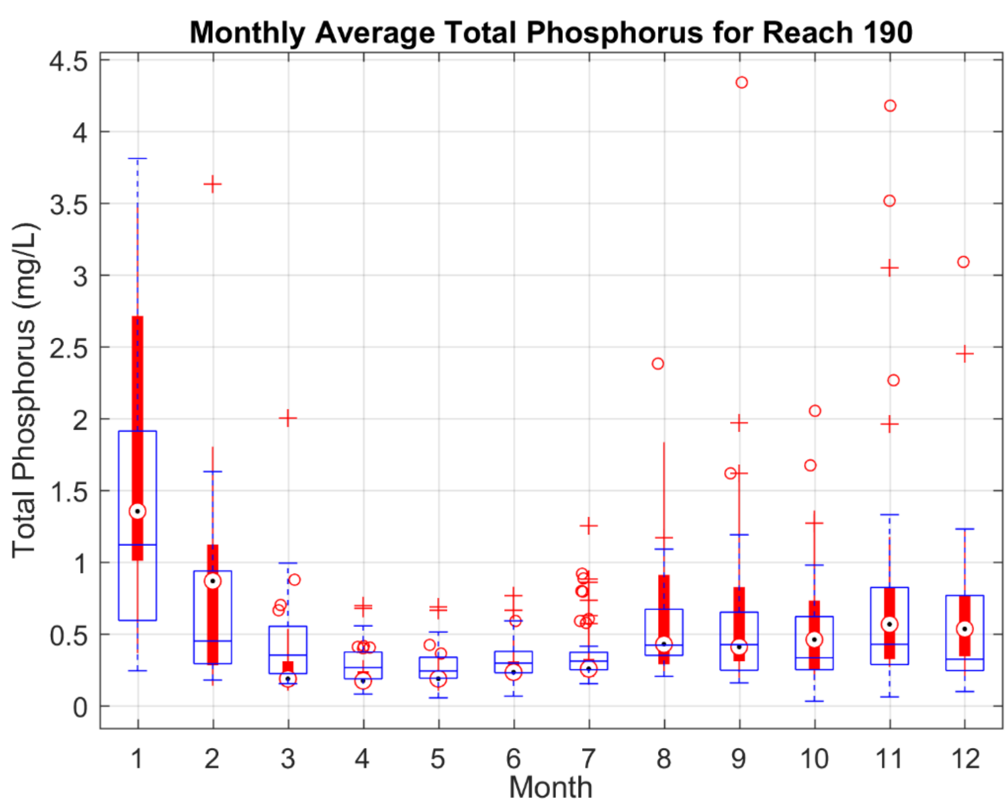

Figure B-11. Average Monthly Boxplot for Total Phosphorus (Example).

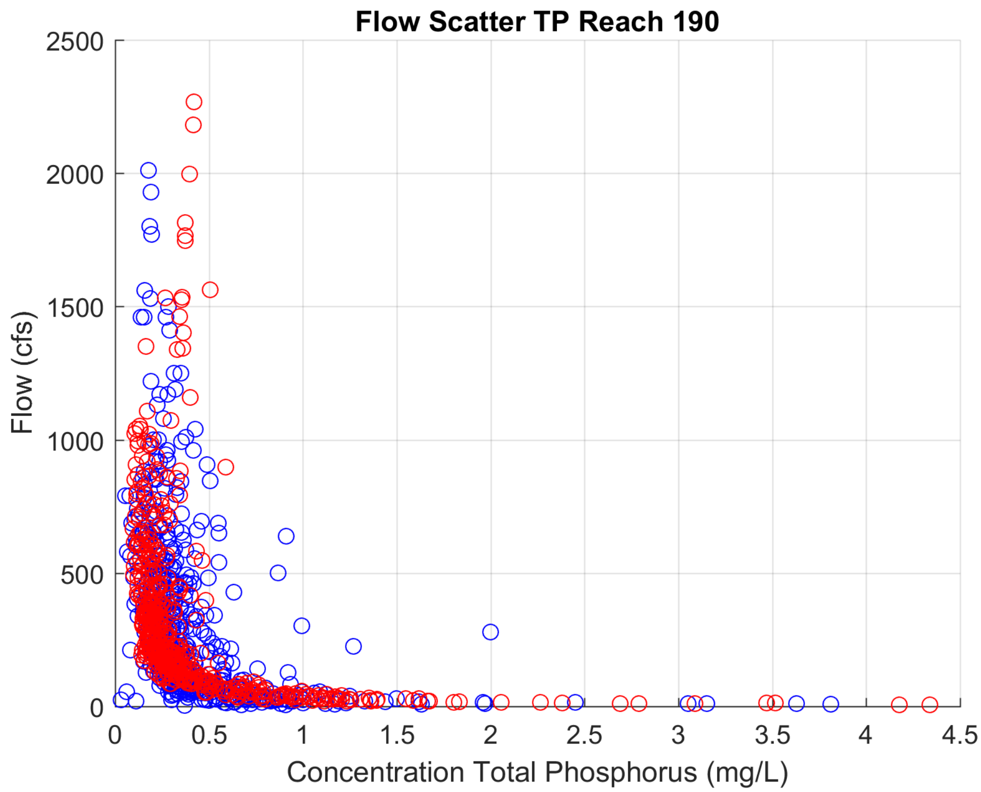

Figure B-12. Flow Scatter Plot for Total Phosphorus (Example).

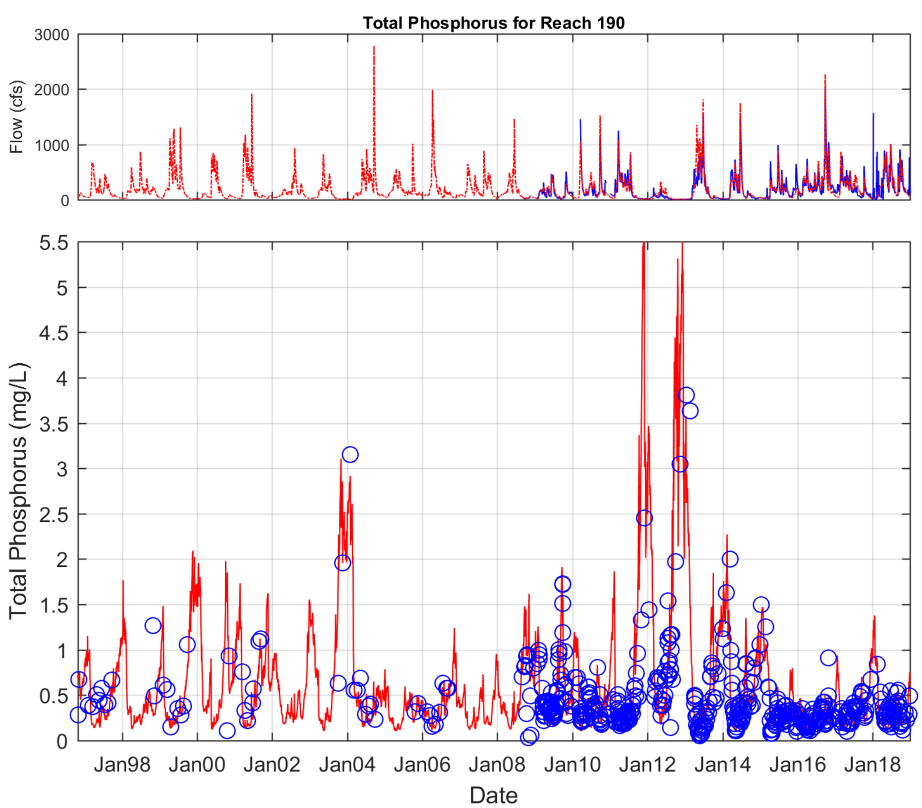

Figure B-13. Time-Series Graph for Total Phosphorus (Example).

Water temperature and DO often fluctuate on a diurnal cycle, so average hourly boxplots are also evaluated in Figure B-14. If continuous data are available, detailed time-series graphs and hourly boxplots are also assessed by sampling season in Figures B-15 and B-16.

B.2.2 NONPOINT-SOURCE ANALYSIS

The NPS calibration occurs in tandem with the instream calibration where pervious and impervious land parameters are set using literature data and then adjusted to reflect concentrations observed in the stream. Graphical and tabular outputs of NPS loading rates and source allocations are reviewed to inform the calibration and ensure that relative contributions are well represented. An example of an annual average loading rate boxplot for sediment is shown in Figure B-17, and a source allocation for total phosphorus is shown in Figure B-18. The loading rates and total loads by subbasin are also mapped in Figure B-19 to spatially assess differences in results.

B.2.3 ADDITIONAL ANALYSIS

Additional plots and tables are output during the calibration to ensure that the model is consistent in its predictions for non-calibration reaches. Erratic instream model behavior (e.g., impossible bed scour values, extreme/accumulating nutrient concentrations, no phytoplankton growth) is often missed on reaches with little to no data and, if left uncorrected, model scenarios will produce unrealistic results. To ensure that instream sediment is reasonable for all reaches, the net scour/deposition for each HSPF class (sand, silt, and clay) over the entire simulation period is output and normalized to pounds per square foot of reach bed per year. When normalized, any outliers can be easily identified and corrected. An example of the analysis is shown in Table B-4, where Reach 11 was identified as having an abnormally high sand deposition rate when compared to streams around it.

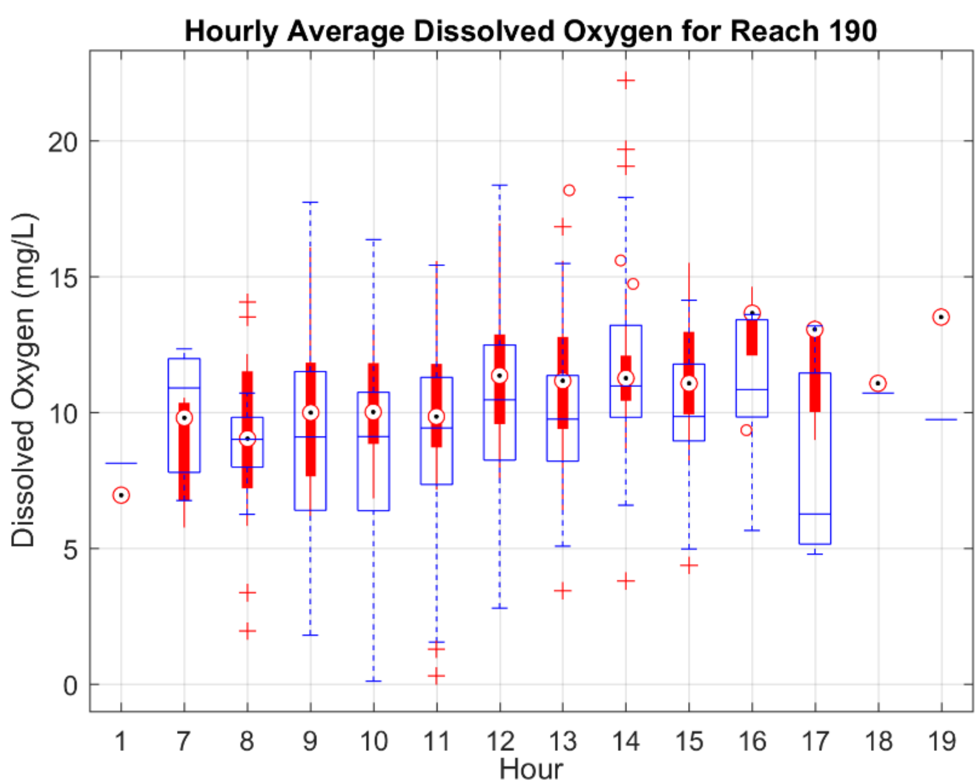

Figure B-14. Average Hourly Boxplot for Dissolved Oxygen (Example).

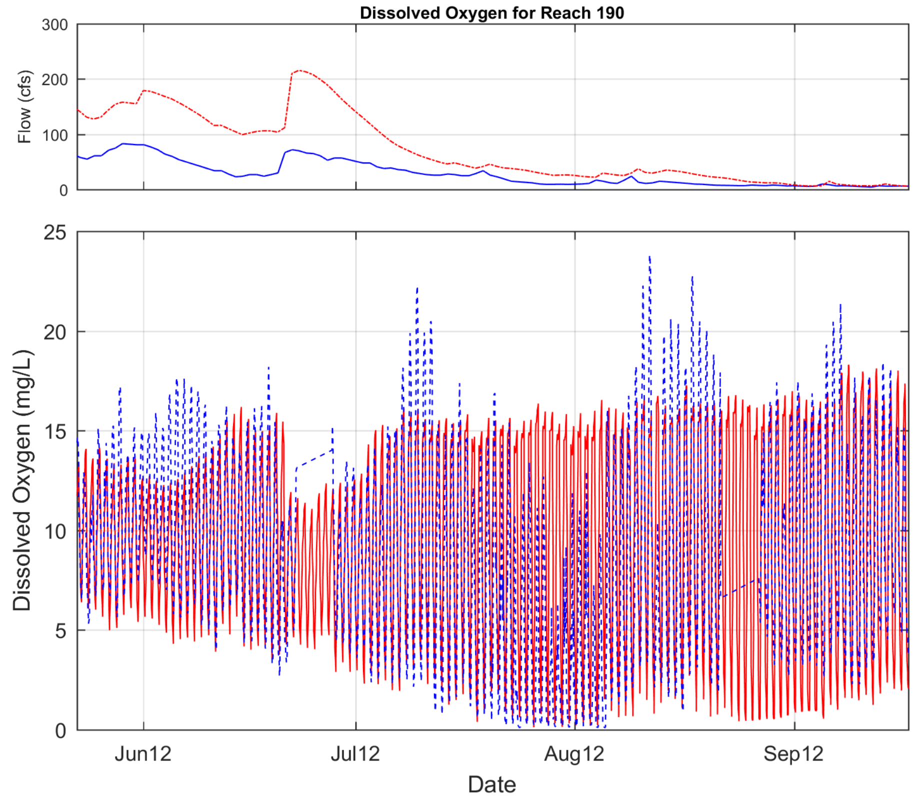

Figure B-15. Continuous Time-Series Graph for Dissolved Oxygen in the 2012 Sampling Season (Example).

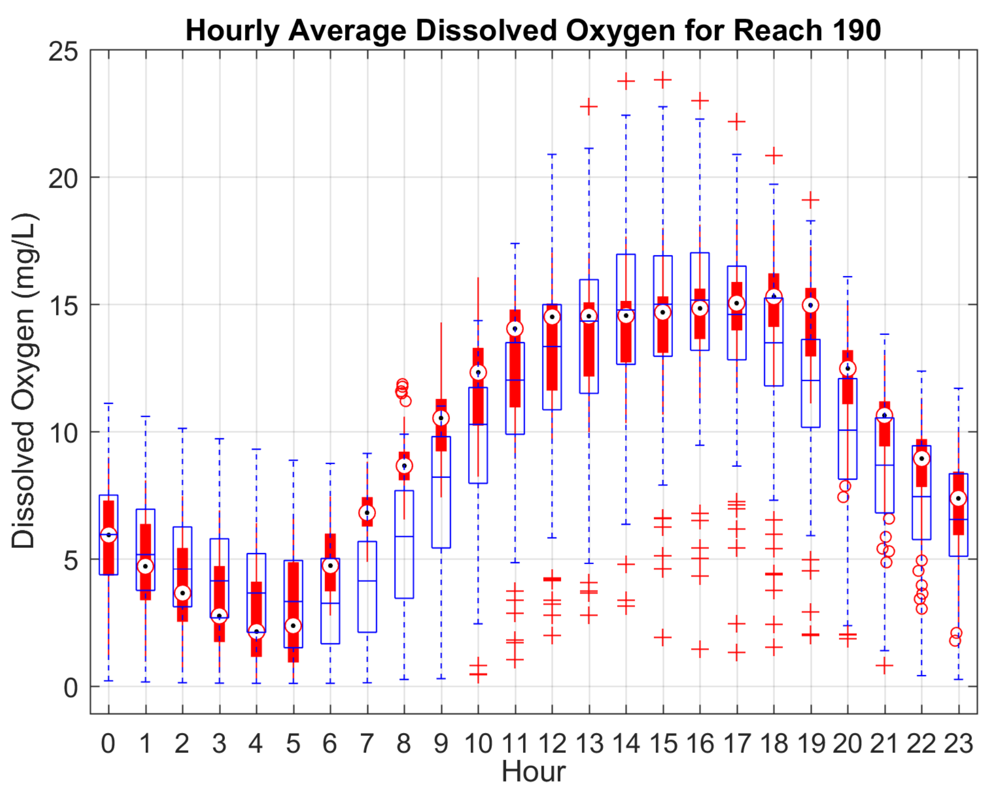

Figure B-16. Average Hourly Boxplot for Continuous Dissolved Oxygen in the 2012 Sampling Season (Example).

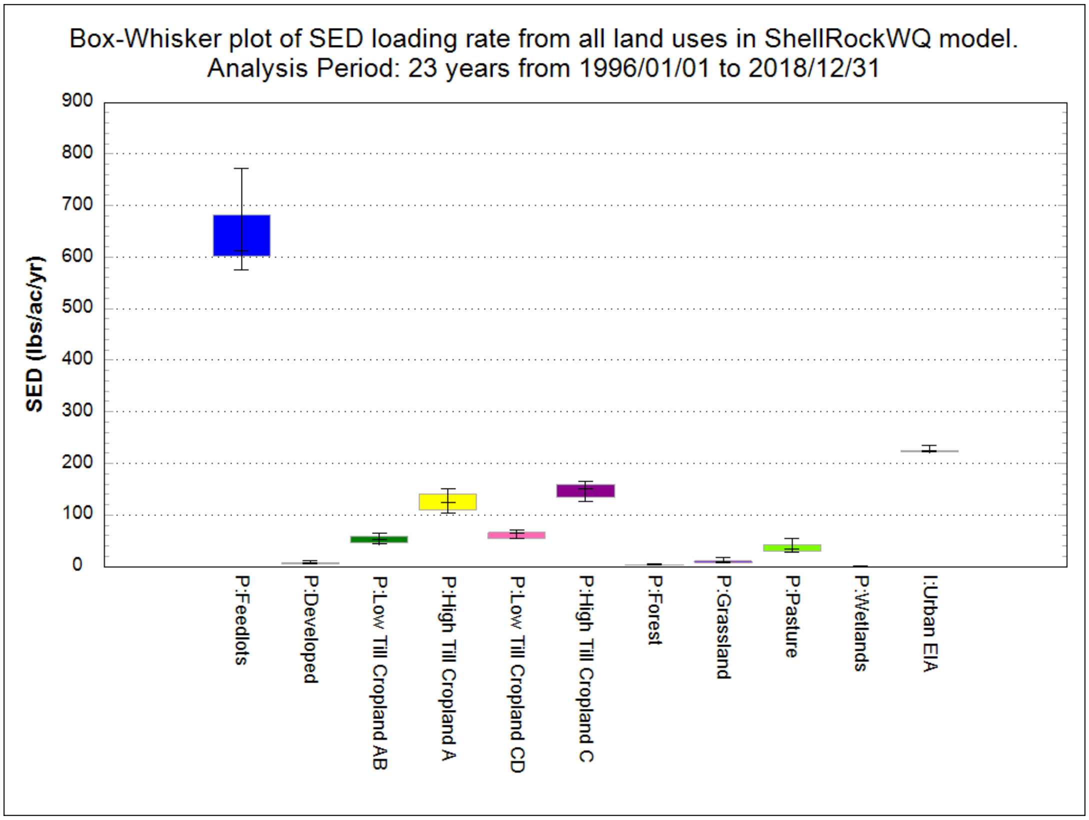

Figure B-17. Annual Average Loading Rates for Sediment (Example).

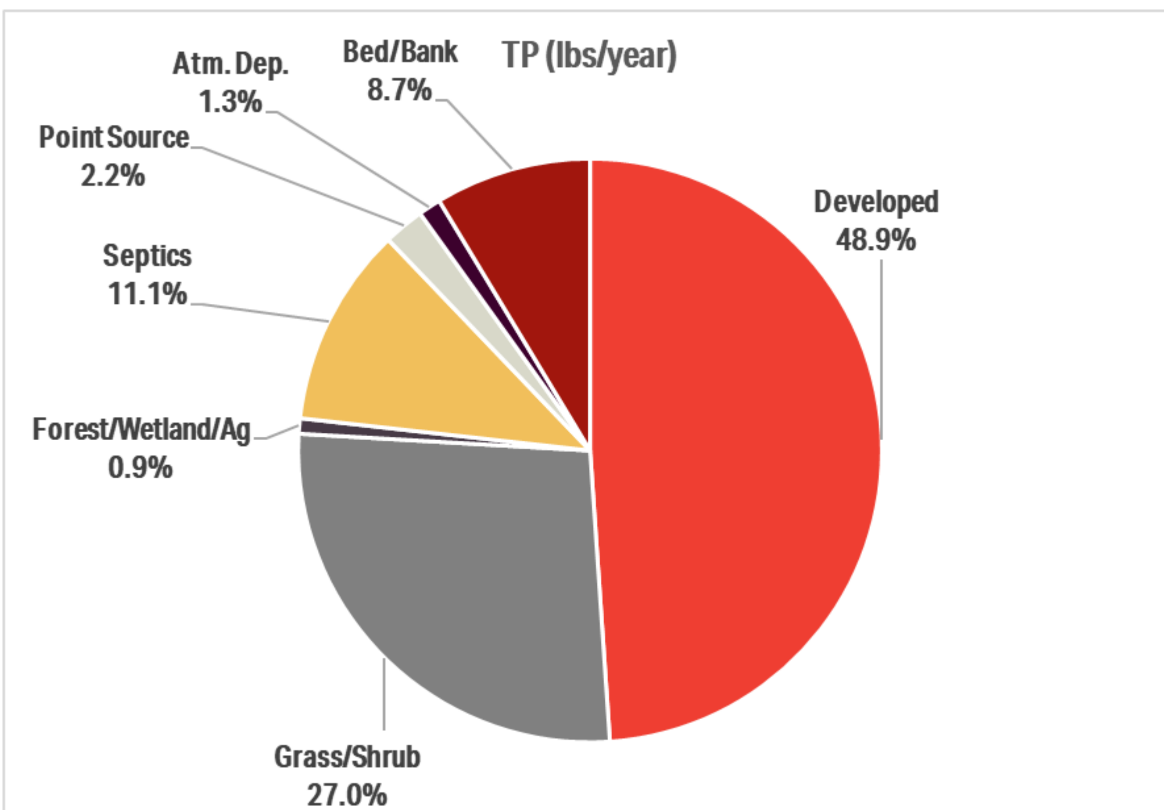

Figure B-18. Source Allocation (Percent Contribution) for Total Phosphorus (Example).

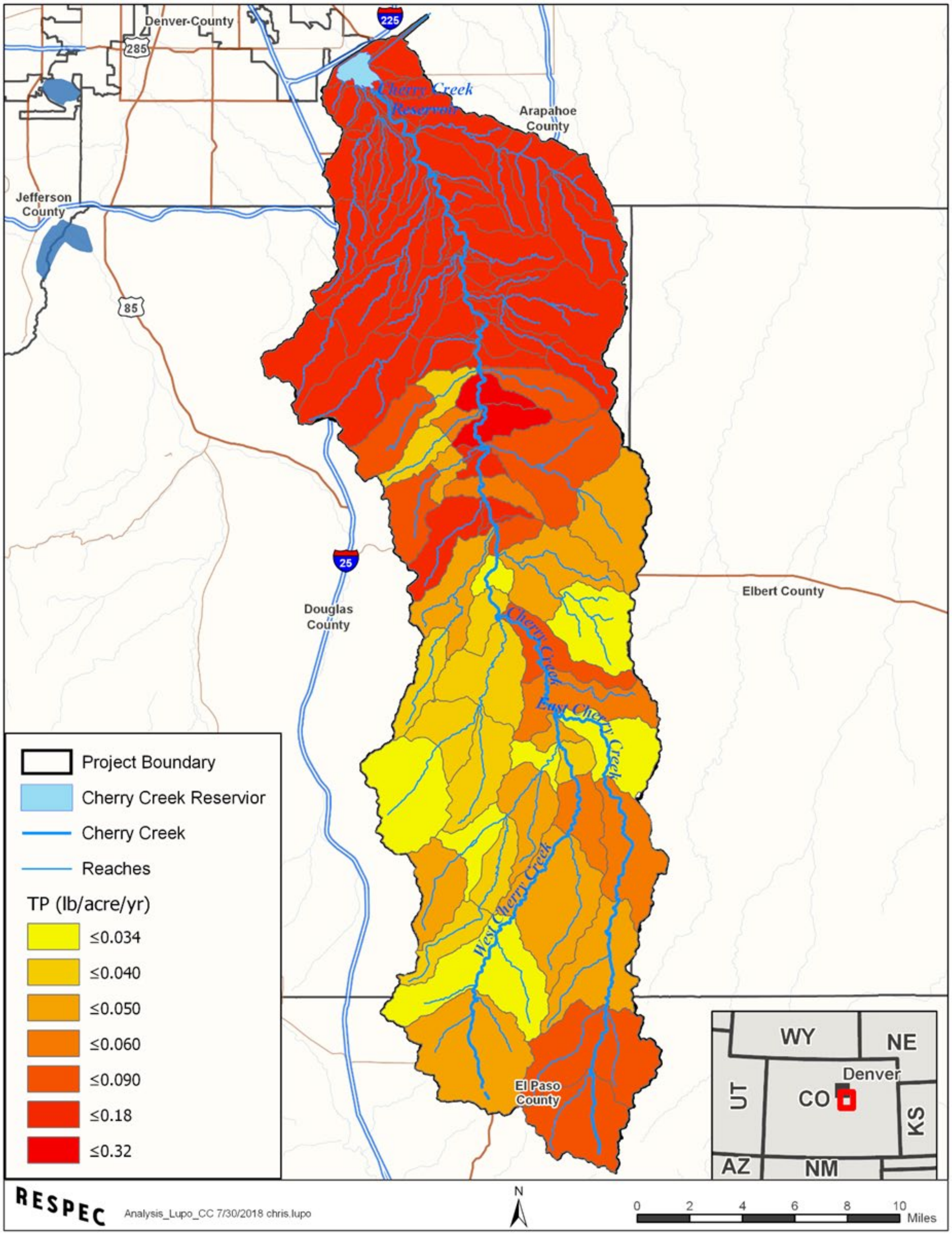

Figure B-19. Average Total Phosphorus Loading Rates by Subbasin (Example).

Table B-4. Normalized Annual Sediment Scour (–) and Deposition (+) (Example)

Reach Number	Length (miles)	Area (acres)	Scour (–) Deposition (+) (lbs/ft^2/yr)			
			Sand	Silt	Clay	Total
1	8.3	27.8	0.29	–0.01	–0.02	0.26
3	11.3	46.5	0.09	–0.02	–0.02	0.05
7	7.8	16.4	0.15	–0.03	–0.03	0.09
11	2.8	2.9	0.59	–0.01	–0.01	0.58
12	4.1	1,510.6	0.00	0.01	0.00	0.02
13	7.1	8.4	0.19	–0.01	–0.02	0.16
19	3.9	12.9	0.04	–0.02	–0.02	0.00
21	4.0	76.0	0.01	0.06	0.01	0.08
23	1.9	2.0	0.19	–0.01	–0.01	0.18
25	10.2	20.8	0.09	–0.01	–0.02	0.05
27	14.6	57.9	0.08	0.00	–0.01	0.07
29	4.4	9.9	0.15	–0.02	–0.02	0.11
31	7.6	7.7	0.19	–0.01	–0.01	0.17

Annual time-series graphs that include all of the nutrient speciation are plotted to identify any lakes or reaches that are accumulating nutrient concentrations or have abnormally high results. An example is shown in Figure B-20.

A similar time-series graph to assess phytoplankton growth and process fluxes is also evaluated to ensure that growth is occurring when it should and to determine limiting factors. Figure B-21 shows an example of a lake that is typically phosphorus limited, becomes nitrogen limited a third of the way through the simulation, and eventually runs out of nutrients, which prevents any growth for approximately 7 years and is unrealistic.

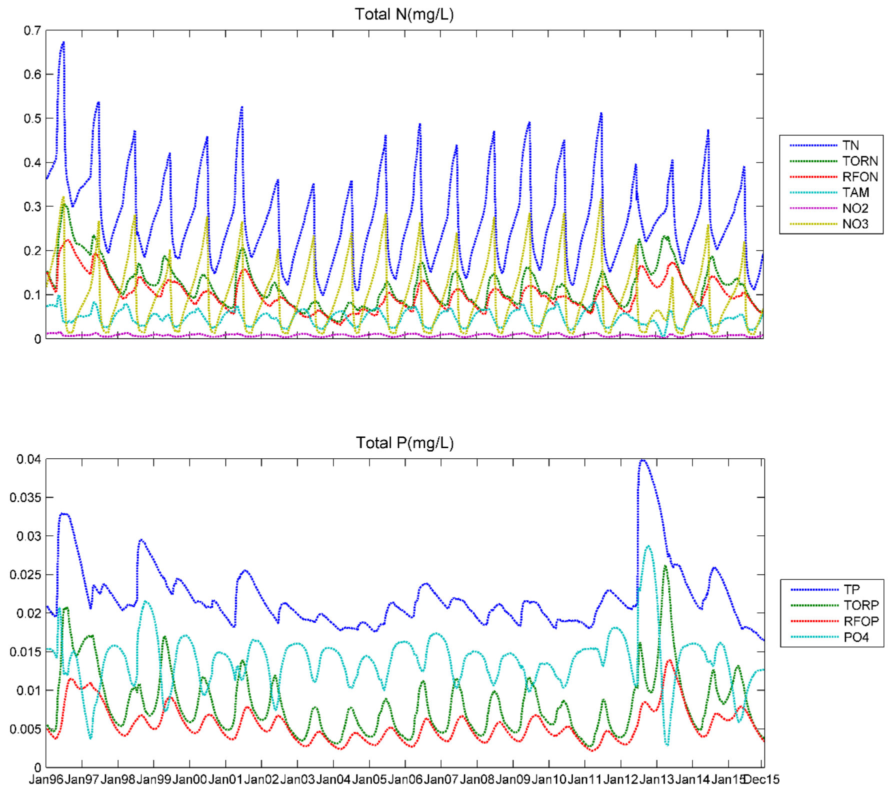

Figure B-20. Simulated Nitrogen and Phosphorus Speciation for the Entire Simulation Period (Example).

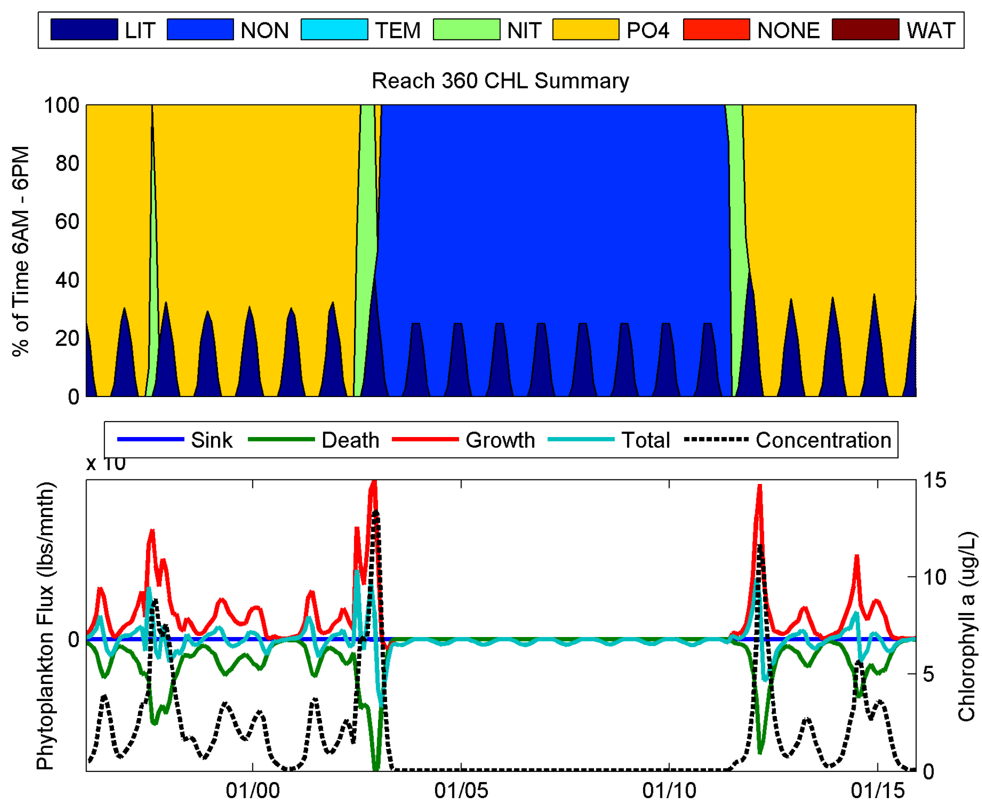

Figure B-21. Phytoplankton Flux and Limiting Factors Plot (Example).

APPENDIX C
WATER QUALITY DATA SUMMARY

Table C-1. Water Quality Data Summary (Page 1 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
USGS	NWIS	USGS-01118500	01118500	PAWCATUCK RIVER AT WESTERLY, RI	Stream/River	4679
RIDEM	RIDEM	1888	WW68	Yawgoo Pond	Lake/Pond	2903
RIDEM	RIDEM	1822	WW02	Barber Pond	Lake/Pond	2071
RIDEM	RIDEM	1880	WW60	Watchaug Pond	Lake/Pond	1939
RIDEM	RIDEM	1850	WW30	Pasquiset Pond	Lake/Pond	1912
RIDEM	RIDEM	1876	WW56	Tucker Pond	Lake/Pond	1779
RIDEM	RIDEM	1826	WW06	Boone Lake	Lake/Pond	1469
RIDEM	RIDEM	2237	WW214	Wincheck Pond	Lake/Pond	1324
RIDEM	RIDEM	1821	WW01	Alton Pond	Reservoir	1221
RIDEM	RIDEM	1837	WW17	Hundred Acre Pond	Reservoir	1185
RIDEM	RIDEM	1854	WW34	Queen River @ Usquepaugh (Glen Rock Reservoir)	Reservoir	1165
RIDEM	RIDEM	1846	WW26	Meadowbrook Pond (Sandy Pond)	Reservoir	1112
RIDEM	RIDEM	1884	WW64	White Pond	Lake/Pond	930
RIDEM	RIDEM	1886	WW66	Worden Pond	Lake/Pond	924
USGS Continuous	NWIS	USGS-01118500	01118500	PAWCATUCK RIVER AT WESTERLY, RI	Stream/River	910
RIDEM	RIDEM	1851	WW31	Pawcatuck River @ Bradford. (Westerly/Hopkinton)	Stream/River	757
RIDEM	RIDEM	1841	WW21	Locustville Pond	Reservoir	746
RIDEM	RIDEM	1942	WW122	Chickasheen Brook @ Rte 138	Stream/River	638
RIDEM	RIDEM	1924	WW104	Barber Pond-Mud Brook	Stream/River	630
RIDEM	RIDEM	1941	WW121	Chickasheen Brook @ Barber Outlet	Stream/River	630
RIDEM	RIDEM	1940	WW120	Chickasheen Brook @ Miskiania	Stream/River	626
RIDEM	RIDEM	1920	WW100	Queens River (Sherman Brook)	Stream/River	619
RIDEM	RIDEM	2440	WW412	White Horn Brook @ Ministerial Rd.	Stream/River	600
RIDEM	RIDEM	1894	WW74	Falls River C - Austin Farm Rd	Stream/River	550
RIDEM	RIDEM	1895	WW75	Falls River D - Stepstone Falls	Stream/River	547
RIDEM	RIDEM	1892	WW72	Falls River A - Twin Bridges	Stream/River	546
RIDEM	RIDEM	2145	WW200	Chapman Pond	Lake/Pond	507
RIDEM	RIDEM	2459	WW435	White Horn Brook @ Bike Trail	Stream/River	470
RIDEM	RIDEM	2247	WW225	Shickasheen Brook @ Liberty Lane	Stream/River	467
RIDEM	RIDEM	1923	WW103	Queens River (Mail Rd) #06b	Stream/River	453
RIDEM	RIDEM	2284	WW245	Chipuxet River @ Rte 138	Stream/River	445
RIDEM	RIDEM	2290	WW252	Pawcatuck River @ Rte 91	Stream/River	403
RIDEM	RIDEM	1939	WW119	Chickasheen Brook @ Rte 2	Stream/River	402
RIDEM	RIDEM	1893	WW73	Falls River B - Sand Bank	Stream/River	401
RIDEM	RIDEM	2287	WW249	Pawcatuck River @ Burdickville Rd (Hopkinton, Chalestown)	Stream/River	391
RIDEM	RIDEM	2294	WW256	Usquepaugh River @ Rte 2	Stream/River	391
RIDEM	RIDEM	2289	WW251	Pawcatuck River below Kenyon Ind. (Charlestown, Richmond)	Stream/River	389

Table C-2. Water Quality Data Summary (Page 2 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
RIDEM	RIDEM	1887	WW67	Wyoming Pond	Reservoir	389
RIDEM	RIDEM	2263	WW244	Pawcatuck River @ Biscuit City Rd (Charlestown, Richmond)	Stream/River	345
RIDEM	RIDEM	2285	WW246	Glen Rock Brook	Stream/River	333
RIDEM	RIDEM	2291	WW253	Queen River @ Rte 102	Stream/River	324
RIDEM	RIDEM	2152	WW207	Queen River @ Locke Brook	Stream/River	288
RIDEM	RIDEM	1921	WW101	Queens River (Brownells - Wm Reynolds Rd)	Stream/River	285
RIDEM	RIDEM	1922	WW102	Queens River #5 (Sand Bridge)	Stream/River	279
USGS	NWIS	USGS-01117420	01117420	USQUEPAUG RIVER NEAR USQUEPAUG, RI	Stream/River	271
USGS	NWIS	USGS-01117350	01117350	CHIPUXET RIVER AT WEST KINGSTON, RI	Stream/River	266
RIDEM	RIDEM	2327	WW296	White Brook @ Pine Hill Rd	Stream/River	262
RIDEM	RIDEM	1953	WW133	Watchaug Pond-Perry Healy Brook	Stream/River	244
RIDEM	RIDEM	2261	WW242	Ashaway River @ Rte 216	Stream/River	240
RIDEM	RIDEM	2331	WW310	Tomaquag Brook @ Chase Hill	Stream/River	234
RIDEM	RIDEM	2262	WW243	Ashaway River @ Wellstown Rd.	Stream/River	222
USGS	NWIS	USGS-01117351	01117351	WHITE HORN BRK AT MINISTERIAL RD NR W KINGSTON, RI	Stream/River	221
USGS	NWIS	USGS-01117455	01117455	PAWCATUCK R AT SHERMAN AVE AT KENYON, RI	Stream/River	221
USGS	NWIS	USGS-01117471	01117471	BEAVER RIVER SHANNOCK HILL RD, NEAR SHANNOCK, RI	Stream/River	221
USGS	NWIS	USGS-01118009	01118009	WOOD RIVER NEAR ALTON, RI	Stream/River	221
USGS	NWIS	USGS-01118030	01118030	PAWCATUCK R AT ALTON-BRADFORD RD AT BRADFORD, RI	Stream/River	221
USGS	NWIS	USGS-01118055	01118055	TOMAQUAG BROOK, AT RT. 216, AT BRADFORD, RI	Stream/River	221
USGS	NWIS	USGS-01118100	01118100	PAWCATUCK RIVER NEAR SOUTH HOPKINTON, RI	Stream/River	221
USGS	NWIS	USGS-01118356	01118356	ASHWAY RIVER AT EXTENSION 184 NEAR ASHWAY, RI	Stream/River	221
USGS	NWIS	USGS-01118360	01118360	ASHAWAY RIVER AT ASHAWAY, RI	Stream/River	221
USGS	NWIS	USGS-01118400	01118400	SHUNOCK RIVER NEAR NORTH STONINGTON, CT	Stream/River	221
RIDEM	RIDEM	370678	WW304	Green Falls - Rte 184	Stream/River	203
RIDEM	RIDEM	1935	WW115	Pasquiset Tributary/Pasquisett Brook	Stream/River	198
RIDEM	RIDEM	1897	WW77	Locustv. Brushy Brook at Woody Hill	Stream/River	185
RIDEM	RIDEM	1898	WW78	Locustv. Brushy Brook at Saw Mill	Stream/River	185
RIDEM	RIDEM	1961	WW141	Pawcatuck River @ Potter Hill	Stream/River	161
RIDEM	RIDEM	370692	WW479	Pawcatuck River - Upstream of Boom Bridge	Stream/River	160
CTDEEP	CTDEEP	CT_DEP01_ WQX-16079	16079	Pendleton Hill Brook Upstream Grindstone Hill Road Pendleton Hill Brook Near Clarks Falls	Stream/River	158

Table C-2. Water Quality Data Summary (Page 3 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
CTDEEP	CTDEEP	CT_DEP01_ WQX-14720	14720	Green Fall River upstream confluence with Wyassup Bk US Clarks Fall Rd.	Stream/River	149
RIDEM	RIDEM	2429	WW391	Wood River @ Switch Rd.	Stream/River	131
RIDEM	RIDEM	2293	WW255	Tomaquag Brk @ Woodville Rd.	Stream/River	106
RIDEM	RIDEM	1958	WW138	Larkin Pond	Lake/Pond	105
USGS	NWIS	USGS-01117800	01117800	WOOD RIVER NEAR ARCADIA, RI	Stream/River	89
RIDEM	RIDEM	1890	WW70	Beaver River #3 (Rte 138)	Stream/River	86
RIDEM	RIDEM	1956	WW136	Breakheart Pond	Reservoir	79
RIDEM	RIDEM	1842	WW22	Long Pond (Hopkinton)	Lake/Pond	72
RIDEM	RIDEM	2206	WRB11	Moscow Brook-Dye Hill Rd	Stream/River	68
RIDEM	RIDEM	2213	WRB18	Unnamed	Stream/River	68
RIDEM	RIDEM	2217	WRB22	Falls River (Wood River)- Baseline Station BL12	Stream/River	68
RIDEM	RIDEM	2218	WRB23	Breakheart Brook- Frosty Hollow Rd USGS 1117780	Stream/River	68
RIDEM	RIDEM	2197	WRB02	Wood River-Rte 91 in Alton	Stream/River	66
RIDEM	RIDEM	2198	WRB03	Wood River-Woodville Rd in Woodville	Stream/River	66
RIDEM	RIDEM	2200	WRB05	Canochet Brook-Palmer Circle	Stream/River	66
RIDEM	RIDEM	2203	WRB08	Wood River-USGS 1118000	Stream/River	66
RIDEM	RIDEM	2204	WRB09	Brushy Brook-Outlet of Locustville Pond on Rte 3	Stream/River	66
USGS	NWIS	USGS-01117500	01117500	PAWCATUCK RIVER AT WOOD RIVER JUNCTION, RI	Stream/River	62
RIDEM	RIDEM	370838	WW580	Saw Mill Pond	Lake/Pond	61
RIDEM	RIDEM	370679	WW411	Parmentier Brk @ Clark Falls Rd.	Stream/River	60
RIDEM	RIDEM	2120	WW195	Queen River #3/Fisherville Brook	Stream/River	56
RIDEM	RIDEM	2292	WW254	Taney Brook	Stream/River	55
CTDEEP	CTDEEP	CT_DEP01_ WQX-14721	14721	Shunock River upstream Route 49	Stream/River	53
RIDEM	RIDEM	2208	WRB13	Outlet of Canob Pond-Rte 3	Stream/River	52
RIDEM	RIDEM	2226	WRB31	Coney Brook-Muddy Brook Rd	Stream/River	52
USGS	NWIS	USGS-01117468	01117468	BEAVER RIVER NEAR USQUEPAUG, RI	Stream/River	49
RIDEM	RIDEM	2332	WW314	White Brook Pond	Lake/Pond	49
USGS	NWIS	USGS-01118000	01118000	WOOD RIVER AT HOPE VALLEY, RI	Stream/River	48
RIDEM	RIDEM	2202	WRB07	Canochet Brook - Outlet of Ashville Pond on Marshall Drifting Rd	Stream/River	47
RIDEM	RIDEM	2244	WW223	Chickasheen @ Potter Road (Skagg's old dam)	Stream/River	46
RIDEM	RIDEM	370363	LPK01	Spring Brook. Spring Brook Road	Stream/River	45
RIDEM	RIDEM	2201	WRB06	Canochet Brook - Route 3 crossing - USGS 1118005	Stream/River	45
RIDEM	RIDEM	2209	WRB14	Wood River-above Wyoming Pond on Dye Hill Rd	Stream/River	45

Table C-2. Water Quality Data Summary (Page 4 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
RIDEM	RIDEM	2210	WRB15	Wood River-Barbersville Baseline Station BL25-Old Nooseneck Rd	Stream/River	45
RIDEM	RIDEM	2212	WRB17	Wood River-USGS 1117800 in Arcadia Management Area	Stream/River	45
RIDEM	RIDEM	2222	WRB27	Unnamed	Stream/River	45
RIDEM	RIDEM	2223	WRB28	Acid Factory Brook-Plains Meeting House Rd	Stream/River	45
RIDEM	RIDEM	370394	PAW05	Unnamed	Stream/River	44
RIDEM	RIDEM	370402	PAW13	Parmenter Brook at USGS gage #1118355 on Wich Way, Hopkinton	Stream/River	44
RIDEM	RIDEM	370404	PAW15	Unnamed Trib to Tomaquag Brook at Collins Road, Hopkinton	Stream/River	44
RIDEM	RIDEM	370406	PAW17	Perry Healy Brook at Klondike Road, Charlestown	Stream/River	44
RIDEM	RIDEM	370409	PAW20	Unnamed	Stream/River	44
RIDEM	RIDEM	370415	PAW25	Unnamed	Stream/River	44
RIDEM	RIDEM	370425	PAW35	Chipuxet River off Route 138 at the USGS gage #1117350	Stream/River	44
RIDEM	RIDEM	370465	QN04	Sherman Brook Before bend on Glen Rock Rd	Stream/River	44
RIDEM	RIDEM	370469	QN08	Stream/River		44
RIDEM	RIDEM	370470	QN09	Queens River & Tribs On William Reynolds Road	Stream/River	44
RIDEM	RIDEM	370478	QNAB	On Mail Rd/Liberty Rd USGS gage	Stream/River	44
RIDEM	RIDEM	370419	PAW29	Beaver River at the USGS gage #1117468 on Route 138, Richmond	Stream/River	43
RIDEM	RIDEM	370467	QN06	Locke Brook Mail Road	Stream/River	43
RIDEM	RIDEM	2288	WW250	Pawcatuck River @ Chase Hill Rd.	Stream/River	43
RIDEM	RIDEM	370365	LPK03	Corner of Babcock Rd and Stone Hill Dr. (off 1A)	Stream/River	42
RIDEM	RIDEM	370390	PAW01	Stream/River		42
RIDEM	RIDEM	370400	PAW11	Stream/River		42
RIDEM	RIDEM	370416	PAW26	Stream/River		42
RIDEM	RIDEM	370418	PAW28	Stream/River		42
RIDEM	RIDEM	370428	PAW38	Stream/River		42
RIDEM	RIDEM	370429	PAW39	Pawcatuck River on Nooseneck Hill Road (Rte 3), Hopkinton	Stream/River	42
RIDEM	RIDEM	370433	PAW43	Stream/River		42
RIDEM	RIDEM	370640	PAW49	Pawcatuck River at Boom Bridge Road	Stream/River	42
RIDEM	RIDEM	370464	QN03	Glen Rock Brook on Gardner Rd.	Stream/River	42
RIDEM	RIDEM	370604	QN21	Queens River at Dugway Bridge Road	Stream/River	42
RIDEM	RIDEM	370431	PAW41	Stream/River		41
RIDEM	RIDEM	2329	WW298	Browning Mill Pond	Lake/Pond	41
RIDEM	RIDEM	2207	WRB12	Brushy Brook-Dye Hill Rd	Stream/River	38
RIDEM	RIDEM	370602	QN10a	Stream/River		37

Table C-2. Water Quality Data Summary (Page 5 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
RIDEM	RIDEM	1899	WW79	Locustv. Moscow Brook at Saw Mill	Stream/River	37
NALMS	STORET	NALMS-7392	7392	Pasquiset Pond	Lake/Pond	36
RIDEM	RIDEM	1980	WW160	Eisenhower Lake	Lake/Pond	35
EPA NARS	STORET	NARS_WQX-NLA06608-2162	NLA06608-2162	Yawgoo Pond	Lake/Pond	31
RIDEM	RIDEM	370411	PAW22	Stream/River		28
RIDEM	RIDEM	370424	PAW34	Alewife Brook at Wordens Pond Road, South Kingstown	Stream/River	28
RIDEM	RIDEM	370846	WW617	Pasquisett Brook @ Rte 2	Stream/River	28
CTDEEP	CTDEEP	CT_DEP01_WQX-14379	14379	Pawcatuck River under White Rock Road Bridge at state line	Stream/River	26
CTDEEP	CTDEEP	CT_DEP01_WQX-14719	14719	Wyassup Brook at mouth upstream of Clarks Falls Road	Stream/River	26
CTDEEP	CTDEEP	CT_DEP01_WQX-19321	19321	Green Fall Reservoir at deepest part of lake	Lake/Pond	24
RIDEM	RIDEM	2163	WRB01	Wood River-Confluence with Pawcatuck River	Stream/River	24
RIDEM	RIDEM	2199	WRB04	Canochet Bk.-Baseline Station BL08-Woodville-Alton Rd	Stream/River	24
RIDEM	RIDEM	2205	WRB10	Moscow Brook-Rockville off Wincheck Pond Rd	Stream/River	24
RIDEM	RIDEM	2211	WRB16	Baker Brook-Old Nooseneck Rd	Stream/River	24
RIDEM	RIDEM	2214	WRB19	Woody Hill Brook-Woody Hill Rd	Stream/River	24
RIDEM	RIDEM	2215	WRB20	Parris Brook-Escoheag Rd	Stream/River	24
RIDEM	RIDEM	2216	WRB21	Parris Brook-Old Voluntown Rd	Stream/River	24
RIDEM	RIDEM	2219	WRB24	Roaring Brook-Outlet of Boon Lake on East Shore Drive	Stream/River	24
RIDEM	RIDEM	2220	WRB25	Roaring Brook-Inlet of Boon Lake on Austin Farm Rd	Stream/River	24
RIDEM	RIDEM	2221	WRB26	Breakheart Brook-Raccoon Hill Trail	Stream/River	24
RIDEM	RIDEM	2224	WRB29	Phillips Brook-Plains Meeting House Rd	Stream/River	24
RIDEM	RIDEM	2225	WRB30	Coney Brook-Outlet of Tillinghast Pond on Plain Rd	Stream/River	24
RIDEM	RIDEM	2227	WRB32	Falls River (Wood River) -Outlet of Hazard Pond on Hazard Rd	Stream/River	24
RIDEM	RIDEM	370398	PAW09	Chickasheen Brook at Waites Corner Road, South Kingstown	Stream/River	23
RIDEM	RIDEM	370809	PAW12a	Ashaway River at Ashaway Rd. (Rte 216)	Stream/River	21
RIDEM	RIDEM	370426	PAW36	Chipuxet River at Yawgoo Valley Road, Exeter	Stream/River	21
RIDEM	RIDEM	370427	PAW37	Chipuxet River at Liberty Road, Slocum	Stream/River	21
RIDEM	RIDEM	370430	PAW40	Stream/River	Stream/River	21
RIDEM	RIDEM	370414	PAW45	Stream/River	Stream/River	21
RIDEM	RIDEM	370810	PAW50	Ashaway River at Ashaway Line and Twine	Stream/River	21
RIDEM	RIDEM	370803	PAW51	Stream/River	Stream/River	21

Table C-2. Water Quality Data Summary (Page 6 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
RIDEM	RIDEM	370804	PAW52	Tomaquag Brook	Stream/River	21
RIDEM	RIDEM	370806	PAW53	Unnamed Trib to Tomaquag Brook Trib at Tomaquag/Ashaway Rd.	Stream/River	21
RIDEM	RIDEM	370813	PAW54	Tomaquag Brook at Diamond Hill Rd.	Stream/River	21
RIDEM	RIDEM	370462	QN01	Usquepaug River On Rte 2/ South County Trail	Stream/River	21
RIDEM	RIDEM	370811	QN01a	Usquepaug River at South County Trail (Rt. 2)	Stream/River	21
RIDEM	RIDEM	370472	QN11	On Rte 102 near Exeter Country Club	Stream/River	21
RIDEM	RIDEM	370474	QN13	Hallville Road (mailbox 111)	Stream/River	21
RIDEM	RIDEM	370603	QN20	Queens For Brook @ Rte 102	Stream/River	21
RIDEM	RIDEM	370812	WRB15a	Wood River at Old Nooseneck Rd.	Stream/River	21
RIDEM	RIDEM	370814	WRB17a	Wood River at Ten Rod Rd. (Rt. 165)	Stream/River	21
RIDEM	RIDEM	370805	WRB36	Brushy Brook at Sawmill Rd.	Stream/River	21
RIDEM	RIDEM	370808	WRB37	Canonchet Brook at Canonchet Rd. (US)	Stream/River	21
RIDEM	RIDEM	370807	WRB38	Canonchet Brook at Canonchet Rd. DS of Lawton Foster Rd N.	Stream/River	21
RIDEM	RIDEM	370820	WRB40	Roaring Brook at Ten Rod Rd. (Rt. 165)	Stream/River	21
RIDEM	RIDEM	370821	WRB41	Baker Brook at K.G. Ranch Rd.	Stream/River	21
RIDEM	RIDEM		PAW24/24a		Stream/River	21
RIDEM	RIDEM	2286	WW248	Pawcatuck River below Bradford Dyeing Assoc.	Stream/River	20
RIDEM	RIDEM	370693	WW480	Pawcatuck River - At Boom Bridge	Stream/River	20
RIDEM	RIDEM	370694	WW481	Pawcatuck River - Downstream of Boom Bridge	Stream/River	20
RIDEM	RIDEM	370773	WW544	Pasquisett Pond (Ferrio Dock)	Lake/Pond	17
CTDEEP	CTDEEP	CT_DEP01_ WQX-15796	15796	Pendleton Hill Brook adjacent to Route 49 on state property upstream of USGS gage, pole #257 and house # 567	Stream/River	16
CTDEEP	CTDEEP	CT_DEP01_ WQX-17781	17781	Hetchel Swamp Brook at confluence with Pendleton Hill Brook	Stream/River	16
CTDEEP	CTDEEP	CT_DEP01_ WQX-17211	17211	Wyassup Brook under and above Route 49	Stream/River	13
CTDEEP	CTDEEP	CT_DEP01_ WQX-14514	14514	Porter Pond 50 meters north of pond outlet dam at southern end	Lake/Pond	10
RIDEM	RIDEM	2001	WW181	Tippencansett Pond	Lake/Pond	10
CTDEEP	CTDEEP	CT_DEP01_ WQX-14859	14859	Shunock River upstream Route 184	Stream/River	8
CTDEEP	CTDEEP	CT_DEP01_ WQX-17746	17746	Anguilla Brook at Route 1	Stream/River	8
RIDEM	RIDEM	370477	QNAA	Trib to Queen On Mail Road at USGS gage	Stream/River	7
RIDEM	RIDEM	2484	WRB22a	Flat River at Midway Trail. Exeter	Stream/River	7
NALMS	STORET	NALMS-5628	5628	Locustville Pond	Lake/Pond	5
EPA NARS	STORET	NARS_WQX- NLA06608-2566	NLA06608-2566	Chapman Pond	Lake/Pond	5

Table C-2. Water Quality Data Summary (Page 7 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
RIDEM	RIDEM	2366	WW301	Wickaboxet Pond	Lake/Pond	5
NALMS	STORET	NALMS-5673	5673	Watchaug Pond	Lake/Pond	4
USGS	NWIS	USGS-01117345	01117345	QUEEN RIVER AT STONY LANE	Stream/River	3
USGS	NWIS	USGS-01117355	01117355	QUEEN RIVER AT REYNOLDS RD NR EXETER RI	Stream/River	3
USGS	NWIS	USGS-01117355	011173555	FISHERVILLE BROOK AT HENRY BROWN ROAD	Stream/River	3
USGS	NWIS	USGS-01117356	01117356	FISHERVILLE BROOK AT STATE HIGHWAY 102	Stream/River	3
USGS	NWIS	USGS-01117357	01117357	DUTEMPLE BROOK AT HALLVILLE ROAD	Stream/River	3
USGS	NWIS	USGS-01117358	01117358	SODOM BROOK AT STATE HIGHWAY 102	Stream/River	3
USGS	NWIS	USGS-01117359	01117359	SODOM BROOK AT HALLVILLE ROAD	Stream/River	3
USGS	NWIS	USGS-01117360	01117360	FISHERVILLE BK AT LIBERTY CHURCH RD NR EXETER RI	Stream/River	3
USGS	NWIS	USGS-01117368	01117368	QUEEN RIVER AT DAWLEY ROAD	Stream/River	3
USGS	NWIS	USGS-01117370	01117370	QUEEN R AT LIBERTY RD AT LIBERTY RI	Stream/River	3
USGS	NWIS	USGS-01117380	01117380	LOCKE BROOK AT MAIL RD AT LIBERTY RI	Stream/River	3
USGS	NWIS	USGS-01117387	01117387	QUEEN RIVER AT DUGWAY ROAD	Stream/River	3
USGS	NWIS	USGS-01117390	01117390	GLEN ROCK BK AT GLEN ROCK RD AT GLEN ROCK RI	Stream/River	3
USGS	NWIS	USGS-01117400	01117400	SHERMAN BK AT GLEN ROCK RD AT GLEN ROCK RI	Stream/River	3
USGS	NWIS	USGS-01117410	01117410	USQUEPAUG RIVER AT RT 138 AT USQUEPAUG, RI	Stream/River	3
USGS	NWIS	USGS-01117354	01117354	QUEEN RIVER AT STATE HIGHWAY 102 AT EXETER, RI	Stream/River	2
NALMS	STORET	NALMS-5594	5594	Alton Pond	Lake/Pond	2
NALMS	STORET	NALMS-5602	5602	Browning Mill Pond	Lake/Pond	2
NALMS	STORET	NALMS-5621	5621	Hundred Acre	Lake/Pond	2
NALMS	STORET	NALMS-5682	5682	Yawgoo Pond	Lake/Pond	2
USGS	NWIS	USGS-01117870	01117870	ROARING BROOK AT BALD HILL RD AT ARCADIA, RI	Stream/River	1
USGS	NWIS	USGS-01117875	01117875	BAKER BK OLD NOOSENECK HILL RD NR HOPE VALLEY,RI	Stream/River	1
USGS	NWIS	USGS-01117886	01117886	UNNAMED TRIBUTARY TO THE WOOD RIVER, HOPE VAL, RI	Stream/River	1
USGS	NWIS	USGS-413234071403701	413234071403701	Baker Brook, Upstream From Unnamed Tributary	Stream/River	1
USGS	NWIS	USGS-413238071410201	413238071410201	Unnamed Tributary to Baker Brook, Arcadia, RI	Stream/River	1
USGS	NWIS	USGS-413330071410701	413330071410701	Roaring Brook at KG Ranch Road, Arcadia, RI	Stream/River	1
NALMS	STORET	NALMS-5595	5595	Barber Pond	Lake/Pond	1
NALMS	STORET	NALMS-5606	5606	Carr Pond	Lake/Pond	1

RESPEC

Table C-2. Water Quality Data Summary (Page 8 of 8)

Source	Provider Name	Source I.D.	Name	Description	Type	Calibration Samples
NALMS	STORET	NALMS-5608	5608	Chapman Pond	Lake/Pond	1
NALMS	STORET	NALMS-5634	5634	Meadowbrook Pond	Lake/Pond	1
NALMS	STORET	NALMS-5666	5666	Tucker Pond	Lake/Pond	1
NALMS	STORET	NALMS-5681	5681	Wyoming Pond	Lake/Pond	1