PAWCATUCK RIVER WATERSHED MODELING QUALITY ASSURANCE PROJECT PLAN

PREPARED BY

John C. Imhoff
Cindie M. McCutcheon

RESPEC
3824 Jet Drive
Rapid City, South Dakota 57703

PREPARED FOR

Connecticut Department of
Energy and Environmental Protection
79 Elm Street
Hartford, Connecticut 06106

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QUALITY ASSURANCE PROJECT PLAN GOVERNANCE

This quality assurance project plan (QAPP) has been prepared according to US Environmental Protection Agency (EPA) guidance provided in the *Template for Developing a Generic or Project-Specific Quality Assurance Project Plan for Model Applications* [EPA, 2009a][1] as well as *EPA Requirements for Quality Assurance Project Plans* [EPA, 2002a][2] and *Guidance for Quality Assurance Project Plans for Modeling* [EPA, 2002b][3] to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use. EPA Region 1's *Quality Assurance Checklist For Modeling QAPPs* [EPA, 2009b][4] has been used to ensure that the contents of this QAPP meet the specific content expectations of EPA Region 1. RESPEC Company, LLC will perform work in conformance with the *US Environmental Protection Agency Region 1 Quality Management Plan* [EPA, 2020][5].

1 **US Environmental Protection Agency, 2009a.** *Template for Developing a Generic or Project-Specific Quality Assurance Project Plan for Model Applications*, prepared by the US Environmental Protection Agency, Office of Environmental Information, Washington, DC. Available online at *https://www.epa.gov/sites/production/files/2015-07/modelqapptemplate2009.doc*

2 **US Environmental Protection Agency, 2002a.** *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5, EPA/240/B-01/003, prepared by the US Environmental Protection Agency, Office of Environmental Information, Washington, DC. Available online at *https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5*

3 **US Environmental Protection Agency, 2002b.** *Guidance for Quality Assurance Project Plans for Modeling,* EPA 240-R-02-007, prepared by the US Environmental Protection Agency, Office of Environmental Information, Washington, DC. Available online at *https://www.epa.gov/sites/production/files/2015-06/documents/g5m-final.pdf*

4 **US Environmental Protection Agency, 2009b.** "Design and Implementation of New Tools for Quality Assurance in Modeling," *epa.org*, accessed March 24, 2020 from *https://www.epa.gov/quality/design-and-implementation-new-tools-quality-assurance-modeling*

5 **US Environmental Protection Agency, 2020.** *U.S. Environmental Protection Agency Region 1 Quality Management Plan, Revision 1.0,* EPARegion1QMP1, prepared by the US Environmental Protection Agency, Washington, DC. Available online at *http://www.epa.gov/quality/quality-management-plan-epa-region-1*

PAWCATUCK RIVER WATERSHED MODELING QUALITY ASSURANCE PROJECT PLAN

TITLE AND APPROVAL PAGE

Development of an HSPF Model for the Pawcatuck River Watershed
(Project Name)

RESPEC Company, LLC
(Responsible Agency)

September 17, 2020
(Date)

RESPEC Project Manager Signature Name/Date	Jason Love September 17, 2020
RESPEC Co-Project Manager Signature Name/Date	Seth Kenner September 17, 2020
RESPEC Project QA/QC Officer Signature Name/Date	John Imhoff September 17, 2020
CTDEEP Project Manager Signature Name/Date	Traci Iott Traci Iott September 29, 2020
RIDEM Project Manager Signature Name/Date	Jane Sawyers Jane Sawyers October 13, 2020
CTDEEP Technical Advisor Name/Date	Kelly L. Streich Kelly Streich September 29, 2020
RAE Grant Manager Signature Name/Date	16 OCT 20 Thomas Ardito
EPA QA Officer Signature Name/Date	NORA CONLON Digitally signed by NORA CONLON Date: 2020.10.20 14:48:21 -04'00' Nora Conlon
EPA Project Officer Signature Name/Date	10/20/20 Margherita Pryor

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1.3 DISTRIBUTION LIST

The persons listed in Table 1-1 will receive copies of the approved quality assurance project plan (QAPP) and any subsequent revisions of the QAPP. A complete copy of the original version and all revisions of the QAPP, including the official, approved QA project plan, will be maintained on file by the project quality assurance/quality control (QA/QC) officer (Mr. John Imhoff) at RESPEC Company, LLC (RESPEC) and will be available upon request. Note that Ms. Mary Garren and Mr. Toby Stover from the US Environmental Protection Agency (EPA) Region 1 (New England) will be provided with a copy of this QAPP because of their supporting roles in the 303d and Nutrient Programs. Coordination with these programs at the regional level will help to ensure project success and support nutrient management planning and implementation activities in the Pawcatuck River Watershed in the future.

1.4 PROJECT ORGANIZATION

This QAPP supports the HSPF modeling of the Pawcatuck River Watershed for the project funded under Southeast New England Program (SNEP) Watershed Grant 6-FULLWG18-CTDEEP-RIDEM. The successful completion of this project requires the involvement of six organizations:

- Connecticut Department of Energy and Environmental Protection (CTDEEP)
- Rhode Island Department of Environmental Management (RIDEM)
- RESPEC Company, LLC
- EPA Region 1
- Restore America's Estuaries (RAE)
- US Geological Survey (USGS).

The organizational roles are as follows:

- CTDEEP: Applicant organization that was awarded and now implements SNEP Grant 6-FULLWG18-CTDEEP-RIDEM in collaboration with RIDEM, which is the partner organization for the grant. CTDEEP provides the point of contact for this project and facilitates collaboration across various organizations associated with the project.
- RIDEM: Partner organization on SNEP Grant 6-FULLWG18-CTDEEP-RIDEM that works in collaboration with CTDEEP to implement the grant.

Table 1-1. Pawcatuck Quality Assurance Project Plan Distribution List (Page 1 of 2)

Name and Title	Organization and Contact Information
Traci Iott Project Team Leader	CTDEEP 79 Elm Street Hartford, CT 06106 *traci.iott@ct.gov* 860.424.3082
Margherita Pryor Project Officer	US EPA Region 1 5 Post Office Square, #100 Boston, MA 02109 *pryor.margherita@epa.gov* 617.918.1597
Nora Conlon Quality Assurance Coordinator	US EPA Region 1 11 Technology Drive North Chelmsford, MA 01863 *conlon.nora@epa.gov* 617.918.8335
Kelly Streich Technical Advisor	CTDEEP 79 Elm Street Hartford, CT 06106 *kelly.streich@ct.gov* 860.424.3864
Jane Sawyers Technical Advisor	RIDEM 235 Promenade Street Providence, RI 02908 *jane.sawyers@dem.ri.gov* 401.222.4700x7300
Thomas Ardito Grant Administrator	Restore America's Estuaries/ SNEP Grant Program P.O. Box 476 Saunderstown, RI 02874 *tardito@estuaries.org* 401.575.6109
Jason Love Project Manager	RESPEC Company, LLC 3824 Jet Drive Rapid City, SD 57703 *jason.love@respec.com* 605.394.6400
Seth Kenner Co-Project Manager	RESPEC Company, LLC 3824 Jet Drive Rapid City, SD 57703 *seth.kenner@respec.com* 605.394.6400

Table 1-1. Pawcatuck Quality Assurance Project Plan Distribution List (Page 2 of 2)

Name and Title	Organization and Contact Information
John Imhoff QA/QC Officer	RESPEC Company, LLC P.O. Box 323 Ouray, CO 81427 *john.imhoff@respec.com* 970.318.8493
Toby Stover 303d and Nutrient Programs EPA Region 1	US EPA Region 1 5 Post Office Square, #100 Boston, MA 02109 *stover.toby@epa.gov* 617.918.1604
Mary Garren 303d and Nutrient Programs EPA Region 1	US EPA, Region 1 5 Post Office Square, #100 Boston, MA 02109 *garren.mary@epa.gov* 617.918.1322

/ **RESPEC**: RESPEC will develop a Hydrological Simulation Program – Fortran (HSPF) watershed model for nutrients, total suspended solids, flow, and related parameters.

/ **EPA**: The EPA is the grantor to RAE for the grant money that is being used for this project. The EPA will review and approve this QAPP. The EPA Region 1 303d and Nutrient Program staff will provide input to the project within their specific program expertise.

/ **RAE**: RAE has been selected by the EPA to manage the SNEP for 2018 and 2019, which includes the grant that funds this project. RAE will oversee the fiscal and technical aspects of the grant project.

/ **USGS**: The USGS is providing technical services for collection and analysis of water quality and flow data in support of the grant project. The USGS also provides QA oversight of data collection and analysis, projects final data results, and reports and posts data to the National Water Information System (NWIS) to make the data publicly accessible. The USGS prepared a separate QAPP entitled *Water Quality Sampling and Monitoring of the Pawcatuck Watershed Revision 3 US Geological Survey Quality Assurance Project Plan* [USGS, 2019] to cover ongoing USGS data collection activities.

RESPEC will conduct work for this project in conformance with the procedures detailed in this QAPP. Table 1-2 identifies the project participants from various organizations and summarizes each participant's title, organization, and responsibility with respect to this QAPP.

The project organization and lines of communication are shown in Figure 1-1. The technical and QA aspects of the project are presented for the client and contractors.

1.5 PROBLEM DEFINITION AND BACKGROUND

Across southeast New England, coastal estuaries, lakes, and impoundments exhibit the effects of excessive nutrients: lost or significantly diminished eelgrass beds, excessive growth of macroalgae, oxygen-depleted waters, and deteriorated substrates. Eelgrass was once commonly found in bays and harbors throughout Long Island Sound but is now largely confined to the Sound's eastern extent. Harmful algae blooms occur regularly in lakes and reservoirs across Connecticut and Rhode Island. Habitat for fish (at all life stages) and other aquatic organisms suffer under these conditions, as do recreational uses and waterfront property values.

Table 1-2. Pawcatuck Quality Assurance Project Plan Project Participants

Name	Title	Organization	Primary Responsibility
Traci Iott	Supervising Environmental Analyst	CTDEEP	Responsible for overall project management and decision-making in consultation with RIDEM. Responsible for coordination among all of the organizations associated with the project.
Jane Sawyers	Supervising Environmental Scientist	RIDEM	Technical advisor to the CTDEEP project team leader with respect to RIDEM issues, watershed knowledge, and studies.
Kelly Streich	Technical Coordinator	CTDEEP	Technical advisor to the CTDEEP project team leader with respect to CTDEEP issues, watershed knowledge, and studies.
Jason Love	Project Manager	RESPEC	Responsible for directing and coordinating technical work and interaction with the CTDEEP project team leader, tracking the budget, and performing administrative functions.
Seth Kenner	Co-Project Manager	RESPEC	Responsible for all of the day-to-day project technical activities.
John Imhoff	QA/QC Officer	RESPEC	Responsible for the project QA/QC activities, including targeted independent review of the project's technical and administrative practices and products.
Nora Conlon	QA/QC Officer	EPA	Responsible for providing review and oversight of the project QAPP.
Margherita Pryor	Project Officer	EPA	Responsible for providing oversight of the project with respect to the SNEP Grant program.
Thomas Ardito	Grant Administrator	RAE/SNEP	Responsible for administering the grant program and overseeing the project for consistency with grant requirements.

State and federal regulators have begun to respond to these nutrient-caused impairments by requiring more stringent permit limits for National Pollutant Discharge Elimination System (NPDES) discharges, but nonpoint sources and stormwater are becoming the largest sources of nutrients in Connecticut and Rhode Island. To target these sources effectively, detailed information is needed regarding nutrients in watersheds at fine spatial and temporal scales. This information is needed to identify where and when the bulk of nutrient nonpoint- and stormwater-source loads are being released to nearby waters. This information is similarly needed as input to drive site-specific models of lakes, reservoirs, and estuaries that can be used to determine total maximum daily loads (TMDLs).

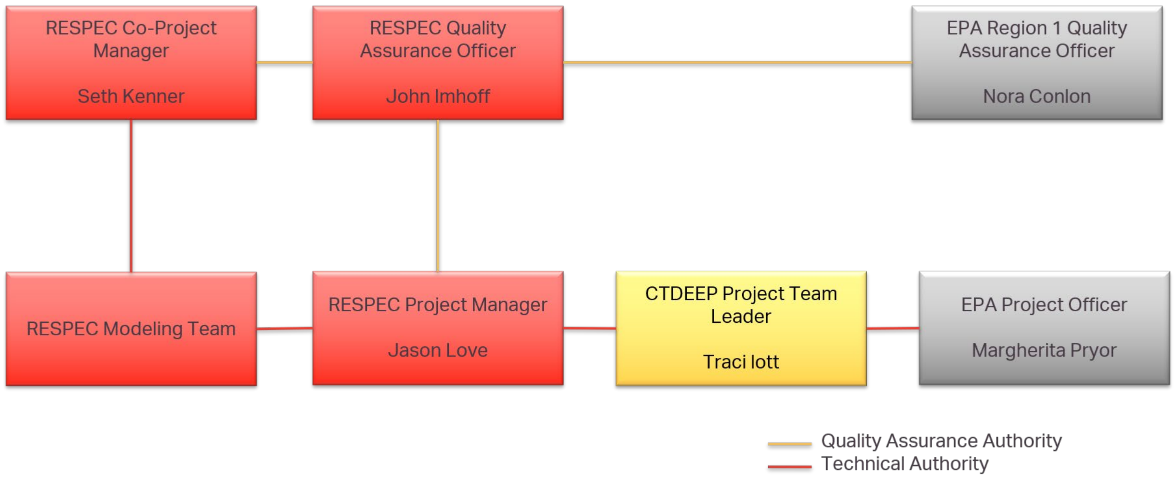

Figure 1-1. Organizational Chart Showing Relationships and Lines of Communication Among Project Participants.

The Pawcatuck River Basin, as shown in Figure 1-2, and the Pawcatuck River Estuary (PRE) and Little Narragansett Bay (LNB) form part of the boundary between the states of Connecticut and Rhode Island. Both of the states have identified water quality impairments within the estuarine waters related to insufficient oxygen with bacteria impairments found throughout the freshwater and estuarine watershed. Connecticut has additionally identified impairments associated with nutrient and eutrophication biological indicators in the estuary.

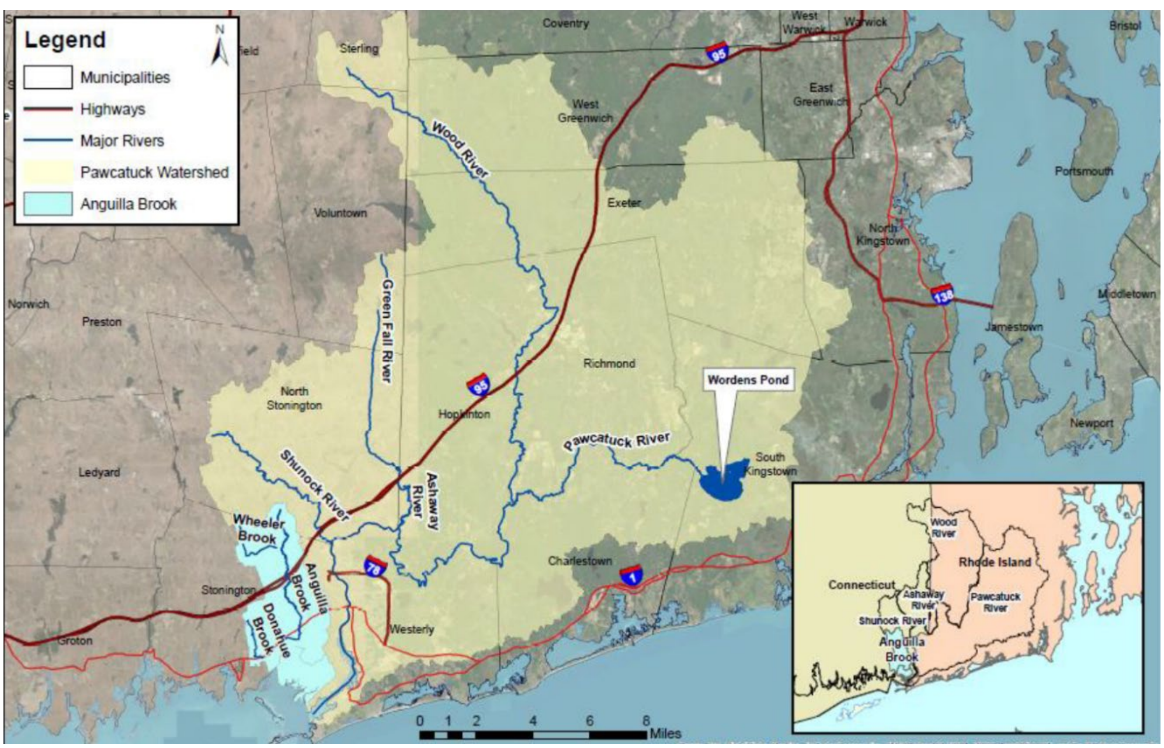

Figure 1-2. Pawcatuck River Basin.

A dynamic watershed modeling approach is the most efficient means to obtain detailed information on nonpoint-source and stormwater nutrient loads across the watershed. Directly measuring nutrient loads at the spatial and temporal scales needed would be impossible. While simplified watershed yield models provide annual nutrient loads, these models lack the temporal variability of loads, which is important for understanding episodic events or predicting loads under different climatic conditions. A dynamic watershed model for Connecticut was completed in 2002 using the EPA's HSPF [Bicknell et al., 2001]. Land-use changes have occurred in Rhode Island and Connecticut's watersheds since 2002 that limit that model's effectiveness in representing current nutrient loadings, fate, and transport. Further, an updated model can take advantage of two decades of advancement in modeling tools that enable significant improvements in evaluating nutrient management alternatives. The 2002 model also did not provide full coverage for watersheds affecting Connecticut waterbodies. The Pawcatuck River Watershed was not included in the previous statewide model for Connecticut. In recent years, a watershed model using HSPF was developed for the Pawcatuck River Watershed as a collaboration between the state of Rhode Island and the USGS; however, that model only focused on stream flow and did not address nutrients and other related parameters. More recent available land-cover layers for Rhode Island and Connect will be used for the updated model. More detail on land cover will be included in the simulation plan document.

Given that the HSPF model was previously used in Connecticut to develop the Connecticut Watershed Model (CTWM) [Donigian and Love, 2002] and in Rhode Island to simulate the effects of water withdrawals and land-use changes on stream flow and groundwater levels in the Pawcatuck River Basin [Gardner et al., 2009], the CTDEEP has selected HSPF as the dynamic watershed model of choice for its ongoing watershed modeling program. HSPF has been widely used throughout the US for analyzing water hydrology and quality in support of developing implementation plans based on attaining environmental goals. This complex and dynamic model can address soil, groundwater, and surface-water processes; storm events; and impacts from point and nonpoint sources of pollution. The model continues to be supported by the EPA and USGS.

To better understand watershed nutrient loads and water quality within the freshwater portion of the Pawcatuck River Watershed, the states of Connecticut and Rhode Island require information on water quality and stream flow in locations throughout the freshwater portion of the watershed. Under a separate project, the USGS is collecting and analyzing additional data that will enhance HSPF watershed model development and calibration for nutrients, total suspended solids, stream flow, and related parameters. The HSPF model will assist in assessing and managing nutrients in the Pawcatuck River Watershed. Information on diurnal dissolved oxygen along with data on nitrogen and phosphorus concentrations are critical components of developing management approaches and will be required as input datasets in a planned watershed-scale hydrology and water quality model. Scripts have been generated to efficiently process the USGS flow and water quality data collected after the first round of the model is calibrated so that new data can be integrated into the model extension.

The project entails the assessment and manipulation of existing, primary, and secondary ambient water quality data and water quality modeling outputs that will be used for decision-making. The purpose of this QAPP is to address the use of primary and secondary data, which will require submittal to the

CTDEEP project team leader and, eventually, the EPA's regional Quality Assurance Unit (QAU) for approval. The QAPP will define the project's QA objectives and the protocols that will be used by project personnel to achieve these objectives.

1.6 PROJECT/TASK DESCRIPTION AND SCHEDULE

CTDEEP seeks to develop a new watershed-focused approach to identifying and managing nutrient inputs into coastal estuaries to support healthy aquatic communities, restore eelgrass and recreational uses, and support nutrient management in the upland watersheds. This approach will employ dynamic watershed models calibrated for both hydrology and water quality characteristics. Such models were chosen to facilitate the analysis of water quality impacts associated with current and future conditions within watersheds across Connecticut and Rhode Island. Models provide a proven platform for analyzing various implementation scenarios to attain water quality goals that can then be translated into implementation plans.

In 2020, CTDEEP contracted RESPEC for the development of two HSPF models: one for the Pawcatuck River Watershed and the other for the remaining portion of Connecticut. This QAPP addresses the Pawcatuck River Watershed HSPF model application. The schedule for the Pawcatuck portion of the project is shown in Table 1-3. The primary water quality parameters to be predicted by the model are nitrogen, phosphorus, suspended sediments, and stream flow. The following constituents will specifically be modeled:

- Flow
- Water Temperature
- Suspended Sediments
- Total Ammonia
- Nitrate and Nitrite
- Organic Nitrogen
- Particulate Nitrogen
- Total Nitrogen
- Orthophosphate
- Organic Phosphorus
- Particulate Phosphorus
- Total Phosphorus
- Biochemical Oxygen Demand
- Dissolved Oxygen
- Chlorophyll a
- Conservative Tracer.

The HSPF model will provide estimates of flow, nitrogen, phosphorus, and sediment into the estuarine Pawcatuck and Little Narragansett Bay and Connecticut's estuaries. Embayment fate and transport models can, in turn, use this information to evaluate estuarine water quality conditions in comparison to water quality-based targets.

Table 1-3. Project Milestones and Completion Dates

Project Milestone	Date for Completion
Kick-Off Meeting	April 2020
Final Pawcatuck River Watershed Modeling QAPP	September 2020
Final Modeling Approach Document	October 2020
Water Quality Modeling Completed	January 2021
Scenario Application Manager (SAM) Framework Completed	March 2021
Water Quality Model Extended	March 2021
HSPF and SAM Training	April 2021
Project Report Completed	April 2021

The results of the dynamic watershed models will be used to link with site-specific models for lakes, reservoirs, and tidal waters to conduct evaluations of these target waterbodies. The models are expected to provide nutrient loads, suspended sediment loads, and freshwater inputs to other site-specific models.

1.7 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA AND MODELS

This section describes the quality objectives for the project, including the performance and acceptance criteria to achieve the objectives. This QAPP has been developed to ensure that (1) modeling input data are valid and defensible, (2) model setup and parameterization (calibration) protocols are followed and documented, (3) model applications and output data are reviewed and evaluated in a consistent manner, and (4) that models are able to predict hydrologic or water quality conditions over time. Project quality objectives and criteria for data will be addressed by (1) evaluating the quality of the data used and (2) assessing the model application results.

1.7.1 DATA ACCEPTANCE CRITERIA

The organizations generating the secondary data that may be used in this project typically apply their own review and verification procedures to evaluate a dataset's integrity and conformance to QA/QC requirements. The data quality will be judged using information from source documents, from websites of origin, or directly from the authors. If the quality of the data can be adequately determined, the data will be used. If no quality requirements are determined to exist or can be established for a dataset that must be used for this task, a case-by-case-basis determination will be made regarding the data use. Table 1-4 summarizes the acceptance criteria for using secondary data in the setup and calibration and validation of the model.

RESPEC currently anticipates that most of the data used in the modeling will have been collected or developed by various sources commonly used for watershed model development. Whenever possible, the modelers will electronically download secondary data directly from various sources to reduce the possibility of introducing errors during data entry. In cases where multiple sources of data are available, the modelers will assess and use the best available data (i.e., that of with the highest quality). Data of unknown quality will be incorporated into the model only if approved by the CTDEEP project team leader, and the inclusion status of the data will be documented. If no information is available regarding the data, the data will either not be used or be qualified with the statement "The quality of this specific secondary dataset used in developing the watershed model could not be determined." Most of the data used for the model will generally be from trusted federal and state sources. Data from trusted state and federal sources are assumed to have undergone the appropriate QA/QC measures. Data that are not from trusted federal and state sources will be evaluated during the modeling process for anomalies or errors and will only be used if the benefit of having those data is greater than a possible assumption to replace them.

Table 1-4. Data Acceptance Criteria for Secondary Data

Quality Criterion	Description
Reasonableness	Datasets will be reviewed to identify anomalous values that may represent data entry or analytical errors. Such values will not be used without clarification from the agency providing the data.
Completeness	Datasets will be reviewed to determine the extent of gaps in space and time. Some data gaps will likely be evident; these gaps and the methods used to fill the gaps will be discussed in the project deliverables.
Comparability	Datasets from different sources will be compared by checking the methods used to collect the data and that the units of reporting are standardized.
Representativeness	Datasets will be evaluated to ensure that the reported variable and its spatial and temporal resolution are appropriate for the project; for example, datasets must be able to be reasonably aggregated (or disaggregated) to represent conditions in the model and must represent conditions during the simulation periods. The goal is for data and information to reflect present-day conditions and, where possible, data from the past 10 years will be used.
Relevance	Data specific to the study site will be used. Regional data and information that most closely represent the study site will be used only if needed.
Reliability	Data and information sources will be considered reliable if they meet at least one of the following acceptance criteria: / The information or data are from a peer-reviewed, government, or industry-specific source. / The source is published. / The author is engaged in a relevant field such that competent knowledge is expected. / The information was presented in a technical conference where it was subject to review by professional experts. Data sources that use unknown collection and data-review procedures are considered less reliable and will be used only if necessary to fill data gaps and following discussion with and approval by CTDEEP.

Secondary data will generally be formatted and reviewed using scripting (MATLAB or Python). Data that are outside of the typical ranges for a given parameter will be flagged for exclusion during model setup, calibration, and validation. Flagged data will only be excluded if the data are determined to be erroneous; for example, faulty calibration of sonde data may occur when dissolved oxygen drops quickly to near zero and stays there for long periods of time. In such cases, characterizing the sonde data as "erroneous" is appropriate.

1.7.2 MODEL PERFORMANCE AND ACCEPTANCE CRITERIA

The EPA's *Guidance for Quality and Assurance Project Plans for Modeling* (EQP AQ/G-5M) [EPA, 2002] discusses the importance of using performance criteria as the basis by which judgments are made on whether or not the model results adequately support the decisions required to address the study objectives. The focus of this section is to specify model performance criteria for the HSPF model to be developed for the Pawcatuck River Watershed. A weight-of-evidence approach that embodies the following principles will be adopted for model calibration in this project [Donigian and Imhoff, 2009]:

- Given that models are approximations of natural systems, the exact duplication of observed data is not a performance criterion. The model calibration process will measure the ability of the model to simulate observed data through comparability goals.
- No single procedure or statistic is widely accepted as measuring (nor capable of establishing) acceptable model performance; thus, quantitative (error statistics) and qualitative (graphical) comparisons of observed data and model results will be used to provide sufficient evidence to weight the decision on model acceptance or rejection.
- All model and observed data comparisons must recognize, either qualitatively or quantitatively, the inherent errors and uncertainty in the model and the measurements of the observed datasets. These errors and uncertainties will be documented in the final report, where possible.

A model is considered calibrated when it reproduces data within an acceptable level of accuracy, as described in Table 1-5. The values in the table provide general guidance in terms of the percent mean errors or differences between simulated and observed values so that users can gauge what level of agreement or accuracy (i.e., very good, good, fair) may be expected from the model application. The target accuracy level for this project will be that which corresponds to "Good" or "Very Good" results at more downstream, mainstem calibration sites and "Fair" or "Good" 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. Before the calibration process begins, the final calibration accuracy targets will be agreed upon in discussion with CTDEEP and RIDEM. The agreed-upon targets will be specified at the beginning of the calibration documentation in the final modeling report.

Table 1-5. General Percent Error Calibration/Validation Targets for Watershed Models (Applicable to Monthly, Annual, and Cumulative Values) [Donigian, 2000]

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

A set of parameters used in a calibrated model might not accurately represent field values, and the calibrated parameters might not represent the system under a different set of boundary conditions or hydrologic stresses; therefore, a model validation period helps to establish greater confidence in the calibration and predictive capabilities of the model. A site-specific model is considered validated if its accuracy and predictive capability have been proven to be within acceptable error limits independently of the calibration data.

1.8 SPECIAL TRAINING REQUIREMENTS/CERTIFICATION

The RESPEC personnel working on this project hold advanced degrees from universities that are well-known for excellence in all aspects of surface-water modeling. Each RESPEC modeler also has more than 5 years of experience in calibrating, validating, and applying HSPF water quality models. No special training or certifications are required for personnel working on this project beyond the high degree of academic training and professional experience that personnel have already obtained to fulfill job requirements commensurate with their current assignments. The QA officer will be responsible for ensuring that individual project staff members are adequately trained to fulfill assignment requirements. At the discretion of CTDEEP's project team leader, a spreadsheet will be prepared and maintained in the project management files that provides documentation of staff qualifications with respect to project responsibilities.

1.9 DOCUMENTS AND RECORDS

All of the data and information collected and generated during this project will be stored in a project folder on the RESPEC network. At the project's completion, RESPEC will transmit a copy of all of the project files to CTDEEP and RIDEM by means of a Microsoft Teams folder created for this project. RESPEC will also maintain a copy of all of the project files on our backed-up network for a minimum of 5 years following the project completion. The following deliverables will be prepared under this project:

- QAPP (draft and final)
- Sampling plan review memorandum
- The proposed approach for the HSPF model memorandum
- Data collection activities memorandum
- Quarterly progress reports
- Teleconference summaries
- Modeling report
- Scenario report
- Final report.

The final report will provide a complete and clear summary of the modeling methodology and all of the data and assumptions used in the model such that the analysis can be easily validated/duplicated by CTDEEP staff.

All other project documents, records, and electronic files that are produced will be included as deliverables with the final model application. This documentation will include but not be limited to:

- Results of technical reviews, model tests, and data quality assessments, as applicable
- Model input and databases used
- Response actions taken
- Spreadsheet data files
- Modeling reports.

In the event that revisions to this QAPP are needed during the project performance, the QA officer will ensure that the individuals identified in the distribution list receive the most current copy of the approved QAPP.

2.0 DATA ACQUISITION/MANAGEMENT

Time-variable and geographic information system (GIS) data of known and documented quality are essential to the success of any water quality modeling study and generate information to use in establishing watershed management strategies. The QA process for the HSPF modeling of the Pawcatuck River Watershed consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. The quality of a modeling study is determined to a large extent by the expertise of the modeling and quality assessment teams.

The quality of an environmental analysis program is achieved by means of three steps: (1) establishing scientific assessment quality objectives, (2) evaluating the program design for whether or not the objectives can be met, and (3) establishing assessment and measurement quality objectives that can be used to evaluate the appropriateness of the methods used in the program. The quality of a dataset is a measure of the type and amount of error associated with the data. Error sources are commonly grouped into two categories: sampling error and measurement error. These types of errors, as well as processing errors, can affect the accuracy and interpretation of results. For various reasons. some of the data evaluated for potential use in developing, calibrating, and testing the models may be judged as acceptable for uses to support this modeling effort. The data acquisition procedures that will be followed for modeling include data review and management practices that will reduce the sources of error and uncertainty in using the data. The considerations involved in data acquisition and management are described in the following sections.

2.1 DATA ACQUISITION

This project will require using secondary data, which are also referred to as non-direct measurements. Secondary data are data that were collected under a different effort outside of this project. Much of the data that will be needed for this model application reside on the CTDEEP and RIDEM servers and will be downloaded from those sites to support this project. As needed, supplemental secondary data will be collected from government publications and databases, scientific literature, related technical studies, watershed groups, and other organizations. Data commonly required for populating a database for use in calibrating watershed models are listed in Table 2-1. The data listed in the table are exemplary and, as such, are not intended to be all-inclusive. Table 1-5 in Section 1.7.2 summarizes the acceptance criteria for using secondary data in the setup, calibration, and validation of the model.

The primary mechanism used for data acquisition will be electronic downloading. RESPEC will adhere to protocols that we have developed while performing hundreds of previous HSPF applications to ensure that we properly address QA considerations related to preventing, detecting, and correcting downloading errors.

RESPEC will include a summary of the data collection activities, data sources, and expected uses of data in a section of the model simulation plan that will be submitted to CTDEEP and RIDEM. The following information will be provided for each dataset in an outline format:

- Data type
- Originating source agencies

- Time period over which the data were collected (if different from the modeling period)
- Available QA/QC documentation (if from sources other than trusted federal or state sources)
- Data gaps
- Planned use in model setup and/or calibration and validation efforts.

Table 2-1. Secondary Environmental Data to Be Assembled for Watershed and Water Quality Modeling in the Pawcatuck River Basin

Data Type	Example Measurement Endpoint(s) or Units
Geographic or Location Information (Typically in GIS Format)	
Hydrologic Unit Code Boundaries	ArcGIS Shapefile or Feature
Hydrography	ArcGIS Shapefile or Feature
Land Use	ArcGIS Shapefile or Raster
Topography	Digital Elevation Model (meters or feet)
Population Distributions	ArcGIS Shapefile or Feature/Number
Soils (Including Soil Characteristics)	ArcGIS Shapefile or Feature/Hydrologic Group
Water Quality and Biological Monitoring and Meteorological Station Locations	Latitude/Longitude
Permitted Point-Source Discharge Locations	Latitude/Longitude
Dam Locations	Latitude/Longitude
Flow	
Historical Record (daily)	cubic feet per second (cfs)
Peak Flows (daily maximum)	cfs
Storm Hydrographs (hourly or less)	cfs
Permit Limits (flow)	cfs
Meteorological Data	
Rainfall	inches
Temperature	degrees C (°C)
Potential Evapotranspiration	inches
Wind Speed	miles per hour
Dew Point	°C
Humidity	percent or grams per cubic meter
Cloud Cover	percent or grams per cubic meter
Solar Radiation	watts per square meter
Water Quality (Surface Water, Groundwater)	
Total Suspended Solids	milligrams per liter (mg/L)
Nutrients	mg/L
Dissolved Oxygen	mg/L
Permit Limits (concentrations)	mg/L, micrograms per liter (µg/L)
Additional Anecdotal Information as Needed	

For any gaps in the necessary data that are identified, RESPEC will assess the potential impact on the project and suggest potential workarounds. A final technical memorandum incorporating comments provided by CTDEEP and RIDEM will be prepared and approved before the model setup. An electronic copy of the data files developed as part of the data acquisition process will be provided to CTDEEP concurrent with submittal of the final technical memorandum.

The data acquisition plans, activities, and results will undergo additional review by means of their incorporation into the modeling approach document that is also a required deliverable of this project. This document has a broader scope that includes consideration of the approach for identifying and using data and the approach for developing, calibrating, validating, and applying the HSPF model. In this context, all of the datasets and watershed-loading estimates that are targeted for use in the model calibration process will be identified. A general list of all of the data needed to run the HSPF model will be assembled and presented. The modeling approach document will be the basis for a webinar/online meeting that includes RESPEC, CTDEEP, and RIDEM staff, as well as partners. As a result of the webinar, the audience of knowledgeable persons that contribute to the data acquisition process will be expanded. This process will help to ensure that the most recent and applicable datasets are used.

The data that are used for modeling will be documented in the final modeling report. The report will include a summary of all of the final data used in the setup, calibration, and validation of the model. The final data used in the model, period of record of the data, and data source will be documented, as will any use of secondary data of unknown quality, data gaps, and assumptions used in filling such gaps.

Included among the data types that the final modeling report will address are the following datasets:

- GIS coverages used in model setup
- Meteorological data used to drive the model
- Point-source loading data used as model input
- Observed data used in model calibration and validation.

2.2 DATA MANAGEMENT

Two data types will be used to support the Pawcatuck River Watershed 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 the protocols that we have developed while performing an abundance of previous HSPF applications to ensure that we properly address QA considerations related to preventing, detecting, and correcting electronic data manipulation errors.

Errors in data manipulation are minimized by automating the data manipulation processes. GIS data are projected automatically using a standard projection library. When a new type of GIS data is added to a project, the projection of that data is translated to match the projection of the project. When time-series data are downloaded, they are automatically imported into the standard HSPF database formats. Having these processes occur automatically minimizes the mistakes that could occur during this process.

When a new dataset is processed, the resulting data are checked versus the data at the beginning of the process to ensure accuracy. GIS and time-series data are checked visually. If the new dataset is very large, the manipulation processes are automated by writing and testing software scripts. We visually inspect all of the data for a selected subset of the dataset while testing the software scripts. If that inspection yields successful results, the software is run as a “production run” for manipulating the entire dataset.

After the production run, we verify that the results exactly duplicate what was produced during software testing. This verification is usually accomplished using comparison software such as Beyond Compare. If that verification holds, we begin to visually cross-check a small portion of the data. We typically visually inspect all of the data for a second subset of the dataset during this phase, as well. We then visually cross-check a small portion of the manipulated data records, perhaps one per thousand, throughout the entire dataset. If errors are found at any point in the process, the entire process must be rerun. If rerun, at the end of that process the visual cross-check is performed again. When no errors are found, the checking ceases.

Because the manipulation processes are performed in an automated manner using custom computer software scripts, the fixes are accomplished by fixing the automated conversion software. After the software has been corrected, the entire visual check process is repeated until satisfactory results are achieved.

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 SARA. 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 of the data sources used in the project will be retained in the project folder on RESPEC’s network. Metadata will be included with spatial datasets.

GIS data will be used in a geodatabase feature-class format. The projection of all of the 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 [Tefft, 2016] that are summarized for any data submissions to the Rhode Island GIS (RIGIS). Connecticut provides a sample metadataset on its website (https://portal.ct.gov/DOT/Engineering-Applications/Sample-Metadata).

Because of the large amount of data that will be required for model development, the modeling approach document (see Section 2.1) will include a section that addresses efficient data management and organization for the Pawcatuck modeling project. The document will also address the transfer of data and other information from agencies to RESPEC (and vice versa) through interaction with publicly accessible databases and file-sharing sites as much as possible. As mentioned in Section 2.1, a draft of the modeling approach document will be the basis for a webinar/online meeting that includes RESPEC, CTDEEP, and RIDEM staff, as well as partners. The webinar will allow for an optimal data management approach to be identified and practiced, thereby further ensuring effective interorganizational QA practices with respect to data management.

At the project's completion, RESPEC will transmit a copy of all of the project files to CTDEEP, RIDEM, and the EPA. RESPEC will maintain a copy of the project files on our network for a minimum of 5 years following the project's completion.

3.0 ASSESSMENT/OVERSIGHT

3.1 ASSESSMENT AND RESPONSE ACTIONS

The QA program under which this project will operate includes surveillance with independent checks of data acquisition, model setup, model application, results analysis, and documentation activities. The essential steps in the QA program are as follows:

- Identify and define the problem
- Assign responsibility for investigating the problem
- Investigate and determine the cause of the problem
- Assign and accept responsibility for implementing the appropriate corrective action
- Establish the effectiveness of and implement the corrective action
- Verify that the corrective action has eliminated the problem.

If quality problems that require attention are identified, the project manager will determine whether attaining acceptable quality requires either short- or long-term corrective actions. The technical problems that might occur can often be solved on the spot by the staff members involved; for example, a staff member can modify the technical approach or correct errors or deficiencies in documentation. Immediate corrective actions form a part of normal operating procedures and are noted in records for the project (e.g., monthly progress reports). Problems that cannot be resolved in this manner require more formalized, long-term corrective action. Examples of major corrective actions include the following:

- Reemphasizing to staff the project objectives, limitations in scope, need to adhere to the agreed-upon schedule and procedures, and need to document QA/QC activities
- Securing additional commitment of staff time to devote to the project
- Retaining outside consultants to review problems in specialized technical areas
- Changing procedures (for example, replacing a staff member if doing so is in the best interest of the project).

The RESPEC project manager has the primary responsibility for monitoring the project activities and identifying or confirming any quality problems. The staff that RESPEC will use on this project have been working together and with their project manager for more than 5 years on similar HSPF model applications. During this time, RESPEC has established the practice of convening weekly internal project meetings that encourage direct, open, and frequent communication of project issues. The project manager and QA officer will participate in this project's weekly meetings.

If significant problems are brought to the attention of the QA officer, he will initiate the corrective actions described above, document the nature of the problem, and ensure that the recommended corrective actions are carried out. The project manager and QA officer have the authority to stop work on the project if problems affecting data quality that will require extensive effort to resolve are identified. The EPA project officer and CTDEEP project team leader will be notified of major corrective actions and stop work orders. The EPA project officer and CTDEEP project team leader have the authority to stop work on the project if QA concerns arise.

RESPEC's project manager and co-project manager will perform surveillance activities throughout the project duration to ensure that the management and technical aspects are being properly implemented according to the schedule and quality requirements specified in this QAPP. These surveillance activities will include assessing how project milestones are achieved and documented, corrective actions are implemented, budgets are adhered to, technical reviews are performed, and data are managed. QA surveillance activities will be documented in quarterly progress reports.

3.2 REPORTS TO MANAGEMENT

RESPEC will prepare quarterly progress reports. These reports will outline the activities during the preceding quarter, difficulties encountered, and planned activities for the following quarter. Each quarterly report will be provided by the project manager to project staff as a draft for review and comment. Comments will be incorporated into draft reports, which will then be finalized and submitted to the project team leader.

4.0 MODEL APPLICATION

The EPA [2000; 2002] emphasizes a systematic planning process to determine the type and quality of output needed from modeling projects. This process begins with a modeling needs and requirements analysis, which includes the following components:

- Assess the need(s) of the modeling project
- Define the purpose and objectives of the model and the model output specifications
- Define the quality objectives to be associated with the model outputs.

CTDEEP has been an active partner with RESPEC in developing the front-end modeling needs and requirements for this project, including the following:

- The updated Pawcatuck River Watershed HSPF model is expected to predict hourly stream flow, dissolved oxygen, nitrogen (total and various species and fractions), phosphorus (total and various species and fractions), suspended sediment (various fractions), chlorophyll a loads, and transport of a conservative pollutant in rivers at the pour points of Hydrologic Unit Code 12 (HUC12) watersheds. The model should ideally have the ability to predict loads at smaller spatial scales than HUC12 watersheds with reasonable accuracy. The model should also be capable of predicting the mixing and transport of a conservative tracer that can be used to assess dilution in river reaches.
- An HSPF model for the Pawcatuck River Basin spanning the border with Rhode Island will be developed under this project QAPP. The final model for the Pawcatuck River will eventually be incorporated into the updated statewide CTWM after it has been developed. A standalone model for this watershed will be retained for use by the project partners in Rhode Island.
- For the Pawcatuck River Watershed, the modeling period is expected to incorporate data through 2020, including enhanced monitoring data being collected by the USGS in 2019–2020 and data previously collected by RIDEM or other partners within the watershed.
- The model is expected to be able to model simulations that combine actual precipitation, predicted future precipitation, and various management scenarios involving discharge limits and land-use change.
- The model is expected to provide nutrient loads, suspended sediment loads, and freshwater inputs to other site-specific models. Examples of site-specific models include BATHTUB for lakes and impoundments and WASP and EcoGEM for embayments and tidal waters. Models for embayments and tidal waters are expected to have the ability to nest within the three-dimensional (3D) linked hydrodynamic and water quality model that is being developed for Long Island Sound.

The quality objectives for the model follow directly from the purposes and objectives that are stated above. The modeling effort generally needs to be designed to achieve an appropriate level of accuracy and certainty in answering the principal study questions. This process takes into account the following elements:

- The accuracy and precision needed for the models to predict a given quantity at the application site of interest to satisfy the study questions

- The appropriate criteria for making a determination of whether or not the models are accurate and precise enough on the basis of past general experience combined with site-specific knowledge and completeness of the conceptual models
- How the appropriate criteria would be used to determine whether or not model outputs achieve the needed quality.

RESPEC will develop a modeling approach document describing how HSPF will be used to model the Pawcatuck River Watershed. This document will provide detail on the data that will be used to support the modeling project as well as an assessment of the perceived quality of the data. This document will provide a roadmap and communication tool for CTDEEP, the EPA, and stakeholders because it will describe the study objectives, available data, water quality and land uses, calibration/validation procedures and targets, and potential scenarios for assessment. The final modeling approach document will be submitted after any written comments or comments received during a webinar/online discussion meeting with CTDEEP and RIDEM staff, as well as other partners, have been incorporated.

The HSPF model application must have the ability to link with a future WASP model that will be developed for the associated estuarine embayment, as well as with future BATHTUB models for the Hundred Acre, Worden, and Watchaug Ponds. These model linkages will be addressed as a component of the modeling approach document. RESPEC will also thoroughly document model development, data development, and calibration and validation activities. Calculations, new coding (if any), model setup, and assumptions and limitations will be clearly documented. The issue of assessing model accuracy and precision is addressed in the remainder of this section and will be further elaborated on in the modeling approach document.

4.1 MODEL PARAMETERIZATION (CALIBRATION)

Model calibration is the process of adjusting model inputs within acceptable limits until the resulting predictions provide good correlation with observed data. Calibration commonly begins with the best estimates for model input based on measurements and subsequent data analysis. Results from initial simulations are then used to improve the concepts of the system or modify the values of the model input parameters. Calibrated models use the scientific veracity of which is well defined and is of paramount importance to this project. Because the goal is to develop a watershed model to determine the reductions in pollutant loads needed to improve water quality, model calibration and validation should strive to minimize the differences between model predictions and observed measurement data; hence, the availability of abundant observed data is an essential element of successful calibration.

The experience and judgment of the modelers will likewise be a significant factor in accurately and efficiently calibrating the model(s). The RESPEC project manager and co-project manager will direct the model calibration efforts with assistance from competent modelers that have significant experience with the model(s) that they are applying. RESPEC Project Manager Mr. Jason Love served as the project engineer for the development and application of the HSPF Connecticut Watershed Model in 2002 and has coauthored several papers to report the results of that effort [Love and Donigian, 2001 and 2002; Donigian and Love, 2002]. Under Mr. Love's supervision, the calibration efforts of RESPEC's HSPF modelers are supported by well-developed internal protocols and customized spreadsheet tools. As a backup to RESPEC's HSPF modeling expertise, detailed guidelines for HSPF calibration [Duda et al., 2012; Michael Baker, Jr., Inc. et al., 2013] are available and will be consulted.

Modeling procedures and model results will be routinely reviewed by senior-level modelers at RESPEC and will be subjected to additional review by CTDEEP, RIDEM, and the EPA Region 1. The results will also be made available to interested stakeholders.

As described below, the model calibration effort will be designed and performed to meet prespecified quantitative measures of accuracy that will establish the model's acceptability in answering the principal study questions. The model calibration process proceeds through qualitative and quantitative analyses. Qualitative measures of the calibration progress are commonly based on the following:

- Graphical time-series plots of observed and predicted values
- Flow and concentration duration plots of observed and predicted values
- Monthly average plots of observed and predicted values
- Annual average plots of observed and predicted values
- Scatterplots of observed versus predicted values
- Tabulation of measured and predicted values and their deviations.

Initial model parameters will be set based on available data and literature. After the model has initially been configured, the modelers will perform model calibration and validation. The watershed model will be calibrated to the best available data, including literature values and interpolated or extrapolated values using existing field data. If multiple datasets are available, an appropriate time period and corresponding dataset will be chosen on the basis of factors characterizing the dataset, such as the corresponding weather conditions, amount of data, and temporal and spatial variability of data. A calibration journal will be kept to document the calibration states at certain stages of calibration. Parameterization will remain as consistent as possible with respect to accepted values for land-cover classifications and stream order. If deviations are needed for a specific area (e.g., an area where changes in the soil type or geology are not represented by land-cover classification or do not correspond to existing implementation practices), the reason for making adjustments to the parameterization values will be noted in the final report.

The sensitivity to variations in the input parameter values is an important characteristic of a model and will be evaluated as a part of the calibration process. Sensitivity analysis is used to identify the most influential parameters in determining the accuracy and precision of model predictions. Sensitivity analysis quantitatively or semi-quantitatively defines the dependence of the model's performance on a specific parameter or set of parameters. Sensitivity analysis can also be used to establish strategies for improving the efficiency of the calibration process.

Model sensitivity can be expressed as the relative rate of change of selected output caused by a unit change in the input. If the change in the input causes a large change in the output, the model is considered to be sensitive to that input parameter. Sensitivity analysis methods are mainly nonstatistical, or even intuitive, by nature. Sensitivity analysis is typically performed by changing one input parameter at a time and evaluating the effects on the distribution of the dependent variable. Nominal, minimum, and maximum values are specified for the selected input parameter.

Note that informal sensitivity analyses (iterative parameter adjustments) provide the basis for model calibration and ensure that reasonable values for model parameters will be obtained and result in acceptable model results. The degree of allowable adjustment of any parameter is often directly proportional to the uncertainty inherent in the parameter's value and is limited to the parameter's expected range of values [Tetra Tech, 2009].

4.2 MODEL CORROBORATION (VALIDATION AND SIMULATION)

Model validation is generally performed using a dataset separate from the calibration data. If only a single time series is available, the series may be split into two segments: one for calibration and another for validation. If the model parameters are changed during the validation, this exercise becomes a second calibration and the first calibration needs to be repeated to account for any changes. Representative stations will be used to guide parameter adjustment to obtain an accurate representation of the individual subwatershed and stream conditions. The calibration and validation approach that is intended for this project will be proposed in the modeling approach document and confirmed at the project's webinar/online meeting and will also be documented in the final project report.

Calibration and validation will be achieved by considering qualitative and quantitative measures involving graphical comparisons and statistical tests. For flow simulations where continuous records are available, both qualitative and quantitative techniques will be employed, and the same comparisons will be performed during the calibration and validation phases. Value comparisons for simulated and observed state variables will be performed for daily, monthly, and annual values in addition to flow-frequency duration assessments. Statistical procedures will include error statistics, correlation and model-fit efficiency coefficients, and goodness-of-fit tests, as appropriate. Figure 4-1 provides value ranges for 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 in Figure 4-1, 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 (especially precipitation).

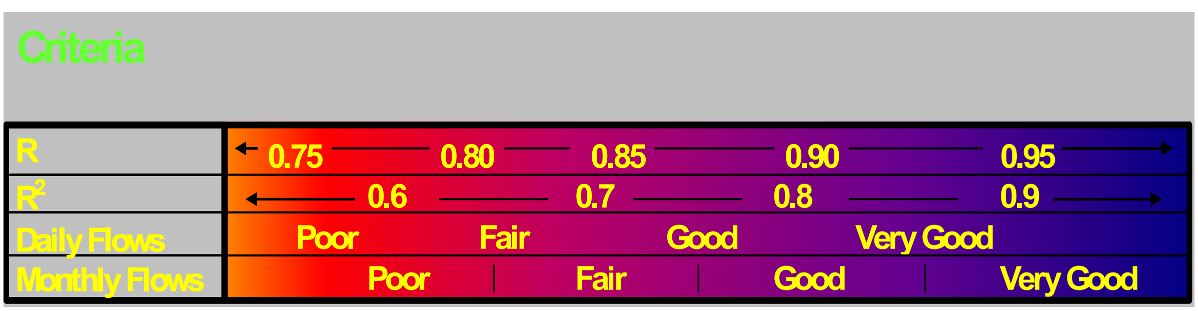

Figure 4-1. R and R^2 Value Ranges for Model Performance [Donigian, 2002].

Various methods are used to compare simulated and observed mean values. The sporadic observed data can be aggregated over annual, seasonal, or monthly time frames and compared to the full range of simulated values. The simulated time series can alternatively be sampled to include only the time periods when samples were gathered, and model-data comparisons can then be limited to those sampled time periods. Both of the approaches clearly have advantages and disadvantages. These approaches and others will be explored as part of the model performance evaluation.

For sediment, water quality, and biotic constituents, model performance will be based primarily on visual and graphical presentations because the frequency of observed data is often inadequate for accurate statistical measures; however, we will also investigate alternative model performance assessment techniques (e.g., error statistics and correlation measures) that are consistent with the population of observed data available for model testing.

The values shown in Figure 4-1 are derived from extensive experience with the individual models and the selected past efforts on model performance criteria discussed above. If preliminary model results do not satisfy the target tolerances listed in Figure 4-1, additional efforts will be required to investigate all of the possible errors in, as well as the accuracy of, input data, model formulations, and field observations. If adjustments in these tolerances are needed, they will be fully investigated and documented, and revisions to this QAPP will be issued through the formal QA process. Given the uncertain state of the art in model performance criteria, inherent errors in input and observed data, and approximate nature of model formulations, absolute criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals.

After calibration and parameter sensitivity analysis have been completed, the uncertainty in the calibrated model caused by uncertainty in the model input parameter estimates can be assessed. Formal uncertainty analyses for watershed model applications have not historically been performed, largely because of the complexity and computational demands of most watersheds that are modeled. To address the need for uncertainty analyses while recognizing the restrictions that occur when complex codes are involved, one approach is to identify key parameters using a sensitivity analysis and then focus on the model uncertainty associated with those parameters identified as most "sensitive." In cases where uncertainty analysis is performed on watershed model applications, a Monte Carlo approach is typically used [Donigian and Imhoff, 2009]. The Statement of Work for this project does not call for (or fund) a formal uncertainty analysis. RESPEC will, however, address the issue of parameter sensitivity by identifying the most sensitive input parameters for the Pawcatuck HSPF model."

4.3 RECONCILIATION WITH USER REQUIREMENTS

The value of the information generated by this project will be determined by evaluating the data quality and comparing the methods and results with published data and scientific literature, as well as the data quality objectives identified in this QAPP. Confidence in model predictions can be limited by numerous factors, including the representativeness of calibration data, knowledge of actual nutrient inputs (external and internal loading), and inherent ability of the model to simulate the conditions.

Data quality indicators will be calculated during model setup, calibration, and validation. Measurement quality requirements will be compared with the data quality objectives to confirm that the correct type, quality, and quantity of data are being used for the model setup and calibration. Computation and post-simulation analysis results will be reviewed for reasonableness. The data sources, assumptions made, and calculations used in the preprocessing, modeling, and postprocessing will be sufficiently detailed in the final report to ensure the reproducibility of the work by CTDEEP.

As part of the reconciliation process, the model deliverables (e.g., modeling reports and technical memoranda) will be reviewed by CTDEEP to assess whether or not the quality requirements of the

QAPP have been met. A comprehensive review of the final model files and documentation will be completed, and recommendations will be provided regarding the effectiveness of the model to predict hydrologic and water quality response.

Inherent in the model reconciliation process is recognition that models are simplifications of the environmental processes that they intend to represent. Although no consensus on model performance criteria exists in the literature, numerous basic statements are likely to be accepted by most professional modelers, as follows:

- Models approximate reality and cannot precisely represent natural systems.
- No single, accepted test determines whether or not a model is validated.
- Models cannot be expected to be more accurate than the sampling and statistical error (e.g., confidence intervals) in the input and observed data.

An accurate numerical representation of the study area is the primary goal of the model application effort because it determines whether the model results can be relied upon and used effectively for decision-making. Using the weight-of-evidence approach (a mainstay of watershed modeling) along with the targets and tolerances for model performance that are presented in this document involves extensive qualitative and quantitative measures involving both graphical comparisons and statistical tests under a wide range of environmental conditions. More specifically, the model reproduces a continuous record of model predictions (on an hourly basis) across wet and dry time periods, back-to-back storms, and so on. The targets presented for model performance are derived from extensive experience with the HSPF model and will ensure that the model application meets the project objectives.

These considerations must be included in the development of appropriate procedures for QA of the models. Despite a lack of agreement on how the models should be evaluated, the following principles provide a final set of evaluation criteria for the modeling projects:

- Exact duplication of observed data is not possible nor a performance criterion for projects. The model corroboration (validation) process will measure the ability of the model to simulate measured values.
- No single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance; therefore, combined graphical comparisons, statistical tests, and professional judgment are proposed to provide sufficient evidence upon which to base a decision of model acceptance or rejection.
- All model and observed data comparisons must recognize, either qualitatively or quantitatively, the inherent error and uncertainty in the model and observations. Model sensitivity and uncertainty will be documented as part of each modeling study, where possible.

A margin of safety will be established as part of the modeling process to compensate for model limitations and assumptions and to gauge the impact on the usability of the results toward decision-based management. This topic will be addressed in the modeling approach report.

5.0 PROJECT REPORTS

The following reporting deliverables will be prepared under this project and submitted to CTDEEP, RIDEM, and the EPA for review and approval:

- Modeling approach document
- Technical memorandum summarizing data collection activities
- Modeling QAPP
- Final modeling report.

The contents of the first three deliverables were addressed with adequate detail in previous sections of this QAPP.

The final modeling report will adhere to the high-level topics and organization that are outlined for final project reports in the EPA's *Template for Developing a Generic or Project-Specific Quality Assurance Project Plan for Model Applications* [EPA, 2009]; however, RESPEC will customize our final project report subtopics and lower-level organization to more closely correspond to the specifics related to an HSPF model application. The following high-level topics will be addressed:

- Introduction and background
- Purpose of modeling and modeling objectives
- Observational data used to support modeling
- Model configuration
- Model parameterization (calibration) and corroboration (validation)
- Performance against the performance criteria
- Model use scenario analysis and results
- Deviations from the QAPP
- Conclusions, recommendations, references, and appendices.

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