Quality Assurance Project Plan

for

Lake Champlain TMDL Support

Contract Number EP-C-08-004
Task Order 80

Prepared for:

United States Environmental Protection Agency Region 1 – New England
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This quality assurance project plan (QAPP) has been prepared according to guidance provided in the following documents to ensure that environmental and related data collected, compiled, or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use:

- *EPA Requirements for Quality Assurance Project Plans.* (EPA QA/R-5, EPA/240/B-01/003, U.S. Environmental Protection Agency, Office of Environmental Information, Washington DC, March 2001 [Reissued May 2006]) (USEPA 2001)
- *Guidance for Quality Assurance Project Plans for Modeling.* (U.S. EPA QA/G-5M, EPA/240/R-02/007, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, December 2002) (USEPA 2002)
- *EPA New England Quality Assurance Project Plan (QAPP). Checklist for Model Applications.* (U.S Environmental Protection Agency, Region 1, Boston, MA, 2009) (USEPA 2009a)
- *Guidance on the Development, Evaluation, and Application of Environmental Models* (EPA/100/K-09/003, U.S. Environmental Protection Agency, Office of the Science Advisor, Council for Regulatory Environmental Modeling, Washington DC, March 2009) (USEPA 2009b)
- *EPA Office of Water Quality Management Plan.* (EPA/821/R-09/001, U.S. Environmental Protection Agency, Office of Water, Washington DC, February 2009c).

Tetra Tech, Inc., will conduct work in conformance with the procedures detailed in this QAPP.

Approvals:

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Acronyms and Abbreviations

ANR	Agency of Natural Resources
BASINS	Better Assessment Science Integrating Point & Non-point Sources
BMP	Best management practice
BMPDSS	Best Management Practices Decision Support System
BSTEM	Bank-Stability and Toe-Erosion Model
CAT	Climate Assessment Tool
CDL	Cropland Data Layer
CFR	Code of Federal Regulations
Co-TOLs	Co-Task Order Leaders
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
CWA	Clean Water Act
DEM	Digital Elevation Model
DP	Dissolved phosphorus
DQO	Data quality objective
EFDC	Environmental Fluid Dynamics Code
EPA	U.S. Environmental Protection Agency
EPIC	Erosion-Productivity Impact Calculator
GCRP	Global Change Research Program
GIS	Geographic information system
GLEAMS	Groundwater Loading Effects on Agricultural Management Systems
GWLF	Generalized Watershed Loading Function
HUC	Hydrologic unit code
HRU	Hydrologic response unit
HSPF	Hydrological Simulation Program–Fortran
LCBP	Lake Champlain Basin Program
LSPC	Loading Simulation Program in C++
MDAS	Mining Data Analysis System
MRLC	Multi-Resolution Land Characteristics
MS4	Municipal separate storm sewer system
NAD83	North American Datum 1983
NARCCAP	North American Regional Climate Change Assessment Program
NAVD88	North American Vertical Datum 1988
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NHD+	National Hydrography Dataset
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PCBs	Polychlorinated biphenyls
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
SSURGO	Soil Survey Geographic Database
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
TAC	Technical Advisory Committee

TC	Total chlorides
TMDL	Total Maximum Daily Load
TO	Task Order
TOM	Task Order Manager
TP	Total phosphorus
Tt	Tetra Tech
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VBA	Visual Basic for Applications
VT DEC	Vermont Department of Environmental Conservation
WASP	Water Quality Analysis and Simulation Program
WERF	Water Environment Research Foundation
WLA	Wasteload allocation
WWTF	Wastewater Treatment Facility

A1.3 Distribution

This document will be distributed to the following U.S. Environmental Protection Agency Region 1 and Tetra Tech, Inc., personnel and any subcontractor staff involved in the project.

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A1.4 Project/Task Organization

This document presents the quality assurance project plan (QAPP) for providing support to U.S. Environmental Protection Agency (EPA) Region 1 in revising the Lake Champlain Total Maximum Daily Load (TMDL), under Contract Number EP-C-08-004, Task Order (TO) 80. Multiple objectives are being addressed under the scope of the overall project, including revising and recalibrating the lake model used to develop the original TMDL and linking it to a watershed model to characterize loading conditions and sources in the watershed and estimate potential for loading reductions in the Vermont and New York portions of the basin. While only the Vermont portion of the TMDL is being revised, the lake and watershed modeling work will encompass the whole watershed because watershed processes do not follow jurisdictional boundaries. One of EPA's goals for the revised TMDL is to ensure that there is adequate Reasonable Assurance that identified nonpoint source reductions are feasible. To support this and other technical needs, EPA intends to develop and apply a watershed model to support the source loading estimation and reduction analysis for the TMDL. The model will be used for providing more detailed loading estimates/allocations for individual source categories (relative to the original TMDL), evaluating results of different load reduction/best management practice (BMP) implementation strategies, evaluating effects on loading from potential changes in climate, and helping to understand the impacts of watershed loading scenarios on lake water quality and in-lake modeling results. Primary technical support for this effort is being conducted by the Fairfax, Virginia, office of Tetra Tech (Tt) in conformance with the quality assurance (QA) program described in this QAPP.

The organizational aspects of the program provide the framework for planning and conducting tasks. They can also facilitate project performance and adherence to quality control (QC) procedures and QA requirements. Key project roles are filled by those persons responsible for ensuring the gathering of valid data and the routine assessment of the data for precision and accuracy, as well as the data users and the person(s) responsible for approving and accepting final products and deliverables. The program organization chart, presented as Figure 1, includes relationships and lines of communication among all participants and data users. The responsibilities of these persons are described below.

The EPA Region 1 Task Order Manager (TOM), Mr. Eric Perkins of EPA Region 1, will provide overall project and program oversight for the TO. He has reviewed and approved the modeling approach and he will review and approve other materials developed to support the project. The EPA TOM will also coordinate with contractors, reviewers, and others to ensure technical quality in all deliverables and adherence to the contract, as appropriate.

The EPA Region 1 QA Coordinator for this TO is Mr. John Smaldone, and his responsibilities include reviewing and approving the QAPP and participating in any EPA reviews of work performed, as appropriate.

Tt's Co-Task Order Leaders (Co-TOLs) are Mr. Andrew Parker and Ms. Teresa Rafi (see Section A1.8 of this QAPP for descriptions of Mr. Parker's and Ms. Rafi's technical backgrounds). They will supervise the overall project, including study design and model applications. Specific project management and QA responsibilities of the Tt Co-TOLs include the following:

- Coordinating project assignments, establishing priorities, and scheduling
- Ensuring completion of high-quality projects within established budgets and time schedules
- Acting as primary points of contact for the EPA Region 1 TOM

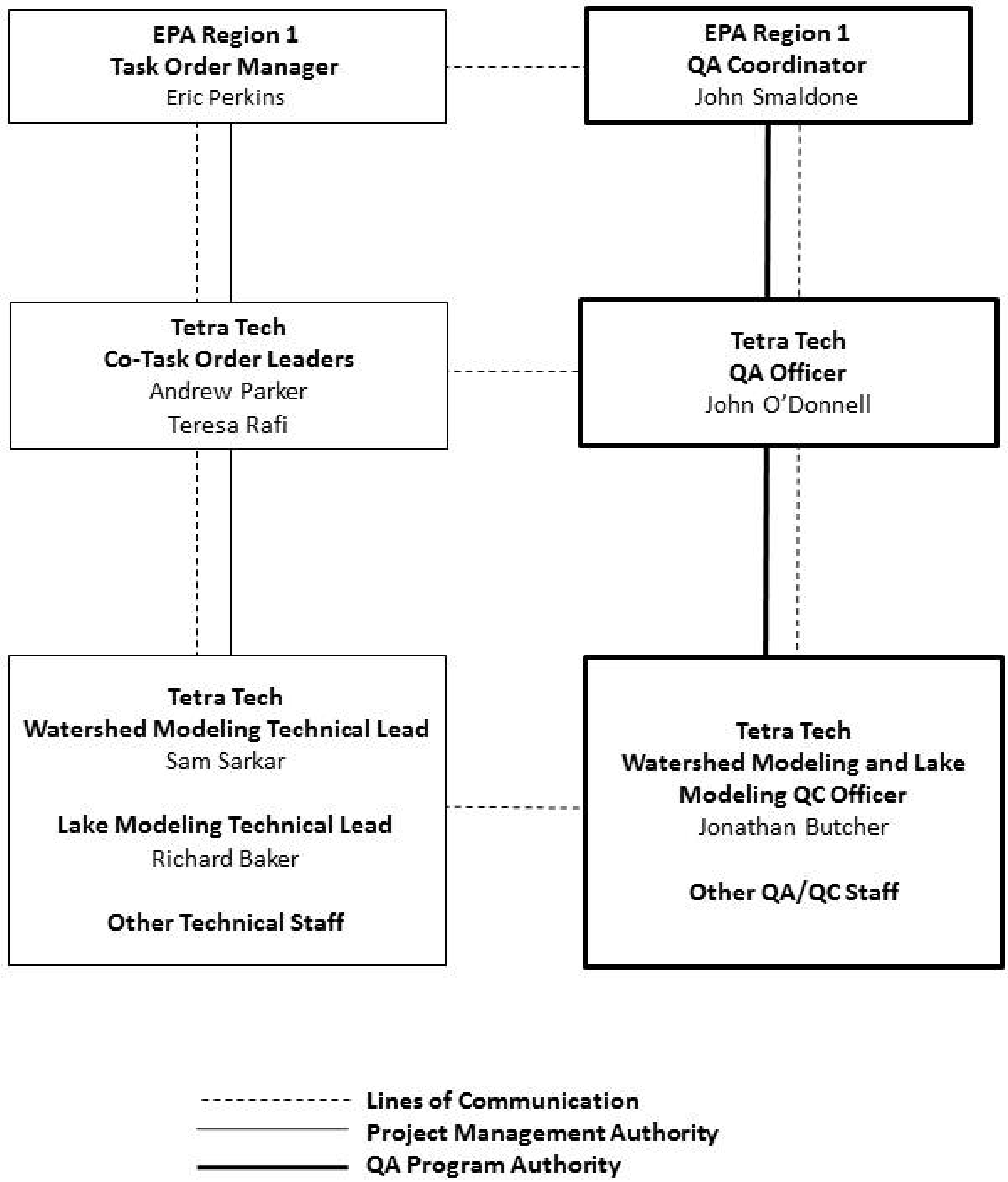


Figure 1. Organizational chart

- Providing guidance, technical advice, and performance evaluations to those assigned to the project
- Implementing corrective actions and providing professional advice to staff
- Preparing or reviewing preparation of project deliverables, including the QAPP and other materials developed to support the project
- Distributing the approved QAPP and any updates to the approved QAPP to staff on the distribution list
- Providing guidance on development of new site-specific models and review of developed models

- Providing support to EPA in interacting with the project team, technical reviewers, and others to ensure that technical quality requirements of the study design objectives are met in accordance with EPA's objectives

Tt's QA Officer is Mr. John O'Donnell. His primary responsibilities include providing support to the Tt Co-TOLs in preparing the QAPP, reviewing and approving the QAPP, and monitoring QC activities to determine conformance with QA/QC requirements.

Tt's Watershed Modeling and Lake Modeling Technical Leads are Mr. Sam Sarkar and Mr. Richard Baker, respectively. They will develop model input data sets, apply the models, compare model results to observed data, calibrate the models, and prepare documentation. They will also oversee and supervise the details of the modeling efforts and provide guidance on revising and debugging existing, U.S. Army Corps of Engineers- and EPA-approved models. They will implement the QA/QC program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation. Other technical staff will perform literature searches; assist in secondary data collection, compilation, and QA review; and help complete draft and final modeling reports.

Tt modeling staff will be responsible for developing model input data sets, calibrating and validating the model, applying the model results, and writing a final report. They will implement the QA/QC program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation.

Tt's Watershed Modeling and Lake Modeling QC Officer is Dr. Jonathan Butcher. He is a member of the project staff and he is familiar with the models to be used. The Modeling QC Officer will not participate in the application of the models. He will be responsible for performing evaluations to ensure that QC is maintained throughout the data collection and analysis process. QC evaluations will include reviewing site-specific model equations and codes (when necessary), double-checking work as it is completed, and providing written documentation of these reviews to ensure that the standards set forth in the QAPP and in other planning documents are met or exceeded. Other QA/QC staff, including technical reviewers and technical editors selected, as needed, will provide review oversight of the content of the work products and ensure that the work products comply with EPA's specifications.

A1.5 Problem Definition/Background

Section 303(d)(1)(c) of the Clean Water Act (CWA) and its associated policy and program requirements for water quality planning, management, and implementation (at Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require the establishment of a TMDL for the achievement of state water quality standards when a waterbody is water quality-limited. A TMDL identifies the pollutant/waterbody-specific assimilative capacity, which includes an appropriate margin of safety. The focus of the TMDL is reduction of pollutant inputs to a level (or "load") that fully supports the designated uses of a given waterbody. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices or effluent limits and monitoring required through National Pollutant Discharge Elimination System (NPDES) permits.

Lake Champlain is one of the largest lakes in North America and is shared by Vermont and New York and the province of Quebec. The lake is 120 miles long, with a surface area of 435 square miles and a maximum depth of 400 feet. The 8,234-square-mile watershed drains nearly half the land area of Vermont and portions of northeastern New York and southern Quebec (Figure 2).

The original phosphorus TMDL was developed jointly by Vermont and New York in 2002. EPA is revising the Vermont portion of the TMDL in response to a 2008 lawsuit by the Conservation Law Foundation.

The 2002 Lake Champlain TMDL model was based on a modified version of the U.S. Army Corps of Engineers BATHTUB program. EPA is interested in updating the model, in collaboration with the Vermont Agency of Natural Resources (ANR), which was used in developing the TMDL. The updated analysis will be conducted for the entire lake basin, including loading sources from Vermont, New York and Quebec. One of EPA's goals for the revised TMDL is to ensure that there is adequate Reasonable Assurance that identified nonpoint source reductions are feasible. To support this and other technical needs, Tt will support EPA Region 1 in developing and applying a watershed model to support the source loading estimation and reduction analysis for the TMDL. The TMDL for Lake Champlain must comply with phosphorus standards set specifically for each lake segment as provided in the State of Vermont Natural Resources Board's *Vermont Water Quality Standards* (2008). The model will be used for providing more detailed loading estimates/allocations for individual source categories (relative to the original TMDL), evaluating results of different load reduction/best management practice (BMP) implementation strategies, evaluating effects on loading from potential changes in climate, and helping to understand the impacts of watershed loading scenarios on lake water quality and in-lake modeling results.

This QAPP describes the quality system that Tt will implement to effectively plan throughout this project and provides general descriptions of the work to be performed to support the revision of the Lake Champlain TMDL and modeling reports, the standards to be met, and the procedures that will be used to ensure that the results are scientifically valid and defensible and that uncertainty has been reduced to a known and practical minimum. This project does not require the collection of primary data. In the unlikely event it is determined during the data evaluation effort and after consultation with the EPA Region 1 TOM that the collection of primary data is required for this project, the TO will be modified, and a separate field sampling QAPP or QAPPs will be developed.

Lake Model Review

Tt performed an initial review of the original BATHTUB lake model along with the results of subsequent relevant lake research and monitoring studies. Based on this review, Tt prepared a set of recommendations for suggested changes and updates to the original BATHTUB model for this project. A description of these recommended changes and updates is provided under Task 3 of Section A1.6 of this QAPP. As described under Task 4 of Section A1.6 of this QAPP, the selected watershed model will be calibrated and used to provide inputs to the updated BATHTUB model for this project.

Watershed Modeling Approach

Tt prepared a *Watershed Modeling Approach Recommendation* (Appendix A) that describes the types of watershed models evaluated and the criteria for model selection. On the basis of a preliminary review of data available for modeling the Lake Champlain Basin, the relative capabilities of the three complex models reviewed, and prior history of model application in the basin, it is recommended that the Soil and Water Assessment Tool (SWAT) model be applied to develop

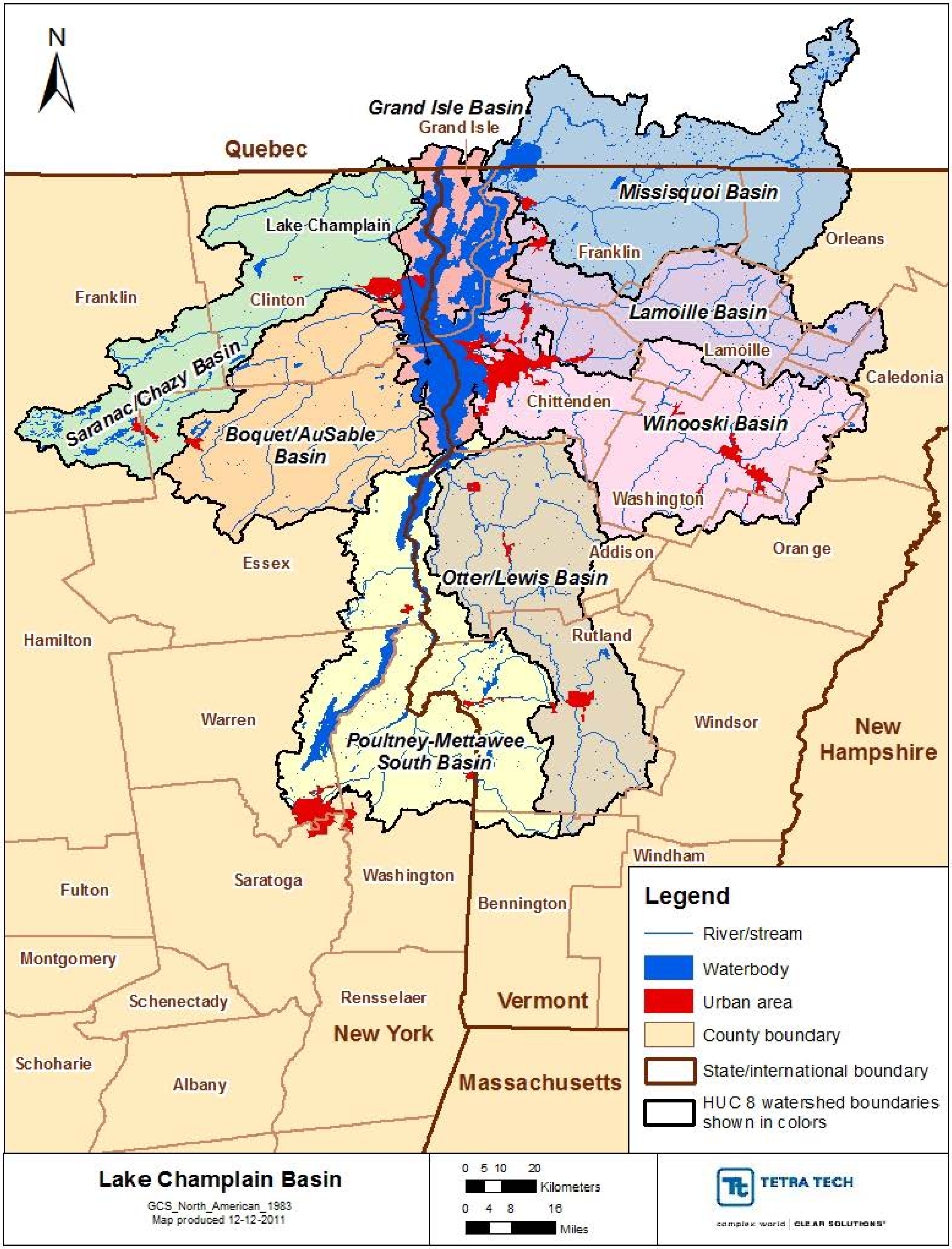


Figure 2. Lake Champlain Basin.

loading estimates for the Lake Champlain Basin and augmented with external techniques to address the basin-specific concerns of channel stability/instream loading sources and urban lands.

SWAT's major advantages over Loading Simulation Program – Fortran in C++ (LSPC) and Hydrological Simulation Program–Fortran (HSPF) are its detailed ability to represent agricultural management practices and to incorporate the impacts of CO_2 fertilization during climate change simulation. Sufficient data are available to satisfy critical model needs for the entire basin, including representative reach and water quality data for calibration, as well as soils (Soil Survey Geographic [SSURGO] Database), and elevation (10 m Digital Elevation Model [DEM] for VT and NY with a comparable layer for the Quebec portion). The U.S. Department of Agriculture (USDA) Cropland Data Layer is also available for the entire basin. This approach also has the advantage of being able to incorporate much of the detailed SWAT modeling work that has been done in the basin.

SWAT does present certain disadvantages relative to the other options because it is not reliable for predicting sub-daily concentrations (which are likely not critical to phosphorus mass loading to the lake) and it does not provide a solid basis for direct evaluation of hydromodification impacts on channel stability. However, those considerations are less critical than the need to simulate agricultural BMPs and CO_2 fertilization or can be mitigated by applying external analysis techniques.

A1.6 Project/Task Description

Tt will support EPA Region 1 in revising the Lake Champlain TMDL. Multiple objectives are being addressed under the scope of the overall project, including revising and recalibrating the lake model used to develop the original TMDL and linking it to a watershed model to characterize loading conditions and sources in the watershed and estimate potential for loading reductions in the Vermont and New York portions of the basin. Major activities for this project, as described in the modeling work plans, Tt's proposal, and EPA's performance work statement, are provided below.

Task 1: Modeling QAPP

Tt has developed this QAPP to meet the requirements of Task 1. This QAPP will be submitted to the EPA TOM and QA Coordinator for their review. In addition, Tt, in consultation with the EPA TOM, will determine what factors will be evaluated to determine whether the data provided in a secondary data source are acceptable for use in supporting EPA Region 1 in revising the Lake Champlain TMDL. A description of the draft factors that will be used to evaluate data acceptability is provided in A1.7 of this QAPP. Tt will submit a description of the final data evaluation factors and limits (as determined in consultation with the EPA TOM) in the interim model report. Tt will follow this QAPP to ensure the quality of the use of those secondary data under this TO.

Task 2: Model Review, Analysis, and Recommendations

Tt began with a review of the existing BATHTUB model and original datasets used to calculate the 2002 TMDL. The goal of the model review was to determine if the level of spatial, temporal and process detail was appropriate to answer the fundamental project objectives. The review focused on the following elements: (1) representation of key lake processes using BATHTUB, and (2) the ability to improve modeling using new monitoring data collected since the original modeling effort. The outcome of this review, following input from the in-lake modeling workgroup and EPA, was a recommendation to use the BATHTUB model with updated data and some enhancements. These recommendations are described under Task 3, below.

Tt also completed a review of watershed modeling approaches appropriate for representing key watershed processes affecting phosphorus loads to the lake. Tt participated in several face-to-face meetings with project partners and two technical workgroups during the development of the modeling recommendations. The outcome from this process is summarized under Task 4, below, and described in more detail in the *Watershed Modeling Approach Recommendation* report in Appendix A.

Deliverables: (1) Draft model review and recommendations memo, available for discussion with EPA, Vermont ANR and the technical work group due no later than October 31, 2011; (2) Final model recommendations, incorporating recommendations from the peer review, as appropriate, to be completed by December 30, 2011; and (3) Attendance at two technical workgroup meetings (one-day each) in Waterbury, Vermont, one prior to draft recommendations and one following recommendations.

Task 3: Lake Model Update and Calibration

3a: Develop Interim Lake Segment Loading Budgets (Total Chlorides)

During task 2, tributary load budgets (flow, total phosphorus [TP] and dissolved phosphorus [DP]) were compiled for each lake segment based on tables contained in Smeltzer et al. (2009). These tables contained flow, TP and DP budgets for 2-year periods, between 1991 and 2008. No budgets were given in Smeltzer et al. (2009) for total chlorides (TC) and these will be needed to calibrate diffusive exchange terms between Lake Model segments. It should be noted that the Smeltzer et al. (2009) data were collected under a QAPP (VT DEC and NYS DEC 2009) and that no data quality problems were reported in the Smeltzer et al. (2009) report. Therefore, the Smeltzer et al. (2009) data are presumed to be of sufficient quality for use in supporting EPA Region 1 in revising the Lake Champlain TMDL.

In order to develop lake model input data sets and to evaluate the impacts of using different lake modeling time-averaging periods, the methods used by Smeltzer et al. (2009) to process the short-term tributary data and develop the 2-year totals could be re-implemented for the period between 1991 and 2010, using the tributary and point source data for flow, TP, DP and TC. This load calculation methodology would require relatively complex calculations and numerous assumptions, in order to estimate loads from the tributaries below gauging stations, unmonitored tributaries, direct runoff to the lake, and point sources such as wastewater treatment facilities.

Use of this approach, which relies completely on tributary measurements and statistical methods to fill in data during unmonitored periods, does not explicitly account for the hydrologic and phosphorus buildup and transport process occurring within the tributary watersheds. Since it is not physically based, this approach also has significant limitations with respect to the evaluation of TMDL phosphorus reduction scenarios (such as BMPs) and the quantification of the likely impacts of climate change.

To overcome these limitations, a watershed hydrologic and phosphorus transport model will be developed in Task 4, for all tributary and direct inputs to each of the thirteen lake segments. During the interim period when the watershed model is being developed and calibrated, the 2-year period flow, DP and TP tributary load budgets contained in Smeltzer et al. (2009) will first be augmented with calculated 2-year period TC budgets. These data will be used initially to update and calibrate the BATHTUB lake model to current conditions. This interim calibration step is necessary in order to meet project deadlines. This calibration step will also provide separate water quality time series to serve as a calibration check for the watershed modeling.

3b: Develop Lake Model Calibration Data

TP, TC, chlorophyll-*a* and Secchi depth measurements were developed for each lake segment during task 2, using a 2-year time-averaging period, between 1991 and 2008. During this task, enhanced data sets defining these measured variables will be developed, based on time-averaging periods between 1 and 10 years, for the period between 1991 and 2010.

3c: Lake Model Update/Calibration

This task will update the previously calibrated BATHTUB model (1991 model) with a re-calibrated version (2010 model). The BATHTUB model was tested in task 2, using the 2-year averaging period data developed by Smeltzer et al. (2009). Based on the favorable testing results, the BATHTUB model was selected as the basis to be used during subsequent modeling in this Task (Task 3). The BATHTUB model testing conducted during task 2 utilized calibration parameters (diffusive exchange and TP sedimentation source/sink terms) determined for the 1991 baseline year, when the DP/TP ratio was much larger than current conditions (2010).

The testing that was performed in task 2 was an evaluation performed to determine whether the model could predict conditions outside of the time period for which it was calibrated. This was performed in earlier phases of the project to determine what lake model should be used for the TMDL.

Preliminary tests utilized a simplified Excel version of BATHTUB provided by VTDEC.
Lake phosphorus, chlorophyll-a, and transparency data were averaged at 2-year intervals to provide a basis for model testing. Chlorophyll-a levels and Secchi depths were predicted from TP concentrations using BATHTUB Sub-Models 4 and 1, respectively, and calibrated to the average observed values in each segment for the 2000-2008 period of record.

Results of model testing against the 1991-2008 data demonstrate that the model captures the basic spatial and temporal trends in the lake data collected after 1991, especially considering the expected level of precision for this type of model (~20%), data limitations, wide range of hydrologic conditions, and the short duration of the calibration dataset. Differences between observed and predicted concentrations reflect the net effects of uncertainty in measured flows and loads, measured lake concentrations, and model error. Preliminary results indicate that it will be possible to recalibrate the model to the longer period of record with relatively small changes in the P sedimentation and/or transport terms.

Smeltzer et al. (2009) concluded that tributary point source phosphorus loads have decreased significantly since 1991, resulting in decreases in the DP/TP ratio for tributary loads entering the lake. In order to define more current conditions as the new baseline for the TMDL modeling, the BATHTUB model will be re-calibrated using tributary and lake data collected between 2000 and 2010.

The original BATHTUB modeling included simplified terms for settling (net loss) of TP to the lake bottom within each segment. It also included a net source of TP from bottom sediments, within St. Albans Bay. The rates of these TP sedimentation losses and internal recycling sources were estimated during model calibration. For this project, such rates will be updated if updated data are available. Internal loading estimates, lake sediment contributions and sediment resuspension will be inherently considered through BATHTUB parameterization.

During the interim period when the SWAT watershed model is being developed and calibrated in Task 4, the 2-year average tributary flow, TP and TC budgets developed during Task 2 and augmented for TC in Task 3 will be used for updating and calibrating the BATHTUB lake model.

When the SWAT modeling results are available, the lake model will be run for 2-year periods between 2000 and 2010, using SWAT model predicted tributary flow, TP and TC data developed in Task 4 and lake TP, TC, chlorophyll-a and Secchi depth data developed in Task 3. The diffusive exchange terms between lake model segments will be adjusted (calibrated) so that predictions of TC within each lake segment agree with the measurements, within acceptable tolerance limits. Acceptable tolerance limits for predictions of TP and TC will be consistent with the accuracy of the previously approved TMDL model. For previous lake modeling, calibration results (performance measures) were given for TP in terms of a total-lake R-squared (about 0.9 after calibration of TP sedimentation) and RMSE around 0.06. For chlorides, the calibration results were within about 3% of measured totals. Tt error targets for this lake modeling exercise are specified as 15% mean error for TP and 5% mean error for chlorides, on a total lake basis. Error measures determined following model recalibration will vary between the segments and the above calibration criteria (15% and 5%) would be applicable to results for the total lake, for a minimum 2-year time-averaging period. Statistics related to prediction error will be produced at the completion of the calibration task and described in the final report.

Following re-calibration of the lake segment diffusive exchange terms, the lake model TP predictions for 2-year periods between 2000 and 2010 will be compared to the TP data within each lake segment. TP sedimentation source/sink terms within each lake model segment will then be adjusted (calibrated) so that predictions of TP within each lake segment agree with the measurements, within acceptable tolerance limits.

3d: Lake Model Sensitivity Analysis

3d.1

The re-calibrated BATHTUB model will be used to investigate the modeling consequences of variations in the proportion of the TP that is DP. BATHTUB simulates phosphorus as TP and the impacts of the relative proportion of TP/DP are captured within the model via the calibrated TP sedimentation source/sink terms for each lake segment. During task 3 these TP calibration parameters were determined for the more recent period between 2000 and 2010. In contrast, during task 2 these same TP calibration parameters were determined for the baseline year 1991, when the DP/TP ratio was much higher.

Comparison of lake TP measurements with 1991 and 2010 model predicted lake TP levels for the period between 1991 and 2010 will be used to define the modeling sensitivity to variations in the proportion of TP that is DP.

Deliverables: (1) A model and draft report describing calibration results and model documentation; available for presentation to EPA, Vermont ANR and the technical workgroup by May 31, 2012; (2) Revised draft report describing calibration results and model documentation due by July 31, 2012; and (3) Presentations at a technical workgroup meeting (Waterbury, Vermont, one-day meeting) and a Lake Champlain Basin Program Technical Advisory Committee (Grand Isle, Vermont, 2-hours), not later than September 30, 2012

Task 4: Watershed Modeling

The analysis will be broken into two main steps: 1) estimating P loading from major sources and 2) estimating reduction potential from existing sources from likely treatment techniques and BMPs.

4a: Load Estimation

SWAT will be utilized to estimate annual P export rates for the study period (e.g., 5yr or 10 yr, TBD) using HRUs representative of a range of land characteristics. Critical landuse source categories include pasture, cropland, forest, wetland,urban/developed land, and transportation (paved and unpaved roads). The urban and transportation categories will be further broken out into both pervious and impervious subsets. The HRUs should be specified in such a way that they distinguish between different types of land uses (especially agricultural land uses) for which different candidate management actions are likely to be considered. Urban land uses should likely distinguish between those that are subject and not subject to MS4 permit requirements because it will ease subsequent analysis of WLAs. The model will be set up with multiple meteorological stations that are suitable for model calibration and evaluation of potential climate change impacts. SWAT will also be used to simulate the transport of WWTF loads, which will be specified to the model based on discharge monitoring data.

For urban/developed land, SWAT will be customized using appropriate loading rates, to generate loads appropriate for Vermont's urban areas. Tetra Tech recommends making use of several additional tools to enhance SWAT's output for these areas. Vermont's existing Best Management Practices Decision Support System (BMPDSS) applications for the stormwater-impaired watersheds, EPA's BMP performance curves (EPA 2010), and detailed impervious cover and existing BMP assessments for Vermont's urban areas, may all be used, where available. These tools and information can be used to adjust pollutant loads predicted for urban areas through appropriate modification of the land cover data layer and the buildup-washoff coefficients used in SWAT.

Annual phosphorus loading from stream channel processes will be estimated outside of SWAT, using: 1) an analysis based on the results of the recent Bank Stability and Toe Estimation Model (BSTEM) application in the Missisquoi watershed, and 2) a stream power analysis. The BSTEM-based approach will only be applied to the Vermont portion of the basin (where sufficient data exist); the stream power analysis will be used throughout the basin.

The BSTEM-based analysis will make use of the relationships between loading rates and certain geomorphic characteristics found in the Missisquoi watershed following an intensive data collection and modeling effort using BSTEM. While additional applications of BSTEM are beyond the feasibility of the TMDL project, the results of the BSTEM work in the Missisquoi provide an opportunity for a simpler, but potentially very effective analysis. The first step will determine the correlation between phosphorus and sediment loading rates per linear kilometer and key geomorphic assessment features such as erodability of the channel boundary materials, confinement and slope of valley, departure from reference condition, and sediment and flow regime. These geomorphic parameters are available for many river and stream reaches throughout Vermont, and therefore the correlations established in the Missisquoi watershed may be used to estimate loading rates in the remainder of the watersheds in the Vermont portion of the basin. The Missisquoi watershed includes examples of virtually all commonly occurring stream reach types in the Vermont portion of the basin, so the relationships found in the Missisquoi are expected to be widely applicable to the other Vermont watersheds. However, the necessary geomorphic data are not as consistently available for streams in New York, so the power analysis described below will be used for the New York portion of the basin. Because the stream power analysis will be applied to the whole basin, it will also provide an additional analysis method for the Vermont portion.

The stream power analysis (Bledsoe et al. 2007) will use SWAT daily flow estimates and will be based on the dominant discharge (Q), including Bagnold's specific stream power, ω, and Chang's mobility index, m, where $\omega = \gamma QS/w$ and m = S [Q/d50]0.5, γ is the specific weight of water, S is the slope, w is the width, and d50 is the median bed material size of the surface layer.

Following model calibration and stream channel source analysis, a master table will be used to store existing source loading estimations by major tributary system and 12 digit HUC. It should be noted that Tt will not be using a channel evolution model. Load estimates will be documented in the draft and final TMDL reports.

4b: Reduction Estimation
TMDL scenarios will require estimates of feasible load reductions obtained from a variety of practices. SWAT will be used to determine reduction efficiencies for certain source category and treatment technique combinations while external reduction calculations will be made for other source/BMP combinations. For example, SWAT will be used directly to estimate load reductions associated with changes in tillage, fertilization, and animal management practices, while potential reductions associated with certain urban practices, stream restoration practices, and other some other BMP programs will be calculated separately using methods referenced above. For urban areas, reduction estimates will be calculated outside of SWAT using EPA's BMP performance curves (customized for Vermont), and other BMP efficiency information available for Vermont stormwater practices. The reduction estimation will be documented in the draft and final TMDL reports.

4c: Linkage to BATHTUB Lake Model
The BATHTUB model will be calibrated using the existing setup, which uses monitoring data to provide inputs. Once the SWAT watershed model is calibrated, it will be used to provide inputs to the lake model on the basis of results of various scenario runs. Tt will evaluate the impacts of the following to the calibrated BATHTUB model:

- the range of inputs generated from running scenarios from the calibrated SWAT model
- in-lake effects from climate change
- SWAT model outputs from climate change

Draft and final modeling reports will discuss the impacts to the BATHTUB model from the various scenarios evaluated.

4d: Scenario Evaluation, Allocations, and Demonstration of Reasonable Assurance
For transparency and to facilitate review by multiple stakeholders, load estimation and reduction analysis results (predicted loading rates and delivery factors) can be exported to a Scenario Evaluation spreadsheet tool. The spreadsheet would serve as an accounting inventory of specific phosphorus source areas in the Champlain Basin. It would be applied during the Reasonable Assurance process to facilitate evaluating the change in predicted load reductions based on application of different BMPs to appropriate source categories in different locations. EPA envisions this tool to display load estimates and predicted reductions by major tributary basin, allowing for further filtering to the HUC 12 level or below.

Deliverables: (1) A concise report on the recommended analytical approach, and presentation to technical workgroup, by December 30, 2011; (2) A model and a draft report describing calibration results and model documentation, not later than August 30, 2012; (3) Presentations at a workgroup meeting (Burlington or Grand Isle, Vermont, one-day meeting) and a LCBP TAC meeting (Grand Isle, Vermont, 2-hours) not later than September 30, 2012; (4) The user-interface tool, a concise user guide, and a one-day meeting with EPA and state staff to demonstrate its application, by October 30, 2012; and (5) Draft and final reports on the costs associated with reasonable assurance, not later than December 30, 2012, and March 15, 2013, respectively.

Task 5: Generation of Loading Capacities

As discussed previously, Tt will modify the modeling system based on the final report recommendations and subsequent direction from the EPA TOM. Should modifications to the modeling system be made that are not described in this QAPP, Tt will submit for approval a description of these modifications as a QAPP revision before work begins. This description will include communication with the TMDL technical workgroups and LCBP TAC and the loading reduction assumptions.

Task 5 will generate loading capacities for Lake Champlain based on the approach selected. With the significance of agricultural and stormwater-based inputs to the lake's phosphorous loads, it is particularly important to have strong communication and facilitation with the TAG around the loading reduction assumptions for BMP, policy and management measures. In addition, assumptions on the potential reductions achievable from WWTP upgrades must be discussed thoroughly with the TAG.

Once the recommended modifications have been made to the BATHTUB model, the SWAT watershed model is calibrated and linked to the BATHTUB model, and modifications are made to the TMDL targets, the loading capacities that will achieve water quality standards will be recalculated for each of the 13 segments. Based on these loading capacities, EPA and the TAG will develop up to ten loading scenarios that represent reductions resulting from policy-based choices (e.g., more aggressive construction site monitoring, agricultural BMP implementation, improved maintenance of stormwater and wastewater treatment systems, MS4 permit changes, WWTP upgrades). The additional detail provided by the SWAT model should provide a better ability to detect differences between allocation scenarios. The loading capacities developed based on the new approach will be provided to EPA in preparation for a technical workgroup workshop to develop as many as ten allocation scenarios. The margin-of-safety (MOS) for the loading scenarios will not be determined based on scenario runs. The methodology for determining the MOS has not been developed; however, it is likely that an explicit MOS will be used, and that the model's calibration error analysis will be used to inform the MOS. Tt will provide support for development of the scenarios as needed. The model will be finalized and documented with a final report.

Deliverables: (1) Workshop with the technical workgroup (in Vermont, two-day meeting) to develop range of model scenarios, by September 15, 2012; (2) Draft final in-lake and watershed models (including applicable user interfaces) and draft final report describing in-lake and watershed model calibration results, model documentation, and model outputs including the results of the scenario analyses, not later than March 15, 2013; and (3) Final models, modeling results, and modeling reports, not later than May 14, 2013.

The general deliverables schedule for the models and scenarios is in Table 1.

Table 1. Schedule for model development[a]

Task No.	Deliverable	Schedule
1	1.1 Quality Assurance Project Plan memo, describing the need for an extension on submittal of the QAPP until additional input from Vermont ANR on the modeling approach is received	Within 30 days of work plan approval
	1.2 Draft QAPP to address modeling steps	February 28, 2012
	1.3 Final QAPP	Within 2 weeks of receiving all comments on draft QAPP
	1.4 Revisions to Final QAPP	As needed
2	2.1 Draft model review and recommendations	October 31, 2011
	2.2 Final model review and recommendations	December 30, 2011
	2.3 Attendance at 2 TAG meetings and meeting summaries	Before October 31, 2011
3	3.1 Model and draft report describing calibration results and model documentation	May 31, 2012
	3.2 Revised draft report describing calibration results and model documentation	July 31, 2012
	3.3 Presentations at a technical work group meeting (Waterbury, VT, one-day meeting) and a Lake Champlain Basin Program Technical Advisory Committee (Grand Isle, VT, 2-hours)	September 30, 2012
4	4.1 Concise report on the recommended analytical approach, and presentation to technical workgroup	December 30, 2011
	4.2 Model and draft report describing calibration results and model documentation	August 31, 2012
	4.3 Presentations at a workgroup meeting (Burlington or Grand Isle, VT, one-day meeting) and a Lake Champlain Basin Program Technical Advisory Committee (Grand Isle, VT, 2-hours)	September 30, 2012
	4.4 The user-interface tool, a concise user guide, and a one-day meeting with EPA and state staff to demonstrate its application	October 30, 2012
	4.5 Draft and final reports on the costs associated with reasonable assurance	December 30, 2012 (draft), and March 15, 2013 (final)
5	5.1 Workshop with TAG to develop range of model scenarios	November 30, 2012
	5.2 Draft final in-lake and watershed model calibration results, model documentation, and model outputs including the results of the scenario analysis	March 15, 2013
	Final models, modeling results, and modelingreports	May 14, 2013

[a] Dates may change on the basis of mutual agreement between EPA and Tt.

A1.7 Quality Objectives and Criteria for Measurement Data

Data quality objectives (DQOs) are qualitative and quantitative statements that are used in the project planning and implementation to clarify the intended use of the data, define the type of data needed to support the decision, identify the conditions under which the data should be collected, and specify tolerable limits on the probability of making a decision error because of uncertainty in the data (if applicable). Data users develop DQOs to specify the data quality needed to support specific decisions.

Data of known and documented quality are essential to the success of any water quality modeling study, which in turn generates data for use in various evaluations and to make decisions. Model setup, calibration, and performance for the project under this QAPP will be accomplished using currently available data. The QA process for this study consists of using data of acceptable quality, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. Project quality objectives and criteria for measurement data will be addressed in the context of the two tasks discussed above: (1) evaluating the quality of the data used, and (2) assessing the results of the model application.

The quality of an environmental monitoring program can be evaluated in three steps: (1) establishing scientific assessment quality objectives, (2) evaluating program design for whether the objectives can be met, and (3) establishing assessment and measurement quality objectives that can be used to evaluate the appropriateness of the methods being used in the program. The quality of a data set is some measure of the types and amount of error associated with the data.

Sources of error or uncertainty in statistical inference are commonly grouped into two categories:

- *Sampling error:* The difference between sample values and in situ *true* values from unknown biases due to sampling design. Sampling error includes natural variability (spatial heterogeneity and temporal variability in population abundance and distribution) not specifically accounted for in a design (for design-based inference), and variability associated with model parameters or incorrect model specification (for model-based inference).
- *Measurement error:* The difference between sample values and in situ *true* values associated with the measurement process. Measurement error includes bias and imprecision associated with sampling methodology; specification of the sampling unit; sample handling, storage, preservation, and identification; and instrumentation.

Sections A1.7.1 through A1.7.7 describe DQOs and criteria for model inputs and outputs for this project, written in accordance with the seven steps described in EPA's *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA QA/G-4) (USEPA 2006).

A1.7.1 State the Problem

The original Lake Champlain TMDL was developed jointly by Vermont and New York in 2002. Since the original Lake Champlain TMDL modeling effort was completed in the mid-1990s, several additional studies were conducted (or are underway) that provide new information on lake dynamics (e.g. the phosphorus/sediment flux in certain segments) and potential future effects of climate change on flow volume and pollutant loads to the lake. In addition, ongoing lake and tributary monitoring has now produced nearly two decades of water quality and flow data subsequent to the original monitoring period (1990-1992) used for the modeling.

EPA is revising the Vermont portion of the TMDL in response to a 2008 lawsuit by the Conservation Law Foundation. One of EPA's goals for the revised TMDL is to ensure that there is adequate Reasonable Assurance that identified nonpoint source reductions are feasible. To support this and other technical needs, EPA will develop and apply a watershed model and additional analysis techniques to support the source loading estimation and reduction analysis for the TMDL. The model will be used for providing more detailed loading estimates/allocations for individual source categories (relative to the original TMDL), evaluating results of different load reduction/BMP implementation strategies, evaluating effects on loading from potential changes in climate, and helping to understand the impacts of watershed loading scenarios on lake water quality and in-lake modeling results.

A1.7.2 Identify the Study Objectives

The objectives of this project are to perform the following tasks to provide support to EPA Region 1 in revising the Lake Champlain TMDL: (1) review the existing TMDL water quality model in conjunction with the new information referenced in the project tasks in Section A1.6, and develop a list of recommended revisions to the model in coordination with EPA, Vermont ANR, and a TAG; (2) make any needed revisions to the model, based on recommendations developed in step 1 above, (3) calibrate the revised model, and (4) generate updated loading capacities for each lake segment based on management scenarios as directed by EPA; (5) recommend and implement a technical approach for developing phosphorus loading estimates from sources in the basin; (6) recommend and implement a technical approach for estimating load reductions to sources of phosphorus in the basin.

A1.7.3 Identify Information Needs

SWAT is a watershed-scale model originally developed for the U.S. Department of Agriculture Agricultural Research Service. It is available with EPA's Better Assessment Science Integrating Point & Non-point Sources (BASINS). SWAT was developed to predict impacts of land management practices on water, sediment, and agricultural chemical yields in complex watersheds with varying soils, land uses, and management practices over long periods. It is a product of combining ideas from several other models including Simulator for Water Resources in Rural Basins (SWRRB); Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS); Groundwater Loading Effects on Agricultural Management Systems (GLEAMS); and Erosion-Productivity Impact Calculator (EPIC). Originally, the model was used to predict sediment, pesticide and nutrient loadings from agricultural areas. Over the years, additional constituents have been added to the model's simulation capabilities including urban land pollutant loading using buildup/washoff or U.S. Geological Survey (USGS) regression routines.

Input data for SWAT includes three main categories of information: (1) landscape data, including topography, point source locations, locations and connection among streams; (2) meteorological data, including precipitation, air temperature, and humidity; and (3) land use and pollutant-specific data (e.g., land use areas, monitoring data). SWAT divides a large watershed into subwatersheds, which are further subdivided into HRUs (unique combinations of soil, land cover type, and management practices in a subwatershed). SWAT simulates hydrology, vegetation growth, and management practices at the HRU level. Thus, as the number of HRUs in a watershed increases, computational demand, run times, and number of output files can increase. Water, nutrients, sediment, and other pollutants such as metals from each HRU are summarized in each subwatershed and then routed through the stream network to the watershed outlet.

Tt is considering using the following model inputs to support will support EPA Region 1 in revising the Lake Champlain TMDL:

- USGS National Hydrography Dataset (NHD+) catchments (USGS 2011)
- USDA Natural Resources Conservation Service (NRCS) 12-digit HUCs (NRCS 2011)
- Subwatershed information (e.g., elevations, slopes, reach lengths)
    - National Elevation Dataset (NED) 1/3 arc-second (10 meter by 10 meter)
- LCBP LULC 2001 (Landcov_LCLULCB01 (1))

- USGS Multi-Resolution Land Characteristics (MRLC)
  - 2006 National Land Cover Dataset
  - 2006 National Land Cover Data (NLCD) Percent Developed Impervious
- USDA National Agricultural Statistics Service's Cropland Data Layer (CDL) 2010
- Meteorological data
  - National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) rainfall data
- NPDES-permitted point sources, design flows and permitted limits, monthly discharge monitoring report data

To the extent data are available from the above model inputs on point sources, non-point sources, and climate change, this information will be identified. Most point sources, including municipal wastewater treatment facilities (WWTFs), industrial WWTFs, and MS4s will be identified. The total acreage and loadings associated with each of the nonpoint source items will be identified on a sub-watershed basis.

A1.7.4 Specify the Characteristics that Define the Population of Interest

Tt will support EPA Region 1 in developing and applying a watershed model to support the source loading estimation and reduction analysis for the TMDL. The model will be used for providing more detailed loading estimates/allocations for individual source categories (relative to the original TMDL), evaluating results of different load reduction/BMP implementation strategies, evaluating effects on loading from potential changes in climate, and helping to understand the impacts of watershed loading scenarios on lake water quality and in-lake modeling results.

In most cases, the statistical criteria for loads and concentrations are detailed in the error discussion in Section A1.7.6.

A1.7.5 Develop the Strategy for Information Synthesis

Tt will use a systematic planning process to develop a watershed model for supporting the source loading estimation and reduction analysis for the TMDL. That 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 regulatory objectives
- The appropriate criteria for making a determination of whether the models are accurate and precise based on past general experience combined with site-specific knowledge and completeness of the conceptual models
- How the appropriate criteria would be used to determine whether model outputs achieve the needed quality

Acceptance criteria that result from systematic planning address the following types of components for modeling projects. Criteria used in selecting the appropriate model will be documented in the modeling reports and typically include the following:

- Technical criteria (concerning the requirements for the model's simulation of the physical system)

- Regulatory criteria (concerning constraints imposed by regulations, such as water quality standards)
- User criteria (concerning operational or economical constraints, such as hardware/software compatibility)

The Tt Co-TOLs compared available models to select the most applicable ones to use for this study, as described in the *Watershed Modeling Approach Recommendation* (Tetra Tech 2012b) in Appendix A. In addition, existing model programming language can be converted into a different programming language to enhance software compatibility. The models that are recommended for use for this project are BATHTUB and SWAT.

A1.7.6 Specify Performance and Acceptance Criteria

Quantitative measures, sometimes referred to as calibration criteria, include the *relative error* between model predictions and observations as defined below.

$$E_{rel} = \frac{\Sigma |O - P|}{\Sigma O} \times 100$$

where E_{rel}= relative error in percent. The relative error is the ratio of the absolute mean error to the mean of the observations and is expressed as a percent.

Models will be deemed acceptable when they are able to simulate field data within predetermined statistical measures. A variety of performance targets have been documented in the literature, including Lumb et al. (1994) and Donigian (2000). Examples based on Donigian (2000) are described in Table 2. This table is provided as an example of typical parameters evaluated and the range of percent differences between modeled and observed values that provide a qualitative assessment of the model calibration. In evaluating a given calibration, it may be useful to look at a number of parameters. In this case, Tt will be looking specifically at phosphorus. Model performance will be deemed acceptable where a performance evaluation of “good” or “very good” is attained. It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian 2000). Should inclusion of future variables be necessary, they will be added to a future appendix and submitted for EPA review and approval. Those statistical criteria will vary depending on the focus of the model study. When applying watershed hydrologic models, for example, Tt will use a hydrologic calibration spreadsheet to determine the acceptability of modeling results. The spreadsheet computes the relative error for various aspects of the hydrologic system.

Statistical targets that have been developed and implemented in previous studies (Lumb et al. 1994) are defined and met for each aspect of the system before accepting the model (Table 3). Similar comparisons of salinity, water temperature, and water quality (nutrients, dissolved oxygen, and chlorophyll-a) are made for other modeling components (e.g., watershed pollutant loads and receiving water quality). These comparisons are made between the simulation and the data. These targets are representative of the level of accuracy expected in watershed modeling.

It should be noted that the limits in Tables 2 and 3 will be used as targets for the calibration; however, they cannot be guaranteed to be met as they may not be achievable.

Table 2. Statistical measures for model comparisons (Donigian 2000)

State Variable	Percent Difference between Simulated and Observed Values		
	Very Good	Good	Fair
Water Quality / Nutrients (Phosphorus)	<15	15-25	25-35
Sediment	<20	20-30	30-45
Chlorides	5[a]		

a. Donigian 2000 does include measures for chlorides; a 5 percent difference will be the target for this modeling exercise.

Table 3. Relative errors and statistical targets for hydrologic calibration (Lumb et al 1994)

Relative errors (simulated-observed)	Statistical target (%)
Error in total volume	10
Error in 50% lowest flows:	10
Error in 10% highest flows:	15
Seasonal volume error - Summer:	30
Seasonal volume error - Fall:	30
Seasonal volume error - Winter:	30
Seasonal volume error - Spring:	30
Error in storm volumes:	20
Error in summer storm volumes:	50

An overall assessment of the success of the calibration can be expressed using calibration levels.

- Level 1: Simulated values fall within the target range (highest degree of calibration).
- Level 2: Simulated values fall within two times the associated error of the calibration target.
- Level 3: Simulated values fall within three times the associated error of the calibration target.
- Level 4: Simulated values fall within *n* times the associated error of the calibration target (lowest degree of calibration).

The model will be considered calibrated when it reproduces data within an acceptable level of accuracy determined in consultation with the EPA TOM and documented in monthly progress reports. Quantitative calibration measure calculations will be included in the revised model and draft report as well as in the final report model report. These reports can be added to future QAPP revisions if deemed necessary.

A1.7.7 Optimize the Design for Obtaining and Generating Adequate Data or Information

The data requirements of this project encompass aspects of both laboratory analytical results obtained as secondary data and database management to reduce sources of errors and uncertainty in the use of the data. Data commonly required for populating a database to supply data for calibrating a model are listed in Table 4.

Table 4. Secondary environmental data to be collected for Lake Champlain TMDL support

Data type	Example measurement endpoint(s) or units
Geographic or location information (typically in Geographic Information System [GIS] format)	
Land use	Acres
Soils (including soil characteristics)	Hydrologic group
Topography (stream networks, watershed boundaries, contours, or digital elevation)	Elevation in feet and meters (North American Vertical Datum of 1988; NAVD88); percent slope
Water quality and biological monitoring station locations	Latitude and longitude, decimal degrees (North American Datum 1983; NAD83)
Meteorological station locations	Latitude and longitude, decimal degrees (NAD83)
Permitted facility locations	Latitude and longitude, decimal degrees (NAD83)
Impaired waterbodies (georeferenced 2009 303(d)-listed AUs)	Latitude and longitude, decimal degrees (NAD83)
Dam locations	Latitude and longitude, decimal degrees (NAD83)
Combined sewer overflow locations	Latitude and longitude, decimal degrees (NAD83)
Flow	
Historical record (daily, hourly, 15-minute interval)	Cubic feet per second (cfs)
Dam release flow records	Cfs
Peak flows	Cfs
Meteorological data	
Rainfall	Inches
Temperature	°C
Wind speed	Miles per hour
Dew point	°C
Humidity	Percent or grams per cubic meter
Cloud cover	Percent
Solar radiation	Watts per square meter
Water quality (surface water, groundwater)	
Chemical monitoring data	Milligrams per liter (mg/L)
Discharge Monitoring Report	Discharge characteristics including flow and chemical composition
Permit Limits	mg/L
Regulatory or policy information	
Applicable state water quality standards	mg/L
EPA water quality standards	mg/L
On-site waste disposal	
Septic systems	Number of systems, locations, failure rates
Illicit discharges	Straight pipes
Land management information	
Agricultural practices (major crops, crop rotation, manure management and application practices, fertilization application practices, pesticide use)	Description of crop rotations; pounds manure applied per acre
Best Management Practices	Length and width of buffer strips

Data type	Example measurement endpoint(s) or units
Additional information	
Stream networks, watershed boundaries, contours or digital elevation, storm water permits, storm characteristics, stream morphology data, mass wasting sources, reservoir characteristics, fish advisories, facility type, permit status, applicable permits, BMPs, major crops, crop rotation, manure management and application practices, livestock population estimates, fertilization application practices, pesticide use, wildlife population estimates, citizen complaints, relevant reports, existing watershed and receiving water models, ground level carbon dioxide	Specific descriptive codes

Secondary data will be downloaded electronically from various sources to reduce manual data entry whenever possible. Secondary data will be organized into a standard model application database. A screening process will be used to scan through the database and flag data that are outside typical ranges for a given parameter; we would only exclude data if they were erroneous (e.g., pH >14) and values outside typical ranges will be flagged to identify data for exclusion during calibration data sets or model kinetic parameters. The data used in the model, the period from which the data were collected, and the quality requirements of the data will be described in the interim model report. That report will document any use of secondary data of unknown quality and any data gaps and the assumptions used in filling such gaps. Several iterations of the draft reports will be reviewed by the two TMDL technical workgroups and the LCBP TAC[1]. In the rare case that a paper or study represents a technical landmark and is considered seminal within a topic/subtopic but has not been peer reviewed or some aspect of study design, methods, or support of results or conclusions is reviewed and found to be poor, that will be documented and discussed (as a caveat) in the draft deliverables when the associated results are presented. Percentages of allowable missing data will be selected using the experience of Tt's modeling staff and they must consult with the EPA TOM and the rest of the TAG and LCBP TAC staff in evaluating secondary data sets for use in developing water quality models. Completeness goals (i.e., acceptable percentage of missing data) for available secondary data sets will be determined in consultation with the EPA TOM. Completeness goals for data sets will vary depending on the type of data, the age of the data, and how the missing data are dispersed throughout the entire data set. A description of all datasets utilized in the modeling will be provided in the draft/final project reports including descriptions of the period of record and/or area of geographic coverage. Datasets that are used in modeling are often not representative of an entire basin or may not cover the entire modeling period and yet may represent the best information that is available. Therefore, in consultation with the EPA TOM and stakeholders who have knowledge of the available data and area, Tt will utilize the best available information.

Tt documents all data sources, including full reference citations in a bibliography and parenthetical references in report text. Tt also maintains paper and electronic copies of all references. Documentation for all data sources (i.e., full bibliographical information and metadata where appropriate) will be collected and recorded.

[1] The technical workgroups were established by EPA and VTDEC specifically for this project and include an in-lake modeling group and a watershed analysis group. Both are comprised primarily of researchers and scientists familiar with Lake Champlain water quality and watershed data and prior modeling work. The LCBP TAC is an ongoing advisory committee to the Lake Champlain Basin Program, and is comprised of a broader group of scientists and resource experts within the basin.

Uncertainty in the data can be due to sampling and measurement errors or errors introduced during data manipulation. Reducing data uncertainty is of high priority. It is important to reduce uncertainty by using appropriate QC protocols. Discussion of conventional data quality indicators—precision, accuracy, representativeness, completeness, and comparability—is in Appendix B of this QAPP.

Tt will document in the interim and final model report the description of justifiable and quantifiable “acceptable” and “unacceptable” criteria and the evaluation for each critical model input data parameter, findings of model algorithm/model calibration/model verification (with measured data) outcomes, uncertainties, and variables of model input parameters and model outputs (e.g., mean, median, sensitivity analyses).

A1.7.8 Quality Control

The project team will follow the policies and procedures detailed in this QAPP. In general, training programs, materials, manuals, and reports prepared by Tt staff will be subjected to internal or external technical and editorial reviews before the final versions are submitted. Specific QC procedures for the development, application, and calibration of the models used for this project are described in this section.

The data quality of model input and output is addressed, in part, by the training and experience of project staff (Section A1.8) and documentation of project activities (Section A1.9). This QAPP and other supporting materials will be distributed to all personnel involved in revising the Lake Champlain TMDL. The Modeling QC Officer will ensure that all tasks described in the project for developing the analysis are carried out in accordance with this QAPP. Staff performance will be reviewed throughout each of the model development phases to ensure adherence to project protocols.

QC is defined as the process by which QA is implemented in a modeling project. All project modelers will conform to the following guidelines:

- All modeling activities including data interpretation, load calculations, or other related computational activities are subject to audit or internal review. Thus, the modelers are instructed to maintain careful written and electronic records for all aspects of model development.
- A written record of where the data used in the models were obtained will be kept, and any information on data quality will be documented in the final report. A written record on where this information is located on a computer or backup media will be maintained in the project files.

The Modeling QC Officer or the Modeling QC Officer’s designee will periodically perform surveillance of each modeler’s work. Modelers will be asked to provide verbal status reports of their work at periodic modeling subgroup teleconferences. Detailed modeling documentation will be made available to members of the modeling subgroup as necessary.

The ability of computer code to represent model theory accurately will be ensured by following rigorous programming protocols, including documentation within the source code. Specific tests will be required of all model revisions to ensure that fundamental operations are verified to the extent possible. Those tests include testing numerical stability and convergence properties of the model code algorithms, if appropriate. Should the model code be modified, appropriate tests will be identified and performed, however, we do not anticipate this occurring. Model results will be generally checked by comparing results to those obtained by other models or by comparison to hand calculations. Visualization of model results will assist in determining whether model simulations are realistic. Model calculations will be compared to field data. If adjustments to model parameters are made to obtain a *fit* to the data, the modelers will provide an explanation and justification that must agree with scientific knowledge and with process rates within reasonable ranges as found in the literature.

Non-project-generated data will be used for model development and calibration. The QA procedures for project-generated data and database development have been discussed elsewhere in this QAPP. All analytical data for the model's target parameters and most supporting data will have been verified through field QAPP processes before release to the modelers.

Rigorous examination of precision, accuracy, completeness, representativeness, detectability, and comparability will be conducted on project-generated data by the Modeling QC Officer during model calibration. Project-generated data will be verified and validated using a process that controls measurement uncertainty, evaluates data, and flags or codes data against various criteria. That portion of the QA process is also associated with the final database construction. Modelers will cross-check data for bias, outliers, normality, completeness, precision, accuracy, and other potential problems. These data and processes will be documented in the interim model report.

Non-project-generated data might be obtained from either published or unpublished sources, and the modelers will examine those data as part of a data quality assessment. Databases that have not been published are also examined in light of a data quality assessment. Data provided by EPA or other sources will be assumed to meet precision objectives established by those entities. For example, we will use results of VT's BMPDSS applications to verify SWAT loadings for urban lands and we will make use of Missisquoi BSTEM modeling results during the channel stability/streambank erosion source analysis. The acceptance criteria for individual data values generally address the issues described in Appendix B. Tt will document in the interim and final model report the description of justifiable and quantifiable "acceptable" and "unacceptable" criteria and the evaluation for each element described in this Section.

A1.8 Special Training Requirements/Certification

Tt staff involved in developing model input data sets and model application have experience in numerical modeling gained through their work on numerous similar projects, described below.

Mr. Parker, a Co-TOL for this project, is Director of the Water Resources Modeling Group and over the past 15 years has managed more than 50 TMDL projects nationwide (in EPA Regions 1, 2, 3, 4, 6, 9, and 10), resulting in over 2,500 TMDLs. He recently managed a multi-million dollar support contract for development of the Chesapeake Bay nutrient TMDL, an 8-year nutrient TMDL modeling project for the Klamath River Basin (which included 4 reservoirs), and TMDL development for the impounded Lower Charles River. He has also worked directly with EPA New England on projects in Vermont and Maine and has managed a range of lake nutrient TMDL modeling projects (in California, Mississippi, Pennsylvania, Delaware, Texas, Maryland, and West Virginia). Mr. Parker currently manages a national-scale climate change modeling project for EPA Office of Research and Development (20 watersheds) which has become a basis for the Lake Champlain climate change assessment (with which he has also been involved). He is one of the original developers of LSPC, Mining Data Analysis System (MDAS), and EPA's TMDL Modeling Toolbox and has extensive experience developing, applying, and training environmental professionals to use models, including

LSPC, HSPF, MDAS, Generalized Watershed Loading Function (GWLF), CE-QUAL-W2, QUAL2K, Environmental Fluid Dynamics Code (EFDC), and Water Quality Analysis and Simulation Program (WASP).

Ms. Teresa Rafi, a Co-TOL for this project, is an environmental scientist with 11 years of professional experience. Her related task experience includes providing programmatic support to several EPA Office of Water programs and initiatives including TMDLs, watershed management, and the American Indian Environmental Office. She has experience conducting watershed assessments and modeling in support of TMDL development for nutrients, bacteria, metals, sediment, dissolved oxygen, mercury and polychlorinated biphenyls (PCBs). For Tt, she provides communications and technical writing services for multiple topics and audiences ranging from model documentation, monitoring plans, and software requirements analysis for modeling related information technology projects.

Mr. Sarkar, the Watershed Modeling Technical Lead is an environmental engineer with 3 years' professional experience. He is an expert SWAT modeler and provided extensive modeling support for the GCRP 20 watersheds project, including development, calibration, and scenario simulation for 10 of the 20 watersheds. Mr. Sarkar has also developed SWAT models for the LaPlatte watershed in Vermont, the Hinkston watershed in Kentucky, and the Grand Lake watershed in Oklahoma, Kansas, and Arkansas. In addition, he is an experienced Visual Basic for Applications (VBA) programmer who has contributed to the development of automation tools for the GCRP project.

Mr. Richard Baker, the Lake Modeling Technical Lead, has more than 30 years of experience in the development and application of a wide range of numerical models in water resources and environmental engineering. He has participated as lead modeler in surface water hydrologic, hydraulic, hydrodynamic, wave, sediment transport and water quality modeling studies of lacustrine, riverine, estuarine and coastal systems. His projects have included modeling the Upper and Lower Charles River, Nashua River, Kickemuit River, Kickemuit Reservoir, Chelsea Creek and Boston Inner Harbor. Mr. Baker has also developed a hydrodynamic and water quality model of Missisquoi Bay, in Lake Champlain.

Dr. Jonathan Butcher, the Modeling QC Officer, is a director and principal engineer, and a registered Professional Hydrologist and environmental engineer with more than 27 years of experience in watershed planning, risk assessment, and the development, application, and communication of hydrologic, hydraulic, and water quality models. He was the Tt lead modeler as well as the subcontractor modeling QC officer for the antecedent project that developed the 20 watershed simulation models. Dr. Butcher is an expert in applying and calibrating both the HSPF and SWAT models at a wide range of spatial scales, including large, regional-scale models. For example, he is the technical lead for development of an HSPF model for the 17,000-square-mile Minnesota River basin in the corn belt and developing a SWAT model for the 6,000-square-mile Verde River in the arid Southwest and is experienced in the challenges of calibration and data management in large-scale models. He has published widely on modeling and ecological risk assessment and has been a lead author for several EPA and Water Environment Research Foundation (WERF) guidance documents.

Senior modelers who have extensive experience using the applicable model(s) will provide guidance to modelers. In addition, model user manuals will be provided to all modelers involved in the project. The Tt Co-TOLs will ensure strict adherence to the project protocols.

A1.9 Documentation and Records

Thorough documentation of all modeling activities is necessary for the interpretation of study results. As directed by the EPA TOM, Tt will prepare progress reports and other deliverables, which will be distributed to project participants as indicated by the EPA TOM. Data and assumptions used to develop the models will be recorded and documented in the interim and final model report. This report will include results of technical reviews, model tests, data quality assessments of output data and audits, actual input and databases used, response actions to correct model development of implementation problems, and if applicable, pre- and post-software development. Documentation of candidate model assessments used for model selection, including references, is provided in the draft and final model approach recommendation reports.

The format of the raw data to be used for model parameters, model input, model calibration, and model output will be converted to the appropriate units, as necessary, for use in revising the Lake Champlain TMDL.

Tt will deliver the project files for revising the Lake Champlain TMDL that will contain copies of all records and documents, including soft copy versions of the data and model input data sets. Tt will deliver those files to EPA at the end of the project. Tt will maintain a copy of the project files at the Fairfax, Virginia, office for at least 5 years after the expiration of the contract (unless otherwise directed by the EPA TOM). The Tt Co-TOLs will maintain files, as appropriate, as repositories for information and data used in models and for the preparation of any reports and documents during the project. They will distribute the approved QAPP and any updates to the approved QAPP to project staff on the distribution list. Electronic project files are maintained on network computers and are backed up nightly during the week. The Tt Co-TOLs will supervise the use of materials in the administrative record. The following information will be included in the hard copy or electronic project files in the administrative record:

- Any reports and documents prepared, including the approved QAPP
- Contract and project information
- Electronic copies of model input/output (for model calibration and allocation scenarios)
- Results of technical reviews, model tests, data quality assessments of output data, and audits
- Documentation of response actions during the project to correct model development or implementation problems
- Assessment reports for acquired data
- Statistical goodness-of-fit methods and other rationale used to decide which statistical distributions should be used to characterize the uncertainty or variability of model input parameters
- Communications (e-mail; memoranda; internal notes; telephone conversation records; letters; meeting minutes; and all substantive written correspondence among the project team personnel, subcontractors, suppliers, or others)
- Maps, photographs, and drawings
- Studies, reports, documents, and newspaper articles pertaining to the project
- Spreadsheet data files: physical measurements, analytical chemistry data, and microbiological data (hard copy and on diskette)

The model application will include complete record keeping of each step of the modeling process. The documentation will consist of reports and files addressing the following items:

- Assumptions
- Parameter values and sources
- Nature of grid, network design, or subwatershed delineation
- Changes and verification of changes made in code
- Actual input used
- Output of model runs and interpretation
- Calibration and performance of the model(s)

Tt will document in the interim and final model report the description of justifiable and quantifiable “acceptable” and “unacceptable” criteria and the evaluation for each critical element described above.

Formal reports submitted to EPA that are generated from the data will be maintained in the central file (hard copy and compact disc) at Tt’s Fairfax office. The data reports will include a summary of the types of data collected, sampling dates, and any problems or anomalies observed during sample collection.

The majority of work conducted by Tt for revising the Lake Champlain TMDL will involve the acquisition or processing of data and the generation of reports and documents, both of which require the maintenance of computer resources. Tt’s computers are either covered by on-site service agreements or serviced by in-house specialists. When a problem with a microcomputer occurs, in-house computer specialists diagnose the trouble and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. For other computer equipment requiring outside repair services and not covered by a service contract, local computer service companies are used on a time-and-materials basis. Routine maintenance on microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes. All computer users have been instructed on the importance of routinely archiving project data files from hard drive to compact disc storage. The Atlanta and Fairfax office network servers are backed up on tape nightly during the week. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems have been placed on Tt’s computer systems and are updated regularly to ensure that viruses are identified and destroyed promptly.

B2.0 Data Acquisition Requirements (Non-direct Measurements)

Nondirect measurements (also referred to as non-project-generated data) are data that were previously collected under a different effort outside this contract. Nondirect data can come from a number of sources, but the nondirect data most often used in TMDL modeling projects are typically obtained from EPA, NOAA NCDC, USGS NHD+ and NED, USDA NRCS, and databases maintained by state agencies.

Non-project-generated data could be obtained from published or unpublished sources. The published data will have been previously peer reviewed. Those data are generally examined by modelers as part of a data quality assessment. Databases that have not been published are also examined in light of a data quality assessment. Data provided by EPA or other sources will be assumed to meet precision objectives established by those entities, as described in the acceptance criteria issues described in Appendix B. If historical data are used, a written record of where the data were obtained and any information on their quality will be documented in the final report.

Tt will document in the interim and final model report the description of justifiable and quantifiable "acceptable" and "unacceptable" criteria and the evaluation for each critical element described above.

B2.2 Data Management

The data management process and the computer hardware and software configuration requirements will be developed and submitted to the EPA TOM for review before model equations and related algorithms are coded into an integrated, efficient computer code. Modeling staff members will work closely with the Tt Co-TOLs and will consult with experts as necessary to ensure the theory is accurately represented in the code. The modeling code is continually checked by the developers and compared to bench test runs to ensure the accuracy of the mechanistic equations and solution techniques. The Modeling QC Officer will conduct internal reviews of the computer code.

C3.0 Assessment/Oversight and Response Actions

The QA program under which this project will operate includes surveillance, with independent checks of the data obtained from sampling, analysis, and data-gathering activities. This process is illustrated in Figure 3. 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 appropriate corrective action
- Establish the effectiveness of and implement the corrective action
- Verify that the corrective action has eliminated the problem

Many of the technical problems that might occur can be solved on the spot by the staff members involved, for example, by correcting errors or deficiencies in documentation. Immediate corrective actions form part of normal operating procedures and are noted in records for the project. Problems that cannot be solved in that way require more formalized, long-term corrective action.

If quality problems that require attention are identified, Tt will determine whether attaining acceptable quality requires either short- or long-term actions. If a failure in an analytical system occurs (e.g., performance requirements are not met), the Modeling QC Officer will be responsible for corrective action and will immediately inform the Tt Co-TOLs or the QA Officer, as appropriate. Subsequent steps taken will depend on the nature and significance of the problem, as illustrated in Figure 4. Note that this figure represents Tt's internal problem assessment and correction operations, and all personnel identified as responsible for corrective action are Tt staff unless otherwise noted. External notification of problems or corrective actions are generally only initiated where problems are identified which impact project delivery schedules, or limit the quality of project deliverables. Under these circumstances problem resolutions are included in routine communications (regular email and telephone calls) and are summarized in regular monthly reports. It is the responsibility of

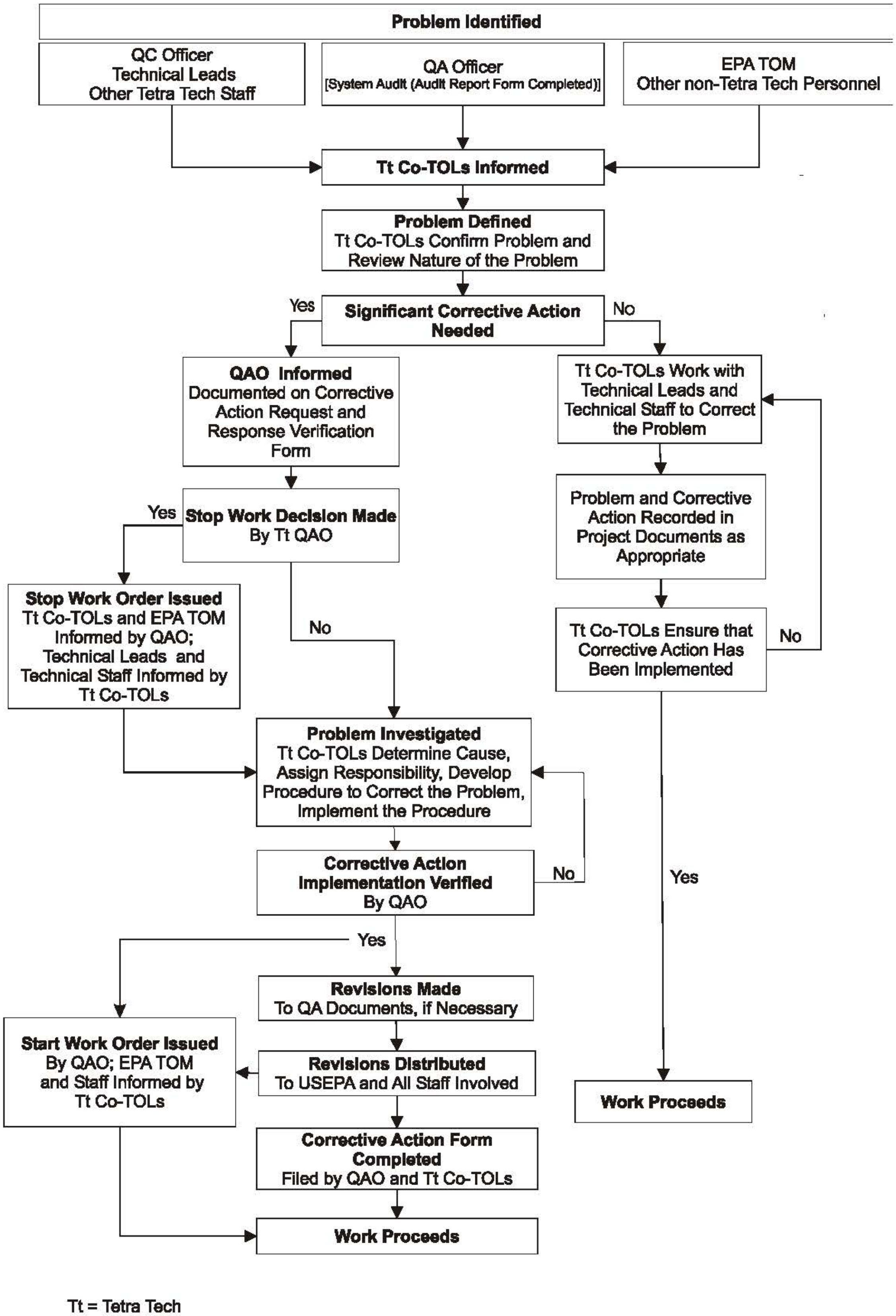
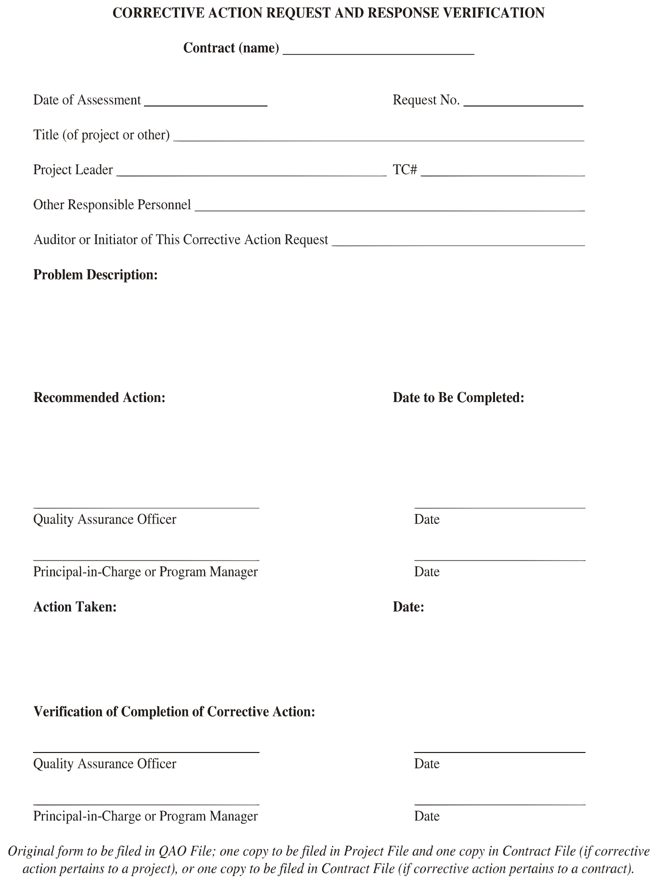


Figure 3. Problem assessment and correction operations.


CORRECTIVE ACTION REQUEST AND RESPONSE VERIFICATION

Contract (name) ______________________

Date of Assessment ______________ Request No. ______________

Title (of project or other) ______________________________

Project Leader ______________________ TC# ______________

Other Responsible Personnel ______________________________

Auditor or Initiator of This Corrective Action Request ______________________

Problem Description:

Recommended Action: **Date to Be Completed:**

Quality Assurance Officer ______________ Date ______________

Principal-in-Charge or Program Manager ______________ Date ______________

Action Taken: **Date:**

Verification of Completion of Corrective Action:

Quality Assurance Officer ______________ Date ______________

Principal-in-Charge or Program Manager ______________ Date ______________

Original form to be filed in QAO File; one copy to be filed in Project File and one copy in Contract File (if corrective action pertains to a project), or one copy to be filed in Contract File (if corrective action pertains to a contract).

Figure 4. Corrective Action Request and Response Verification form.

the TOM to engage EPA's quality organization, should it be necessary, to assist in resolving issues, defining their impact on project quality objectives, assisting in the selection of corrective measures, and documentation systems.

The Tt Co-TOLs have primary responsibility for monitoring the activities of this project and identifying or confirming any quality problems. These problems will also be brought to the attention of the Tt QA Officer, who will initiate the corrective action system described above, document the nature of the problem (using a form such as that shown in Figure 4), and ensure that the recommended corrective action is carried out. The Tt QA Officer has the authority to stop work on the project if problems affecting data quality that will require extensive effort to resolve are identified.

The EPA TOM and Tt Co-TOLs will be notified of major corrective actions and stop work orders. Corrective actions could include the following:

- Reemphasizing to staff the project objectives, the limitations in scope, the need to adhere to the agreed-upon schedule and procedures, and the need to document QC and QA activities.
- Securing additional commitment of staff time to devote to the project.
- Retaining outside consultants to review problems in specialized technical areas.
- Changing procedures. The Tt Co-TOLs can replace a staff member, if appropriate, if it is the best interest of the project to do so.

Performance audits are quantitative checks on different segments of project activities; they are most appropriate for sampling, analysis, and data-processing activities. The Modeling QC Officer is responsible for overseeing work as it is performed and periodically conducting internal assessments during the data entry and analysis phases of the project. As data entries, model codes, calculations, or other activities are checked, the Modeling QC Officer will sign and date a hard copy of the material or complete Tt's standard Technical/Editorial Review Form, as appropriate, and provides it to the Tt Co-TOLs include in the administrative record. Performance audits will consist of comparisons of model results with observed historical data. Performing control calculations and post-simulation performance of predictions are major components of the QA framework.

The Tt Co-TOLs will periodically perform or oversee the following qualitative and quantitative assessments of model performance to ensure that the model is performing the required task while meeting the quality objectives:

- Data acquisition assessments
- Model calibration studies
- Sensitivity analyses
- Uncertainty analyses
- Data quality assessments
- Model evaluations
- Internal reviews

Sensitivity to variations, or uncertainty in input parameters, is an important characteristic of a model. Sensitivity analysis is used to identify the most influential parameters in determining the accuracy and precision of model predictions. That information is important to the user who must establish required accuracy and precision in model application as a function of data quantity and quality. Sensitivity analysis quantitatively or semi-quantitatively defines the dependence of the model's performance assessment measure on a specific parameter or set of parameters. Sensitivity analysis can also be used to decide how to simplify the model simulation and to improve 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 mostly 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.

Sensitivity analyses (iterative parameter adjustments) will be performed during model calibrations to ensure that reasonable values for model parameters will be obtained, resulting in acceptable model results. The degree of allowable adjustment of any parameter is usually directly proportional to the uncertainty of its value and is limited to its expected range of values. Formal sensitivity analyses will be performed in accordance with technical direction from the EPA TOM when a certain aspect of the system requires further investigation.

Uncertainty analyses are different from sensitivity analyses. Uncertainty analyses include the uncertainties and variabilities around the model parameters, model itself, as well as model outputs (e.g., uncertainty around the mean). Uncertainty analysis must be performed and must be performed separately from sensitivity analyses. The model's calibration error analysis will be used to inform the margin-of-safety. Propagation of error from model to model will not be explicitly evaluated. However, Tt will be calibrating each model from upstream to downstream to ensure that error does not propagate. Calibration results will be presented and error statistics for both models will be generated and presented .

Internal reviews, as well as results of EPA modeling subgroup reviews provided to Tt, will be documented in the project and QAPP files. Documentation will include the names, titles, and positions of the reviewers; their report findings; and the project management's documented responses to their findings.

The Tt Co-TOLs will perform surveillance activities throughout the duration of the project to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in this QAPP. The surveillance activities will include assessing how project milestones are achieved and documented, corrective actions are implemented, budgets are adhered to, reviews are performed, and data are managed and whether computers, software, and data are acquired in a timely manner.

System audits are qualitative reviews of project activity to check that the overall quality program is functioning and that the appropriate QC measures identified in the QAPP are being implemented. If requested by the EPA TOM, and additional funding is provided by EPA, the Tt QA Officer or designee will conduct an internal system audit of the project and report results to the EPA TOM and Tt Co-TOLs. Tt will update in the interim and final model report the description of justifiable and quantifiable “acceptable” and “unacceptable” criteria and the evaluation for each element described in this Section.

C4.1 Model Parameterization (Calibration)

If sampling is required for this project, the calibration and frequency of calibration for instruments and equipment used to collect new data will be addressed in a separate field sampling QAPP.

A model calibration is a measure of how well the model results represent field data. The use of a calibrated model, the scientific veracity of which is well defined, is of paramount importance.

The Tt Co-TOLs will direct the model calibration efforts. Some model parameters will need to be estimated using site-specific field data for the model’s application. Some example parameters follow:

- Kinetic coefficients and parameters (e.g., partition coefficients, decay coefficients)
- Forcing terms (e.g., sources and sinks for state variables)
- Boundary conditions (specified concentrations, flows)

Models are often calibrated through a subjective trial-and-error adjustment of model input data because a large number of interrelated factors influence model output. The model calibration *goodness of fit* measure can be either qualitative or quantitative. Qualitative measures of calibration progress are commonly based on the following:

- Graphical time-series plots of observed and predicted data
- Graphical transect plots of observed and predicted data at a given time interval
- Comparison between contour maps of observed and predicted data, providing information on the spatial distribution of the error
- Scatter plots of observed versus predicted values in which the deviation of points from a 45-degree straight line gives a sense of fit
- Tabulation of measured and predicted values and their deviations

The Lake Champlain lake and watershed models will be calibrated to the best available data, including literature values and interpolated or extrapolated existing field data. If multiple data sets are available, an appropriate period and corresponding data set will be chosen on the basis of factors characterizing the data set, such as corresponding weather conditions, amount of data, and temporal and spatial variability of data. The model will be considered calibrated when it reproduces data within an acceptable level of accuracy or approved by the EPA modeling subgroup (See Tables 2 and 3).

For the climate change analysis, the Climate Assessment Tool (CAT) (USEPA 2009d) will be used to generate climate scenario data in conjunction with the SWAT weather generator in a manner consistent with the methodology used in the climate change analysis project highlighted in Johnson et al. 2011.

Sensitivity analysis (refer to Section C3.0) is used to identify the most influential parameters in determining the accuracy and precision of model predictions. Sensitivity analysis will be used to improve the efficiency of the calibration process.

Quantitative calibration measures include time series error measures, and other statistic based dimensionless performance indices. Quantitative measures allow comparison of the level of calibration and performance between modeling studies of different water bodies and different modeling studies of a specific water body. Time series error measures, particularly root mean square errors, are typically used to evaluate model performance with respect to predicting water surface elevation, temperature and salinity. There are not quantifiable limits because the Tt modelers and the TAG and LCBP TAC may decide for a particular station that the statistics (quantitative) are more or less important that the graphical plots (qualitative). Tt will update in the interim and final model report the description of these limits as well as justifiable and quantifiable “acceptable” and “unacceptable” criteria and the evaluation for each element described in this Section.

C4.2 Model Corroboration (Validation and Simulation)

Data review and validation services provide a method for determining the usability and limitations of data and provide a standardized data quality assessment. Verification of new model components or parameters (when applicable) improves the predictive capabilities of new models or modified existing models. Experienced professionals will be used in the data review, compilation, and evaluation phases of the study. Tt will be responsible for reviewing data entries, transmittals, and analyses for completeness and adherence to QA requirements. The data will be organized in a standard database on a microcomputer. A screening process that scans through the database and flags data that are outside typical ranges for a given parameter will be used. Values outside typical ranges will not be used to develop model calibration data sets or model kinetic parameters.

The Modeling QC Officer will review or oversee review of all data related to the project for completeness and correctness. The Tt modeling staff will make all data available to the Modeling QC Officer within 2 weeks of receiving data. The Modeling QC Officer will identify any issues of concern, and he will resolve those issues with the modeling team.

Raw data received in hard copy format will be entered into the standard database. All entries will be compared to the original hard copy data sheets by the team personnel. Screening methods will be used to scan through the database and flag data that are outside typical ranges for a given parameter. Data will also be manipulated using specialized programs and Microsoft Excel 2007. Unless otherwise directed by the EPA TOM, Tt anticipates that it will recalculate ten percent of the calculations to ensure that correct formula commands were entered into the program. EPA has performed 10 percent QC checks of samples collected for water quality monitoring for bacteria (USEPA 2011a), for air emission inventories (USEPA 2011b), and for checking vehicle fuel economy ratings to confirm manufacturer’s results (USDOE and USEPA 2011). If 5 percent of the data calculations are incorrect, all calculations will be rechecked after the correction is made to the database. Data quality will be assessed by comparing entered data to original data; performing the data and model evaluations described in Sections A1.7, B2.0, and C3.0; and comparing results with the measurement performance or acceptance criteria summarized in the data review and technical approach documentation to determine whether to accept, reject, or qualify the data. Results of the review and performance processes will be reported to the EPA TOM.

General guidelines and procedures for model data performance and calibration are listed in Sections A1.6, A1.7, and C4.1. Verification will be performed by comparing new model parameters or components to theory. The model will be considered calibrated when it reproduces data within an acceptable level of accuracy determined in consultation with the EPA TOM and alternate TOM/Technical Lead and based on input from the modeling subgroup. The quantitative calibration measure calculations will be included in the final model report.

Model performance evaluates the model's ability to appropriately simulate conditions under a data set or period that is independent from those used in the calibration. The calibration and performance process will be documented in the final model report.

Because the goal is to be able to predict when point and nonpoint source loads produce water quality impairment on the basis of the ambient water quality criteria, model calibration and performance should strive to reduce errors (deviations between model predictions and observed measurement data) to zero.

A set of parameters used in the 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 second model performance period helps establish greater confidence in the calibration and the 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 limits of error independently of the calibration data. In general, model performance is performed using a data set that differs from the calibration data set (i.e., low-flow data set for calibration versus higher-flow data set for verification). If only a single time series is available, the series can be split into two sub-series, one for calibration and another for performance. If the model parameters are changed during the performance, the exercise becomes a second calibration, and the first calibration needs to be repeated to account for any changes. Acceptable limits are those defined by the combined process of quantitative and qualitative examination of the model versus the data. There are not quantifiable limits because the Tt modelers and the TAG and LCBP TAC may decide for a particular station that the statistics (quantitative) are more or less important that the graphical plots (qualitative). The limits used will be documented in the interim model report.

Model performance will be accomplished by calibration. A model calibration is the process of adjusting model inputs within acceptable limits until the resulting predictions give good correlation with observed data. Commonly, the calibration begins with the best estimates for model input on the basis of measurements and subsequent data analyses. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters. The success of a model calibration is largely dependent on the validity of the underlying model formulation.

Tt will update in the interim and final model report the description of justifiable and quantifiable "acceptable" and "unacceptable" criteria and the evaluation for each critical model input data parameter, findings of model algorithm/model calibration/model verification (with measured data) outcomes, uncertainties and variabilities of model outputs (e.g., mean, median), and sensitivity analyses.

C4.3 Reconciliation with User Requirements

All data quality indicators will be calculated at the completion of the data analysis phase. Measurement quality requirements will be met and compared with the DQOs to confirm that the correct type, quality, and quantity of data are being used for revising the Lake Champlain TMDL. The interpretation and presentation stage includes inspection of the form of the results, and the meaning and reasonableness of the computation results and post-simulation analysis.

The Tt Modeling QC Officer (Jonathan Butcher) will perform internal reviews to assess departures from assumptions established in the planning phase of the modeling process. In addition, the TAG and LCBP TAC will evaluate departures from assumptions established in the planning phase of the modeling process. Tt, in consultation with the EPA TOM, will determine how anomalies will be resolved.

If requested by the EPA TOM and funding is provided, Tt will perform a post-audit for the project. A post-audit is an evaluation of the correctness of the initial model predictions conducted several years after the original modeling study is completed. If the models' predictions were accurate, the model can be considered valid for the specific site and the actual stresses. A post-audit requires new field observations for the predicted variables, which are to be collected at a time after the system has had a chance to adjust to the management changes. Uncertainties and limitations in the use of such data and interpretation of results will be provided to EPA.

C4.4 Reports to Management

The Tt Co-TOLs will provide the EPA TOM with a draft model review and recommendation reports, an interim model report, a revised draft model report, and a final model report. In addition, Tt will deliver the project files for revising the Lake Champlain TMDL that will contain copies of all records and documents, including soft copy versions of the data and model input data sets. Tt will deliver the files to EPA at the end of the project.

Tt will document in the interim and final model report the description of justifiable and quantifiable "acceptable" and "unacceptable" criteria and the evaluation for each critical model input data parameter, findings of model algorithm/model calibration/model verification (with measured data) outcomes, uncertainties and variabilities of model outputs (e.g., mean, median), and sensitivity analyses.

D5.0 Modeling Reports

The draft, interim, and final Lake Champlain TMDL reports will include a separate section titled *Data Quality* to relate the results of the study back to this QAPP and the modeling work plans. The report will include results of technical reviews, model tests, data quality assessments of output data and audits, actual input and databases used, response actions to correct model development of implementation problems, and if applicable, pre- and post-software development. The final Lake Champlain TMDL report will also cover the elements listed under Section D5.0 of *EPA's New England Quality Assurance Project Plan (QAPP) Checklist for Model Applications* (Appendix C).

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APPENDIX A

WATERSHED MODELING APPROACH RECOMMENDATION

Lake Champlain Phosphorus TMDL

Watershed Modeling Approach Recommendation

Prepared for:

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Contents

Introduction

This report was prepared for the U.S. Environmental Protection Agency (EPA) Region 1, in support of activities pursuant to the revision of the Lake Champlain Phosphorus total maximum daily load (TMDL). Multiple objectives are being addressed under the scope of the overall project, including revising and recalibrating the lake model used to develop the original TMDL and linking it to a watershed model to characterize loading conditions and sources in the watershed and estimate potential for loading reductions in the Vermont and New York portions of the basin.

This report is intended to inform the selection of an appropriate watershed modeling application. Project-specific criteria for model selection are identified, several potentially applicable modeling applications are discussed in context of the criteria, and a modeling approach that best addresses the multiple management objectives is recommended.

Background

Lake Champlain is one of the largest lakes in North America and is shared by Vermont and New York and the province of Quebec. The lake is 120 miles long, with a surface area of 435 square miles and a maximum depth of 400 feet. The 8,234-square-mile watershed drains nearly half the land area of Vermont and portions of northeastern New York and southern Quebec (Figure 1).

The original TMDL was developed jointly by Vermont and New York in 2002. EPA is revising the Vermont portion of the TMDL in response to a 2008 lawsuit by the Conservation Law Foundation. While only the Vermont portion of the TMDL is being revised, the lake and watershed modeling work will encompass the whole watershed because watershed processes do not follow jurisdictional boundaries. One of EPA's goals for the revised TMDL is to ensure that there is adequate Reasonable Assurance that identified nonpoint source reductions are feasible. To support this and other technical needs, EPA intends to develop and apply a watershed model to support the source loading estimation and reduction analysis for the TMDL. The model will be used for providing more detailed loading estimates/allocations for individual source categories (relative to the original TMDL), evaluating results of different load reduction/best management practice (BMP) implementation strategies, evaluating effects on loading from potential changes in climate, and helping to understand the impacts of watershed loading scenarios on lake water quality and in-lake modeling results.

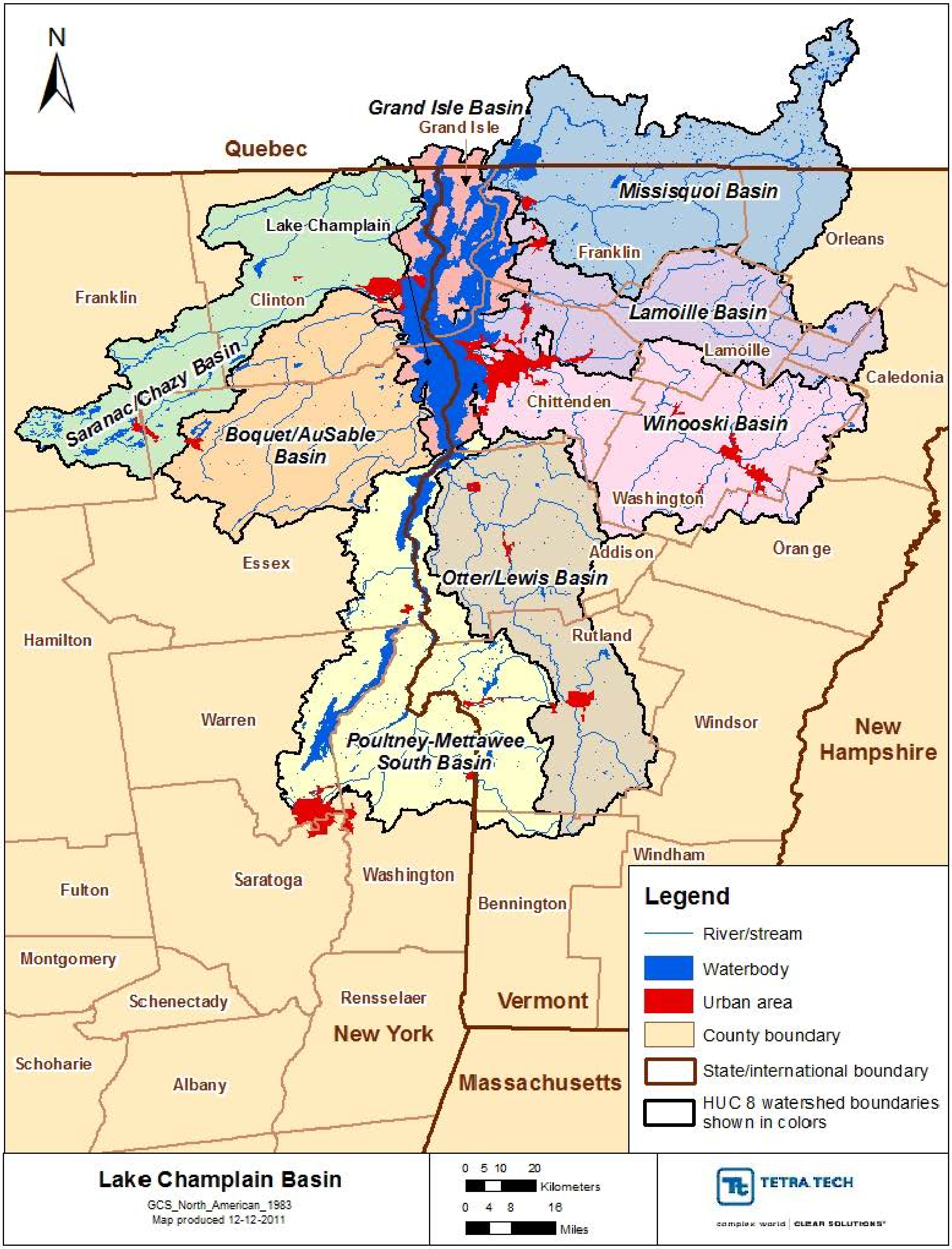

Figure 1. Lake Champlain Basin.

Types of Models

Models used to simulate the water quality effects of watershed processes range in complexity and can be classified into three basic types: data-driven, mid-range, and complex models. Data-driven models can be very general, for example using a simple empirical relationship to estimate the amount of runoff produced by a certain level of precipitation. Data-driven models are represented by techniques that are based on monitoring data or literature values and apply simple equations to describe pollutant behavior. Examples include export coefficients and load duration curves. The mid-range and complex models differ from data-driven approaches in that they apply a set or sets of equations to analyze key components of a watershed system. Models can use different techniques to analyze the same component. More complex models generally provide for an increased number of processes and parameters that can be represented.

The key processes that are represented by watershed models include the following:

- Rainfall/runoff: calculates the amount and timing of runoff from a land area.
- Erosion and sediment transport: simulates soil detachment, erosion, and sediment movement from a land area.
- Pollutant loading: simulates wash-off of pollutants from a land area.
- Stream transport: represents the stream portion of watershed models, which is needed, at a minimum, to collect the runoff/sediment/pollutants from the various land areas (the watershed) and to route it through to the mouth of the basin.
- Management practices: represents management measures and expected impacts to water quality, including land-based (e.g., tillage or fertilizer application), structural (e.g., stormwater ponds), or input/output to a stream (e.g., wastewater treatment). Land-based management can be generalized (e.g., number of acres treated) or specific (e.g., field-specific practices).

The mid-range category of models includes models such as the Generalized Watershed Loading Functions model (GWLF) or the Program for Predicting Polluting Particles Passage through Pits, Puddles, and Ponds, Urban Catchment Model (P8). The complex category includes models such as the Hydrologic Simulation Program Fortran (HSPF), the Loading Simulation Program C++ (LSPC), the Soil and Water Assessment Tool (SWAT), and the Stormwater Management Model (SWMM), which simulate many dynamic processes and their inter-relationships. By separately addressing each physical process, those latter category models can be adapted to local conditions, and the simulation can be made more sensitive to land use activities and management changes.

It is important to note that models that represent certain processes in a more simplified manner than other models are not necessarily less appropriate for use in a given situation. For example, a one-dimensional receiving water model might be appropriate for situations where a waterbody is reasonably well mixed in the lateral direction as opposed to a two- or three-dimensional model. In such a case, the one-dimensional model will have the advantage of easier setup and, most likely, lower cost. As a result, selecting an appropriate model application must always be evaluated against the unique characteristics of the system to which it will be applied, and, given the particular issues that might or might not be critical to simulate, certain representational trade-offs could be deemed acceptable.

Criteria for Model Selection

To select an appropriate model for the Lake Champlain Basin, EPA conducted a review process in which the applicability of several candidate approaches was evaluated against specific project needs, listed as follows:

- The model should enable prediction of contributions from different sources in each major tributary watershed, including phosphorus loads from forested and agricultural land sources, developed land sources, and loads from within the stream channel system.
- The model should be able to provide output using the concept of a hydrologic response unit (HRU) to facilitate management and implementation. An HRU is defined as an area of land having unique soil, slope, and land use characteristics.

- The model should enable prediction of potential phosphorus reductions from sources associated with potential future BMP implementation in each tributary watershed
- The model should facilitate assigning wasteload allocations (WLAs) to Vermont-permitted sources (e.g., municipal separate storm sewer systems [MS4s] and wastewater treatment plants [WWTPs].
- The calibrated model will be used to perform loading evaluations related to source reduction scenarios and whether the Lake TMDL conditions are being met.
- The calibrated model should facilitate identification of critical loading areas for targeting priority implementation activities and providing Reasonable Assurance for the TMDL.
- The model should facilitate assessing the impacts of temporally variable drivers such as precipitation and should allow for evaluation of climate change and landuse change scenarios.

Related to the specific project needs listed above, other technical, regulatory, and management criteria are also relevant to the model selection process. Technical criteria refer to the selected model's ability to simulate the physical system in question, including physical characteristics or processes and constituents of interest. A variety of technical issues and how they will be addressed must be considered during model selection. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. Management criteria comprise the operational or economic constraints imposed by the end user and include factors such as financial and technical resources and intended model application. Several specific concepts related to modeling the Lake Champlain Basin for this project are noted below. EPA believes the selection of the modeling approach should be based in part on how well all purposes are met.

Snow Hydrology—Elevation and associated precipitation phenomena (e.g., rain/snowfall, snowpack accumulation and snowmelt) can have a significant influence on the hydrology in the Lake Champlain Basin. The snowfall/snowmelt process acts like a reservoir of stored precipitation during the winter, which is ultimately released during the spring. Therefore, those processes will be important considerations.

Stream Bank Erosion—A significant source of sediment in the basin, it is anticipated that stream bank erosion will be the focus of significant reduction measures. An application that can be used to quantify stream bank erosion and support analysis of reduction scenarios related to implementing stream channel BMPs is desirable.

Climate Change Impacts—A major objective of the watershed model will be the analysis of the impacts of climate change to phosphorus loading in the watershed. An important, but sometimes ignored, aspect of climate change is an increase in ground level CO_2 concentrations. The Intergovernmental Panel on Climate Change predicts an increase in future CO_2 concentrations under all emissions scenarios. Plants require CO_2 from the atmosphere for photosynthesis. An important effect of CO_2 fertilization is increased stomatal closure because plants do not need to transpire as much water to obtain the CO_2 they need for growth. That effect can counterbalance predicted increases in temperature and potential evapotranspiration and thus has a profound effect on hydrology. It could also reduce water stress on plants, resulting in greater biomass and litter production, which in turn will influence pollutant loads.

The selected model will need to facilitate running scenarios designed to evaluate the potential effects on flow and loading of phosphorus if climate/precipitation patterns are altered. That could also involve running scenarios to evaluate BMP performance under alternative climate scenarios.

HRU-Based Analysis—To allow for maximum flexibility in developing implementation plans for the revised TMDL, it is highly desirable to apply an application that will enable the evaluation of outputs for units that are similar in hydrologic response. Such units are highly amenable for use in post-TMDL tracking systems since HRU modeling results can be expressed in simple terms such annual runoff yields and pollutant export rates.

Nutrient Representation—Data and analysis suggest that it will be important to consider the distribution between particulate and dissolved forms of phosphorus. As a result, the selected model must be able to simulate appropriate nutrient and sediment parameters, including total and constituent phosphorus, nitrogen, and sediment.

Review of Candidate Watershed Models

EPA reviewed a variety of publicly available and accepted technical approaches for estimating phosphorus loading to develop the model recommendation in this report. Models selected for this review include applications that range in complexity, are applicable in mixed use watersheds, have a previous track record of use in New England or have been used to support TMDL development. For context, techniques from each category of model (data-driven, mid-range, and complex) were evaluated against the project modeling needs and criteria. The mid-range approaches include GWLF model and P8. The complex models include the HSPF, LSPC, and SWAT. Tables 1 and 2 provide an assessment of the capabilities of the technical approaches/models to address various criteria.

Table 1 was adapted from a recent EPA review of available models and summarizes basic capabilities of each of the reviewed watershed models (USEPA 2005). It illustrates differences between approaches but does not highlight differences in the way the models simulate similar pollutants. Table 2 provides a qualitative assessment of the models' abilities to address project-specific requirements.

Table 1. Comparison of reviewed watershed models

Model	Type	Level of complexity			Time step				Hydrology		Water quality		
	Stream routing included	Export coefficient	Loading curves	Physically based	Sub-daily	Daily	Monthly	Annual	Surface	Surface and ground	User-defined	Sediment	Nutrients
Data-driven			●					●				●	●
GWLF		●					●	●		●		●	●
P8	●			●	●	●	●	●		●		●	
HSPF/LSPC	●			●	●	●	●	●		●	●	●	●
SWAT	●			●		●	●	●		●		●	●

Source: Adapted from USEPA 2005

Table 2. Comparison of capability of candidate models to satisfy project objectives

Capability key: ● **High** ◒ **Medium** • **Low**					
	Technical approach options				
Criteria	**Data**	**GWLF**	**P8**	**HSPF/LSPC**	**SWAT**
Technical					
Spatial Scale and Representation					
• Ability to customize segmentation	--	●	●	●	●
• Predict loads for multiple scales	--	◒	◒	●	●
• Ability to predict HRU-based loading	--	--	--	●	●
Temporal Scale and Representation					
• Long-term trends and averages	●	●	●	●	●
• Continuous –predict shorter time period variability	--	◒	●	●	●
• Sub-daily concentrations	--	--	●	●	•
Sources					
• Land uses (urban and non-urban)	◒	●	●	●	●
• WWTPs	◒	◒	--	●	●
Land and Water Features					
• Agricultural, urban, forest land covers	--	◒	◒	●	●
• Stream network/routing	--	--	◒	●	●
• Impoundments	--	--	•	●	●
Pollutants					
• Total nutrient concentrations	◒	●	●	●	●
• Dissolved/particulate partitioning	◒	●	--	●	●
• Particle fate	--	--	◒	●	●
• Sediment loading	◒	●	●	●	●
• In-stream sediment transport	--	--	◒	●	●
Physical Processes/Critical Basin Factors					
• Snow hydrology	--	--	•	●	◒
• Streambank erosion	--	--	--	◒	•
Regulatory					
• Assign VT WLAs	◒	◒	•	●	●
• Technically defensible (previous use/validation, thoroughly tested, results in peer-reviewed literature, previous TMDL studies)	◒	●	●	●	●
Management Scenarios					
• Linkage to Lake TMDL model	●	◒	◒	●	●
• Urban BMP representation	--	--	◒	◒	•
• Agricultural BMP representation	--	•[a]	--	◒	●
• Ability to represent climate change	--	--	--	●	●
• Ability to address CO2 fertilization	--	--	--	•	●

Notes:

a. GWLF-E version

● = High: detailed simulation of processes associated with land feature

◒ = Medium: moderate level of analysis; some limitations

• = Low: simplified representation of features, significant limitations

-- = Not supported

Conclusion

Of the technical approaches reviewed, the complex models clearly provide the best ability to accomplish a majority of the analysis goals. A major advantage of utilizing a dynamic model for the basin is the ability to represent multiple critical processes and effectively analyze loads and potential reductions from a variety of sources across the watershed. While EPA is recommending one of the complex models be used (see below for discussion of each), EPA recognizes that not all sources and phosphorus reduction practices can be appropriately simulated with a watershed process model. To accommodate this concern, it is recommended that the selected model be supplemented with a spreadsheet tool to account for a broader spectrum of phosphorus sources and loads, and to evaluate implementation scenarios involving reductions for practices simulated with the watershed model as well as those calculated through other means external to the model.

The differences between the complex models have largely to do with how well they address important management and application needs. Below are brief descriptions of each of the three complex models reviewed and discussion of critical advantages and disadvantages in applying them for the Lake Champlain Basin analysis.

HSPF/LSPC

HSPF is the culmination of consolidating three earlier watershed models (Stanford Watershed Model, Agricultural Runoff Model, and Nonpoint Source Loading Model), into an integrated, basin-scale model combining watershed processes with in-stream fate and transport in one-dimensional streams. It simulates watershed hydrology, land and soil contaminant runoff, and sediment-chemical interactions. For in-stream fate and transport, overland sediment is divided into three particle sizes (sand, silt, clay). The most recent release of HSPF is version 12.2. HSPF is part of EPA's Better Assessment Science Integrating point and Nonpoint Systems (BASINS). BASINS provides WinHSPF, a Windows-based interface system for HSPF through which the HSPF model can be parameterized, edited, and executed.

The model conceptualizes a subwatershed as a group of land uses that are all routed to a stream segment. The model accounts for pervious and impervious surfaces in each land use. Small subwatersheds and stream segments can be networked to represent a larger watershed drainage area. HSPF predicts loadings from different land use scenarios for nutrients, sediment, bacteria and toxics. Various modules can be activated to simulate specific processes but are not required for every application.

LSPC is a watershed model that includes selected HSPF algorithms for simulating hydrology, sediment, and general water quality on pervious and impervious land. It also includes a one-dimensional stream transport model and is available as part of EPA's Modeling Toolbox.[1] It was designed to handle very large-scale, yet complex watershed modeling applications (8-digit HUCS) and is derived from the Mining Data Analysis System (MDAS), which was developed for EPA Region 3 to address mining areas and TMDLs.

The LSPC model is organized in a slightly different way than its predecessor HSPF model. Both models are modular in nature and are based on the same underlying algorithms. For land segments, HSPF is divided into PERLND (pervious land) and IMPLND (impervious land segments), which represent the smallest modeling units, while LSPC has only one LAND module in which flagged impervious land segments have subsurface activity disabled. Both models have a simple stream segment model for flow and pollutant transport. There are also various simulation options for physical processes. The most

[1] The TMDL Modeling Toolbox is a collection of models, modeling tools, and databases that have been used over the past decade in developing TMDLs. For more information, see http://www.epa.gov/athens/wwqtsc/Toolbox-overview.pdf.

significant difference between the two is that HSPF simulates each land segment for all time *before* routing the resulting flow and pollutants to the stream network; whereas LSPC simulates each routing network element (by subwatershed, with land and stream components) for each time step. In general, the same advantages and disadvantages apply to both so they are listed together below.

Advantages

- Able to represent the various sources and all necessary constituents.
- Able to simulate peak and low flows and a variety of time steps.
- Can provide spatially explicit representation of point sources (WWTPs) in the watershed.
- Can be set up to simulate BMPs (urban or agricultural or both).
- Can include Special Actions programming that allow a lot more flexibility in simulating BMPs.

Disadvantages

- Simulation processes for each land use type are lumped at the subwatershed level, which means that the model does not account for spatial variation between similar land use types within a subwatershed. Greater detail can be achieved by finer subwatershed delineation, but that can increase model complexity and run times.
- Representation of cropping or tillage management practices requires additional customization and can be difficult in HSPF.
- Requires substantial hydrologic and water quality calibration and generally requires a high level of expertise for application.
- For BMP simulation, Special Actions programming is time-consuming and difficult to use.
- Does not address CO_2 fertilization and is not easily built into the model because it does not simulate plant growth.

SWAT

SWAT is a watershed-scale model originally developed for the U.S. Department of Agriculture Agricultural Research Service. It is available with EPA's BASINS (the BASINS version is SWAT2000). SWAT was developed to predict impacts of land management practices on water, sediment, and agricultural chemical yields in complex watersheds with varying soils, land uses, and management practices over long periods. It is a product of combining ideas from several other models including Simulator for Water Resources in Rural Basins (SWRRB); Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS); Groundwater Loading Effects on Agricultural Management Systems (GLEAMS); and Erosion-Productivity Impact Calculator (EPIC). Originally, the model was used to predict sediment, pesticide and nutrient loadings from agricultural areas. Over the years, additional constituents have been added to the model's simulation capabilities including urban land pollutant loading using buildup/washoff or USGS regression routines.

SWAT divides a large watershed into subwatersheds, which are further subdivided into HRUs (unique combinations of soil, land cover type, and management practices in a subwatershed). SWAT simulates hydrology, vegetation growth, and management practices at the HRU level. Thus, as the number of HRUs in a watershed increases, computational demand, run times, and number of output files can increase. Water, nutrients, sediment, and other pollutants such as metals from each HRU are summarized in each subwatershed and then routed through the stream network to the watershed outlet.

Advantages

- Ability to simulate the effects of CO_2 fertilization on plant growth and evapotranspiration.
- Ability to use U.S. soils data directly.
- Ability to directly represent agricultural tillage, fertilization, and cropping practices.
- Ability to simulate the pollutants and sources of concern.

- Underlying databases for crop growth and land management are detailed.
- Has already been applied on a smaller and more detailed scale in various subwatersheds in the basin; as a result, it is very likely that parameters established for nearby efforts can be applied to the basin modeling effort.
- Widely applied and validated for monthly and seasonal nutrient load estimates.

Disadvantages

- Not reliable for simulating sub-daily pollutant concentrations (e.g., single storm events or diurnal changes in dissolved oxygen).
- Does not provide a solid basis for evaluating hydromodification impacts on channel stability; less adept (in comparison to HSPF/LSPC) at representing in-stream processes.
- Represents hydrology using a simplified Curve Number approach (unless the Green-Ampt option is selected).
- Routines for simulating bacteria and in-stream dissolved oxygen concentrations are not reliable.
- Representation of urban sources is limited by use of composite Curve Number approach

Recommended Approach

On the basis of a preliminary review of data available for modeling the Lake Champlain Basin, the relative capabilities of the three complex models reviewed, and prior history of model application in the basin, it is recommended that the SWAT model be applied to develop loading estimates for the Lake Champlain Basin and be augmented with external techniques to address the basin-specific concerns of channel stability/instream loading sources and the potential reductions from certain other BMP categories less suitable for simulation with a watershed process model such as SWAT.

SWAT's major advantages over LSPC and HSPF are its detailed ability to represent loads and potential reductions associated with agricultural management practices and to incorporate the impacts of CO_2 fertilization during climate change simulation. Sufficient data are available to satisfy key SWAT modeling needs for the entire basin, including representative reach and water quality data for calibration, as well as soils (SSURGO), and topographic (10 m DEM for VT and NY and 20 m DEM for the Quebec portion). The National Agricultural Statistics Service Cropland Data Layer is also available for the entire basin. Several additional datasets, including impervious cover (2011), farmsteads, and areas suitable for certain agricultural BMPs, are available for the Vermont portion of the basin only – an acceptable limitation because these additional layers will primarily assist with the identification of potential reduction options, something that is especially important for the Vermont portion of the TMDL. The use of SWAT also has the advantage of being able to incorporate much of the detailed SWAT modeling work already conducted in the basin, including in the Missisquoi watershed (Lake Champlain Basin Program, 2011), the Rock River (Ghebremichael et al., 2010), the Pike River (Michaud_et al.,2007) and the LaPlatte River (EPA, in progress).

SWAT does present certain disadvantages relative to the other options because it is not reliable for predicting sub-daily concentrations and it does not provide a solid basis for direct evaluation of hydromodification impacts on channel stability and in-stream phosphorus loads. However, those considerations do not pose a problem in this case because: 1) sub-daily concentrations are not critical to phosphorus mass loading to the lake, 2) EPA is proposing a separate, alternative approach to estimating in-stream loads (see below), and 3) if sub-daily fow data is needed for any reason, SWAT can be configured with the Green-Ampt option.

Approach Overview

The analysis will be broken into two main steps: 1) estimating P loading from major sources and 2) estimating reduction potential from existing sources from likely treatment techniques and BMPs.

Load Estimation

SWAT will be utilized to estimate annual P export rates for the study period (e.g., 5yr or 10 yr, TBD) using HRUs representative of a range of land characteristics. Critical landuse source categories include pasture, cropland, forest, wetland,urban/developed land, and transportation (paved and unpaved roads). The urban and transportation categories will be further broken out into both pervious and impervious subsets. The HRUs should be specified in such a way that they distinguish between different types of land uses (especially agricultural land uses) for which different candidate management actions are likely to be considered. Urban land uses should likely distinguish between those that are subject and not subject to MS4 permit requirements because it will ease subsequent analysis of WLAs. The model will be set up with multiple meteorological stations that are suitable for model calibration and evaluation of potential climate change impacts. SWAT will also be used to simulate the transport of WWTF loads, which will be specified to the model based on discharge monitoring data.

For urban/developed land, SWAT will be customized using appropriate loading rates, to generate loads appropriate for Vermont's urban areas. Tetra Tech recommends making use of several additional tools to enhance SWAT's output for these areas. Vermont's existing Best Management Practices Decision Support System (BMPDSS) applications for the stormwater-impaired watersheds, EPA's BMP performance curves (EPA 2010), and detailed impervious cover and existing BMP assessments for Vermont's urban areas, may all be used, where available. These tools and information can be used to adjust pollutant loads predicted for urban areas through appropriate modification of the land cover data layer and the buildup-washoff coefficients used in SWAT.

Annual phosphorus loading from stream channel processes will be estimated outside of SWAT, using: 1) an analysis based on the results of the recent Bank Stability and Toe Estimation Model (BSTEM) application in the Missisquoi watershed, and 2) a stream power analysis. The BSTEM-based approach will only be applied to the Vermont portion of the basin (where sufficient data exist); the stream power analysis will be used throughout the basin.

The BSTEM-based analysis will make use of the relationships between loading rates and certain geomorphic characteristics found in the Missisquoi watershed following an intensive data collection and modeling effort using BSTEM. While additional applications of BSTEM are beyond the feasibility of the TMDL project, the results of the BSTEM work in the Missisquoi provide an opportunity for a simpler, but potentially very effective analysis. The first step will determine the correlation between phosphorus and sediment loading rates per linear kilometer and key geomorphic assessment features such as erodability of the channel boundary materials, confinement and slope of valley, departure from reference condition, and sediment and flow regime. These geomorphic parameters are available for many river and stream reaches throughout Vermont, and therefore the correlations established in the Missisquoi watershed may be used to estimate loading rates in the remainder of the watersheds in the Vermont portion of the basin. The Missisquoi watershed includes examples of virtually all commonly occurring stream reach types in the Vermont portion of the basin, so the relationships found in the Missisquoi are expected to be widely applicable to the other Vermont watersheds. However, the necessary geomorphic data are not as consistently available for streams in New York, so the power analysis described below will be used for the New York portion of the basin. Because the stream power analysis will be applied to the whole basin, it will also provide an additional analysis method for the Vermont portion.

The stream power analysis (Bledsoe et al. 2007) will use SWAT daily flow estimates and will be based on the dominant discharge (Q), including Bagnold's specific stream power, ω, and Chang's mobility index, m, where $\omega = \gamma QS/w$ and $m = S [Q/d50]0.5$, γ is the specific weight of water, S is the slope, w is the width, and d50 is the median bed material size of the surface layer.

Following model calibration and stream channel source analysis, a master table will be used to store existing source loading estimations by major tributary system and 12 digit HUC.

Reduction Estimation

TMDL scenarios will require estimates of feasible load reductions obtained from a variety of practices. SWAT will be used to determine reduction efficiencies for certain source category and treatment technique combinations while external reduction calculations will be made for other source/BMP combinations. For example, SWAT will be used directly to estimate load reductions associated with changes in tillage, fertilization, and animal management practices, while potential reductions associated with certain urban practices, stream restoration practices, and other some other BMP programs will be calculated separately using methods referenced above. For urban areas, reduction estimates will be calculated outside of WSAT using EPA's BMP performance curves (customized for Vermont), and other BMP efficiency information available for Vermont stormwater practices. Potential reductions from all sources will be brought together in the spreadsheet tool discussed below.

Table 3 and

Table 4 are *working conceptual* tables that summarize some of the major load estimation and reduction analysis components of the technical approach.

Table 3. Load Estimation Techniques for Major Source Categories

Load Estimation		
SWAT		
Source	***Inputs***	***Outputs***
Forest	*landuse land practices, soils, topography, weather, point sources datareach network, etc.*	*stream flows and pollutant loads by source by tributary*
Agriculture		
Wetlands		
Transportation (Paved and unpaved Roads)		
WWTF		
Urban (using SWAT customized with supplemental BMP effic. data)		
Channel Model*		
Source	***Inputs***	***Outputs***
Streambank Sediment	*Geomorphic data; daily/subdaily flows***	*pollutant loads*

*Based on Missisquoi BSTEM results or stream power analysis

** Obtained from separate SWAT run with Green-Ampt infiltration

Table 4. Reduction Analysis Techniques for Example Source/BMP Combinations

Reduction Analysis		
Source	***SWAT Estimation***	***External Calculation***
Forest	Forest bmp 1 Forest bmp 2 …..	
Agriculture	-Vegetated buffer -Cover crops -No-till -Reduced P manure -Ag bmp 5 -Ag bmp 6 …	
Wetlands	…	
Transportation (Dirt Roads)	…	-Drainage ditch armoring
WWTF		-Permit Limits
Urban	-P fertilizer ban	-Infiltration -Disconnection -Wet ponds …..
Stream channel Sediment	...	-Bank slope 2:1, 5 yr vegetation -Floodplain access

Scenario Evaluation, Allocations, and Demonstration of Reasonable Assurance

For transparency and to facilitate review by multiple stakeholders, load estimation and reduction analysis results (predicted loading rates and delivery factors) can be exported to a Scenario Evaluation spreadsheet tool. The spreadsheet would serve as an accounting inventory of specific phosphorus source areas in the Champlain Basin. It would be applied during the Reasonable Assurance process to facilitate evaluating the change in predicted load reductions based on application of different BMPs to appropriate source categories in different locations. EPA envisions this tool to display load estimates and predicted reductions by major tributary basin, allowing for further filtering to the HUC 12 level or below.

Linkage to BATHTUB Lake Model

The BATHTUB model will be calibrated using the existing setup, which uses monitoring data to provide inputs. Once the SWAT watershed model is calibrated, it will be used to provide inputs to the lake model on the basis of results of various scenario runs.

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APPENDIX B

DATA QUALITY INDICATOR DEFINITIONS

DATA QUALITY INDICATOR DEFINITIONS

Measurement acceptance or performance criteria are quantitative statistics used to interpret the degree of acceptability or utility of the data to the user. The quality of existing environmental monitoring data and generated data is some measure of the types and amount of error associated with the data. Those criteria, also known as *data quality indicators*, are the following:

- Precision
- Accuracy
- Representativeness
- Comparability
- Completeness

Data used in model development are generally data in federal and state government water quality databases. Data obtained from government agency databases should have already been screened and met specified measurement performance criteria. Those criteria might not be reported for the parameters of interest in the databases. In consultation with the EPA TOM, it will be determined how much effort should be expended to find reports or metadata that might contain that information. Measurement performance or acceptance criteria for various parameters will be documented in the modeling report. Parameters for which measurement performance or acceptance criteria could be set are the following:

- Software run time
- Software processing capabilities
- Model prediction results relative to decision error
- Data used in model(s)

Precision is a measure of internal method consistency. It is demonstrated by the degree of mutual agreement between individual measurements or enumerated values of the same property of a sample, usually under demonstrated similar conditions. Precision of field sampling methods is estimated by taking duplicate samples for analysis. This QC calculation also addresses uncertainty due to natural variation and sampling error.

Precision of available data used for this project will be noted if available. Precision of generated data produced by the model will be examined by performing replicate runs.

Accuracy is defined as the degree of agreement between an observed value and an accepted reference or true value. Accuracy is a combination of random error (precision) and systematic error (bias), which are due to sampling and analytical operations. Bias is the systematic distortion of a measurement process that causes errors in one direction so that the expected sample measurement is always greater or lesser to the same degree than the sample's true value. Because accuracy is the measurement of a parameter and comparison with a *truth,* and the true values of environmental physicochemical characteristics cannot be known, use of a surrogate is required.

Accuracy of non-direct data obtained from government agency databases and entered into the project database can be expressed as the percentage of values, by field, not included as valid values in their associated system reference tables. For example, a code entered incorrectly or in the wrong field would constitute inaccurate data. The accuracy of non-direct data will be controlled by double-checking all automatically mapped data. Accuracy of the model will be determined by comparing the contaminant concentrations calculated for a given area with actually measured contaminant concentrations reported in the database under conditions used in the model simulation. Accuracy of data entry into the project database will be controlled by double-checking all manual data entries.

Data representativeness is defined as the degree to which data accurately and precisely represent a characteristic of a population, a parameter, variations at a sampling point, a process condition, or an environmental condition. It therefore addresses the natural variability or the spatial and temporal heterogeneity of a population. Comparisons of the loadings data and measured environmental concentrations will be made to examine sources and sinks of materials. Preliminary knowledge of the area will be used to select appropriate sites and stations in the vicinity of point source discharges for the initial and later modeling phases.

Two data sets are considered to be comparable when there is confidence that the two sets can be considered equivalent with respect to the measurement of a specific variable or group of variables. Measurement data used in the model will follow protocols established by the appropriate government agency to permit comparisons of water quality data at different sites on the study site. Data sets will be examined with respect to variables of interest, commonality of units of measurement, and similarity in analytical and QA procedures. Additional comparability of data can be ensured by similarity in geographic, seasonal, and sampling method characteristics.

Completeness is defined as the percentage of measurements made that are judged to be valid according to specific criteria and entered into the data management system. To achieve that objective, reasonable effort is made to avoid accidental or inadvertent sample or data loss. Lack of data entered into the databases will reduce the ability of the project to calibrate and verify the model. Although some fields in the project database should never contain blanks (e.g., facility name), other fields could be impossible to fill or might not be filled until later (e.g., completion date of an activity). Completeness is thus also defined as the percentage of data available to cover all aspects of model development. In any complex model study, it is inevitable that some data gaps will exist. The data gaps and the assumptions used in filling the gaps will be documented in the modeling report. Percent completeness (%*C*) for measurement parameters can be defined as follows:

$$\%C = \frac{v}{T} \times 100$$

where v = the number of measurements judged valid and T = the total number of measurements. Completeness goals for data sets will vary depending on the type of data, the age of the data, and how the missing data are dispersed throughout the entire data set.

Acceptance criteria will be obtained from any existing QAPPs, sampling and analysis plans, standard operating procedures, laboratory reports, and other correspondence for a given source of non-direct measurement data, if available. The data assessment and quality guidelines associated with a given type of measurement will be developed from those sources and documented. The secondary data will be reviewed and compared with the guidelines in this QAPP. Data not meeting the acceptance criteria requirements will be rejected or their status documented, as deemed appropriate by the EPA TOM and Tt Co-TOLs.

Model Sensitivity Analysis

The sensitivity to variations or uncertainty in input parameters is an important characteristic of a model. Sensitivity analysis is used to identify the most influential parameters in determining the accuracy and precision of model predictions. That information is of importance to the user who must establish required accuracy and precision in model application as a function of data quantity and quality. Sensitivity analysis quantitatively or semi-quantitatively defines the dependence of the model's performance assessment measure on a specific parameter or set of parameters. Sensitivity analysis can also be used to decide how to simplify the model simulation and to improve 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 then considered to be sensitive to that input parameter. Sensitivity analysis methods are mostly 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.

Informal sensitivity analyses (iterative parameter adjustments) will be performed during model calibrations to ensure that reasonable values for model parameters will be obtained, resulting in acceptable model results. The degree of allowable adjustment of any parameter is usually directly proportional to the uncertainty of its value and is limited to its expected range of values. Formal sensitivity analyses will be performed in accordance with technical direction from the EPA TOM when a certain aspect of the system requires further investigation.

APPENDIX C

EPA'S NEW ENGLAND QUALITY ASSURANCE PLAN (QAPP) CHECKLIST FOR MODEL APPLICATIONS

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
A		**PROJECT MANAGEMENT**						
A1		**Title and Approval Sheet (s)**						
A1.1		Contains Quality Assurance Project Plan (QAPP) title					i	
		Indicates revision number, if applicable					i	
		Indicates organization's name					i	
		Dated signature of organization's project manager present					i	
		Signature block for Organization’s Project Manager					i	
		Signature block for Organization’s QA Officer					i	
		Other signatures					i	
A1.2		**Table of Contents**						
		Lists QAPP information sections.					ii	
		Document control information indicated.					see note	Document control information is included in the headers on each page of the QAPP.
		Provides lists of tables and figures.					iii	
		Provides contents of each Appendix.					iii	
		Lists all attached SOPs (with names, not just numbers).					NA	
A1.3		**Distribution List**						
		Includes all individuals who are to receive a copy of the QAPP and identifies their organization.					vi	
A1.4		**Project/Task Organization**						
		Identifies key individuals involved in all major aspects of the QAPP, including contractors. Discusses their responsibilities.					1-3 (A1.4)	
		Identifies that the QA Manager has independence from unit(s) generating data and model outputs.					2 (A1.4)	
		Identifies individual responsible for maintaining the official, approved QAPP.					1 (A1.4)	Tetra Tech Co-TOLs maintain the official, approved QAPP.

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Organizational chart shows lines of authority and reporting. responsibilities					2 (A1.4)	
		Clearly identifies who is part of the Project Team and who is related to the Project in an advisory role (but is not responsible for delivery of any product).					1-3 (A1.4)	
A1.5		**Problem Definition/Background**						
		States decision(s) to be made, actions to be taken, or outcomes expected from the information to be obtained from modeling activities.					3-6 (A1.5)	
		Clearly explains the reason (site background or historical context) for initiating this QAPP.					3-5 (A1.5)	
		Identifies regulatory information, applicable criteria, action limits, etc. that model outcomes will reference.					5 (A1.5)	
		Identifies assumptions for the modeling process.					5,6 (A1.5), Appendix A	
		Provides for notification when new models will be created and justifies inability to use existing models.					NA	
		Provides for notification of modifications to model code.					NA	No modifications to model code are planned.
		Describes how suitability of models to resolve application niche will be evaluated, including:					A1.6, A1.7.3, A1.7.7, C3.0, Appendix A	
		Mapping model attributes to problem statements					6-11 (A1.6)	
		Degree of certainty needed in model outputs					27 (C3.0), Appendix A	Additional information will be provided in the interim and final model reports.

QAPP element numbers	**Element**	**Element Name and Review Aspect**	**A** Acceptable	**U** Unacceptable	**NI** Not Included	**NA** Not Applicable	**Page # (Section #)**	**Comments (and notes)**
		Amount of reliable data, available resources and technical expertise					13-14 (A1.7.3); 16-18 (A1.7.7); 20-21 (A1.8)	Data used will be documented in the interim and final model reports.

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
A1.6		**Project/Task Description**						
		Summarizes work to be performed, for example, measurements to be made, data files to be obtained, etc., that support the modeling.					6-11 (A1.6)	
		Provides schedules indicating critical project points, e.g., start and completion dates for such activities.					11 (A1.6)	Completion dates from EPA's Task Order are provided.
		Details geographical locations to be studied, including maps where possible.					4 (A1.5)	
		Discusses resource and time constraints, if applicable.					27 (C3.0); 30 (C4.3)	
A1.7		**Quality Objectives and Criteria for Measurement Data**						
		Describes how the objectives of projects and the associated data quality acceptance criteria/model performance criteria will be established for all information to be collected including information obtained from previous studies. Explains how performance criteria will relate to the quality of model outputs.					12-20 (A1.7)	
		Identifies acceptance criteria for all previously collected information.					23 (B2.0)	The description of justifiable and quantifiable "acceptable" and "unacceptable" data quality criteria will be documented in the interim and final model reports.
		Includes statement(s) of the general objectives and demonstrate knowledge of the overarching purpose for the QAPP. Phrase decisions in terms of "…if…then…" type of statements.					13 (A1.7.2)	
		Describes the data quality needed to support project decisions. Discusses the data quality indicators (DQIs) and the acceptance criteria/measurement performance criteria for each DQI, and identifies the quality control (QC) or other mechanism to be used to assess if the criteria were met.					30 (C.4.3), Appendix B	
		Identifies how acceptance/performance criteria will be established for existing data, model calibration, validation, sensitivity and uncertainty.					15-16 (A7.6), 30 (C.4.3), Appendix B	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
A1.8		**Special Training/Certifications**						
		Identifies any project personnel specialized training or certifications					20-21 (A1.8)	
		States that the QA Officer is responsible for overseeing training.					20-21 (A1.8)	Note that senior modelers who have extensive experience using the applicable model(s) will provide guidance to modelers
		Discusses how this training will be provided.					20-21 (A1.8)	Tetra Tech modelers have experience with these models; additional guidance will be provided by senior modelers, as needed
		Indicates personnel responsible for assuring these are satisfied.					NA	
		Identifies where this information will documented.					NA	
A1.9		**Documentation and Records**						
		Identifies report format and summaries of all data report package information including model parameterization, model inputs, and model outputs.					11 (A1.6), 21-23 (A1.9)	
		Lists all other project documents, record, and electronic files that will be produced, including:					22 (A1.9)	
		Results of technical reviews, model tests, data quality assessments of output data and audits.						
		Documentation of candidate model assessments used for model selection, including references.						
		Actual input used and databases used						
		Response actions taken during projects to correct model development of implementation problems.						
		Pre and post software development						
		Spreadsheet data files containing monitoring data						
		Copy of the modeling reports						
		Identifies where project information should be kept and for how					21-22 (A1.9)	
		Discusses back up plans for records stored electronically.					23 (A1.9)	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		States how individuals identified in A1.4 will receive the most current copy of the approved QA Project Plan, identifying the responsible individuals.					22 (A1.9)	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
B2.0		**Data Generation and Acquisition**						
B2.1		**Data Acquisition Requirements (Non-Direct Measurements)**						
		Identifies the range of data sources, for example, computer databases or literature files, or models that may be accessed and used.					23 (B2.0), Appendix B	The description of justifiable and quantifiable "acceptable" and "unacceptable" data quality criteria will be documented in the interim and final model reports.
		Describes the intended use of this information and the rationale for their selection, i.e., its relevance to the QAPP objectives.					23 (B2.0), Appendix B	
		Indicates how the acceptance criteria for data sources and/or models will be established. Criteria are related to model performance.					23 (B2.0), Appendix B	
		Identifies key resources/support facilities needed.					13-14 (A1.7.3), 23 (B2.0)	
		Identifies any types of data needed (for project implementation or decision making) that are obtained from non-direct measurement sources such as existing data from another project, photographs and maps, literature files, and historical databases.					13-14 (A1.7.3), 23 (B2.0)	
		Identifies procedures to ensure data are not outdated, consistency in excluding data and documentation of data exclusions.					16-18 (A1.7.7)	
B2.2		**Data Management**						
		Describes how data will be managed, tracing the path of data generation in the field or laboratory to final use or storage.					23 (B2.2)	The data management process and the computer hardware and software configuration requirements will be developed and submitted to the EPA TOM for review before model equations and related algorithms are coded into an integrated, efficient computer code.
		Describes or references the standard record-keeping procedures, and discusses the approach to be used for data storage and retrieval of electronic media.					21-23 (A1.9, B2.2)	
		Discusses the plan for detecting and correcting errors from conversion of data, as well as for preventing loss of data during reduction, reporting, and entry to forms, reports, and databases.					28, 29 (C4.2)	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Identifies and describes all data handling equipment and procedures to process, compile, analyze and interpret the model data, including any required computer hardware and software. Addresses any specific performance requirements and describes the procedures that will be followed to demonstrate acceptability of the hardware/software configuration required.					23 (B2.2)	
		Identifies who in the organization is responsible for each data management task.					23 (B2.2)	
C3.0		**Assessment/Oversight and Response Actions**						
		Describes the assessments to be performed during projects to ensure activities are being conducted as planned. States the frequency and purpose of assessments, along with the success/acceptance criteria for assessments. Lists the approximate schedule of activities, and identifies potential organizations and participants.					15 (A1.7.6), 23-27 (C3.0)	
		Defines the scope of authority of the assessors, including stop work orders. Discusses how response actions to non-conforming conditions shall be addressed and by whom. Defines the conditions under which the assessors are authorized to act.					23-27 (C3.0)	
		Indicates that a summary of any assessments will be included in the modeling report and in a modeling journal.					27 (C3.0)	
		Describes how and to whom the results of the assessments shall be reported.					23-27 (C3.0)	
		Provides examples of any forms or checklists to be used to document assessment and response/corrective action activities in an appendix/attachment.					23-27 (C3.0)	
C4.0		**Model Application**						
C4.1		**Model Parameterization (Calibration)**						
		Describes the range of calibration performance measures that will be applied.					27, 28 (C4.1)	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Identifies critical activities and methods for model calibration.					27, 28 (C4.1)	
		Describes how criteria will be established to stop calibration.					27, 28 (C4.1)	
		Describes activities for parameter estimation and criteria for defaulting to non site-specific data.					27, 28 (C4.1)	
		Describes how parameters for calibration will be selected and how parameters kept constant will be determined.					27, 28 (C4.1)	
		Identifies how statistically important parameters will be determined.					27, 28 (C4.1)	
		Describes how calibration uncertainty and soundness will be determined and how they will relate to calibration performance					26, 27 (C3.0)	
		Identifies activities and methods for sensitivity analyses.					27 (C3.0)	
		Identifies how records of calibration/validation will be maintained.					21-23 (A1.9)	
		Identifies how deficiencies should be resolved and documented.					23-27 (C3.0)	
C4.2		**Model Corroboration (Validation and Simulation)**						
		Describes the activities and (qualitative and quantitative (statistical) methods to be used for model corroboration (validation).					29,30 (C4.2)	
		Describes how model corroboration performance measures will be established.					29,30 (C4.2)	
		Describes how the validation uncertainty and soundness will be determined.					29,30 (C4.2)	
		Describes how the simulation uncertainty and soundness will be determined.					29,30 (C4.2)	
		Describes the use of independent data sets for model parameterization and corroboration.					29,30 (C4.2)	
		Discusses how issues shall be resolved and identifies the authorities for resolving such issues.					23-27 (C3.0)	

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Provides examples of any forms or checklists to be used in an appendix/attachment. All associated criteria identified in the documentation should be consistent with and/or supportive of the model quality objectives and model performance criteria.					30 (C4.2)	The description of justifiable and quantifiable "acceptable" and "unacceptable" data quality criteria will be documented in the interim and final model reports.
C4.3		**Reconciliation with User Requirements**						
		Describes how sample results (which have already been reviewed, verified, and validated/evaluated) will be reconciled with the project objectives and measurement performance criteria/acceptance criteria.					30 (C4.3)	
		Outlines the proposed methods to analyze modeling results and determine possible anomalies or limitations on the use for the intended purposes and how departures from assumptions established in the planning phase of the modeling process will be assessed.					30 (C4.3)	
		Describes how anomalies will be resolved, and discusses how limitations on the use of the data from anomalies and departures from assumptions will be reported to decision makers.					30 (C4.3)	
C4.4		**Reports to Management**						
		Identifies the frequency and distribution of reports issued to inform management of the status of the project, results of performance evaluations and systems assessments, results of data quality and modeling evaluations, and any significant quality assurance problems and recommended solutions.					30-31 (C4.4)	
		Identifies the preparer and the recipients of the reports, and any specific actions management is expected to take as a result of the reports.					30-31 (C4.4)	
D5.0		**Modeling Reports**						
		Describes the content of modeling reports as including the following:					31 (D5.0)	
		Introduction						
		Background						
		Purpose of Modeling/Modeling Objectives						

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Scope and Approach for Each Model Used (including):						
		Physical Setting						
		Hydrology, if applicable						
		Observational Data Used to Support Modeling						
		Quality and Quantity of Acquired Data (and references to data quality re ports)						
		Achievement in Meeting Acceptance Criteria						
		References to Monitoring Data						
		Discussion on Excluded Data and Basis for Exclusion						
		Description of Model(s) (including):						
		Documentation of Candidate Model Assessments Used for Model Selection (includes references to successful applications).						
		Model Configuration (discusses how model was applied, including):						
		Spatial and Temporal Resolution						
		Nature of Grid, Network Design or Sub-watershed Delineation						
		Application of Sub-models						
		Model Inflows, Loads and Forcing Functions						
		Key Assumptions (and associated limitations, if any)						
		Changes and Verification of Changes Made in Code						
		Model Parameterization (Calibration) and Corroboration (Validation) including:						
		Objectives, Activities and Methods						
		Parameter Values and Sources						
		Rational for Parameter Values in the Absence of Data						
		Model Validation Results						
		Calibration Targets						

QAPP element numbers	Element	Element Name and Review Aspect	A Acceptable	U Unacceptable	NI Not Included	NA Not Applicable	Page # (Section #)	Comments (and notes)
		Measures of Calibration Performance						
		Calibration Input, Output and Results Analysis						
		Model Use Scenario Analysis and Results (should relate to purpose)						
		Output of Model Runs and Interpretation						
		Summary of Assessments and Response Actions						
		Soundness of Calibration, Validation and Simulations						
		Review of Initial Assumptions and Model Suitability						
		Performance Against Acceptance Criteria for Calibration, Validation, Sensitivity and Uncertainty						
		Pre- and Post-Processing Software Development						
		Maps, Photographs and Drawings (if appropriate)						
		Deviations from the QAPP Including a List of Non-Applicable Reporting Elements with Explanations.						
		Conclusions and Recommendations						
		References and Appendices						
		Reviewer Name/Date:						
		NOTE: For references for this checklist, see the companion QAPP template.						
x3								