# 1.0 PROJECT MANAGEMENT

## 1.1 Title & Approvals

# Identification of Critical Source Areas of Phosphorus Pollution within the Vermont Sector of the Missisquoi Bay Basin

2010 Secondary Data Quality Assurance Project Plan: Version 1.0

Project ID 092056

Prepared by:
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| Michael Winchell, Project QA/QC Manager, Stone Environmental | 8/30/10<br>Date |
| Eric Howe, Project Officer, LCBP | 8/18/10<br>Date |
| Nicole Grohoski, Project QA/QC Officer, LCBP | 8/18/10<br>Date |
| Erik Beck, IJC Contract Officer's Representative, EPA | 18 Aug 2010<br>Date |
| Steve DiMattei, QA/QC Officer, EPA | 08/23/10<br>Date |
| Michael Jennings, Quality Assurance Program Manager, NEIWPCC | 8/19/10<br>Date |

## 1.2 Table of Contents

## 1.3 Distribution List

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## 1.4 Project Organization

The diagram in Figure 1 below outlines the primary project participants and their roles in the project.

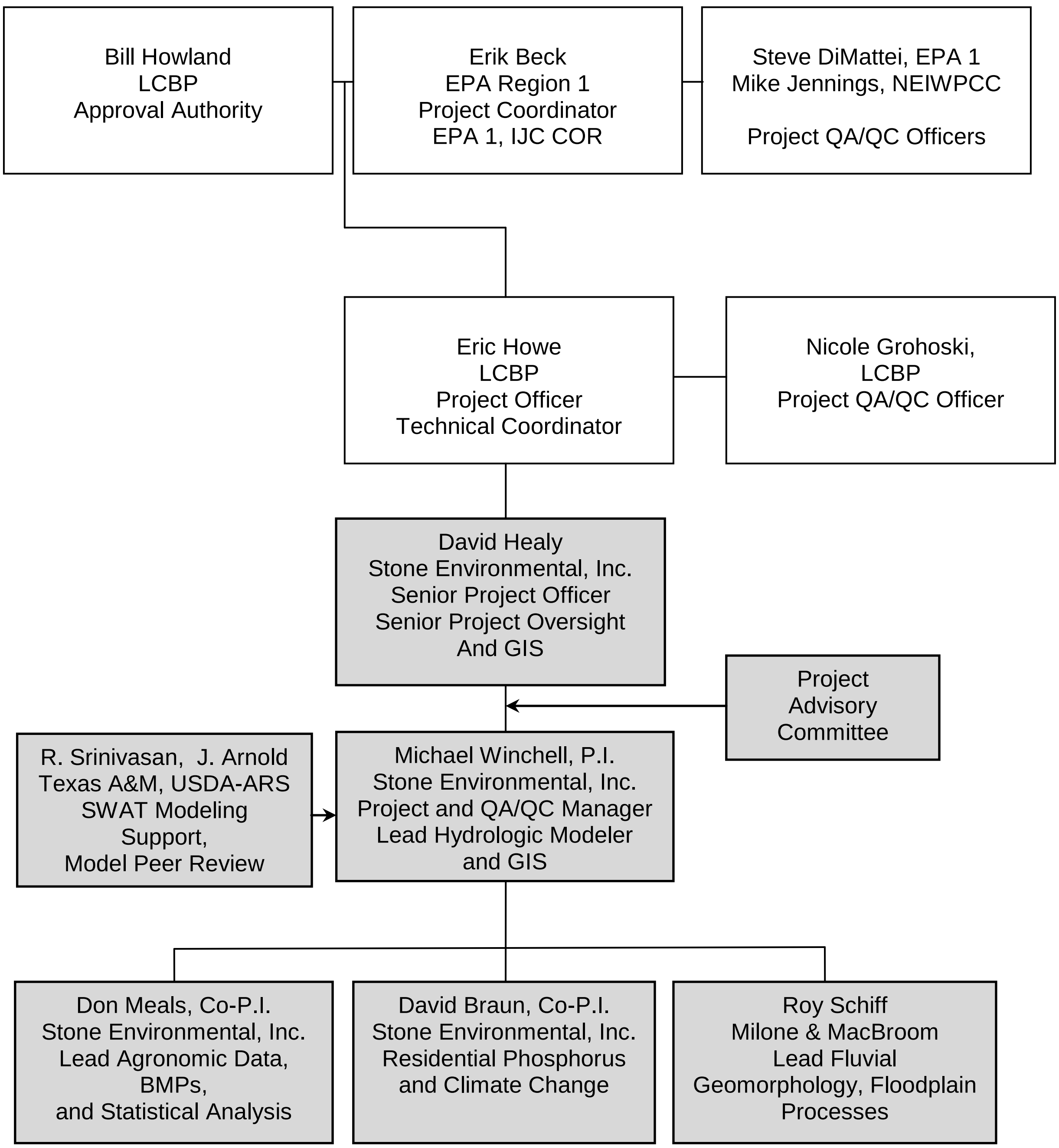


Figure 1: Project organizational chart.

Project personnel roles are as follows:

- Mike Winchell: Principal Investigator, project manager, chief modeler and GIS analyst, and primary contact with the Lake Champlain Basin Program. Implement final approved version of QAPP. Maintain the approved QAPP and distribute new versions of the QAPP, as necessary.
- Don Meals: Co-Principal Investigator focused on compilation of agronomic data, development of best management practices scenarios, and interpretation of results.
- Dave Braun: Co-Principal Investigator focused on hydrologic effects of climate change and P transport from urban lands and onsite wastewater systems.
- David Healy: Project Officer (senior management) focused on acquisition and processing of remotely sensed spatial datasets and certification of all project deliverables.
- Roy Schiff: Team Partner focusing on the function of streams and floodplains in P transport, acquire and interpret available data on stream adjustment and stream corridor sources of sediment and P.
- Raghavan Srinivasan and Jeff Arnold: Team Partners, will provide SWAT modeling support, peer review of model calibration and validation, and quality assurance of the model implementation.

## 1.5 Problem Definition/Background

The Missisquoi Bay Basin (MBB) has one of the highest in-lake phosphorus (P) concentrations of any segment of Lake Champlain. Phosphorus loads to and concentrations in the Bay greatly exceed target levels and this P contributes significantly to blue-green algae blooms in Missisquoi Bay during the summer months. While management efforts have made significant progress in reducing P loads to the Bay, more needs to be done in order to meet water quality goals. In the MBB, the intersection of high phosphorus (P) source areas and hydrologic transport mechanisms defines critical source areas (CSAs) at high risk for excessive P export to surface waters. The goal of this project is to identify and delineate areas of the MBB that contribute disproportionately large amounts of P and by doing so, help improve effectiveness of P management efforts.

The project team, consisting of Stone Environmental, Inc. (Stone), Texas A&M Blackland Research and Extension Center and the USDA-ARS, and Milone & MacBroom will conduct strategic identification and ranking of P CSAs at the MBB scale. These identifications and rankings will be based on the best available basin-scale data sources using a variable source area hydrology adaptation of the Soil and Water Assessment Tool (SWAT-VSA). SWAT, developed by USDA-ARS, is a watershed-scale, continuous, physically-based, semi-distributed model designed for the simulation of flow, sediment, nutrient, and pesticide transport in ungaged watersheds (Arnold et al. 1998, Neitsch et al. 2009). SWAT is one of the most commonly used and well supported water quality modeling systems used for water quality assessments, nutrient and sediment loss studies, evaluating the effectiveness of best management practices, climate change impact studies, calibration, sensitivity and uncertainly analysis, and pesticide transport studies in complex watersheds (Gassman et al. 2007). SWAT has been used to in a variety of studies to identify and study P CSAs (e.g., Tripathi et al. 2003, Srinivasan et al. 2005, Busteed et al. 2009, White et al. 2009), while the SWAT-VSA approach (Easton et al., 2008) has been developed and applied specifically to address spatially distributed and time varying CSAs in Northeastern agricultural watersheds.

Our analysis will include all of the Vermont sector that drains into Missisquoi Bay, and the portions of Quebec that contribute to the rivers and streams that enter the Bay on the Vermont side of the international border. Greater spatial detail in the model will be focused on the Vermont side of the border where the CSA identification will occur. The geographic extent of the modeled area and the area of CSA identification is shown in Figure 2.

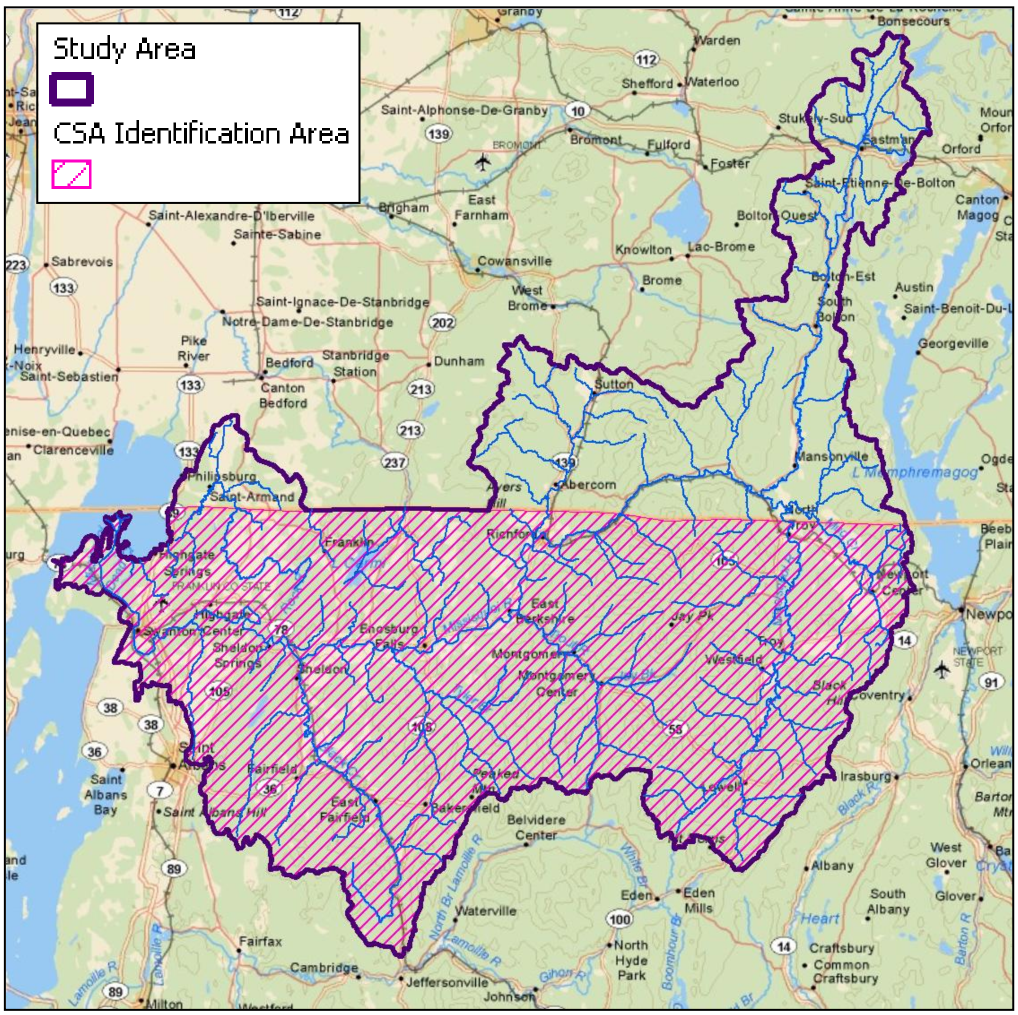

Figure 2: Study area and CSA identification extent.

SWAT-VSA accounts for the dynamic and spatially variable distribution of runoff contributing areas across the landscape based on terrain and soil characteristics. The model also represents loading due to river bank and channel erosion. We will apply the latest science and spatial analysis techniques (including the variable source area SWAT approach (Easton et al., 2008) and LiDAR-based topographic analysis) to determine critical model inputs with greater precision and at a higher resolution than is commonly performed. This approach will yield sub-field level model simulation results and facilitate CSA identification at levels not typically achieved at the basin scale. We will address model uncertainty by taking a probabilistic approach to ranking CSAs that provides planners with both predictions and their associated confidence levels. Model validation is essential, so we will complement standard desktop watershed modeling validation procedures with on-the-ground field verification of model-predicted high and low priority P source areas through site visits to identified high and low-ranked CSAs. Along with such visual assessments, we may (where feasible) sample sediments from ditches or stream channels receiving flow from our verification sites for P, providing us with an independent verification of the SWAT model-based CSA rankings. If such environmental samples are collected, this QAPP will be revised to include an appropriate primary data component.

To produce a product appropriate for watershed management, we will scale up our high-resolution CSA results into field units for identification and prioritization. Having prioritized CSAs at the field level, we will assess the potential impacts of alternative management scenarios on P loads at multiple scales by comparing loads from simulations assuming both random and targeted implementation of best management practices (BMPs) across the MBB. Taking the results of our high-resolution strategic analysis one step further, we will conduct a more detailed tactical analysis at a micro-watershed scale where we can obtain high-quality, site-specific data and apply a farm-scale model to validate our basin-scale approach, provide more site-specific CSA definition, and evaluate the effectiveness of BMPs targeted directly at the local conditions. Finally, we will extrapolate our work by testing GIS-based multivariate overlay procedures against our more complex modeling approach in an effort to validate simpler tools that can be readily applied to other regions of the Lake Champlain Basin before an intensive modeling analysis can be implemented.

## 1.6 Project/Task Description and Schedule

The project is divided into a Strategic and a Tactical Analysis as defined in the approved Project Workplan (see section 7.1 Appendix). The objectives of the Strategic Analysis are to identify CSAs for the Vermont Sector of the MBB scale, map their physical locations, rank them in priority order, and illustrate how the targeted application of management measures can reduce P loads. This analysis will provide managers with information required to target management measures to reduce P loads to Missisquoi Bay. The objective of the Tactical Analysis is to refine the strategic approach using more precise, site-specific input data and better spatial resolution to improve identification, ranking, and prioritization of CSAs at the small catchment scale where improvements in resolution and several additional components will improve identification and mitigation of CSAs.

The tasks and sub-tasks of the strategic analysis are as follows:

**Task 1** Construction and testing of the SWAT-VSA model

**Task 2** Development of a secondary data Quality Assurance Project Plan (QAPP)

**Task 3** Data collection and evaluation

- 3.1 Topographic data
- 3.2 Land cover data

3.3 Soils data
3.4 Stream channel characteristics
3.5 Climate data
3.6 Agronomic practices
3.7 Non-agricultural nonpoint sources of P
3.8 Point sources of P

**Task 4** SWAT-VSA model development and calibration
4.1 Calculation of watershed topographic characteristics
4.2 Watershed disaggregation into hydrologic response units (HRUs)
4.3 Initialization of model soil P levels
4.4 Project Advisory Committee review of model inputs and assumptions
4.5 Model calibration and validation
4.6 Peer review of model calibration and validation

**Task 5** Application of the SWAT-VSA model to identify phosphorus CSAs
**Task 6** Field verification of CSA rankings
**Task 7** Evaluation of alternative management scenarios in reducing P loads
**Task 8** Assessment of P CSAs based on projected climate conditions
**Task 9** Application and testing of simpler CSA approaches

The tasks of the tactical analysis are as follows:
**Task 10** Development of enhanced hydrologic network
**Task 11** Prioritization of CSA locations using enhanced hydrologic network
**Task 12** Site-specific modeling to refine tactical objectives

The following tasks relate to both the strategic and tactical level analyses:
**Task 13** Quarterly reporting
**Task 14** Final report, maps, and data deliverables

The project schedule for completion of the tasks described above is provided in the Table 1.

Table 1. Project task schedule.

| Project Objective* | Task | Date(s) | Deliverable |
|---|---|---|---|
| S | Task 1: Construction and Testing of SWAT-VSA Model | 6/1/2010-8/1/2010 | |
| R | Task 2: Development of QAPP | 6/1/2010 - 8/1/2010 | Approved QAPP |
| S | Task 3: Data Collection and Evaluation | August 2010 - 10/1/2010 | |
| S | Task 4: Model Development and Calibration | 10/1/2010 - 2/1/2011 | |
| S | Task 5: Identify P CSAs | 1/1/2011 - 3/1/2011 | |
| S | Task 6: Field Verification of CSAs | 3/1/2011 - 5/1/2011 | |
| S | Task 7: Evaluate Management Scenarios | 3/1/2011 - 5/1/2011 | |
| S | Task 8: Evaluate Climate Scenarios | 3/1/2011 - 5/1/2011 | |

| Project Objective* | Task | Date(s) | Deliverable |
|---|---|---|---|
| S | Task 9: Compare Simple CSA Methods | 4/1/2011 - 5/1/2011 | |
| T | Task 10: Develop Enhanced Hydrologic Network | 1/1/2011 - 5/1/2011 | Enhanced Hydrologic Network Layer |
| T | Task 11: Prioritize CSAs | 5/1//2011 - 6/1/2011 | |
| T | Task 12: Site-Specific Modeling | 5/1/2011 - 7/1/2011 | |
| R | Task 13: Quarterly Reporting | 6/30/2010 – 6/30/11 | |
| R | Task 14: Final Report, Maps, and Data Deliverables | 6/1/2011 - 8/19/2011 | Final Report, SWAT-VSA Model |

* S = Strategic Analysis, T = Tactical Analysis, R = Reporting

## 1.7 Quality Objectives and Criteria

Data quality objectives apply to two principal areas of the project: (1) model data inputs; and (2) the modeling process.

For data inputs, the project data quality objective is to collect, provide, maintain, analyze, display, and document valid geophysical and other data obtained from recognized sources. These datasets will serve as input to the SWAT-VSA modeling analysis. Although in many cases, there is only one source for the required data (e.g., long-term US climate data from the US National Climatic Data Center), where a choice exists (e.g., soils data from USDA-NRCS), the most detailed and recent dataset will be selected (e.g., SSURGO, the most detailed level of soil mapping done by the NRCS). Acquired datasets will be maintained at their original level of accuracy. When modifications are necessary, documentation will accompany the changes. Any modifications to existing datasets will be documented in Federal Geographic Data Committee (FGDC) compliant metadata. In addition, existing metadata on unaltered datasets may be amended to reflect why, how, and when the data were collected for the purposes of this project.

The quality objectives and criteria requirements for the modeling component of the project will follow standard practice for watershed scale modeling with the SWAT model. For model calibration, we will aim to identify an acceptable range of difference between model predictions and observed values required to accept the model results. Calibration and validation criteria will be based on recommendations in recent literature that are applicable to the SWAT-VSA modeling approach. Sensitivity analysis will be a component of the calibration process, and an analysis of the effects of model parameter and input uncertainty will play a role in the interpretation of final model results. Greater detail on the processes and criteria that will be followed in the model calibration, validation, and application phases is provided in sections 4.1.2 and 4.2 in this document.

## 1.8 Special Training Requirements/Certification

The team of scientists performing the work on this project was selected through a peer review process. All personnel involved in data collection and analysis, model calibration, validation, and development have the appropriate education and training required to effectively perform their duties. No additional training or special certifications are required.

## 1.9 Documents and Records

All notes and records describing data development, model development and testing, model calibration, model evaluation, and sensitivity/uncertainty analysis will be documented in electronic "notes" files and/or "Observations and Remarks" (O&R) documents. These electronic documents will provide detailed descriptions on the processes followed and scientific justifications made throughout the project in support of the modeling effort.

Quarterly progress reports disseminated to the Lake Champlain Basin Program and the Project Advisory Committee (PAC) for this project will note activities conducted in connection with the project, issues or problems encountered, and actions taken to address any problems. Any variations from or modifications to this QAPP will be addressed to the individuals listed in section 1.3.

A comprehensive final report presenting the results of the modeling and analysis will be developed and distributed. All sources, characteristics, applications, and modifications of secondary data will be documented in the final report. The contents of the final report are outlined in section 5.0 of this QAPP.

In addition to the written final report, electronic deliverables will include the final spatial datasets and related databases used in the analysis and modeling, all project O&R documents, and summarized model output results. All datasets will include metadata.

Details on all data storage and backup can be found in Section 2.2, Data Management. Stone will retain all materials associated with this project for five years after project completion. The LCBP will permanently archive this information, as stated in the approved Secondary Data Evaluation, dated July 30, 2009 (Appendix 7.2).

### 1.9.1 QA Project Plan Distribution

Amendments to the QAPP may be necessary to reflect changes in project organization, tasks, schedules, objectives and methods; address deficiencies and non-conformances; improve operational efficiency; and/or accommodate unique or unanticipated circumstances. Requests or amendments are directed from the Stone Senior Project Officer to the LCBP Project Officer in writing. The changes are effective immediately upon approval by the LCBP Project Officer and QA/QC Officer, or their designees. Amendments to the QAPP and the reasons for the changes will be documented, and copies of the approved QAPP Expedited Amendment form will be distributed to all individuals on the QAPP distribution list by the LCBP QA/QC Officer. Amendments shall be reviewed, approved, and incorporated into a revised QAPP as needed.

# 2.0 DATA GENERATION AND ACQUISITION

## 2.1 Data Acquisition Requirements

The sources of existing data will be primarily government agencies from both the US and Canada. Many of these datasets have been identified and have already been compiled by the LCBP for use in this project. While we cannot be certain of all the datasets that will be used in every component of our analysis at this time, we have specified many of the datasets and their sources in Table 2 below. If, in the course of the project, any additional or alternative datasets that meet data acceptance criteria are found to be necessary for this work, they will be documented in the final report.

The existing datasets collected during this project will be used to facilitate the identification of P CSAs throughout the Vermont sector of the MBB. The majority of the datasets collected will be used in the parameterization, calibration, and validation of the SWAT-VSA model. The anticipated uses of the datasets that have been identified for use in CSA identification and to support the SWAT-VSA modeling are specified in Table 2.

The limitations on the use of each dataset collected to support CSA identification will be carefully considered. We anticipate that some datasets collected will have minimal limitations with regards to their intended use, while others may have more substantial limitations. Such limitations relative to the purpose of this study will not be fully understood until a thorough review of the dataset has been completed. The current understanding of dataset use limitations has been compiled in Table 2; any additional limitations encountered will be fully documented in project records and reporting.

Table 2. Data sources for use in phosphorous CSA identification.

| Secondary Data Type (Task) | Data & Source(s) | Additional processing | How Data Will be Used | Limitations to Data Use |
|---|---|---|---|---|
| Topographic data (3.1) | 1.4-m LiDAR DEMs for Rock River and a portion of VT Sector of MBB, USGS | If necessary, resample raw DEM to a 2 - 5 m resolution for use in SWAT model application | Calculation of subbasin boundaries, slope, topographic index, and flow path analysis | None anticipated |
| Topographic data (3.1) | Vermont Hydro DEM, VCGI | Possible resampling for use in SWAT model application | For DEM requirements in small section of VT MBB sector not covered by LiDAR. | The resolution of this DEM will be of limited use in some components of the tactical analysis |
| Land cover data (3.2) | Land cover/use for Vermont & Lake Champlain 2001 (LCLULCB01), VCGI | Combining with crop specific land use classifications from NASS CDL dataset. | Data will be used to define the land cover component of the SWAT model | Will require that generic agricultural class be refined using additional data sets |

| Secondary Data Type (Task) | Data & Source(s) | Additional processing | How Data Will be Used | Limitations to Data Use |
|---|---|---|---|---|
| Land cover data (3.2) | 2009 NASS Cropland Data Layer (CDL), USDA-NASS | Combining with non-agricultural classifications from LCLULCB01 dataset. | Data will be used to define the land cover component of the SWAT model | Will require assumptions of crop rotation in the absence of additional years of data<br><br>Only available in VT sector |
| Soils data (3.3) | SSURGO, USDA-NRCS | Processing to combine with Canada soils data<br><br>Extraction of attributes required for SWAT model input | Model input for soil characteristics and soil classification boundaries | Potential alignment and classification inconsistencies at international border. |
| Soils data (3.3) | Quebec: 1:20,000 scale soils data, IRDA | Processing to combine with U.S. soils data<br><br>Extraction of attributes required for SWAT model input | Model input for soil characteristics and soil classification boundaries | Potential alignment and classification inconsistencies at international border |
| Soils data (3.3) | Soil P levels from:<br>UVM Agricultural Testing Laboratory<br>Published data (Magdoff et al. 2007, Gaddis 2007, Bushey et al. 2009)<br>USDA agencies<br>Watershed farmers | Discussions with soils and agricultural professionals, producers, and Project Advisory Committee to agree upon representative soil test P assumptions | Model input for estimated initial conditions of soil P levels | Confidentiality policies limit access to agency soils data<br><br>Lack of comprehensive, spatially-referenced soil P data will require extrapolations based on numerous assumptions and professional judgment. |
| Stream channel characteristics (3.4) | Missisquoi River watershed (Basin 6) Geomorphic Data available via the Vermont Stream Geomorphic Assessment Data Management System on the Internet | Majority of the data have passed quality control. Provisional data will be discussed with VT River Management Program and data collector | Characterize the mainstem and tributary channels in the MBB. Evaluate channel-floodplain connection<br><br>Allow for process-based extrapolation across watershed of sediment data. | |
| Stream channel characteristics (3.4) | USDA-ARS National Sedimentation Laboratory *Quantifying Streambank-Derived Nutrient and Sediment Loadings in the Missisquoi River Watershed* including: | Establish representative channel sediment and P loading rates from data | Extrapolate sediment and P data with geomorphic stream data to parameterize the channel contributions of sediment and P in | Protocols based on representative cross sections so caution must be used in extrapolating data |

| Secondary Data Type (Task) | Data & Source(s) | Additional processing | How Data Will be Used | Limitations to Data Use |
|---|---|---|---|---|
| | Surveys of bank geometry and condition;<br>Simulations of bank erosion using BSTEM model;<br>Identification of unstable channels | | SWAT-VSA | |
| Climate data (3.5) | US National Climatic Data Center (NCDC) cooperative observer database (COOP), NOAA-NCDC | Filling in missing data from nearby stations<br><br>Spatial interpolation of the daily weather station time series using the PRISM precipitation climatology regressions data products to account for topographic effects on precipitation and temperature | A topographically adjusted daily time series of precipitation and temperature data specific for each subbasin modeled with SWAT | None anticipated |
| Climate data (3.5) | Canada weather database, Environment Canada Weather Office | Filling in missing data from nearby stations<br><br>Spatial interpolation of the daily weather station time series using the PRISM precipitation climatology regressions data products to account for topographic effects on precipitation and temperature | A topographically adjusted daily time series of precipitation and temperature data specific for each subbasin modeled with SWAT | None anticipated |
| Climate data (3.5) | PRISM precipitation dataset, Oregon State University | Possible extrapolation into Canada | Used to spatially interpolate point climate data to account for orographic effects on precipitation and temperature | Not available in Canada |
| Agronomic practices (3.6) | Land management data (e.g., nutrient applications, cropping practices, tillage, animal density, and existing BMPs) will be obtained VTAAFM (e.g., LFO, MFO and AAP regulations), local cooperators from the Watershed Farmers' Alliance, UVM Extension, and Quebec data provided by IRDA. | Anecdotal data from a variety of sources will be reality-checked through the Project Advisory Committee. | A set of representative agricultural management parameters applicable for use in defining SWAT model inputs | The representative agronomic data will be of limited precision and unknown accuracy. To account for this uncertainty, these conditions will be varied over the observed range in behavior as part of the model uncertainty analysis |

| **Secondary Data Type (Task)** | **Data & Source(s)** | **Additional processing** | **How Data Will be Used** | **Limitations to Data Use** |
|---|---|---|---|---|
| Non-agricultural nonpoint sources of P (3.7) | Impervious land cover from:<br>2009 NAIP orthos, USDA, LCLULCB01 land cover, VCGI | Some additional processing necessary to refine impervious surface coverage from land cover dataset and aerial photography. | A dataset estimating the impervious surface characteristic for parameterization of SWAT residential and urban land uses and P build-up rates | Some uncertainty in estimates of impervious surface coverage and pollutant build-up and wash-off assumptions |
| Non-agricultural nonpoint sources of P (3.7) | Residential lawn areas from:<br>2009 NAIP orthos, USDA | Some additional processing necessary to refine lawn coverage from land cover dataset and aerial photography. | A dataset estimating the lawn cover area for parameterization of SWAT residential fertilizer use rates | Some uncertainty in estimates of lawn areas and residential fertilizer applications |
| Non-agricultural nonpoint sources of P (3.7) | Locations of septic systems, VT e911 dataset, VCGI | Classification of which building sites are on septic versus sewer | Characterization of P inputs from septic systems. | Assumptions about septic system type and/or failure are necessary |
| Point sources of P (3.8) | Flow rate and the nutrient concentration data from VT-DEC discharge permits from all MBB wastewater treatment plants | None anticipated | Point source P inputs to SWAT model | None anticipated |
| Projected future climate conditions (8) | Precipitation and temperature time series, North American Regional Climate Change Assessment Program (NARCCAP) as part of EPA's *Hydrologic and water quality change scenarios for 20 U.S. watersheds* project. | These weather time series may need to be adjusted to reflect local variability due to orographic effects, similar to what was done in baseline analysis | Climate input data for SWAT model to simulate effects of projected climate change on performance of BMPs and P loading in the MBB | None anticipated |
| Enhanced hydrologic network (10) | The 1:5,000 scale Vermont Hydrography Dataset (VHD), VCGI | None expected | Basis for an enhanced hydrography dataset applicable to the Tactical Analysis at the catchment scale | None anticipated |
| Enhanced hydrologic network (10) | VT DEC mapped MBB stormwater outfalls, VT DEC | None expected | Added as features to the hydrologic network | None anticipated |
| Enhanced hydrologic network (10) | 1.4-m LiDAR DEMs for Rock River and remaining VT Sector of MBB, USGS | Flow accumulation algorithms will be used to identify concentrated flow channels representing streams and ditches | Ephemeral stream and ditch features identified from the LiDAR dataset and will be joined to the existing VHD as features to extend the network applicable to the Tactical Analysis | May not be available for the eastern-most portion of the Vermont sector of the MBB |

## 2.2 Data Management

Data will be managed in a combination of spreadsheets, relational databases, and spatial databases. The spreadsheet software used will be Microsoft Excel 2007, the relational database software will be Microsoft Access 2007, and the spatial database format will be ArcGIS 9.x compatible. Analysis of spatial data used for model input and generated from model results will be performed using ArcGIS 9.x software. Additional data analysis software may be required as needed. This software will be run on laptop and desktop personal computers running Microsoft Windows XP or Windows 7 operating systems. Storage of data will also occur on network servers running a Windows Server operating system.

Spreadsheets will most often be used for storage of raw data, in the evaluation of data, and in performing data processing tasks. Relational databases will be the preferred approach to storing final datasets to be used in direct model parameterization and identification of inputs. In addition, relational databases will be used to store model output data in order to provide an efficient mechanism for storage and querying of results. A significant amount of spatial data will be collected and generated throughout this project. These data will be stored in ArcGIS 9.x format personal and/or file geodatabases and raster GRID file format. Because of the amount of data used and generated in this project, these spatial data will be stored logically in multiple spatial databases and collections of raster files.

A “metadata database” will be used to track the acquisition, processing, and usage of individual datasets used in the development of model inputs and assumptions. This database will be an MS Access relational database that will serve as a tool for tracing data generation and documenting data handling throughout the project.

Tasks that require data conversion and data processing will be documented in a project O&R document. The accurate performance of these tasks will be checked and documented in a task Quality Control Check (QCC) document. The QCC documents are reported to the Stone Quality Assurance Manager and are included with the final data deliverables at the conclusion of the project. The person responsible for performing the QCC will be different from the individual that performed the original analysis.

Electronic spreadsheet and databases stored on the project’s network server folders are backed up daily to Stone’s external backup tape system, and archived offsite weekly. Off-network project computers are backed up daily to external hard drives. In the event of a catastrophic systems failure, the tapes’ external drives can be used to restore the data in less than a day. Data generated on the day of the failure may be lost but can be reproduced from raw data in most cases.

The Stone Project Manager will be responsible for all data management tasks and responsibilities for this project.

# 3.0 ASSESSMENT AND OVERSIGHT

## 3.1 Project Oversight

Project tasks will be completed according to the organization and schedule presented in the approved Project Work Plan in section 7.1 of this QAPP.

David Healy (Stone) is the Senior Project Officer and will provide overall project oversight, particularly with regard to remotely-sensed and other geophysical data acquisition, documentation, and GIS analysis. He will be responsible for certification of all project deliverables. Michael Winchell (Stone) is Project Manager and lead modeler and will be responsible for all SWAT activities, including parameterizing the model, model calibration, and model validation. Raghavan Srinivasan (Texas A&M) and Jeff Arnold (USDA) will provide SWAT modeling support and peer review.

Mr. Healy will review all acquired geophysical data—including metadata—to ensure that data quality is consistent with project needs, the project workplan, and the terms of this QAPP.
Mr. Winchell will review and approve all SWAT model parameters and inputs, and will oversee calibration, validation, and model application. All members of the project team will review and assess model outputs and conclusions.

NEIWPCC may implement, at their discretion, various audits or reviews of this project to assess conformance and compliance to the Quality Assurance Project Plan in accordance with the *NEIWPCC Quality Management Plan*.

## 3.2 Documentation of Project Oversight

Project activities and outputs will be documented in quarterly reports to the Project Advisory Committee (PAC) and the LCBP. A final project report, including all data and models, will be provided to the LCBP at the end of the project. Other project deliverables and intermediate products will be documented in memos and meetings with LCBP personnel and the PAC.

## 3.3 Problem Resolution and Corrective Action

The first step in resolution of problems encountered in acquired secondary data will be to address the issue(s) with the data provider. Access to alternate data sources is unlikely, given that only a single data source exists for most of the data required for the project. Small problems, such as inconsistencies in the land cover database, may be resolved by interpreting data from other sources, e.g., digital orthophotography. All such actions will be documented in project files and in the metadata provided with project deliverables.

Deviations from the QAPP will be addressed by the Project QA/QC Officer and subject to the necessary approvals, in order to either correct the problem or amend the QAPP as needed.

# 4.0 MODEL APPLICATION

## 4.1 Model Parameterization (Calibration)

### 4.1.2 Data Review and Verification Process

The data quality will be peer reviewed for logical consistency and coding errors. The QA/QC Manager and Project Manager will be responsible for overall validation and final approval of the data in accordance with project purpose and use of the data.

Data interpretation and modeling assumptions required during the development of the SWAT-VSA model will be reviewed by the Project Advisory Committee prior to beginning model calibration. These assumptions include current soil test P, crop rotations, tillage and residue management, agricultural and residential fertilizer application rates and frequencies, and manure management and field application practices. After receiving PAC comments, Stone will provide written responses and make modifications to model inputs and assumptions as necessary. Limitations and uncertainty in these data will be addressed by varying their values in the modeling analysis following model validation (see Section 4.2).

The Project Manager and QA/QC Manager will provide review and approval of the data before closure of the project. All geospatial data layers will include FGDC-compliant metadata. Datasets lacking appropriate metadata will not be used in any analysis or delivered to outside agencies.

The Project Manager and QA/QC Manager will review QC reports and the model development and calibration peer reviews (see Section 3.1) to ensure they are acceptable. The managers will also compare final datasets with original source information for consistency as needed.

### 4.1.2 Model Calibration

Calibration is the process where the model input parameters are adjusted until the simulated data from the model match closely with observed data. Model calibration, in this setting, is defined as how well the model is able to reproduce current observed streamflow rates, sediment, and phosphorus loading as measured from multiple monitoring locations throughout the watershed. SWAT-VSA is built with state-of-the-art components with an attempt to simulate the processes physically and realistically. Most of the model inputs are physically based (that is, based on readily available information). It is important to understand that SWAT-VSA is not a parametric model with a formal optimization procedure (as part of the calibration process) to fit any data. Instead, a few input variables that are not well defined physically such as runoff curve number and Universal Soil Loss Equation's cover and management factor (C factor) may be adjusted to provide a better fit. Moreover, these model parameters are adjusted within literature-recommended values so that the results are scientifically valid and defensible.

Model parameters related to landscape and channel processes will be adjusted to match the model simulations to the observed data at several locations in the watershed. Calibration will be done over a multi-year period that includes normal, wet, and dry years. Time series plots and cumulative distribution plots (between simulated and observed data) as well as statistical measures including the percent bias (PBIAS), the Nash-Suttcliffe efficiency (NSE), and the ratio of the root mean square error to the standard deviation of measured data (RSR) will be used to quantitatively evaluate the performance of the model during calibration. Calibration will be performed systematically, first for flow, then for sediment, and finally for phosphorus.

Calibration will be performed at locations along the main stem Missisquoi River and its tributaries for which sufficient water quality and flow data exist. Other locations along other rivers within Vermont that drain to Missisquoi Bay, such as the Rock River and the headwaters of the Pike River, will serve as additional calibration locations. There are a significant number of monitoring locations throughout the study area that contain data that could be used in calibration. It may not necessarily be practical to include all of these sites in the formal calculation of calibration performance metrics. As such, an effort will be made to select a sub-set of these locations identified as having the best monitoring data records for this purpose.

Parameters subject to adjustment during calibration will be chosen based upon a combination of modeling team experience, literature references, and results of sensitivity analyses conducted on sub-watersheds within the study area. Calibration of those parameters will be conducted through a combination of manual and automatic techniques. The tools used for any sensitivity analysis and automatic calibration performed will be from within the most recent version of ArcSWAT for SWAT 2009 (Winchell et al., 2010) or the SWAT Calibration and Uncertainty Program (SWAT-CUP; Abbaspour, 2009).

Numerous studies have reported on levels of calibration performed using the SWAT model. The variability in the levels of performance reported are dependent upon the parameter being calibrated (flow, sediment, or nutrients), the time step of the data being compared for calibration (daily, monthly, or yearly), and upon the particular model application. There are many factors related to the particular model application that impact the calibration performance. These include the quality and uncertainty of the input data, the quality and uncertainty of the observed monitoring data, and the model implementation and soundness of the calibration. Some of these factors will be outside the control of the modeling team for this project; however, we will have direct control over the model implementation and soundness of the calibration and will aim to optimize this aspect of the model application.

A recent paper by Moriasi et al. (2007), has classified the performance levels of monthly calibration performance statistics for different model outputs into “very good”, “good”, “satisfactory”, and “unsatisfactory”. This work was based heavily on reported calibration statistics in applications of the SWAT model. Their table of levels of performance-classified calibration statistics is shown in Table 3. Our goal will be to achieve performance ratings of “good” for each of the statistics at all the primary calibration locations and for all output parameters (flow, sediment, and nutrient) prior to stopping calibration; however, we will accept “satisfactory” performance for some locations and parameters if an investigation into the model inputs and parameters provides no reasonable course of action for improvement. In these situations, the suspected reasons for the lower level of performance will be documented. If "unsatisfactory" results are encountered at any of the calibration locations, the Stone Project Manager will meet with the LCBP QA Officer to arrive at an agreeable course of action.

A peer review of the model calibration for a particular sub-watershed or group of sub-watersheds will be performed by a member of the project modeling team who was not responsible for the primary calibration of the model. The most likely strategy for this peer review will be to have a modeler from the Texas A&M/USDA group review the work of a modeler from the Stone group, or vice versa. A Quality Control Check (QCC) document will be prepared during this review.

Table 3. SWAT model performance criteria classifications, from Moriasi et al., 2007.

**Table 4. General performance ratings for recommended statistics for a monthly time step.**

| Performance Rating | RSR | NSE | PBIAS (%) | | |
|---|---|---|---|---|---|
| | | | Streamflow | Sediment | N, P |
| Very good | 0.00 ≤ RSR ≤ 0.50 | 0.75 < NSE ≤ 1.00 | PBIAS < ±10 | PBIAS < ±15 | PBIAS< ±25 |
| Good | 0.50 < RSR ≤ 0.60 | 0.65 < NSE ≤ 0.75 | ±10 ≤ PBIAS < ±15 | ±15 ≤ PBIAS < ±30 | ±25 ≤ PBIAS < ±40 |
| Satisfactory | 0.60 < RSR ≤ 0.70 | 0.50 < NSE ≤ 0.65 | ±15 ≤ PBIAS < ±25 | ±30 ≤ PBIAS < ±55 | ±40 ≤ PBIAS < ±70 |
| Unsatisfactory | RSR > 0.70 | NSE ≤ 0.50 | PBIAS ≥ ±25 | PBIAS ≥ ±55 | PBIAS ≥ ±70 |

## 4.2 Model Corroboration (Validation and Simulation)

In the validation process for SWAT, the model is operated with input parameters set during the calibration process, as described in Section 4.1.2, without any change. The model is run for a time period independent of the time period used in the calibration phase, the results are compared to those measured for that period, and the model performance is evaluated. The same evaluation measures will be used for assessing the performance of the model during validation as were used for calibration.

It is not uncommon for model performance metrics during the validation period to be lower than during the calibration period. During model calibration, we specified that the goal would be to achieve "good" model performance on all evaluation metrics, but that "satisfactory" performance would be accepted. During the validation period, we will relax our quality criteria slightly and have the goal of all model evaluation performance statistics falling in the "satisfactory" or better classification. Only if the evaluation criteria falls in the "unsatisfactory" classification will we revisit the calibrated model parameters.

In applying the calibrated and validated model to identify phosphorus CSAs, we will acknowledge that uncertainty still exists in some of the model inputs and the calibrated parameters. This will be accomplished by running Monte Carlo type simulations which sample the model parameter space and input variability across a limited distribution and range. In this analysis, the validated model will be run thousands of times over a long term (30-year) simulation period representative of historical climate conditions. The inputs and parameters considered in this uncertainty analysis will include sensitive parameters that affect surface runoff, soil erosion, in-channel processes, residential fertilizer application rates, impervious surface P buildup, and wash-off characteristics, as well as agronomic management practices such as fertilizer and manure application rates and timing. This uncertainty analysis will be conducted within the SWAT-CUP software framework (Abbaspour, 2009). The resulting output uncertainty will result in rankings of identified CSAs that are based upon, in some capacity, analysis of the statistical distribution of predicted P loads from each HRU that reflects uncertainty in the model parameters and key inputs.

## 4.3 Reconciliation with User Requirements

Once the datasets for use in modeling and analysis are compiled, the QA/QC Manager and Senior Project Officer will review the data quality to determine if it falls within acceptable limits per user requirements. Criteria for this review will include:

- Are datasets unbiased and representative?
- Are datasets complete?
- Are the data of sufficient precision for the required analyses?
- Were data collected and/or processed using acceptable techniques?

Applicability of the data will be evaluated on a task-by-task basis when necessary. Limitations of the data will be discussed with the PAC and LCBP. If the quality of the data does not meet the project's requirements, the data may be reevaluated to determine why the data quality did not meet the goals. Efforts will be made to determine inconsistencies in the base data or correct errors in the attribute data. If inconsistencies are found in the quality of the base data, an effort will be made to identify and obtain more accurate base data.

The SWAT-VSA modeling framework developed for this project will be used to identify phosphorus CSAs throughout the Vermont Sector of the MBB. Those datasets developed for use in the SWAT-VSA model, and the appropriateness and validity of the SWAT-VSA model developed will be critical to the accurate and defensible identification of these CSAs. The model performance statistics calculated during the calibration and validation phases described in sections 4.1.2 and 4.2 will form the basis for ensuring that the modeling results meet the user requirements.

All final data and model results will be reviewed by the Senior Project Officer to ensure that they meet the requirements as described in this QAPP. Data that have been reviewed, verified, and validated will be summarized for their ability to meet the quality criteria of the project and the informational needs of project sponsors. These summaries, along with a description of any limitations on data use, will be included in the final report.

## 4.4 Reports to Management

The schedule for planned project communication is provided in the Table 4. All progress reports indicated in Table 4 will be prepared by the Stone P.I.s.

Table 4. Project communication schedule.

| Task | Date(s) | Deliverable |
|---|---|---|
| Quarterly Progress Report 1 | 6/30/2010 | Progress Report |
| Informal Project Check-in | 8/15/2010 | |
| Quarterly Progress Report 2 | 9/30/2010 | Progress Report |
| Informal Project Check-in | 11/15/2010 | |
| Quarterly Progress Report 3 | 12/31/2010 | Progress Report |
| Informal Project Check-in | 2/15/2011 | |
| Quarterly Progress Report 4 | 3/31/2011 | Progress Report |
| Informal Project Check-in | 5/15/2011 | |
| Quarterly Progress Report 5 | 6/30/2011 | Progress Report |

The Project Advisory Committee (PAC) will meet periodically and review draft progress reports prior to submission to the LCBP.

## 5.0 REPORTS

A final report will submitted for review by the project PAC, the LCBP TAC, and others. This report will include the following elements with respect to the use of secondary data and modeling applications and results:

- Introduction
- Background
- Purpose of modeling/modeling objectives
- Scope and approach for each model used (including physical setting and hydrology)
- Observational data used to support modeling
  - Quality of acquired data (and references to data quality reports)
  - Achievement in meeting acceptance criteria
- References to monitoring data
- Discussion of excluded data and basis for exclusion
- Description of model including benefits of this approach as compared to other models
- Model configuration (discusses how model was applied)
  - 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)
  - Changes and verification of changes made in code
- Model parameterization (calibration) and corroboration (validation)

  - Objectives, activities, and methods
  - Parameter values and sources
  - Rationale for parameter values in the absence of data
  - Model validation results
  - Calibration targets
  - Measures of calibration performance
  - Calibration input, output, and results analysis
  - Model validation results
- 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 evaluation
- Performance against acceptance criteria for calibration, validation, sensitivity, and uncertainty
- Pre- and post-processing software development
- Maps and schematics (if appropriate)
- Complete copies of the applicable approved QAPP
- Deviations from the QAPP including a List of Non-Applicable Reporting Elements with Explanations
- Conclusions and recommendations
- References and appendices

## 6.0 REFERENCES

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# 7.0 APPENDICES

## 7.1 Approved Project Workplan

# Identification of Critical Source Areas of Phosphorus Pollution within the Vermont Sector of the Missisquoi Bay Basin

**PROJECT WORKPLAN**

**Project ID 092056**

**May 12, 2010**


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# 2. PROJECT SUMMARY

Stone Environmental will conduct strategic identification and ranking of phosphorus (P) critical source areas (CSAs) at the Missisquoi Bay Basin (MBB) scale based on best available basin-scale data sources using a variable source area hydrology adaptation of the Soil and Water Assessment Tool (SWAT-VSA). SWAT-VSA accounts for the dynamic and spatially variable distribution of runoff contributing areas across the landscape based on terrain and soil characteristics. We will apply the latest science and spatial analysis techniques to identify critical model inputs with greater precision and at a higher resolution than is commonly performed. This approach will yield sub-field-level model simulation results and facilitate CSA identification at levels not typically achieved at the basin scale, allowing concurrent achievement of both strategic and tactical-level objectives. We will address model uncertainty by taking a probabilistic approach to ranking CSAs that provides planners with both predictions and their associated confidence levels. Model validation is essential, so we will complement standard desktop watershed modeling validation procedures with on-the-ground field verification of model-predicted high-and low-priority P source areas. To produce a product appropriate for watershed management, we will scale up our high-resolution CSA results into field units for identification and prioritization. Having prioritized CSAs at the field level, we will assess the potential impacts of alternative management scenarios on P loads at multiple scales by comparing loads from simulations assuming both random and targeted implementation of best management practices (BMPs) across the MBB. Taking the results of our high-resolution strategic analysis one step further, we will conduct a more detailed tactical analysis at a micro-watershed scale where we can obtain high-quality, site-specific data and apply a farm-scale model to validate our basin-scale approach, provide more site-specific CSA definition, and evaluate the effectiveness of BMPs targeted directly at the local conditions. Finally, we will extrapolate our work by testing GIS-based multivariate overlay procedures against our more complex modeling approach in an effort to validate simpler tools that can be readily applied to other regions of the Lake Champlain Basin (LCB) before an intensive modeling analysis can be implemented.

# 3. INTRODUCTION

The intersection of high phosphorus (P) source areas and hydrologic transport mechanisms defines critical source areas (CSAs) at high risk for excessive P export to surface waters. It is widely recognized that a relatively small fraction of a watershed can generate a disproportionate amount of pollutant load and that watershed management to reduce P export could be more cost-effective if treatments were targeted to these high P source areas.

The existence of high P sources across the landscape is predominantly a function of land use and management. For example, soil P status plays an important role in P runoff as excess P may accumulate in soils from over-application of nutrients from fertilizer or manure relative to crop need or from long-term imbalance between P imports and exports. Excessive soil P levels have been linked to high P losses in runoff, especially in areas of animal-based agriculture. P transport in a watershed occurs mainly through surface runoff and erosion. It is widely believed that limited watershed areas generate surface runoff that may transport P to a stream. In the humid Northeast, most storm runoff is believed to derive from saturation excess in areas where precipitation cannot infiltrate because the soil is already saturated. These saturated runoff-contributing areas vary spatially and temporally by geology, topography, soils, evapotranspiration rates, and precipitation form and amount, and are referred to as variable source areas (VSAs). As a result of these two principles, only a small proportion of a watershed is believed to be responsible for the majority of P exported in runoff – the Critical Source Areas.

Probable saturated areas can be identified at a watershed scale through a topographic index derived from analysis of a digital elevation model (DEM). A topographic index is an expression that reflects the tendency of water to accumulate at any point in the watershed and the tendency for gravitational forces to move that water downslope. The topographic index concept has been found to effectively predict VSAs for many watersheds dominated by saturation-excess runoff.  Easton et al. (2008a and b) added a term for soil hydraulic conductivity to the topographic index and incorporated this principle in the SWAT-VSA (Soil and Water Assessment Tool – Variable Source Area) watershed model.

The Soil and Water Assessment Tool, developed by USDA-ARS, is a watershed-scale, continuous, physically-based, semi-distributed model designed for the simulation of flow, sediment, nutrient, and pesticide transport in ungaged watersheds. SWAT is one of the most commonly used and well supported water quality modeling systems used for water quality assessments, nutrient and sediment loss studies, evaluating the effectiveness of best management practices, climate change impact studies, calibration, sensitivity and uncertainly analysis, and pesticide transport studies in complex watersheds.

We believe that it is essential to capture the variability of both P source areas and runoff generation across the landscape to successfully identify CSAs. We will apply SWAT-VSA to the entire MBB to identify at a fine resolution the combinations of landscape characteristics and management practices that define

CSAs. In addition, because of limitations in data precision at the basin scale, we will conduct a detailed tactical analysis at the micro-watershed scale where we can obtain high-quality, site-specific data to validate our basin-scale approach and provide more site-specific CSA identification. Finally, we will extrapolate our work by testing several GIS overlay procedures against our modeling approach in an effort to provide simpler tools that can be applied to other regions of the Lake Champlain Basin before more intensive modeling analysis is performed.

*Opportunities for Action: An Evolving Plan for the Future of the Lake Champlain Basin* (Lake Champlain Steering Committee, 2003) describes high-priority goals and actions that have been established to "protect and restore the ecological and cultural resources of the Basin while maintaining a vital regional economy". One of those goals is to reduce P inputs to the Lake to promote a healthy and diverse ecosystem and provide for sustainable human use and enjoyment of the Lake. In order to achieve this goal, eleven prioritized actions have been defined. The proposed project will directly support the highest priority action: **Action 1 – Develop and Assess Options to Achieve the Remaining Targeted Phosphorous Loading Reductions Needed to Achieve the In-Lake Phosphorous Standards.** By identifying the locations and relative importance of P CSAs throughout the Missisquoi Bay Basin, this project will provide the necessary guidance for prioritized mitigation of phosphorus loading to the Lake, enabling an accelerated path to achieving the required phosphorus reduction targets. The results of the project will also support progress on several other identified priority actions, including guiding implementation of important P management measures. These priority areas are:

- Action 3 (High Priority) – Estimate the Nonpoint Source Phosphorous Load that is Being Generated by Developed Land Uses (Urban and Suburban Land, Roads, etc.) in the Basin and Work Aggressively to Reduce this Load
- Action 5 (High Priority) – Expand Programs for Streambank Restoration and the Installation of Vegetated Buffers Areas Along Eroding Streams and Rivers
- Action 7 (High Priority) – Promote the Implementation of Comprehensive Nutrient Management Planning (CNMP)

# 4. OBJECTIVES AND TASKS

We will conduct a strategic identification and ranking of CSAs in the Missisquoi Bay Basin using available basin-scale data sources and the SWAT-VSA model. Because of the need to calibrate and validate the model at points along the main stem Missisquoi River, the model will encompass the entire MBB, thereby including both the Vermont and Quebec portions of the watershed. A greater level of spatial detail and the analysis of CSAs will be focused in the Vermont sector. Our analysis will predict a distribution of runoff contributing areas across the landscape based on terrain and soils analysis. Highly ranked P source areas will be translated into field or land tract units for identification and prioritization of CSAs. These results will enable watershed managers to focus on the most important regions of the MBB for P reduction. We will then perform this analysis on a smaller micro-watershed scale where highly site-specific data can be obtained or generated in a tactical analysis of fine-scale CSAs that will permit conservation planners to target management efforts to specific land areas. Finally, we will test simple multivariate GIS overlay procedures against our SWAT-VSA approach to validate simple tools for use in extrapolating elsewhere in the Lake Champlain Basin.

In collaboration with the Lake Champlain Basin Program (LCBP), the project investigators will convene a Project Advisory Committee (PAC) to provide advice and guidance throughout the project. The advisory committee will include representatives from state and federal agencies, MBB farmers, agricultural professionals, conservation groups, and land use planners. The PAC will assist in disseminating the project results in their respective agencies, departments, and organizations.

## 4.1. Strategic Analysis (S)

The objectives of the strategic analysis are:

1. To identify the principal types of CSAs of P loads in the MBB
2. To map their physical locations on a field or tract scale
3. To rank them in priority order
4. To illustrate how the targeted application of management measures can reduce P loads

This analysis will provide managers with information required to target management measures to reduce P loads to Missisquoi Bay. The foundation of our approach is the application of SWAT-VSA to the MBB at sufficient resolution to achieve the strategic objectives and to largely address the tactical analysis.

### Task 1: Construction And Testing of SWAT-VSA Model (S)

The SWAT-VSA model will be based on the most recent SWAT 2009 model that includes new routines for modeling unstable river channels, including the nutrient balance within the channel bed and banks, and for explicit simulation of nutrient contributions from septic systems. In addition, the simulation of

BMPs has been enhanced in SWAT 2009, including an improved method for modeling vegetated buffer strips and the ability to simulate grassed waterways. Using SWAT 2009, the Stone Team will reproduce the variable source area hydrology modifications made by Easton et al. (2008a) in a previous version of SWAT. The SWAT-VSA approach will be applied to a subbasin of the MBB using preliminary topography, land use, and soils data. The purpose of this exercise will be to ensure that the VSA approach to SWAT HRU (hydrologic response unit) delineation and parameterization can be confidently extended to the full MBB. Finally, we will evaluate the SWAT modifications developed by Quebec IRDA (Michaud 2010) that were shown to improve tile drainage simulations in the Canadian portion of the MBB, and consider their implementation into the SWAT-VSA model.

**Outcome:** A working SWAT-VSA model.

## Task 2: Development of Quality Assurance Project Plan (R)

A secondary data quality assurance project plan (QAPP) will be developed for EPA approval prior to the beginning of secondary data collection to support the SWAT-VSA modeling effort. The purpose of the QAPP is to identify sources of secondary data, to ensure that secondary data meet quality requirements, and to define important data reduction and reporting procedures to be used in the project. If collection of primary data is required in support of the SWAT-VSA parameterization and validation (e.g., ditch sediment collection in Task 6), the necessary procedures to address this data collection will be developed and added to the project QAPP.

**Outcome:** A draft and final approved QAPP to guide the collection, evaluation, and use of geospatial and other data inputs to the project.

## Task 3: Data Collection and Evaluation (S)

An extensive collection of relevant GIS databases covering the US and Canadian portions of the MBB have been described in a recent memo from the LCBP. We will draw from many of these datasets and others in the development of the MBB SWAT-VSA model. We have also obtained a commitment from IRDA (Institut de récherche et de developement en agroenvironnement) to provide available geospatial and other data from the Quebec side of the MBB. Several unique enhancements and additions to these datasets that will be performed to support the modeling effort are described here.

**Outcome:** The databases required to apply SWAT-VSA to the MBB.

### *Task 3.1 Topographic Data (S)*

For the entire Vermont side of the MBB, we will use the LIDAR-based 1-m resolution digital elevation models (DEMs) currently being developed as the basis for our analysis. For use in parameterizing the SWAT-VSA model, we will resample the raw DEM to a resolution of 2 to 5 m to remove anomalies that often challenge terrain analysis. The resulting DEM will still provide sufficient detail for accurate calculation of slope and the topographic index.

**Outcome:** A high-resolution DEM that enables accomplishment of strategic and tactical objectives.

### *Task 3.2 Land Cover Data (S)*

The source land cover/land use (LCLU) datasets for the Vermont side of the MBB will include the Land cover/use for Vermont & Lake Champlain 2001 (LCLULCB01) and the National Agricultural Statistics Service Cropland Data Layer (CDL) from 2009. The CDL differentiates between crops and agricultural land uses, including corn, soybean, hay, pasture, and other specialty crops. In addition, we will extract roads from the LULCB01 urban category as a separate class to model these areas independently. Finally, we will evaluate recently updated federal and state wetland maps as potential data sources to provide refinements to wetland delineation.

**Outcome:** A hybrid LCLU dataset for use as input to the SWAT-VSA model that uses the CDL classifications of agricultural lands and the LCLULCB01 classification for non-agricultural lands.

### *Task 3.3 Soils Data (S)*

The Soil Survey Geographic (SSURGO) database will be used as the soils dataset to parameterize SWAT-VSA in Vermont. The predominant soil for each agricultural parcel in the USDA-FSA Common Land Unit dataset (CLU) will be identified and used as the soils input to SWAT-VSA. On the Quebec side, 1:20,000 scale soils data acquired from IRDA will serve as the primary soils input to the model. Initial feedback suggests that some useful soils data are available to initialize soil P and best professional judgment will be used to accept appropriate soil data into the model. We will access several sources of soil P data that will be used in estimating initial soil P levels for this analysis: soil test records from UVM Agricultural Testing Laboratory, a basin-wide study of relationships between soil P levels and potential release to surface waters (Magdoff et al., 1997), soil test data collected from agricultural and residential land in the St. Albans Bay watershed, aggregated data from nutrient management planning in the LCB (Bushey et al., 2009), and data provided by the Watershed Farmers Alliance.

**Outcome:** A soils dataset including estimated soil test P levels for use as input to the SWAT-VSA model.

### *Task 3.4 Stream Channel Characteristics (S)*

P loading from bank erosion is an important component of particulate and soluble P export and has even been shown to be the major source of sediment and associated P during spring runoff. SWAT 2009 accepts initial stream channel soil P levels, simulates erosion/deposition of soil P with channel bed and bank sediment, and calculates P loading from channels. Data to initialize channel characteristics, including sediment P levels, will be obtained from the USDA-ARS National Sedimentation Laboratory study of stream bank erosion contributions to P loading currently taking place in the MBB. In this study, the Bank-Stability and Toe-Erosion Model (BSTEM) by Simon and Langendoen is currently being applied to model bank-stability conditions and to determine stable-bank configurations. Twenty field sites were initially evaluated in 2009 by ARS on the mainstem Missisquoi River and tributaries downstream of the Canadian border. This data provides a way to quantify the portion of the estimated suspended-sediment loadings, calculated by the US Geological Survey (USGS) and the Vermont Agency of Natural Resources (VTANR) on an event-flow basis over the past 20 years, due to streambank erosion. An additional 10 field sites will be evaluated in 2010 upstream of the Canadian border.

While data will not be available for all stream channels, we will utilize existing geomorphic data previously collected in the MBB to establish representative channel P loading rates associated with geomorphic stream type, dominant channel adjustment processes (e.g., erosion or deposition), and stage of channel evolution for the mainstem and major tributaries. The ongoing VTANR project investigating bank erosion in the MBB will also be evaluating relationships between sediment loading from river banks and geomorphic stream type, and the role of floodplains in sediment storage. We plan to work with the state to establish the most accurate model parameterization possible with these data.

**Outcome:** Stream channel characteristics used to parameterize SWAT-VSA model stream channel geometry and composition.

### *Task 3.5 Climate Data (S)*

We will compile 30 years of data from the US National Climatic Data Center (NCDC) cooperative observer database (COOP) and the Environment Canada Weather Office to represent the temporal variability in weather conditions. To more rigorously account for spatial variability and the effects of topography on precipitation and temperature, we will spatially interpolate the daily weather station time series using the PRISM precipitation climatology regressions data products (Daly et al. 2008).

**Outcome:** A topographically adjusted daily time series of precipitation and temperature data specific for each SWAT-VSA subbasin.

### *Task 3.6 Agronomic Practices (S)*

Land management (e.g., manure and fertilizer application, cropping practices, tillage, animal density, and existing BMPs) largely determines the amount of P available at a location for transport. Because specific management data for every land unit in the MBB cannot be obtained, we will make reasonable estimates of representative conditions based on data from VT LFO, MFO and AAP regulations, cooperators from the Watershed Farmers' Alliance, UVM Extension, and Quebec data provided by IRDA. We will "reality-check" our estimates through members of our PAC. Furthermore, we will vary some of these conditions over the observed range in behavior as part of the model uncertainty analysis.

**Outcome:** A set of representative agricultural management parameters applicable to the SWAT-VSA modeling process.

### *Task 3.7 Non-Agricultural Nonpoint Sources of P (S)*

Non-agricultural sources of P—including residential fertilizer applications, P runoff from impervious surfaces and roads, and P contributions from septic systems—need to be considered in the CSA analysis. In the more developed village centers within the MBB, such as Swanton and Highgate, stormwater drainage systems are present. The SWAT-VSA model is not designed to explicitly model stormwater collection systems; however, we will use our land cover dataset and/or aerial imagery to carefully characterize the percent impervious area in these village centers. This characterization will be a driving factor in the delineation and parameterization of HRUs representing these developed areas and their phosphorus loading levels. In addition, modeling P transport from impervious surfaces in SWAT requires assumptions about the rates at which P and sediment build up during dry periods and the rates at which they wash off during rainfall events. We will search the literature to determine the most appropriate build-up and wash-off parameters for residential impervious areas in the MBB. Datasets such as the VT IDDE dataset will be reviewed during the parameterization of developed area HRUs, primarily as a guide for identification of HRUs within stormwater drainage systems.

We will address lawn fertilizer in SWAT by creating explicit residential area HRUs based on the developed land use classifications. The fraction of the residential areas that are lawns will be estimated based upon high-resolution aerial photos from a few sample neighborhoods within the MBB. The fraction of lawns receiving fertilizer and P mass applied will be based on a review of recent literature. Although we believe that on the basin scale, the P contribution by septic systems is small, we will use the capability of SWAT 2009 for explicitly accounting for P inputs to shallow groundwater from septic systems. We will estimate the locations of septic systems within the MBB using the e911 dataset of structure locations and make assumptions on the likely types and flow rates of septic systems.

**Outcome:** A dataset estimating the non-agricultural sources of P including lawn runoff, runoff from impervious surfaces, and septic systems.

### *Task 3.8 Point Sources of P (S)*

We will obtain flow rate and the nutrient concentration data from discharge permits from all wastewater treatment plants operating in the Missisquoi watershed.

**Outcome:** A dataset defining point source P inputs to SWAT-VSA.

## Task 4: SWAT-VSA Model Development and Calibration (S)

SWAT-VSA will be built and managed using the ArcSWAT GIS interface, the primary interface to the SWAT model developed by Stone Environmental in collaboration with Texas A&M University and the Blackland Research Center.

### *Task 4.1 Calculation of Watershed Topographic Characteristics (S)*

We will develop several customizations to the ArcSWAT interface algorithms to determine important topographic characteristics with accuracy exceeding that of the standard model interface methods. First, we will incorporate a multiple flow direction algorithm for use in watershed delineation and upslope contributing area calculations. Second, we will calculate the USLE LS-factor (topographic factor) using land cover data and a high-resolution DEM to accurately represent the spatial variability of the LS-factor across the landscape. Third, we will incorporate calculation of the soil topographic index required for SWAT-VSA across the MBB using the high-resolution LIDAR DEM and a multiple flow direction algorithm. We will follow an approach based upon Easton et al (2008a) to classify the areas of the MBB according to their relative wetness class for use in the delineation and parameterization of HRUs in the SWAT-VSA model.

**Outcome:** Calculation of essential topographic elements of SWAT-VSA.

### *Task 4.2 Watershed Disaggregation into Hydrologic Response Units (HRUs) (S)*

The method chosen for disaggregation of the MBB into HRUs will fundamentally influence how the strategic and tactical objectives are achieved. Our approach to defining HRUs will include Easton's (2008a) method of using the soil topographic index as a component of the HRU delineation and expand on that by using soil properties at the farm field level. This HRU disaggregation strategy allows for the majority of both strategic and tactical objectives to be satisfied concurrently. The CSA potential of individual agricultural fields or non-agricultural parcels will be characterized as follows:

- Agricultural fields based on common land unit (CLU) boundaries will be classified according to land cover from our hybrid LCLU and assigned a unique ID;
- The dominant soil classification from SSURGO will be determined and assigned to the field;
- Up to ten classes of the soil topographic index will be calculated for each gaged MBB subbasin and used in place of the standard ArcSWAT slope classification.

**Outcome:** An HRU scheme that permits subbasin, field, and sub-field scale identification of CSAs.

### *Task 4.3 Initialization of Model Soil P Levels (S)*

The basis for the initialization of model soil P levels will be established through a collection of observed data developed in Task 3.3. We will then explore several possible approaches to better represent the spatial variability in soil P levels across the MBB. The first type of approach considered will be a geostatistical approach (such as regression kriging or kriging with external drift) which uses additional datasets with complete sampling (such as land use, topography, or other soil properties) to predict the values of soil P at unsampled locations. The second approach will be to use SWAT to simulate the spatial variability of current soil P levels by running the model for a very long “warm-up” period using historical climate and agronomic practice data. Using the SWAT model in this capacity would account for the natural variability in soil morphologic characteristics, landscape topographic characteristics, and climate to determine appropriate soil P levels to initialize the primary model run for CSA identification. The "warm-up" model will be calibrated using the observed soil P data that are available. We anticipate that the results of soil P estimation through either of these techniques will require careful review prior to incorporation into the SWAT-VSA model for use in identifying phosphorous CSAs, and it is possible that a much more generalized estimate of soil P based purely on observed samples is ultimately chosen to initialize the model.

**Outcome:** A soil P dataset that represents the MBB according to the best available data and the best professional judgment.

### *Task 4.4 Project Advisory Committee Review of Model Inputs and Assumptions (S)*

Data interpretation and modeling assumptions required during the development of the SWAT-VSA model will be reviewed by the PAC prior to beginning model calibration and validation. These assumptions include current soil test P, crop rotations, tillage and residue management, agricultural and residential fertilizer application rates and frequencies, and manure management and field application practices. After receiving PAC comments, Stone will provide written responses and make modifications to model inputs and assumptions as necessary.

**Outcome:** An initial SWAT-VSA model that represents a consensus of stakeholder knowledge.

### *Task 4.5 Model Calibration and Validation (S)*

The SWAT model will be calibrated using historical streamflow from USGS flow gages, P concentration and interpolated loading data that have been collected on the main stem Missisquoi and Pike rivers since 1990 as part of the Lake Champlain Long-Term Tributary Monitoring Program, and flow and P data that have been collected as part the Missisquoi Bay Short-Term Monitoring Program that began in November 2009. Ideally, calibration of a SWAT model for a watershed the size of the MBB would be based upon several flow and nutrient monitoring stations with at least 10 years of continuous data. The USGS flow gages on the Missisquoi River at North Troy, East Berkshire, and Swanton, as well as the Pike River near Enosburg Falls are locations with ample data for hydrologic calibration of SWAT. To extend the length of the flow data at the Lake Champlain Basin Program tributary locations (e.g., Tyler Branch near Enosburg Falls and Hungerford Brook near Highgate Center) we will synthesize flow records for these sites based upon an analysis of the flows at the nearby gages with data, the relative drainage area, and relevant watershed characteristics; the model calibration and evaluation at these sites will acknowledge and account for the higher level of uncertainty in the "observed" data at these tributary sites. Calibration will be performed through a semi-automated approach using the SWAT Calibration and Uncertainty Program (SWAT-CUP). We will also evaluate the upland components of the model to ensure that they are simulating key processes correctly, including simulated crop yields and the variability of simulated soil P at the field level to ensure predicted values fall within the range of published data. Validation of model performance will be based upon an additional, independent 10-year historical time period, likely from 1991 – 2000. Validation will also include evaluation of flow and nutrient simulation performance at the Short-Term Monitoring sites (as available) and the historical P data from the Lake Champlain Long-Term Tributary Monitoring Program

**Outcome:** Preliminary calibration and validation of the MBB SWAT-VSA model.

### *Task 4.6 Peer Review of Model Calibration and Validation (S)*

The calibration and validation of the SWAT-VSA model will be conducted by sub-watershed defined by the locations of monitoring data. For some sub-watersheds, Stone Environmental will lead the initial calibration effort, while for others, Blackland Research and Extension will lead the effort. In either case, the group that was not responsible for the initial calibration will conduct an internal technical peer review of that initial calibration upon its completion.

**Outcome:** A final calibrated and validated model that has undergone a critical technical review prior to its use in identifying CSAs.

## Task 5: Application of the SWAT-VSA Model to Identify Phosphorus CSAs (S)

The calibrated and validated SWAT-VSA model will be used to locate, size, and rank phosphorus CSAs throughout the MBB.

### *Task 5.1 Identification of Critical Source Areas (S)*

The identification of P CSAs will encompass all residential, agricultural, and undeveloped non-agricultural areas represented in the SWAT –VSA model. In order to account for the variability in weather conditions and the uncertainty in model inputs, a probabilistic modeling approach will be followed to generate a distribution of results. To account for the uncertainty in model inputs, the SWAT-VSA model will be run thousands of times over the full 30-year simulation period in a Monte Carlo analysis. The inputs and parameters used in this Monte Carlo analysis will include sensitive parameters that affect surface runoff, soil erosion, in-channel processes, residential fertilizer application rates, impervious surface P buildup and wash-off characteristics, as well as agronomic management practices such as fertilizer and manure application rates and timing. The model output generated from this type of analysis will be massive, but extremely valuable and necessary to properly characterize CSAs. The output data will be summarized and statistics generated to describe the P loading potential at multiple scales (basin, subbasin, HRU, and field). While sub-field-scale model output will be important from a tactical perspective, from a management perspective a more appropriate scale to rank CSAs will be the field, tract, or neighborhood scale. All P loading model outputs will therefore be aggregated from the HRU level to the field level for all agricultural areas. CSA assessments for non-agricultural areas will remain at the HRU level unless an obvious aggregation unit like a discrete institution or tract is apparent.

**Outcome:** SWAT-VSA simulated P CSAs aggregated to field level for agricultural areas and HRU or land tract level for non-agricultural sources.

### *Task 5.2 Ranking of Critical Source Areas (S)*

CSAs defined in Task 5.1 will be ranked on the basis of simulated annual P export following a statistical analysis of SWAT-VSA output. Ranking could be as simple as identification of the top 10 or 20% of land units by modeled P output. Alternatively, critical units could be identified as significant outliers from a continuous distribution of P output plotted by land use or management metrics. For in-channel P sources, a ranking of each subbasin stream reach in the MBB will be conducted based upon the model output statistics of the simulated net loss of P within each reach and the geomorphic stream type and adjustment processes with input from the PAC.

Prior to having collected the data, built the MBB model, and performed the simulations, it is impossible to say precisely how the CSAs will be ranked; however there we can say with some certainty the ranking process will include several components. First, the ranking will be based on long term simulations, which include crop rotations, and could include changes in crop management practices. In addition, the ranking will also be based upon, in some capacity, analysis of the statistical distribution of predicted P loads from each HRU based upon the Monte Carlo analysis. Assessment of common characteristics that make up top-ranked CSAs may be assessed by enumerating input characteristics that are obviously common among top-ranked CSAs or through the application of more quantitative techniques such as cluster analysis, principal component analysis, or canonical correlation.

**Outcome:** A preliminary ranked array of P CSAs at the strategic level.

## Task 6: Field Verification of CSA Rankings (S)

To help verify our model results, we will make site visits to up to 10% of upland locations identified as among the highest and lowest CSA ranking classification. We will include trained land treatment planners from the Franklin County Natural Resource Conservation District or NRCS on our site visits to help evaluate the physical conditions and vulnerability. Along with such visual assessments, we will (where feasible) sample sediments from ditches or stream channels receiving flow from our verification sites for P, providing us with an independent verification of the SWAT model-based CSA rankings.

**Outcome:** Verification of CSA rankings.

## Task 7: Evaluation of Alternative Management Scenarios in Reducing P Loads (S)

SWAT provides many options for simulating P-reduction practices on both agricultural and urban land, e.g., nutrient management, changes in tillage, application of vegetated filter strips or buffers, street sweeping, or lawn fertilizer management. The specific management scenarios evaluated will be based on consultation with the PAC. In addition to the assessment of the effects of various practices on P export, we will specifically compare the P-reduction effects of implementing a quantity of practices randomly across eligible land units against application of the same quantity of the same practices targeted to the highest risk CSAs.

**Outcome:** Estimates of the effects of implementing P-reduction practices on MBB P loads; comparison of effects of random vs. targeted implementation.

### Task 8: Assessment of P CSAs Based on Projected Climate Conditions (S)

The initial model runs used in the identification of CSAs based on 30 years of historical climate data will provide the basis for assessing the impacts of the spatial and temporal variability of precipitation, runoff, and seasonal flooding on P loading. Assessment of the impact of projected climate changes on P transport will require a series of additional model simulations using predicted precipitation and temperature regimes for future climate. These meteorological inputs will be based on the changes in seasonal precipitation and temperature predicted for a set time in the future (e.g., 2040- 2070). As with the historical climate analysis, a 30-year simulation will be run for the projected climate to capture inter-annual variability. The projected meteorological time series for the SWAT-VSA model will be based on previously generated precipitation and temperature time series developed by the North American Regional Climate Change Assessment Program (NARCCAP) as part of EPA's *Hydrologic and water quality change scenarios for 20 U.S. watersheds* project. The EPA has agreed to provide 6 to 14 downscaled climate projection scenarios specifically for the MBB to support this project. We will work the EPA and the PAC to select up to three of these climate scenarios to incorporate into the SWAT-VSA model.

**Outcome:** Information on how P loadings from the MBB may change in response to climate projections if best management practices are not adopted to mitigate the situation.

### Task 9: Application and Testing of Simpler CSA Approaches (S)

Development and application of the SWAT-VSA analysis to identify CSAs in the MBB is a complex and demanding task, one that will be challenging to repeat in other areas of the LCB where the need for targeting P reduction measures is also great. Simpler procedures have been used to identify CSAs, often with some success. We will apply two simpler multi-variate GIS overlay procedures for identifying CSAs to the MBB and compare the CSAs developed by these simpler methods to those identified in our strategic analysis. The techniques to be tested are: (1) the modified USLE factor map approach reported by Sivertun and Prange (2003); and (2) the topographic index weighting of export coefficients method of Endreny and Wood (2003).

**Outcome:** Evaluation of and possible recommendation for the application of simpler tools for preliminary assessment of CSAs in other basins within the LCB before full application of SWAT-VSA.

## 4.2. Tactical Analysis (T)

The objective of the tactical analysis is to refine the strategic approach using more precise, site-specific input data and better spatial resolution to improve identification, ranking, and prioritization of CSAs. The modeling approach employed in the strategic analysis was designed so that the primary tactical analysis objective could be simultaneously met; namely, the field and sub-field identification of P CSAs. There are, however, improvements in resolution and several additional components to the tactical analysis that will improve identification and mitigation of CSAs at a finer scale. Results of the tactical analysis will be analogous to the kind of site-specific consideration given to development of a conservation plan for a particular farm or very small watershed.

### Task 10: Development of Enhanced Hydrologic Network (T)

Surface waters, channels, ditches, and gullies that periodically fill with water during storm events are critical pathways of P to the tributaries and main stem rivers that deliver P to Missisquoi Bay. Identification of these surface water features will serve as an important component in determining the optimal locations for management measures and approaches to mitigation of P CSAs.

The 1:5,000 scale Vermont Hydrography Dataset (VHD) will be serve as the basis for an enhanced hydrography dataset that will include more detailed ephemeral and intermittent streams, ditches, and stormwater outfalls. The ephemeral stream and ditch features will be identified using the 1-m resolution LIDAR dataset following methods described in recent publications. Where possible, we will join these new stream and ditch segments to the exiting VHD dataset as part of the hydrologic network. Stone has mapped stormwater outfalls in all significant municipalities in the MBB for the Vermont Department of Environmental Conservation. These outfalls and the connected storm water conduits will be added as features to the enhanced hydrologic network.

**Outcome:** An enhanced hydrologic network GIS coverage to assist in the identification of CSAs at the tactical level.

### Task 11: Prioritization of CSA Locations Using Enhanced Hydrologic Network (T)

The high ranking CSAs identified by the SWAT-VSA model will be further prioritized based on their proximity (based on hydrologic flow path distance) to hydrologically active areas. These active areas will include channels, ditches, and gullies identified from the LIDAR analysis, as well as areas that fall within designated fluvial erosion hazard zones of perennial streams. The hydrologic distance calculation will be based on the high-resolution DEM developed from the LIDAR dataset. CSAs closer to hydrologically active areas will be more likely to deliver P to surface waters entering the Bay and should receive highest priority for site-specific tactical analysis and mitigation

**Outcome:** Incorporation of proximity to hydrologic transport as a component of CSA ranking.

### Task 12: Site-Specific Modeling to Refine Tactical Objectives (T)

Additional site-specific modeling in support of the tactical analysis will focus on agricultural areas because of the dominance of this source type in the MBB. With cooperation and assistance from the PAC and the Watershed Farmers Alliance, we will identify one or two micro-watersheds within the Vermont MBB that contain parts of one to two dairy farms where we can obtain site-specific data required to identify CSAs at the level necessary to determine specific management measures required to reduce P loads. While we will strive to encompass a diversity of agricultural and landscape features, the selection of specific locations for this activity will depend in large measure on obtaining cooperation of individual landowners necessary to access confidential data. Examples of these data include actual soil test P, manure/fertilizer application rates, nutrient management plans, cropping patterns, design and management of barnyard areas and milking center waste discharge.

In the micro-watershed(s), we will apply the Agricultural Policy Environmental Extender Model (APEX) to identify farm-scale CSAs and to evaluate BMPs specifically targeted to the characteristics of the farm operation(s). We will emphasize proximity to surface waters at a level of detail permitted by the small-scale approach and the enhanced hydrologic network. This analysis will include explicit representation of barnyards, manure storage areas, micro-channels and ditches, tile drains, vegetated filter strips and riparian buffers that was not possible at the strategic level due to lack of site-specific information. Particular attention will be paid to the representation of barnyards and productions areas in the APEX model in order to assess their level of significance as phosphorus CSAs. We will simulate targeted BMPs, including those aimed at barnyard/production area sources, to mitigate the P CSAs in the micro-watershed following an approach that would be used in developing a conservation plan for the farm(s).

**Outcome:** CSA identification and BMP prescriptions at a highly specific tactical level.

## 4.3. Outreach and Reporting (R)

### Task 13: Quarterly Reporting (R)

Five quarterly progress reports will be prepared to update the Lake Champlain Basin Program Technical Advisory Committee (TAC) and the PAC on the project status. Meetings between the project's principal investigators and the PAC will occur in conjunction with three of the five quarterly progress reports to discuss the progress report and other project needs. We suggest that the first of these meetings be scheduled in June 2010 to serve as both a project "kick-off" meeting and an opportunity to report on progress made since the initial work plan presentation to the Lake Champlain Basin Program TAC in early May. We propose that the timing of the second and third PAC meetings coincide with the September 2010 and March 2011 progress reports.

Outcome: Regular review and comment opportunities among project staff and advisory committee; required quarterly progress reports to LCBP.

## Task 14: Final Report, Maps, and Data Deliverables (R)

The SWAT-VSA model and thorough documentation of its use will be presented to LCBP and other stakeholders once the modeling is complete. Stone Environmental will conduct a half-day workshop to ensure that project partners are able to perform basic model runs and manipulations for future investigations. A final report will be prepared describing all details of the CSA analysis approach and findings. The final report will include maps of CSAs identified through the SWAT-VSA modeling analysis and will include both the highest resolution, HRU-level CSAs and CSAs at one or more levels or aggregation, such as field, land tract, or subbasin.

**Outcome:** Final written report and delivery of watershed model and supporting datasets.

# 5. DELIVERABLES

The following are deliverables that will be prepared throughout the duration of the project:

## Secondary Data QAPP

A Quality Assurance Project Plan (QAPP) for secondary data collected in support of this project will be prepared. In addition, a primary data component will be added to this QAPP in the event that samples of soil, ditch, or channel sediment are taken as part of the strategic or tactical analyses.

## Quarterly Progress Reports

Brief quarterly progress reports will prepared at the end of each calendar quarter in conjunction with PAC meetings. The specific dates for the delivery of each report are presented in the Schedule section of this workplan.

## Spatial Data Layers

Spatial data layers developed for use as inputs to the SWAT-VSA model during Task 3 will be provided in ArcGIS-compatible vector or raster formats. Metadata associated with each layer will also be included.

## SWAT-VSA Model

The final SWAT-VSA model developed for the identification of phosphorus critical source areas will be provided for future use by LCBP partners. Documentation will be provided to allow users to make basic model runs using modified model inputs and scenarios. In addition, a half day of training will be provided to small group (up to 5) of potential model users on the use of the model. The anticipated complexity of the model developed may require that these users have some previous skills in modeling, GIS, and database management in order to work with the model and its output.

## Enhanced Hydrologic Network Spatial Dataset

A spatial data layer representing an enhanced hydrologic network, described in Task 10, will be developed as part of the tactical analysis. This data layer will be generated for the Vermont portion of the Missisquoi Bay Basin and delivered in an ArcGIS geodatabase feature class format.

## Final Report

A final report detailing all aspects of the strategic and tactical critical source area identification will be prepared. This will include data collection and analysis, model development and application, and critical source area identification. Both electronic and hard copies of the report will be provided.

Maps of phosphorus critical source areas at multiple levels of aggregation will be included as a component of the final report.

# 6. SCHEDULE

The project schedule for completion of the tasks described in Section 4 is provided in the table below.

| Project Objective* | Task | Date(s) | Deliverable |
|---|---|---|---|
| S | Task 1: Construction and Testing of SWAT-VSA Model | 6/1/2010-8/1/2010 | |
| R | Task 2: Development of QAPP | 6/1/2010 - 6/30/2010 | Approved QAPP |
| S | Task 3: Data Collection and Evaluation | 6/15/2010 - 9/1/2010 | |
| S | Task 4: Model Development and Calibration | 9/1/2010 - 1/1/2011 | |
| S | Task 5: Identify P CSAs | 1/1/2011 - 3/1/2011 | |
| S | Task 6: Field Verification of CSAs | 3/1/2011 - 5/1/2011 | |
| S | Task 7: Evaluate Management Scenarios | 3/1/2011 - 5/1/2011 | |
| S | Task 8: Evaluate Climate Scenarios | 3/1/2011 - 5/1/2011 | |
| S | Task 9: Compare Simple CSA Methods | 4/1/2011 - 5/1/2011 | |
| T | Task 10: Develop Enhanced Hydrologic Network | 1/1/2011 - 5/1/2011 | Enhanced Hydrologic Network Layer |
| T | Task 11: Prioritize CSAs | 5/1//2011 - 6/1/2011 | |
| T | Task 12: Site-Specific Modeling | 5/1/2011 - 7/1/2011 | |
| R | Task 13: Quarterly Reporting | 6/30/2010 – 6/30/11 | |
| R | Task 14: Final Report, Maps, and Data Deliverables | 6/1/2011 - 8/19/2011 | Final Report, SWAT-VSA Model |

* S = Strategic Analysis, T = Tactical Analysis, R = Reporting

The schedule for planned project communication is provided in the table below.

| Task | Date(s) | Deliverable |
|---|---|---|
| Quarterly Progress Report 1 | 6/30/2010 | Progress Report |
| Informal Project Check-in | 8/15/2010 | |
| Quarterly Progress Report 2 | 9/30/2010 | Progress Report |
| Informal Project Check-in | 11/15/2010 | |
| Quarterly Progress Report 3 | 12/31/2010 | Progress Report |
| Informal Project Check-in | 2/15/2011 | |
| Quarterly Progress Report 4 | 3/15/2011 | Progress Report |
| Informal Project Check-in | 5/15/2011 | |
| Quarterly Progress Report 5 | 6/30/2011 | Progress Report |

# 7. DETAILED BUDGET

| Task | Personnel | Communications | Travel | Total Task Cost |
|---|---|---|---|---|
| 1. Construction and Testing of SWAT-VSA* | $4,950 | $130 | | $5,080 |
| 2. Development of QAPP | $4,750 | $140 | | $4,890 |
| 3. Data Collection and Evaluation | $29,396 | $736 | | $30,132 |
| 4. SWAT-VSA Model Development/Calibration | $70,054 | $1,055 | $1,500 | $72,609 |
| 5. Application of the SWAT-VSA Model to Identify CSAs | $34,034 | $581 | | $34,615 |
| 6. Field Verification of CSA Rankings | $15,204 | $350 | $1,100 | $16,654 |
| 7. Evaluation Alternative Management Scenarios in Reducing P Loads | $18,696 | $527 | | $19,223 |
| 8. Assessment of P CSAs Based on Projected Climate Conditions | $7,458 | $208 | | $7,666 |
| 9. Application and Testing of Simpler CSA Approaches | $4,650 | $137 | | $4,787 |
| 10. Development of Enhanced Hydrologic Network | $17,952 | $456 | | $18,408 |
| 11. Prioritization of CSAs Using Enhanced Hydrologic Network | $11,154 | $230 | | $11,384 |
| 12. Site-Specific Modeling to Refine Tactical Objectives | $26,692 | $787 | | $27,479 |
| 13. Quarterly Reporting | $6,655 | $196 | $281 | $7,132 |
| 14. Final Report, Maps, and Data Deliverables | $38,850 | $1,084 | | $39,936 |
| **Project Total** | **$290,495** | **$6,618** | **$2,881** | **$299,995** |

**The Blackland Research and Extension Center has offered to match $10,000 in Task 1, Construction and Testing of SWAT-VSA Model, to support modifications to the ArcSWAT interface to enable the enhanced topographic analysis techniques which will aide in the identification of critical source areas.*

# 8. REFERENCES

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## 7.2 Lake Champlain Basin Program MISSISQUOI BAY BASIN PROJECT: SECONDARY DATA EVALUATION 2009 Quality Assurance Project Plan, Version 4

SECTION A: PROJECT MANAGEMENT

1.1 Title & Approvals

# MISSISQUOI BAY BASIN PROJECT: SECONDARY DATA EVALUATION

2009 Quality Assurance Project Plan
Version 4

EPA RFA Number: 09176

Prepared By:

Lake Champlain Basin Program
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Eric Howe, Project Manager, LCBP — Date: 9/10/09

Nicole Grohoski, Project QA/QC Officer, LCBP — Date: 9/10/09

Erik Beck, IJC Contract Officer's Representative, EPA — Date: 9-10-09

Steve DiMattei, QA/QC Officer, EPA — Date: 09-17-09

Michael Jennings, QA/QC Officer, NEIWPCC — Date: 9/15/09

## 1.2 Table of Contents

## 1.3 Distribution List

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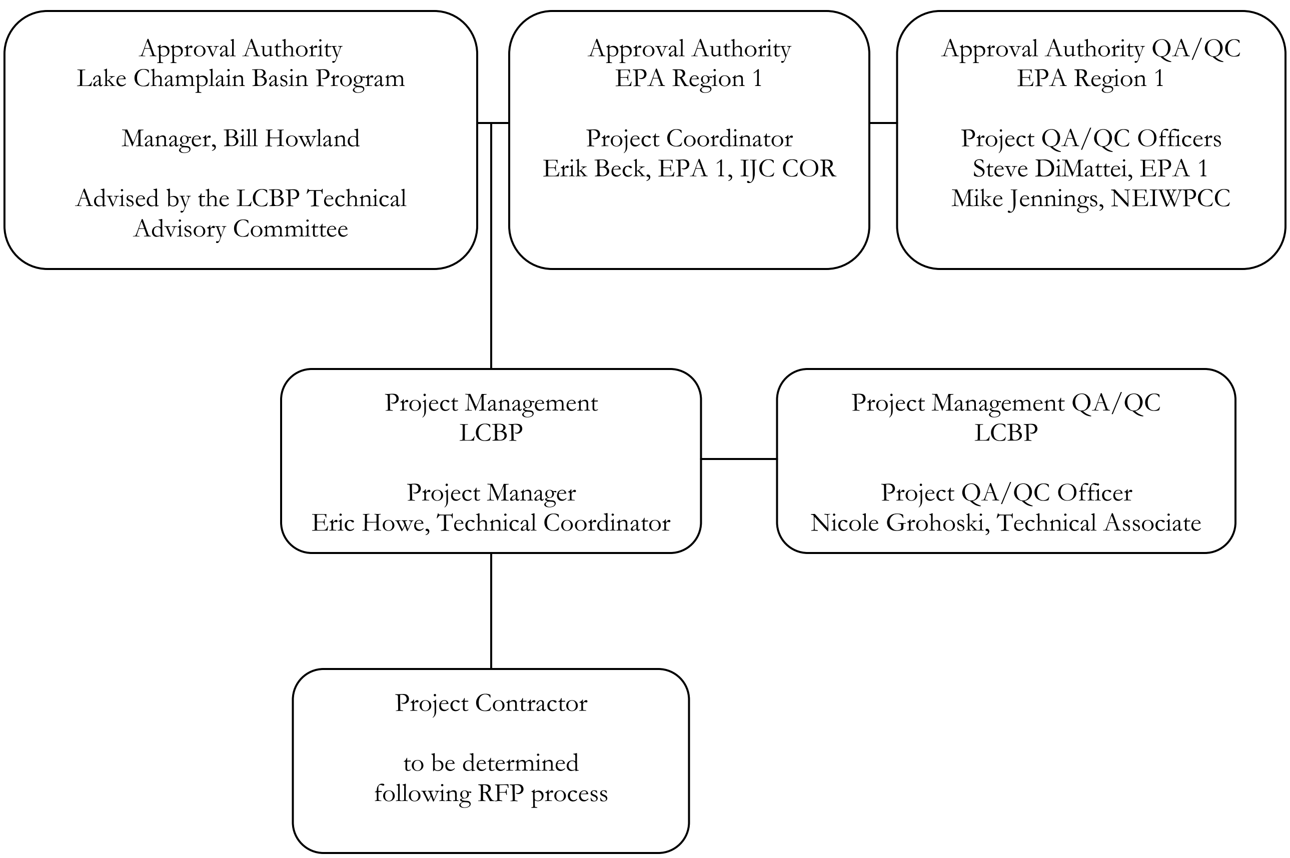
## **1.4 Project/Task Organization**

*Key Individuals and Responsibilities*

The Lake Champlain Basin Program (LCBP) will identify management objectives and desired outcomes for this project, and outline these in a Request for Proposals (RFP). Respondents will propose a modeling approach to satisfy the RFP, which will be subject to an external peer review process before the final contractor is selected. The selected contractor will then provide a detailed workplan for approval by the LCBP and the IJC study board. The contractor will be responsible for selecting and utilizing secondary data that is of sufficient quality for the future modeling effort briefly described in this document. The selected contractor also will be responsible for creating a separate QAPP that will be directly applicable toward the modeling process, as detailed below in Section 1.7.

The LCBP will oversee the contract but will not be responsible for generating any modeling products. LCBP Technical Coordinator, Eric Howe, will oversee the contractor and evaluate compliance with contract requirements. The Project QA/QC Officer, Nicole Grohoski, LCBP, will maintain the approved QAPP and ensure that the contractor follows QAPP procedures and provides appropriate documentation of methodology and model outputs. LCBP technical staff will provide data collection and documentation assistance to the contractor.

*Project Organization*



## 1.5 Problem Definition/Background

Missisquoi Bay has one of the highest in-lake phosphorus concentrations of any segment of Lake Champlain. Phosphorus loads to and concentrations in the Bay greatly exceed target levels designated by water quality criteria for phosphorus endorsed by the governments of New York, Quebec, and Vermont. Furthermore, this phosphorus contributes significantly to blue-green algae blooms (cyanobacteria) in Missisquoi Bay during the summer months. These blooms are frequently dense enough to preclude recreational water contact for many weeks at a time. Loads of sediment and nitrogen to the Bay are also a concern.

While the governments of Vermont and Quebec have made significant progress in reducing the loads of phosphorus to the Bay, more needs to be done in order to meet the target loads. A 2002 agreement between the governments of Vermont and Quebec established that their relative target contributions of phosphorus in the watershed are 60% and 40%, respectively. The Province of Quebec has undertaken several programs to reduce its share of phosphorus loads. Similarly, Vermont has initiated phosphorus reduction programs, but has found reducing phosphorus to be more problematic in its sector of the Basin. On August 1, 2008, the Governments, pursuant to Article IX of the Boundary Waters Treaty of 1909, requested the International Joint Commission (IJC) to assist in the implementation of the transboundary initiative to reduce phosphorus loadings. Recognizing the recent advances made by the Province of Quebec within its areas of jurisdiction, the Commission was requested to coordinate a number of tasks on the U.S. side of the border, in close partnership with the Lake Champlain Basin Program.

As part of this coordination, the IJC has contracted with the LCBP to acquire, assimilate, and publish relevant datasets in order to develop a transboundary understanding of pollutant loads from the Missisquoi Bay Basin (MBB) and to facilitate the development of a pollutant loading model for the Bay. The model will be created, validated, and operated by a contractor in accordance with contract requirements and an approved workplan in order to better inform the current understanding of nutrient pollution to the Missisquoi Bay. The information generated by modeling will be used by local stakeholders and agencies to guide management decisions and efficient implementation of phosphorus reduction strategies. Ultimately, the goal of this work is to reduce external loads of phosphorus, nitrogen, and sediments into Missisquoi Bay so that water quality standards are consistently achieved.

## 1.6 Project/Task Description

Work to support modeling efforts will be determined by the scope of the RFP and the selected approach to identifying critical source areas (CSAs) of phosphorus pollution. Such work might include acquiring relevant monitoring results (e.g. water quality, stream flow, meteorological) in appropriate time units or contacting agencies to aggregate and release confidential agricultural data. A schedule for completing this work and the model construction, corroboration, and application will be defined within the final contract and the project workplan. All work will be completed before September 1, 2011, when the final project report is due to the IJC. The project will be limited to the Missisquoi Bay Basin (defined as all watersheds flowing into the Bay) of Vermont and Quebec, but will be refined further, depending on submissions in response to the RFP.

## 1.7 Quality Objectives and Criteria for Measurement Data

The selected project contractor (following the RFP process) will be responsible for specifying data quality indicators for all model data inputs. Such indicators should discuss the type and quality of data that are appropriate for use in this project, the spatial and temporal extent of data inputs, data currency, and the technical soundness of the collection methodology. Acceptance criteria will be designed to help assure that the modeling effort meets defined management objectives.

A separate QAPP, to be prepared by the selected project contractor, will address quality assurance procedures specifically related to the modeling process. Acceptance criteria for model calibration will aim to identify an acceptable range of difference between predicted and observed values of the model to optimize the model results. Calibration criteria will be based on relevant literature for the modeling approach specified by the contractor. Statistical tests may be applied as appropriate. Model validation should call upon data excluded from the calibration process, to determine the predictive abilities of the model. Validation techniques will be applied based on the spatial and temporal characteristics of the model. The contractor will assess the sensitivity of the model to determine how changing input parameters affects the model outcome. Potential sources of uncertainty include: estimated model parameter values, observed model input data, and model structure and forcing functions. The LCBP will conduct periodic uncertainty analyses as the model is applied in the future to determine the magnitude and frequency of differences between predicted and observed values. Such analyses will occur after this project is completed and will help to inform users of the character of the model output information and guide related management actions.

## 1.8 Special Training/Certifications

The contractor selected through a peer review process will be familiar with the modeling approach proposed and how it should be applied to meet specified objectives. Therefore, no special training or certifications should be required for project personnel.

## 1.9 Documentation and Records

The project contract will require the successful respondent to produce a project workplan, quarterly reports and a comprehensive final report. These reports and the project workplan will detail the following project information, as it is determined or becomes relevant:

- **Model Structure**
    - Explanation of and justification for modeling approach
    - Adjustments made to modeling software or development of new modeling protocols
    - Model parameters
    - Model assumptions
    - Calibration, sensitivity, and validation procedures
    - An approved Quality Assurance Project Plan for the modeling task
- **Data Inputs**
    - List of data inputs to the model
    - Adherence to the QA/QC procedures before use of data
    - Documentation of data limitations and effect on data outputs

- List of data used to calibrate and validate models
- Metadata for acquired datasets
- Documentation of any edits made to acquired datasets

- **Data Outputs**
  - List of data outputs produced
  - Quality assessments of output data
  - Metadata for final geographic data files

Data generated by this project will be stored by the contractor for the duration of the contract and for five years subsequent to the conclusion of the contract and also will be permanently stored by the LCBP after the project is completed. Supporting documentation and submitted reports will be stored by the LCBP. Final products will be made digitally available to the public on the LCBP website. Digital products will be stored both at the LCBP office server and archived on discs. All changes to the QAPP will be distributed to the appropriate officers and the contractor by the Project QA/QC Officer, following approval by NEIWPCC, EPA, and the International Joint Commission Contract Officer's Representative (IJC COR).

## SECTION B. DATA GENERATION AND ACQUISITION

### 2.1 Data Acquisition Requirements

All secondary data and information that will be used for the project, including originating sources, planned uses of the secondary data and information, and limitations on use of this data and information will be identified by the contractor and provided as a deliverable with the final product, following the format guidelines exemplified in Table 1, below. Data to support modeling may be obtained from governmental agency or group databases or files and from geographic data clearinghouses. It may also be collected from other research/modeling efforts. Some data may require aggregation by data-holders before it can be shared with the contractor. All data used must be publicly available so that final results can be published. Values for parameters may be obtained from published scientific literature.

| **Non-direct measurement data type** | **Data source** (originating organization, report title, publication date) | **Data generator(s)** (originating organization, data type, data generation/collection date) | **How data will be used** | **Limitations on data use** |
|---|---|---|---|---|
| Land use/land cover grid | Vermont Center for Geographic Information, "LandLandcov_ LCLULCB01 ", 03/2007 | University of Vermont Spatial Analysis Lab, raster file of 8-class land use/cover data, 2001 | To represent land use/cover in the Basin for 2001, especially agricultural and urban | 1. Overall accuracy calculated at 88%. 2. Limited classification of land use/cover. 3. Coarse resolution (30m) |

**Table 1**. Example of a table to be filled out by the contractor for any data considered for use in a model.

Such a table will be used to document types of data needed from non-direct measurements, including their sources, relevancy, uses, and limitations on use. The contractor will use publicly-available data that are the most recent, high resolution, and spatially uniform available and required by the modeling approach. In the case of low-resolution or outdated data, the modeler must justify how use of these data will help refine the model outputs, rather than confound them, and document how use of these data will affect the accuracy and precision of the model output.

### 2.2 Data Management

Both non-direct measurement data and primary data used in this project will be compiled from relevant data sources by the contractor and shared with the LCBP for permanent, electronic storage. All data will be obtained in a digital format from their generators, thus eliminating database entry error by the contractor. In addition to this data, the LCBP maintains a geospatial database for this project and a spreadsheet describing included files, which will be shared with the contractor. The contractor will then update this file as data is added or eliminated from the project database. Any data obtained for this project must include metadata, whether written in a standard format by the data generator or documented with the best information available to the contractor.

Once the project is completed, the LCBP will permanently archive relevant input and output datasets in its office. The LCBP will then publish a list of these datasets on its website. Each data entry on the list will be hyperlinked to metadata, so that users can determine the utility of the data for their needs. This data list will be updated as new data is developed or becomes available, so that it is not a static source. Users interested in acquiring data will be instructed to contact the LCBP or original data providers in order to receive desired data. The website also will provide links and/or contact information for primary data sources of spatial or monitoring data. All LCBP data handling tasks will be organized and overseen by the Project QA/QC Officer.

The contractor shall provide any software and hardware necessary for data and model processing during this project. The performance capacity of these software and hardware packages will be documented by the contractor and must be adequate to accomplish specified project goals. Minimum hardware requirements for the software packages must be met, as specified by the manufacturer.

## SECTION C. ASSESSMENT AND OVERSIGHT

### 3.1 Assessment and Response Actions

The contractor will evaluate data generated as part of the modeling during the validation process by comparison with observed historical data. This assessment will be included in the final project report, with modeling decisions and parameters explained. Data and intermediary project deliverables will be reviewed by the LCBP to ensure that methodologies and processes are consistent with this QAPP and the project workplan. Deviations from the QAPP will be addressed by the Project QA/QC Officer and subject to NEIWPCC, EPA, and IJC COR approval, in order to either correct the problem or amend the QAPP as needed. Contractors will be notified in writing of any nonconformance and must take appropriate corrective action. NEIWPCC may implement, at its discretion, various audits or reviews of this project to assess conformance and compliance to the quality assurance project plan in accordance with the NEIWPCC Quality Management Plan.

The LCBP will conduct a confidential peer review of the contractor's final project report and will obtain a technical assessment of the results of the review from the LCBP Technical Advisory Committee (TAC). Once approved by the LCBP, the contractor's final report will be submitted to the IJC COR in the final Missisquoi Bay Basin Project report. The final Missisquoi Bay Basin Project report by the LCBP, submitted to the IJC COR, will include a summary of the steps taken to select the modeling approach.

### 3.2 Reports to Management

The contractor will be responsible for submitting quarterly reports to the LCBP for the duration of the project. These reports will describe the status of the project, accomplishments made during the reporting period, activities planned for the next period, and any challenges or problems faced. Other intermediary reports addressing topics such as data assessment, model construction, and model calibration/validation may be specified in the project contract. All reports must be submitted to the LCBP according to the project schedule or be granted extensions by the Project Manager. The Project Manager will determine if the reports satisfy the contract, workplan, and QAPP requirements before accepting them.

## SECTION D. MODEL APPLICATION

### 4.1 Model Parameterization and Corroboration

Model parameterization and corroboration activities will be defined within the contractor's workplan once the scope and methodology of this project are defined. This may include methods for: calibration, stopping calibration, parameter estimation, determining uncertainty, sensitivity analyses, validation, use of independent datasets for validation, and future calibration/validation maintenance. The contractor will provide a separate Model QAPP addressing quality assurance issues for each of these steps in the workplan.

### 4.2 Reconciliation with User Requirements

The LCBP is committed to the development of a representative modeling product that meets the management goals specified in the RFP. The LCBP will ensure that the contractor maintains complete documentation so that the modeling data can be properly reviewed. The final project report will be peer-reviewed to assess adherence to quality assurance requirements and the ability of the model to produce results of sufficient quality. The reviewers will provide recommendations about the effectiveness of the modeling effort for watershed planning and decision-making, which will be submitted to the LCBP TAC and the Project Manager. Once approved by this group and the IJC COR, the model and its results will begin to inform local management decisions.

## 4.3 Model Limitations

All models are a simplification of environmental processes and cannot precisely represent natural systems. There is no simple test that can determine the validity of a model; models cannot be expected to be more accurate than the sampling and statistical error inherent in the input and calibration data. Thus, the following principles provide a final set of evaluation criteria for this modeling project.

- Exact duplication of observed data is not possible, so the model validation process must assess the ability of the model to simulate these values.
- All model and observed data comparisons must recognize, either qualitatively or quantitatively, the inherent error and uncertainty in both the model and the observations. Model sensitivity and uncertainty will be documented, where possible.

## SECTION E. MODELING REPORTS

The final modeling report submitted by the contractor should follow the format outlined below. Additional information to include may be specified in the contract or required by the Project Manager, as deemed necessary. This final report, once reviewed by the LCBP and its TAC, will be submitted to the IJC COR with a summary of LCBP activities, including the process of choosing the successful applicant to the RFP.

- Introduction
- Background
- Purpose of modeling/modeling objectives
- Scope and approach for each model used (including physical setting and hydrology)
- Observational data used to support modeling
    - Quality of acquired data (and references to data quality reports)
    - Achievement in meeting acceptance criteria
- References to monitoring data
- Discussion of excluded data and basis for exclusion
- Description of model including benefits of this approach as compared to other models
- Model configuration (discusses how model was applied)
    - 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)
    - Changes and verification of changes made in code
- Model parameterization (calibration) and corroboration (validation)
    - Objectives, activities and methods
    - Parameter values and sources
    - Rationale for parameter values in the absence of data
    - Model validation results
    - Calibration targets
    - Measures of calibration performance
    - Calibration input, output and results analysis
    - Model validation results
- 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 evaluation
- Performance against acceptance criteria for calibration, validation, sensitivity and uncertainty
- Pre- and post-processing software development
- Maps and schematics (if appropriate)
- Complete copies of the applicable approved Modeling QAPP and Secondary Data QAPP
- Deviations from either the Modeling QAPP or the Secondary Data QAPP
    - List of non-applicable reporting elements with explanations
- Conclusions and recommendations
- References and appendices