Missisquoi Bay Basin Project:
Identifying Critical Source Areas of Pollution

Final Workplan for Modeling
13 May 2010

On April 13, 2010, the LCBP Executive Committee – based on a thorough review process including recommendations from five confidential peer reviewers, the LCBP Technical Advisory Committee (TAC), and the IJC Study Board – approved the project proposal of Stone Environmental, Inc. to model and identify sources of phosphorus pollution in the Missisquoi Bay Basin of Vermont. Stone Environmental submitted a draft project workplan to the LCBP on April 28, 2010. This workplan was reviewed in detail by a team consisting of LCBP staff and members of a LCBP phosphorus reduction workgroup, representing the LCBP TAC. On the whole, the workgroup was satisfied that the workplan addressed the intent of the original RFP as well as the proposal itself. The workgroup recommended the elimination of a web-based mapping application to share modeling results; the resources allocated to this task have been redistributed to strengthen the tactical analysis of agricultural areas. The workgroup also recommended several minor clarifications to the workplan, which were forwarded to Stone Environmental for incorporation into their revised workplan.

Stone Environmental, Inc. addressed many of these comments in their workplan presentation at the May 5, 2010 TAC meeting. The TAC provided comments, improvements, and modifications to the workplan which have been incorporated into the project workplan. On May 7, 2010, members of the IJC Missisquoi Bay Study Board, IJC representatives, and LCBP staff discussed the workplan by conference call and generally agreed with prior comments and revisions. Stone Environmental was provided with their additional comments, incorporated them, and produced the final *Project Workplan*, as appended here. The LCBP submits this workplan, as written by Stone Environmental, in fulfillment of the first deliverable of Task 9.3.4.2.1.

Appended File

1. Identification of Critical Source Areas of Phosphorus Pollution within the Vermont Sector of the Missisquoi Bay Basin: Project Workplan [May 13, 2010]

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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