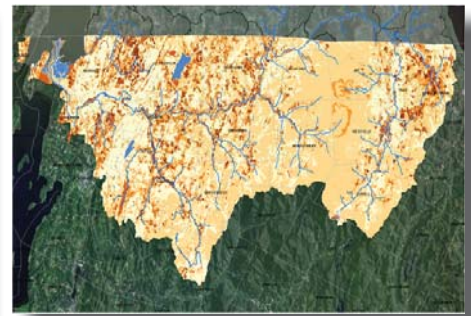Lake Champlain
Basin Program

Modeling Efforts and Identification of Critical Source Areas of Phosphorus Within the Vermont Sector of the Missisquoi Bay Basin

December 2011

Prepared by Eric Howe, William Howland, and Stephanie Strouse
Lake Champlain Basin Program

for
The International Joint Commission

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Modeling efforts and identification of critical source areas of phosphorus in the Vermont sector of the Missisquoi Bay basin

Avg. Annual Total P (kg/ha)
- <= 0.10
- 0.11 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- > 2.00
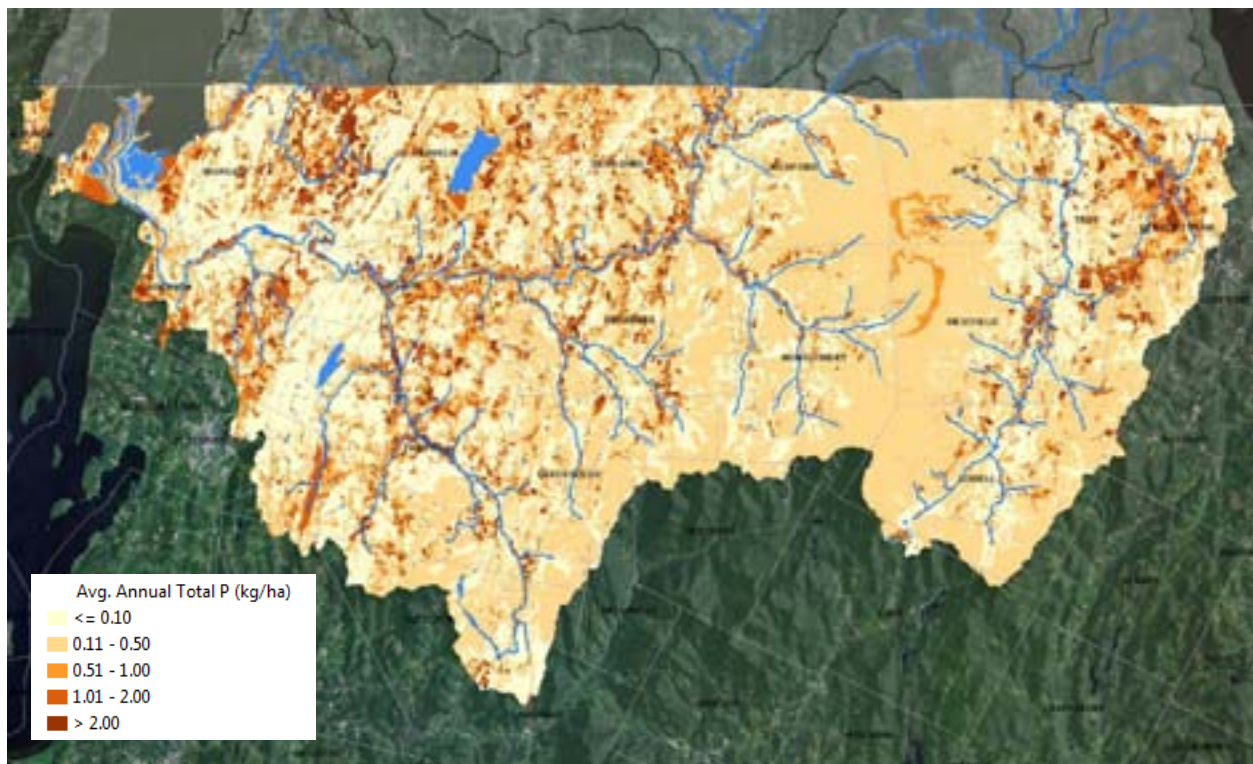
A Final Report to the International Joint Commission by the Lake Champlain Basin Program

21 December 2011

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Background

In 2008, the International Joint Commission (IJC) entered into a contract with the Lake Champlain Basin Program (LCBP) to develop a project to identify critical source areas (CSAs) of phosphorus in the Missisquoi Bay watershed of Lake Champlain. Missisquoi Bay, a cross-boundary segment of Lake Champlain (US and Canada) has one of the highest in-lake phosphorus concentrations of any watershed in the Lake Champlain basin. Phosphorus loads and concentrations in the Bay greatly exceed target levels designated by water quality criteria endorsed by the governments of Québec and Vermont. Total sediment loads and nitrogen to the Bay are also a concern. Average annual loadings of phosphorus are 188 metric tons/year, with an estimated 63% from Vermont and 37% from the Québec portion of the watershed. The combined average flow of the three primary tributaries to Missisquoi Bay (Pike, Rock, and Missisquoi rivers) is 2,500 cubic feet per second (cfs), of which the Missisquoi is the largest with an average annual flow of 1,700 cfs and an approximate length of 154 km. The total drainage area of the Missisquoi watershed is 310,527 ha, approximately 60% of which lies within Vermont and the remaining 40% lies within Québec. In 2008, the IJC was tasked by the governments of the United States and Canada with assisting in the identification of CSAs of phosphorus loadings in the watershed in order to inform water quality management efforts. Recent research advances made by the Province of Québec within its jurisdiction provided a model that was helpful to the LCBP in formulating critical source area research tasks on the U.S. side of the border. A series of workshops was held in late 2008 and early 2009 to discuss and design the research components of the project, including additional tributary monitoring to support the modeling effort that would be the primary deliverable; definitions of critical source areas of phosphorus pollution; approaches to understanding phosphorus pollution including identification of applicable models to identify CSAs; and a final workshop to identify data needs to support a CSA modeling project in the Missisquoi Bay Basin. More information about these IJC-funded projects, including reports, approved deliverables, and relevant datasets can be found on the LCBP website at http://www.lcbp.org/ijc.htm.

Historical and current modeling work in the Missisquoi Bay Basin

Québec

In 2004, IRDA completed a study to develop a model that simulated phosphorus transport from fields through tile drainage in the Missisquoi Bay basin (Simard, et al., 2004). The study concluded that though tile drainage accounted for less than 10% of the total phosphorus runoff in a given watershed, a significant amount of water and phosphorus from upland sources moved through tile drains before entering the waterways. The study provided key interpretations of phosphorus movement through tile drainage systems.

In 2004, a different study investigated land use effects on phosphorus export in the Missisquoi Bay watershed (Michaud and Laverdiere, 2004). The study simulated rainfall on runoff areas with an array of land use, crop cover, manure application and soil type. The investigators concluded that the type of soil accounted for 70 % of the total phosphorus export variability. Cropping interaction with different soil types also accounted for a significant portion of phosphorus export, while manure application accounted for 35 % of the export variability.

In 2010, scientists at McGill University studied the daily phosphorus flux in Missisquoi Bay and identified that bare land after harvest contributed 82 % of the annual phosphorus discharge in the watershed (Adhikari, Madramootoo and Sarangi, 2010). The study focused on indicators of non point source phosphorus pollution in the Pike River basin, a tributary to Missisquoi Bay. Primarily using remote sensing with the capability of applying SWAT parameters, the study concluded that 73% of available phosphorus in the watershed could be explained based on phosphorus budgets in land specified as agricultural. These conclusions led researchers to identify specific features of agricultural land and land use that enhanced phosphorus loading to the hydrographical network. A more conclusive study with more detailed land use, including tile drainage areas and BMP scenarios, was necessary to create a comprehensive phosphorus loading model.

In 2007, IRDA has applied SWAT to the Pike River Watershed, a 600 square-kilometer basin to characterize the landscape and reproduce the transport of water. It was also used to quantify the amount of phosphorus non-point source runoff and to target and predict the effectiveness of BMP scenarios. Monitoring data from the watershed calibrated and validated the model. The results of the model show that there is a high spatial variability within the Pike River Watershed, with 10% of the agricultural areas contributing 50% of the total phosphorus export. BMP scenarios were tested to optimize phosphorus reductions and feasibility of implementation. While the model could determine what is feasible, the exercise did not indicate where the BMPs should be placed at the field scale.

Remote sensing was used to determine the location of vegetation, wet areas, tile drains, and buffer strips. Multispectral imagery was used to develop a wetness index, to help identify areas that are prone to runoff. Techniques that can determine microtopography, including GPS, LiDAR and Corelator 3-D, were found useful for identifying critical source areas. The Phosphorus Export Diagnostic Tool (p-edit), a quantitative phosphorus index for Quebec is continuing to be applied and further developed using readily available information.

Vermont
Two modeling approaches were recently completed for the Rock River Watershed by researchers at the University of Vermont: a farm-scale model (IFSM) and a watershed scale model (SWAT). The farm scale model was used to identify farm phosphorus imbalances that have a potential to cause elevated soil phosphorus levels. The watershed model was used to identify critical source areas of phosphorus. More information can be found in the project completion report on the LCBP website, at http://www.lcbp.org/techreportPDF/60%20P%20Accounting%202010.pdf.

The Integrated Farm System Model (Rotz and Coiner, 2006) was used to account for farm phosphorus inputs and outputs on three Vermont dairy farms with different farming practices (a grass-based organic farm, a full confinement farm, and a mixed system farm with confined mature dairy cows and grazed heifers). The modeling results illustrated the extent of the phosphorus imbalance for each farm and the potential alternative strategies that might address these problems. Addressing phosphorus imbalance problems directly targets the root cause of phosphorus soil build-up on the farms and ultimately will reduce phosphorus loadings to streams flowing to Lake Champlain.

The three farms studied each had phosphorus imbalances, which ranged from 4.9 lbs/acre to 16.7 lbs/acre among the farms. Though each study farm's case was different, critical sources of phosphorus imbalances common among the farms were: 1) feeding levels of supplementary dietary mineral phosphorus, 2) sources and types of protein and energy supplements, and 3) levels of productivity and use of homegrown feeds in animal diets. Overfeeding of mineral phosphorus supplements, low-productivity of homegrown feed (including grazing land) coupled with lower utilization of homegrown feed in animal diets, and a higher reliance on purchased protein and energy feed supplements to meet animal requirements for growth and production (milk, meat and others) were all contributors to the imbalances on these farms. Modeling results demonstrated that by implementing alternative management strategies for each farm, farm imbalance problems could be addressed while maintaining farm profitability. This model-based approach is widely applicable, as is the methodology of representing existing and alternative whole-farm system management strategies to evaluate and quantify the impacts of implementing these strategies on farm-level phosphorus and farm profitability.

The Soil and Water Assessment Tool (SWAT; Neitch et. al 2008) was used by in the Rock River watershed to model the hydrology, sediment transport, and phosphorus in the watershed. Proportions of phosphorus loss contributed by subbasins of the Rock River Watershed and different landuses within each subbasin were estimated. One of the conclusions from this study indicated that, due to variability in topographic, hydrologic, soil, and management factors, nonpoint phosphorus sources do not contribute equally to water impairment. Some nonpoint sources (CSAs) contribute disproportionally higher phosphorus losses than others. This SWAT-based study identified and quantified Critical Source Areas for phosphorus losses in the Rock River Watershed, and presented the extent and landscape characteristics of these CSAs for phosphorus loss.

Based on the modeling results, about 24% of the upland watershed area was producing more than 1.4 kg/ha of total phosphorus and about 80% of the total phosphorus load. The same 24% of the watershed area also was responsible for about 91% of the total sediment load. Critical source areas for phosphorus loss had the following landscape characteristics: less ground cover, easily eroded soil types, steep slopes, and phosphorus availability. Depending on the phosphorus reduction planned, and the availability of resources needed, other threshold values for phosphorus loss can be used to define critical source areas and would target different percentages of the watershed at high risk for phosphorus losses.

In 2007, LCBP awarded an IJC-funded project to Bourdeaus & Bushey, Inc. to prepare Nutrient Management Plans (NMPs) that meet the NRCS 590 standard, for thirty small farm operations in the Missisquoi Bay Basin. The project encompassed 400 fields and approximately 4,500 acres. The data gathered in this project helped farmers make better management decisions. The project included data from 30 farms for 385 individual crop fields encompassing 4,286 acres of tillable crop land. The potential phosphorus loss reductions that could have been achieved by NMP implementation were calculated as the difference between the 2008 Actual Total P, Sediment Bound P, and Dissolved P Index scores and the calculated 2008 P Index scores from practices outlined in the 2008 Plans. The actual farm records compiled from 2007 and 2008 were used to compare pre-and post-planning changes in farm practices,

reported as a change in P Index scores for all fields. The 2007, 2008 and 2009 Plans were presented to each farmer for their use in their management decision process.

The average Total P Index score across all farms decreased by 8% from 54.6 in 2007 to 50.3 in 2008. The Sediment Bound P Index score portion of the Total P Index score was reduced 10% from 17.0 to 15.3, while the Dissolved P Index portion was reduced 7% from 37.6 to 34.9. The overall reduction in Total P Index score was less than the potential reduction of 18% which could have been achieved if the 2008 nutrient management plan had been strictly followed by all farmers. Lack of adoption of specific practices, including streamside vegetated buffers, manure spreading setbacks and reduction of total P applications from manure, contributed to the lower than expected reductions achieved. Similar reductions in P Index scores were shown in the 2009 Plan which was provided to each participant farmer to enhance their ability to continue with the Nutrient Management Plan process. More information can be found in the project completion report on the LCBP website, at
http://www.lcbp.org/techreportPDF/58_Phos_Runoff_missisquoi_2009.pdf

In 2009, the VT Agency of Natural Resources and the LCBP jointly entered into an agreement with the USDA National Sedimentation Laboratory to conduct a study to determine rates and loadings of sediment and phosphorus from streambank erosion along the main stem of the Missisquoi River and four secondary tributaries, including Hungerford Brook, Trout Brook, Tyler Branch, and Black Creek. This work was conducted using the Bank-Stability and Toe-Erosion Model (BSTEM). The final report for this project will be completed in early 2012.

Preliminary conclusions from this study, released in fall 2011, indicate that streambank erosion appears to be an important contributor of sediment to the Missisquoi River, contributing at least 29 – 42% of the suspended-sediment load. Additionally, streambank erosion appears to be an important contributor of total phosphorus to the Missisquoi River, contributing about 50% (73.4 T/y) of the TP load and average, annual streambank loadings may exceed 41,000 m^3/yr. Delivery of fine-grained bank sediment to Lake Champlain ranges from 14,500 (silt/clay) to 21,500 m3/y (silt/clay plus very-fine sand). Vegetation was found to be critically important in reducing streambank erosion rates. Load-reduction scenarios showed mixed results: reducing slope banks to a 2:1 pitch provided a 2-3% reduction in phosphorus load; reducing slopes to a 2:1 pitch with vegetation established after 5 years, provided a 90-91% reduction in phosphorus load; and allowing vegetation to mature without altering stream bank slope provided a 9% reduction in phosphorus load. However, the contractor advised that attaining the 90-91% load reduction is unlikely without additional measures.

In 2009, the LCBP awarded a contract to LimnoTech, Inc., to develop a predictive model of phosphorus responses to changes in external loading in the Missisquoi Bay watershed. Output from this model will allow the contractor to investigate temporal dynamics and internal sediment interactions on a seasonal basis. This study is investigating the importance of legacy sediments and internal nutrient cycling mechanisms, to identify the critical point at which external nutrient load reduction will no longer be a driving factor in the Bay's water quality. This project is expected to be completed in early 2012. Preliminary results are not yet available.

Request for Proposals

Informed by the outcomes of the workshops, a critical source area of phosphorus was defined as the intersection of a source of excess phosphorus and a transport mechanism, usually a waterway. A Request for Proposals (RFP) was developed in coordination with the IJC Missisquoi Bay Study Board and the LCBP Missisquoi Bay Project Workgroup. The outcome of the selected proposal would be the identification of critical source areas (CSAs) of phosphorus pollution in the Missisquoi Bay basin, information that would subsequently enable resource managers to reduce phosphorus loading in the Missisquoi Bay watershed. This goal would be accomplished by identifying and delineating areas within the Vermont sector of the basin that contribute disproportionately large amounts of pollution to Missisquoi Bay, in order to efficiently target limited resources to reduce phosphorus loads. The RFP was released on January 25, 2010, and proposals were accepted until March 5, 2010. Through a competitive selection process, the project was awarded to Stone Environmental, Inc. in spring 2010 to conduct the work.

The Critical Source Area project

Stone Environmental proposed to parameterize an updated version of the Soil and Water Assessment Tool (SWAT), with a Variable Source Area function (SWAT-VSA), allowing the SWAT model to more accurately identify CSAs in the Missisquoi watershed. Once the SWAT-VSA model was parameterized, Stone Environmental proposed to apply the model at a strategic level to identify CSA sectors of the Missisquoi watershed. Subsequent objectives at the strategic level were: to evaluate phosphorus load reduction potential for a suite of Best Management Practices (BMPs) that could be implemented in the Missisquoi Bay watershed; a comparison of phosphorus load reduction potential of random implementation of BMPs (current practice) against implementation of BMPs targeted to CSAs; a comparison of the results from the SWAT-VSA model to simpler multivariate GIS techniques that could be applied to other sectors of the Lake Champlain Basin; and evaluation of phosphorus loading changes in response to predicted precipitation and temperature changes from leading climate change models. At the tactical-level, Stone Environmental proposed to explore the application of precise, site-specific input data and improved spatial resolution to improve identification and ranking of CSAs at the farm-scale.

The first task undertaken by Stone Environmental was to develop a secondary data Quality Assurance Project Plan (QAPP) under which all work for this project could be quality-assured. After the QAPP was approved by the contracting agencies, Stone Environmental commenced data collection and parameterization of the model. Stone Environmental assembled a Project Advisory Committee, recruiting experts from federal, state, academic and private institutions in the region, who are familiar with various land use practices applied in the Missisquoi Bay watershed, the regulations governing those practices, and the overarching water quality issues in the Bay. This advisory committee met with Stone three times, providing advice on specific aspects of the project – data acquisition and availability, interpretation of available data, assumptions for parameterizing the model, and model calibration and validation.

SWAT model parameterization

To parameterize the model, Stone acquired data from several sources, primarily from federal and state agencies, provincial ministries, local academic institutions, and the agronomic community in the Missisquoi watershed, to guide both the strategic-level and tactical-level models.

Topographic data

Recently acquired LiDAR data (airborne laser swath mapping), along with a hydrographic elevation model, provided the digital elevation models (DEMs) necessary for topographic analysis in the Vermont portion of the watershed. The Canada Digital Elevation layer provided topographic data for the Québec portion of the basin. A compound topographic index (CTI) layer of the watershed was then developed from these DEMs at a 10-m resolution identifying hydrologic flow-paths to delineate Hydrologic Response Units (HRUs). The CTI layer indicates areas of increased saturation and likely excess surface runoff. LiDAR topographic data also were used in selected areas in the tactical scale analyses.

Weather and Climate data

Weather and climate data were acquired from climate data projects, such as PRISM, the National Climatic Data Center (NCDC), and the Institut de Recherche et de Développement en Agroenvironnement (IRDA). These data were compiled in SWAT to develop a climate time series specific to the Missisquoi Bay watershed, to calibrate the model for execution of daily runoff simulations.

Land use data

Land use data for Vermont were acquired primarily from the University of Vermont Spatial Analysis Laboratory and the National Land Cover Dataset, both originating in 2001. Québec land use data, originating in 2010, were acquired from IRDA. Stone Environmental merged these datasets to create a hybrid land use layer to utilize strengths from both datasets and new enhancements. Supplementary datasets were acquired to better classify agricultural fields, farmsteads, roads, waterbodies and waterways, and wetland areas.

Soils data

Accurate soils data are extremely important for correct identification of HRUs in the SWAT model. The Soil Survey Geographic database (SSURGO), developed by the USDA-NRCS in 2009, was acquired as the primary base soils layer in Vermont and complementary data were provided by IRDA for Québec. These two primary datasets were then merged into one hybrid soils data layer for the Missisquoi watershed and incorporated into the SWAT model.

Soil phosphorus data

Soil phosphorus data are one of the critical and challenging required inputs of the SWAT model. Soil phosphorus data availability is very limited for the Missisquoi watershed. Available data are primarily aggregated at the town level, making it very challenging to spatially-reference soil P conditions in the watershed. Soil-test P values that were available were evaluated and cross-referenced with known land

uses for those regions. A suite of default soil-test P values was then assigned to each of the land use categories identified in the SWAT model.

Agronomic data

Parameterizing the model for specific agronomic practices was very challenging, as most of the existing data are confidential and not available for inclusion in the SWAT-VSA model. To address this problem, Stone Environmental primarily relied on default SWAT-VSA model values and modified those values based on input from experts in the field and from information provided by the farming community in the watershed. Ultimately, given the paucity of available data, informed assumptions were made regarding crop rotation practices and manure application rates.

Other data sources

Data for urban and developed lands, paved and unpaved roadways, and residential fertilizer applications were synthesized by modifying SWAT-VSA default values for these parameters, informed by anecdotal information for the Missisquoi area. Stream channel characteristics were parameterized by geomorphic assessment data provided by the Vermont Agency of Natural Resources, a Missisquoi river Bank Erosion study conducted coincidentally by the USDA National Sedimentation Laboratory, and soils data collected by the NRCS and the University of Vermont.

The Enhanced Hydrologic Network

LiDAR data available for a majority of the Vermont side of the Missisquoi watershed enabled the development of an enhanced hydrologic network for this portion of the basin. This allowed for delineation of minor waterways in the basin – ditches, gullies, overland flow paths – and connections of these features to primary tributaries and ultimately delivery of sediment and nutrients to the major tributary network. From this information, hydrologic proximity of phosphorus sources to the hydrologic network were calculated. Data sources applied in this exercise are described above in the topographic data section.

Model calibration and validation

Model calibration and validation exercises were conducted using the data sources described above. The calibration period was 10/1/2005 – 9/30/2010; the validation period was 10/1/2001 – 9/30/2005. Calibration and validation routines were examined for hydrology, sediment load, and phosphorus load. Once the model was calibrated and validated for the hydrology component, the sediment and phosphorus components were calibrated, as these routines are dependent on accurate hydrology. Overall, the model met or exceeded all pre-established targets. The model simulations did appear to miss some of the larger event peaks in the hydrology component, and this modest error carried through to affect the sediment and phosphorus components. However, the error estimates between the observed and simulated data were well below typical thresholds, indicating the model was accurately calibrated, given available data.

Model results

Strategic analysis

The SWAT-VSA analysis estimated that approximately 59% of the average annual sediment and and 61% of annual phosphorus loads are contributed by the upland areas of the watershed, with the remainder for each coming from the stream channel. These findings are consistent with those of a concurrent study conducted by the USDA Agricultural Research Station, National Sedimentation Laboratory, which focused on sediment and phosphorus loadings from the stream banks of the main stem of the Missisquoi River and five secondary tributaries (report to be released in early 2012; see BSTEM project above for more details). The SWAT-VSA analysis also estimated that approximately 20% of the watershed area likely generates nearly 74% of the total phosphorus exported within the study area from the upland portion of the watershed.

The CSA information provided through the SWAT-VSA will be extremely useful for optimizing management resources to target critical sources of phosphorus in the Missisquoi watershed. An analysis of the representative land uses in the watershed indicates that fields in corn-hay and corn-soy rotation contribute the greatest amount of phosphorus on an annual basis in the basin, followed by forested lands and hay-cropped fields.   Forested lands are high contributors because of the large percentage of acreage of the basin that is forested; on an acre-for-acre basis, forested lands are very low contributors of phosphorus. Please see Table 3.4 of the attached report for more detailed information.

Factors found to most greatly influence phosphorus export included combinations of soil hydrologic group (sand-dominant vs. clay-dominant soils), slope, and proximity to waterways. Sub-watersheds with the greatest percentage of agricultural land (e.g. Rock River, Mud Creek, and others) were estimated to have the highest phosphorus loading rates in the Missisquoi watershed. Heavily forested sub-watersheds (e.g. Trout, Tyler Branch) had lower phosphorus loading rates. Analysis of the 109,811 hydrologic response units (HRUs) identified in the model indicated that 6,145 could fall into the CSA category (the remaining 103,666 HRUs were not near a waterway). The HRUs with the highest phosphorus loading rates exceeded 2 kg P/hectare and generally contained agricultural fields and farmsteads.

BMP targeting

An analysis was conducted to explore the utility of targeting specific areas of the watershed (CSAs) for BMP implementation, compared to a random implementation of BMPs across the landscape, as is more characteristic of the current practice. Cover cropping, nutrient management, and crop rotation were selected for this analysis because of data availability and compatibility with the SWAT-VSA model. The model simulations estimated that with implementation of these three BMP practices in targeted CSAs, improvements by factors of 1.8, 2.1, and 2.9 for nutrient management, cover cropping and crop rotation shifts, respectively, could be achieved compared to random implementation. This represents an estimated decrease of over 11,000 kg P annually if all three BMPs were implemented on the most critical 20% of eligible targeted lands with the highest phosphorus loading rates.

Comparison of SWAT-based CSA identification to GIS-based CSA identification

A simpler, less data-intensive GIS-based analysis was performed to identify CSAs in the Missisquoi watershed using available remote sensing imagery and known land uses in the watershed. These results were then compared to CSAs identified in the SWAT-VSA-based CSA analysis. Overall, the results were similar for agricultural, dense urban, and forested areas of the watershed. The results of the SWAT-VSA -based analysis could be used more effectively to update the GIS-based model for wetland, brush and urban open land classes for future analyses, particular for expansion of a CSA analysis to other segments of the Lake Champlain watershed.

Climate change analysis

Given recent concerns with the potential effects of climate change, two climate scenarios were evaluated to predict possible changes in phosphorus loading rates in the Missisquoi watershed. The two scenarios were selected to represent upper and lower bounds of predicted climate impacts on the watershed. These models also were selected based on recent work in the LaPlatte River watershed of Lake Champlain (Perkins 2011). Overall, sediment load was predicted to increase by 21-57% from 2041-2070 over the baseline generated for this analysis, and phosphorus load would increase 13-46%. The increases would not occur uniformly across the landscape; hay and pasture lands would see the greatest increases in load generation of both sediment and phosphorus. Farmsteads, roads and wetland areas represented the lowest increases.

Tactical analysis

The enhanced hydrologic network was used to identify hydrologic features on the Vermont-portion of the Missisquoi watershed that could connect sources of phosphorus to the tributary network. This information complements the SWAT-VSA -derived assessments for total P loading rates for individual landscape units. Hydrologic proximity rankings and total phosphorus load rankings were assigned across the entire network. A weighting scheme was developed to then rank the CSAs based on these two metrics across the watershed. Trained field staff visited 19 sites identified by the model and agreed with 17 of the model assessments (as a CSA or not a CSA).

At the farm-level scale, a conventional 100-cow dairy farm in Franklin county was selected for tactical CSA analysis. There is also a second-order tributary in very close proximity to the barnyard area of the farm. The farmer had installed several BMPs on the farm; these were included in the tactical-level model analysis. The Agricultural Policy Environmental Extender Model (APEX) model was used to identify critical source areas of phosphorus at the farm-level, and to evaluate and assess the effectiveness BMPs specifically designed for a particular farm may have. New BMPs were explored with the farmer, and incorporated into an APEX model for the farm, and reductions to phosphorus runoff from the farm with the new BMPs were simulated. Phosphorus reductions from buffers along waterways were estimated to reduce as much as 55% of the phosphorus leaving those fields, and grassed waterways were found to reduce as much as 30%. A recently established buffer between the barnyard and the tributary is estimated to remove as much as 60% of the phosphorus runoff from the barnyard area. Additional BMPs on the farm that could be implemented included contour farming, more grassed waterways, and conversion of some fields from permanent corn to into a corn-hay rotation; these practices could reduce phosphorus runoff from the farm by as much as 8-40%,

depending on where a particular BMP was implemented. This exercise demonstrated that for farms with detailed agronomic records, the APEX model can be used for tactical estimates of current and future reductions in phosphorus loads from a given farm.

Conclusions, synopsis of technical reviews, and next steps

The SWAT-VSA model analysis of the Missisquoi watershed provides significant insight into optimizing management resources for reducing phosphorus loading to Missisquoi Bay of Lake Champlain. As much as 60% of the total phosphorus load in the Missisquoi River can be attributed to upland sources; the remaining 40% is largely attributed to stream bank erosion. This estimate has been tentatively validated by a separate modeling project (BSTEM), to be completed in early 2012. Approximately 20% of the upland watershed contributes as much as 75% of the phosphorus loading to the tributary network. Analysis of different land uses within the watershed illustrates the disproportionate contributions of each of those land classes; for example, agricultural land uses represent approximately 17% of the land area in the Missisquoi watershed, but 65% of the upland phosphorus load into the bay can be attributed to agriculture in this watershed.

Targeting critical source areas of phosphorus in the watershed for BMP implementation can result in two-to-three fold improvements in phosphorus reduction over random BMP targeting. An evaluation of climate change scenarios indicated that sedimentation and phosphorus loading rates may increase from 21-57% and 13-46%, respectively, and that most of these increases will come from hay and pasture lands. The analysis at the tactical farm-level identified potential reductions of phosphorus from BMPs that have already been implemented, and from BMPs that could be implemented in the future. This application has the potential to be highly useful for farms with accurate, detailed agronomic records.

Technical reviews of the final report produced by Stone Environmental were provided by ten members of the LCBP Technical Advisory Committee and an additional four confidential reviewers from outside the basin, all experienced with SWAT modeling work. Overall, the reviews were extremely positive. All reviewers conveyed their positive opinions of the work that Stone Environmental had completed over the short duration of the project. As the authors, themselves, noted in their report, one of the greatest challenges to this project was acquisition of current and accurate data to populate the model. For several parameters (notably soil phosphorus), farmers or federal agencies have obtained data that would be useful to include in the model for this project, but those data could not be released to the contractor due to confidentiality agreements.

Although the peer review process has not been concluded, and certain editorial corrections may be required of the contractor, the LCBP is overall very pleased with this effort, and we expect to use the invaluable information generated from the Stone Environmental final report on Critical Source Analysis to optimize future implementation efforts.

Acknowledgements

References

Adhikari, B.K., C.A. Madramootoo, A. Sarangi. 2010. Temporal variability of phosphorus fluc from Pike River watershed to the Missisquoi Bay of Quebec.Current Science 98 (1), 58-64.

Michaud, A.R., M.R. Laverdiere, 2004. Cropping, soil type and manure application effects on phosphorus export and bioavailability. Canadian Journal of Soil Science, 84 (3), 295-305. DOI: 0.4141/S03-014.

Michaud, A.R., I. Beaudin, J. Deslandes, F. Bonn, and C.A. Madramootoo. 2007. SWAT-predicted influence of different landscape and cropping system alterations on phosphorus mobility within the Pike River watershed of south-western Québec. Canadian Journal of Soil Science, 87 (3), 329-344.

Neitsch, S. L., J. G. Arnold, T. R. Kiniry, and J. R. Williams. 2002a. Soil and Water Assessment Tool:Users Manual Version 2000. Report No. TR-192. College Station,Texas: Texas Water Resources Institute.

Perkins, E. 2011. Recommendations on climate change scenarios representing the range in projected P loading. Personal Communication.

Rotz, C.A., and C.U. Coiner. 2006. Integrated Farm System Model (IFSM): Reference Manual Version 2.0. Agricultural Research Service, USDA. http://www.ars.usda.gov/Main/docs.htm?docid=8519

Simard, G., P. Enright, C. Madramootoo, 2004. Comparison of experimental and simulated results for nutrients transport on agricultural fields in Quebec. American Society of Agricultural and Biological Engineers. Paper Number 042156.