International Missisquoi Bay Study Board

Missisquoi Bay Critical Source Area Study

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INTERNATIONAL JOINT COMMISSION
Canada and United States

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International Missisquoi Bay Study Board

Final report to the International Joint Commission

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1. Introduction

Missisquoi Bay (Vermont and Québec), an international watershed within the Lake Champlain Basin, has one of the highest in-lake phosphorus concentrations of any segment of Lake Champlain. Phosphorus loads to and ambient levels in the bay greatly exceed the target levels called for in water quality criteria for phosphorus endorsed by the governments of Vermont, Québec, and New York. Further, 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 Missisquoi Bay are also a concern.

While the governments of Vermont and Québec have done significant work to reduce the loads of phosphorus, more needs to be done in order to meet the target levels for load reduction. The Governments of the United States and Canada support the work being done on the Missisquoi Bay watershed and encourage the acceleration of progress in reducing phosphorus loadings. On August 1, 2008, the Governments, pursuant to Article IX of the Boundary Waters Treaty of 1909, requested the International Joint Commission (IJC or Commission) to assist in the implementation of a complementary transboundary initiative to reduce phosphorus loadings. Recognizing the recent technical advances made by the Province of Québec 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 partners in Québec. The Reference is intended to support identification of critical source areas in the Vermont Sector. On September 15, 2008, the Commission established the International Missisquoi Bay Study Board (Board) to assist it in carrying out these responsibilities. This document describes the tasks the Board has determined it should follow in order to accomplish these phosphorus reduction efforts.

The Missisquoi Bay Reference, received by the IJC on 1 August 2008 from the US and Canadian governments, requested assistance with determining ways to reduce phosphorus loads to Missisquoi Bay, and to advance the state of information regarding loads of nitrogen and sediment into the bay. In particular, the reference requested that the IJC:

- Organize a workshop to explore the best means to identify and delineate critical source areas, using modeling and other techniques;
- Compile and acquire data needed, such as digital photographic imagery, in order to identify and delineate critical source areas;
- Oversee a short-term tributary monitoring program in Vermont to provide more detail regarding phosphorus, nitrogen, and sediment loads (with an emphasis on phosphorus) to Missisquoi Bay;
- Compile and analyze information on critical sources of phosphorus in Vermont;
- Combine all new work with existing work in Québec and Vermont to provide a transboundary picture of pollution issues in the entire watershed.

The Board has been working since that time to fulfill the terms of the reference. It has overseen the IJC's contractor for this work, the Lake Champlain Basin Program, in their efforts to meet the terms of their contract. The contract was designed to support the elements of the reference. The major items of the contract were:

- Identification of modeling, data, and other needs for the identification of critical source areas through a series of workshops;
- Short-term tributary monitoring;
- Acquisition of data needed to identify and delineate critical source area;
- Modeling to identify and delineate critical source areas of phosphorus loads into Missisquoi Bay.

Work accomplished under these elements will be more fully described in later sections of this report.

2. Background

The setting of Missisquoi Bay was well-described in a previous report by the International Joint Commission (2005). Missisquoi Bay (Figure 1) is a shallow embayment on the northern end of Lake Champlain divided by the international boundary separating the State of Vermont and the Province of Québec. Slightly over one half of the watershed area lies in Vermont (58%) and the remainder (42%) is in Québec. The bay itself has an area of approximately 77.5 km^2 (19,150 acres) and a mean depth of 2.3 meters (7.5 ft). Major tributaries entering the bay from its 3,105 km^2 (767,246 acres) watershed are the Missisquoi, Pike and Rock Rivers. A population of approximately 23,000 resides in the Québec portion of the Missisquoi Bay basin and another 28,000 people live in the Vermont part of the basin.

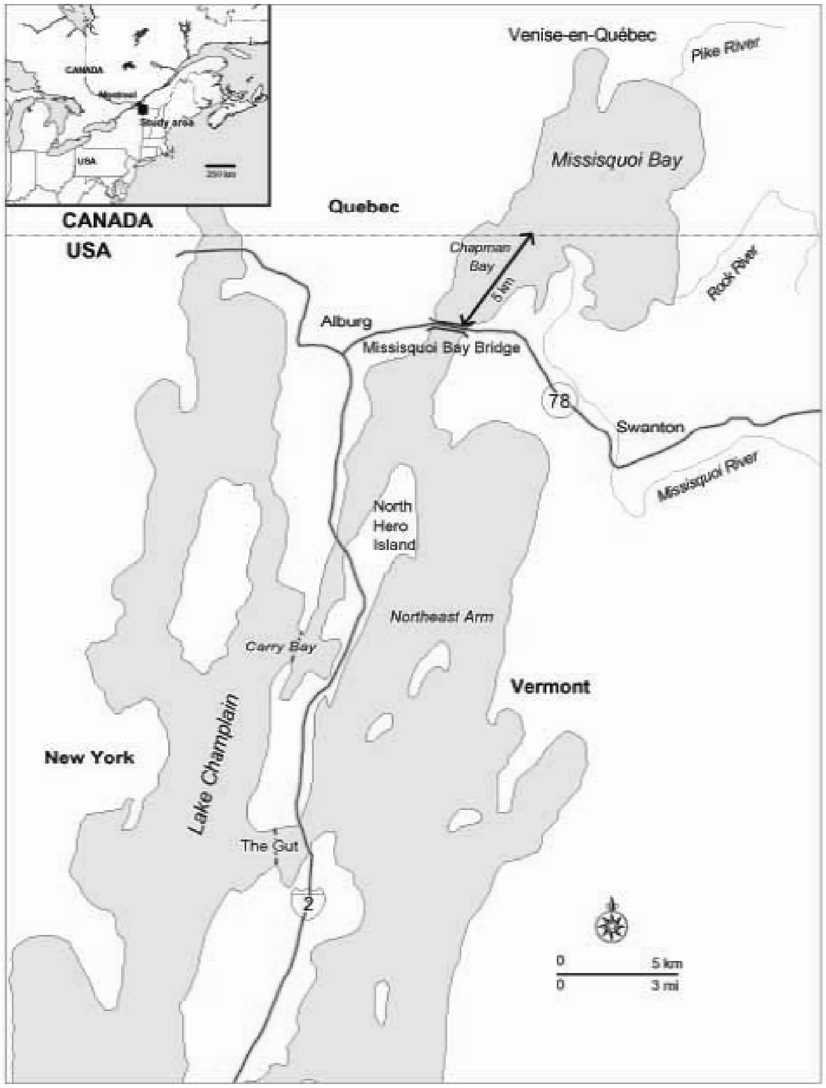

Figure 1. Map of Missisquoi Bay and northern Lake Champlain (International Joint Commission, 2005).

Eutrophication has been increasing in Missisquoi Bay since around 1980. Total phosphorus concentrations in the bay increased by 79% during 1979-2009 (Figure 2), and Missisquoi Bay currently has some of the highest phosphorus concentrations measured anywhere in Lake Champlain (Figure 3). Total phosphorus concentrations in Missisquoi Bay have averaged around 50 µg/L in recent years, far above the water quality criterion of 25 µg/L adopted by Vermont and Québec in a 1993 Water Quality Agreement for Lake Champlain. Harmful algal blooms of cyanobacteria (blue-green algae) are frequent in the bay (Figure 4), and cyanobacteria are much more prevalent in the phytoplankton community now than in the 1970s (Smeltzer et al., 2012). These findings of relatively recent proliferation of cyanobacteria in Missisquoi Bay are consistent with fossil pigment evidence in sediment cores (Levine et al., 2011).

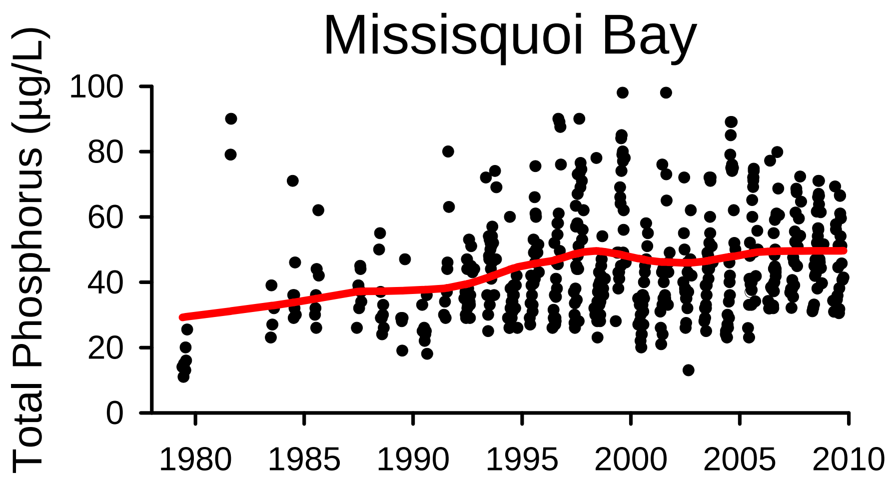

Figure 2. Long-term trend in total phosphorus concentrations in Missisquoi Bay (Smeltzer et al. 2012).

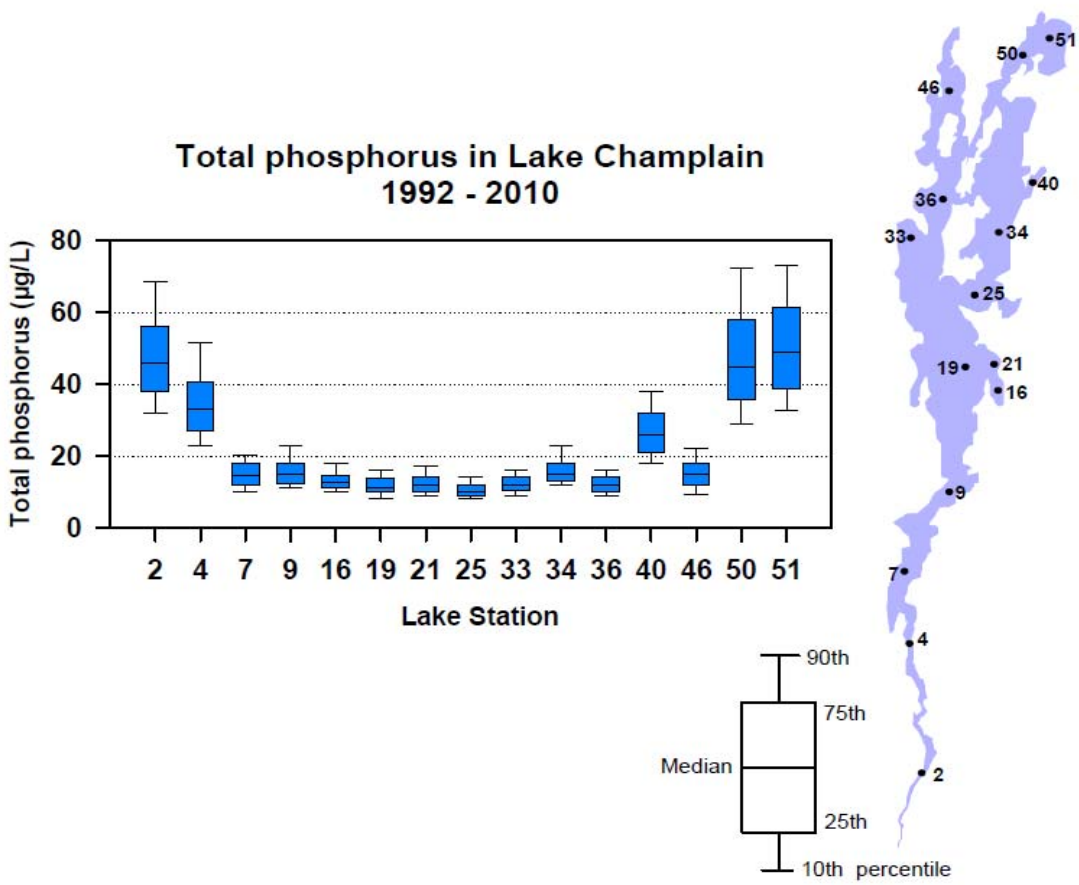

Figure 3. Total phosphorus concentrations at Lake Champlain monitoring stations (Lake Champlain Long-Term Water Quality and Biological Monitoring Program).
http://www.anr.state.vt.us/dec/waterq/lakes/htm/lp_longterm.htm

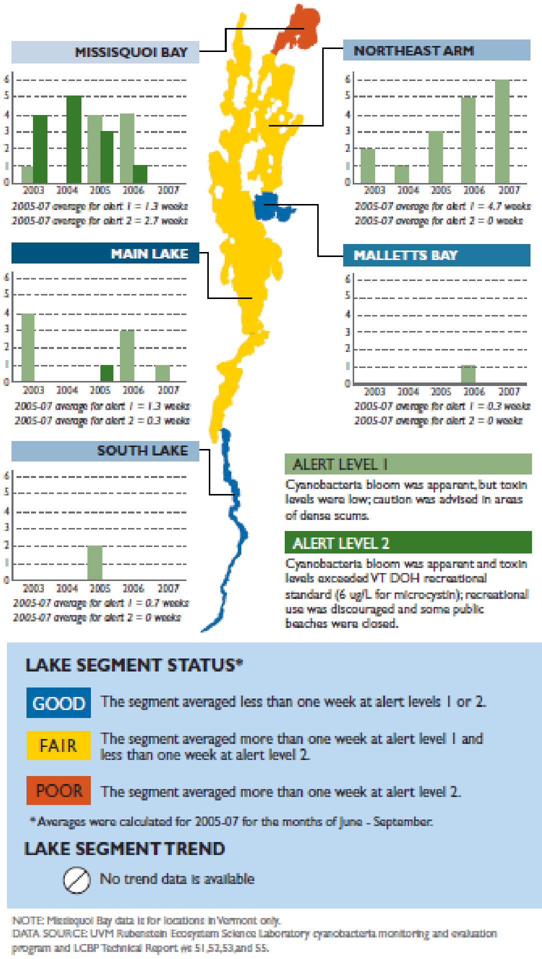

Figure 4. Weeks of cyanobacteria blooms in Lake Champlain at alert levels (Lake Champlain Basin Program, 2008).

In response to the problem of excessive phosphorus and algae blooms in Missisquoi Bay, the State of Vermont and the Province of Québec adopted in 2002 an Agreement Concerning Phosphorus Reduction in Missisquoi Bay. This agreement reaffirmed the in-bay total phosphorus criterion of 25 µg/L and established a total phosphorus loading capacity of 97.2 metric tons per year (mt/yr) from the bay's watershed. This total loading capacity was divided between Vermont and Québec sources according to a 60/40% ratio, with a maximum allocation of 58.3 mt/yr accepted by Vermont and an allocation of 38.9 mt/yr accepted by Québec. The Vermont allocation for Missisquoi Bay was incorporated into the 2002 Lake Champlain Phosphorus Total Maximum Daily Load (TMDL). In 2011, the U.S. Environmental Protection Agency revoked its approval of the 2002 Lake Champlain TMDL and is in the process of developing a new TMDL for Lake Champlain which could possibly result in revised total loading capacities for the various segments of the lake including Missisquoi Bay.

Both Vermont and Québec have made significant efforts to reduce phosphorus loading to Missisquoi Bay from both wastewater and nonpoint sources. However, monitoring of phosphorus loading from the Missisquoi River, the bay's largest tributary, has shown no significant decrease during 1991-2008, although a marginally significant decrease in phosphorus loading from

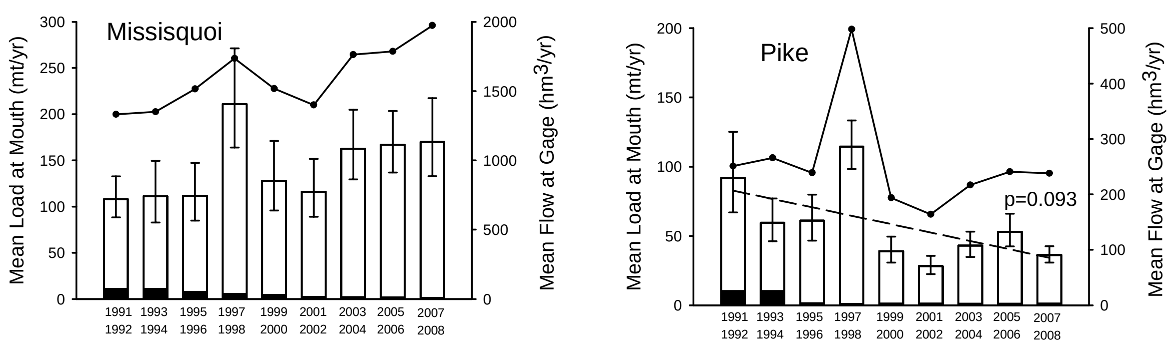

Figure 5. Mean total phosphorus loading rates (bars) and flow rates (points) in the Missisquoi and Pike Rivers for two-year intervals, 1991-2008. Filled portions of the bars indicate the wastewater component of the total loads. Error bars are approximate 95% confidence intervals. Regression line (p=0.093) for loading rates vs. time in years is shown for the Pike River. (Smeltzer et al., 2009)

the Pike River was documented (Figure 5). Phosphorus loading to the bay from all sources has averaged around 200 mt/yr since 2001 (Smeltzer et al., 2009), well above the total loading capacity of 97.2 mt/yr established by Vermont and Québec. The need for more effective targeting of phosphorus reduction practices to critical source areas in the Missisquoi Bay watershed is evident.

3. Current Situation in the Province of Québec

The Québec portion of the Missisquoi Bay watershed is 1,356 km^2, or 42% of the watershed. It is drained mainly by the North Missisquoi River (651 km^2) in the east and by the Pike River (554 km^2) in the west. The population of about 23,000 people live in 29 municipalities that form four regional county municipalities. The 700 farm businesses, including 400 in the Pike River watershed, occupy 33% of the area, but nearly 50% of the Pike River watershed. Forests cover 59% of the watershed, and the water system covers 7%. Urban areas make up 1% of the watershed.

As of 2012, all point sources of phosphorus are treated to achieve an effluent concentration of 1.0 mg/l or less. All municipalities with sewer systems have phosphorus discharge requirements for their treatment plants. All industry, commerce and institutions (ICI) not on sewer treat their wastewater. Municipal treatment plants and ICI are monitored regularly by the Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP), to ensure their effectiveness. The loadings from these point sources account for approximately 4-5% of the total phosphorus loadings from Québec in Missisquoi Bay. That is why, for many years now, the Government of Québec has undertaken a number of studies to better understand the many non-point sources of phosphorus (non-point source pollution).

Since the early 2000s, the Government of Québec, in addition to conducting its own studies, has given a number of mandates to the Institut de recherche et de développement en agroenvironnement (IRDA), regarding the effectiveness of good agri-environmental practices and regarding non-point sources of phosphorus pollution. The latter component involved the modeling of agricultural phosphorus loading reduction scenarios in the Pike River watershed, identification of the priority areas for action and description of farming practices that would reduce phosphorus loading.

The SWAT model, LiDAR and hydrological data, and sampling results for a number of parameters were used by IRDA to carry out its main mandates. Among other things, it was observed that most of the phosphorus loading was from annual crops (corn, soybeans, and vegetables) and that about 10% of the cultivated area was responsible for about 50% of the phosphorus loading. IRDA recommended replacing annual crops in flood-prone areas with pasture, incorporating manure into the soil following spreading, establishing buffer strips, creating run-off control works (drainage ditches) on the most hydrologically active parcels, and growing corn and soybeans on residue to substantially reduce agricultural phosphorus loading.

Following much discussion on agriculture, including the comments made by the public at hearings held by the Commission sur l'avenir de l'agriculture et de l'agroalimentaire québécois, and environmental studies done in agricultural settings, the Government of Québec amended its regulations and programs.

The key sections of the *Agricultural Operations Regulation* (AOR) (http://www.mddep.gouv.qc.ca/milieu_agri/agricole/index.htm) currently prohibit the increasing of cultivated areas in degraded areas (where there is excess phosphorus in the stream), prohibit the access of farm animals to streams, make it mandatory for most of the farms to have an annual agri-environmental fertilization plan (PAEF), including a phosphorus balance report, and prohibit cultivation of the first three metres of the riparian zone. This regulation is applied with cross-compliance measures: the producer can lose grants for failing to produce annual balance phosphorus report. (http://www.mddep.gouv.qc.ca/milieu_agri/agricole/phosphore/bilan.htm).

With regard to agricultural practices, the government modified its Prime-Vert program to subsidize good agri-environmental practices and control non-point source pollution, including the installation of runoff control works (drainage ditches) and stream edge stabilization works. Also, the government promotes growing on residue and widening buffer strips. For more information on the Prime-Vert program and good agri-environmental practices, see the Web sites of the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), at :

- http://www.mapaq.gouv.qc.ca/fr/Productions/Agroenvironnement/mesuresappui/Pages/mesuresappui.aspx
- http://www.agrireseau.qc.ca/agroenvironnement/documents/Prime-Vert_2009_anglais.pdf
- http://www.mapaq.gouv.qc.ca/fr/Productions/Agroenvironnement/Pages/agroenvironnement.aspx

In the late 2000s, as part of the Lisière Verte project, a number of agricultural businesses in the Pike River watershed agreed to put into practice the recommendations that had come out of the various Government of Québec and IRDA studies. Several scientific reports on this project have been published since 2009, including by IRDA.

Monitoring of Pike River water quality indicates a downward trend in total phosphorus loads (Smeltzer et al., 2009) and flow-normalized annual mean phosphorus concentrations (Medalie et al., 2011) since 1991. This decrease is because of point source wastewater treatment and reduction of non-point source contamination. In the absence of exhaustive studies, it is not yet possible to identify exactly what the contribution has been of each of the actions to better manage these non-point sources.

4. Study Board Workshops

The Study Board has supervised work undertaken by the contractor, the Lake Champlain Basin Program (LCBP), in several major areas. The first was holding a series of four workshops to better understand what a critical source area was and how to identify them. The eventual goal of these workshops was to guide the development of a Request for Proposals for a critical source area subcontract. The first workshop was convened to discuss the existing water quality monitoring network and tributary monitoring programs, and to help determine the best locations for new monitoring sites. The eventual outcome of this meeting and follow-up discussions was the establishment of ten short-term monitoring sites. The short-term monitoring program that resulted from these discussions will be further described in a later section.

The purpose of the second workshop was to discuss the definition of a critical source area (CSA) and to explore what types of information would be most useful for people working in the basin to reduce phosphorus pollution. The workshop used a series of facilitated discussions with local experts and potential end users of the information resulting from a critical source area study to help elucidate the answers to these questions. The general consensus was that a critical source area is defined by the intersection of a phosphorus source and a transport pathway at the same place and time. It is an area where a disproportionate amount of pollution (phosphorus, sediment, etc) is released relative to its physical size. These areas can occur in both the agricultural and developed landscapes. The workshop also explored the types of information that would be most useful for people working in the basin to reduce phosphorus pollution. A variety of people from different backgrounds provided their perspectives on what would be useful to their work.

The third workshop convened a panel of experts to discuss critical source areas and various models that might be useful to delineate them. These included HSPF, BASINS, SWAT, SPARROW, AVGWLF, WMS, IROWC-P (Indicator of Risk of Water Contamination by Phosphorus), high resolution mapping, and spatial analysis.

The fourth workshop explored data availability, data gaps, and the coordination of transboundary datasets within the Missisquoi Bay Basin. Data requirements for potential models as well as other research needs were also discussed.

One key concept that emerged from the workshop series as a whole was the need to provide CSA analyses at both a broad watershed scale (strategic level) and at a more localized level, such as at the field level (tactical). This would help target resources at both levels to help provide the most value for the effort and funds that would be expended. The strategic approach would consider the entire basin and would determine combinations of characteristics or practices that lead to significant nutrient loading. These combinations would be ranked relatively based on their estimated contributions to loading in order to help prioritize action. The tactical approach would consider the farm-level or micro-watershed scale to locate sites where phosphorus sources and/or transport mechanisms should be mitigated.

A full report on the workshop series was prepared by the contractor (LCBP) and is appended as Appendix A.

5. LiDAR Acquisition

In May 2010, a flight to acquire Light Detection and Ranging (LiDAR) data for a large portion of the Missisquoi basin was flown. This flight acquired imagery for 550 square miles of the basin. The flight area was decided upon by a binational workgroup. See Figure 6 for the area acquired. This data was used with previously acquired LiDAR coverage for the eastern portion of the basin in Vermont as part of the critical source area modeling project, and is also useful in its own right (e.g., developing better hydrological and topographical models). The dataset provides very high resolution detail (1.4 meter resolution supporting two foot contours) on the topography of the target area. It was used to help build the topographic data needed for the critical source area analysis to proceed. Further, 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. It also allowed for the determination of hydrologic proximity of phosphorus critical source areas to the hydrologic network.

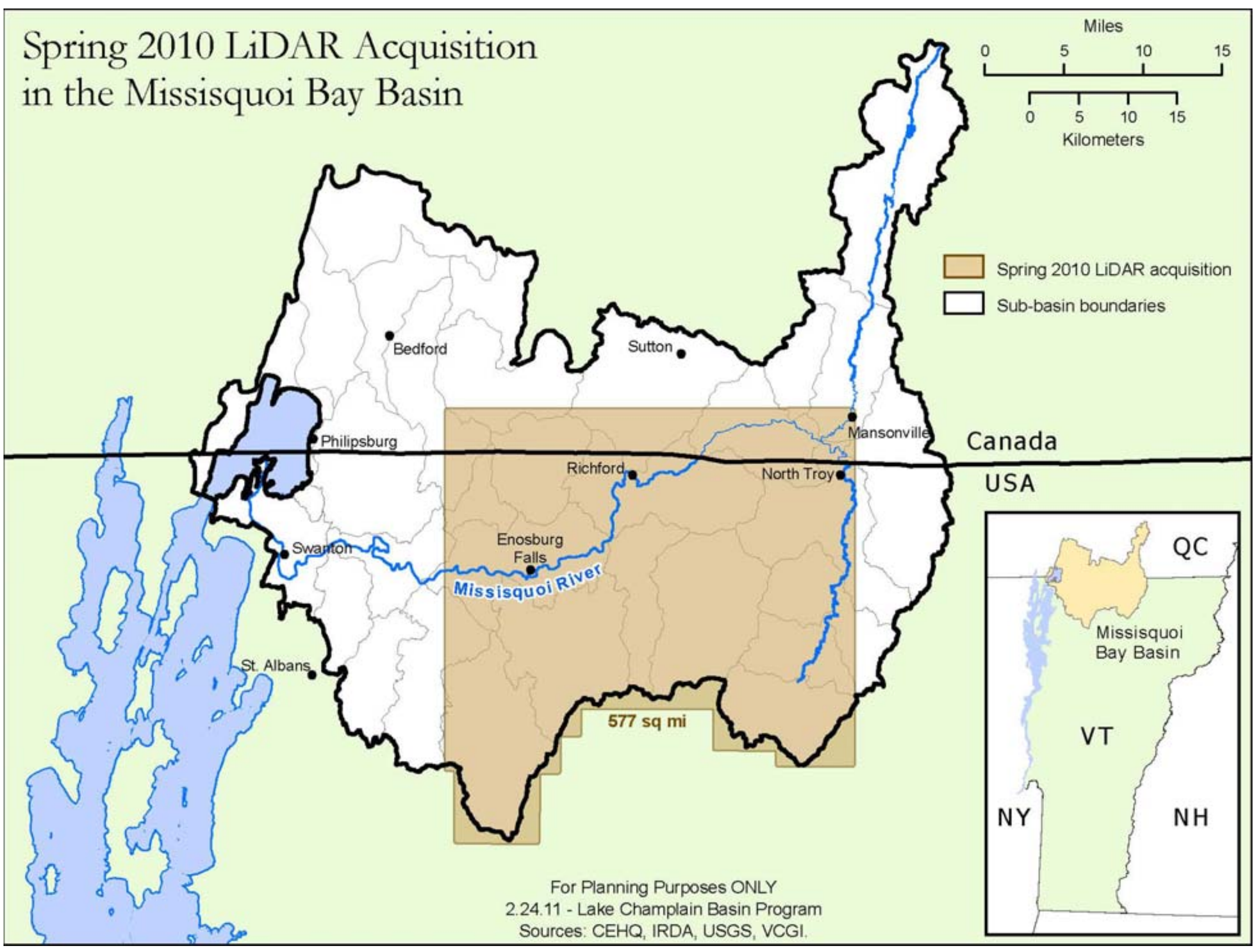

Figure 6: LiDAR Acquisition Area

6. Short Term Monitoring

The Lake Champlain Basin Program and the U.S. Geological Survey established and operated six new stream monitoring stations and four meteorological monitoring stations in the Missisquoi Bay watershed in Vermont as part of this study. The stream monitoring stations were established on tributaries to the Missisquoi River to fill gaps in the previously existing Vermont and Québec monitoring network in the watershed. Manual sampling of several water quality parameters was conducted at four of these sites, automated sampling was conducted at one site, and flow was recorded continuously at all six sites. These stations were operated for a two-year period from September 2009 to September 2011. The station locations and results are summarized in a report by the Lake Champlain Basin Program (2011), appended as Appendix B.

The data from this Short-Term Monitoring Program were used by Stone Environmental to support the calibration of the SWAT model developed for the critical source area analysis. Additional uses of the data include development of phosphorus load estimates at the sub-basin level as part of the Vermont and Québec phosphorus load monitoring effort in the Missisquoi Bay watershed (Smeltzer and Simoneau, 2008).

7. Public Outreach

In October, 2010 and January, 2012, the Study Board held public meetings in both the Vermont and Québec sectors of the basin. The purpose of these meetings was to provide to the public an overview of the project and progress made to date. At each of the four meetings, the work was well received by the public. However, at the first two meetings in 2010, there was a sentiment that it would be better to have implementation rather than another study. This sentiment was absent in the second set of meetings in 2012, where the public felt that the study was useful. We heard appreciation being expressed for the high-quality scientific work, and also some strong statements that the resource management agencies should put the results to use, and not let the report sit on a shelf.

8. Identification of Critical Source Areas of Phosphorus within the Vermont Sector of the Missisquoi Bay Basin

The main objective of this project was to locate and characterize the hotspots at risk for phosphorus (P) loss, defined as Critical Source Areas (CSAs), in the Vermont landscape of the Missisquoi Bay Basin (MBB). The goal of locating CSAs in landscape is to plan and target best management practices (BMPs) to mitigate or reduce P losses from land to streams. This approach has existed for approximately ten years and has been used worldwide but has not yet been long-term validated at a wide scale such as the Missisquoi Bay (Sharpley et al., 2011). However, many studies reported that CSA management yielded significant reduction of nutrient loss (N and P) at field and small watershed scales (10 to 300 ha) at short-term time scales (1 to 10 years). At smaller scales, several studies showed no short-term benefits from CSA management which seems to be overwhelmed by in-stream processes, vertical stratification of P in no-till fields (increase soluble P loss), and legacy landscape sources of P (enriched soils). This indicates that important time lags exist between implementation practices and measurable water quality improvement.

The CSA concept is based on the interaction between saturated-P soils and soil hydrologic reactivity. Agricultural and private lawn soils have limited capacity to store or sorb phosphate added in excess of crop growth requirements. Repeated applications of P in excess continuously enriches the soil surface horizon to the point it becomes saturated and starts releasing soluble P in runoff water (P desorption) and tile drainage (Maquire and Sims, 2002). Enriched P soils may also be physically eroded by water or wind and consequently loose P binds to sediment (particulate) in streams. Phosphorus enriched or saturated soils constitute sources of P at risk for water contamination if this piece of land is connected to a stream. The risk of P loss from land to water increases proportionally to the field proximity with ditches, brooks, rivers, or wetlands (connectivity concept) which could be accurately determined with high-tech tools such as LiDAR images and topographic indices.

A series of expert workshops summarized in section 4 and a peer-reviewed call for proposals organized in 2008-2009 led to a contract Stone Environmental, Inc. to realize the CSA project using the SWAT-VSA model. Stone Environmental had access to the high resolution LiDAR images and short-term water monitoring data acquired during the actual initiative. The modeling work was considerable in terms of data collection, preparation, model calibration-validation, and computing. Its achievement has been a challenge but was successful in a 16-month period. Stone Environmental, Inc. submitted the CSA project final report and executive summary to LCBP on November 15, 2011, which produced a final report for the IJC in the same month. A second version of the final report and executive summary were delivered by Stone Environmental on December 15th after integration of corrections recommended by the LCBP Technical Advisory Committee (TAC). The LCBP consequently updated its report to the IJC on December 21, 2011.

a. Study Board interpretation of the report

The Stone Environmental report (Appendix C) is very well written and clearly, objectively and extensively presents and discusses the results anticipated in their proposal. The critical source areas for phosphorus loads in the Vermont sector of the Missisquoi Bay Watershed were identified, located and ranked. It includes a detailed research methodology, assumptions and limitations, and results of the analysis at both strategic and tactical levels. The report also comprises comprehensive georeferenced maps locating critical source areas at a defined resolution for various phosphorus parameters in the Missisquoi Bay landscape.

The LCBP final report to the IJC (Appendix D) summarizes well the model parameterization and results. In general, 61% of the total P loads to the streams originate from upland areas and the remainder from the stream banks. Total P loads from upland areas comes 64% from agricultural land, 6% from developed land (residential, dirt and paved roads) and 30% from undeveloped land. Twenty percent of these upland areas, mainly fields in corn-hay and corn-soybean rotations, contribute to 74% of the total P exported from upland areas. These agricultural areas are at the highest risk for P loss due to their fertilization rates combined with bare soils and large row crops enhancing soil water erosion of P-rich soils where soil hydrology, slopes and proximity to streams are critical. However, most of this phosphorus is particulate (bound to sediments) and less bioavailable to algae growth than the soluble P loss from grassland.

Several BMP scenarios such as cover cropping, nutrient management and crop rotation were simulated by the model in critical source areas and improved water quality by 2 to 3 fold. The report also discussed results of a tactical analysis at a conventional dairy cow farm scale which allowed assessing impacts of different BMP placement on P reduction. However, such tactical analysis requires availability and accessibility to detailed and historical agronomic data.

Finally, lower and upper bound climate change scenarios evaluated with the SWAT model indicated that total P loads might increase respectively by 13 to 46% in Missisquoi Bay, but the land uses that ranked as highest CSAs did not change under future climate change scenarios.

i. Outcomes, weaknesses and gaps

The major study result is the importance of erodible stream banks as a source of sediments and phosphorus (40% of the total) in the MBB. This estimation is supported by an independent project contracted by LCBP and using the BSTEM model. This report to be soon (2012) delivered by the USDA National Sedimentation Laboratory indicates that stream bank erosion may contribute up to 42% of suspended sediment and 50% of the total P loads to Missisquoi Bay. Although these models may estimate stream bank erosion reasonably well, their uncertainty on P loss quantification may likely be high. In fact, the stream bank profiles being eroded should not be homogeneously P enriched because P fertilizers are applied and tend to be retained in the surface horizon (0-30 cm). However, it is our understanding that soil P samples were obtained at various depths in the stream banks and results averaged for modeling analysis.

Secondly SWAT estimated that agriculture constitutes 64% and forest 20% of the total P contribution to streams from upland (non-streambank) areas. But developed areas of the basin didn't yield much P to water (6% of the total) because of the small extent of developed land in the basin. The corn-hay rotation system contributed 29% of the total P load from upland sources because of the vulnerability of cultivated land to soil erosion. Particulate P losses are significant from soybean-hay, corn-hay and permanent corn, but soluble P loss dominates in the permanent hay and pasture system (66 to 72%). Particulate and soluble P forms are not equally responsible for algae growth in lake systems because the soluble form is highly bioavailable while only a small fraction of the particulate P will be later released to the water column. Consequently, it will be important to target priority mitigation practices that reduce soluble P losses from upland areas to streams.

However, the limit of this study is the uncertainty of soil P levels and agronomic data that were extrapolated on the basis of simplified (watershed uniform) assumptions due to unavailable or non-existent data. While the assumption methodology is scientifically sound and well described one cannot assess that a high P contributing corn-hay system for example is located in a specific area or determine if this area had historically received repeated application of P in excess of crop needs and thus potentially desorbed high P amounts in runoff water. This lack of real P source data in MBB is the weakness of the SWAT model results as they are precise but highly uncertain. Nevertheless, the topographic and hydrologic sub-components are of high resolution and accurately determined so that areas prone to surface runoff and saturation excess runoff are likely satisfactorily located and ranked. This may explain why the topography (slopes) and hydrology (soil hydrology group and connectivity) factors most greatly influenced phosphorus export and why there was good model validation.

The Stone Environmental and LCBP reports clearly evaluate excess P fertilizers use in most of the agricultural and private lawn systems in MBB. It is also explained that soil P analyses and agronomic data are barely available due to infrequent collection or confidentiality issues related to private farms. However, these two elements are key parameters towards the control of P losses in the Vermont sector of MBB. In fact, it is well known that most of the P excess applications will build up in the soil surface with time and constitute P sources at risk in the landscape that will likely end up in the nearest stream.

The strategic analysis is a first step to identify in which systems of MBB the critical source areas might be located but ground truthing (detailed site evaluations), such as soil P testing, is still required to plan BMPs and other conservation practices due to the uncertainty related to agronomic data and estimated soil P levels.

ii. The importance of agricultural P Sources and high phosphorus inputs from manure and fertilizers in the Missisquoi Bay Basin

Although many eutrophic lakes around the world have shown no to minor response to nutrient reduction, a recent study (Levine et al., 2011) on the eutrophication history of Lake Champlain's Northeastern Arm including Missisquoi Bay has concluded that the effective restoration of Missisquoi Bay water quality is possible but will require severe reduction of nutrient inputs from animal manure and crop fertilizers. Paleolimnological analyses showed clearly that Lake Champlain has been resilient to deforestation but that agricultural intensification in the Missisquoi Basin including high density feedlots, importation of nutrient-fortified grains, use of fertilizers in the reduction of silage, extensive drainage tiling, and application of manure directly to crop fields coincided with an acceleration of eutrophication in the bay starting in the 1980s. The authors also found that causeway impacts on eutrophication were relatively minor and concluded that causeway removal and other engineering solutions (e.g. sediment sealing, artificial circulation) would be less effective than reduction of external nutrient influx.

b. Summary of the peer-review findings

The LCBP received comments from four confidential peer-reviewers outside from their technical advisory committee. In addition, two internationally renowned experts on CSAs agreed to review the Stone Environmental, Inc. final report for the IJC. The Missisquoi Board discussed the six peer-review reports and agreed on summarizing the major reviewer comments as follows:

General evaluation:

All reviewers stated that the study CSA approach was very interesting and that initial objectives were achieved. The SWAT modeling methodology and application were appropriate and appeared technically sound. They also complimented the detailed and comprehensive manner in which objectives, methodology (data inputs, assumptions) and results have been explained though some methodological details are still missing.

However, not all reviewers agreed on the study accuracy, data used and validity of assumptions but more importantly the understanding of the CSA concept, see major comments below:

Specific comments on study limitations:

1. The rationale provided for moving beyond the traditional SWAT model is generally weak and not adequately documented.

2. The authors have an incomplete understanding of the CSA concept because they consider an area at risk for a large amount of phosphorus export as a CSA while a CSA is an area where significant source of P intersects a high probability of transport.

3. The assumption that all livestock manure produced within a county was applied on all agricultural lands of this county is not true so in reality some fields may have had a higher manure application rate than the average one used in the model. This may lead to underestimated high P sources.

4. The average daily rate for a dairy cow used in the study is underestimated and greatly skews the estimates of P application in the SWAT model.

5. Fertilizer P applications other than some banded starter P have been ignored in the study.

6. It is not clear how tile-drained information was used within the CSA model. In fact, there is always a trade-off between tile drainage and runoff which should be taken into account. In tile-drained areas the saturation excess runoff concept may not apply and little to no direct runoff is generated. However, deep drainage and soluble phosphorus loss may be enhanced in tile-drained soils which are normally well connected to ditches and streams.

7. The study showed that targeting three BMPs on 20% of the eligible land provide greater benefits than a random application. However, costs of implementation of BMPs and level of uncertainty have not been evaluated. These will be needed to move forward.

8. The effectiveness of a Conservation Reserve Enhancement Program (CREP) buffer on filtering the barnyard runoff was not discussed given the extreme levels of P inputs. In fact, even with a high level of effectiveness the barnyard remains a highly concentrated source of phosphorus export.

9. The importance of proximity to surface water as a critical source factor was not supported by independent evidence. A more robust approach would have been to incorporate the proximity index into the SWAT model and assess whether inclusion of proximity as a factor improved the prediction of P export.

10. Long-term validation of the model results will be needed. This could be done through comparisons with other models such as SPARROW and AVGWLF at the regional level.

9. Conclusions and Recommendations

1. The study was competently executed and the results were generally supported by the peer reviews. We believe the results are valid although limitations on the P source estimations have to be taken into account as previously discussed. The study results should be put to use by resource management agencies in the Missisquoi Bay watershed.

2. The project has brought the scientific capability in Vermont up to a comparable level to what exists in Québec with respect to watershed modeling and critical source area analysis in the Missisquoi Bay watershed. Complementary research in the Québec portion of the watershed arrived at similar conclusions regarding the high percentage of the phosphorus load that is coming from a small percentage of the land area.

3. The United States Department of Agriculture (USDA) should make sure that state Natural Resource Conservation Service (NRCS) offices retain the flexibility to apply local ranking criteria that give high weight to sites having critical source area characteristics when making funding decisions for applications under EQIP and other programs. National standards for ranking criteria should not be imposed in a way that limits the ability of local offices to target critical source areas. The need to make maximum use of the available dollars to reduce phosphorus loading to Missisquoi Bay should outweigh concerns about inequities in funding allocations when applying a critical source area targeting approach.

4. Critical source area targeting should be implemented at two spatial scales:

   Sub-watershed scale: Separate Environmental Quality Incentive Program (EQIP) funding pools should be established for areas identified as critical sub-watersheds, as has been done for the Rock River and Lewis Creek watersheds in Vermont.

   Farm scale: Ranking of funding applications should be based on site physical characteristics (e.g., slope, topographic index, soil group, proximity to water) available from this study and accurate site information on land use and cropping patterns, management practices in place, and soil phosphorus tests (STP) obtained by field surveys. Resource management agencies should be proactive in their outreach, targeting landowners where potential critical source areas have been identified by this study, rather than passively responding to applications for funding.

5. More management attention should be paid to reducing phosphorus loads from streambank erosion caused by channel disequilibrium, since this process represents a high percentage of the phosphorus load delivered to the Missisquoi River. Resource management must promote strategies to regain and maintain the stream channel's equilibrium conditions, such as the restoration of a channel's access to the floodplain and the restoration of a stable slope and planform, in order to achieve phosphorus load reductions over the long term.

6. The long-term goal of state and federal resource management agencies should be to limit or mitigate the effects of intensive cropping and animal use in critical source areas. This should be accomplished by educational outreach and technical assistance, financial incentives for mitigating practices such as cover cropping, multi-crop grain rotations, changes in tilling practices, and conservation buffers, and a structure of those incentives to place greater value on the areas that pose the greatest risk of export. Stronger regulatory approaches should be used where voluntary incentives are not working or are not being applied on the critical source areas. It is likely that much of these efforts will need to be focused on small farms in Vermont since medium and large farms already fall under higher levels of state water quality regulation.

7. The maps and other supporting GIS data files from this study should be made available to resource management agencies in the basin for placement on agency computer servers and at the Vermont Center for Geographic Information. Field staff should make use of these files to prioritize site visits and to support more in-depth farm assessments at the field and sub-field levels. Field tablet technology under development by NRCS to support on-site BMP analysis and scenario testing with farmers should incorporate the critical source area data produced by this study. Public notice should be provided before critical source areas maps are made broadly available so that landowners are not caught by surprise and appropriate disclaimers about the limitations of the analysis should be included.

8. The Partner Liaison position established under the President's America's Great Outdoors Initiative in Vermont will support coordination among water quality management agencies in implementing an agricultural-based critical source area targeting approach in the Lake Champlain Basin. Funding for this new position should be sustained in the future.

9. Tactical basin plans developed as part of the Vermont Surface Water Management Strategy should incorporate the findings of this analysis into their priorities.

10. The newly revised USDA national conservation practice standard on nutrient management in order to help producers better manage the application of nutrients on agricultural land should be used in priority in the Missisquoi Bay Basin as it has shown significant results in other watersheds such as the Upper Mississippi Basin, the Chesapeake Bay Watershed and the Great Lakes Basin. The nutrient management standard provides a roadmap for NRCS staff and others to help producers apply available nutrient sources in the right amount, from the right source, in the right place, at the right time for maximum agricultural and environmental benefits: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/crops/npm

11. There is a need for further research on the relationship between soil P concentrations (STP) and P concentrations in field runoff for Missisquoi Bay Basin agricultural soils to better rank critical source areas in terms of risk of soil P desorption (soil P release in runoff).

12. Vermont AAFM should compile and retain soil phosphorus concentration data available from farm nutrient management plans and other sources in a database for use in making more accurate critical source area assessments. These data could be aggregated if necessary to preserve farmer confidentiality.

13. The IJC has made valuable contributions to phosphorus and water quality management in Missisquoi Bay in recent years through involvement in the causeway issue, support for small farm nutrient management planning, and the present critical source area analysis. Future involvement by the IJC in specific study issues such as these would be very welcome. The Missisquoi Study Board has considered the topic of future involvement by the IJC at a broader oversight level for the Lake Champlain Basin. We have concluded that broad IJC oversight is not warranted because of the strong bilateral presence of the Lake Champlain Basin Program. Through the existing MOU between Vermont, Québec, and New York, and the involvement of US and Provincial partners on the Lake Champlain Basin Program's Steering Committee, considerable coordination and collaboration between partners and across the border regularly occur. We feel that adding a permanent monitoring board to this existing structure would be redundant.

14. The critical source area modeling approach is fundamentally sound, particularly when used over the short term, and should be applied throughout the Lake Champlain Basin, in Vermont, New York, and Québec. Development of supporting data and refinements of the methods to better

address developed land and in-stream sources will be needed in applying the approach to other watersheds. Nevertheless, water quality improvements from long-term critical source area management remain difficult to estimate due to spatial complexity and variability of large watershed systems.

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11. Acronyms

µg	Micrograms
AOR	Agricultural Operations Regulation
AVGWLF	Generalized Watershed Loading Function with an ArcView (AV) geographic information systems (GIS) interface
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best Management Practice
BMPs	Best Management Practices
Board	International Missisquoi Bay Study Board
CEHQ	Centre d'expertise hydrique du Québec
Commission	International Joint Commission
CREP	Conservation Reserve Enhancement Program
CSA	Critical Source Area
CSAs	Critical Source Areas
e.g.	For example
EQIP	Environmental Quality Incentives Program
GIS	Geographic Information System
ha	hectares
HSPF	Hydrological Simulation Program--Fortran
ICI	Industry, Commerce, and Institutions
IJC	International Joint Commission
Inc.	Incorporated
IRDA	Institut de recherche et de développement en agroenvironnement
IROWC-P	Indicator of Risk of Water Contamination by Phosphorus
km	Kilometers
km^2	Square kilometers
L	Liter
LCBP	Lake Champlain Basin Program
LiDAR	Light Detection and Ranging
MAPAQ	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
MBB	Missisquoi Bay Basin
MDDEP	Ministère du Développement durable, de l'Environnement et des Parcs
mi	Miles
MOU	Memorandum of Understanding
mt	Metric Tons
N	Nitrogen
NH	State of New Hampshire
NRCS	National Resource Conservation Service
P	Phosphorus
PAEF	Annual agri-environmental fertilization plan
QC	Quebec Province
SPARROW	Spatially Referenced Regressions On Watershed attributes
sq	Square
STP	Soil phosphorus tests
STP	Soil phosphorus concentrations
SWAT	Soil and Water Assessment Tool

SWAT-VSA	Soil and Water Assessment Tool-Variable Source Area Hydrology
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
USA	United States of America
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VCGI	Vermont Center for Geographic Information
vs.	Versus
VT	State of Vermont
WMS	Watershed Modeling System
yr	Year

Appendix A: Memorandum from the Lake Champlain Basin Program

MEMORANDUM

FROM THE

LAKE CHAMPLAIN BASIN PROGRAM

To: **Erik Beck** - IJC Contract Officer's Representative **5 June 2009**

U. S. Environmental Protection Agency

New England Region

From: **Bill Howland**, Manager

Lake Champlain Basin Program

54 West Shore Road

Grand Isle, Vermont 05458

cc: **Willem Brakel,** IJC

Beth Card, NEIWPCC

Re: IJC - New England Interstate Water Pollution Control Commission/Lake Champlain Basin Program Contract, *Missisquoi Bay Basin Project: Identification of Critical Source Areas of Phosphorus Pollution,* **Deliverable: Workshop Report**

Please accept this memorandum and attachments as the deliverable for Task 1, Subtask 1 (9.3.1.1.1) **–** *Workshop Report* – under the IJC-NEIWPCC contract number 1042-800734.

Summary of Activities

The objectives of the workshop and meeting series were:

- to explore optimal spatial scale and extent, modeling methods, and parameters for the definition, identification and delineation of critical source areas
- to discuss available existing data and gaps in data that would need to be filled
- to assist in structuring and designing the short-term monitoring program and to discuss long term monitoring needs
- to discuss optimal means to compile and analyze information to provide a transboundary understanding of pollutant loads
- to examine the role of spring runoff and flooding on nutrient loads
- to evaluate the recent information compiled by the USDA NRCS Missisquoi Areawide Plan

To meet the objectives, the LCBP convened the following four workshops and two workgroup meetings (please see attached summaries for workshop or meeting details):

- *December 15th, 2008* – LCBP convened the *Workshop on Tributary Monitoring in the Missisquoi Bay Basin* to discuss short and long-term tributary monitoring needs in the Missisquoi Basin. The parameters to be measured, sampling intervals and sampling locations for the short term monitoring program to be funded under the IJC-NEIWPCC contract were discussed at the workshop.
- *January 22nd, 2009* – LCBP convened the *Workshop on Defining Critical Source Areas and Management Needs* to discuss how to define a critical source area and the type of information or outcomes that would be most useful to people working in the Basin to reduce phosphorus pollution.
- *January 23rd, 2009* – LCBP convened a project workgroup meeting. The workgroup debriefed the previous day's workshop, discussed types of approach (strategic and/or tactical) to identifying critical source areas, and the desired outcomes of the identification. The group also discussed the short-term tributary monitoring program and the recommendations from participants at the *Workshop on Tributary Monitoring in the Missisquoi Bay Basin*. The workgroup recommended potential monitoring locations and procedures.
- *March 12th and 13th, 2009* – LCBP convened the *Workshop on Approaches to Identifying Critical Source Areas in the Missisquoi Bay Basin* to review current and previous research on phosphorus pollution and to explore possible modeling approaches to identifying critical source areas. Two keynote speakers, Dr. Andrew Sharpley and Dr. David Dilks, provided an overview of critical source areas and the potential usefulness of models in identifying critical source areas. The first day of the workshop consisted of short presentations on topics including the Vermont Phosphorus Index, The Missisquoi Areawide Plan, the identification of runoff contributing areas, and SWAT modeling in the Rock River Watershed. The second day of the workshop consisted of presentations on the following CSA identification approaches: HSPF, BASINS, SWAT, SPARROW, AVGWLF, LIDAR and High Resolution Mapping, and Spatial Analysis.
- *April 13th, 2009* – LCBP convened a project workgroup meeting. The workgroup discussed the previous workshops and began to outline management and research objectives as well as desired outcomes for the critical source area identification. The group also considered possible approaches, including WMS.

- *April 28th, 2009* – LCBP convened the *Workshop on Data Availability and Data Needs* to review available datasets, to identify additional data needs and to explore transboundary data coordination.

Summary of the Workshop Series

Critical Source Area Identification

A critical source area is defined by the intersection between a phosphorus source and a transport mechanism. Two levels of identification, strategic and tactical, were considered during the workshop series. Strategic level identification would consider the entire basin and would be quantitative in nature. Tactical level identification would consider the farm- or micro-watershed scale and would be relative in nature. Both are valid approaches and would yield information that could be used by managers and others working in the Basin. A basin-wide analysis would be most beneficial for allocating funding between agency programs, while a field-scale approach would be most helpful for implementing specific management practices on farms. It is hoped that both levels of identification will be addressed by this project.

The critical source area identification could be used to set priorities for management actions and to better allocate funds to management programs. It will also improve the understanding of the sources and transports of phosphorus over land and within the hydrologic network. Desired outcomes include both a relative ranking of types of phosphorus sources as well as physical locations of high phosphorus loadings and transport networks. The final product of this project should be available to all partners and should remain dynamic over time, as new data becomes available.

Multiple modeling approaches were explored during the workshop series. These included HSPF, BASINS, SWAT, SPARROW, AVGWLF, WMS, high resolution mapping, and spatial analysis. These models all appeared valid for this project, depending on the management objectives. Models that require a more detailed temporal scale may better represent important seasonal variations such as spring runoff and flooding events. The best way to determine the appropriate model may be to outline the management or research objectives and desired outcomes in a RFP and have the respondent propose suitable methods.

Data

The LCBP has begun acquiring datasets to help develop a transboundary understanding of pollutant loads and to facilitate the development of a pollutant loading model to identify critical source areas. The data compiled and developed by USDA NRCS for the Missisquoi Areawide Plan including farmstead locations, field crops, and gaps in riparian buffers, has been acquired by the Basin Program and will help the support the identification of critical source areas.

Additional available data was identified by workshop participants and included soils, soil phosphorus, use value parcel identification, town parcels, storm-water infrastructure, and land use/land cover. Some data is currently not available in electronic form and would have to be organized and aggregated by agencies. Other data are subject to confidentiality restrictions.

Summarizing or aggregating the data may allow it to be used in this study. Notable data gaps included crop rotation schedules and locations of tile drainage. Additional gaps in data may become apparent once a specific model is chosen.

In many cases data is not consistent between Vermont and Quebec due to resolution and classification differences. For instance, the hydrography data is available at different scales on either side of the border and data are not edge-matched over the border. Integrating cross-border datasets would help to better understand phosphorus loading in the Missisquoi Bay Basin. Other data to be integrated or related include subwatershed boundaries, surface water impairment classification systems, soil types, and phosphorus estimates per animal unit.

Monitoring

Short-Term Monitoring

In consideration of the current basin-wide monitoring programs and recommendations from workshop and workgroup participants, the LCBP has designed a short-term monitoring program that will include tributary monitoring stations and meteorological monitoring stations. LCBP will establish a minimum of ten monitoring locations within the Missisquoi Bay Basin to be sampled over a two-year period. The increased sampling in the Basin will address the need for more detailed spatial data of tributary nutrient loads and meteorological (precipitation) data.

The monitoring program plans to extend the current long-term monitoring network using similar collection and analysis techniques at the following five tributaries: Hungerford Brook, Black Creek, Tyler Branch, Trout River, and Mud Creek. Installation of a flow gage on the Sutton River also will improve the accuracy of current monitoring. Water quality will include measurements of total and dissolved phosphorus, nitrogen, and suspended sediments.

LCBP will establish a total of four meteorological stations in the Basin. Three meteorological stations will be co-located with stream gages. The fourth meteorological station will be located in East Fletcher, VT.

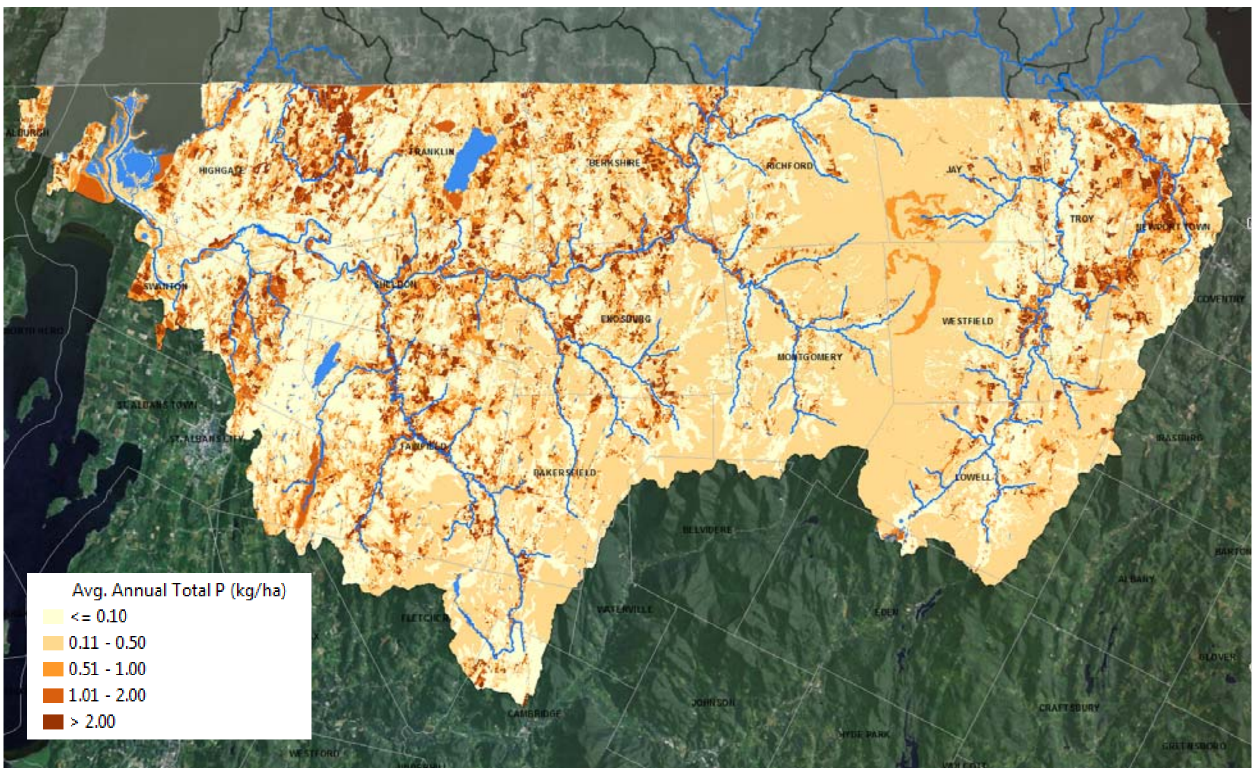
Long-Term Monitoring

Long-term monitoring stations in the Missisquoi Bay Basin were recently analyzed to determine the phosphorus load from ten sub-basins in the report *Phosphorus Loading to the Missisquoi Bay from Sub-Basins in Vermont and Quebec, 2002-2005* written by Marc Simoneau (MDDEP) and Eric Smeltzer (VTDEC). Adding long-term stations to this program will increase the understanding of pollution sources by allowing the Missisquoi Bay Basin to be divided into more monitored subbasins. In addition, increased long-term monitoring would better support modeling efforts in the future.

**A copy of the complete report is contained in the enclosed compact disk*

Appendix B: Lake Champlain Basin Program Report to the Study Board

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



A Final Report to the International Joint Commission by the Lake Champlain Basin Program

21 December 2011

Prepared by:

Eric Howe, LCBP Technical Coordinator
William Howland, LCBP Program Manager
Stephanie Strouse, LCBP Technical Associate

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

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**A copy of the complete report is contained in the enclosed compact disk*

Appendix C: Short Term Monitoring Report

Executive Summary

Missisquoi Bay, located in the northeastern portion of Lake Champlain, historically has the highest in-lake Phosphorus concentrations of Lake Champlain. Frequent blooms of cyanobacteria in Missisquoi Bay during the summer months compromise the recreational value of this resource to Québec and Vermont residents as well as tourists from other locations around northeastern North America. The International Joint Commission tasked the Lake Champlain Basin Program to initiate a two-year monitoring program of secondary tributaries to the Missisquoi River, the largest tributary to Missisquoi Bay and among the largest tributaries to Lake Champlain. This program was designed to complement and support the Long-Term Monitoring Program, in which monitoring data are collected for over 20 years from all of the major tributaries in the Lake Champlain basin. In this study, water chemistry monitoring stations were established near the mouth of five tributaries (Hungerford Brook, Black Creek, Tyler Branch, Trout Brook, and Mud Creek) to collect nutrient (Phosphorus, Nitrogen), sediment (Total Suspended Solids) and other analytes (i.e. metals, chloride, alkalinity) to support ongoing research in this watershed. A total of 23 high-flow and 6 low-flow samples were collected from each of the five tributaries. An additional 54 samples were collected on Hungerford Brook by an automated sampler (ISCO) to augment the sample size for total Phosphorus and total suspended solids on this tributary. Monitoring data were reduced to high-flow, low-flow, and Spring 2011 flood events. Results from the study indicate that among the five tributaries, Hungerford Brook yielded the greatest mean concentrations for nearly all parameters measured in this study, including flow-weighted concentrations of total Phosphorus, total Nitrogen, and total suspended solids.

**A copy of the complete report is contained in the enclosed compact disk*

Appendix D: Stone Environmental Report

Exective Summary

The Missisquoi Bay Basin (MBB) straddles the Vermont-Québec border, and is dominated by forests (67%) and agricultural lands (17%). Urban and other built-up uses comprise less than 5% of the land cover in the watershed. Due to the extensive nature of agricultural land use in the watershed, an estimated 64% of the total upland phosphorus (P) load delivered by the MBB annually is attributable to agricultural sources.

Public concern over water quality in Missisquoi Bay remains high. Missisquoi Bay shows some of the most profound effects of P pollution, with recurrent blue-green algae blooms that are both unsightly and potentially toxic. Since 2002, Vermont has invested approximately $10 million annually, in combined state and federal resources, in programs designed to improve water quality in Lake Champlain. These efforts are subject to intense scrutiny, in part because to date they have failed to yield the desired improvements in Lake Champlain water quality. Further, in this era of shrinking government resources it is unlikely that increased annual funding will be provided to this effort. Tools are needed that can help program managers identify priorities for implementation and better target their efforts to those areas of the landscape that disproportionately contribute P pollution, often termed critical sources areas (CSAs).

The overall purpose of this project was to identify CSAs in order to improve the cost-effectiveness and efficiency of land treatment efforts to reduce P loads. This report presents the results of intensive watershed modeling of the MBB to identify critical source areas of phosphorus pollution at both a strategic and a tactical scale.

The strategic level assessment of critical source areas employed a Soil and Water Assessment Tool (SWAT) model that was capable of assessing broad watershed-scale trends, while also able to evaluate land use categories, sub-watershed characteristics, and field-level assessments of P source areas. In all cases, the SWAT model was applied over the entire watershed. The tactical level work combined data generated through the strategic assessment with other high-resolution datasets to define CSAs at a scale practical for specifying Best Management Practices (BMPs) at the farm and field scale.

Project Objectives

The principal goal of this project is to identify, locate, and rank the most important critical source areas of phosphorus loads in the Vermont sector of the Missisquoi Bay Basin. Key project objectives include:

- Identification and ranking of CSAs in the MBB at the watershed (i.e., strategic) scale using available basin-wide data sources and a calibrated/validated watershed model;
- Evaluation of the P load reduction potential for alternative BMP strategies following a traditional implementation approach versus implementation targeted to identified CSAs;
- Comparison of watershed model results with a simpler multivariate GIS-overlay technique that might be more easily applied to other regions of the Lake Champlain Basin;
- Evaluation of potential changes to P loading in the MBB and CSA ranking potentially resulting

from climate change; and
- Use of more precise, site-specific input data and better spatial resolution to improve identification, ranking, and prioritization of CSAs at a farm-scale (i.e., tactical) level.

Key Findings

Strategic Analysis

The SWAT model was used to evaluate sediment and P contributions at several scales as part of the strategic level analysis.

The watershed-scale SWAT simulations indicate that about 60% of the sediment and P loads from the assessment area (Vermont portion of the MBB) come from upland sources, whereas about 40% are attributable to erosion of streambanks. These values are within the same range of the 29% -42% sediment contribution and ~50% total P contribution from bank sources suggested by a separate project (BSTEM modeling) recently conducted within the Missisquoi River watershed.

Some of the key findings, with respect to upland sources by land use type, are:

- Land in corn-hay rotation produced the greatest contribution (29%) of the total MBB P load from upland sources;
- Forest has the lowest total P areal loading rate at 0.14 kg/ha/yr, but because it is the predominant land use in the basin, is the second highest total contributor at 20% of the total;
- For cultivated cropland (soybean-corn, corn-hay, and permanent corn), the vast majority of total P load is in the form of sediment P (85 to 90%);
- For agricultural grassland (permanent hay and pasture), the majority of the total P load is in the form of soluble P (66% to 72%);
- The developed land use classes (medium and low density residential, dirt and paved roads) fall in the middle among the different land uses in terms of average P loading rates; however, because these areas comprise only a small fraction of the total area assessed (3.5%), their overall impact of total P load in the watershed is quite small; and
- Total P contribution as a percent of the total MBB load from upland sources can be summarized as follows for broad land uses classes:
    - Agricultural: 64%
    - Developed: 6%
    - Undeveloped: 30%

The SWAT model allowed identification of critical MBB subwatersheds based on P loading rate. Within the MBB, those watersheds with the highest fractions of agricultural land, such as the Rock, Mud, Pike, and Hungerford, have the higher total P loading rates, ranging from 0.55 – 0.81 kg P/ha/yr (subwatershed average). The modeling effort also calculated estimated sediment and P loading rate from HUC-12 sub-watersheds and from some 103,666 individual Hydrologic Response Unites (HRUs). Phosphorus loading rates have been mapped at each of these scales; maps are presented in the full report.

Three factors—hydrologic soil group, compound topographic index (CTI), and slope—were shown to be the most important factors driving the magnitude of P export and the incidence of CSAs. The CTI class was found to have the greatest influence on soluble P losses, while slope was most influential on particulate P export. Hydrologic soil group was highly influential for total P export, including both particulate and soluble forms of P. It should be noted, however, that interaction among different landscape and soils characteristics makes identification of one or two factors as direct predictors of the magnitude of total P export difficult. This complexity of interactions is what makes the SWAT model well suited to sorting out the subtleties in different characteristics that influence P export. This is accomplished through the independent parameterization of HRUs based on localized variability in soils, topographic, climate, and agronomic conditions. The HRU-level identification of P CSAs is presented and discussed in later sections of this report. CSAs identified at multiple scales are mapped in detail in the full report.

See Section 3.1 for additional detail on the strategic-level analysis

Traditional vs. Targeted BMP Implementation

To evaluate potential P load reduction when BMP strategies are targeted to priority problem areas (i.e., CSAs) as compared to implementation in a traditional manner (i.e., essentially random, based primarily on landowner voluntary participation), the model was used to test three BMPs. These were: manure P reduction, cover cropping, and changes in crop rotations. For each BMP tested, significant benefit resulted from implementing the BMP on a targeted area representing the eligible land in the highest CSA category. Phosphorus load reductions from targeted implementation were two to three times those achieved by random implementation for all three of the tested practices.

See Section 3.5 for a more detailed explanation.

Utility of GIS-based Techniques

The results of the GIS-based CSA analysis were generally as expected, and compare moderately well with the SWAT model assessment. Visually, the GIS-based results appear to be heavily influenced by land use classes. In general, agricultural, farmstead, and developed areas had higher risk values compared with areas of natural vegetation, such as forests and wetlands. Risk predicted by the GIS-based analysis increased as distance to stream decreased. The effect of the soil was less apparent in the GIS-based analysis then it was with the SWAT model, but in general, areas with clayey or silty soils tended to have higher risk than areas with sandy soil. Similarly, high slope seemed to have less influence over the result in the GIS-based approach than in SWAT; however, most areas with high slopes are forested and these areas are assumed to have extremely low risk under the GIS-based approach. The GIS-based method's prediction of wetlands as less significant potential CSAs compared to the SWAT model assessment results from the GIS method's lack of consideration of the phosphorus geochemical cycling simulated by SWAT.

See Section 3.4 for additional detail.

Climate Change Scenarios

Two different climate change scenarios were evaluated using the MBB SWAT model, for the period 20412070. These scenarios represented the upper and lower bounds of projected changes in P loading, based on recent work in the LaPlatte River watershed in central Vermont (Perkins 2011). The SWAT model predicted an increase in the total sediment load of 21% and 57% over the baseline load for the lower and upper bound climate scenarios, respectively. This load increase did not occur uniformly over the different land uses with the study area. The farmstead and road land use classes saw the lowest increases in sediment; hay and pasture land uses saw the largest increases in sediment load both showing greater than 100% increases under the upper bound climate scenario. For total P, the load increased by 13% and 46% over the baseline for the lower and upper bound climate scenarios, respectively.

Although the magnitudes of the change in P loading rates varied across the land use classes, the land uses that ranked as highest P CSAs in the baseline scenario did not change under the future climate scenarios. The data suggest that designing BMPs and P reduction strategies based on an analysis of current climate conditions should target the same groups of P CSAs that will probably continue to be the most important under future climate conditions.

See Section 3.6 for additional detail on the predicted effects of climate change on P loading in the MBB.

Tactical Analysis

The SWAT model was built so that agricultural field boundaries were directly incorporated into the model structure. This strategy enabled the highly detailed field-level information to be developed as part of the strategic analysis. This was carried forward in the tactical analysis by combining the field-level results with additional information on the proximity of each field to the nearest receiving water.

Areas of intensive agriculture, such as the Rock, Hungerford, lower Black, and Mud sub-watersheds, still stand out as having high concentrations of CSAs; however, hydrologic proximity is an important determining factor in the total P load. This is most evident in considering undeveloped, higher elevation areas with shallow soils on steeper slopes that move up higher in the rankings when consideration of hydrologic proximity is included.

See Sections 3.2 and 3.3 for further information on the tactical analysis.

Limitations to the Analysis

Statistician George Box is generally credited with saying: “All models are wrong, some models are useful.” The SWAT model required that certain agronomic management operations such as tillage, planting, and harvest dates, manure or fertilizer application rates, and crop rotations be specified for each unit of cropland, even though such data did not exist for specific fields in the MBB. Nevertheless, SWAT parameters had to be estimated. Thus, we developed reasonable descriptions of these agronomic operations, based on known conditions in the MBB and applied them basin-wide, because we were reluctant to create a bias by arbitrarily assuming different practices/conditions for different fields in the watershed. Although this approachmay tend to over-estimate the contribution of fields that have already implemented management measures, the long-term simulation and uniform assumptions provide field-specific risk predictions that should hold great value for program managers in targeting the use of certain BMP interventions. Further, the model clearly demonstrates the value of implementing BMPs in the areas of highest risk.

Conclusions

The results of this project show that that some land uses within the watershed produce a disproportionately high amount of P relative to the fraction of the total watershed area they represent. For example, while agricultural land uses represent 17% of the total land area in the MBB, they contribute nearly 65% of the total P load. Similarly, developed land uses (residential areas and roads) that account for less than 3% of the watershed area contribute approximately 6% of the total P load.

The MBB SWAT model was able to evaluate the P load associated with specific landscape units, from major sub-watersheds, through smaller subbasins, down to the highest resolution landscape representation—the unique combinations of land use, soils, and topographic characteristics that form a SWAT HRU. These areas have been mapped and described quantitatively. Identifying CSAs at multiple scales allows future management activities to be focused on major sub-watershed, subbasin, and field scale goals.

The model also clearly demonstrated the value of targeting BMPs to the areas of highest risk. For each BMP tested, significant benefit was realized by implementing the BMP on areas representing the most important CSAs. For the three BMP scenarios tested, targeted BMPs gave two to three times the P load reduction that resulted from traditional, more random, implementation.

As would be expected, model results also demonstrated that the proximity of a particular CSA to a surface water feature is quite important in estimating its relative impact. Specifically, giving consideration to surface water proximity allowed for important distinctions within an otherwise uniform ranking class that was largely driven by land use and soils.

A separate modeling analysis was also performed for a single farm operation in the MBB. This model was designed to identify CSAs at the level necessary to determine individual management measures that could be expected to have the greatest success in reducing P loads. In addition, the farmer was interested in using the farm-specific model to quantify the benefits of practices he has already installed. The ability to produce meaningful results at this scale was heavily influenced by the agronomic records the farmer made available for the project. Without detailed, farm-specific data the value of this modeling analysis would have been greatly reduced.

The methods used to identify CSAs in the MBB should have value to other efforts in other regions of the Champlain Basin. That said, the MBB represents a unique set of land use, soil, slope, and receiving water conditions and the modeling analysis relied on a suite of data (e.g., LiDAR, CLU boundaries) that is not currently available basin-wide. It would therefore be imprudent to simply extend the SWAT MBB model results directly to the rest of the Champlain Basin. Nevertheless, there are several key observations from this effort that should have broad application. These include:

- There is enormous value to long-term simulation. Wet weather events drive the annual P loads delivered to Missisquoi Bay, and are subject to a significant amount of year-to-year variability; coupled with ongoing crop rotations, it is virtually guaranteed that no two years will look the same. The value of a long-term simulation is that it can smooth the variability, and identify particular land units will contribute the greatest pollution load over the long term.
- The model also demonstrates the value of targeting BMPs to the areas of highest risk. For each BMP tested, significant benefit was realized by implementing the BMP in the areas identified as having the highest P loading rates in the baseline scenario. From both an environmental quality

and an economic perspective, choosing a targeted BMP implementation strategy offers clear benefits.

- Although it can be tempting to use all available data, it is important to avoid introducing bias into the model by relying on incomplete datasets. For example, farmers who have invested heavily in conservation practices are understandably interested in having these investments reflected in the model. The challenge, however, is that complete, spatially-referenced datasets of all of the conservation practices that have been implemented in the MBB are simply not available. To incorporate data on a case-by-case into the model is neither practical, nor particularly useful for improving model results.
- Higher resolution data on the location of surface water features has important influence on identifying the most significant CSAs. Land use, soils, and slope tend to be the critical drivers in identifying CSAs. Introducing more detailed information on the location of surface water features created important distinctions within otherwise uniform ranking classes
- Although a simpler, GIS-based analysis showed some promise for identifying CSAs in the MBB, results were only moderately well-correlated with the intensive SWAT analysis and application of the specific GIS approach to other parts of the Lake Champlain Basin cannot be fully recommended at this time as a substitute.
- The predicted effects of climate change do not appear to reorder implementation priorities. Although the magnitude of P loading rates are predicted to increase as a result of the changing climate, the land areas that ranked as the most significant P CSAs under current conditions did not change with future climate scenarios. The data suggest that designing BMPs and P reduction strategies based on an analysis of current climate conditions will target the same groups of P CSAs that will also be the most important under future climate conditions.

Finally, it must be emphasized that the process undertaken by this project cannot, nor is it intended to, be used as a wholesale substitute for site visits and one-to-one work between management agency staff and a landowner. Rather, the model results can help guide agency efforts at major sub-watershed, subbasin, and field scales in prioritizing and implementing land treatment measures. Such targeting will improve cost-effectiveness of conservation and restoration programs by helping deploy financial and technical resources to areas that will yield the maximum benefit to Lake Champlain

**A copy of the complete report is contained in the enclosed compact disk*