RECENT LCBP-FUNDED PROJECTS IN THE MISSISQUOI BASIN

- An Environmental Accounting System to Track Nonpoint Source Phosphorus Pollution in the Lake Champlain Basin (2008-2010)
- Critical Source Area Identification within the Vermont-sector (2009-2011) [see LCBP handout & Winchell presentation]
- Streambank erosion study (2009-2012)
- Missisquoi Bay Phosphorus Mass Balance Study (2009-2012)
- Targeted Implementation of BMPs in the Rock River (2011-2014)

Technical Report No. 60

An Environmental Accounting System to Track Nonpoint Source Phosphorus Pollution in the Lake Champlain Basin

Second Year Report

Prepared by
Lula Ghebremichael and Mary Watzin, UVM Rubenstein School of Environment and Natural Resources

for
Lake Champlain Basin Program and
Vermont Agency of Natural Resources

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An Environmental Accounting System to Track Nonpoint Source Phosphorus Pollution in the Lake Champlain Basin

Prepared for the Vermont Agency of Natural Resources and the Lake Champlain Basin Program

By

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May 20, 2010
Second Year Report

Final

I- EXECUTIVE SUMMARY

Lake Champlain exhibits eutrophication primarily as a result of continuing nonpoint source inputs of phosphorus from the surrounding watershed. The goal of our project was to develop a framework and model that could be used to account for major sources and potential reductions of phosphorus across the landscape. In our first year report, we presented a literature review that evaluated the relative magnitude of phosphorus sources and transport pathways in the watershed, and summarized the relative reductions that might be achieved using various BMPs in both agricultural and urban/suburban land areas. We used this information to develop a framework to examine critical sources and potential reduction scenarios for phosphorus in agricultural watersheds. This framework includes both a farm-level model-based phosphorus accounting system and a watershed-level model-based phosphorus accounting system. This report presents that framework and the results of our modeling efforts in four sections.

The *FARM-LEVEL PHOSPHORUS ACCOUNTING SYSTEM* section of this report presents the details of a phosphorus accounting system used to track phosphorus movement within farms, calculate a farm specific phosphorus mass balance, and assess alternative farming strategies that might be used to balance phosphorus inputs and outputs. The Integrated Farm System Model was used to account for farm phosphorus inputs and outputs on three Vermont dairy farms with different farming practices (grass-based organic farm, full confinement farm, and a mixed system farm with confined mature dairy cows and grazed heifers). The modeling results illustrate 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 will ultimately reduce phosphorus loadings to streams flowing to the Lake Champlain.

The three farms studied all had phosphorus imbalances, which ranged from 4.9 lb/acre to 16.7 lb/acre across the farms. Though each study farm's case was different, critical sources of phosphorus imbalances common across 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 employed 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 flows and farm profitability.

The *WATERSHED-LEVEL PHOSPHORUS ACCOUNTING SYSTEM* section presents the details of a model-based phosphorus accounting system used to track phosphorus movement in an example watershed, the Rock River Watershed in the Missisquoi Bay lake segment. The Soil and Water Assessment Tool (SWAT) was successfully used to represent the hydrology, sediment, and phosphorus in the watershed, phosphorus being the main focus of the effort. Proportions of phosphorus loss contributed by subbasins of the Rock River Watershed and different landuses within each subbasin are presented. Moreover, because of variability in topographic, hydrologic, soil, and management factors, all nonpoint phosphorus sources do not contribute equally to water impairment. Some nonpoint sources contribute disproportionally higher phosphorus losses than others. These high risk areas for phosphorus loss are referred to in this report as Critical Source Areas for Phosphorus Loss. This model-based study identified and quantified Critical Sources Areas for phosphorus losses in the Rock River Watershed, and presented the extent and landscape characteristics of these Critical Source Areas 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 was also responsible for about 91% of the total sediment load. Critical sources areas for phosphorus loss had the following landscape characteristics less ground cover, erosive soil types, steep slopes, and phosphorus availability. Depending on the phosphorus reduction planned to achieve and availability of resources needed, other threshold values for phosphorus lose can be used to define critical source areas and would target different percentages of the watershed with high risk for phosphorus losses.

The *EFFECTIVENESS OF AGRICULTURAL MANAGEMENT PRACTICES* section of this report presents effectiveness of various alternative management practices for the Rock River Watershed assessed primarily by using the SWAT model. The alternative management practices were assessed for their potential to reduce phosphorus loadings at a watershed scale. Based on the modeling results, the highest potential reduction of total phosphorus was achieved when management strategies were focused on critical sources of phosphorus loss. Focusing management strategies on areas where they are needed will have the greatest potential for achieving a phosphorus reduction goal set at the watershed level. Lastly, an approach was presented showing how to evaluate potential management practices toward achieving phosphorus reduction goals set at a watershed scale. The potentials of various individual management strategies and combinations of selected management strategies toward achieving the phosphorus reduction goals in the Rock River Watershed are presented. Based on the modeling results, a TMDL goal of 52% total phosphorus reduction can be met by focusing on areas with higher risk for phosphorus loss.

The LESSONS LEARNED- A Framework for Nonpoint Phosphorus Accounting and Management section presents a summary of findings, a discussion of how the modeling system can be extrapolated to other similar watersheds throughout the Lake Champlain Basin, and a discussion of how this approach might be integrated with a similar approach for urban/suburban land uses and to consider stream restoration for phosphorus reductions.

TECHNICAL REPORT NO. 63 A

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

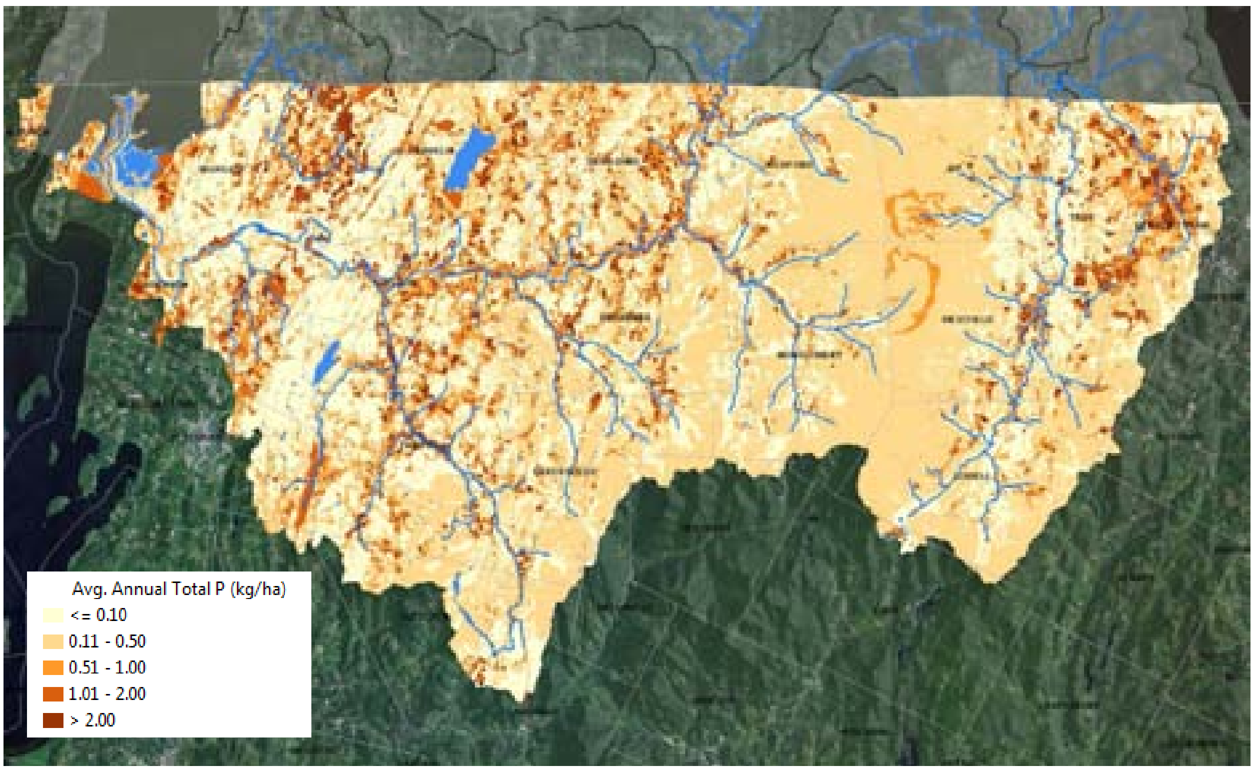


December 2011

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

for
The International Joint Commission

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.

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.

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.

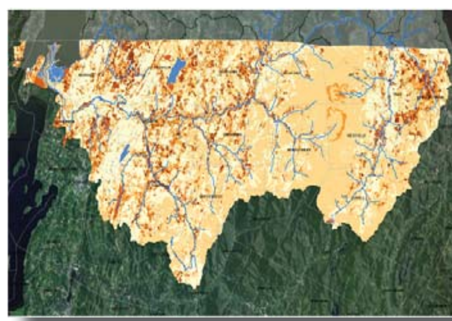
In 2007, LCBP awarded an IJC-funded project to Bourdeaus & Bushey, Inc. to prepare Nutrient Management Plans (NMPs) that meet the NRCS 590 standard, for thirty small farm operations in the Missisquoi Bay Basin. The project encompassed 400 fields and approximately 4,500 acres. The data gathered in this 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,

Lake Champlain Basin Program

TECHNICAL REPORT NO. 63 B

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

STONE ENVIRONMENTAL INC



FINAL REPORT

December 15, 2011

Stone Project ID 092156-G

Prepared by:
Michael Winchell, Project Manager, Don Meals, Solomon Folle, Julie Moore, Dave Braun, Christine DeLeo, and Katie Budreski, Stone Environmental, Inc. and Roy Schiff, Milone and MacBroom, Inc..

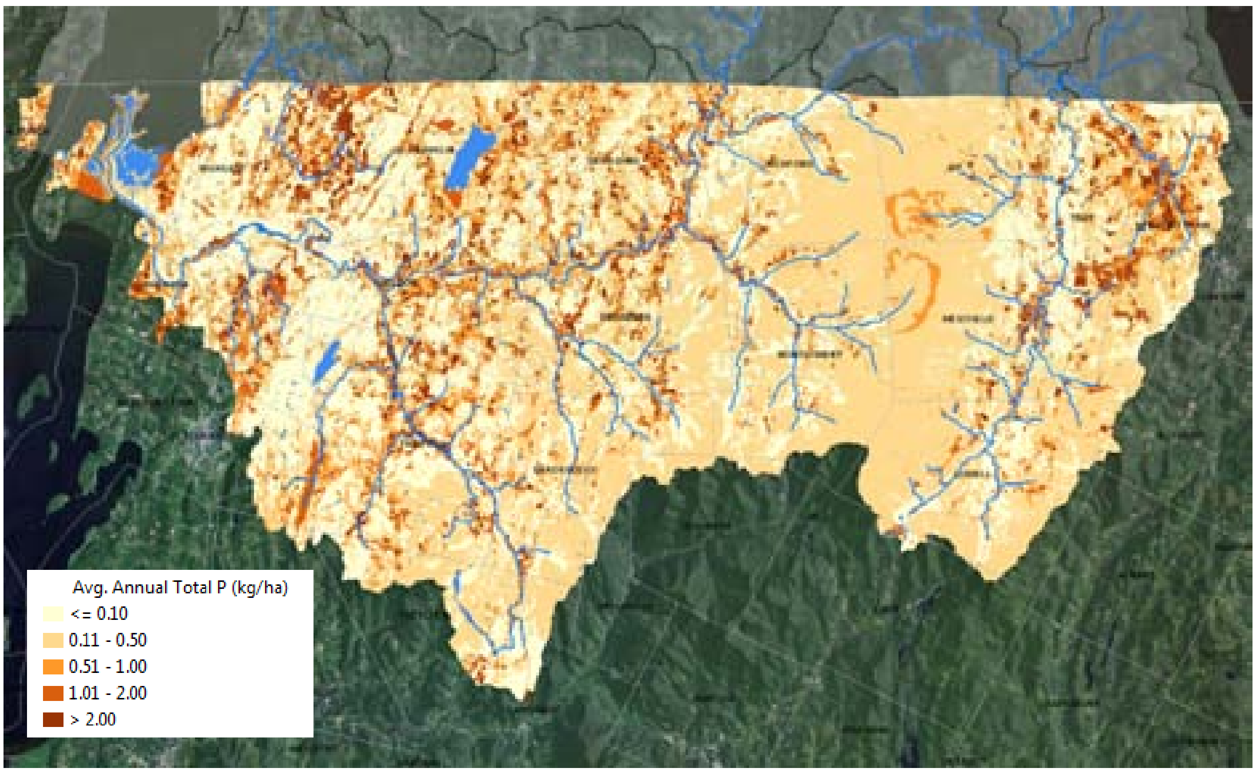
for the
Lake Champlain Basin Program

IDENTIFICATION OF CRITICAL SOURCE AREAS OF PHOSPHORUS WITHIN THE VERMONT SECTOR OF THE MISSISQUOI BAY BASIN

FINAL REPORT

Stone Project ID 092156-G

December 15, 2011



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Technical Contributors: David Healy, Project Officer, and Lesley Allen, Stone Environmental, Inc., Raghavan Srinivasan, Spatial Sciences Laboratory, Texas A&M University, Susan Wang, Blackland Texas AgriLife Research and Extension Center, and the members of the Project Advisory Committee: Michaud Aubert, IRDA, Laura DiPietro, Agency of Agriculture and Markets, Heather Darby, UVM Extension, Eric Smeltzer, Rick Hopkins, and Mike Kline, Department of Environmental Conservation, Jarlath O'Neil-Dunne, Spatial Analysis Lab, UVM, Kip Potter and Reed Sims, NRCS, and Roger Rainville, Vermont Farm Bureau. The authors also want to thank the members of the LCBP Technical Advisory Committee who provided comments and edits on the draft version of this document.

PROJECT STEERING

Eric Howe and Bill Howland, Lake Champlain Basin Program

EXECUTIVE 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 2041-2070. 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 approach may 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.

Lake Champlain Basin Program

TECHNICAL REPORT NO. 72

Quantifying Sediment Loadings from Streambank Erosion in Selected Agricultural Watersheds Draining to Lake Champlain



December 2012

Final Report

Prepared by:
Eddy J. Langendoen, Andrew Simon, Lauren Klimetz, Natasha Bankhead, and Michael E. Ursic

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National Sedimentation Laboratory
Watershed Physical Processes Research Unit

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

Watershed Physical Processes Research Unit - National Sedimentation Laboratory
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National Sedimentation Laboratory Technical Report 79 **December 2012**

Quantifying Sediment Loadings from Streambank Erosion in Selected Agricultural Watersheds Draining to Lake Champlain

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EXECUTIVE SUMMARY

Excessive erosion, transport, and deposition of sediment in surface waters are major water quality problems in the United States. Since 1992 the series of biennial National Water Quality Inventory Reports (Section 305(b) Report to Congress) have indicated that sediments and nutrients are ranked as leading causes of water-quality impairment of assessed rivers and lakes. At its mouth the Missisquoi River has a history of exceedance of phosphorus concentration target levels endorsed by the governments of Vermont, Québec, and New York. Observations along the study reach of the Missisquoi River and several of its tributaries, investigated in this report, have indicated that the river's streambanks could be a significant source of the suspended sediment and hence phosphorus to Missisquoi Bay. Indeed, significant portions of the study reach were estimated to have greater than 50% of their banks failing in the analysis carried out as part of this report. The main objective of this study, therefore, was to determine rates and loadings of sediment from streambank erosion along main stem reaches of the Missisquoi River located in the United States (US) and select Tributaries (Black Creek, Hungerford Brook, Jay Branch, Mud Creek, Trout River and Tyler Branch). Further, three mitigation scenarios were analyzed to determine the percent reduction in loadings that can be obtained by stabilizing streambanks: mitigation scenario 1) 25 year old mature trees on the bank top, mitigation scenario 2) banks graded to a 2H:1V slope, and mitigation scenario 3) banks graded to a 2H:1V slope in combination with 5-year old vegetative treatment on bank top and face.

Bank stability and toe erosion analyses were carried out using the model BSTEM at 27 study sites along the study reach using a 30-year, historic flow record. The flow record was constructed separately for each study site using the observed discharges at USGS gages 04293000 (MISSISQUOI RIVER NEAR NORTH TROY, VT) and 04293500 (MISSISQUOI RIVER NEAR EAST BERKSHIRE, VT) for the period 10/1/79 to 9/30/10. Predicted volumes of sediment eroded from the streambanks at each site ranged from 0.0559 to 1780 m^3 of sediment per one kilometer reach per year (m^3/km/yr) under existing conditions with a median value of 69.3 m^3/km/yr and an interquartile range (IQR) of 367 m^3/km/yr. Contributions of sediment from streambank erosion along the US study reaches of the Missisquoi River were found to be about 36% (31,600 t/yr) of the total suspended-sediment load entering Missisquoi Bay. Maximum associated phosphorus loadings of up to 1,540 kg/km/yr were calculated in the lower portion of Tyler Branch and the confluence of the Missisquoi and Trout Rivers. The median calculated phosphorus loading was 41.7 kg/km/yr and the IQR was 312 kg/km/yr. The calculated streambank erosion volumes contributed about 36% (52.0 t/yr) to the total phosphorus load entering Missisquoi Bay.

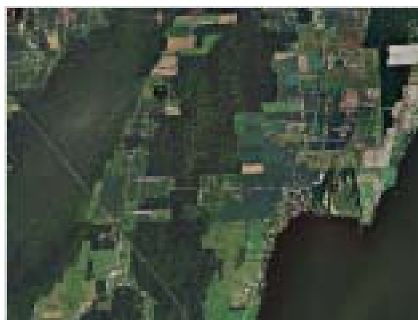
Mitigation scenarios 1 and 2 provided similar percent reductions in sediment loadings. Median erosion volumes were reduced by 60% to 27.7 m^3/km/yr for scenario 1 and 50% to 34.8 m^3/km/yr for scenario 2. The IQR was reduced by 48% (190 m^3/km/yr) for scenario 1 and 40% (221 m^3/km/yr) for scenario 2. However, maximum eroded volumes of bank material increased to 2510 m^3/km/yr (scenario 1) and 2360 m^3/km/yr (scenario 2). The calculated reductions in eroded bank material volumes were greatest for scenario 3. The median value was reduced by 100% (0 m^3/km/yr), the IQR was reduced by 99% (3.12 m^3/km/yr), and the maximum value was reduced by 59% (740 m^3/km/yr). Contributions of sediment from streambank erosion along the US study reaches of the Missisquoi River to the total suspended-sediment load entering

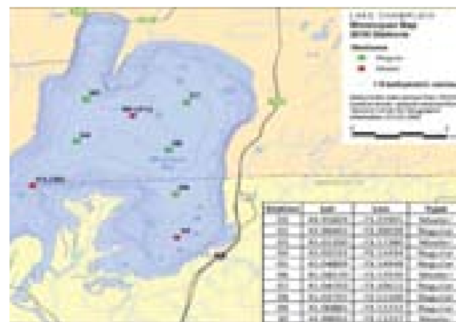
Missisquoi Bay were reduced by: scenario 1) 21% (25,000 t/yr), scenario 2) 12% (27,700 t/yr), and scenario 3) 85% (4,870 t/yr). The mitigation scenarios have a similar impact on phosphorus loadings as they have on sediment loadings, since phosphorus loadings are directly related to bank material loadings. Reductions in phosphorus loadings provided by mitigation scenarios 1 and 2 were moderate, whereas scenario 3 provided a significant reduction. The median value of calculated phosphorus loadings was reduced by 51% (20.3 kg/km/yr) for scenario 1, 34% (27.6 kg/km/yr) for scenario 2, and 97% (1.29 kg/km/yr) for scenario 3. The IQR of calculated phosphorus loadings was reduced by 55% (141 kg/km/yr) for scenario 1, 17% (260 kg/km/yr) for scenario 2, and 86% (44.2 kg/km/yr) for scenario 3. The maximum calculated phosphorus loading was reduced by 1% (1,520 kg/yr/km) for scenario 1, 7% (1,390 kg/yr/km) for scenario 2, and 80% (305 kg/yr/km) for scenario 3. The calculated contribution to the total phosphorus load into Missisquoi Bay is reduced by 29% (37.1 t/yr) for scenario 1, 14% (44.8 t/yr) for scenario 2, and 84% (8.43 t/yr) for scenario 3.

Lake Champlain Basin Program

TECHNICAL REPORT NO. 65

Development of a Phosphorus Mass Balance Model for Missisquoi Bay





March 30, 2012

Prepared for:
Lake Champlain Basin Program

Under Contract to:
New England Interstate Water Pollution Control Commission
NEI Job Code: 989-003-006
Project Code: L-2010-034

Prepared at:
Ann Arbor

by Limnotech

Development of a Phosphorus Mass Balance Model for Missisquoi Bay

Prepared for: **Lake Champlain Basin Program**

March 2012

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March 30, 2012

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1. EXECUTIVE SUMMARY

Missisquoi Bay has a long history of excessive nutrient loading and eutrophication. Efforts to deal with these issues began in the 1970s with phosphorus detergent bans and states requiring enhanced phosphorus removal from point source dischargers within the watershed. Over the last several years Missisquoi Bay has suffered from an increased recurrence of nuisance cyanobacteria blooms that have produced toxins and severely limited use of the bay for drinking water supply and recreation.

While it is clear that the external load of phosphorus to Missisquoi Bay is high, the relative contribution of external and internal loads of available phosphorus to creating and sustaining late summer cyanobacteria blooms is not clear. The primary objective of this project is to develop a fine-scale, time-variable linked hydrodynamic–water quality model that captures the major cycling pathways of phosphorus in Missisquoi Bay as they relate to future management of the system and its watershed. The Missisquoi Bay Phosphorus Model, termed MBPHOS, uses available atmospheric, hydrologic, and nutrient monitoring data to simulate the transport of phosphorus from the major tributaries, deposition and release from the sediment bed, and export through the bay, and out into the Northeast Arm of Lake Champlain.

Development of the model consisted of several major components including the selection of an appropriate model framework, site-specific configuration to Missisquoi Bay, development of boundary conditions and other external forcings, and then modification of model coefficients to achieve an acceptable fit with monitoring data. The details of model development are discussed in Section 3. Monitoring data from 2006 to 2010 were used during the model calibration process. After calibration the MBPOS model was evaluated against monitoring data collected from 2001 to 2005. This period served to independently verify model calibration and confirm the models ability to accurately simulate water quality conditions in Missisquoi Bay. To support the calibration of the sediment digenesis model a field effort was designed to measure P release rates under anoxic and oxic conditions.

A model grid was designed to cover all of Missisquoi Bay with enough detail to simulate the impacts of the major tributaries on the nearshore portions of the Bay. In addition, the model grid was developed to accurately represent key bathymetric features in the system while minimizing the time required for running multi-year model simulations. An open model boundary is located at the southern edge of the model grid at the Highway 78 bridge causeway. The total number of grid cells used in the model grid is 1,486.

The data sources utilized in this project originated from a range of sources including samples collected by the Miner Institute as part of this project, routine tributary and lake monitoring data from the VT DEC, daily water level, tributary flow, and load estimates from the USGS, daily tributary flow estimates from the Quebec Ministry of Environment, and atmospheric data from NOAA sponsored weather stations. Data were either downloaded from the internet where available or obtained directly from a contact at each agency.

The atmospheric and tributary datasets were used to generate model boundary conditions while the datasets collected in 2010 by the Miner Institute in the bay and from the long-term data collected by VT DEC in the bay were used in the calibration and confirmation of the model (Section 5 and 6). Tributary loads of total phosphorus, dissolved phosphorus, and total suspended solids were obtained from the USGS for the Missisquoi and Pike Rivers. Rock River TP, DTP, and TSS concentrations were estimated from concentrations/flow regressions using monitoring data from 2006 to 2010 and daily average flow data.

The model calibration approach was to focus first on the hydrodynamic model and then on the water quality model. The water quality calibration focused primarily on model-observation comparisons of total phosphorus data over several spatial and temporal scales. Model to data comparisons are made for 2010, which includes high temporal and spatial comparisons, and 2006 to 2010, which is the calibration period, and 2001 to 2005, which is the confirmation time period. The June through September summer average TP concentration for both of the long term VT DEC stations and the model predicted bay-wide surface average concentrations is shown below in Figure 1-1. The 10-year summer average surface TP concentration at the VT DEC station is 48.7 ug/L, which is within 2% of the 10-year average model predicted concentration of 49.5 ug/L. The year to year variation in the median relative error is very reasonable at 7%, and even the average relative error is 12%. These statistics demonstrate that the model is well calibrated to the season average TP concentration.

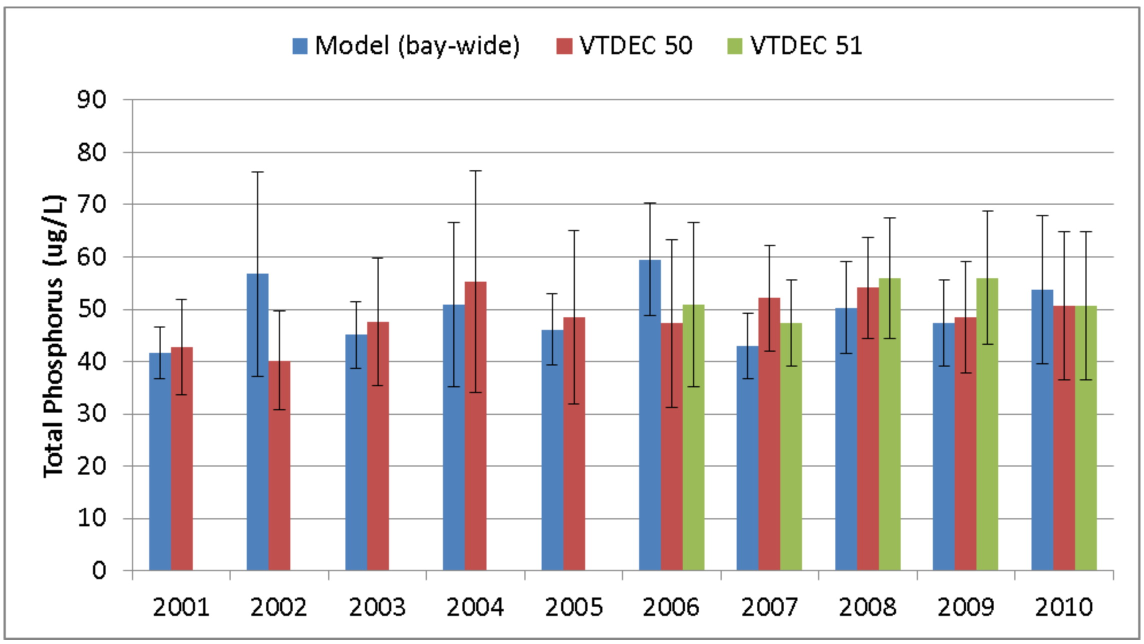

Figure 1-1. Comparison of measured and model predicted summer average TP concentrations.

One of the powerful features of the water quality model is the ability to develop a mass balance model of the major pathways of phosphorus movement within the bay. Figure 1-2 shows the average phosphorus mass balance from 2001 to 2010 on an annual and summer basis. Over the ten year period sediment flux averages 20% and 43% of the total P inputs during the whole year and summer period, respectively.

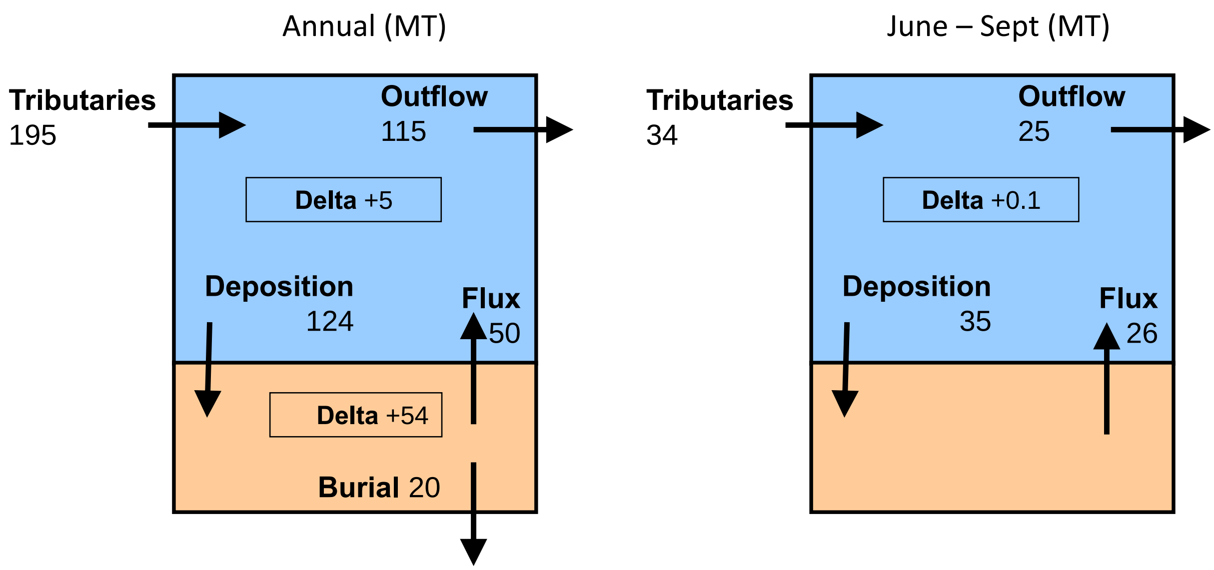

Figure 1-2. Average total phosphorus (metric tons) mass balance for 2001 to 2010.

A diagnostic simulation done with the calibrated model shows that the bay-wide average water column TP concentration from June to September decreases from 54 ug/L to 31 ug/L (a 43% decrease) when fluxes of TP from the sediment are eliminated. The calibrated model was also run in a forecasting scenario mode to project the summer average TP concentration under a range of tributary TP load reductions. For each run, total phosphorus concentrations were reduced for all of the tributaries in equal proportions for every day of the year. Inorganic solids concentrations were not reduced for any of the scenarios. A plot of the June to September average water column TP concentration for the first ten years of the load reduction scenarios is shown in Figure 1-3 for each of the load reduction scenarios.

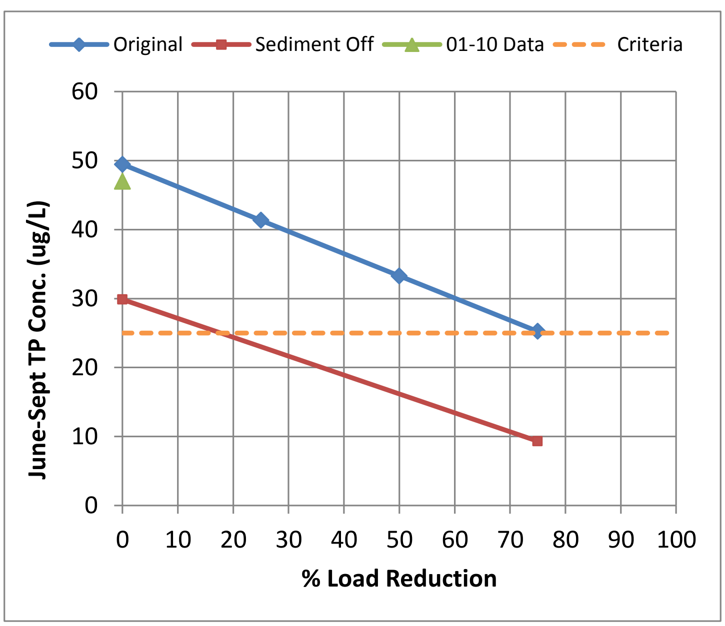

Figure 1-3. Average summer TP concentration for first 10 years of load reduction scenario run with and without sediment feedback.

A closer look into the mass balance information obtained from the water quality model shows that the diffusive flux of phosphorus from the sediments averages approximately 31 MT/yr across the whole bay from 2001 to 2010. Resuspension of bottom sediments in the shallower parts of the bay contributes an additional 19 MT/yr. Resuspension rates are highest in the spring and late summer and fall when wind speeds are higher. The combined impact is the delivery of an additional 50 MT/yr of phosphorus to the water column per year. The timing of each of these sediment flux components is different as the diffusive fluxes are highest in the summer and the resuspension fluxes are higher in the fall. The average June to September diffusive flux is approximately 18 MT, while the resuspension flux is 8 MT for a total of 26 MT.

The results of the model application provided useful insights into the phosphorus cycle in Missisquoi Bay. The mass balance results showed that the flux of phosphorus from the sediments to the water column is and will continue to be an important component of the P load to Missisquoi Bay and shouldn't be ignored in the selection of load reduction alternatives.