501 Avis Drive
Ann Arbor, MI 48108
734.332.1200
www.limno.com

Memorandum

From:	Ed Verhamme, Derek Schlea, and Joe DePinto	**Date:**	May 22, 2015
		Project:	MBPHOS2
To:	Eric Howe Lake Champlain Basin Program	**CC:**	Greg Peterson

SUBJECT: **Missisquoi Bay Phosphorus Model – Extended Load Reduction Simulation Period Results**

DRAFT

Introduction

The Missisquoi Bay Phosphorus Model (MBPHOS) was used to evaluate load reduction scenarios to inform a TMDL analysis of Lake Champlain. The development, calibration, and an initial application of the model is described in the "Development of a Phosphorus Mass Balance Model for Missisquoi Bay" report (LimnoTech, 2012). The purpose of this memorandum is to present model results from four 100-year simulations: the baseline simulation and scenarios simulating tributary phosphorus load reductions of 25%, 50%, and 75%.

Scenario Setup

The model was run in a forecasting scenario mode to estimate bay-wide TP concentration under a range of tributary TP load reductions 70 years from the present. Atmospheric conditions, tributary flows, and concentrations from 2001 to 2010 were repeated consecutive times to produce a continuous long term simulation. In addition to a baseline simulation, tributary TP load reductions of 25%, 50%, and 75% were run for the long term simulation period. For each scenario run, TP concentrations were reduced for all of the tributaries in equal proportions for every day of the year. Sediment concentrations of phosphorus were carried over between consecutive 10-year runs to produce a valid representation of sediment phosphorus trends for each load reduction scenario.

It should be noted that the load reduction scenario posed here are not designed to represent the expected change in tributary loading with actual nutrient reduction practices nor projected future climate conditions. Rather, the scenarios are meant to demonstrate the whole-lake average annual response over a very long simulation period (100 years) to annual TP load reductions.

Scenario Results

A plot of the average annual bay-wide water column TP concentration is shown in Figure 1 for each of the load reduction scenarios. Table 1 presents the decade average TP concentration of the annual bay-wide averages for the 70 years the model was run beyond 2010. The summer (June-September) average bay-wide water column TP concentration is shown in Figure 2. Table 2 presents the decade average of the summer average bay-wide TP concentration.

The results of these scenarios suggest a tributary TP load reduction between 50% and 75% is necessary to achieve an annual average bay-wide concentration of 25 µg/l.

For both the baseline and 25% reduction scenario results the water column TP concentrations gradually increase over the course of the 100 year simulation period. This is due to the initial sediment concentration and does not affect the calculated steady state TP concentration. The 50% and 75% load reduction scenarios show a quick initial drop in water column TP concentrations, but after approximately 20 to 30 year the TP concentration remains relatively stable for the remainder of the simulation period.

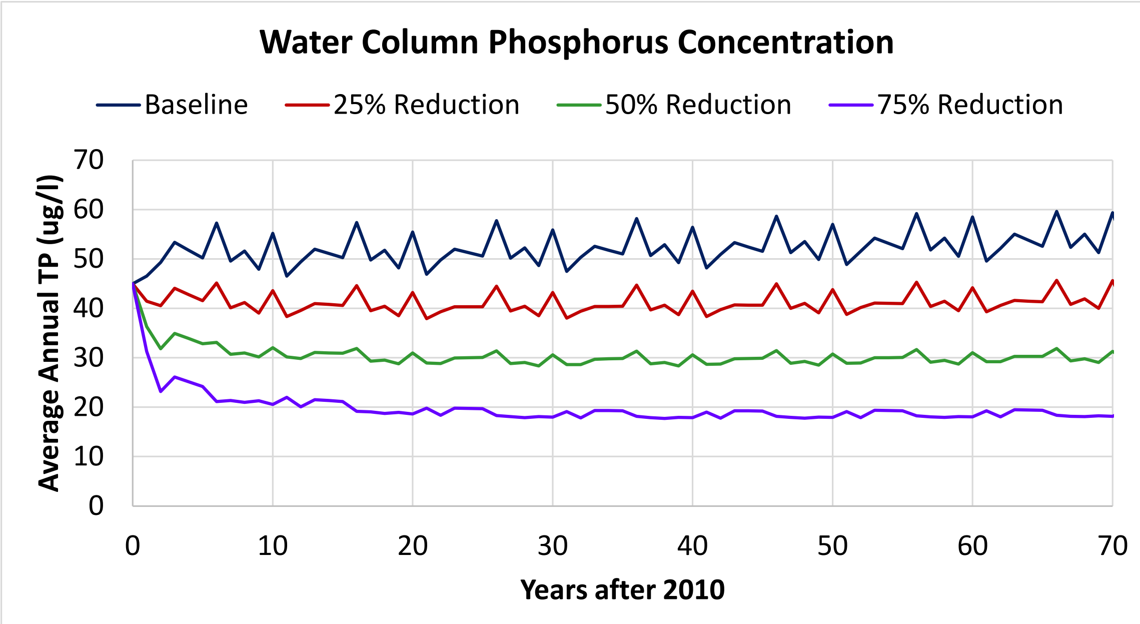

Figure 1: Average annual bay-wide water column TP concentration

Table 1. Decade average of annual bay-wide TP (ug/L) concentrations (after 2010).

Decade	*Baseline*	*75% Reduction*	*50% Reduction*	*25% Reduction*
1	50.8	23.8	32.8	41.8
2	51.2	20.3	30.5	40.7
3	51.5	18.8	29.6	40.4
4	52.0	18.4	29.5	40.6
5	52.6	18.4	29.6	40.9
6	53.3	18.5	29.8	41.2
7	54.0	18.7	30.0	41.7

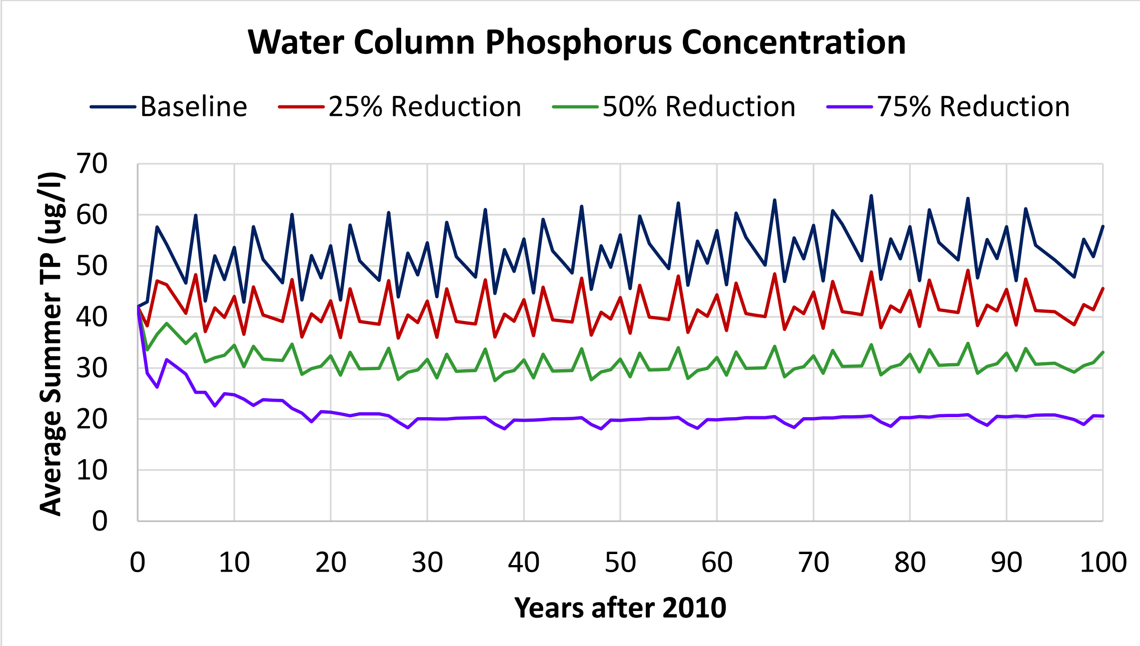

Figure 2: Average summer (June-September) bay-wide water column TP concentration

Table 2. Decade average of summer bay-wide TP (ug/L) concentrations (after 2010).

Decade	*Baseline*	*75% Reduction*	*50% Reduction*	*25% Reduction*
1	50.8	26.9	34.7	42.7
2	50.4	22.3	31.5	40.8
3	50.8	20.3	30.3	40.3
4	51.5	19.7	30.0	40.4
5	52.3	19.7	30.1	40.8
6	53.2	19.8	30.4	41.3
7	54.0	19.9	30.7	41.8

Sediment Results

Figure 3 shows the change in sediment phosphorus concentration over time for the four scenarios. Under both the baseline and 25% reduction scenarios the sediment TP concentration continued to increase slightly over the 70-year simulation period. This suggests the sediments have not reached equilibrium with the incoming phosphorus loads, and even at a 25% TP load reduction, the sediments still have capacity to have a net gain of phosphorus. The 50% TP load reduction scenario results in slightly lower predicted sediment TP concentrations over the 100 year period relative to the starting concentration, but is the nearest to reaching equilibrium between water column and sediment phosphorus concentrations of the four scenarios. The 75% TP load reduction scenario results in a downward trending sediment TP concentration, suggesting phosphorus that has accumulated in the sediment over time will reverse course and become a net loss to the water column until equilibrium is reached.

These results demonstrate the long time frame it takes for the sediments to respond to load changes. Although the water column can respond fast, legacy sediment can continue to provide at least some impact on the water column for a long time.

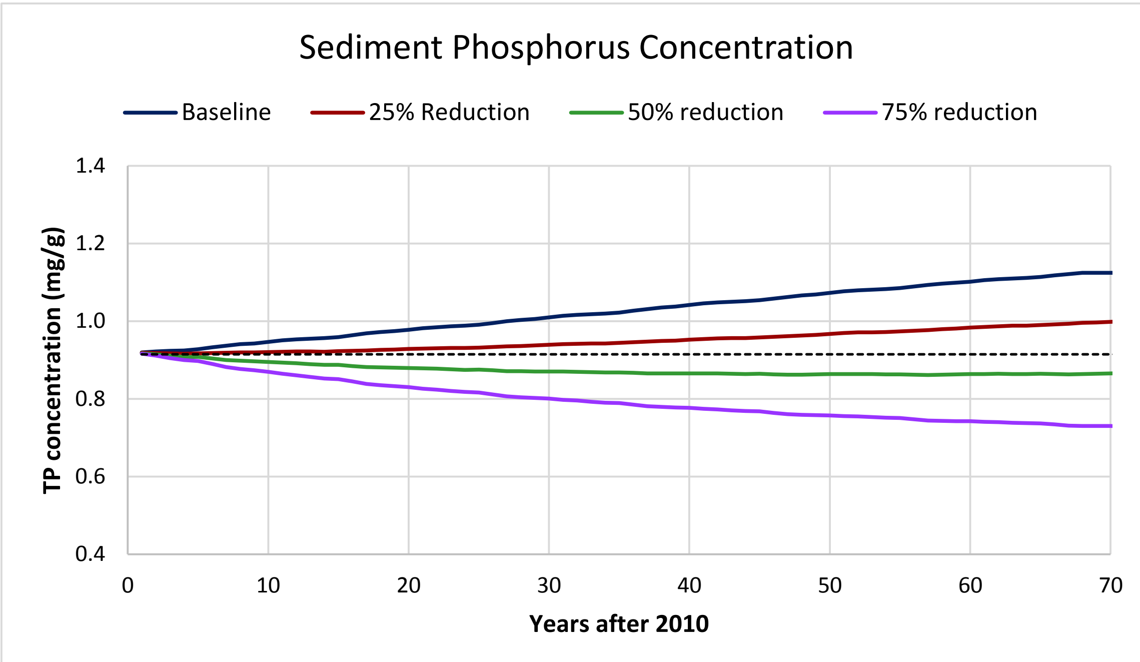

Figure 3: Average annual bay-wide sediment TP concentration