A Pollutant Reduction Optimization Analysis for the Lower Fox River Basin and Green Bay Area of Concern

Introduction

The 638 mi[2] Lower Fox River Basin is located in northeastern Wisconsin and encompasses the following counties: Brown, Calumet, Outagamie, and Winnebago, and most of the Oneida Nation Reservation (Figure 1). The Lower Fox River drains into Lower Green Bay; the Green Bay Area of Concern (AOC) includes a little over 21 mi[2] of southern Green Bay out to Point au Sable and Long Tail Point. The Lower Fox River Basin and Green Bay AOC are impaired by phosphorus and sediment, whose sources include runoff from agricultural and urban areas and permitted discharges from municipal and industrial wastewater treatment facilities. The excess loading has led to algae growth, oxygen depletion, and water clarity problems in the river and bay. The Wisconsin Department of Natural Resources (WDNR) is developing a Total Maximum Daily Load (TMDL) to address the impairments and restore water quality in the basin and bay.

As part of an integrated watershed approach demonstration project sponsored by the U.S. Environmental Protection Agency (EPA), The Cadmus Group, Inc. (Cadmus) partnered with Paul Baumgart of the University of Wisconsin Green Bay (UWGB) to design a watershed-level optimization framework for determining the most cost-effective combinations of agricultural best management practices (BMPs) that achieve the greatest phosphorus load reductions in the Lower Fox River Basin and Green Bay AOC.

Figure 1. Map of the Lower Fox River Basin and Green Bay

Runoff from agricultural fields into a small tributary stream to the south branch of Apple Creek (5/23/04)

Runoff from agricultural fields into a small tributary stream to Ashwaubenon Creek (5/14/04)

Technical Approach

The optimization analysis was conducted using the Soil & Water Assessment Tool (SWAT) in conjunction with a site-specific Optimization Model (OptiMod). The agricultural BMPs evaluated in the project were selected by a team of local water resource and agricultural experts from WDNR, EPA, UWGB, UW-Extension, Oneida Nation Reservation, Brown County Land Conservation Department (BCLCD), and Green Bay Metropolitan Sewerage District. The estimated BMP costs were developed based on input from researchers and practitioners at UWGB, UW-Extension, and BCLCD. Table 1 identifies the final agricultural BMPs, and their associated costs, selected for the demonstration analysis.

Table 1. Agricultural BMPs Evaluated in the Optimization Analysis

Agricultural Management Practice		Estimated Implementation Cost ($/acre)
1. Nutrient Management (reduce phosphorus in dairy cow feed ration by 25%)		$0
2. Manure Incorporation (increase proportion of applied manure that is incorporated within 72 hours)		$15
3. Nutrient Management (stabilize soil-test phosphorus averages at current average of 40 ppm*)		$28
4. Conservation Tillage	Mulch Tillage	$15
	Zone Tillage	$25
5. Cover Crops (on low residue fields)		$30
6. Vegetative Buffer Strips		$1,300
7. Decrease Soil Phosphorus Levels from 40 ppm to 25 ppm*		$60
8. Biofuel Crops (switch grass)		$75

* Bray P1 Soil Test

A total of 416 unique agricultural BMP scenarios were created using various combinations of the individual agricultural BMPs. Each of the 416 BMP scenarios represents a combination of one or more agricultural BMPs applied to relevant portions of the Upper Bowers Creek Sub-basin ("test basin") at different implementation rates (varying from 0% to 100%, depending on the BMP). The SWAT model was used to simulate phosphorus load reductions associated with implementation of each of the 416 BMP scenarios in the test basin. To help illustrate this, Table 2 provides SWAT simulation results for 12 of the 416 BMP scenarios. Each of the 12 scenarios in Table 2 includes different combinations of implementation rates for mulch tillage, conventional tillage, reduced phosphorus in dairy feed, and vegetative buffer strips.

Table 2. Example of SWAT Simulation Results for a Sub-Set of the Agricultural BMP Scenarios

Agricultural BMP Scenarios	Total P Load (kg)
Conservation Tillage - 100% MT; VBS (100%)	4,611
Conservation Tillage - 100% MT, Dairy P reduced-100%; VBS (100%)	4,225
Conservation Tillage - 100% MT, Stable soil P-100%; VBS (100%)	3,832
Conservation Tillage - 100% MT, Stable/Lower Soil P-100%; VBS (100%)	2,835
Conservation Tillage - 50% MT & 50% CT; VBS (100%)	5,129
Conservation Tillage - 50% MT & 50% CT, Dairy P reduced-100%; VBS (100%)	4,734
Conservation Tillage - 50% MT & 50% CT, Stable soil P-100%; VBS (100%)	4,316
Conservation Tillage - 50% MT & 50% CT, Stable/Lower Soil P-100%; VBS (100%)	3,115
Conservation Tillage - 25% MT & 75% CT; VBS (100%)	5,388
Conservation Tillage - 25% MT & 75% CT, Dairy P reduced-100%; VBS (100%)	4,989
Conservation Tillage - 25% MT & 75% CT, Stable soil P-100%; VBS (100%)	4,558
Conservation Tillage - 25% MT & 75% CT, Stable/Lower Soil P-100%; VBS (100%)	3,254

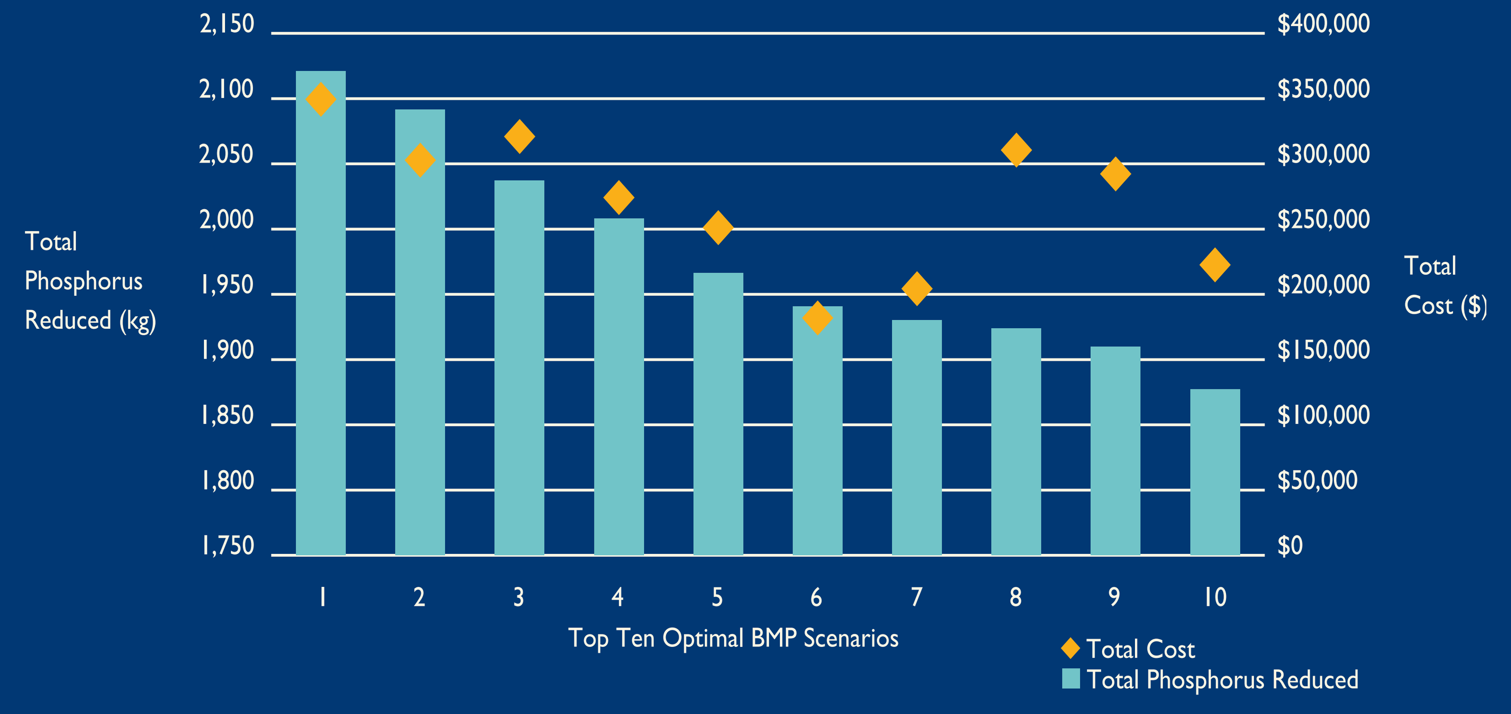
MT = mulch tillage; VBS = vegetative buffer strips; CT = conventional tillage

Results

Upper Bower Creek Sub-basin Test Site

Using simulated load reductions from SWAT and estimated BMP costs, OptiMod was used to determine the top ten cost-effective combinations of BMPs that achieve the greatest phosphorus load reductions in the test basin. Figure 2 shows the estimated load reductions and total costs associated with implementing each of the top ten scenarios in the test basin.

Figure 2. Estimated Phosphorus Load Reductions and Estimated Implementation Costs for Top Ten Optimal BMP Scenarios



Lower Fox River Basin

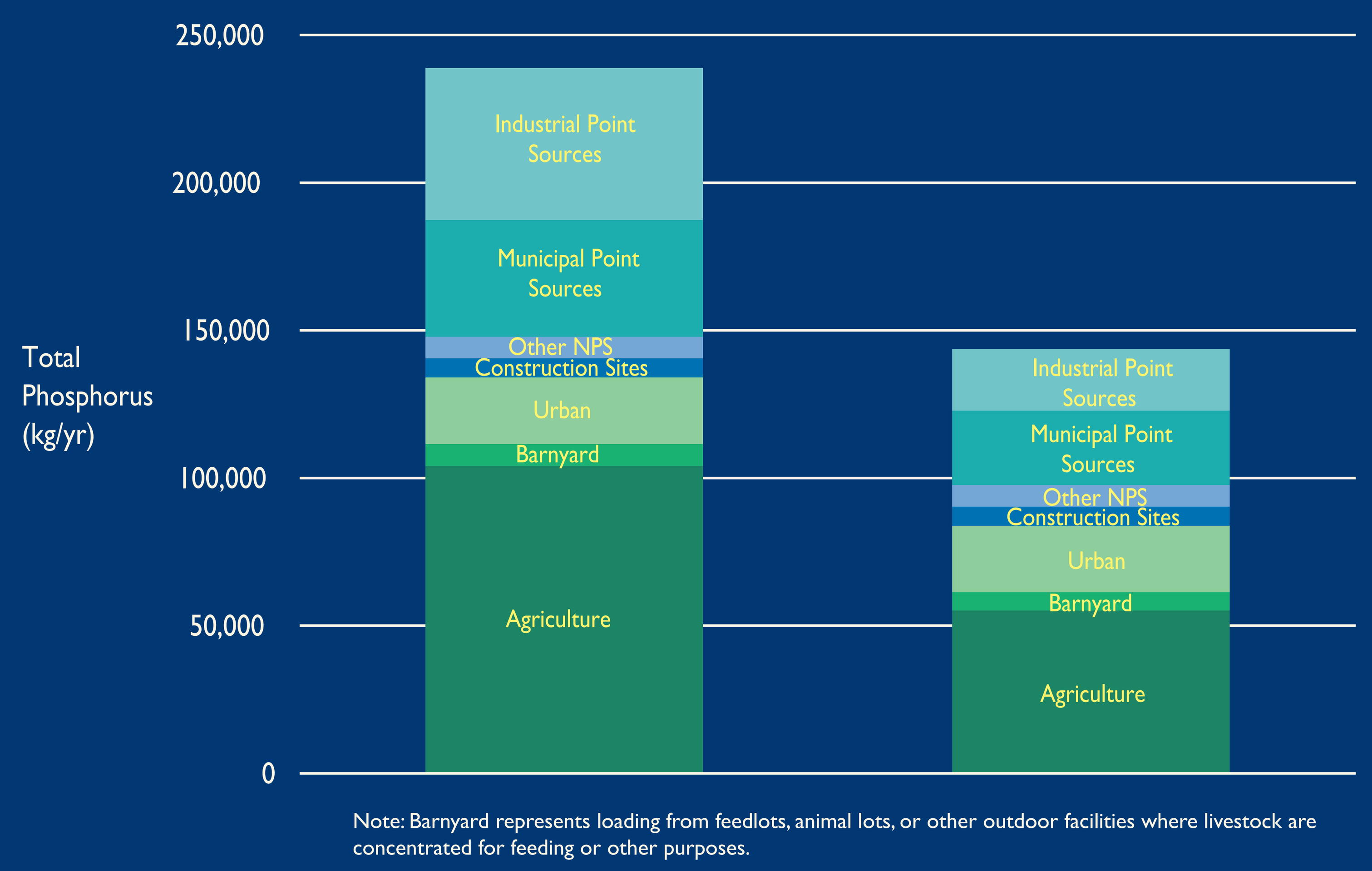
Following determination of the *Optimal Scenario* of agricultural BMPs for the test basin, SWAT was used to simulate phosphorus load reductions for the entire Lower Fox River Basin using the combination of agricultural BMPs from the *Optimal Scenario*. Table 3 shows the simulated phosphorus load reductions and total and incremental costs associated with the implementation of the *Optimal Scenario* of agricultural BMPs in the entire Lower Fox River Basin. According to SWAT, total estimated phosphorus loading in the entire Lower Fox River Basin under *2004 Baseline* conditions is 238,912 kg/yr, which accounts for both point and nonpoint sources of phosphorus. Implementation of the *Optimal Scenario* results in an estimated phosphorus load reduction of about 50,000 kg/yr from agricultural nonpoint sources in the entire basin, which translates to a 21% reduction in total phosphorus loading to Lower Green Bay. The cost of implementing the *Optimal Scenario* of BMPs is $6.9 million per year, or about $138 per kilogram of phosphorus reduced from agricultural nonpoint sources.

Table 3. Simulated Phosphorus Load Reductions and Estimated Costs Associated with Implementing the *Optimal Scenario* of Agricultural BMPs

Agricultural BMP Scenarios	Total P (kg)	% Total P Reduced	Total Cost ($)	Average Cost per kg of Phosphorus Reduced ($)
Baseline 2004 Conditions	147,900			
1. Nutrient Management - Dairy P Feed Ration: Reduce by 25%; Implement 90%	140,600	4.9%	$0	$0.00
2. Plus: Increase manure incorporation from 50% to 85%	133,800	9.5%	$393,907	$27.94
3. Plus: Stabilize Soil P (90% implementation)	125,300	15.3%	$1,645,710	$72.82
4. Plus: Conservation Tillage - CT40%, MT45%, NT15%	115,100	22.1%	$2,730,621	$83.25
5. Plus: Cover Crops on corn silage and some soybean fields	111,600	24.5%	$2,730,621	$75.22
6. Plus: Buffer Strips installed on 100% of 1:24k hydrology streams	107,600	27.2%	$2,730,621	$67.76
7. Plus: Reduce Soil P to 25 ppm; Implementation = 35%	100,600	32.0%	$5,900,796	$124.75
8. Plus: Biofuel Switch grass crop; 7% of all total crop acres	97,700	33.9%	$6,929,204	$138.03

Although not evaluated within the optimization framework, potential phosphorus load reductions and costs associated with point source facility upgrades were estimated for comparison to the agriculture BMPs. Potential estimated point source facility upgrades in the basin results in an estimated 19% phosphorus load reduction (45,045 kg/yr). Total estimated cost associated with point source facility upgrades is $10.8 million a year. Figure 3 shows the combined effect of implementing the *Optimal Scenario* of agricultural BMPs and upgrading point source facilities on total phosphorus loading to Lower Green Bay. Taking into account estimated reductions from both agricultural nonpoint sources and point sources in the Lower Fox River Basin, total phosphorus loading to Lower Green Bay decreases by about 40% (from 238,912 kg/yr to 143,700 kg/yr). These numbers do not reflect phosphorus loading from Lake Winnebago, which is about 287,980 kg/yr. Also, these estimates do not take into account potential reductions from the inclusion of urban BMPs.

Figure 3. Simulated Phosphorus Loading to Lower Green Bay from the LFR Basin
(2004 Baseline vs. Optimal Scenario of BMPs and Point Source Reductions)



Note: Barnyard represents loading from feedlots, animal lots, or other outdoor facilities where livestock are concentrated for feeding or other purposes.

Discussion

The total cost of implementing the *Optimal Scenario* of agricultural BMPs and upgrading point source facilities in the entire Lower Fox River Basin is estimated to be $17.7 million per year, or $186 per kg of total phosphorus reduced. The estimated cost associated with agricultural nonpoint source reductions alone is about $6.9 million per year or about $138 per kilogram of phosphorus reduced and the estimated cost associated with point source facility upgrades is $10.8 million a year or about $240 per kilogram of phosphorus reduced (Table 4). As the demonstration analysis shows, applying an equal phosphorus reduction target to both point sources and nonpoint sources in the Lower Fox River Basin may not be the most cost-effective strategy, as agricultural BMPs have the potential to achieve the greatest phosphorus load reductions at the lowest cost.

Table 4. Summary of Estimated Phosphorus Load Reductions and Costs Associated with Implementation of the *Optimal Scenario* of Agricultural BMPs and Potential Upgrades to Point Source Facilities

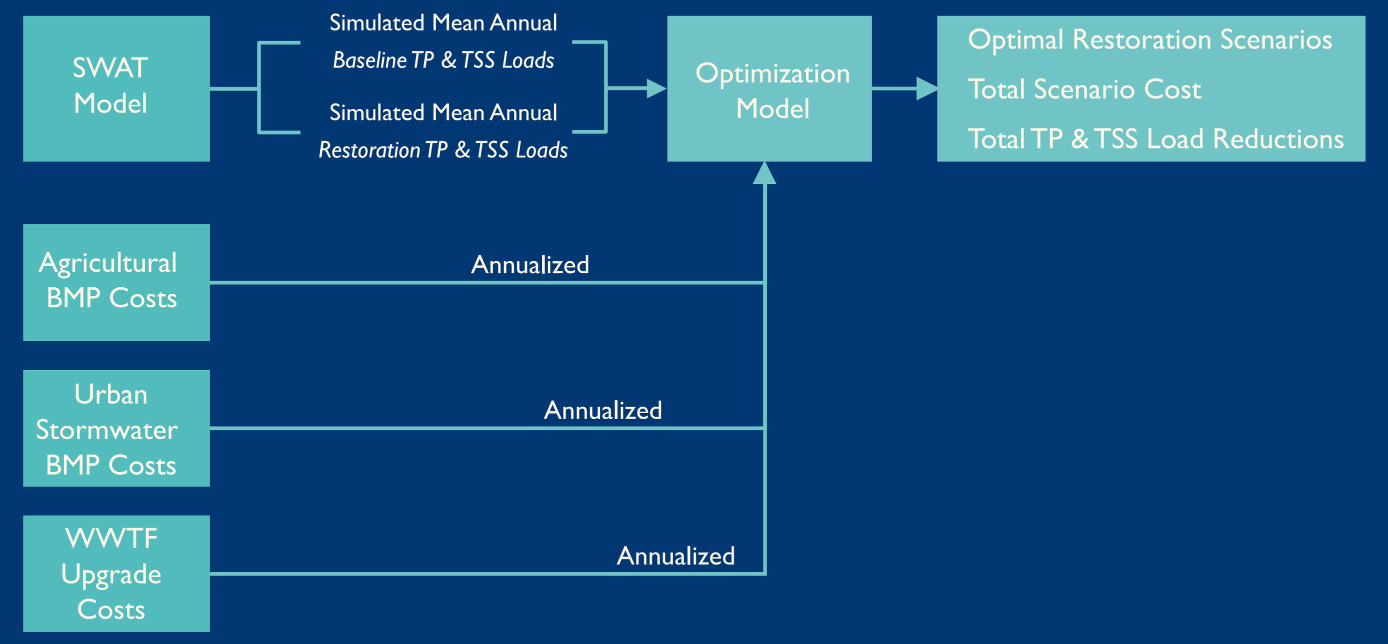
Sources	Total Phosphorus Loading to Green Bay (kg/yr)		Potential Load Reduction (kg/yr)	Total Annual Implementation Cost	Cost per kg TP Reduced
	2004 Baseline	*Optimal Scenario*			
Agricultural Nonpoint Sources	147,900	97,700	50,200	$6,929,204	$138.03
Point Source Facilities	91,019	45,974	45,045	$10,820,500	$240.22

As illustrated in this demonstration analysis, restoring water quality in the Lower Fox River Basin and Green Bay AOC will require extensive implementation of multiple BMPs and other watershed management activities. The use of an optimization modeling framework, such as SWAT-OptiMod, can help managers to identify cost-effective combinations of agricultural BMPs, stormwater BMPs, and point source facility upgrades to meet water quality goals for the Lower Fox River Basin and Green Bay AOC.

Next Steps

Only changes in agricultural practices were simulated for nonpoint sources in the demonstration analysis. Greater total phosphorus reductions are expected from nonpoint sources once urban stormwater controls are included in the analysis. To support the development of the Implementation Plan for the Lower Fox River Basin and Green Bay AOC TMDL, OptiMod will be refined to also evaluate urban stormwater BMPs and point source facility upgrades. This will allow for the assessment of the cost-effectiveness of implementing BMPs for both agricultural and urban nonpoint sources, as well as the cost-effectiveness of upgrading point source facilities. Further, additional agricultural BMPs will likely be included in future analyses for the TMDL Implementation Plan. Figure 4 illustrates the optimization modeling framework that will be used for the TMDL Implementation Plan. Taking into account potential reductions and implementation costs from both nonpoint sources and point sources, OptiMod will be able to identify the most cost-effective means of achieving the load reduction target established for the TMDL.

Figure 4. Pollutant Reduction Optimization Modeling Framework for the TMDL



Acknowledgements

This project was conducted under the direction of Dean Maraldo, the EPA Project Manager for the project entitled Integrated Watershed Approach Demonstration Project (Phase 1) - Green Bay AOC/Lower Fox River Watershed, which is funded by EPA Contract No. 68-C-02-109. This poster was prepared by Laura Blake and Sandra Brown of The Cadmus Group, Inc. Contributors for this poster include Paul Baumgart of the University of Wisconsin – Green Bay, Samuel Ratick of The Cadmus Group, Inc., and Nicole Richmond of Wisconsin Department of Natural Resources.

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EPA United States Environmental Protection Agency

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