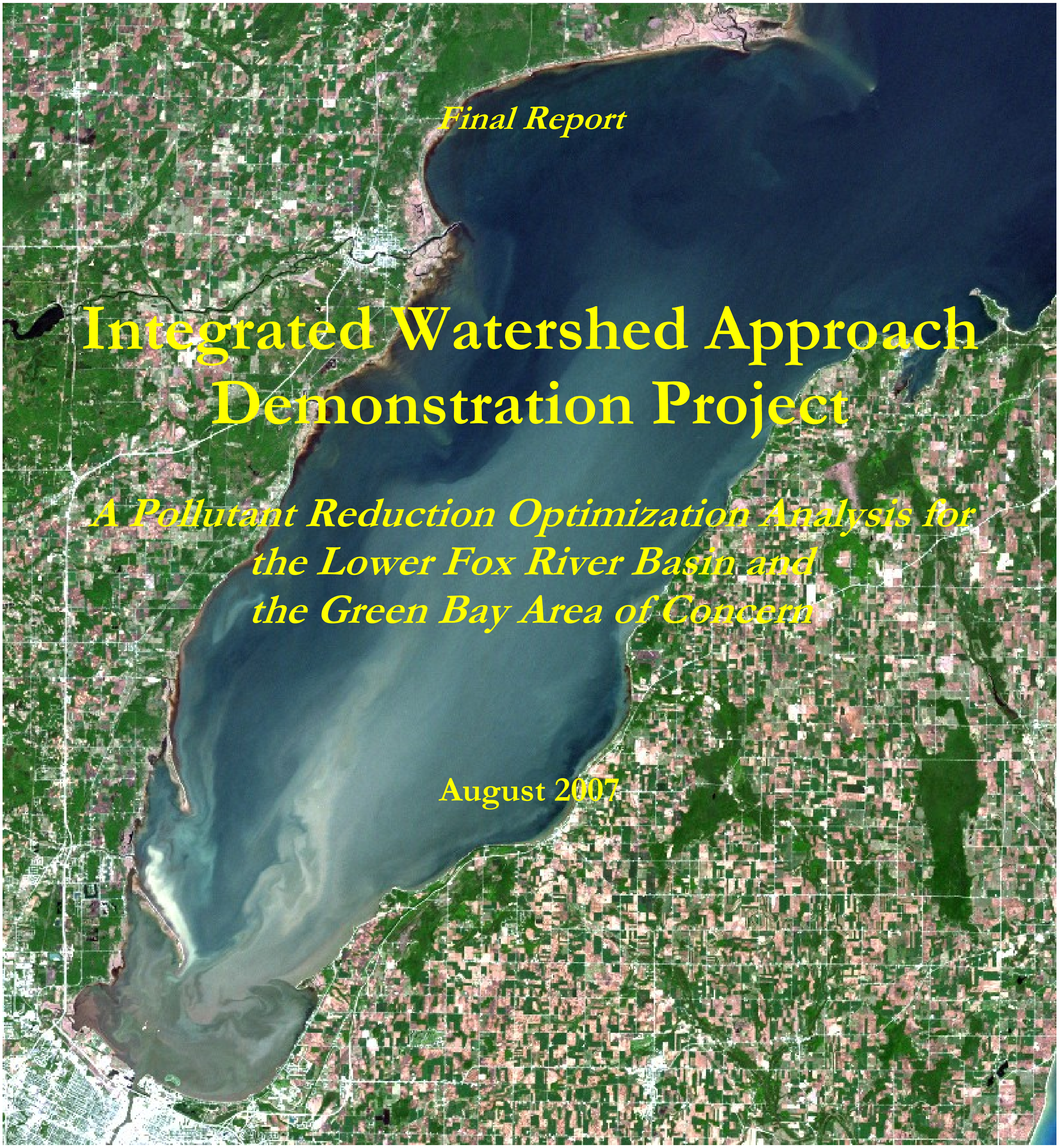

Final Report

Integrated Watershed Approach Demonstration Project

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

August 2007

Prepared for:

United States Environmental Protection Agency

Prepared by:

THE CADMUS GROUP, INC.

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ACKNOWLEDGEMENTS

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1.0 EXECUTIVE SUMMARY

Lower Green Bay is impaired by excessive phosphorus and sediment loading from the Lower Fox River (LFR), which leads to algae growth, oxygen depletion, submerged aquatic vegetation, and water clarity problems. Studies have shown that phosphorus load reductions up to 50% will be necessary to achieve noticeable improvements in algae production and water clarity in the LFR Basin and Green Bay Area of Concern (AOC). The Wisconsin Department of Natural Resources has given the LFR Basin and Green Bay AOC a high priority for the development of a total maximum daily load (TMDL) to address the impairments.

As part of an integrated watershed approach demonstration project sponsored by the U.S. Environmental Protection Agency (EPA), the Cadmus Group, Inc. (Cadmus) was brought on to design an optimization framework for identifying the optimal combination of watershed management practices for restoring water quality in the LFR Basin and Green Bay AOC through the reduction of phosphorus and sediment loading. The optimization analysis was accomplished using the Soil & Water Assessment Tool (SWAT) in conjunction with an Optimization Model (OptiMod) to compare a total of 416 agricultural best management practice (BMP) scenarios, along with their implementation costs, and identify the *Optimal Scenario* (i.e., cost-effective scenario) of BMPs that achieves the greatest phosphorus load reduction. Urban and construction stormwater BMPs were not included in this demonstration analysis, but will be included in future analyses (i.e., for the TMDL). Although not evaluated within the optimization model, potential phosphorus load reductions and costs associated with permitted point source facility upgrades were estimated as part of this demonstration project.

The 1993 Lower Green Bay Remedial Action Plan (RAP) phosphorus load reduction goal of 50% was used as the overall reduction target for this demonstration project; this target is not the final TMDL target. Implementation of the *Optimal Scenario* of agricultural BMPs in the LFR Basin results in an estimated phosphorus load reduction of about 50,000 kg/yr (21%). Potential point source facility upgrades in the LFR Basin results in an estimated phosphorus load reduction of 45,045 kg/yr (19%). These potential reductions combined results in an estimated 40% decrease in phosphorus loading to Lower Green Bay (from 238,912 kg to 143,700 kg per year). While the 50% reduction goal was not achieved during this demonstration, potential load reductions from urban stormwater BMPs were not considered. Also, as revealed during the analysis, the list of agricultural BMPs should be expanded upon to meet the 50% reduction goal.

The cost of implementing all of the agricultural BMPs associated with the *Optimal Scenario* in the LFR Basin is $6.9 million per year, or about $138 per kilogram of total phosphorus reduced from agricultural nonpoint sources. The total estimated cost associated with point source facility upgrades in the LFR Basin is $10.8 million a year (on average), or about $240 per kilogram of total phosphorus reduced from point sources. The total cost of implementing the *Optimal Scenario* of agricultural BMPs and upgrading point source facilities in the entire LFR Basin is estimated to be $17.7 million per year, or $186 per kg of total phosphorus reduced.

As the analysis shows, applying a 50% reduction to all source categories (i.e., both point sources and nonpoint sources) may not be the most cost-effective strategy, as agricultural BMPs achieve the greatest phosphorus load reductions at the lowest cost. Cadmus is in the process of developing a point source optimization tool, which will be incorporated into OptiMod and used to assess the cost-effectiveness of implementing BMPs for nonpoint sources vs. upgrading point source facilities.

2.0 INTRODUCTION

2.1. Project Purpose and Scope

Green Bay, a world-class freshwater resource, is impaired by excessive phosphorus and sediment loading from the Lower Fox River, which leads to algae growth, oxygen depletion, submerged aquatic vegetation, and water clarity problems. The Wisconsin Department of Natural Resources' (WDNR) 2006 Clean Water Act (CWA) Section 303(d) list of impaired waters includes the Green Bay Area of Concern (AOC) and 13 impaired stream reaches in the Lower Fox River (LFR) Basin.[1] WDNR has given the LFR Basin and Green Bay AOC a high priority for the development of a total maximum daily load (TMDL) to address the impairments.

Restoring water quality in the LFR Basin and Green Bay AOC will involve the implementation of multiple best management practices (BMPs) and other watershed management activities to address nonpoint sources. Such activities could require a significant amount of resources. However, economic and management resources are limited; therefore, it is imperative that steps be taken to ensure that each dollar spent maximizes pollutant reduction potential.

As part of a demonstration project sponsored by the U.S. Environmental Protection Agency (EPA), the Cadmus Group, Inc. (Cadmus) was brought on to design an optimization framework for identifying the optimal combination of watershed management practices for restoring water quality in the LFR Basin and Green Bay AOC through the reduction of phosphorus and sediment loading in the basin. The tools developed for this demonstration project will likely continue to be used as part of the development of a TMDL for the LFR Basin and Green Bay AOC.

2.2. The Integrated Watershed Approach

The LFR Basin and Green Bay AOC are impacted by both point and nonpoint sources of phosphorus and sediment loading. Over the years, water quality issues have grown in complexity. As a result, addressing water quality issues requires an integrated problem-solving framework. The use of an integrated watershed approach increases the potential to achieve greater effectiveness in addressing complex water quality problems. This demonstration project utilized an integrated watershed approach through the inclusion of stakeholder input, application of innovative technical approaches, integration of CWA programs, and examination of potential social barriers; specific examples are summarized below.

Coordinated Stakeholder Input

Meetings of the *Lower Fox River TMDL Outreach and Public Involvement Committee* facilitated discussions on the restoration and protection goals for the LFR Basin and Green Bay AOC, including identification of phosphorus and sediment load reductions needed to restore water quality in the basin and in the bay.

The list of agricultural BMP scenarios evaluated for this project were developed by the *LFR Basin and Green Bay AOC TMDL Core Group*, which includes representatives from WDNR, EPA,

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[1] These segments are listed specifically for impairments resulting from sediments, low dissolved oxygen, and excessive nutrients.

University of Wisconsin Green Bay (UWGB), University of Wisconsin (UW) Extension, Oneida Tribe of Indians, Brown County Land Conservation Department, and Green Bay Metropolitan Sewerage District (GBMSD).

Technical Approach

Cadmus utilized a team of experts to accomplish the technical analyses of this project, including: Ms. Laura Blake of Cadmus, who has significant knowledge of the CWA and experience working with EPA and states on TMDL development; Mr. Paul Baumgart of UWGB, who works extensively on water quality monitoring and watershed modeling in the LFR Basin; Dr. Samuel Ratick of Cadmus, who is a national expert in the use of research tools to solve optimization problems; and engineers from Camp Dresser & McKee, Inc. (CDM), a national engineering and environmental consulting firm whose staff have superior knowledge and understanding of point source control and treatment. The use of a team of experts with different areas of expertise allowed for a comprehensive and efficient approach to accomplishing the goals of this demonstration project.

The project's technical analyses utilized existing monitoring (and other) data and built upon previous watershed modeling analyses conducted for the LFR Basin and Green Bay AOC. Many stakeholders are already informed about the previous modeling efforts and have bought into the approach and preliminary model results. Therefore, in addition to being cost and time effective, using existing data and building upon previous efforts reduces the amount of time necessary to gain buy-in on the technical approach.

Integration of CWA Programs

Both regulatory CWA programs (e.g., point source facility permitting) and non-regulatory pollutant reduction measures (e.g., BMPs) were evaluated for their ability to reduce phosphorus and sediment loading in the LFR Basin and Green Bay AOC. Taking into account both point and nonpoint sources of phosphorus and sediment loading reflects an understanding of the need to utilize a watershed-based approach to restore water quality in the basin and in the bay. As the project proceeds to the TMDL development phase, additional CWA programs (e.g., stormwater permitting) will also be examined as additional means of reducing phosphorus and sediment loading in the basin.

Consideration of Social Issues

Nonpoint source (NPS) pollution can often be traced back to the way humans use and change the natural environment (McDermaid and Barnstable, 2001). As a result, NPS implementation projects often require the need to influence human behavior. The *LFR Basin and Green Bay AOC Outreach and Public Involvement Committee* is conducting an assessment to identify socioeconomic indicators that will be used to gain a better understanding of the social systems that influence water quality in the LFR Basin and Green Bay AOC. The use of social indicators in the planning process for the TMDL will help to gauge the potential effectiveness of the various BMPs that have outreach and behavior change components.

Social indicators can help resource managers understand the knowledge and skills needed by landowners in order to properly implement comprehensive nutrient management plans. They can also help to determine why certain populations will install BMPs when others will not, thus helping managers determine when a preliminary outreach component will be most useful. Social indicators can also be used to measure the environmental outcomes of NPS projects. For example, increasing a landowner's understanding of the benefits of using fertilizer containing lower levels of phosphorous may lead to their use of soil tests to modify the amount of phosphorus applied to a lawn or agricultural crops. Documenting intermediate outcomes, such as changes in the knowledge of a target audience, helps demonstrate accountability for the use of NPS funds (University of Wisconsin Extension, 2007).

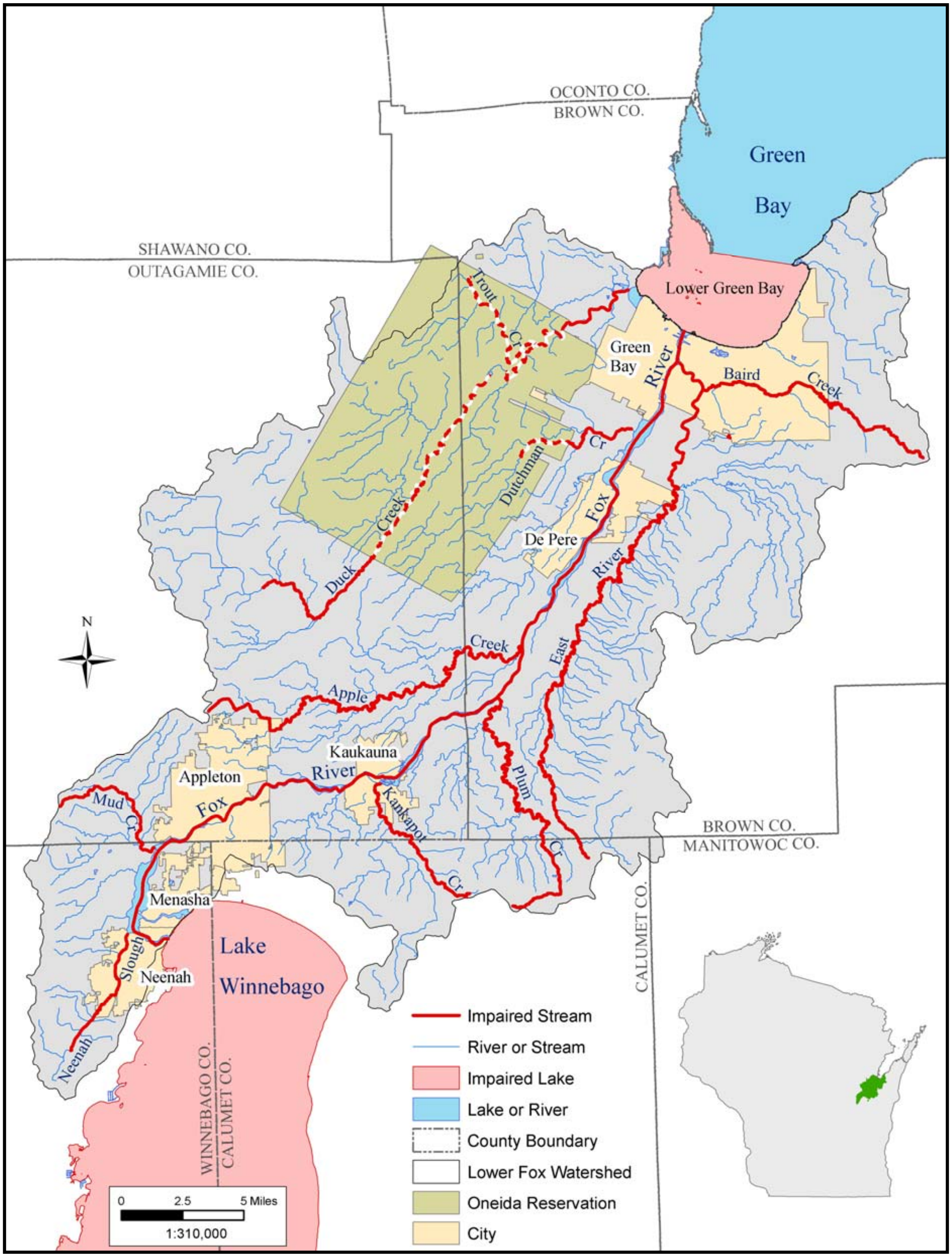
Many of the BMPs necessary to achieve the phosphorus and sediment reduction goals for the LFR Basin and Green Bay AOC will require voluntary cooperation from landowners. If landowners are expected to voluntarily implement the elements of a TMDL implementation plan, the plan must not only address ecological functions in the basin, but also consider issues that directly impact the individual. The consideration of social issues in the TMDL planning process for the LFR Basin and Green Bay AOC will increase the chances of successfully reducing pollutant loading from nonpoint sources through implementation of BMPs.

2.3. Description of the Study Area

The 638 mi^2 LFR 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 AOC includes a little over 21 mi^2 of southern Green Bay out to Point au Sable and Long Tail Point (Wisconsin Department of Natural Resources, 2003). The Lower Fox River and Green Bay are important environmental and economic resources for the state, as well as the local community. People have long used the river and bay for transportation, commerce, energy, food, and recreation. Green Bay is the largest freshwater estuary in the world; the bay itself is an inflow to Lake Michigan. The wetlands along Green Bay's west shore, as well as the wetlands lining the Lower Fox River, provide critical fish spawning habitat for perch, northern, walleye and the elusive spotted musky. The natural resources of the LFR Basin and Green Bay support popular recreational activities such as boating and fishing.

The LFR Basin and Green Bay AOC are impaired by excessive phosphorus and sediment loading. Although phosphorus is an essential nutrient for plant growth, excess phosphorus in the bay increases the occurrence of unwanted algae blooms, which can damage the ecology and aesthetics of the bay, as well as the economic well-being of the surrounding community. Excessive algae growth severely depletes the supply of oxygen in the waterbodies of the LFR Basin and Green Bay AOC, endangering fish and other aquatic life. Excess sediments in the LFR Basin and Green Bay AOC reduce light availability to critical aquatic plants, restricting their ability to grow. Aquatic plants serve as vital habitat and food sources for fish, birds, frogs, turtles, insects, and other kinds of wildlife. They also produce life-giving oxygen, help stabilize bottom sediments, protect shorelines from erosion, and take up nutrients that would otherwise be available for nuisance algae growth. When aquatic plants die due to excess sediments in the river or bay, water quality is degraded.

Figure 1. Map of the Lower Fox River Basin and Green Bay. The impaired segments (colored in red on the map) include: Apple Creek, Baird Creek, Duck Creek, Dutchman Creek, East River, Fox River, Kankapot Creek, Mud Creek, Neenah Slough, Plum Creek, Trout Creek, and Lower Green Bay.



2.4. Surface Water Monitoring

The original LFR Basin monitoring framework included the following four U.S. Geological Survey (USGS) stream discharge and water quality monitoring stations (Figure 2):

1. Bower Creek at CTH MM (36 km^2 drainage area); data record: 1990-1997, 2006 to present
2. Duck Creek at CTH FF (276 km^2 drainage area); data record: 1988-2003, upgraded in 2004
3. East River at Midway (122 km^2 drainage area); data record: 1993-95
4. East River at Monroe Street (374 km^2 drainage area); data record: 1985-86

Daily stream flow is available for the USGS monitoring stations for the time period of operation. Also, for this time period, daily phosphorus and total suspended sediment loads were calculated by the USGS for Bower Creek and the East River at Monroe Street sites. WDNR and USGS brought the Bower Creek station back into service in October 2006 for the purposes of performing a post-BMP analysis; UWGB is currently assisting with sample collection at this site.

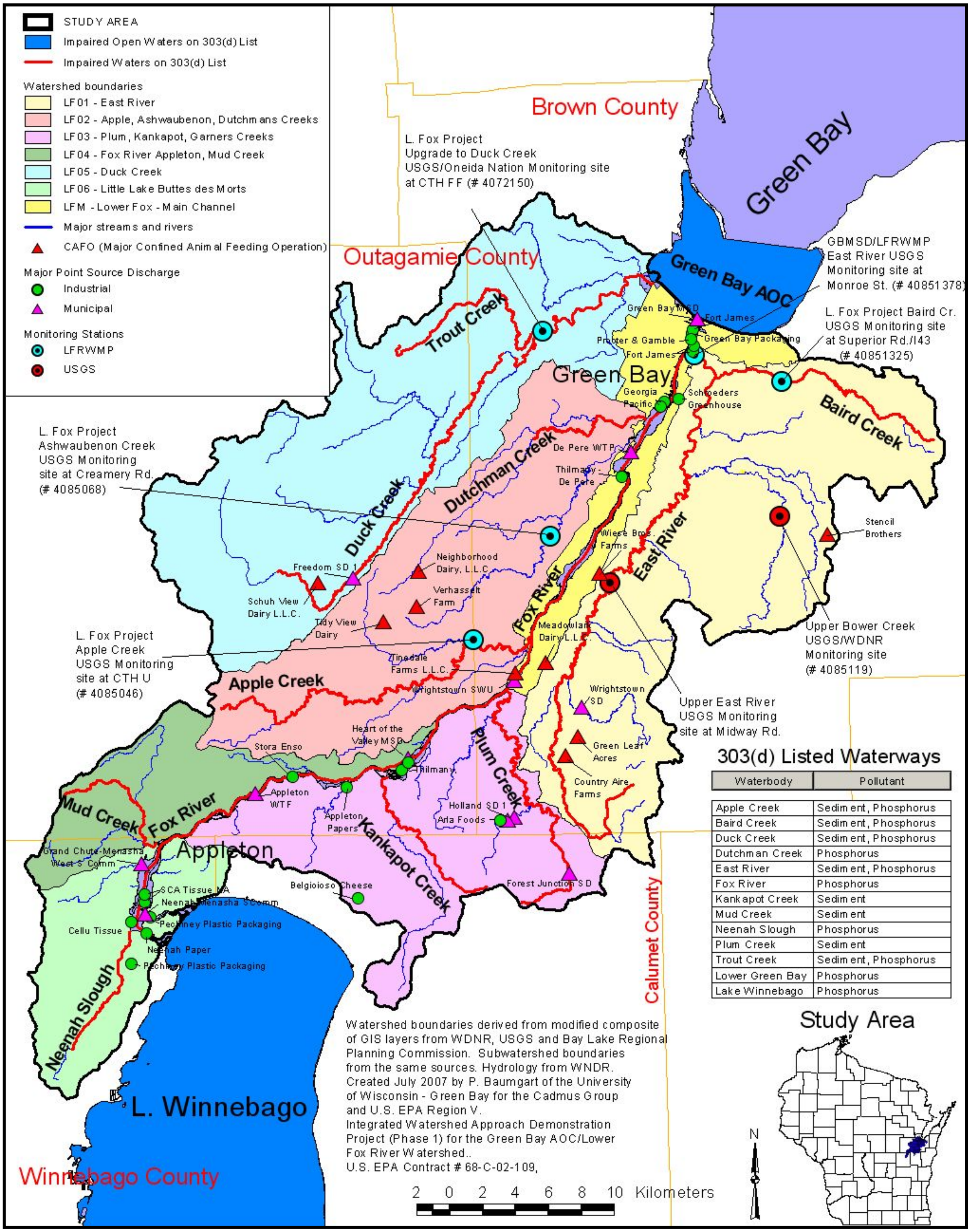
In 2003, the Lower Fox River Watershed Monitoring Program (LFRWMP) was initiated. The multi-year monitoring and assessment program was made possible through a $1.5 million grant to UWGB. As part of this program, continuous discharge is measured and water samples are collected and analyzed for phosphorus and total suspended sediment. The monitoring network includes the following five stations (Figure 2):

1. Duck Creek at CTH FF (276 km^2 drainage area); data record: 2004-present
2. Baird Creek at Superior Road (54 km^2 drainage area); data record: 2004 to present
3. East River at Monroe Street (374 km^2 drainage area); data record: 2004 to present
4. Apple Creek at CTH U / Campground (117 km^2 drainage area); data record: 2004-06
5. Ashwaubenon Creek at Creamery Road (48 km^2 drainage area); data record: 2004-06

The LFRWMP stations are operated cooperatively by USGS, UWGB, GBMSD, UW-Milwaukee, and the Oneida Tribe of Indians. USGS computes daily phosphorus and total suspended sediment loads for each stream based on continuous discharge and discrete low-flow and automated event sampling. Discharge, water quality data, and loads are published in annual USGS data reports and input to a USGS database. Data from these sites were utilized for the watershed modeling component of this project. Although three years of discharge and water quality data (from October 2003 through September 30, 2006) had been collected at the time that the model was being validated and updated for this project, data from USGS water year 2006 were still provisional, so they were not included in the analysis.

The GBMSD has also been conducting extensive monitoring since 1986 at seven fixed stations located on the Lower Fox River and in Green Bay. Grab samples collected from these sites have been analyzed by the GBMSD's certified lab for total phosphorus, total suspended sediment, volatile suspended solids, chlorophyll *a*, dissolved oxygen, and other parameters. An older data set is also available for historical analysis. The UWGB collected samples from Green Bay during a 1970 to 1985 period. Grab samples were analyzed for total phosphorus during 9 of these years, and chlorophyll *a* was analyzed during 5 years.

Figure 2. Monitoring Framework for the Lower Fox River Basin and Green Bay.



303(d) Listed Waterways

Waterbody	Pollutant
Apple Creek	Sediment, Phosphorus
Baird Creek	Sediment, Phosphorus
Duck Creek	Sediment, Phosphorus
Dutchman Creek	Phosphorus
East River	Sediment, Phosphorus
Fox River	Phosphorus
Kankapot Creek	Sediment
Mud Creek	Sediment
Neenah Slough	Phosphorus
Plum Creek	Sediment
Trout Creek	Sediment, Phosphorus
Lower Green Bay	Phosphorus
Lake Winnebago	Phosphorus

Watershed boundaries derived from modified composite of GIS layers from WDNR, USGS and Bay Lake Regional Planning Commission. Subwatershed boundaries from the same sources. Hydrology from WNDR. Created July 2007 by P. Baumgart of the University of Wisconsin - Green Bay for the Cadmus Group and U.S. EPA Region V. Integrated Watershed Approach Demonstration Project (Phase 1) for the Green Bay AOC/Lower Fox River Watershed.. U.S. EPA Contract # 68-C-02-109,

2.5. Sources of Impairment

Sources of phosphorus and sediment loading to the LFR Basin and Green Bay AOC include treated effluent from permitted municipal and industrial point source dischargers and polluted runoff from nonpoint sources, such as pastures and crop land, rural and urban land, and construction sites. Point source facilities have already begun to reduce their discharge of phosphorus as part of their permit requirements established by WDNR. Regulations requiring increased phosphorus removal from large municipal wastewater treatment facilities on the Fox River have reduced municipal loading of phosphorus by about 84% since the 1970s (Wisconsin Department of Natural Resources, 1993).

Studies have shown that phosphorus load reductions up to 50% will be necessary to achieve noticeable improvements in algae production and water clarity in the LFR Basin and Green Bay AOC (Wisconsin Department of Natural Resources, 1993). In 1993, the Public Advisory Committee for the Lower Green Bay Remedial Action Plan (RAP) identified a phosphorus load reduction target of 50% from point and nonpoint sources (combined) for the entire LFR Basin (Wisconsin Department of Natural Resources, 1993). While additional reductions from point source facilities may be needed to restore water quality in the river and bay, reducing phosphorus and sediment loading to the LFR Basin and Green Bay AOC will require significant reductions in polluted runoff from nonpoint sources.

3.0 METHODOLOGY

The goal of this demonstration project was to design an optimization framework for identifying the optimal combination of watershed management practices (i.e., BMPs) for reducing phosphorus and sediment loading in the LFR Basin and Green Bay AOC. For this demonstration project, "optimal combination" is defined as the cost-effective combination of BMPs that results in a 50% reduction (or as close to 50% as possible) in phosphorus loading in the basin. The reduction target for this demonstration project was selected based on the RAP phosphorus load reduction objective of 50% (Wisconsin Department of Natural Resources, 1993). This is not the final TMDL target. The final phosphorus (and sediment) reduction targets for the TMDL will be developed based on recent data and analyses.

The optimization analysis was accomplished using the Soil & Water Assessment Tool (SWAT) in conjunction with an Optimization Model (OptiMod) to compare multiple combinations of BMP scenarios along with their costs of implementation. Nonpoint source reductions in the LFR Basin and Green Bay AOC will be needed from both agricultural and urban sources; however, the focus of this demonstration project was on agricultural BMPs. OptiMod will be expanded upon during the development of the TMDL to also take into consideration urban stormwater BMPs, as well as permitted point source dischargers. The following sub-sections summarize the technical approach taken for the analysis; additional details are provided in the Appendices.

3.1. SWAT Watershed Model

3.1.1. *Model Overview*

The SWAT model was selected to simulate phosphorus and sediment loading in the basin, including estimated load reductions associated with the implementation of the agricultural BMPs and reduced loads associated with potential point source facility upgrades. SWAT is a distributed parameter, daily time-step model that was developed by the U.S. Department of Agriculture - Agricultural Research Service (USDA-ARS) to assess nonpoint source pollution from watersheds and large complex river basins (Arnold et al., 1996, Neitsch et al., 2001). SWAT simulates hydrologic and related processes to predict the impact of land use management on water, sediment, nutrient, and pesticide export. With SWAT, a large heterogeneous river basin can be divided into hundreds of subwatersheds; thereby, permitting more realistic representations of the specific soil, topography, hydrology, climate and management features of a particular area. Crop and management components within the model permit reasonable representation of the actual cropping, tillage, and nutrient management practices typically used in northeastern Wisconsin.

Modeled output data from SWAT can be easily input to a spreadsheet or database program, thereby making it easier to model large complex watersheds with various management scenarios efficiently. Major processes simulated within the SWAT model include: surface and groundwater hydrology, weather, soil water percolation, crop growth, evapotranspiration, agricultural management, urban and rural management, sedimentation, nutrient cycling and fate, pesticide fate, and water and constituent routing. SWAT also utilizes the QUAL2E sub-model to simulate nutrient transport. A detailed description of the SWAT model can be found in the Quality Assurance Project Plan (QAPP) developed for this project (Appendix A), in Appendix B (SWAT Model Refinements), and on the SWAT Web site (http://www.brc.tamus.edu/swat/).

3.1.2. *Model Refinement*

The SWAT model framework that Baumgart (2005) successfully applied to the LFR Basin in 2005 was refined as part of this demonstration project (by Baumgart) and reapplied in order to estimate the load reduction associated with various combinations of agricultural BMP scenarios. Model refinements were necessary because the previous modeling effort relied heavily on daily loads from a single intensively-monitored USGS station (Bower Creek), although other more limited flow and water quality data were used by Baumgart (2005) for model validation. The extensive data set of continuous flow and daily loads of total phosphorus and suspended sediment from the five LFRWMP monitoring stations made it possible to further test the ability of the model to simulate flow and total phosphorus and suspended sediment loads with a reasonable level of accuracy. Appendix B provides a detailed description of the methods and data used to refine SWAT, as well as summarizes the results of the assessment of the refined model.

3.1.3. *Model Application*

The SWAT model simulation periods used for this project include a 2000 to 2005 period (called *2004 Baseline*) for model validation and assessment and a 1977 to 2000 period for the simulations of the BMP *Optimal Scenario*. Measured daily precipitation and temperature were utilized in all simulations. It is important to note that *2004 Baseline* conditions involve inputs with slightly different time frames. The most recent landuse available for the basin was from 2001. Also, point source phosphorus loads from 2005 were utilized; however, the total load does not necessarily change that much from year to year. Finally, the crop residue levels and associated tillage practices for the 2004 – 2005 period were estimated from the years 1999 to 2002. The phosphorus load reduction target selected for this analysis was 50% from *2004 Baseline* levels.

3.2. Agricultural BMPs and Costs

The agricultural BMPs (and maximum implementation rates) evaluated in this demonstration project were selected through a series of meetings and one-on-one interactions with members of the *LFR Basin and Green Bay AOC TMDL Core Group*, a team of local water resource and agricultural experts from WDNR, EPA, UWGB, UW-Extension, Oneida Tribe of Indians, Brown County Land Conservation Department, and GBMSD. Some of the BMP scenarios discussed with the team were not included in the final demonstration analysis due to resource and time constraints. However, during the development of the TMDL, the BMPs not evaluated during this demonstration may be re-visited. Table 1 identifies the final agricultural BMP scenarios (along with their associated costs) selected for the demonstration analysis. A brief summary of each of the BMP scenarios follows Table 1.

Table 1. Agricultural BMP Scenarios Selected for Optimization Analysis.

Agricultural Management Practice	Maximum Implementation Rate (%)	Estimated Implementation Cost ($/acre)
1. Nutrient Management (reduce phosphorus in dairy cow feed ration by 25%)	90%	$0
2. Manure Incorporation (increase proportion of applied manure that is incorporated within 72 hours)	85%	$15
3. Nutrient Management (stabilize soil-test phosphorus averages at current average of 40 ppm [Bray P1[2]])	90%	$28
4. Conservation Tillage (mulch tillage and zone tillage)	60% (mulch-till), 15% (zone-till), with total conservation tillage not to exceed 60%	$15 (mulch till) and $25 (zone till)
5. Cover Crops (on low residue fields)	72%	$30
6. Vegetative Buffer Strips	100%	$1,300
7. Decrease Soil Phosphorus Levels from 40 ppm to 25 ppm (Bray P1)	35%	$60
8. Biofuel Crops	7%	$75

1. Nutrient Management (reduce phosphorus in dairy cow feed ration by 25%)

Dietary phosphorus in dairy cow feed ration frequently exceeds the required amount. A 2002 study conducted in Wisconsin found that reducing phosphorus in the diet of dairy cows greatly reduces the measured level of phosphorus in the corresponding manure, and the subsequent load of phosphorus in runoff from fields where the manure was applied (Ebeling et al., 2002).

For this nutrient management scenario, phosphorus in dairy cow feed ration is reduced by 25% as compared to 2000 levels. The maximum implementation rate is set at 90%, which implies that 90% of the total manure produced and applied in the basin contains 25% less phosphorus due to an

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[2] In Wisconsin, the recommended soil analysis for assessing the phosphorus status of agricultural fields is called the Bray P1. The Bray P1 is a soil fertility test designed to indicate the concentrations of phosphorus in the soil that can be used by crops. Research has shown a good correlation between soil Bray P1 and total phosphorus.

associated reduction of phosphorus in the dairy feed ration. This translates to roughly a 25% reduction in manure phosphorus concentrations. A detailed justification of these assumptions is described in Baumgart (2005). The fertilizer/manure SWAT input file was adjusted accordingly to simulate this scenario.

In most cases, reducing phosphorus in the dietary dry matter of ration for dairy cows will save money without affecting milk production or reproductive performance; however, some farmers may have to pay more for feed without excessive phosphorus as imported feeds have lower costs since most are typically byproducts (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007). Therefore, no net costs ($0) were assumed for this BMP scenario.

2. Manure Incorporation (increase proportion of applied manure that is incorporated within 72 hours)

Manure, like fertilizer, has a very high concentration of soluble phosphorus. If a rainfall event occurs soon after a surface application of manure, the concentration of soluble phosphorus in the runoff (that is delivered to a nearby stream or waterbody) can be extremely high. Incorporating manure into soil (as opposed to just applying it to the field, on top of the soil) will minimize flash losses of soluble phosphorus associated with rainfall runoff events.

In this scenario, the level of manure incorporated into soil immediately or within 72 hours following application is assumed to be 50% for *2004 Baseline* conditions, which is the same level utilized by Baumgart (2005). The remaining manure is applied as needed without intentional incorporation. The maximum implementation rate was set at 85%, which implies that manure incorporation is taking place on up to 85% of agricultural land in the basin where manure is applied. The estimated cost of manure incorporation is $15/acre, which reflects costs associated with mulch tillage following surface application of manure (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007).

3. Nutrient Management (stabilize soil-test phosphorus averages at current average of 40 ppm [Bray P1])

This nutrient management scenario simulates the estimated effect of a comprehensive nutrient management plan, which requires that phosphorus inputs be limited to crop agronomic needs, thereby stabilizing soil-test phosphorus levels such that they remain at the current average level of 40 ppm. In this scenario, a number of watershed management practices were instituted to ensure that soil phosphorus levels do not increase over time due to net gains from commercial fertilizer or manure applications; the management changes are as follows:

- Supplemental phosphorus in the form of starter fertilizer is not added to soybean crops, nor is supplemental phosphorus in the form of commercial fertilizer added to alfalfa crops.
- Under the cash crop rotation, commercial fertilizer is applied at crop agronomic needs (i.e., harvest removal rates) for corn (the same was done for the *2004 Baseline* simulations).
- Under the dairy crop rotation, only the minimal recommended starter rate of 87 lbs/acre of 9-23-30 was initially applied to the corn crop (Kelling et al., 1998). Even when soil nutrients are sufficient to meet crop needs, starter fertilizer still boosts yields slightly under the right

conditions. However, soil phosphorus levels still increased in the simulations, so 80% of the recommended starter was added to corn planted under the dairy rotation.

- Phosphorus levels in dairy feed ration were reduced by 25% to further decrease the potential for increasing soil phosphorus levels.
- The combined measures above were not enough to stabilize simulated soil phosphorus levels, which continued to increase, although at a much lower rate than before. Therefore, to keep simulated soil phosphorus levels from continuing to increase, the amount of applied manure is reduced by about 22%. This reduction is accomplished through redistributing the manure to fields that are mostly managed as cash cropped fields (i.e., usually because they are the distant from the manure source).

The maximum implementation rate for this scenario was set at 90% of the available cash-crop land in the basin. The cost of reducing the amount of fertilizer applied to cropland is assumed to be $0. For reasons previously discussed, the cost of reducing phosphorus in dietary dry matter of ration for dairy cows is assumed to be $0. The cost of evenly distributing manure to fields further from the farm where commercial fertilizer may currently be utilized is estimated at $28/acre. This estimate is based on the even application of manure an additional mile away from farm at typical manure application rates (e.g., 14,000 gal/acre) at a cost of $0.002/gallon of manure. The total cost associated with this scenario is $28/acre (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007).

4. Conservation Tillage

When crop land is being prepared for replanting, plows are typically used to clear the field of residue or any growing vegetation (e.g., weeds, cover crop, etc.) from the previous season. With no crop residue or vegetation on the surface to restrict the lateral movement of water, plowed fields are highly vulnerable to runoff, with excess phosphorus and sediment transported to nearby surface waters. Conservation tillage systems are highly effective at reducing soil erosion and runoff events. Conservation tillage is a term used to describe any system that leaves about a third of the soil covered up to and after the crop is planted.

Both mulch till and zone till (two forms of conservation tillage) were considered as one of the scenarios for the analysis. Mulch till is a conservation tillage and planting system that disturbs the soil surface prior to planting but still leaves 30 percent or more of the soil surface covered by crop residue after planting, to reduce soil erosion by water and wind. Zone till (or strip till) is a conservation tillage and planting system where the soil is left undisturbed from harvest to planting except for strips up to 1/3 of the row width. In general, zone-tillage should leave greater than 50 percent of the soil surface covered by crop residue after planting.

Under this scenario, the area of land dedicated to conservation tillage (i.e., reduced tillage practices) is allowed to increase from the estimated *2004 Baseline* levels of 15.2% mulch till, 1.7% zone till, and 83.1% conventional tillage, to a maximum of 60% of land under conservation tillage (i.e., mulch till or zone till), but not more than 15% under zone-till management. The estimated cost of mulch tillage ($15/acre) and zone tillage ($25/acre) reflect incentive payments provided to farmers who engage in conservation tillage practices (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007).

5. Cover Crops (on low residue fields)

For this scenario, a cover crop of rye is planted after corn silage and soybean are harvested in the fall. This scenario is simulated in the following incremental steps: 1) All corn-silage fields (maximum implementation of 36%); and 2) All corn-silage and soybean fields (maximum implementation of 72%). To limit the maximum practical implementation rate, this scenario is applied only to dairy crop rotations, although it could also be utilized for soybean grown within cash-crop rotations. A potential future modeling option may involve adding an additional set of hydrologic response units to allow a continuously variable proportion of cover crops.

The cover crop scenario is only applied to fields under mulch tillage management because conventional tilled management is inconsistent with planting cover crops. However, fields under zone tillage management could benefit when corn-silage is in the rotation. The estimated cost of cover crops ($30/acre) includes estimated costs for rye seed ($8/acre), planting or drilling the seed ($15/acre), and cover crop kill with Roundup prior to planting ($7/acre) (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007).

6. Vegetative Buffer Strips

Vegetative buffer strips (VBS), also known as vegetative filter strips, riparian buffers strips, or filter strips, can reduce sediment and phosphorus loading to nearby waterbodies. In this scenario, it is assumed that VBS are installed along 100% of all streams adjacent to crop land as delineated in the WDNR 1:24k hydrology Geographic Information Systems (GIS) data layer. Streams with existing VBS or that have "natural" VBS were included in the *2004 Baseline* model simulation (Baumgart, 2005). It is important to note that there are many additional streams, drainage ditches, channels, and road ditches that are not delineated in the WDNR 1:24 k hydrology layer, which could also have VBS installed to improve water quality and riparian habitat.

The estimated cost of VBS represents incentive payments paid through the Conservation Reserve Enhancement Program (CREP). CREP provides Wisconsin landowners with an opportunity to voluntarily enroll agricultural lands into conservation practices, such as VBS. The estimated costs of VBS run from $350 to $1,115 an acre and include federal and state cost sharing, as well as additional state incentives. Brown County also has a flat rate payment ranging from $500 - $1,300 acre (Jim Jolly, Brown County Land Conservation Department, personal communication, 2007). The maximum potential cost of $1,300/acre was used for the analysis in this demonstration project.

7. Decrease Soil Phosphorus Levels from 40 ppm to 25 ppm (Bray P1)

In this scenario, the current average soil phosphorus concentration of 40 ppm (Bray P1) is reduced to 25 ppm through improved nutrient management techniques. This soil phosphorus level was present in the recent past, so it is technically achievable with changes in management and given enough time to reduce excess phosphorus currently present in the soil. Justification of the soil test phosphorus concentration of 25 ppm is discussed in more detail by Baumgart (2005).

The maximum implementation rate for this scenario is set at 35% of the total agricultural land in the basin. This scenario assumes that soil phosphorus levels have already been stabilized under previous/existing nutrient management activities. Further reductions in soil phosphorus levels (to 25 ppm) require decreased application of phosphorus fertilizer and application of manure to fields further from the farm. The estimated cost of $60/acre associated with this scenario reflects the application of manure an additional mile away from farm at lower than typical manure application rate (e.g., 10,000 gal/acre) and at a cost of $0.006/gallon of manure (Kevin Erb, UW-Extension and Paul Baumgart, UWGB, personal communication, 2007).

8. Biofuel Crops

This scenario simulates the effect of adding switchgrass as a biofuel crop to the typical cash-crop rotation of alternating years of soybean and corn-grain. Switchgrass is a perennial crop that can be used to provide cellulose feedstock for ethanol production, or possibly for direct combustion. The maximum implementation rate for this scenario is set at 7% of all agricultural land in the LFR Basin.

The estimated costs associated with this scenario represent an incentive payment to grow switchgrass instead of soybean or corn-grain. The current average cost to grow corn in Wisconsin is about $200/acre (Kevin Erb, UW-Extension, personal communication, 2007). The estimated cost to grow swichgrass ranges from $48 to $132 per ton, depending on the type of production system used (Chariton Valley Biomass Project, 2007). The cheapest method involves high yields (6 tons per acre) using frost-seeding on grassland. Low yields (1.5 tons per acre) using spring-seeding on cropland result in higher production costs. These assumptions translate to estimated costs ranging from $198 to $288 per acre for growing switchgrass. Incentive payments ranging from $50/acre to $100/acre were identified as reasonable estimates for encouraging farmers to grow switchgrass; the intermediate ($75/acre) cost was used for the analysis.

3.3. OptiMod Analysis of Agricultural BMPs

Cadmus developed an Optimization Model (OptiMod) to use in conjunction with SWAT for comparing multiple combinations of BMPs to reduce phosphorus loading in the LFR Basin and Green Bay AOC. OptiMod was designed to identify cost-effective combinations of BMPs for achieving various levels of pollutant reduction goals. OptiMod is formulated as a mixed-integer linear programming model that uses simulation results from SWAT to choose either the least cost combination of BMPs in the basin that will achieve a given phosphorus reduction target, or the maximum phosphorus reduction that can be achieved within a given budget. A detailed summary of the development of OptiMod is provided in Appendix C.

In order to evaluate the effectiveness of many combinations of BMP scenarios in a time-efficient manner, a representative subwatershed of the LFR Basin (rather than the entire LFR Basin) was selected for the demonstration analysis. The subwatershed chosen for the analysis was the largely agricultural Upper Bower Creek subwatershed (36 km^2, LF01-15). The Upper Bower Creek subwatershed has silty-clay to clay-loam soils with slow infiltration rates (NRCS hydrologic group C soils), shallow overland slopes, and landuse comprised of 83% agriculture (mostly dairy) and 9% forest and wetland (in 2000). These characteristics are typical of most agricultural areas within the LFR Basin. Also in the interest of time, only phosphorus was used for the optimization analysis; future analyses (i.e., for the TMDL) will take into account both phosphorus and sediment reductions during the optimization analysis.

A total of 416 agricultural BMP scenarios were created using various combinations of the individual agricultural BMPs (see Appendix D for complete list of the BMP scenarios). SWAT was used to simulate the effects of the 416 agricultural BMPs scenarios (both individually and in combination with one another) on reducing phosphorus loading in the Upper Bower Creek subwatershed test site. For the BMP scenarios, SWAT was applied over a 1977 to 2000 long-term climatic period and the simulated phosphorus and suspended sediment loads were summarized on an average annual basis to ensure that typical climatic conditions were represented.

Each of the 416 BMP scenarios simulated by SWAT represents a combination of one or more agricultural BMPs applied to relevant portions within the study area at different implementation rates (varying from 0% to 100%, depending on the BMP). To help illustrate this, Table 2 provides SWAT simulation results for 12 of the 416 BMP scenarios (all of which are listed in Appendix D). 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 VBS.

Table 2. SWAT Simulation Results for a Sub-Set of the Agricultural BMP Scenarios Applied in the Upper Bower Creek Subwatershed Test Site.

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

Notes: MT = mulch till; VBS = vegetative buffer strips; CT = conventional tillage

SWAT simulation results for each of the BMP scenarios were statistically analyzed using multivariate regression analysis. For ease of use in OptiMod, the BMP scenarios were given abbreviated names based on the types of BMPs included in the scenario and then re-organized for input into OptiMod. For example, one of the BMP scenarios in Table 2 is called "MT_VBS_DairyP" – representing SWAT simulation results for the application of mulch tillage from 0 to 100%, reduction of phosphorus in feed for dairy cows at 0 to 100% of farms, and full utilization of vegetative buffer strips (100% application) where possible.

Appendix E provides the detailed, step-by-step overview of the application of OptiMod for the analysis of the BMP scenarios, including screen captures from the model itself.

4.0 RESULTS AND DISCUSSION

4.1. Application of SWAT - OptiMod in the Upper Bowers Creek Subwatershed Test Site

SWAT was used to simulate phosphorus load reductions associated with the application of each of the BMP scenarios in the Upper Bowers Creek subwatershed. The simulated load reductions, along with the estimated costs for the BMPs served as input for OptiMod, which was then run to calculate the *Optimal Scenario* of BMPs, which is defined as the cost-effective agricultural BMP scenario that achieves a 50% (or as close to 50% as possible) phosphorus load reduction.

Using the Minimize Cost (Z1) mode, OptiMod was first run for the with the maximum phosphorus loading target set at 3,000 kg (about a 50% reduction). Given the restrictions on the maximum implementation rates for some BMPs, no feasible solution was able to achieve the 50% load reduction target. This indicates the need to re-evaluate maximum implementation rates, as well as additional BMPs in future analyses.

OptiMod was then run using the Minimize Phosphorus Load (Z2) mode with a large enough budget to not constrain the solution. The *Optimal Scenario* of BMPs that produced the maximum reduction in phosphorus loading in the Upper Bower Creek subwatershed test site was "MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN," which represents a combination of the following BMPs: mulch tillage, planting switchgrass as a bio-fuel crop, vegetative buffer strips, reducing soil phosphorus to 25 ppm, planting cover crops on corn silage and soybean crop fields, and manure incorporation. This *Optimal Scenario* of BMPs is estimated to reduce total phosphorus loading in the Upper Bower Creek subwatershed test site by approximately 37% from the *2004 Baseline* load of 5,688 kg to 3,567 kg (a reduction of 2,121 kg). The total cost of implementing this *Optimal Scenario* of BMPs in the Upper Bower Creek subwatershed is slightly less than $350,000.

In addition to identifying the *Optimal Scenario*, OptiMod was also used to identify the nine next best cost-effective BMP scenarios that reduce total phosphorus loading in the Upper Bower Creek subwatershed test site by as close to 50% as possible. The top ten cost-effective BMP scenarios that achieve the greatest phosphorus load reductions are provided in Tables 3 and 4. Figure 3 shows the estimated load reductions and total costs associated with implementing each of these ten scenarios in the Upper Bower Creek subwatershed test site. The cost to reduce 1 kg of phosphorus ranges from $164.75 per kg of phosphorus reduced for the *Optimal Scenario*, which achieves the greatest load reduction, to $93.72 per kg of phosphorus reduced for the sixth best scenario, which achieves a load reduction of 1,941 kg/yr.

Table 3. Area of BMP Application for the Top Ten Optimal BMP Scenarios for Upper Bowers Creek Subwatershed Test Site

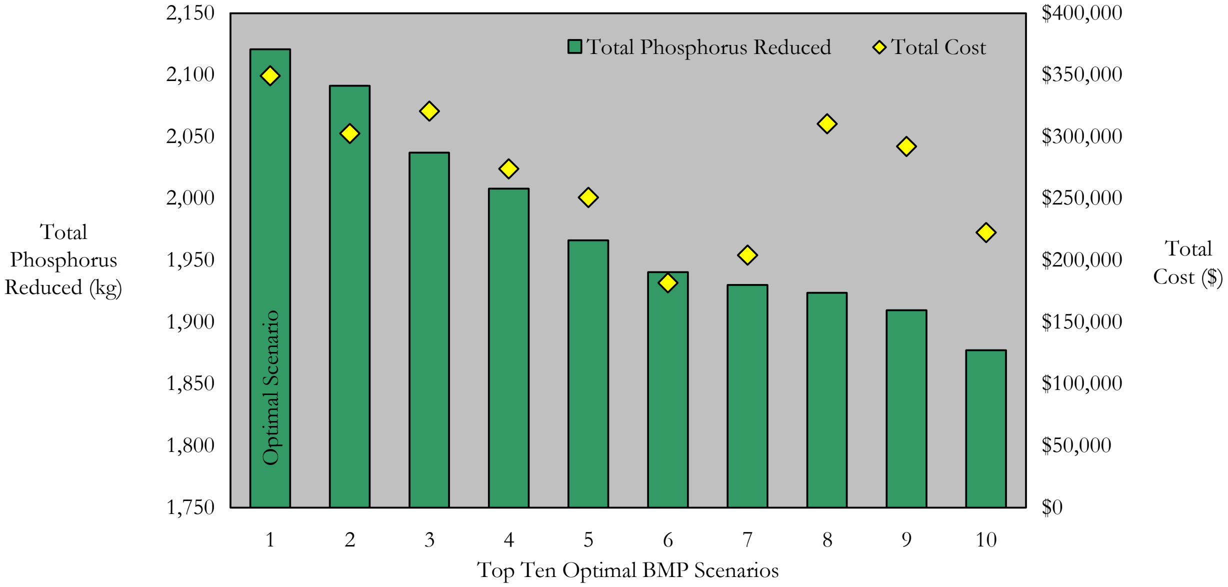
BMP Regime	Scenario Rank by Phosphorus Reduction	Area BMP Applied (acres)										
		CT	MT	ZT	DP	MAN_INC	STABLE_P	STABLE_LOWER_P	VBS	CvrCrop Slge	CvrCropSlge(SOY)	BioFuel
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	1	2145.55	3218.33			951.66		1541.37	75.66		1903.31	519.09
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN	2	2145.55	3218.33			951.66	1635.12		75.66		1903.31	519.09
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN	3	2145.55	3218.33			951.66		1541.37	75.66	951.66		519.09
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN	4	2145.55	3218.33			951.66	1635.12		75.66	951.66		519.09
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN	5	2145.55	3218.33			951.66		1541.37			1903.31	519.09
Complex Regime*	6	2145.55	2413.75	804.58			1180.92	1541.37				
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN	7	2145.55	3218.33			951.66	1635.12				1903.31	519.09
MT_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	8	2145.55	3218.33			951.66		1541.37	75.66		1903.31	
MT_BioFuel_VBS__LowerStableP_ALLMAN	9	2145.55	3218.33			951.66		1541.37	75.66			519.09
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN	10	2145.55	3218.33			951.66		1541.37		951.66		519.09

Table 4. Phosphorus Reductions and Costs Associated with the Top Ten Optimal BMP Scenarios for Upper Bowers Creek Subwatershed Test Site

BMP Regime	Scenario Rank by Phosphorus Reduction	Total Phosphorus Reduced (kg)	Cost ($)	Cost per kg of Phosphorus Reduced
MT_BioFuel_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	1	2,121	$349,424	$164.75
MT_BioFuel_VBS_StableP_CvrCropSlge(SOY)_ALLMAN	2	2,091	$302,725	$144.74
MT_BioFuel_VBS_LowerStableP_CvrCropSlge_ALLMAN	3	2,037	$320,875	$157.51
MT_BioFuel_VBS_StableP_CvrCropSlge_ALLMAN	4	2,008	$274,176	$136.53
MT_BioFuel_LowerStableP_CvrCropSlge(SOY)_ALLMAN	5	1,966	$251,063	$127.69
Complex Regime*	6	1,941	$181,869	$93.72
MT_BioFuel_StableP_CvrCropSlge(SOY)_ALLMAN	7	1,930	$204,364	$105.88
MT_VBS_LowerStableP_CvrCropSlge(SOY)_ALLMAN	8	1,924	$310,493	$161.39
MT_BioFuel_VBS__LowerStableP_ALLMAN	9	1,910	$292,325	$153.07
MT_BioFuel_LowerStableP_CvrCropSlge_ALLMAN	10	1,877	$222,513	$118.53

*** Composition of Complex Regime**	**Percent Application**
Stable_P	4.4%
LowerStableP	42.3%
MT_Stable_P	40.0%
ZT_Stable_P	13.3%

Figure 3. Estimated Total Implementation Costs and Estimated Phosphorus Load Reductions for Top Ten Optimal BMP Scenarios



4.2. SWAT Analysis of the Optimal Scenario for the Entire LFR Basin

According to SWAT, total estimated phosphorus loading in the entire LFR Basin under *2004 Baseline* conditions is 238,912 kg/yr, which accounts for both point and nonpoint sources of phosphorus. As previously discussed, the *Optimal Scenario* of BMPs was calculated in OptiMod using the Upper Bower Creek subwatershed as a test site. Following identification of the *Optimal Scenario*, SWAT was then used to simulate phosphorus load reductions for the entire LFR Basin using the combination of BMPs from the *Optimal Scenario*. Average annual simulated nonpoint sources of total phosphorus (and suspended sediment) loads for the entire LFR Basin under both the *2004 Baseline* conditions and the *Optimal Scenario* are summarized in Table 5. These estimates do not reflect estimated loading from point source facilities in the LFR Basin, which are addressed later on in the report. Nonpoint source loads and yields were computed at the basin outlet (i.e., to Lower Green Bay). 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 LFR Basin, which translates to a 21% reduction in total phosphorus loading to Lower Green Bay.

Again, only changes in agricultural practices were simulated for nonpoint sources. Greater total phosphorus reductions are expected from nonpoint sources once urban stormwater controls are included in the analysis. Further, additional agricultural BMPs will likely be included in future analyses (i.e., for the TMDL implementation plan).

Table 5. Simulated Average Annual Suspended Sediment and Phosphorus Nonpoint Source Loads from the Lower Fox River Basin (*2004 Baseline* vs. *Optimal Scenario*). These estimates do not reflect loading from point source facilities in the LFR Basin, which are 91,019 kg/yr for *2004 Baseline* and 45,974 for the *Optimal Scenario*.

		Load Originating from Subwatersheds				Load Delivered to Lower Green Bay			
		SS	**Sed-P**	**Sol-P**	**Total P**	**SS**	**Sed-P**	**Sol-P**	**Total P**
	Area (km^2)	**(ton)** **(t/ha)**	**(kg)** **(kg/ha)**	**(kg)** **(kg/ha)**	**(kg)** **(kg/ha)**	**(ton)** **(t/ha)**	**(kg)** **(kg/ha)**	**(kg)** **(kg/ha)**	**(kg)** **(kg/ha)**
Baseline 2004 Scenario (1977-2000 Annual Average)									
LF01	**372.9**	12,100	17,300	21,500	38,800	12,100	17,300	21,500	38,800
East River		(0.32)	(0.46)	(0.58)	(1.04)	(0.32)	(0.46)	(0.58)	(1.04)
LF02	**291.0**	11,500	15,300	16,200	31,500	10,600	14,100	16,200	30,300
Apple, Dutchman, Ash.		(0.40)	(0.53)	(0.56)	(1.08)	(0.36)	(0.48)	(0.56)	(1.04)
LF03	**213.5**	13,200	16,800	14,700	31,500	11,900	15,200	14,700	29,900
Plum, Kankapot, Garners		(0.62)	(0.79)	(0.69)	(1.48)	(0.56)	(0.71)	(0.69)	(1.40)
LF04	**98.0**	4,100	4,300	3,700	8,000	3,700	3,900	3,700	7,600
Fox River, Mud Cr.		(0.42)	(0.44)	(0.38)	(0.82)	(0.38)	(0.40)	(0.38)	(0.78)
LF05	**389.2**	8,800	9,200	16,600	25,700	8,800	9,200	16,600	25,700
Duck Creek		(0.23)	(0.24)	(0.43)	(0.66)	(0.23)	(0.24)	(0.43)	(0.66)
LF06	**106.6**	4,300	4,500	4,700	9,200	3,800	3,900	4,700	8,700
LLBDM, Neenah Slough		(0.40)	(0.42)	(0.44)	(0.86)	(0.36)	(0.37)	(0.44)	(0.82)
LFM	**83.4**	3,800	3,700	3,300	7,000	3,600	3,500	3,300	6,800
L. Fox Main Channel		(0.46)	(0.44)	(0.40)	(0.84)	(0.43)	(0.42)	(0.40)	(0.82)
Lower Fox	**1554.6**	57,800	71,100	80,700	151,700	54,500	67,100	80,700	**147,800**
Subbasin		(0.37)	(0.46)	(0.52)	(0.98)	(0.35)	(0.43)	(0.52)	**(0.95)**
Optimal Scenario (optimized for phosphorus from agricultural sources only)									
LF01	**372.9**	10,100	11,500	13,700	25,200	10,100	11,500	13,700	25,200
East River		(0.27)	(0.31)	(0.37)	(0.68)	(0.27)	(0.31)	(0.37)	(0.68)
LF02	**291.0**	8,400	9,700	10,400	20,200	7,700	9,000	10,400	19,400
Apple, Dutchman, Ash.		(0.29)	(0.33)	(0.36)	(0.69)	(0.26)	(0.31)	(0.36)	(0.67)
LF03	**213.5**	9,200	10,000	8,800	18,800	8,300	9,000	8,800	17,900
Plum, Kankapot, Garners		(0.43)	(0.47)	(0.41)	(0.88)	(0.39)	(0.42)	(0.41)	(0.84)
LF04	**98.0**	3,600	3,500	3,000	6,500	3,300	3,200	3,000	6,200
Fox River, Mud Cr.		(0.37)	(0.36)	(0.31)	(0.66)	(0.34)	(0.33)	(0.31)	(0.63)
LF05	**389.2**	7,400	6,400	10,600	17,000	7,400	6,400	10,600	17,000
Duck Creek		(0.19)	(0.16)	(0.27)	(0.44)	(0.19)	(0.16)	(0.27)	(0.44)
LF06	**106.6**	3,700	3,400	3,600	7,000	3,300	3,000	3,600	6,600
LLBDM, Neenah Slough		(0.35)	(0.32)	(0.34)	(0.66)	(0.31)	(0.28)	(0.34)	(0.62)
LFM	**83.4**	3,400	2,900	2,800	5,700	3,200	2,800	2,800	5,500
L. Fox Main Channel		(0.41)	(0.35)	(0.34)	(0.68)	(0.38)	(0.34)	(0.34)	(0.66)
Lower Fox	**1554.6**	45,800	47,400	52,900	100,400	43,300	44,900	52,900	**97,800**
Subbasin		(0.29)	(0.30)	(0.34)	(0.65)	(0.28)	(0.29)	(0.34)	**(0.63)**

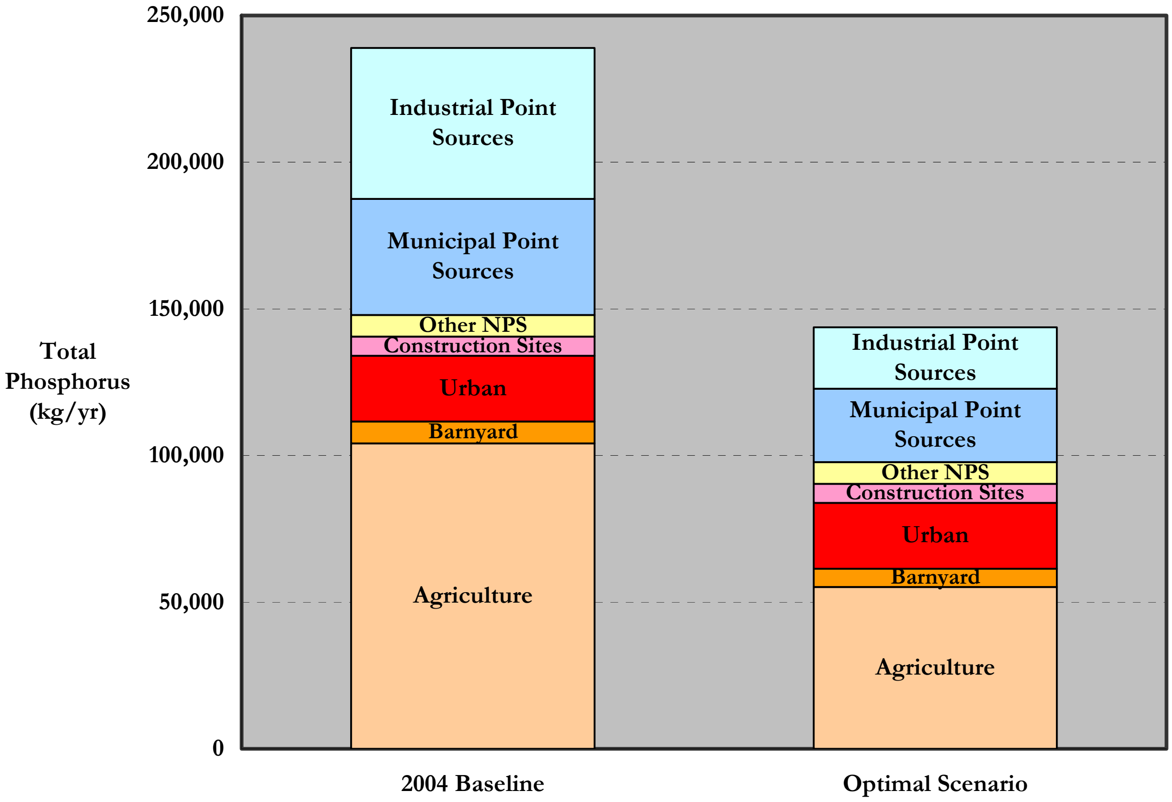
Although not evaluated within the optimization framework, potential phosphorus load reductions and costs associated with point source facility upgrades were estimated as part of this demonstration project. Cadmus contracted CDM to develop planning level cost estimates for reducing overall phosphorus loading from all point sources combined to 50% of current (2005) levels. It is important to clarify that the 50% reduction was selected based on the reduction target identified in the RAP and is for demonstration purposes only; this target does not reflect final loading targets for the TMDL.

Average flow rates and phosphorus concentrations for all of the point source facilities in the LFR Basin were obtained from discharge monitoring reports. These data were used in SWAT to simulate current (2005) phosphorus loading from the facilities (combined) to the outlet of the Lower Fox River (i.e., Lower Green Bay), which is about 91,019 kg/year. The phosphorus load discharging from all facilities combined was then reduced by about 50% and SWAT was used to calculate the estimated reduced point source loading to Lower Green Bay, which was 45,974 kg/yr. This translates to an approximate 19% reduction in overall loading to Lower Green Bay.

Figure 4 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 LFR Basin, total phosphorus loading to Lower Green Bay is estimated to decrease by about 40% (from 238,912 kg/yr to 143,700 kg/yr). These loading estimates do not reflect phosphorus loading originating from Lake Winnebago, which is about 287,980 kg/yr. These estimated also do not take into account potential additional reductions from the inclusion of urban BMPs.

Cadmus is in the process of developing a point source optimization tool, which will be incorporated into OptiMod and used to assess the cost-effectiveness of implementing BMPs for nonpoint sources vs. the cost-effectiveness upgrading point source facilities.

Figure 4. Simulated Phosphorus Loading to Lower Green Bay from the LFR Basin (*2004 Baseline* vs. *Optimal Scenario* of BMPs and Point Source Reductions). These numbers do not reflect phosphorus loading originating from Lake Winnebago, which is about 287,980 kg/yr. Note: Barnyard represents loading from feedlots, animal lots, or other outdoor facilities where livestock are concentrated for feeding or other purposes.



4.3. Implementation Costs for the Entire LFR Basin

The phosphorus load reduction estimates were coupled with individual BMP implementation costs to generate the estimated total cost of implementing the *Optimal Scenario* of BMPs in the entire LFR Basin (Table 6). Table 6 shows the load reductions and total and incremental costs associated with the *Optimal Scenario*, as each of the individual BMP scenarios are added, with the last step representing the cumulative effect from all of the simulated BMPs together. The order in which individual BMPs were added does not necessarily coincide with how they ought to be implemented. However, the last two steps are the least cost-effective in reducing phosphorus loads to Lower Green Bay, for the cumulative cost per kilogram of total phosphorus increases sharply as these two steps are added.

As shown in Table 6, the cost of implementing all of the agricultural BMPs associated with the *Optimal Scenario* is $6.9 million per year, or about $138 per kilogram of total phosphorus reduced from agricultural nonpoint sources. Further analysis may indicate that implementation of some of the specific BMPs may be able to continue at reduced or no costs after an initial "start up" period (e.g., 4 - 6 years). However, historically, the majority of farm land for which a farmer is paid to put in conservation practices (e.g., conservation tillage, grassed waterways, short-term buffer strips without a deed restriction) eventually reverts back after payments are discontinued.

Table 6. Simulated Phosphorus Load Reductions and Estimated Costs Associated with Implementation of the *Optimal Scenario* of Agricultural BMPs. Optimal scenario presented as a step-wise implementation.

BMP Scenarios	SS (ton)	Total P (kg)	%Reduced		Total Cost ($)	Average Cost per kg of Phosphorus Reduced
			SS	Total P		
Baseline 2004 Conditions	54,500	147,900				
1. Nutrient Management: Dairy P Feed Ration: Reduce by 25%; Implement 90%	54,500	140,600	0.0%	4.9%	$0	$0.00
2. plus: Increase manure incorporation from 50% to 85%	54,500	133,800	0.1%	9.5%	$393,907	$27.94
3. plus: Stabilize Soil P (90% implement)	54,500	125,300	0.1%	15.3%	$1,645,710	$72.82
4. plus: Conservation Tillage - CT40%, MT45%, NT15%	48,200	115,100	11.6%	22.1%	$2,730,621	$83.25
5. plus: Cover Crops on corn silage and some soybean fields	46,400	111,600	14.9%	24.5%	$2,730,621	$75.22
6. plus: Buffer Strips installed on 100% of 1:24k hydrology streams	44,900	107,600	17.6%	27.2%	$2,730,621	$67.76
7. plus: Reduce Soil P to 25 ppm; Implementation = 35%	44,900	100,600	17.6%	32.0%	$5,900,796	$124.75
8. plus: Biofuel Switch grass crop; 7% of all total crop acres	43,300	97,700	20.6%	33.9%	$6,929,204	$138.03

Cost curves developed by EPA in 1978 were used as the basis for estimating point source facility upgrade costs. These estimates were updated to 2007 dollars using the Engineering News Record (ENR) Construction Cost Index. The 2005 average discharge flow rate for each facility was used to scale proposed improvements to treatment technology and the associated estimated cost. Estimates include costs for the specific improvements, plus mobilization, instrumentation and control, electrical improvements, and yard piping. For the purposes of this analysis, it was assumed that sufficient land is already available at each site for the needed improvements.

Estimated total capital costs were annualized over 20 years for use in comparison with costs associated with BMPs. According to commonly used standard manuals of practice, annual operation and maintenance (O&M) costs are approximately 1% of the capital cost. This was used to calculate estimated annual O&M for each facility; however, based on experience, this estimate could be low. Potential upgrades to industrial facilities alone could cost approximately $96.9 million in total (or $4.9 million a year), with an estimated annual O&M just under $1 million. Potential upgrades to municipal facilities could cost approximately $83 million in total (or $4.1 million a year), with an estimated annual O&M of approximately $830,000. Potential upgrades at all facilities combined has an estimated total capital cost of approximately $180 million (or $9 million a year, on average). Combined with estimated annual O&M costs ($1.8 million a year), the total estimated cost associated with point source facility upgrades combined is about $10.8 million a year on average, or about $240 per kilogram of total phosphorus reduced from point sources (Table 7).

The total cost of implementing the *Optimal Scenario* of agricultural BMPs and upgrading point source facilities in the entire LFR Basin is estimated to be $17.7 million per year, or $186 per kg of total phosphorus reduced. As the analysis shows, applying a 50% reduction to all source categories (i.e., both point sources and nonpoint sources) may not be the most cost-effective strategy, as agricultural source controls achieve the greatest phosphorus load reductions at the lowest cost (Table 7).

As already mentioned, the point source load reduction and cost estimates were not developed using OptiMod. Cadmus is in the process of developing a point source optimization tool, which will be incorporated into OptiMod and used to assess the cost-effectiveness of implementing BMPs for nonpoint sources vs. upgrading point source facilities. Taking into account potential reductions and implementation costs from both nonpoint sources and point sources, OptiMod will be used to identify the most cost-effective means of achieving the load reduction target established for the TMDL.

Table 7. 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

5.0 CONCLUSION

The use of an optimization modeling framework (e.g., SWAT-OptiMod) can help managers to identify the cost-effective combination(s) of agricultural BMPs, stormwater BMPs, and point source facility upgrades (as necessary) to meet water quality goals for the LFR Basin and Green Bay AOC. As illustrated in this demonstration analysis, restoring water quality in the LFR Basin and Green Bay AOC will require extensive implementation of multiple BMPs and other watershed management activities to address nonpoint sources, including loading from urban stormwater runoff, which was not considered in this analysis. While upgrades to permitted point source facilities may also be needed in order to meet the TMDL target, this demonstration analysis has shown that agricultural BMPs achieve the greatest phosphorus load reductions at the lowest cost.

The tools developed for this demonstration project will be revised and expanded upon in the coming months and used as part of the development of the TMDL for the LFR Basin and Green Bay AOC. Further, Cadmus will continue to utilize a watershed-based approach for developing the TMDL. Such an approach allows for the inclusion of previous and ongoing efforts, integrates multiple programs and approaches to restoring water quality, and also takes into consideration, multiple stakeholder perspectives. The result will be a well-informed, concerted effort to restore water quality in the LFR Basin and Green Bay AOC.

6.0 RECOMMENDATIONS

The following are recommendations for additional analyses and/or model refinements to consider for the analysis that will be conducted for the development of the TMDL for the LFR Basin and Green Bay AOC.

BMP Cost Estimates

- Conduct a comprehensive agricultural BMP cost analysis for the LFR Basin and Green Bay AOC, potentially taking into account information obtained through the social indicator assessment. The analysis would provide close to accurate cost estimates for implementing agricultural BMPs (including costs over time). Such an analysis would result in more precise estimates of BMP costs, including: private costs incurred by the farmer, which take into account net returns; costs incurred by government agencies forming agreements with farmers who are required to change management practices; and cost-share program reimbursement and incentive funds provided to farmers who implement appropriate BMPs. Having as accurate as possible cost estimates for BMPs is essential to successfully developing the optimal solution(s) of BMPs.
- Identify urban stormwater and construction site BMPs, along with their total phosphorus and suspended sediment reduction potential and implementation costs. Incorporate the urban BMPs into SWAT and OptiMod analyses for the TMDL.

SWAT

- Update SWAT using data from USGS water year 2006 and 2007 (if available).

OptiMod

- Convert OptiMod into a user-friendly Excel-based format. OptiMod currently operates within the AIMMS framework, which is a proprietary software application (Bisschop and Marcel, 2007). Cadmus could develop a user-friendly version of OptiMod (along with a 1-day training workshop) that will enable resource managers and interested stakeholders to use OptiMod themselves to compare the environmental and economic effectiveness of different BMPs.
- Integrate a point source optimization tool into OptiMod for use in evaluating load reductions associated with point source facility upgrades along with costs.

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